The Red Book

Window Glass Made Clear

Cardinal
Glass Industries Inc.

Index

This brochure provides technical information on glass products for windows. While the primary focus is on residential applications, much of the information can be used to gain a better understanding of glass performance in all types of buildings.

Icons Used in this Brochure

Throughout the document additional information will be presented in the margin to provide the reader with more background and/or external links to expanded information:

Definition	Technical Service Bulletin	Reference Information on the Web	"Did You Know"

Readers of this document are encouraged to visit the Cardinal website where the links to the TSBs and reference information will give you immediate access to the additional materials. Revisions and updates to the data in the Red Book will occur on the website immediately and will then be incorporated into printed copies only when they are reprinted with a new date. In all cases updates to the website information will make the paper copy obsolete.

Listing of Cardinal's facilities: www.cardinal-corp.com/locations

National Fenestration Rating Council: www.nfrc.org

Corporate Divisions

Built on the vision of Product Quality Leadership, Cardinal is considered by the world's premium residential window brands as the leading provider of superior quality glass products. From the melting of sand to produce clear float glass to the vacuum sputtering of silver to produce low-emissivity coatings, Cardinal manufactures the quality components and finished insulating glass products used in all top of the line residential windows.

Cardinal operates three wholly-owned subsidiaries:

Cardinal IG Company (insulating and laminated glass)
Cardinal CG Company (coated glass)
Cardinal FG Company (float and tempered glass)

Fenestration the arrangement, proportioning and design of windows and doors in a building

Methodology

Throughout this brochure we'll make a variety of claims for "glass-only" characteristics in order to differentiate between glazings. It is important to remember though that the window properties are the final determinant of performance. For this reason, Cardinal supports the use of industry standards, third-party certifications, and whole product ratings. As an example, the National Fenestration Rating Council rates whole window energy performance and is referenced as the source for window energy performance ratings in the model building codes.

Single sheets of glass are formed using the float glass manufacturing process. From this monolithic form the glass is modified for increased strength, improved insulating capability, safety glazing requirements and other features.

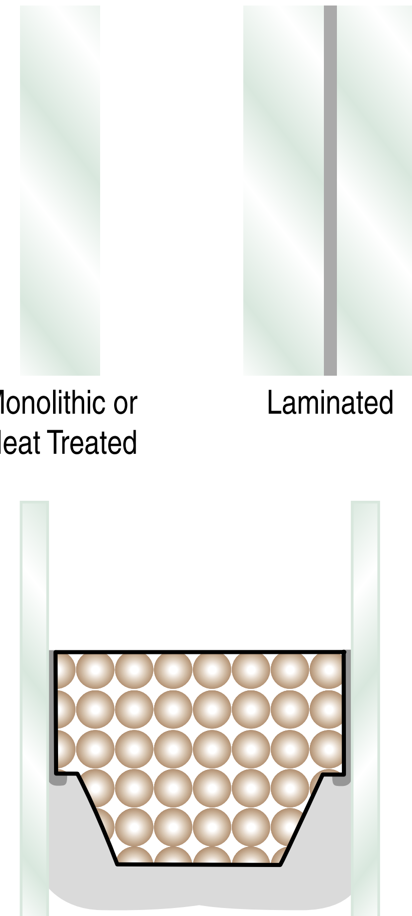
Installed as a single pane, the glass can be annealed, heat-treated, or bonded to another piece of glass with a plastic interlayer to form laminated glass. From a thermal standpoint, all three variants operate the same. Heat loss rates will be extremely high, and room side glass temperatures will be cold in the winter and hot in the summer.

Three main components in glass are sand, soda ash, and limestone. In the "float" process, molten glass forms a ribbon on top of melted tin. As the glass solidifies, the thin continuous sheet transfers onto metal rollers for further cooling and is then cut to size.

During the glass manufacturing process, alloying materials can be added to the glass as tinting agents. The depth of color in a body-tinted glass will change with the glass thickness. Body-tinted glass products absorb sunlight and will get very hot when installed as a single pane; tinting does not improve insulating value. Body-tinted glass is seldom used in residential windows as clear glass is usually preferred in homes.

Double glazing, or insulating glass (IG) units, have two discrete layers of glass with an airspace cavity between them. The insulation added by the airspace will isolate the room from the outdoor temperatures. Insulating value can be improved by adding low emissivity coatings, inert gas fills, or adding even more glass layers.

Fig. RB4-1 Glass Types



Variations such as heat-treated and laminated glass can be incorporated where additional strength and security may be desirable. Thickness of the glass used will depend on window size and building design requirements (e.g. wind load).

Cardinal uses metric designations for glass thickness. The conversion from metric to actual inch thickness in the Fig. RB4-2 is accurate. The traditional designations are shown for guidance only.

ASTM International: www.astm.org

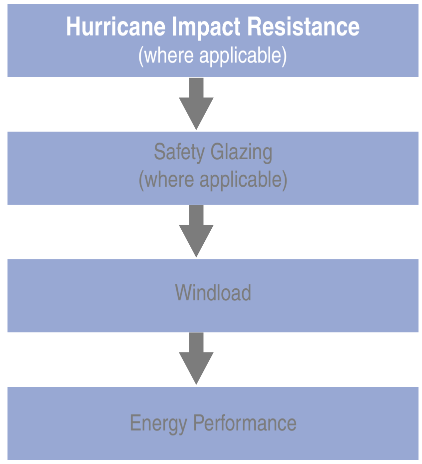
Fig. RB4-2 Glass Thickness Designations

Thickness Designation, mm	Nominal Thickness, in	Traditional Designation
2.2	0.087	Single Strength, 3/32 inch
2.3	0.092	---
3.0	0.117	Double Strength, 1/8 inch
3.1	0.122	DST
3.9	0.153	5/32 inch
4.0	0.160	---
4.7	0.187	3/16 inch
5.7	0.223	1/4 inch

(All thicknesses conform to requirements in ASTM C1036 – Standard Specification for Flat Glass)

The key to an effective glass design is a combination that enables a comfortable, energy-efficient view of the outside without compromising safety. Glass selection should begin with the structural requirements first. Energy performance and aesthetics can be optimized once the minimum glass needs have been established.

Hurricane Impact Resistance



In coastal regions that are subjected to hurricane winds and the risk of flying debris, building codes may require glazing systems that resist penetration after impact. Specially designed laminated glass products can fulfill these requirements - the multiple layers of glass may break from an impact, but the plastic interlayer and the structural bonding of the glass to the window frame allows the panel to remain in place, protecting the interior of the building. In most cases, laminated glass that passes hurricane impact requirements will also qualify as a safety glazing.

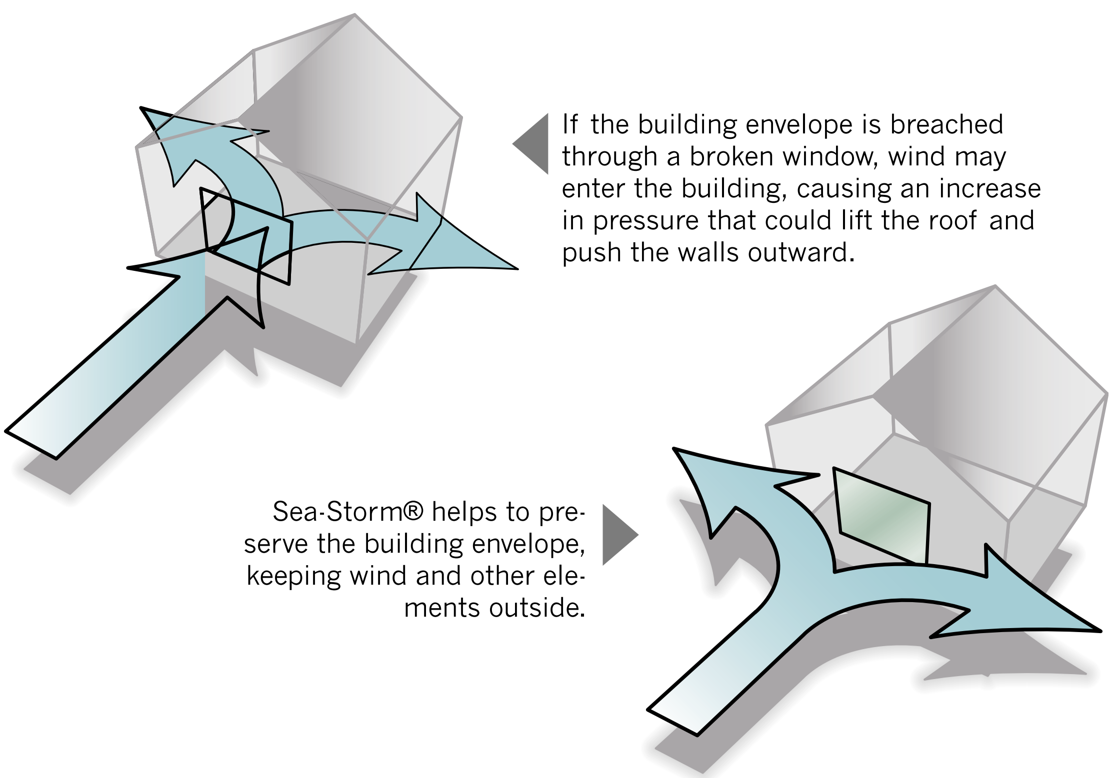
Note that the design of an impact resistant window requires an appropriate glazing and the means to structurally fasten that glass to the frame. The test method for compliance involves impacting the window in multiple locations and then subjecting the assembly to cycles of positive and negative pressures to replicate the exposure seen during a hurricane.

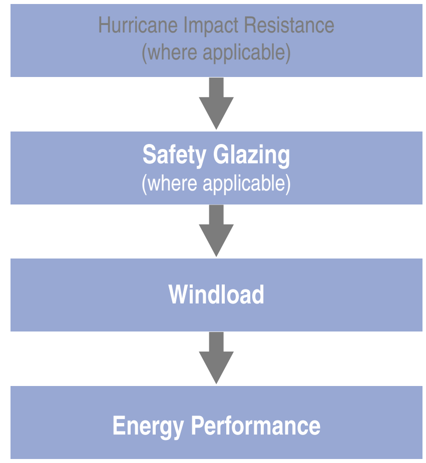
Cardinal's Sea-Storm® glass represents a family of laminated glass products that are engineered and tested in conjunction with the window to meet the design pressure requirements. Cardinal maintains a test laboratory specifically for this purpose and assists our customers in selecting the right product designs prior to the window manufacturer's pursuit of third-party certification.

