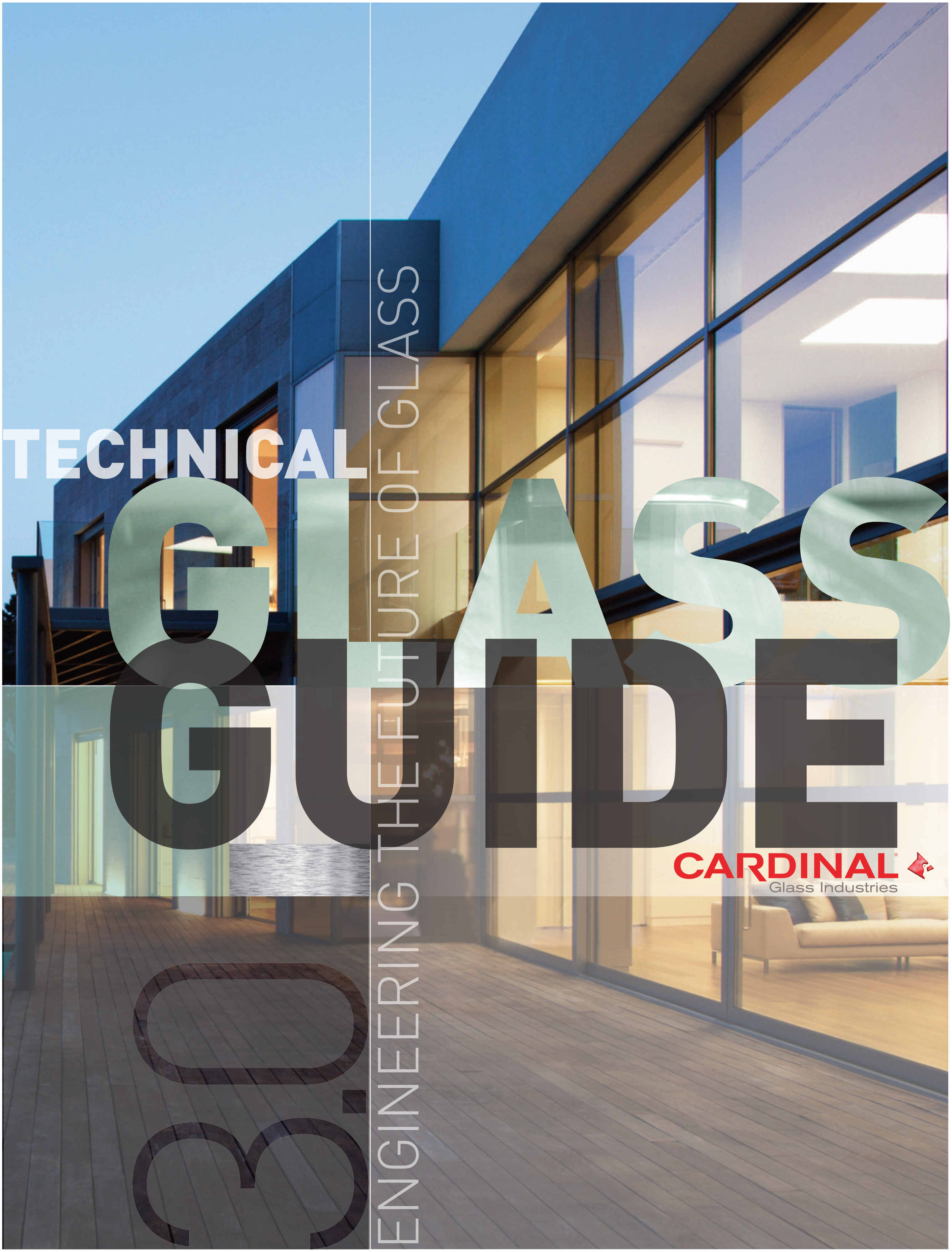


TECHNICAL GLASS GUIDE

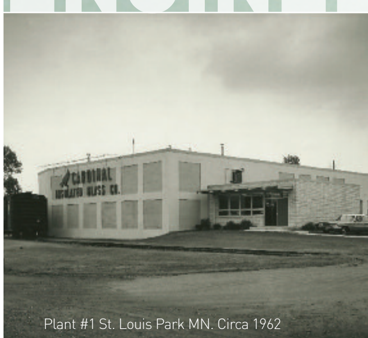
3.0

ENGINEERING THE FUTURE OF GLASS

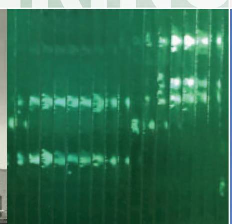
CARDINAL
Glass Industries

Cardinal Glass Industries is a privately held, management-owned company headquartered in Eden Prairie, Minnesota, operating from five wholly owned subsidiaries with factories located across the United States. More than 7,000 employees serve a broad domestic and international customer base.

ENGINEERING THE FUTURE OF GLASS



Plant #1 St. Louis Park MN. Circa 1962



Founded in 1962, Cardinal Glass is a leading provider of superior-quality glass products. Architects, designers and manufacturers worldwide trust Cardinal for the glass technologies and energy-saving insulating glass designs they need to specify top-of-the-line residential windows and doors.

Our extensive footprint and vertically integrated operations enable consistently high levels of manufacturing agility and fulfillment responsiveness for our customers.

Plant #45 BEIG. Buckeye AZ. 2020

INTERACTIVE TABLE OF CONTENTS

How to use this guide

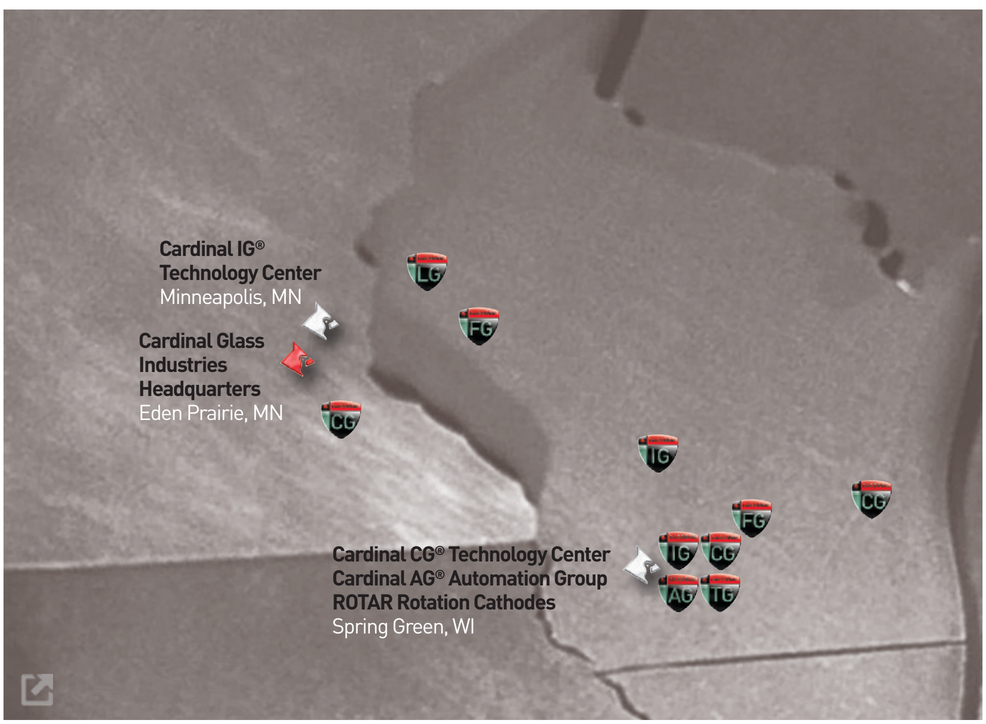
This document is interactive. These tools are included throughout to help you navigate more easily and quickly find the information you need.

1. **Links in the Table of Contents** allow you to jump directly to any of the seven sections or specific subject within each.
2. **External links** take you to the Cardinal website for more detailed information on specific subjects.
3. **Page navigation tools** give you the option to print, go to last page, go back or forward one page, or return to the Table of Contents from any page.

With Cardinal facilities and service teams nationwide, you'll receive the products and support you need, when you need it.

Cardinal IG® Co.
(Insulating Glass)
Buckeye, AZ
Fargo, ND
Fremont, IN
Greenfield, IA
Hood River, OR
Roanoke, VA
Spring Green, WI
Tomah, WI
Waxahachie, TX
Wilkes-Barre, PA

Cardinal CG® Co.
(Coated Glass)
Buford, GA
Galt, CA
Northfield, MN
Spring Green, WI
Tumwater, WA
Waxahachie, TX
(Tempered Only Production)
Casa Grande, AZ
Moreno Valley, CA
Loveland, CO
Mazomanie, WI



Cardinal LG® Co.
(Laminated Glass)
Amery, WI
Jessup, PA
Ocala, FL

Cardinal CT® Co.
(Custom Tempering)
Adel, GA
Easton, PA
Fort Worth, TX
Los Angeles, CA
Mount Airy, NC
Uitca, OH

Cardinal FG® Co.
(Float Glass)
Durant, OK
Menomonie, WI
Mooresville, NC
Portage, WI
Winlock, WA
(Tempered Only Production)
Chehalis, WA

LoĒ Coated Glass

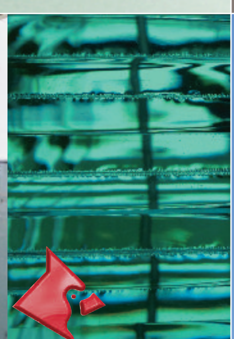
Laminated Glass

Insulating Glass

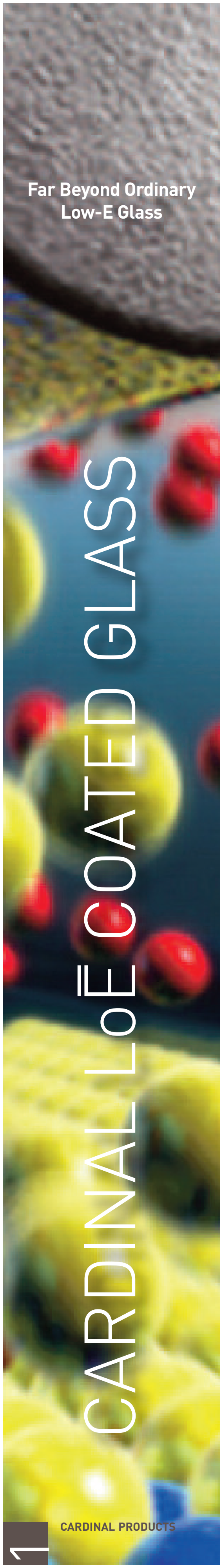
Neat+™ Glass

Preserve® Film

From LoĒ coated glass to insulating glass units and naturally cleaner glass, Cardinal is your one-stop partner for products that exceed your customers' expectations, now and well into the future.



PRODUCTS SECTION



Cardinal LoĒ glass sets the industry standard for energy-efficient coated glass. Our patented, world-class sputtered LoĒ coatings remain unmatched for their quality, aesthetics and performance. These coatings are virtually clear, blocking the heat and reducing solar gain while optimizing light transmission. This helps to reduce electrical loads while protecting interior furnishings from UV damage.

Options for Every Application

The vast portfolio of energy-efficient Cardinal LoĒ glass options includes one, two, three and now even four layers of performance to keep rooms comfortable, views glare-free and energy bills manageable for homeowners in any weather.