TSB

TSB #IG12: Hurricane Impact Codes

Fig. RB5-1 Sea-Storm Protection





Safety Glazing

Safety glazing is a description used for glass products that reduce the risk of serious injury in the case of human impact with the glass. Examples of fenestration installations that require safety glazing include:

- Swinging, sliding, and storm doors
- Windows adjacent to a door
- Windows where the bottom edge is less than 18 inches above the floor or a walking surface is within 36 inches
- Skylights
- Safety glazing is also required in non-fenestration location like tub and shower enclosures, glass panels in closet doors and glass in railings or adjacent to stairways.

Windload

Design wind pressures on a building facade come from meteorological records of fastest wind speeds and the building exposure conditions. The type of glass (e.g. monolithic, insulating, laminated) defines how much of the wind pressure is carried on each layer of the glazing.

The windload capability of the glazing can be increased using either thicker annealed glass or through the use of heat-strengthened or tempered glass. Which strategy is used depends on a number of performance parameters. If thicker annealed glass is used, the overall weight of the window will increase, as well as the cost. Heat-strengthed or tempered glass can be a lower cost option to increasing glass strength, but the heat treatment process can create visual distortion in the glass.

Energy Performance

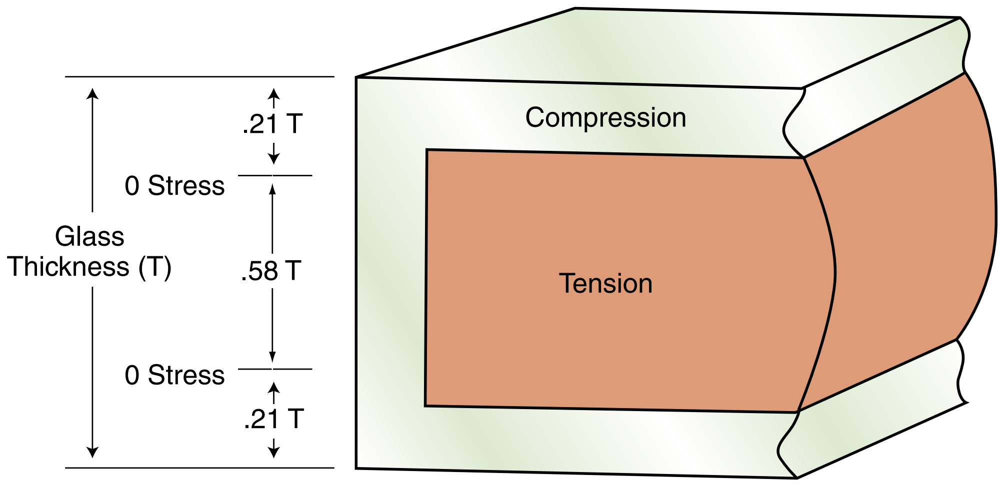
U-factor (heat loss) and Solar Heat Gain (SHGC) are the principle energy concerns for a window. Regional energy code requirements, along with the choice of window framing materials, will determine if enhancements like LoĒ^{2}® coatings, XL Edge™ IG systems and argon fill are needed. The overwhelming preference for residential buildings is a clear, neutral appearing glass. Occasionally a tinted glazing may be desired for glare control. Cardinal's LoĒ^{2}-140® glass is an example product that provides reduced light transmission as well as energy control by means of a lower U-factor and SHGC.

	Product	Description
Cardinal CG Company	Low-E Coated Glass	LoĒ^2-172® - All climate, all season thermal protection LoĒ^2-170® - All climate, solar control LoĒ^2-140® - Maximum glare and solar control/blue tint LoĒ^2-138® - Maximum glare and solar control/bronze tint LoĒ-178™ - Good for winter (heating only) climates
	Lower-Maintenance Glass	Permanent overcoat reduces cleaning -Dries quickly, reducing watermarks
Cardinal IG Company	Insulating Glass	Warm edge IG spacer system - lasts longer
	Protective Film	Shields glass from manufacturing and construction debris - Factory-applied on IG units
	Laminated Glass	Hurricane-resistant & safety glazing

Cardinal produces two types of glass that qualify for safety glazing:

- fully tempered
- laminated

Fig. RB8-1 Tempered Glass Compression Layers



Tempering is a process where annealed float glass is heated to near its softening point (approximately 1300°F) and then rapidly cooled with air. The resulting compression layer increases the glass strength to nearly 4 times that of ordinary annealed glass.

When tempered glass is fractured, the energy stored in the compression layer causes the glass to break into small particles. The particles are sufficiently small in size and the glass is considered to "break safe".

ASTM Standard C 1048 – 04 Specification for Heat-Treated Flat Glass— Kind HS, Kind FT, Coated and Uncoated Glass

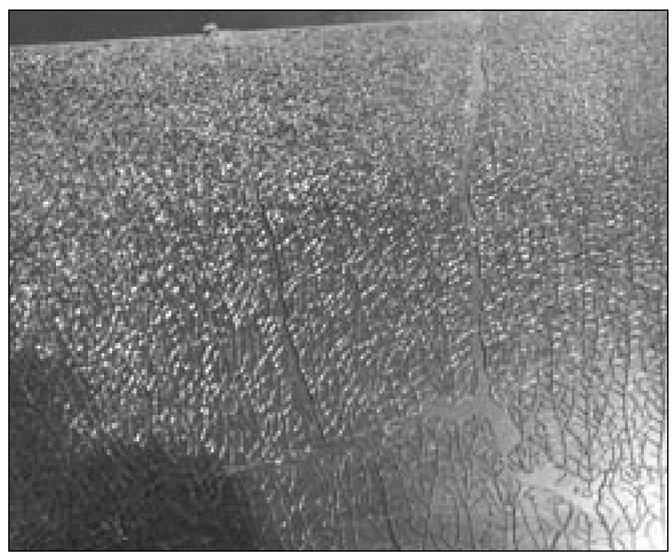
ASTM Standard C 1172 – 03 Specification for Laminated Architectural Flat Glass

Cardinal's tempered glass is available in thicknesses of:

- 3.1 mm
- 3.9 mm
- 4.7 mm
- 5.7 mm

Laminated glass can qualify as a safety glazing with any combination of annealed, heat-strengthened, or tempered glass as the layers. The plastic interlayer material, typically a polyvinyl butyral, must have sufficient integrity that should the glass layers break, the pieces are retained and do not "fly off" after an impact.

Fig. RB8-2 Tempered Glass Breakage Pattern

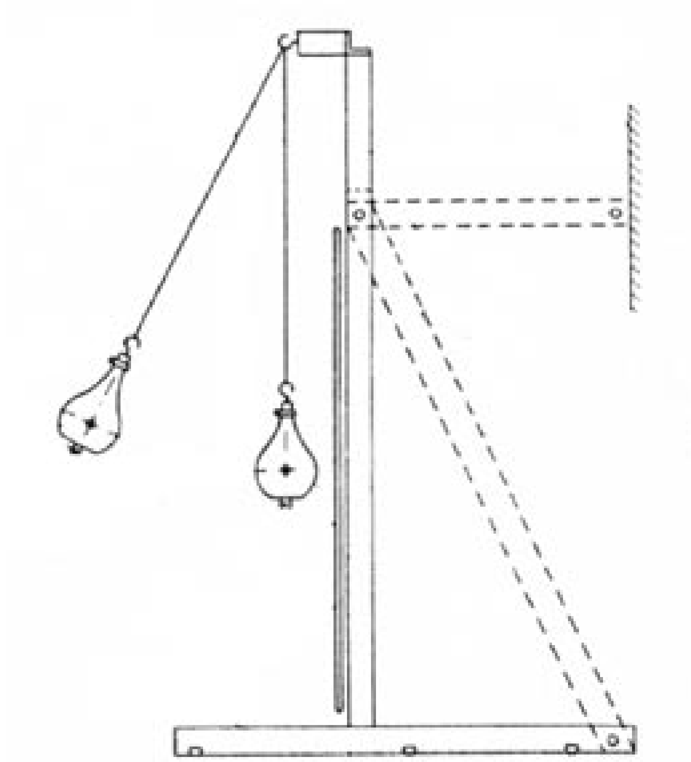


For an insulating glass unit to qualify as a safety glazing, all layers must be an approved (and labeled) safety glass. The layers can be any combination of tempered or laminated glass.

The basic test methodology for evaluating safety glazing involves impacting the panel with a 100 lb shot-bag that is swung on a pendulum from a defined height.

Compliance is gained if the glass does **not** break when impacted, or by breaking in a manner set forth in the tabulation of Fig. RB9-2. A hole in laminated glass from the impact is permitted when the opening size is less than 3 inches.

Fig. RB9-1 Safety Glass Test Rig



Consumer Product Safety Commission: www.cpsc.gov

Safety Glazing Certification Council: www.sgcc.org

Fig. RB9-2 Safety Glazing Requirements

	Category I	Category II
Glass Size	9 sq. ft. maximum	Unlimited
Pendulum Drop Height	18 inch	48 inch
Tempered Break Requirement	Ten largest particles must weight less than (10) square Inches of the glass tested	
Laminated Glass Requirement	No hole through which a 3-inch diameter sphere can pass	

(From Consumer Product Safety Commission Standard 16 CFR 1201)

Laminated glass with 0.015 in. thick interlayer can qualify as a safety glass, but will be limited to Category 1 size (9 sq. ft. maximum). The same interlayer can be used for safety glazing requirements in overhead glazing at a maximum size of 16 square feet provided the highest point of the glass is within 12 feet of the floor.

Category II laminated glass will require a minimum interlayer thickness of 0.030 in.

Cardinal's safety glazing products are certified and labeled in compliance with the Safety Glazing Certification Council. As a licensee of the SGCC program, our tempered and laminated glass products are inspected and tested in an on-going third party process.

The windload strength of glass is analyzed using the minimum allowable thickness and with the assumption that the surface condition is that of a product that has been in use for several years. The maximum load is derived at a statistical limit called the “probability of breakage”. For vertical glazing, a breakage risk of 8 lites per 1000 is typically used.

“Probability of breakage” represents the fraction of glass lites that would break at the first occurrence of a design load.

The design wind pressure requirement for a window depends upon:

- Location. Special regions can exist in the mountains and along coastal areas.
- Building height. The taller the building, the greater the wind pressure. There is little effect on a residential structure of 3 stories or less.
- Local exposure conditions. A low-rise structure in open terrain will have 20-40% greater wind pressure than the same building in a suburban exposure.
- Window location on the building façade. A corner window on the downstream side of the wind can see 30% more pressure than a window on the opposite side in the middle of the wall.

The basic wind speed for inland regions of the United States is 90 mph. Design pressures for low-rise residential buildings could range from 20 to 35 pounds per square foot (psf) depending on exposure and window location on the façade.

ASTM E1300 – Standard Practice for Determining Load Resistance of Glass in Buildings provides background information necessary for an analysis of glass strength in many configurations.

The size limits shown in Fig. RB10-1 have been established as practical maximums for safe handling of the glass in the Cardinal factory, for shipment/handling at the window manufacturer, and for window delivery to the job site with a minimum of shipment damage.

FIG. RB10-1 Insulating Glass Unit Size Limits[1]

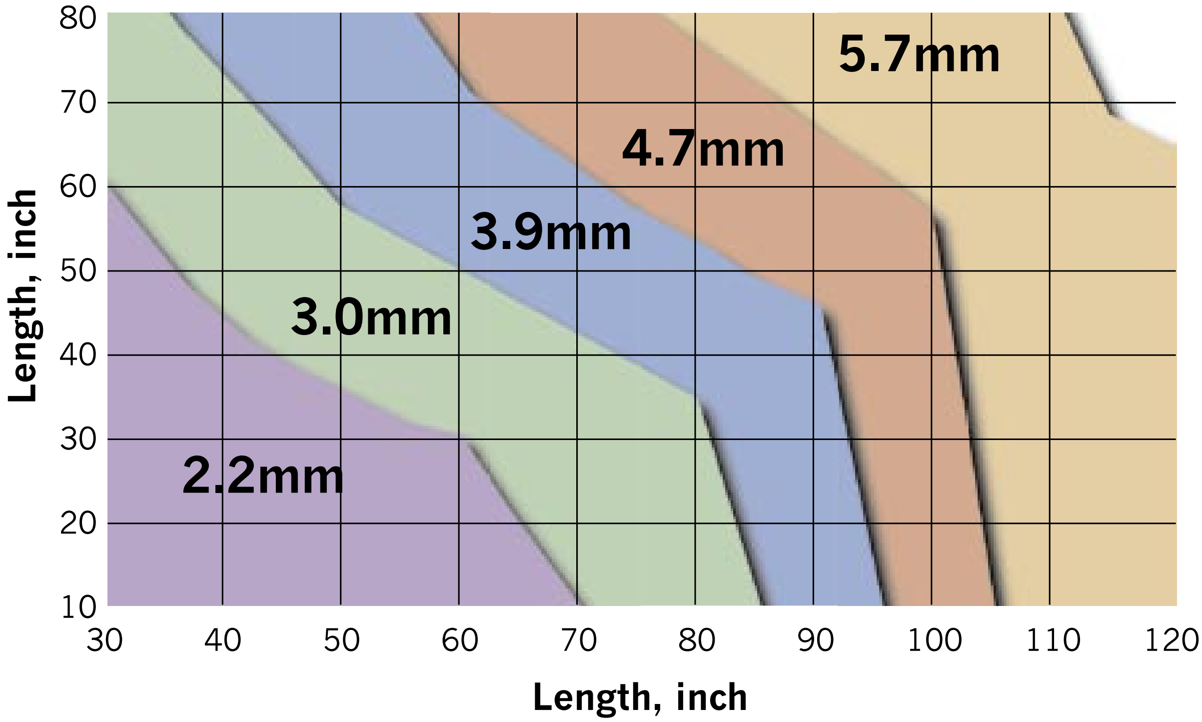
Annealed Glass Thickness	Maximum Long Dimension	Maximum Area (ft²)
2.2	70	12
3.0	80	18
3.9	90	24
4.7	100	34
5.7	120	44

[1]These size limits are applicable to aspect ratios (long side ÷ short side) less than 2.

IG units fabricated to these size guidelines with annealed glass will approximate a 40 psf windload capability. For applications where the windload requirement is less than 40 psf these handling recommendations, rather than the design load, establish the maximum allowable glass sizes.

The size limits in Fig. RB10-1 were developed using the 40 psf windload chart shown in Fig. RB11-1. The size limit for long narrow lites (aspect ratios greater than 2) can be determined using this chart.

Fig. RB11-1 40 PSF Size Limits for IG Units with Annealed Glass



TSB #IG03 Glass Windload Charts

Example: a 30 x 50 in. unit (10.4 ft^2) is acceptable with 2.2 mm glass while a 40 x 60 inch unit (16.7 ft^2) requires 3.0 mm as the minimum thickness.

Heat-strengthened glass is considered to be twice as strong as annealed while tempered is four times that of annealed. The windload capability of heat treatment options in insulating glass can be determined by applying the scalars in Fig. RB11-2 to the 40 psf limits shown in Fig. RB11-1.

Fig. RB11-2 Load Factors for Heat Treated Insulating Glass Units

AN/AN	1.0
AN/HS or FT	1.1
HS/HS	1.8
FT/FT	4.0

AN = Annealed, HS = Heat-Strengthened, FT = Fully Tempered

Example: a 40 x 60 inch unit with 3.0 mm annealed glass will meet a 40 psf windload. Heat-strengthening or tempering on one of the lites in the IG will increase the wind load to 44 psf (1.1 * 40).

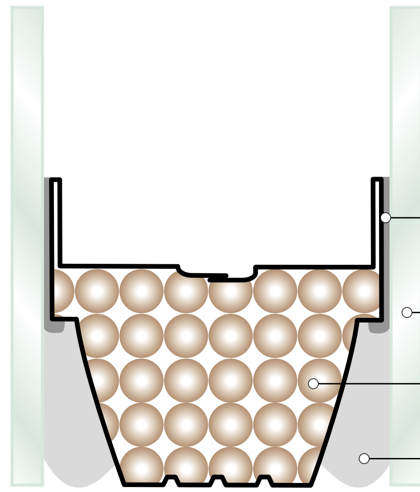
For laminated glass, IG units with unequal glass thicknesses, unusual frame support conditions, or for windload requirements in coastal regions, contact Cardinal Technical Services.

Storm windows, or double glazing panels, can improve the insulating value of a window, but there will be frequent times when moisture condenses between the panes. The condensate disrupts the view and all four glass surfaces will need regular cleaning. A **sealed** insulating glass unit prevents the center of glass condensation, delivers a clear view year-round, and from a cleaning perspective looks like single pane glass.

To provide the best durability all Cardinal IG units are fabricated with metal spacers and use a dual-seal construction. A primary sealant of polyisobutylene creates a low permeability barrier that "seals" the spacer to the glass. The secondary sealant of silicone creates a weather-able structural bond to hold the glass and spacer together.

The acronym IG is used to describe Insulating Glass.

Fig. RB12-1 XL Edge™ Design



The metal spacer is a key component for the moisture and gas barrier characteristics of the edge seal. Spacer corners are bent and a sealed joint along one side provides a continuous peripheral seal. The largely inorganic cross-section reduces the risk of volatile out-gassing that could degrade low-E coatings in the airspace.

Failure of an insulating glass unit is defined as "obstruction of view" due to fog formation on the internal glass surfaces. Early failures, less than 5 years after manufacture, are most often due to workmanship problems. Defects like sealant voids and unsealed joints allow rapid moisture migration into the airspace that will quickly consume desiccant capacity.

The ultimate longevity of an IG unit will be determined by the durability of the sealants used to bond the pieces together. Beyond the initial workmanship issues, field failures are most often the result of catastrophic sealant degradation from weathering. In the laboratory we test to failure in an effort to replicate these failure modes and predict the longevity of new designs in the field. Cardinal IG Company has 40+ years of manufacturing and research experience in the development of durable insulating glass units. Through that time our IG design has gone through these milestones in development:

- Introduction of dual-seal technology (added PIB primary sealant)
- Conversion from polysulfide to silicone secondary seal
- Conversion from soldered aluminum corner keys to bent aluminum spacer
- Introduction of XL Edge™: a warm-edge spacer product with long-term durability

Sealant material used for insulating glass units fall into two main categories:

- Organic sealants used in either single or dual-seal construction
- Silicone secondary seals used in a dual-seal construction

Organic sealants include products such as polysulfide, polyurethane, hot melt butyl and some newer generation formulations occasionally referred to as "dual-seal equivalent". The underlying characteristic of these materials is that the "organic" polymer structure is susceptible to degradation when exposed to sunlight and thermal cycling.

Silicone sealants resist aging and weathering, but require a primary seal for low moisture permeability.

The tabulation in figure RB13-1 shows the four basic steps in the evolution of Cardinal's IG products. At each step, the new design demonstrates greater resistance to weathering in the laboratory. Field performance establishes an excellent correlation—seal systems that resist premature failure can be expected to deliver superior durability.

The XL Edge product has out performed the aluminum spacer system in both the accelerated test phases and in the first 10 years of field history. Warranty data suggests that the 20-year durability of XL Edge insulating glass will be significantly better than the 20-year history of the aluminum spacer system with a dual-seal silicone seal.

For homeowners with the desire to invest in energy-efficient window technologies, Cardinal's commitment to long-term performance will provide long-term savings.

Fig. RB13-1 Correlation of Accelerated Tests to Cardinal Field History

Sealant & Spacer Type		Longevity in Accelerated Tests	Field Failure Rate	
			10-Year Warranty History	20-Year Warranty History
Organic Sealant	Single Seal	7 weeks	4%	
	Dual Seal	15 weeks	2%	8%
PIB/ Silicone	Aluminum Spacer	40 weeks	0.4%	1.1%
	XL Edge™	80+ weeks	0.1%	0.2%[1]

[1] *Projected from 10-year history*

In addition to our continuous in-house quality testing, Cardinal certifies all units to Class CBA through the Insulating Glass Certification Council Program (IGCC). We also participate in the Insulating Glass Manufacturers Alliance (IGMA).

WWW.

Insulating Glass Certification Council: www.igcc.org

Insulating Glass Manufacturers Alliance: www.igmaonline.org

U-factor is the term used to quantify heat transfer. This is most commonly associated with heat loss – energy that transfers through the window when the outside temperature is cold. Inch-Pound units for U-factor are btu/hr/ft²/°F. Lower U-factors are desirable as this minimizes heat loss from the building.