PREMIUM PERFORMANCE GLASS FOR ALL CLIMATES

[Four silver layers]

Quad LoĒ-452+™ has superior solar control with SHGC (solar heat gain coefficient) of 0.22, best-in-class low emissivity, low exterior reflection and 99% UV radiation blocking which is the highest among Cardinal coated glass, to protect interior furnishings from fading. This coating is designed to be on surface #2 in a double-pane or triple-pane insulating glass unit.

ULTIMATE PERFORMANCE GLASS FOR ALL CLIMATES

[Three silver layers]

LoĒ³-366® delivers the perfect balance of solar control and high visible light transmission. This coating is designed to be on surface #2 in a double-pane or triple-pane insulating glass unit. It will provide comfort and energy savings during hot weather days and provide a great thermal insulating quality by preventing heat to conduct through the insulating glass unit. It also blocks 95% of UV light infiltration.

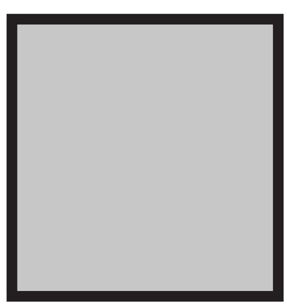
LOW SOLAR GAIN GLASS

[Three silver layers]

Solar radiation and glare control (three silver layers), designed to be on surface #2 in a double-pane or triple-pane insulating glass unit. LoĒ³-340® provides an industry-leading Solar Heat Gain Coefficient (SHGC) of 0.18 in a double-pane insulating glass unit. It also blocks 98% of UV light infiltration.

CLEAR | Quad LoĒ-452+

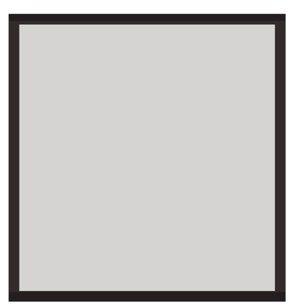
TRANSMITTED APPEARANCE



EXTERIOR APPEARANCE

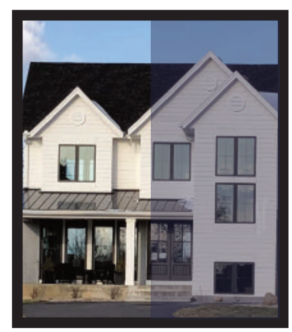
CLEAR | LoĒ³-366

TRANSMITTED APPEARANCE



EXTERIOR APPEARANCE

CLEAR | LoĒ³-340



TRANSMITTED APPEARANCE

EXTERIOR APPEARANCE

ADVANCED PERFORMANCE GLASS FOR MOST CLIMATES

[Two silver layers]

Balanced solar control coating (two silver layers), provides year-round thermal performance and comfort. Designed to be on surface #2 in a double-pane or triple-pane insulating glass unit.

ADVANCED PERFORMANCE GLASS FOR MOST CLIMATES

[Two silver layers]

Balanced solar control coating (two silver layers), provides year-round thermal performance and comfort. Filters more solar radiation than the LoĒ²-272® coating, which provides a slightly better solar heat gain coefficient (SHGC) value. Designed to be on surface #2 in a double-pane or triple-pane insulating glass unit.

HIGH SOLAR GAIN GLASS

[One silver layer]

LoĒ-180® and 180 ESC™: High solar gain coating (one silver layer), LoĒ-180 and LoĒ-180 ESC are ideal for passive solar applications. They allow the sun's radiant heat to pass into the home while providing a thermal insulating quality to prevent conductive heat loss to the outside. Both coatings are designed for surface #3 placement in the insulating glass unit. Because of the high visible light transmission, it is the ideal coating for use in combination with Cardinal's low SHGC products in triple-pane windows. LoĒ-180 ESC was specifically engineered to meet the Energy Star Canada performance requirements.

ENHANCED PERFORMANCE GLASS

[One indium tin oxide layer]

High solar gain coating (Indium Tin Oxide), neutral in color and designed as a durable room side glass coating, thus reflecting escaping heat back into the room and lowering U-Factors. LoĒ-Di89™ is LoĒ-i89® coating sputtered onto both sides of a single lite of glass. It is designed to be used on the indoor lite of an insulating glass (IG) unit. LoĒ-Di89 can be used to optimize Canadian ER values to meet the Energy Star Canada building codes.

MOISTURE CONTROL GLASS

[One indium tin oxide layer]

LoĒ-x89® is a neutral color exterior glass surface coating (indium tin oxide) which reduces outdoor glass condensation. Designed for surface #1 in a double-pane insulating glass unit to reduce heat loss and the occurrence of the glass falling below the dew point. This reduces the opportunity for exterior condensation to occur. In addition, LoĒ-x89 has a titanium dioxide coating which keeps the exterior glass surface cleaner for a longer period.

CLEAR | LoĒ²-272

TRANSMITTED APPEARANCE

EXTERIOR APPEARANCE

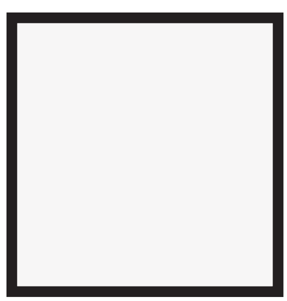
CLEAR | LoĒ²-270

TRANSMITTED APPEARANCE

EXTERIOR APPEARANCE

CLEAR | LoĒ-180

TRANSMITTED APPEARANCE



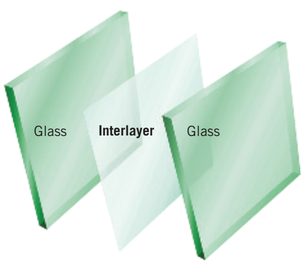
EXTERIOR APPEARANCE

LoĒ-i89 AND LoĒ-Di89 HAVE MINIMAL TO NO EFFECT ON REFLECTED AND TRANSMITTED COLOR. THE ACCOMPANYING LOE GLASS SPECIFIED WILL DOMINATE THE COLOR PROFILE OF THE IGU.

LoĒ-x89 HAS MINIMAL TO NO EFFECT ON REFLECTED AND TRANSMITTED COLOR. THE ACCOMPANYING LOE GLASS SPECIFIED WILL DOMINATE THE COLOR PROFILE OF THE IGU.

Laminated glass remains a highly a popular option due to its unique combination of desirable performance properties. Laminated glass is constructed with two or more plies of glass permanently bonded together with one or more polymeric interlayers.

When breaking on impact, the glass fragments adhere to the interlayer, keeping the glass intact and resisting penetration. This construction also offers an excellent buffer against sound and harmful UV radiation infiltration.



Facilitated by our defect-free float glass and stringent quality control measures, Cardinal leads the market in premium laminated glass. We offer multiple configurations for the full range of applications and building codes. Our vertical integration and vast manufacturing network ensure rapid order fulfillment, from our factory to yours.

Safe and Secure

If laminated glass is broken, the glass fragments adhere to the interlayer for a strong barrier against forced entry. It also cannot be cut with glass cutters. Cardinal laminated glass can be specified to meet the American Society of Testing Materials standard for preventing forced entry (ASTM F1233) and the burglary-resistant guidelines issued by Underwriters Laboratories (UL972).

Exceptional Sound Control

Laminated glass offers an effective approach to reducing unwanted outside noise. ASTM has developed the Sound Transmission Class (STC) and Outdoor/Indoor Transmission Class (OITC) rating systems to describe how well a building partition attenuates airborne sound. The higher the STC/OITC rating, the greater the sound transmission loss.

Cardinal laminated glass has much higher STC/OITC ratings than monolithic glass. When combined with an insulating glass (IG) unit, the rating increases even more.

Protects from Fading

Fabric, furniture and other materials fade and become discolored over time when portions of the solar energy spectrum enter a room. Cardinal laminated glass blocks over 99% of damaging UV energy while allowing most of the visible light to make it through. That's significantly more fade protection than ordinary glass to help keep your furnishings looking like new.

SAFETY

SOUND

UV PROTECTION

Impact-Rated Laminated Glass

Certified Impact-Rated Glass for Hurricane Zones

During windstorms and hurricanes, windows must resist penetration from windborne wreckage and remain in place to protect a home. Specially designed laminated glass products pass windborne debris impact tests because broken glass fragments remain integral and adhere to the plastic interlayer, helping to preserve the stability of the building envelope.

Featuring a heavy-duty interlayer that is three times thicker than our standard high-strength laminated glass, Sea-Storm® Impact-Rated laminated glass meets the most stringent building codes in areas prone to hurricanes or other high-wind events such as tornados. Investing in windows and doors made with Sea-Storm laminated glass could save a home or even a life.

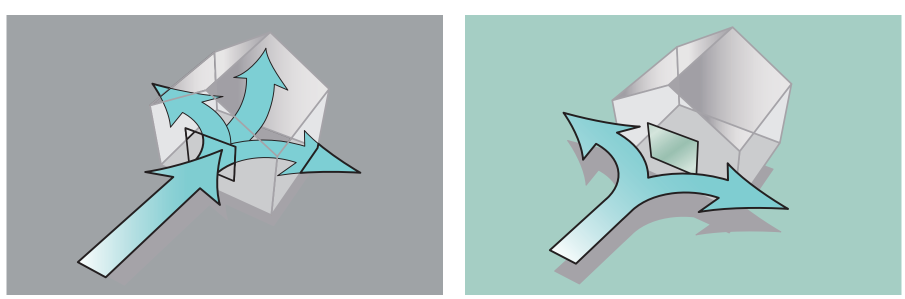


Figure 1-1

When a building envelope is breached through a broken window, wind can enter the building and create a sudden pressure increase that lifts the roof and pushes the walls outward, causing the building to collapse. Sea-Storm® Impact-Rated laminated glass helps preserve the building envelope, minimizing the damage from wind, rain and other elements.

Setting the Standard for Long-Term Glass Performance

CARDINAL INSULATING GLASS

Most glass manufacturers focus on U-Factor and SHGC with their products' performance. Durability, which speaks to performance over the long term, is equally critical to these other glass attributes.

Cardinal insulating glass (IG) units deliver the industry's lowest failure rate and most comprehensive factory warranty, plus superior thermal performance and solar control to handle both weather extremes. With its proven seal durability, Endur IG® will save heating and cooling energy for years to come.

Endur IG: Industry's Lowest Failure Rate
Endur IG glass is built on proven technologies that help Cardinal IG units achieve a seal failure rate of only 0.20% over 20 years, allowing us to offer the industry's leading comprehensive 20-year factory warranty. More than 350,000,000 Cardinal IG units are currently under warranty.

To validate this long-term seal durability, Endur IG units are subjected to the demanding P-1 test involving test critieria that simulate worst-case, real-world scenarios: Constant 140 ºF, water spray and UV exposure. See Figure 1-2 below.

Specifying Endur IG helps to mitigate risk and protect your margins while also reducing your warranty service costs.

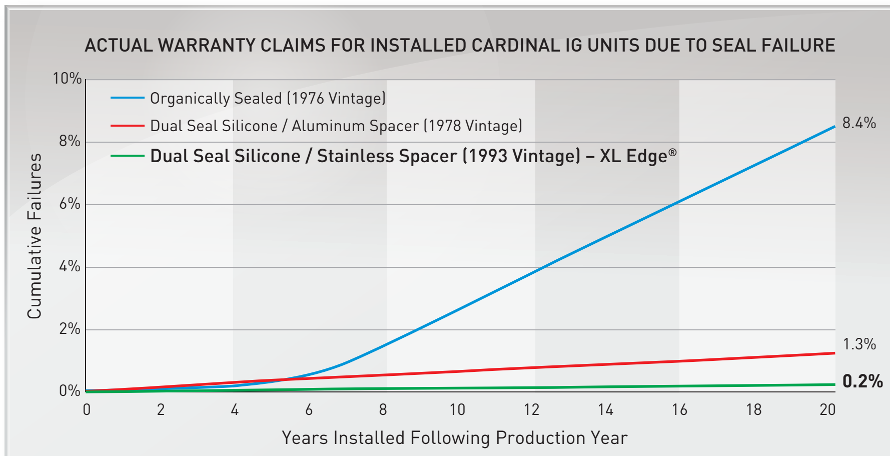
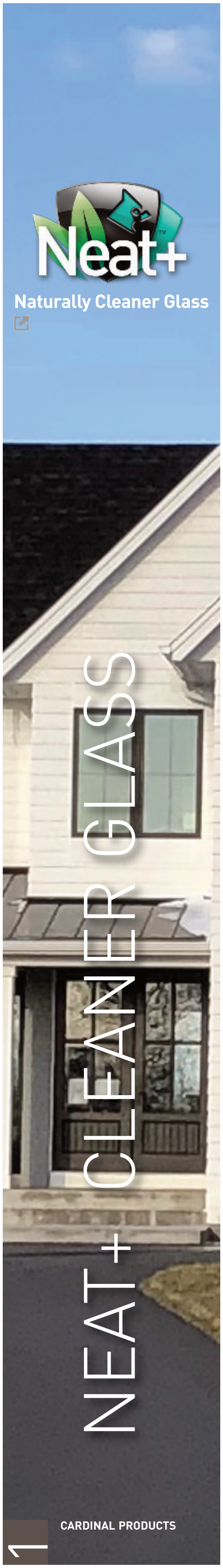


Figure 1-2

Innovative Spacer is Key
Endur IG incorporates a warm-edge, stainless steel spacer that improves sightline temperature by 1 to 2 degrees Fahrenheit compared to traditional Cardinal XL Edge®, and improves resistance to condensation. It is also more aesthetically pleasing. The spacer's corrugated shape adds strength. Bent corners (not notched or open joints) create a continuous, impermeable metal barrier around the entire perimeter, keeping moisture out and argon in.

The end result is an IG unit that can improve overall window U-Factor, making Endur IG one of the warmest edge products on the market.



Since 2006, more than 50 million windows with Neat® glass have been sold, serving as the leading product for low-maintenance glass.

Now, Cardinal CG offers Neat+™ glass, the next generation of coating technology that results in naturally cleaner glass.

Less Dust, Fast and Easy to Clean

Exterior window surfaces require constant maintenance, but not so with Neat+ glass, because the glass stays cleaner longer. And when you must clean your glass, it will be faster and easier.

Neat+ is 25% more photoactive than Neat. It uses static dissipation to reduce the amount of dust on the window's surface, as a titanium oxide layer reacts chemically with the sun's UV rays to break down greenhouse gases and other pollutants to clean the window naturally.

The Greener Choice

Test results from an outside lab show 40% less dust on the Neat+ surface compared to uncoated glass, keeping the window cleaner longer. Homeowners use less water and cleaning chemicals as a result, saving time, money and the environment.

Cardinal's Neat+ fabrication methods also contribute to environmental efficiency. Our patented double-sputtering process permanently deposits silicon and titanium dioxide on the bottom of the glass during the same pass through the coater as our energy-efficient LoĒ coatings, reducing the amount of energy needed to coat both glass surfaces.

LoĒ Comfort and Efficiency

When fabricated with Cardinal's low-emissivity LoĒ coatings, Neat+ glass provides year-round indoor comfort and annual savings in heating and cooling.

Conductive Surface = 40% Less Dust

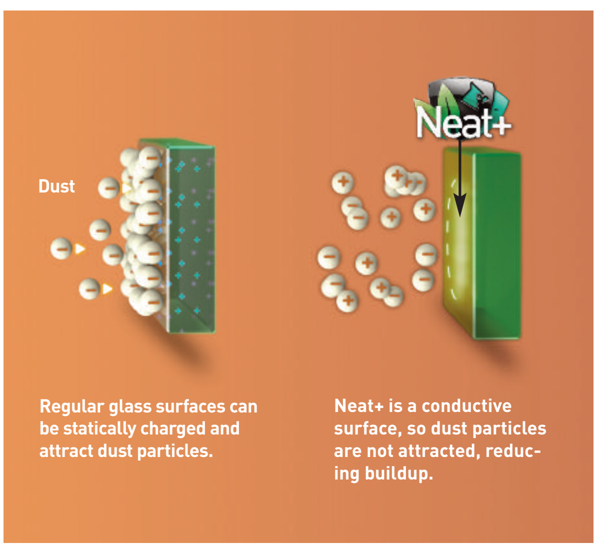


Figure 1-3

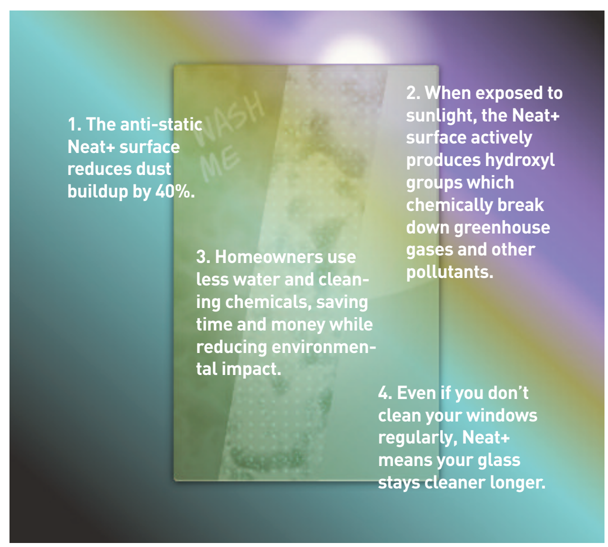


Figure 1-4

Protective Film

PROTECTIVE FILM

At Cardinal, our goal is to ensure that glass leaves our factories in perfect condition. However, after it leaves the production facility, glass can be damaged in shipping and handling. Glass can get scratched or damaged on the job site during construction. It can also get spattered with materials used in the construction process; i.e., paint, stains, stucco, spackling, etc. Glass is also exposed to the dirty environment in construction that will leave mud, dust and dirt on the glass.

With Preserve® film, cleanup is a snap. Preserve film is a clear, protective film that is factory-applied in overlapping layers, ensuring that the entire glass surface is protected. It can be applied to both the inner and outer surfaces of insulating glass (IG) units.

After the job is completed, Preserve film easily peels off, taking all the accumulated dirt and labels with it. There's no need for razor blade cleanup, so you reduce the risk of scratched glass and the costly window replacement associated with it.

Because Preserve film contains no harmful chemicals or byproducts, it can be recycled or disposed of with the rest of the normal construction site debris. Preserve film saves you time, money and a lot of hassle.

Facts About Preserve Film

- Preserve film incorporates a water-based adhesive and is a low-density polyethylene film.
- Preserve film should be removed within nine months of installation.
- Do not affix permanent grilles or external fixtures directly to Preserve film.
- Use of Neat+, highly absorptive coatings, or exposure to high-humidity and high-temperature locations may increase the degradation rate of the Preserve film, which may lead to required early film removal.
- Do not use razor blades or metal scrapers to remove Preserve film.
- Preserve film is covered by one or more of the following U.S. patents: 5,020,288; 5,107,643; 5,599,422; and 5,866,260.

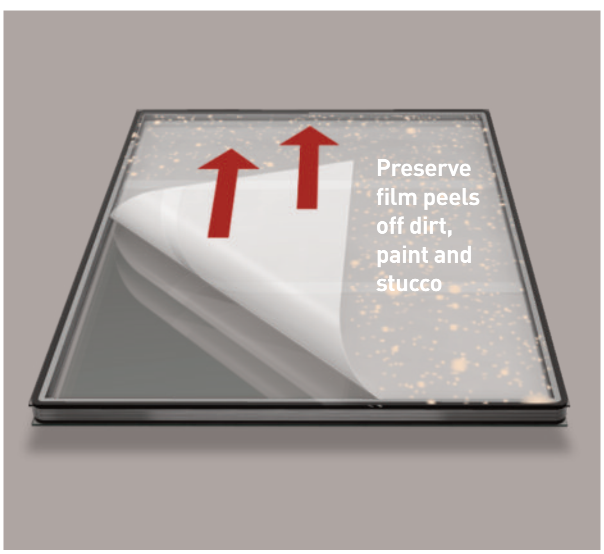


Figure 1-5

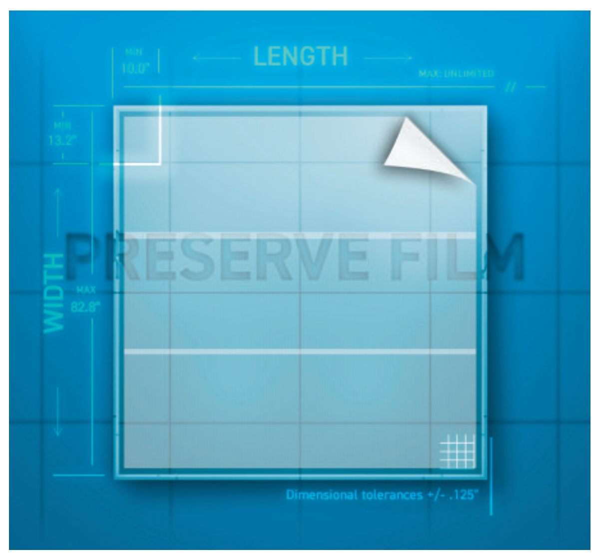
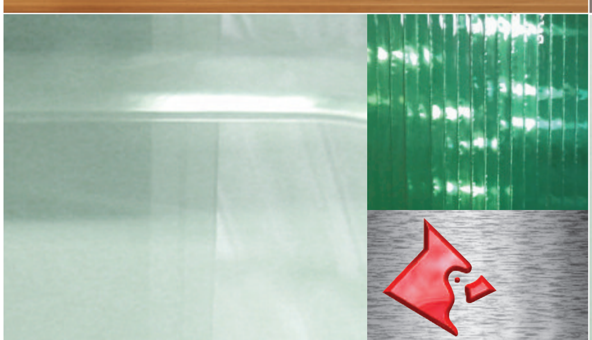


Figure 1-6

From thermal performance to solar energy transmission to fading protection and more, this section contains technical data comparing the performance of Cardinal glass products with each other as well as with clear double-pane, LoĒ coated double-pane and LoĒ coated triple-pane, where applicable.



PER-FOR-MANCE SECTION

2

Energy Terminology

Center of Glass
Values that do not take into account the effects of the window frame or sash. Center of Glass values are the properties of the glass or insulating glass unit only.

Condensation Resistance (CR) measures how well a window resists the formation of condensation on the inside surface. CR is expressed as a number between 1 and 100. The rating value is based on interior surface temperatures at 30%, 50% and 70% indoor relative humidity for a given outside air temperature of 0 ° Fahrenheit under 15 mph wind conditions. The higher the number, the better a product is able to resist condensation. CR is meant to compare products and their potential for condensation formation.

ISO-CIE Function
A method for calculating damage-weighted transmittance developed by the International Standards Organization (ISO), which uses a weighting function recommended by the International Commission on Illumination (CIE). This method assigns a specific damage weighted transmittance to each wavelength of UV and visible light according to its contribution to the fading of materials and fabrics. Its spectral range is from 300 to about 700 nm.

Outdoor Visible Light Reflectance
In the visible spectrum, the percentage of light that is reflected from the glass surface(s) relative to the CIE Standard Observer.