To determine the overall window U-factor we need to know the performance at the center of glass, the edge of glass (the perimeter zone around the daylight opening) and the frame system.

The *Therm 5* program, developed by Lawrence Berkeley National Laboratory, is the standard computer tool used to simulate heat flow through the edge of glass and window frame regions.

Read as Btu (British thermal unit) per Hour per Square Foot of area per degree F temperature difference.

The LBNL *Window 5* program calculates the center of glass performance given all the combinations of number of glass layers, airspace gap widths, use of low-E coatings, and inert gas fills.

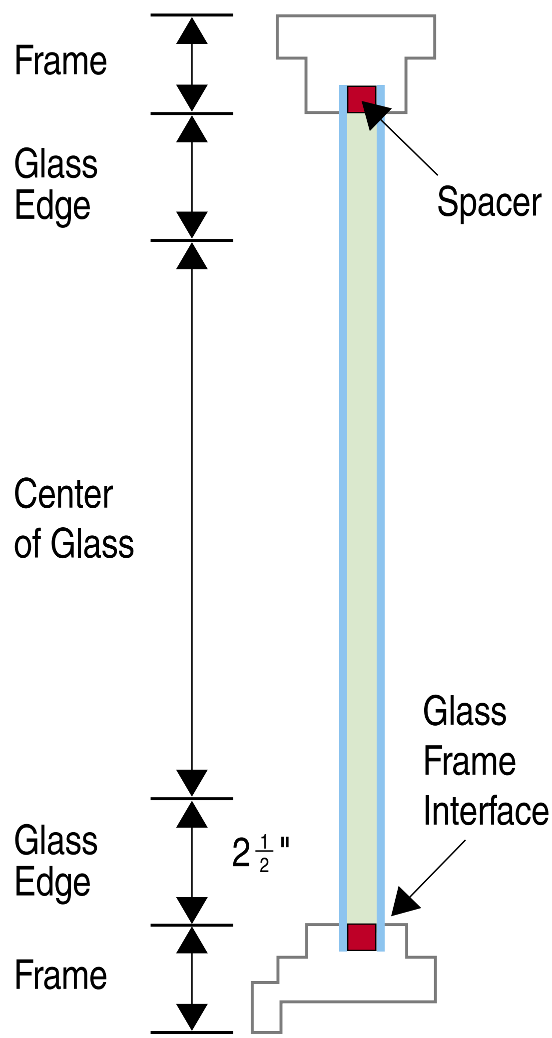
Window 5 sums up the respective contribution of each component to determine the whole window **U-factor**. This calculated window performance is validated through the procedures of the National Fenestration Rating Council and it is this whole window value that is called out in building energy code requirements.

For many years, single pane glass was the most common type of glazing used in windows. To improve comfort in cold climates, homeowners installed “storm windows” or “double glazing” panels. The airspace created between two layers of glass can nearly double the thermal resistance — improving comfort due to warmer room-side glass surface temperatures and dramatically reducing heat loss.

Window 5 Software: http://windows.lbl.gov/software/window

Insulating glass, or factory-sealed double glazing, is used in most windows today. Thermally speaking, an IG unit made from clear glass will have similar performance to the window with a storm or double glazing panel. The big step in glass performance comes with the ability to incorporate a low-emissivity coating and argon gas fill inside the IG unit. Triple and quad pane insulating values can be achieved in the same window design used for ordinary double glazing.

Fig. RB14-1 Window Thermal Cross Section

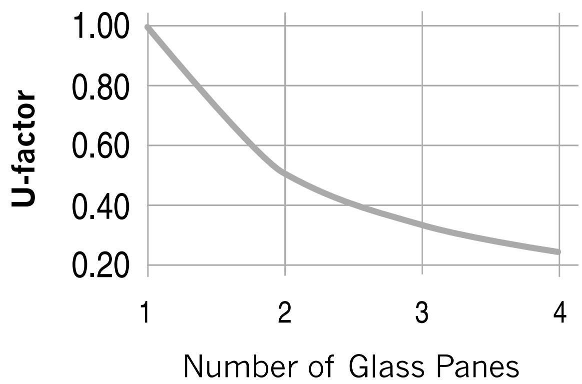


The center of glass region represents the largest heat loss area in the window. As the glass performance improves, this presents the opportunity to enhance the frame and edge of glass areas. Warm-edge spacer systems reduce the likelihood of perimeter condensation in cold weather. Better insulating frame systems can further improve on the overall window U-factor.

Adding layers of glass (e.g., single to double, double to triple) will improve the glass insulating value, but at a diminishing rate.

	Improvement
Single to Double	50%
Double to Triple	33%
Triple to Quad	25%

Fig. RB15-1 Center-of-Glass U-factor vs. No. of Panes



Heat transfer across the airspace of an insulating glass unit occurs via two separate thermal mechanisms:

- Thermal radiation between glass surfaces
- Conduction through the enclosed air or gas

About 2/3 of the heat transfer in a clear glass unit is from radiation. Adding a low-E coating can improve the insulating value by nearly 40%. Adding argon to an IG after the low-E coating gives a combined effect of nearly doubling the insulating value - a 48% reduction in U-factor compared to an ordinary clear glass unit.

Fig. RB15-2 Air Space Heat Transfer

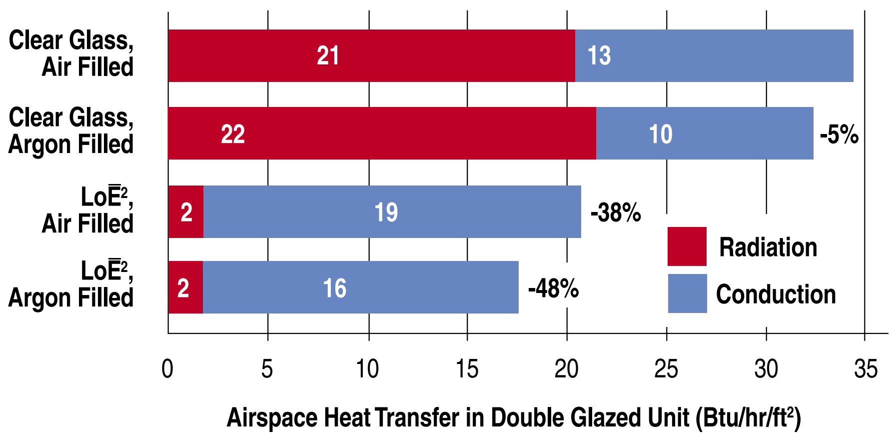


Figure RB15-3 shows how glass performance can be expanded far beyond the basic number of layers through the inclusion of low-E and argon. The heat loss through ordinary double glazing will be cut in half and triple glass unit can perform like 8 panes.

Fig. RB15-3 Glass U-factor Center of Glass Summary

No. of Panes	U-factor Additions	Equivalent No. of Panes	Room-side Glass at 0°F Outside
1	Single Pane	1	16°F
2	Single Pane + Storm 2 Pane IG	2	43°F
3 2	Triple Pane 2 Pane IG with LoĒ^2	3	52°F
4 2	Triple Pane + Storm Panel 2 Pane IG with LoĒ^2 + argon	4	57°F
3	Triple Pane with (1) LoĒ^2 + argon	6	61°F
3	Triple Pane with (2) LoĒ^2 + argon	8	63°F

Radiation Non-contact heat transfer through a gas or vacuum

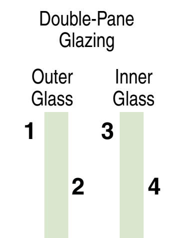
Conduction Heat transfer between materials in contact

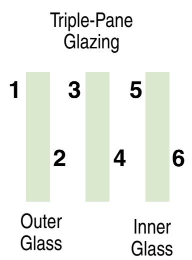
The actual center-of-glass performance for an improved double pane IG will vary with:

- Coating emittance
- Argon gas fill level
- Airspace gap width

Of the three variables, coating emittance will have the largest effect, followed by gas fill level, with gap width having the least impact.

Glass Surface Designations



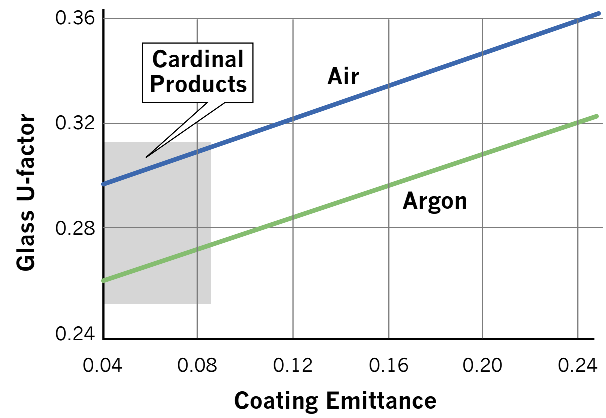


Air is 78% nitrogen, 21% oxygen and 1% argon. Argon gas is distilled from air during production of liquid nitrogen and oxygen. It is non-toxic, non-reactive and has a thermal conductivity 30% lower than air.

Low-E Coating

Cardinal's LoĒ™ and LoĒ^2® coatings have an emissivity of 0.08 and 0.04 respectively. As the chart shows, they deliver the lowest U-factor. Units fabricated with pyrolytic type coatings ($\varepsilon \sim 0.20$) will have U-factors 20-28% higher (more heat loss) than that of the Cardinal product. The U-factor does not change whether the coating is on surface 2 or 3.

Fig. RB16-1 U-factor vs. Emittance

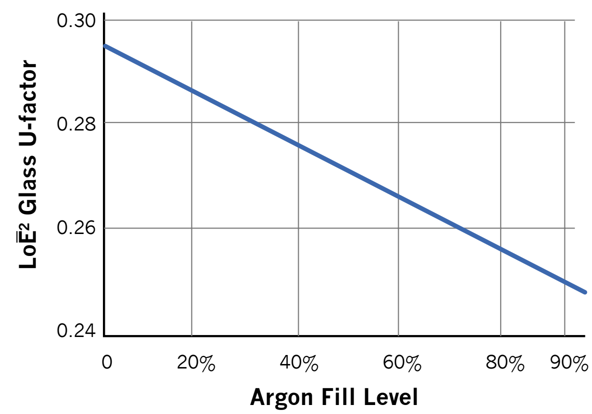


Argon Gas Fill

The U-factor improvement for argon filling of a LoĒ^2 unit will be 16%. There is a straight-line relationship to argon level: if the unit is 50% filled, the performance gain will be 8%.