Relative-Heat Gain (RHG)
The total amount of heat gain through a glazing system at NFRC (National Fenestration Rating Council) and ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) specified summer conditions, incorporating the U-Factor and the solar heat gain coefficient (SHGC). The conditions are 230 BTU/hr/ft^2 (726 W/m^2) outdoor temperature of 89 °F (32 °C), indoor temperature of 75 °F (24 °C) and 6.2 mph (2.8 m/s) wind (RHG = Usummer x (89-75) + SHGC x (230). Expressed in terms of BTU/hr/ft^2.

R-Value
The thermal resistance of a glazing system expressed in hr•ft^2•°F/BTU. R-Value is the reciprocal of U-Factor, R=1/U. The higher the R-Value, the less heat is transmitted through the glazing material. R-Values are not listed in this document.

Sightline
The area of the IGU that is not transparent due to the presence of the spacer and sealants.

Glass Surfaces
The industry convention is to label the outermost, outdoors-facing surface as #1 and then work sequentially toward the final indoors-facing surface.

Solar Radiation Reflected
In the solar spectrum (300 to 2,500 nm), the percentage of solar energy that is reflected from the glass surface(s).

Solar Radiation Transmitted
In the solar spectrum (300 to 2500 nm), the percentage of ultraviolet, visible and near infrared energy that is transmitted through the glass.

Solar Heat Gain Coefficient (SHGC)
The fraction of incident solar radiation that enters a building as heat. It is based on the sum of the solar energy transmittance, plus the inwardly flowing fraction of absorbed solar energy on all lites of the glazing. Dimensionless and varying between 0 and 1, the smaller the number, the better the glazing is at preventing solar gain.

U-Factor
The heat flow rate through a given construction, expressed in BTU/hr/ft^2/°F (W/m^2/°C). The lower the U-Factor, the less heat is transmitted through the glazing material. Values given for summer daytime are calculated for outside air temperature at 89 °F (32 °C), outside air velocity at 6.2 mph (2.8 m/s), and inside air temperature of 75 °F (24 °C), and a solar intensity of 248 BTU/hr/ft^2 (783 W/m^2). Winter nighttime U-Factors are calculated for outside air temperature at 0 °F (-18 °C), outside air velocity at 12.3 mph (5.5 m/s) and a solar intensity of 0 BTU/hr/ft^2 (0 W/m^2). Unless otherwise noted, all U-factors provided use winter nightime conditions.

Ultraviolet Light
In a portion of the solar spectrum (300 to 380 nm), the energy that accounts for the majority of fading of materials and furnishings.

Visible Indoor Reflectance
The percentage of visible light that is reflected from the glass surface(s) to the inside of the building. It is better to have a low visible indoor reflectance to enhance visibility when viewing objects outdoors in overcast or nighttime sky conditions.

Visible Light Transmittance
In the visible spectrum (380 to 780 nm), the percentage of light that is transmitted through the glass relative to the CIE Standard Observer.

U.S. CUSTOMARY TO METRIC CONVERSION TABLE

To Convert U.S. Customary Units	To Metric	Multiply By
Inches (in)	Millimeters (mm)	25.4
Feet (ft)	Meters (m)	0.305
Square inches (in^2)	Square millimeters (mm^2)	645
Square feet (ft^2)	Square meters (m^2)	0.093
Pounds (lb)	Kilograms (kg)	0.453
Pounds force (lbf)	Newtons (N)	4.45
Pounds force/in (lbf/in)	Newtons/meter (N/m)	175
Pounds force/inch^2 (lbf/in^2)	Kilopascals (kPa)	6.89
Pounds force/feet^2 (lbf/ft^2)	Kilopascals (kPa)	0.048
BTU/hr	Watts (W)	0.293
BTU/hr·ft^2·°F	W/m^2·°C	5.678
BTU/hr·ft^2	W/m^2	3.15

Figure 2-1

Optical Properties of IG Units

The Optical Properties data shown below can be used to compare performance data on the insulating glass constructions listed.

The visible data given below indicate the amount of visible light transmitted and reflected by the insulating glass construction relative to the CIE Standard Observer.

Solar heat gain coefficient (SHGC) data points indicate the amount of solar gain obtained with the insulating glass construction. The lower the SHGC value, the better the product is at reducing solar gain, resulting in greater summer comfort and reduced cooling costs.

OPTICAL PROPERTIES OF INSULATING GLASS UNITS - DOUBLE PANE

IG Configuration Outboard Lite / Inboard Lite	Glass Thickness		Visible Light			Fading		
	inches	mm	Trans. (%)	Refl. Out (%)	Refl. In (%)	UV Trans. (300 to 380 nm)	ISO-CIE Trans. (300 to 700 nm)	SHGC
Clear / Clear	1/8	3.0	82	15	15	58%	75%	0.78
	1/4	5.7	80	15	15	48%	70%	0.72
Clear / LoĒ-180®	1/8	3.0	79	15	15	29%	63%	0.69
	1/4	5.7	77	14	15	24%	60%	0.64
Clear / LoĒ-180 ESC™	1/8	3.0	79	15	15	25%	61%	0.71
	1/4	5.7	77	14	15	21%	59%	0.62
Clear / LoĒ-Di89™ (#3 & #4)	1/8	3.0	79	14	14	53%	70%	0.71
	1/4	5.7	76	14	13	44%	66%	0.66
LoĒ²-272® / Clear	1/8	3.0	72	11	12	16%	55%	0.41
	1/4	5.7	70	10	11	14%	53%	0.40
LoĒ²-270® / Clear	1/8	3.0	70	12	13	14%	52%	0.37
	1/4	5.7	68	12	12	13%	50%	0.36
LoĒ³-366® / Clear	1/8	3.0	65	11	12	5%	43%	0.27
	1/4	5.7	63	11	12	4%	41%	0.27
Quad LoĒ-452+™ / Clear	1/8	3.0	52	10	15	1%	33%	0.22
	1/4	5.7	51	9	15	1%	32%	0.22
LoĒ³-340® / Clear	1/8	3.0	39	11	13	2%	27%	0.18
	1/4	5.7	38	11	13	2%	26%	0.18
LoĒ²-240® / Clear	1/8	3.0	40	14	11	16%	35%	0.25
	1/4	5.7	37	13	10	13%	32%	0.24
LoĒ-180® / LoĒ-i89® (#4)	1/8	3.0	77	15	14	27%	61%	0.62
	1/4	5.7	75	15	13	23%	58%	0.58
LoĒ²-272® / LoĒ-i89® (#4)	1/8	3.0	70	11	11	16%	53%	0.41
	1/4	5.7	68	10	11	14%	51%	0.39
LoĒ²-270® / LoĒ-i89® (#4)	1/8	3.0	68	12	13	14%	50%	0.36
	1/4	5.7	66	12	12	12%	48%	0.35
LoĒ³-366® / LoĒ-i89® (#4)	1/8	3.0	63	11	12	5%	42%	0.27
	1/4	5.7	61	11	11	4%	40%	0.26
Quad LoĒ-452+™ / LoĒ-i89® (#4)	1/8	3.0	51	10	14	1%	32%	0.21
	1/4	5.7	50	9	14	1%	31%	0.21
LoĒ³-340® / LoĒ-i89® (#4)	1/8	3.0	38	11	12	2%	26%	0.17
	1/4	5.7	37	11	12	2%	25%	0.17
LoĒ²-240® / LoĒ-i89® (#4)	1/8	3.0	39	14	10	15%	34%	0.24
	1/4	5.7	37	13	9	13%	31%	0.23

1. Calculated values using LBNL Window computer program per NFRC environmental conditions.
2. Double-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoĒ products, otherwise air-filled cavity. Coatings on surfaces #2, #3 and/or #4.

Figure 2-2

OPTICAL PROPERTIES OF INSULATING GLASS UNITS - TRIPLE PANE

IG Configuration Outboard Lite / Inboard Lite	Glass Thickness inches	Glass Thickness mm	Visible Light Trans. (%)	Visible Light Refl. Out (%)	Visible Light Refl. In (%)	Fading UV Trans. (300 to 380 nm)	Fading ISO-CIE Trans. (300 to 700 nm)	SHGC
Clear / Clear / Clear	1/8	3.0	75	21	21	48%	67%	0.70
	1/4	5.7	72	20	20	37%	62%	0.63
LoĒ-180® / Clear / LoĒ-180®	1/8	3.0	70	20	20	13%	50%	0.56
	1/4	5.7	67	20	20	11%	47%	0.51
LoĒ²-272® / Clear / LoĒ-180®	1/8	3.0	63	15	18	8%	44%	0.37
	1/4	5.7	60	14	17	7%	42%	0.35
LoĒ²-270® / Clear / LoĒ-180®	1/8	3.0	62	16	19	7%	43%	0.33
	1/4	5.7	59	15	18	6%	41%	0.32
LoĒ³-366® / Clear / LoĒ-180®	1/8	3.0	57	14	18	2%	36%	0.25
	1/4	5.7	54	14	17	2%	34%	0.24
Quad LoĒ-452+™ / Clear / LoĒ-180®	1/8	3.0	57	14	18	2%	36%	0.25
	1/4	5.7	54	14	17	2%	34%	0.24
LoĒ³-340® / Clear / LoĒ-180®	1/8	3.0	34	15	21	1%	23%	0.15
	1/4	5.7	33	14	20	1%	22%	0.18
LoĒ²-240® / Clear / LoĒ-180®	1/8	3.0	35	16	17	7%	28%	0.22
	1/4	5.7	32	15	16	6%	25%	0.20
LoĒ-180® / LoĒ-180® / LoĒ-i89®	1/8	3.0	68	21	19	13%	49%	0.53
	1/4	5.7	65	20	18	10%	46%	0.48
LoĒ²-272® / LoĒ-180® / LoĒ-i89®	1/8	3.0	62	15	16	8%	43%	0.36
	1/4	5.7	59	15	16	6%	41%	0.34
LoĒ²-270® / LoĒ-180® / LoĒ-i89®	1/8	3.0	60	16	18	6%	41%	0.32
	1/4	5.7	57	16	17	5%	38%	0.30
LoĒ³-366® / LoĒ-180® / LoĒ-i89®	1/8	3.0	56	15	17	2%	35%	0.24
	1/4	5.7	53	14	16	2%	33%	0.23
Quad LoĒ-452+™ / LoĒ-180® / LoĒ-i89®	1/8	3.0	45	12	19	1%	27%	0.19
	1/4	5.7	43	12	18	1%	26%	0.18

Figure 2-3

1. Calculated values using LBNL Window computer program per NFRC environmental conditions.
2. Triple-pane IG construction: 5/16" (8.0 mm) airspace, 90% argon filled for LoĒ products. Coatings on surfaces #2 and #5, or #2, #4 and #6.

Center of Glass U-Factors of IG Units

The following tables show how Cardinal LoĒ coatings and argon filling improve center of glass U-Factors.

U-Factor vs. Airspace Thickness
In addition to showing the benefit of LoĒ coatings and argon filling, this table shows that the optimum airspace thickness can range between 7/16" (11.5 mm) and 5/8" (16.0 mm). This illustrates that increasing airspaces greater than 16.0 mm increases U-Factor, thereby decreasing thermal performance.