Cardinal's quality testing shows that a production claim of 90% argon fill is a realistic representation of the gas filling process capability for all units.

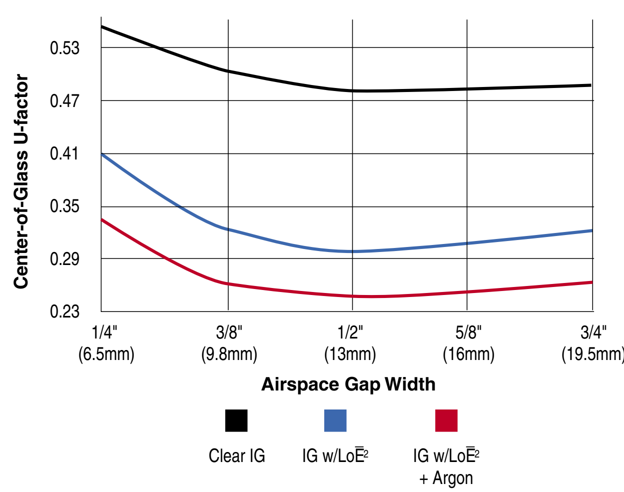
Fig. RB16-2 U-factor vs. Argon Fill



Gap Width

There's about a 5% change in the center of glass U-factor for air space gap widths ranging from 9.8 to 19.5 mm (3/8 in to 3/4 in.). The optimum point for most combinations is around 13 mm (1/2 in.). The U-factor will start to degrade significantly when the gap width is less than 9.8 mm (3/8 in.). A gap wider than 13 mm (1/2 inch) does not add any additional insulating value. In these wide gaps, the enclosed air (or gas) will circulate when exposed to a temperature difference. Convection circulation negates any benefit from the wider gap spacing.

Fig. RB16-3 U-factor vs. Gap Width



The edge-of-glass region is defined as a band 2.5” wide around the daylight opening of the window. Typically the coldest surface temperatures are along the sightline at the window sill. When the IG spacer is a highly conductive material like aluminum, the temperature drop can be great enough that significant condensation forms during cold weather. The resulting water runoff is both a nuisance and a source of damage for the interior finish of the window and wall surfaces below the window.

XL Edge™ is an IG unit with a low conductance spacer design that will dramatically reduce the risk of condensation. The XL Edge design utilizes very thin stainless steel to reduce edge heat transfer and retains the proven polyisobutylene/silicone dual seal sealant system for maximum long-term durability.

The sightline temperature is influenced by:

- The U-factor of the framing system (e.g. aluminum vs. vinyl)
- The U-factor of the glass (e.g. clear IG vs. LoĒ^{2})
- The conductance of the spacer system
- The positioning of the spacer relative to the daylight opening

The interaction between components is tabulated in Fig. RB17-2. Edge temperatures improve significantly when XL Edge is combined with glass and frame improvements.

Fig. RB17-1 XL Edge Design

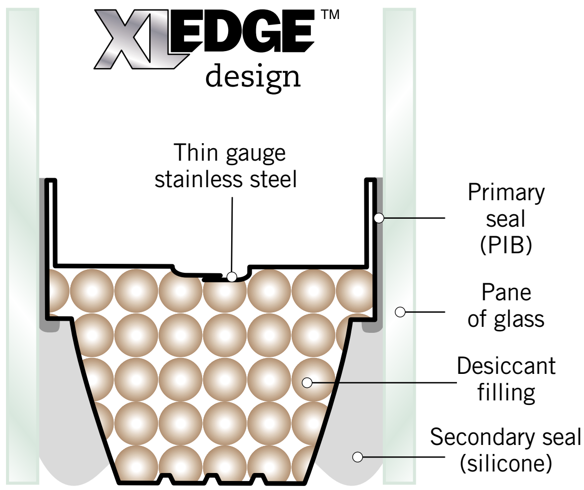


Fig. RB17-2 Sightline Temperature at 0°F Outdoor

	Clear IG	**LoĒ^{2}**	
Window Frame	Aluminum Spacer	Aluminum Spacer	XL Edge
Aluminum with Thermal Break	25°	26°	33°
Aluminum Clad Wood	26°	28°	37°
Wood or Vinyl	27°	29°	38°

Sightline or daylight opening: Point of the window where the frame stops and the visible portion begins

Fig. RB17-3 compares a wood/vinyl window with 3 glazing options in two cold climate regions.

The cumulative benefits from an improved center of glass and edge of glass yield a dramatic reduction in the risk of perimeter condensation.

Fig. RB17-3 Fraction of Heating Hours w/ Sightline Condensation

	Climate Zone	
	Northern	North Central
Clear IG Aluminum Spacer	25%	10%
LoĒ^{2} Aluminum Spacer	18%	6%
LoĒ^{2} XL Edge	6%	1%

(Climate zones are from Energy Star Windows - see p23)

*30% RH room humidity

In an operable sized residential window, the edge of glass represents about 25% of the overall window area. The reduction in edge area heat transfer from XL Edge will enhance the overall window U-factor by 3-4% with clear glass and 5-8% with LoĒ^{2}.

To calculate the overall window performance the following information is required:

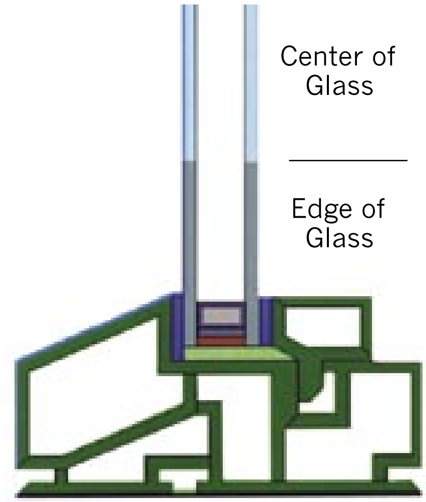
- Center-of-glass U-factor
- Edge-of-glass U-factor
- Frame U-factor
- Window Size

The NFRC program defines window product lines by operator type: double-hung, casement, picture window (fixed), sliding doors and others. For the purpose of comparing products, a standard size is used for each type.

Typical frame types (in order of improved thermal performance) are:

- Aluminum
- Aluminum with thermal break
- Aluminum clad wood
- Wood or vinyl

Fig. RB18-1 Frame & Edge Cross Section

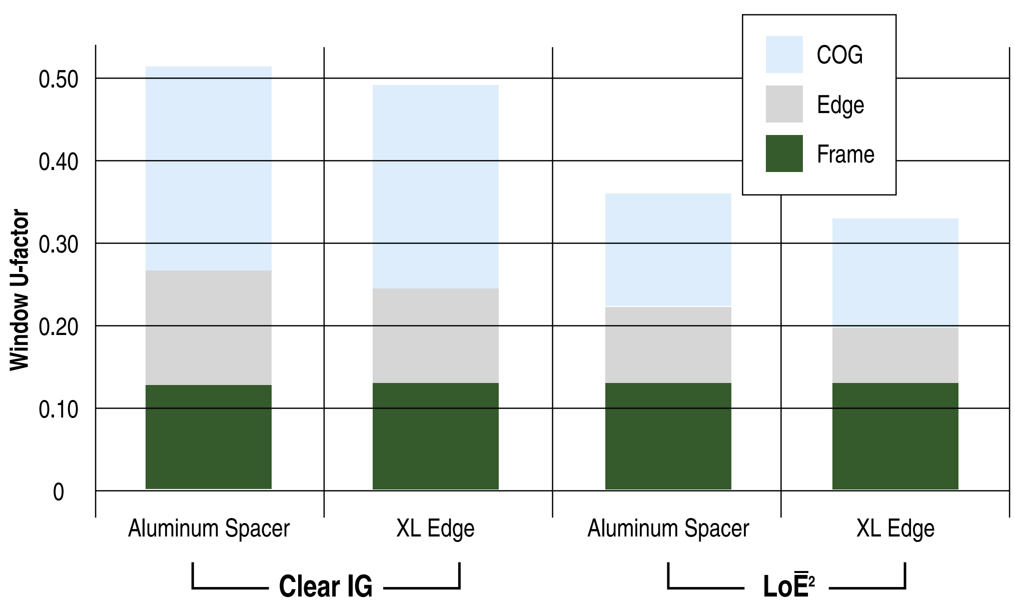


The tabulation below shows the range of performance with a variety of glazing types.

Fig. RB18-2 Example Window U-factors

Frame Type	Clear IG Aluminum Spacer	Clear IG XL Edge	LoĒ² Aluminum Spacer	LoĒ² XL Edge
Aluminum	0.74	0.73	0.57	0.54
Aluminum with thermal break	0.58	0.57	0.41	0.39
Aluminum-clad wood	0.52	0.51	0.37	0.34
Wood or vinyl	0.51	0.49	0.36	0.33

Fig. RB18-3 Component Contribution to Wood/Vinyl Window U-factor



TSB #IG05 Low-E Performance Comparison

The solar performance of glass products can be visually deceptive - less than ½ of the solar energy is visible to the human eye. Because of this it is important to compare window performance based on the NFRC-rated Solar Heat Gain Coefficient: SHGC.

This tabulation compares the light and solar transmission for clear, green and gray body-tinted single pane glass.

Fig. RB19-1 Tinted Glass Comparison

	Transmission	
Tint	**Visible Light**	**Total Solar**
Clear	88%	81%
Green	77%	47%
Gray	45%	45%

Our "eye" suggests that the green glass has high solar gain due to the light transmission when in actuality the solar properties are similar to the dark body-tinted gray glass.

The green glass exhibits what's referred to as "solar selective" transmission. The formulation of the tint allows solar energy to transmit in the visible spectrum while blocking energy in the (invisible) near-infrared spectrum.

HSLE is an acronym use for high solar gain low-E products, LSLE for low solar gain low-E.

LoĒ-178 is similar to clear glass as the transmission is high across the entire solar spectrum. LoĒ^2 coatings on the other hand are solar selective, and will commonly be referred to a low solar gain product. The multiple layers within the LoĒ^2 coating block solar infrared while allowing the visible energy to pass through the glass. The plot below compares visible light transmission and SHGC for clear, LoĒ and LoĒ^2 glass.