CENTER OF GLASS U-FACTOR FOR DOUBLE-PANE IG UNITS

Nominal Airspace	1/4 in (6.5 mm)		5/16 in (8.0 mm)		3/8 in (9.8 mm)		7/16 in (11.5 mm)		1/2 in (13.0 mm)		9/16 in (14.5 mm)		5/8 in (16.0 mm)		11/16 in (17.5 mm)		3/4 in (19.5 mm)	
Gas Fill	air	argon	air	argon	air	argon	air	argon	air	argon	air	argon	air	argon	air	argon	air	argon
Clear / Clear BTU/hr·ft^2·°F	**0.54**	**N/A**	**0.52**	**N/A**	**0.50**	**N/A**	**0.48**	**N/A**	**0.48**	**N/A**	**0.48**	**N/A**	**0.48**	**N/A**	**0.48**	**N/A**	**0.49**	**N/A**
(W/m^2·K)	(3.07)	(N/A)	(2.95)	(N/A)	(2.84)	(N/A)	(2.73)	(N/A)	(2.73)	(N/A)	(2.73)	(N/A)	(2.73)	(N/A)	(2.73)	(N/A)	(2.78)	(N/A)
Clear / LoĒ-180® BTU/hr·ft^2·°F	**0.40**	**0.33**	**0.36**	**0.29**	**0.33**	**0.27**	**0.31**	**0.26**	**0.31**	**0.26**	**0.31**	**0.27**	**0.32**	**0.27**	**0.32**	**0.27**	**0.32**	**0.28**
(W/m^2·K)	(2.27)	(1.87)	(2.04)	(1.65)	(1.87)	(1.53)	(1.76)	(1.48)	(1.76)	(1.48)	(1.76)	(1.53)	(1.82)	(1.53)	(1.82)	(1.53)	(1.82)	(1.59)
Clear / LoĒ-180 ESC™ BTU/hr·ft^2·°F	**0.40**	**0.33**	**0.36**	**0.30**	**0.33**	**0.27**	**0.31**	**0.26**	**0.31**	**0.27**	**0.31**	**0.27**	**0.32**	**0.27**	**0.32**	**0.28**	**0.33**	**0.28**
(W/m^2·K)	(2.27)	(1.87)	(2.04)	(1.70)	(1.87)	(1.53)	(1.76)	(1.48)	(1.76)	(1.53)	(1.76)	(1.53)	(1.82)	(1.53)	(1.82)	(1.59)	(1.87)	(1.59)
LoĒ^2-272® / Clear BTU/hr·ft^2·°F	**0.39**	**0.32**	**0.35**	**0.28**	**0.32**	**0.26**	**0.30**	**0.25**	**0.30**	**0.25**	**0.30**	**0.26**	**0.31**	**0.26**	**0.31**	**0.26**	**0.31**	**0.27**
(W/m^2·K)	(2.21)	(1.82)	(1.99)	(1.59)	(1.82)	(1.48)	(1.70)	(1.42)	(1.70)	(1.42)	(1.70)	(1.48)	(1.76)	(1.48)	(1.76)	(1.48)	(1.76)	(1.53)
LoĒ^2-270® / Clear BTU/hr·ft^2·°F	**0.39**	**0.32**	**0.35**	**0.29**	**0.31**	**0.25**	**0.30**	**0.25**	**0.30**	**0.25**	**0.30**	**0.25**	**0.30**	**0.26**	**0.31**	**0.26**	**0.31**	**0.26**
(W/m^2·K)	(2.21)	(1.82)	(1.99)	(1.65)	(1.76)	(1.42)	(1.70)	(1.42)	(1.70)	(1.42)	(1.70)	(1.42)	(1.70)	(1.48)	(1.76)	(1.48)	(1.76)	(1.48)
LoĒ^3-366® / Clear BTU/hr·ft^2·°F	**0.39**	**0.31**	**0.34**	**0.28**	**0.31**	**0.25**	**0.29**	**0.24**	**0.29**	**0.24**	**0.30**	**0.25**	**0.30**	**0.25**	**0.30**	**0.25**	**0.31**	**0.26**
(W/m^2·K)	(2.21)	(1.76)	(1.93)	(1.59)	(1.76)	(1.42)	(1.65)	(1.36)	(1.65)	(1.36)	(1.70)	(1.42)	(1.70)	(1.42)	(1.70)	(1.42)	(1.76)	(1.48)
Quad LoĒ-452+™ / Clear BTU/hr·ft^2·°F	**0.39**	**0.31**	**0.34**	**0.27**	**0.31**	**0.25**	**0.29**	**0.24**	**0.29**	**0.24**	**0.29**	**0.25**	**0.30**	**0.25**	**0.30**	**0.25**	**0.31**	**0.26**
(W/m^2·K)	(2.21)	(1.76)	(1.93)	(1.53)	(1.76)	(1.42)	(1.65)	(1.36)	(1.65)	(1.36)	(1.65)	(1.42)	(1.70)	(1.42)	(1.70)	(1.42)	(1.76)	(1.48)
LoĒ^3-340® / Clear BTU/hr·ft^2·°F	**0.39**	**0.32**	**0.35**	**0.28**	**0.31**	**0.25**	**0.29**	**0.24**	**0.29**	**0.25**	**0.30**	**0.25**	**0.30**	**0.25**	**0.31**	**0.26**	**0.31**	**0.26**
(W/m^2·K)	(2.21)	(1.82)	(1.99)	(1.59)	(1.76)	(1.42)	(1.65)	(1.36)	(1.65)	(1.42)	(1.70)	(1.42)	(1.70)	(1.42)	(1.76)	(1.48)	(1.76)	(1.48)
LoĒ^2-240® / Clear BTU/hr·ft^2·°F	**0.40**	**0.33**	**0.36**	**0.29**	**0.32**	**0.26**	**0.30**	**0.25**	**0.30**	**0.26**	**0.31**	**0.26**	**0.31**	**0.27**	**0.32**	**0.27**	**0.32**	**0.27**
(W/m^2·K)	(2.27)	(1.87)	(2.04)	(1.65)	(1.82)	(1.48)	(1.70)	(1.42)	(1.70)	(1.48)	(1.76)	(1.48)	(1.76)	(1.53)	(1.82)	(1.53)	(1.82)	(1.53)

1. Calculated values using LBNL Window computer program per NFRC environmental conditions. 2. For double-pane IG units, the LoĒ coatings are on surfaces #2 or #3. 3. U-Factor calculated at center of glass. 4. Glass thickness is 3.0 mm. 5. Argon fill is 90%.

Figure 2-4

CENTER OF GLASS U-FACTOR FOR DOUBLE-PANE IG UNITS WITH LoĒ-i89® COATING

Nominal Airspace	1/4 in (6.5 mm)		5/16 in (8.0 mm)		3/8 in (9.8 mm)		7/16 in (11.5 mm)		1/2 in (13.0 mm)		9/16 in (14.5 mm)		5/8 in (16.0 mm)		11/16 in (17.5 mm)		3/4 in (19.5 mm)	
Gas Fill	air	argon	air	argon	air	argon	air	argon	air	argon	air	argon	air	argon	air	argon	air	argon
LoĒ-180® (#2) / LoĒ-i89® (#4) BTU/hr·ft^2·°F	**0.31**	**0.26**	**0.28**	**0.24**	**0.26**	**0.22**	**0.24**	**0.21**	**0.24**	**0.21**	**0.24**	**0.21**	**0.25**	**0.21**	**0.25**	**0.22**	**0.25**	**0.22**
(W/m^2·K)	(1.76)	(1.48)	(1.59)	(1.36)	(1.48)	(1.25)	(1.36)	(1.19)	(1.36)	(1.19)	(1.36)	(1.19)	(1.42)	(1.19)	(1.42)	(1.25)	(1.42)	(1.25)
LoĒ^2-272® (#2) / LoĒ-i89® (#4) BTU/hr·ft^2·°F	**0.30**	**0.26**	**0.28**	**0.23**	**0.25**	**0.21**	**0.24**	**0.20**	**0.23**	**0.20**	**0.24**	**0.20**	**0.24**	**0.21**	**0.24**	**0.21**	**0.24**	**0.21**
(W/m^2·K)	(1.70)	(1.48)	(1.59)	(1.31)	(1.42)	(1.19)	(1.36)	(1.14)	(1.31)	(1.14)	(1.36)	(1.14)	(1.36)	(1.19)	(1.36)	(1.19)	(1.36)	(1.19)
LoĒ^2-270® (#2) / LoĒ-i89® (#4) BTU/hr·ft^2·°F	**0.30**	**0.26**	**0.28**	**0.23**	**0.25**	**0.21**	**0.24**	**0.20**	**0.23**	**0.20**	**0.24**	**0.20**	**0.24**	**0.21**	**0.24**	**0.21**	**0.24**	**0.21**
(W/m^2·K)	(1.70)	(1.48)	(1.59)	(1.31)	(1.42)	(1.19)	(1.36)	(1.14)	(1.31)	(1.14)	(1.36)	(1.14)	(1.36)	(1.19)	(1.36)	(1.19)	(1.36)	(1.19)
LoĒ^3-366® (#2) / LoĒ-i89® (#4) BTU/hr·ft^2·°F	**0.30**	**0.25**	**0.27**	**0.23**	**0.25**	**0.20**	**0.23**	**0.19**	**0.23**	**0.20**	**0.23**	**0.20**	**0.23**	**0.20**	**0.24**	**0.20**	**0.24**	**0.21**
(W/m^2·K)	(1.70)	(1.42)	(1.53)	(1.31)	(1.42)	(1.14)	(1.31)	(1.08)	(1.31)	(1.14)	(1.31)	(1.14)	(1.31)	(1.14)	(1.36)	(1.14)	(1.36)	(1.19)
Quad LoĒ-452+™ (#2) / LoĒ-i89® (#4) BTU/hr·ft^2·°F	**0.30**	**0.25**	**0.27**	**0.22**	**0.25**	**0.20**	**0.23**	**0.19**	**0.23**	**0.20**	**0.23**	**0.20**	**0.23**	**0.20**	**0.24**	**0.20**	**0.24**	**0.21**
(W/m^2·K)	(1.70)	(1.42)	(1.53)	(1.25)	(1.42)	(1.14)	(1.31)	(1.08)	(1.31)	(1.14)	(1.31)	(1.14)	(1.31)	(1.14)	(1.36)	(1.14)	(1.36)	(1.19)
LoĒ^3-340® (#2) / LoĒ-i89® (#4) BTU/hr·ft^2·°F	**0.30**	**0.25**	**0.27**	**0.23**	**0.25**	**0.21**	**0.23**	**0.20**	**0.23**	**0.20**	**0.23**	**0.20**	**0.24**	**0.20**	**0.24**	**0.21**	**0.24**	**0.21**
(W/m^2·K)	(1.70)	(1.42)	(1.53)	(1.31)	(1.42)	(1.19)	(1.31)	(1.14)	(1.31)	(1.14)	(1.31)	(1.14)	(1.36)	(1.14)	(1.36)	(1.19)	(1.36)	1.19
LoĒ^2-240® (#2) / LoĒ-i89® (#4) BTU/hr·ft^2·°F	**0.31**	**0.26**	**0.28**	**0.23**	**0.26**	**0.21**	**0.24**	**0.21**	**0.24**	**0.21**	**0.24**	**0.21**	**0.24**	**0.21**	**0.25**	**0.21**	**0.25**	**0.22**
(W/m^2·K)	(1.76)	(1.48)	(1.59)	(1.31)	(1.48)	(1.19)	(1.36)	(1.19)	(1.36)	(1.19)	(1.36)	(1.19)	(1.36)	(1.19)	(1.42)	(1.19)	(1.42)	(1.25)

1. Calculated values using LBNL Window computer program per NFRC environmental conditions. 2. For double-pane IG units the LoĒ coatings are on surfaces #2 or #3. 3. U-Factor calculated at center of glass. 4. Glass thickness is 3.0 mm. 5. Argon fill is 90%.

Figure 2-5

CENTER OF GLASS U-FACTOR FOR TRIPLE-PANE IG UNITS

Nominal Airspace / Gas Fill	1/4 in (6.5 mm) air	1/4 in (6.5 mm) argon	5/16 in (8.0 mm) air	5/16 in (8.0 mm) argon	3/8 in (9.8 mm) air	3/8 in (9.8 mm) argon	7/16 in (11.5 mm) air	7/16 in (11.5 mm) argon	1/2 in (13.0 mm) air	1/2 in (13.0 mm) argon
Clear/Clear/Clear BTU/hr·ft²·°F	**0.37**	**N/A**	**0.35**	**N/A**	**0.33**	**N/A**	**0.32**	**N/A**	**0.31**	**N/A**
(W/m²·K)	(2.10)	(N/A)	(1.99)	(N/A)	(1.87)	(N/A)	(1.82)	(N/A)	(1.76)	(N/A)
LoĒ-180® (#2) / LoĒ-180® (#5) BTU/hr·ft²·°F	**0.25**	**0.20**	**0.22**	**0.17**	**0.19**	**0.15**	**0.17**	**0.14**	**0.16**	**0.13**
(W/m²·K)	(1.42)	(1.14)	(1.25)	(0.97)	(1.08)	(0.85)	(0.97)	(0.79)	(0.91)	(0.74)
LoĒ²-272® (#2) / LoĒ-180® (#5) BTU/hr·ft²·°F	**0.25**	**0.19**	**0.22**	**0.17**	**0.19**	**0.15**	**0.17**	**0.13**	**0.16**	**0.13**
(W/m²·K)	(1.42)	(1.08)	(1.25)	(0.97)	(1.08)	(0.85)	(0.97)	(0.74)	(0.91)	(0.74)
LoĒ²-270® (#2) / LoĒ-180® (#5) BTU/hr·ft²·°F	**0.25**	**0.19**	**0.21**	**0.17**	**0.19**	**0.15**	**0.17**	**0.13**	**0.16**	**0.13**
(W/m²·K)	(1.42)	(1.08)	(1.19)	(0.97)	(1.08)	(0.85)	(0.97)	(0.74)	(0.91)	(0.74)
LoĒ³-366® (#2) / LoĒ-180® (#5) BTU/hr·ft²·°F	**0.25**	**0.19**	**0.21**	**0.17**	**0.19**	**0.14**	**0.17**	**0.13**	**0.16**	**0.13**
(W/m²·K)	(1.42)	(1.08)	(1.19)	(0.97)	(1.08)	(0.79)	(0.97)	(0.74)	(0.91)	(0.74)
Quad LoĒ-452+™ (#2) / LoĒ-180® (#5) BTU/hr·ft²·°F	**0.25**	**0.19**	**0.21**	**0.16**	**0.18**	**0.14**	**0.17**	**0.13**	**0.16**	**0.13**
(W/m²·K)	(1.42)	(1.08)	(1.19)	(0.91)	(1.02)	(0.79)	(0.97)	(0.74)	(0.91)	(0.74)
LoĒ³-340® (#2) / LoĒ-180® (#5) BTU/hr·ft²·°F	**0.25**	**0.19**	**0.21**	**0.17**	**0.19**	**0.14**	**0.17**	**0.13**	**0.16**	**0.13**
(W/m²·K)	(1.42)	(1.08)	(1.19)	(0.97)	(1.08)	(0.79)	(0.97)	(0.74)	(0.91)	(0.74)
LoĒ²-240® (#2) / LoĒ-180® (#5) BTU/(hr-ft²-°F)	**0.25**	**0.19**	**0.21**	**0.17**	**0.19**	**0.14**	**0.17**	**0.13**	**0.16**	**0.13**
(W/m²·K)	(1.42)	(1.08)	(1.19)	(0.97)	(1.08)	(0.79)	(0.97)	(0.74)	(0.91)	(0.74)

Figure 2-6

1. Calculated values using LBNL Window computer program per NFRC environmental conditions.
2. For double-pane IG units the LoĒ coatings are on surfaces #2 or #3.
3. U-Factor calculated at center of glass.
4. Glass thickness is 3.0mm.
5. Argon fill is 90%.

CENTER OF GLASS U-FACTOR FOR TRIPLE-PANE IG UNITS WITH LoĒ-i89® COATING

Nominal Airspace / Gas Fill	1/4 in (6.5 mm) air	1/4 in (6.5 mm) argon	5/16 in (8.0 mm) air	5/16 in (8.0 mm) argon	3/8 in (9.8 mm) air	3/8 in (9.8 mm) argon	7/16 in (11.5 mm) air	7/16 in (11.5 mm) argon	1/2 in (13.0 mm) air	1/2 in (13.0 mm) argon
LoĒ-180® (#2) / LoĒ-180® (#4) / LoĒ-i89® (#6) BTU/hr·ft²·°F	**0.21**	**0.17**	**0.18**	**0.15**	**0.16**	**0.13**	**0.15**	**0.12**	**0.14**	**0.12**
(W/m²·K)	(1.19)	(0.97)	(1.02)	(0.85)	(0.91)	(0.74)	(0.85)	(0.68)	(0.79)	(0.68)
LoĒ²-272® (#2) / LoĒ-180® (#4) / LoĒ-i89® (#6) BTU/hr·ft²·°F	**0.21**	**0.17**	**0.18**	**0.15**	**0.16**	**0.13**	**0.15**	**0.12**	**0.14**	**0.11**
(W/m²·K)	(1.19)	(0.97)	(1.02)	(0.85)	(0.91)	(0.74)	(0.85)	(0.68)	(0.79)	(0.62)
LoĒ²-270® (#2) / LoĒ-180® (#4) / LoĒ-i89® (#6) BTU/hr·ft²·°F	**0.21**	**0.17**	**0.18**	**0.15**	**0.16**	**0.13**	**0.15**	**0.12**	**0.14**	**0.11**
(W/m²·K)	(1.19)	(0.97)	(1.02)	(0.85)	(0.91)	(0.74)	(0.85)	(0.68)	(0.79)	(0.62)
LoĒ³-366® (#2) / LoĒ-180® (#4) / LoĒ-i89® (#6) BTU/hr·ft²·°F	**0.20**	**0.16**	**0.18**	**0.14**	**0.16**	**0.13**	**0.14**	**0.12**	**0.14**	**0.11**
(W/m²·K)	(1.14)	(0.91)	(1.02)	(0.79)	(0.91)	(0.74)	(0.79)	(0.68)	(0.79)	(0.62)
Quad LoĒ-452+™ (#2) / LoĒ-180® (#4) / LoĒ-i89® (#6) BTU/hr·ft²·°F	**0.20**	**0.16**	**0.18**	**0.14**	**0.16**	**0.13**	**0.14**	**0.12**	**0.14**	**0.11**
(W/m²·K)	(1.14)	(0.91)	(1.02)	(0.79)	(0.91)	(0.74)	(0.79)	(0.68)	(0.79)	(0.62)
LoĒ³-340® (#2) / LoĒ-180® (#4) / LoĒ-i89® (#6) BTU/hr·ft²·°F	**0.20**	**0.16**	**0.18**	**0.14**	**0.16**	**0.13**	**0.15**	**0.12**	**0.14**	**0.11**
(W/m²·K)	(1.14)	(0.91)	(1.02)	(0.79)	(0.91)	(0.74)	(0.85)	(0.68)	(0.79)	(0.62)
LoĒ²-240® (#2) / LoĒ-180® (#4) / LoĒ-i89® (#6) BTU/hr·ft²·°F	**0.20**	**0.16**	**0.18**	**0.14**	**0.16**	**0.13**	**0.15**	**0.12**	**0.14**	**0.11**
(W/m²·K)	(1.14)	(0.91)	(1.02)	(0.79)	(0.91)	(0.74)	(0.85)	(0.68)	(0.79)	(0.62)

Figure 2-7

1. Calculated values using LBNL Window computer program per NFRC environmental conditions.
2. For double-pane IG units the LoĒ coatings are on surfaces #2 or #3.
3. U-Factor calculated at center of glass.
4. Glass thickness is 3.0mm.
5. Argon fill is 90%.

Overall Window U-Factors

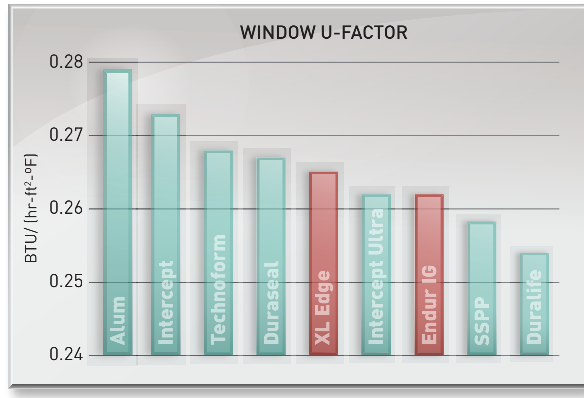
U-Factor and Glass Frame Interface Temperatures
The tables here compare various spacer types in the industry and their effect on the overall window U-Factor, NFRC CR rating, and sightline temperature. The simulations were made by a Certified NFRC Simulator, using a wood or vinyl frame with sightlines of the spacer system equal in all cases.

LoĒ³-366® DOUBLE-GLAZED UNIT

Spacer Type	NFRC U-Factor	NFRC CR	Sightline Temp °F
Aluminum	0.28	56	30.8
Intercept	0.27	57	32.5
Technoform	0.27	58	33.8
Duraseal	0.27	59	35.1
XL Edge®	**0.26**	**60**	**35.9**
Intercept Ultra	0.26	60	36.2
Endur IG®	**0.26**	**61**	**36.9**
Super Spacer Premium Plus	0.26	61	37.7
Duralite	0.25	63	39.0

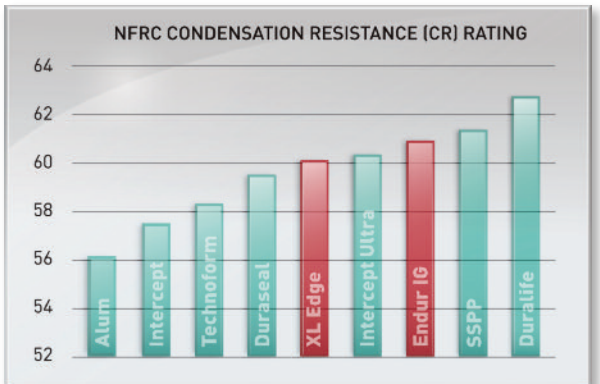
1. 3.1 mm LoĒ³-366® / 0.5" Argon / 3.1 mm Clear

Figure 2-8



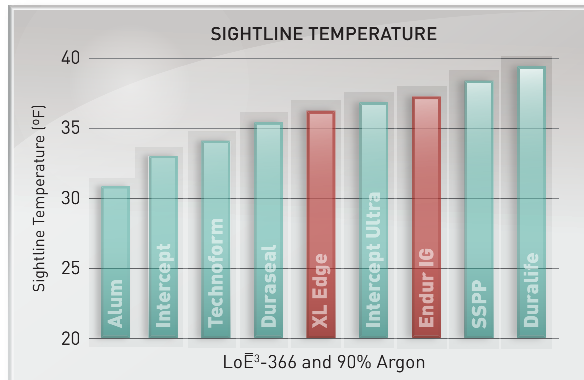
1. 3.1 mm LoĒ³-366 / 0.5" Argon / 3.1 mm Clear
2. Generic Wood / Vinyl Frame

Figure 2-9



1. 3.1 mm LoĒ³-366 / 0.5" Argon / 3.1 mm Clear
2. Generic Wood / Vinyl Frame

Figure 2-10



1. 3.1 mm LoĒ³-366 / 0.5" Argon / 3.1 mm Clear
2. Generic Wood / Vinyl Frame

Figure 2-11

Effect of Spacer Systems on Overall U-Factors
In most windows that exist today, the rate of heat flow through the frame and the 2-1/2" band of glass near the frame is greater than the heat flow through the center of an argon-filled, LoĒ insulating glass (IG) unit. In addition, the U-Factor of the edge, frame and overall window are improved when using Cardinal's stainless steel spacer over the typical aluminum spacer (Figure 2-9).