Fig. RB19-2 Visiable Light & SHGC Comparison

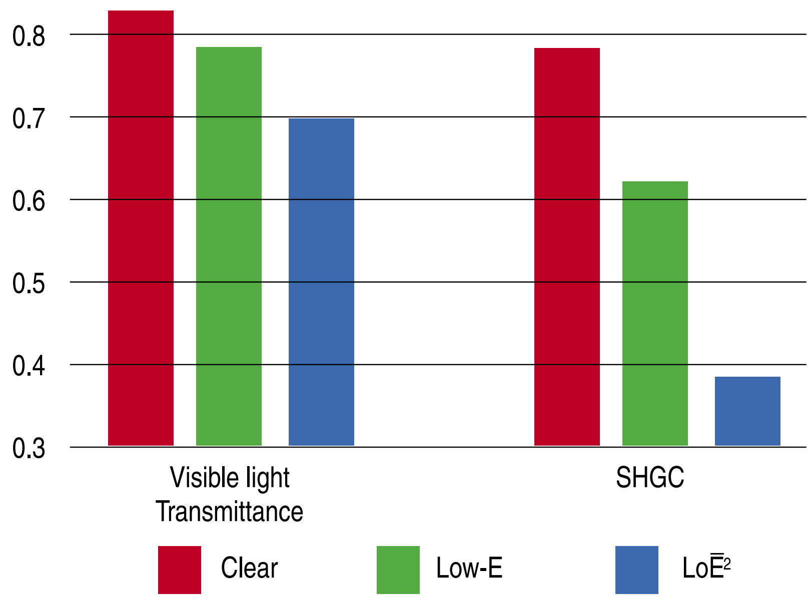


Fig. RB19-3 Comparison of Insulating Value and Solar Gain

Adding a LoĒ or LoĒ^2 coating to a double pane unit creates a matrix of performance properties.

	Tint	**Insulating Value**	**Solar Gain**
Double Pane with clear glass	Clear	Poor	High
Double Pane with LoĒ^2	Clear	Good	High
Double Pane with LoĒ^2	Clear	Good	Low
LoĒ^2-138 / 140	Bronze/ Gray	Good	Low

When sunlight strikes a window, it will transmit through the glass, reflect to the exterior, or be absorbed into the glass layers. Solar Heat Gain Coefficient includes both the direct solar transmittance and the inward flowing fraction of absorbed energy that is re-radiated into the room.

The impact of solar absorption in the room-side pane is demonstrated with this comparison. When LoĒ^2 is installed on the #2 surface (airspace side of outboard lite) about 3% of the incident solar radiation is absorbed and radiated into the room. Turn the unit around so that the LoĒ^2 coating is on surface 3 and the total solar gain increases by 9 percentage points. Note also how hot the room-side glass gets with a #3 surface coating location.

The number of glazing layers, the use of tinted or low-E glass, and the orientation/location of the coating will impact solar gain. Airspace gap width has little effect. Solar transmission does not change when argon gas is added to an IG. In the chart below, the size of the inward flowing fraction is an indication as to how hot the room-side glass will get in sunlight (red = hotter). Body-tinted glazing and third-surface low-E coatings will be uncomfortable for an occupant near the glass.

Fig. RB20-1 Solar Energy Flow

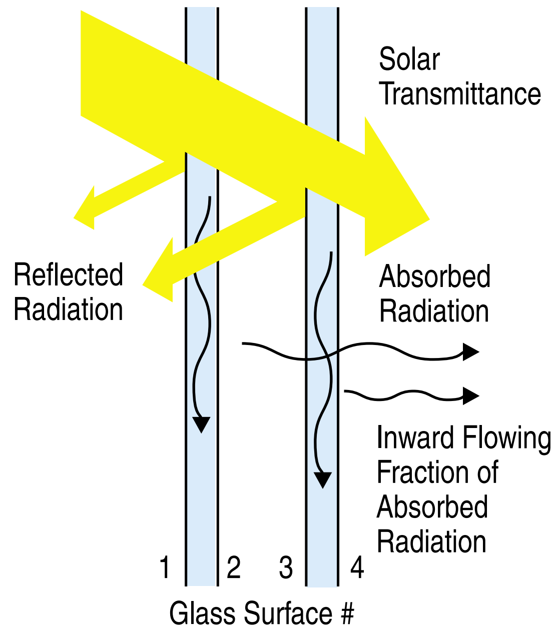
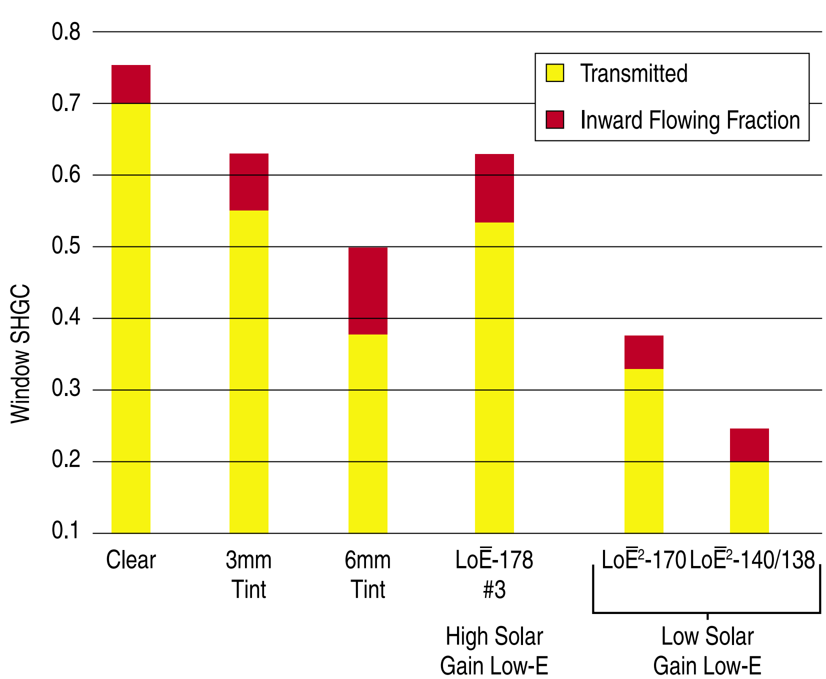


Fig. RB20-2 LoĒ^2 Coating Location

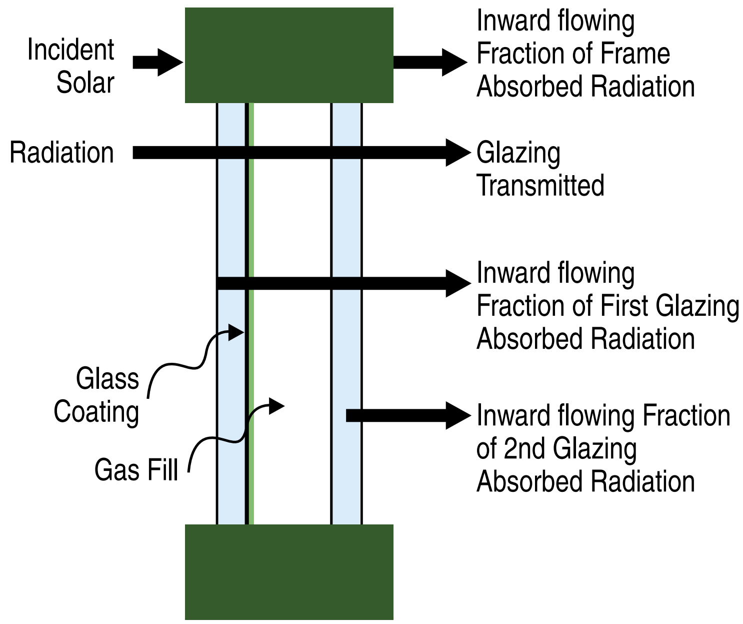
	Surface 2	Surface 3
Direct Transmission	0.34	0.34
Inward Flowing Fraction	0.03	0.12
SHGC	**0.37**	**0.46**
Roomside Glass Temperature	83°F	99°F

Fig. RB20-3 Energy Transmission vs. Glass Type



Window SHGC is the summation of heat gains through the transparent and opaque areas. Frame area is the biggest variable affecting the opaque region.The magnitude of solar gains through the frame is minor - typically less than 2% impact on the window SHGC.

Fig. RB21-1 Window Solar Gain

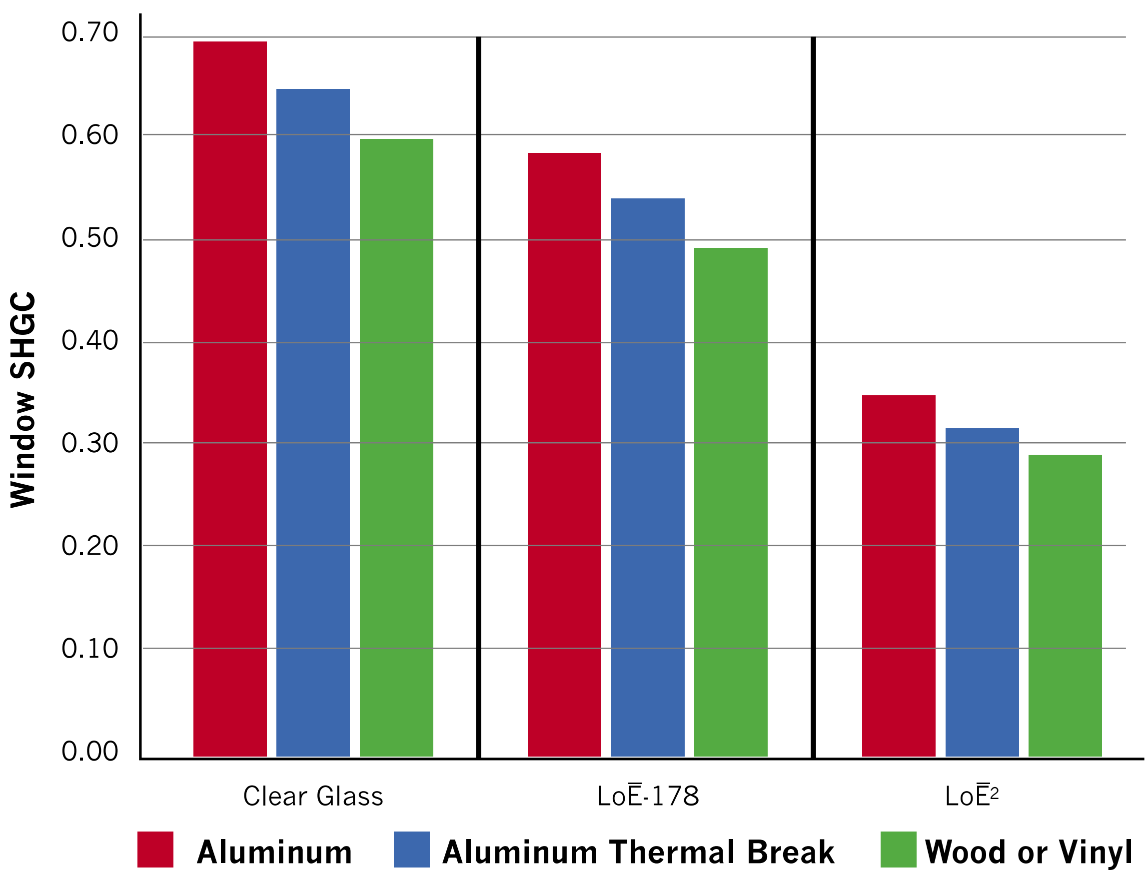


Aluminum frames will generally be narrow in section when compared to a wood or vinyl window. A large picture window with a narrow aluminum frame could have a glass fraction representing 90% of the total area while a small operable wood or vinyl window may have only 50% transparency area. When comparing two windows of the same size and glass type, a wood or vinyl window will have a lower SHGC, because the glass area will be smaller than in an aluminum-framed window.