In winter conditions, the Endur IG spacer will increase the glass/frame interface temperature resulting in less opportunity for indoor condensation around the periphery of the glass (Figures 2-10).

Overall Window Comparisons
Spacer choice is only one aspect of overall window performance. Frame material type (for example: wood, fiberglass, aluminum, steel or composite) plays a major role in the overall window performance to a degree that may be much larger than spacer choice. Consumers can refer to rating organizations like NFRC to find overall window performance for various brands and window types.

The relative relationships between spacer types, shown in the figures above, should hold true regardless of a particular window design. The absolute values will not match directly to those that are listed due to differences in the design simulated and a particular manufacturer's design.

Small variations in the modeling of the spacer and window often have notable effects on simulated performance. Reach out to Cardinal IG Technical services for simulation information for Cardinal IG spacer and design. Care should be taken in making comparisons between spacer and design to ensure each is being modeled appropriately.

Heat Transfer: Winter Heat Gain (Passive Solar)

Passive solar heating aims to maximize heat gain from direct transmission of solar radiation and the inward flowing fraction of absorbed solar radiation while minimizing the outward flowing energy from conduction and radiative heat loss from inside the house. Passive solar products balance high solar heat gain coefficient (SHGC) values with low U-Factors. Passive solar heating is intended only for climates with extremely high heating requirements and for buildings designed to take advantage of passive solar heating.

Figures on the page illustrate the high solar heat gain of products utilizing Cardinal LoĒ-180® and LoĒ-i89® while maintaining very low U-Factors.

WINTER DAY TIME SOLAR HEAT GAIN COMPARISONS

Insulating Glass Unit	U winter BTU/hr·ft²·°F (W/m²·K)	SHGC	Solar Radiation Reflected BTU/hr·ft² (W/m²)	Solar Radiation Transmitted BTU/hr·ft² (W/m²)	Total Energy Rejected BTU/hr·ft² (W/m²)	Total Energy Gained BTU/hr·ft² (W/m²)
Clear / Clear	**0.46** (2.61)	**0.78**	**32** (101)	**181** (571)	**87** (274)	**193** (609)
Clear / LoĒ-180® (#3)	**0.26** (1.48)	**0.68**	**52** (164)	**149** (470)	**97** (306)	**169** (533)
LoĒ³-366® / Clear	**0.24** (1.36)	**0.28**	**116** (366)	**62** (196)	**196** (618)	**69** (218)
LoĒ-180® (#2) / LoĒ-i89® (#4)	**0.21** (1.19)	**0.62**	**52** (164)	**136** (429)	**109** (344)	**154** (486)
LoĒ³-366® (#2) / LoĒ-i89® (#4)	**0.20** (1.14)	**0.27**	**117** (369)	**60** (189)	**195** (615)	**67** (211)
LoĒ-180® / Clear / LoĒ-180® (#5)	**0.17** (0.97)	**0.56**	**62** (196)	**117** (369)	**121** (382)	**139** (439)
LoĒ³-366® / Clear / LoĒ-180® (#5)	**0.17** (0.97)	**0.25**	**119** (375)	**52** (164)	**198** (625)	**62** (196)
LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)	**0.15** (0.85)	**0.53**	**62** (196)	**109** (344)	**128** (404)	**131** (413)
LoĒ³-366® / LoĒ-180® / LoĒ-i89® (#6)	**0.14** (0.79)	**0.24**	**119** (375)	**52** (164)	**198** (625)	**60** (189)

1. Calculated values using LBNL Window computer program with 248 Btu/(hr-ft²) solar radiation, 0°F exterior temperature an 70°F interior temperature.
2. Double-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoĒ products, otherwise air-filled cavity. Coatings on surfaces #2, #3 and/or #4.
3. Triple-pane IG construction: 5/16" (8.0 mm) airspace, 90% argon filled for LoĒ products. Coatings on surfaces #2 and #5, or #2, #4 and #6.
4. All insulating glass systems contain 1/8" (3 mm) glass.

Figure 2-12

DOUBLE-PANE CLEAR UNIT WITH AIR (WINTER DAY)

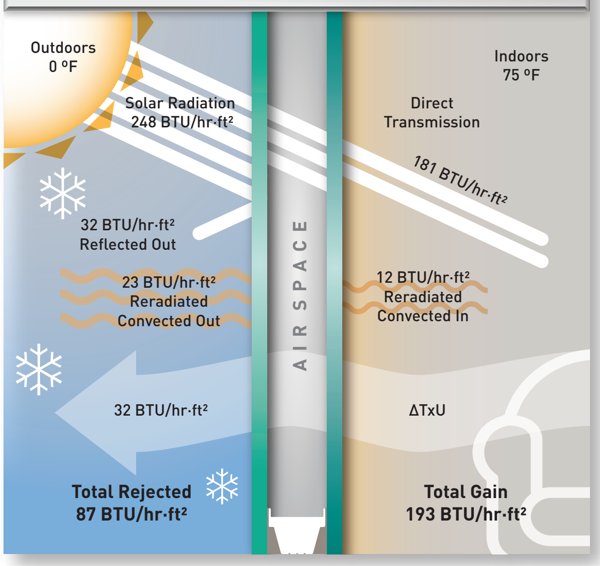


Figure 2-13

DOUBLE-PANE CLEAR/LoĒ-180 UNIT WITH ARGON (WINTER DAY)

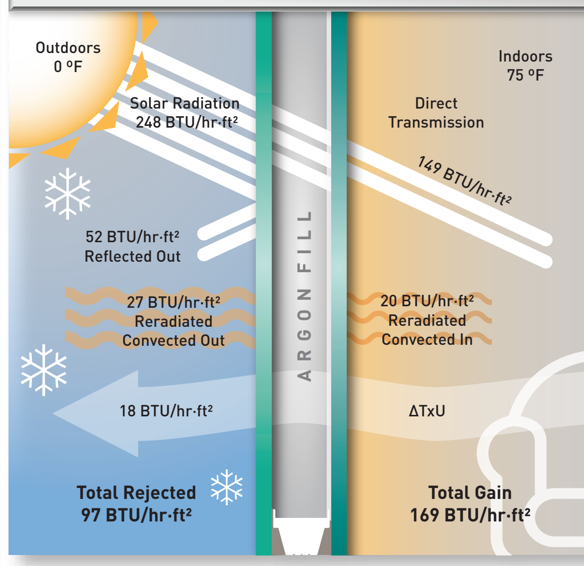


Figure 2-14

DOUBLE-PANE LoĒ-180/LoĒ-i89 UNIT WITH ARGON (WINTER DAY)

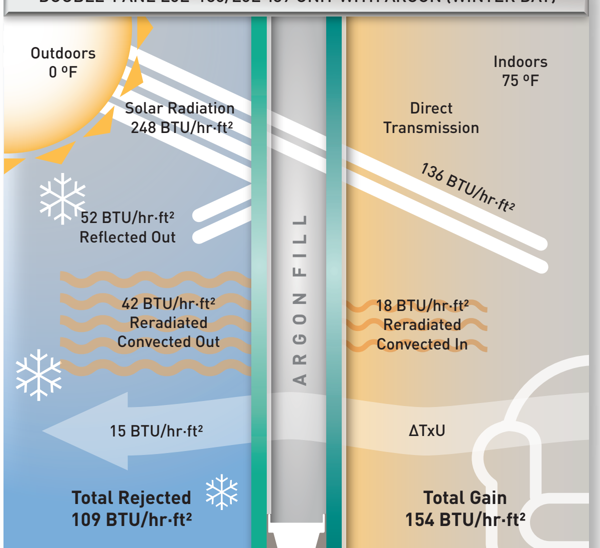


Figure 2-15

TRIPLE-PANE LoĒ-180/LoĒ-180/LoĒ-i89 UNIT WITH ARGON (WINTER DAY)

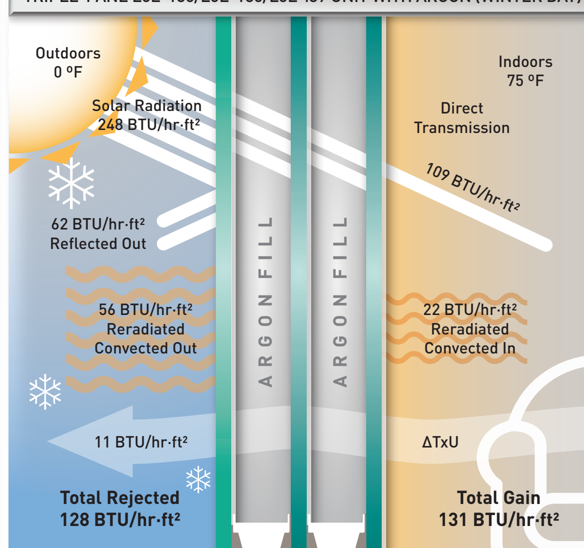


Figure 2-16

Heat Transfer: Winter Heat Loss

Heat transfer across the cavity of insulating glass units primarily occurs by two separate mechanisms:

- Thermal radiation from glass surface to glass surface
- Conduction through the molecules of air

In a double-pane clear unit, over 60% of the total heat transfer is by thermal radiation. Incorporating a low-emissivity coating on one surface facing the airspace blocks enough radiation transfer to reduce the total heat loss from 34 to 17 BTU/hr/ft². By adding the low emissivity coating, the heat loss by thermal radiation is now reduced to only 6% of the total heat transfer. The LoĒ³-366® unit with argon In figure 2-17 shows this effect

The heat transfer characteristics of the LoĒ-180 products with argon airspace vs. double-pane clear with air are shown at right. The lower thermal conductivity of argon lowers conductive heat transfer and reduces the heat loss to 18 BTU/hr/ft², double the performance of standard double-pane insulating glass with air.

WINTER NIGHT TIME AIRSPACE HEAT TRANSFER

Insulating Glass Unit	U winter BTU/hr·ft²·°F (W/m²·K)	Radiative Heat Loss BTU/hr·ft² (W/m²)	Conductive Heat Loss BTU/hr·ft² (W/m²)	Total Heat Loss BTU/hr·ft² (W/m²)
Clear / Clear	**0.48** (2.73)	**21** (66)	**13** (41)	**34** (107)
Clear / LoĒ-180® (#3)	**0.26** (1.48)	**3** (9)	**15** (47)	**18** (57)
LoĒ³-366® / Clear	**0.24** (1.36)	**1** (3)	**16** (50)	**17** (54)
LoĒ-180® (#2) / LoĒ-i89® (#4)	**0.21** (1.19)	**2** (6)	**13** (41)	**15** (47)
LoĒ³-366® (#2) / LoĒ-i89® (#4)	**0.20** (1.14)	**1** (3)	**13** (41)	**14** (44)
LoĒ-180® / Clear / LoĒ-180® (#5)	**0.17** (0.97)	**2** (6)	**10** (32)	**12** (38)
LoĒ³-366® / Clear / LoĒ-180® (#5)	**0.17** (0.97)	**1** (3)	**11** (35)	**12** (38)
LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)	**0.15** (0.85)	**1** (3)	**10** (32)	**11** (35)
LoĒ³-366® / LoĒ-180® / LoĒ-i89® (#6)	**0.14** (0.79)	**1** (3)	**9** (28)	**10** (32)

1. Calculated values using LBNL Window computer program per NFRC environmental conditions. 2. Double-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoĒ products, otherwise air-filled cavity. Coatings on surfaces #2, #3 and/or #4. 3. Triple-pane IG construction: 5/16" (8.0 mm) airspace, 90% argon filled for LoĒ products. Coatings on surfaces #2 and #5, or #2, #4 and #6. 4. All insulating glass systems contain 1/8" (3 mm) glass.