In Fig. RB21-2 note how the SHGC performance is grouped around the basic glass type. The width of the frame (frame type) can influence the overall value but it does not alter the way the performance band is grouped together.

SHGC is dimensionless. The maximum value is 1 (100% gain) and the minimum is 0 (no solar gain).

Fig. RB21-2 Window SHGC for Various Frame/Glass Options



Thermal Comfort

The accurate prediction of window energy performance requires a detailed understanding of the house into which the windows are installed. Energy analysis programs presume that the thermostat set point defines adequate comfort for all rooms in the building during the entire year.

Fig. RB22-1 demonstrates how erroneous this assumption can be in cold climates. At 0°F outside, single pane glass has a room-side glass temperature of 15°F - a room with this window "feels" like the thermostat has been turned down by 8°F.

Double pane glass is 30°F warmer than single pane, but still 25°F below the thermostat. More than 20% of the room occupants would express dissatisfaction the thermal conditions using this glass.

LoĒ^{2}® glass warms the glass temperature to within 1°F of a room with no windows.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55 provides a method to specify the indoor environmental and personal factors that produce thermal conditions acceptable to occupants.

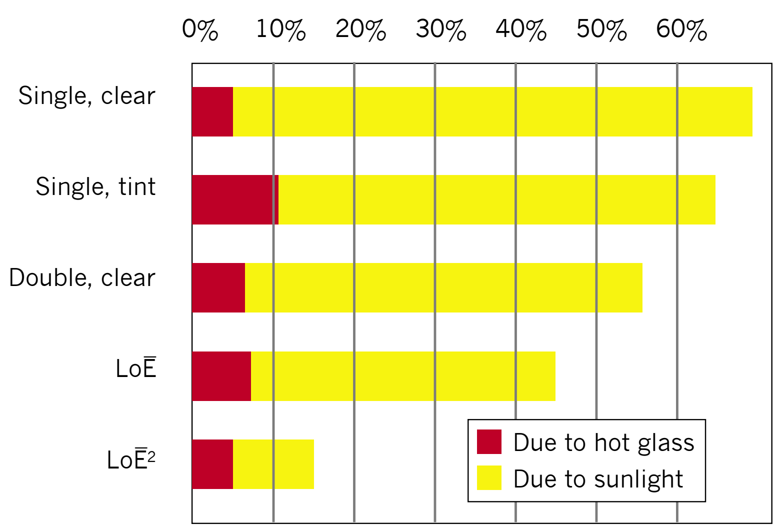
Fig. RB22-1 Comfort Comparisons at 0°F Outdoor Temperature

	Roomside Surface Temperature	Room "Feels" Like	Thermostat Increase to Equal Wall
Single Pane	15°F	61°F	+8°F
Double Pane	45°F	66°F	+3°F
LoĒ^{2} / Argon	56°F	68°F	+1°F
Insulated Wall	66°F	69°F	–

Summertime discomfort comes from two sources: hot glass surfaces and direct solar gain. LoĒ^{2} glass, with its low solar gain characteristics, is the most effective for improving occupant comfort during hot weather.

Sitting in the direct sun with high solar gain glass makes the room feel like 86°F or hotter, even though the cooling thermostat is set to 78°F.

Fig. RB22-2 Summer Discomfort



TSB #IG05 Low-E Performance Comparison

Fig. RB22-3 Thermostat Settings for Window Comfort

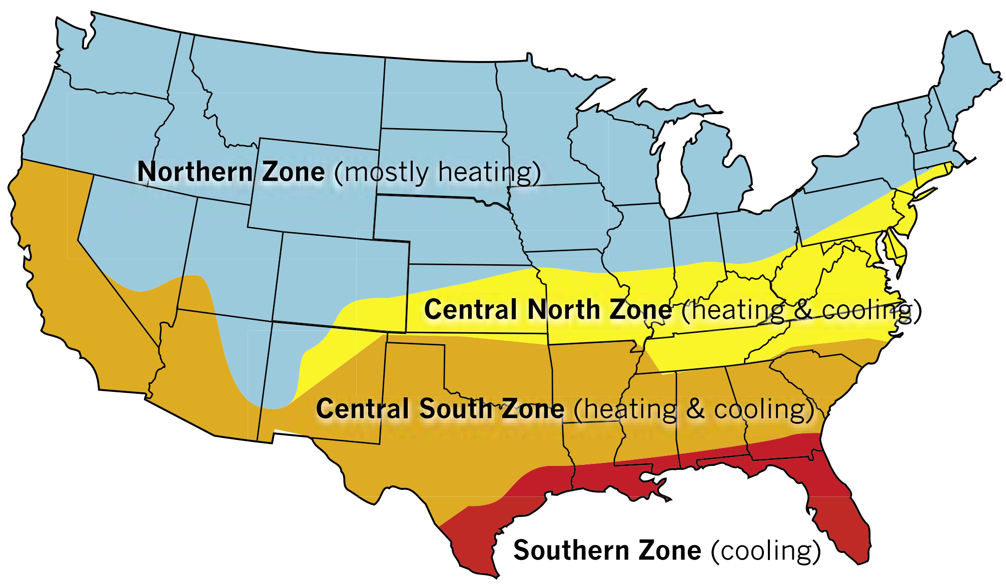
	Heating	Cooling
Double Pane	72°F	74°F
LoĒ or other HSLE	70°F	74°F
LoĒ^{2}	70°F	78°F

The U.S. Department of Energy (DOE) and the Environmental Protection Agency (EPA) have developed the ENERGY STAR® designation for windows used in new and replacement construction. The purpose of the designation is to identify products that meet specific requirements for the benefit of protecting the environment through superior energy efficiency.

The four zones depicted on the map below are used to delineate the program requirements across the country. The program requires NFRC certification of the window U-factor and SHGC.

Energy Star: www.energystar.gov

Fig. RB23-1 Energy Star Zones



Temperature Comparisons at 0°F Outdoor Temperature

Zone	Max. U-factor	Max. SHGC
Northern	0.35	Any
North/Central	0.40	0.55
South/Central	0.40	0.40
Southern	0.65	0.40

In practice these requirements are nearly identical to those in the latest edition of the model energy code by the International Code Council. In those areas of the country where the code has been adopted and enforced, the Energy Star Windows program simply reinforces code requirements in a consumer friendly, easy to understand format.

In regions where code adoption is lagging, the program gives builders a straight forward message to help promote efficient windows in new construction and remodeling.

For the do-it-yourself homeowner, Energy Star makes the selection of efficient replacement windows simple.

The performance targets established by the program will generally require the use of a low-E coating everywhere in the country. Nationally, about one half of the windows sold use low-E so the program can assist in increasing the use of this energy efficient glazing.

Energy Savings & Payback

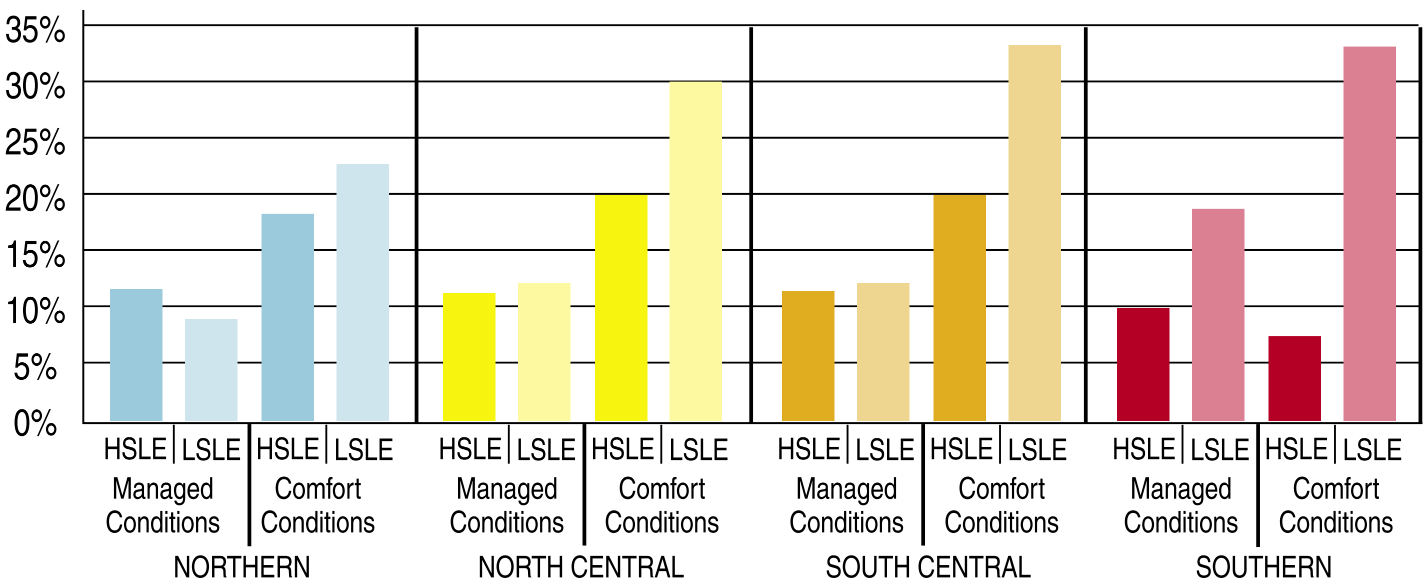
How much can one save in energy costs by using low-E glass in their windows? The answer partly depends on the behavior of the actual homeowner.

Do you use a setback thermostat, open and close the drapes to control the sun, open the windows to ventilate during the swing seasons, and tolerate some seasonal discomfort? If so, you fit the designation of "managed conditions". This homeowner's active participation has already reduced the home energy bill to a large extent.

Do you adjust the thermostat to provide the best comfort year-round? Do you like to see out your windows during the daytime? Are you more concerned with the livability of the space than your energy bills? This type of homeowner fits into the category of "comfort conditions" and can derive the most savings from low solar gain low-E windows.

Fig. RB24-1 compares a high solar gain low-E (HSLE) to a low solar gain low-E (LSLE) across the four Energy Star climate zones for the two types of homeowners. With the exception of a "managed conditions" homeowner in the northern climate zone, the low solar gain low-E option provides the best energy savings and year-round comfort.

Fig. RB24-1 Annual Savings vs. Double Pane



The payback period for an investment in low-E glass will vary with the operational style. Consider an example house in the northern climate zone that has a total heating and cooling bill of $1000 a year when operated in the "comfort conditions" mode. That same house operated in a "managed conditions" style could have an energy bill 20% lower - $800 per year. If the incremental cost to add low-E into all the windows of the house is $400, the range in payback will be 2 to 5 years. Note also that good windows will have diminished much of the impact of the lifestyle characteristics. Low-E glass and in particular LSLE allow the homeowner to enjoy their living space to the fullest extent possible and without a significant energy penalty.

Acoustics

Like U-factor and SHGC, the acoustical performance of windows is best evaluated as a whole product. Even with the best glazing, a window with air-leakage problems will have poor sound control. Some general rules on glass selection include:

- Laminated glass is a very effective glass product for sound control
- The more glass layers (single, double, triple pane), the greater the sound attenuation will be
- Mismatching of glass thicknesses in IG and laminated units can further enhance sound reduction
- Airspaces greater than 2" improve sound reduction
- Argon gas has no effect on sound transmission

Distortion

Distortion in a glass unit refers to the perception of optical imperfections. Distortion is caused by light being reflected and refracted at different angles through non-parallel glass surfaces. Normally distortion is only viewable from the outside with reflected light. It is difficult to see distortion from the inside as the viewer can't get far enough away from the glass to see the refractions. For monolithic glass, distortion will typically be caused by the rapid heating and cooling process used for heat strengthening or tempering. Deflection of window framing systems, glazing pressure around the periphery of the glass, and windloads are some of the other common sources of distortion. With insulating glass units, distortion can be caused by all of these factors plus the response of the sealed unit to changes in environmental conditions (e.g., altitude, temperature, barometric changes).

It is important to understand that many of the distortions seen in glass are not defects, but rather the result of glass processing or the response to external influences.

TSB #IG09 Glass Acoustical Information

TSB #IG20 Distortion in Glass Products

TSB #IG11 Fading

Fading

Research has shown that the spectrum of damaging solar radiation is a broad range of sunlight – starting with the ultraviolet and continuing into most of the visible light region. The spectrum of fade potential is called Damage Weighted Transmittance and is the best representation of relative fade rates between glazing products.

Fig. RB25-1 Damage-Weighted Transmittance

	Color	UV Only	Damage Weighted (Tdw)
Laminated Glass	Clear	2%	65%
Double Pane, Clear	Clear	58%	61%
LoĒ-178™	Clear	23%	62%
LoĒ²-170®	Clear	14%	53%
LoĒ²-140®	Tinted	16%	35%

Glass products with reduced visible light transmission provide the greatest protection against fading.

Glazing Requirements

Good glazing practices can prevent glass breakage problems and premature IG seal failure. General guidelines include:

- Setting blocks at the 1/4 points
- 4-sided support
- Drain system (weep) for bottom rail
- Compatible gaskets and sealants

For detailed glazing recommendations, see the 2004 GANA Glazing Manual.

High Altitude

GANA—Glass Association of North America www.glassweb-site.com

Atmospheric pressure goes down with altitude. When a sealed insulating glass unit is installed at high altitude, the pressure change will bow the glass panes outward. The maximum allowable pressure change could be limited by one of three factors:

1. Glass breakage
2. Damage to the IG seal
3. Unacceptable visual distortion

The limits below have been developed based on glass and edge seal strength, without regard to possible distortion concerns.

Fig. RB26-1 Altitude Limits for Insulating Glass Units

Short Glass Dimension:		10"	15"	20"	25"	30"	35"	40"	45"	50"
Glass Thickness & Type		Maximum Installed Altitude (ft. elevation)								
2.2 mm	Annealed Tempered	5000	5000 7000	6000 10000	8000 10000	10000				
3.0 mm	Annealed Tempered		5000	6000 7000	7000 9000	8000 10000	10000			
3.9 mm	Annealed Tempered			5000	5500 7000	6000 9000	7000 10000	8000 10000	10000	
4.7 mm	Annealed Tempered				5000	5500 7000	6000 9000	7000 10000	8000 10000	10000 10000
5.9 mm	Annealed Tempered					5000	6000	7000 8000	8000 10000	9000 10000

In most instances there is no concern for ship-through limits.

Fringes

An optical phenomenon called Interference Fringes can be observed in IG units with matched glass thickness. The fringes can look like an oil stain or iridescence in the glass, and are the result of inter-reflections through equal glass thicknesses. Fringes are more pronounced when viewed at an angle to the glass surface and in units with thin glass (2.2 & 3.0 mm thick).

Glass that has been heat-strengthened or tempered is less likely to show the interference due to the surface undulations inherent with the heat treatment process. Fringes are not a defect, but can be suppressed by mismatching the glass thicknesses. A thickness difference as small as 0.1 mm (0.004 in.) has been selected by some window manufacturers in an effort to deliberately suppress the likelihood of fringe occurrence.

Plant Growth

Generally speaking, if a plant will grow behind ordinary glass it will also grow behind "clear" LoĒ™, LoĒ^2®, and laminated glass products. The spectral range in which plant photosynthesis occurs includes only the visible light region. Even though a glass product may block portions of the UV and/or solar infrared, the visible light transmission can be used as the indicator of relative growth rates. Low-E coatings have been used in windows for over 20 years with no evidence of an impact on plant growth characteristics.

Plant growth can still be acceptable with lower light transmission products such as LoĒ^2-140® glass if the window area is large enough. Photosynthesis comes from the total energy a plant is exposed to. Larger windows will increase both the total illumination and the total time a plant is exposed to sunlight.

Fig. RB27-1 Size Limits & Physical Properties for Cardinal IG Units

Glass Thickness (mm)	Approximate Weight (lb/ft^2)	Min. Short Glass Dimension for Argon Filled Unit (in.)	ANNEALED GLASS: Max. Long Dimension (in.)	ANNEALED GLASS: Max. Area (ft^2) Aspect Ratio Less than 2	ANNEALED GLASS: Max. Area (ft^2) Aspect Ratio Greater than 2	HEAT-TREATED GLASS: Max. Short Dimension (in.)	HEAT-TREATED GLASS: Max. Long Dimension (in.)	HEAT-TREATED GLASS: Max. Area (ft^2)
2.2	2.4	8	70	12	8	---	70	15
3.0	3.2	12	81	18	12	36	81	21
3.9	4.2	16	91	24	20	48	91	30
4.7	5.0	20	100	34	26	60	100	40
5.7	6.5	24	120	44	36	83	143	60

(Area limits based on 40 psf windload)

Thermal Stress

Thermal expansion occurs when the center of glass is warmer than the edge of glass; this induces a tensile stress on the edge and creates a risk of breakage. For residential windows, the cold winter night condition is usually the worst case. When solar absorptive glass products are used (low-E coating on #3 surface or any body-tinted glass) the daytime conditions could become the worst case.

If the glass was chipped or damaged during window production the risk of breakage can be higher. A low-stress thermal break initiates at the area of edge damage and is characterized by a single fracture line that runs out perpendicular from the edge. Most low stress breaks occur during the first exposure to extreme weather. In the second year of installation the chance of any subsequent breakage is greatly diminished.

High thermal stress fractures will have multiple break lines emanating from the edge. These types of breaks indicate a window design problem. TSB #IG07 presents heat treatment guidelines to avoid high stress conditions. Follow these additional recommendations for all windows:

- Install drapes and blinds away from the glass and provide proper ventilation
- Air registers for heating/cooling should be on the room side of shading devices (not between the glass and shade).
- Do not install solar control retro-fit films on the room-side glass. These products absorb sunlight which will stress the inboard lite.

TSB #IG07 Heat Treatment Guidelines

Fig. RB27-2 Glass Performance Data

Glass: Type	Glass: Coating	Visible Light Transmittance	Reflectance: Out	Reflectance: In	SHGC	U-Factor: Air	U-Factor: Argon	Fading Transmission
1-Pane	Clear	0.90	0.08	0.08	0.86	1.04	---	0.84
1-Pane	Bronze Tinted	0.68	0.07	0.07	0.73	1.04	---	0.58
2-Pane	Clear	0.81	0.15	0.17	0.76	0.48	---	0.74
2-Pane	Bronze Tinted	0.61	0.10	0.14	0.63	0.48	---	0.52
2-Pane	LoĒ-178 #3 Surface	0.78	0.12	0.12	0.63	0.31	0.27	0.62
2-Pane	LoĒ^2-172 #2 Surface	0.72	0.11	0.12	0.41	0.30	0.25	0.55
2-Pane	LoĒ^2-170 #2 Surface	0.70	0.12	0.13	0.37	0.30	0.25	0.53
2-Pane	LoĒ^2-140 #2 Surface	0.40	0.14	0.10	0.25	0.30	0.26	0.35
2-Pane	LoĒ^2-138 #2 Surface	0.38	0.13	0.12	0.24	0.30	0.25	0.33
3-Pane	LoĒ^2-172 #2 Surface	0.66	0.15	0.18	0.38	0.22	0.19	0.50
3-Pane	LoĒ^2-172 #2 & #5 Surfaces	0.58	0.13	0.13	0.35	0.16	0.13	0.40

Notes: All values calculated using Window 5.2 and represent center of glass properties. (See http://windows.lbl.gov/software/default.htm for more on the Window program) All glass is 3mm thick, 1/2" gap width, and argon assumes 90% fill (10% air).