Figure 2-17

DOUBLE-PANE CLEAR UNIT WITH AIR (WINTER NIGHT)

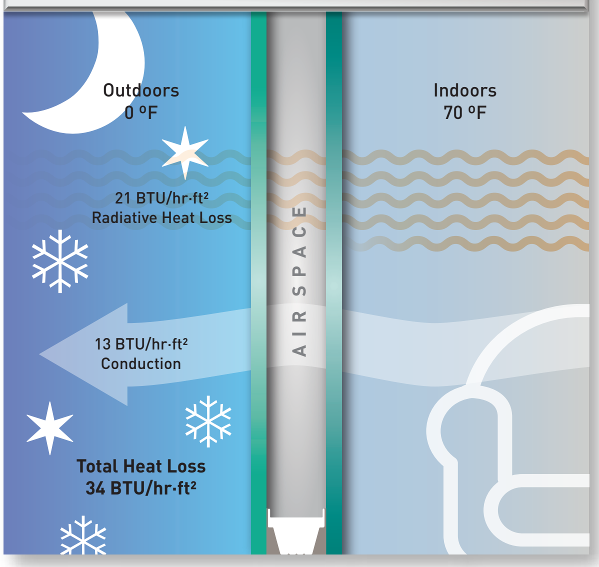


Figure 2-18

DOUBLE-PANE CLEAR/LoĒ-180 UNIT WITH ARGON (WINTER NIGHT)

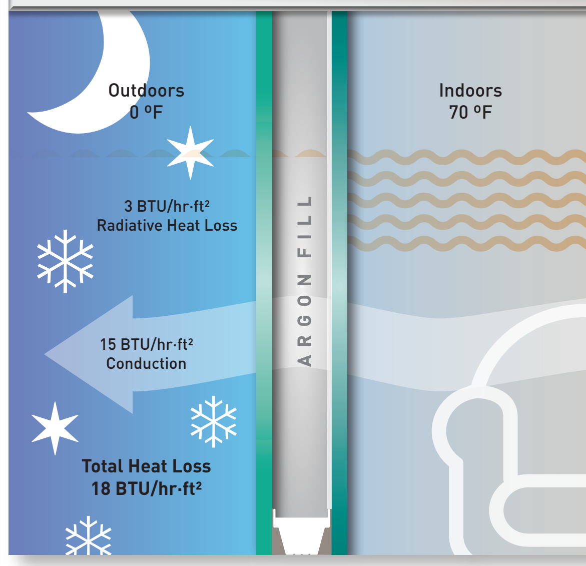


Figure 2-19

DOUBLE-PANE LoĒ-180/LoĒ-i89 UNIT WITH ARGON (WINTER NIGHT)

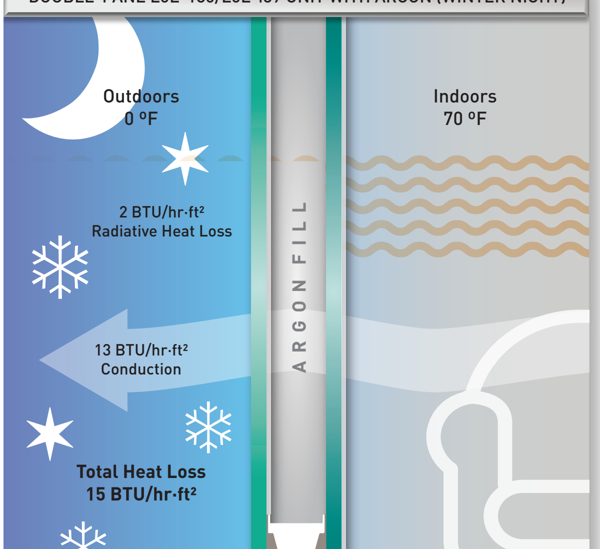


Figure 2-20

TRIPLE-PANE LoĒ-180/LoĒ-180/LoĒ-i89 UNIT WITH ARGON (WINTER NIGHT)

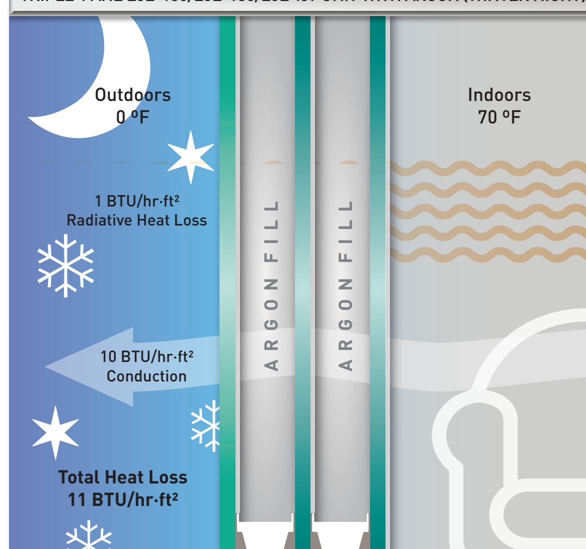


Figure 2-21

Heat Transfer: Summer Heat Gain

Summertime heat gain is based on all three heat gain loads:

- Direct transmission of solar radiation
- Inward flowing fraction of absorbed solar radiation
- Air-to-air heat gain from high outdoor temperatures

The table and illustrations show the heat gain characteristics of double-pane clear and LoĒ^3-366® products. In using the LoĒ^3-366 product, the heat gain is reduced 65% compared with a double-pane clear insulating glass unit.

The data and figures illustrate that low solar heat gain products have a distinct advantage over other glass choices for summertime performance.

SUMMER DAY TIME SOLAR HEAT GAIN COMPARISONS

Insulating Glass Unit	U summer BTU/hr·ft²·°F (W/m²·K)	SHGC	Solar Radiation Reflected BTU/hr·ft² (W/m²)	Solar Radiation Transmitted BTU/hr·ft² (W/m²)	Total Energy Rejected BTU/hr·ft² (W/m²)	Total Energy Gained BTU/hr·ft² (W/m²)
Clear / Clear	**0.50** (2.84)	**0.78**	**32** (101)	**181** (571)	**55** (174)	**200** (631)
Clear / LoĒ-180® (#3)	**0.23** (1.31)	**0.68**	**52** (164)	**149** (470)	**79** (249)	**172** (543)
LoĒ^3-366® / Clear	**0.20** (1.14)	**0.27**	**116** (366)	**62** (196)	**181** (571)	**70** (221)
LoĒ-180® (#2) / LoĒ-i89® (#4)	**0.18** (1.02)	**0.62**	**52** (164)	**136** (429)	**94** (297)	**157** (495)
LoĒ^3-366® (#2) / LoĒ-i89® (#4)	**0.16** (0.91)	**0.27**	**116** (366)	**60** (189)	**181** (571)	**69** (218)
LoĒ-180® / Clear / LoĒ-180® (#5)	**0.18** (1.02)	**0.56**	**62** (196)	**117** (369)	**109** (344)	**142** (448)
LoĒ^3-366® / Clear / LoĒ-180® (#5)	**0.17** (0.97)	**0.25**	**119** (375)	**52** (164)	**186** (587)	**64** (202)
LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)	**0.15** (0.85)	**0.53**	**62** (196)	**109** (344)	**117** (369)	**133** (420)
LoĒ^3-366® / LoĒ-180® / LoĒ-i89® (#6)	**0.14** (0.79)	**0.24**	**119** (375)	**52** (164)	**188** (593)	**62** (196)

1. Calculated values using LBNL Window computer program per NFRC environmental conditions.
2. Double-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoĒ products, otherwise air-filled cavity. Coatings on surfaces #2, #3 and/or #4.
3. Triple-pane IG construction: 5/16" (8.0 mm) airspace, 90% argon filled for LoĒ products. Coatings on surfaces #2 and #5, or #2, #4 and #6.
4. All insulating glass systems contain 1/8" (3 mm) glass.

Figure 2-22

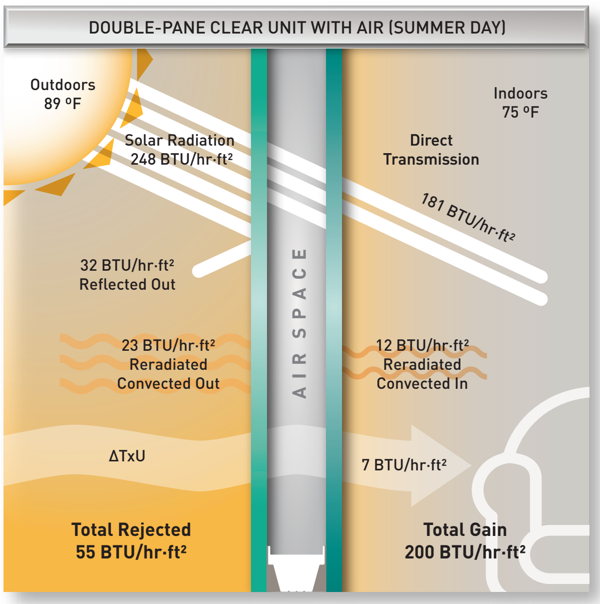


Figure 2-23

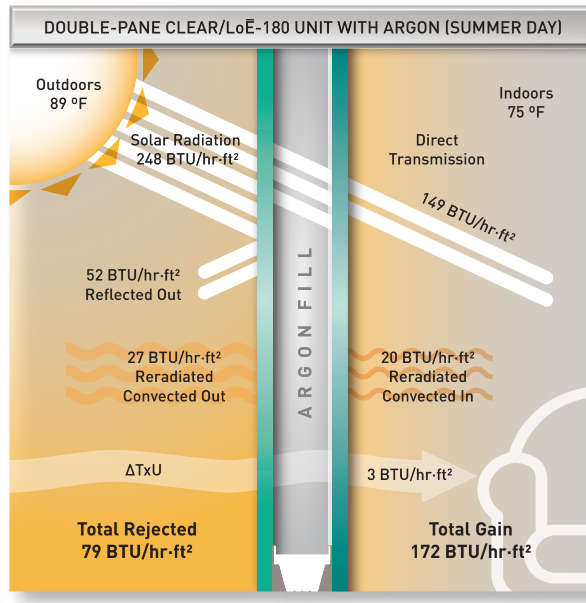


Figure 2-24

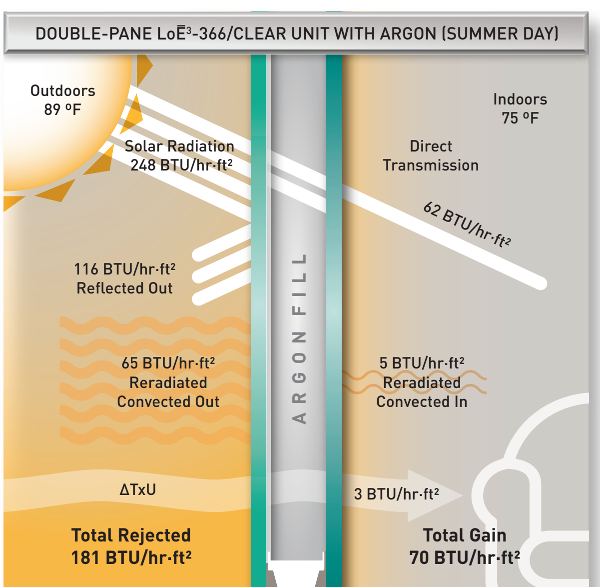


Figure 2-25

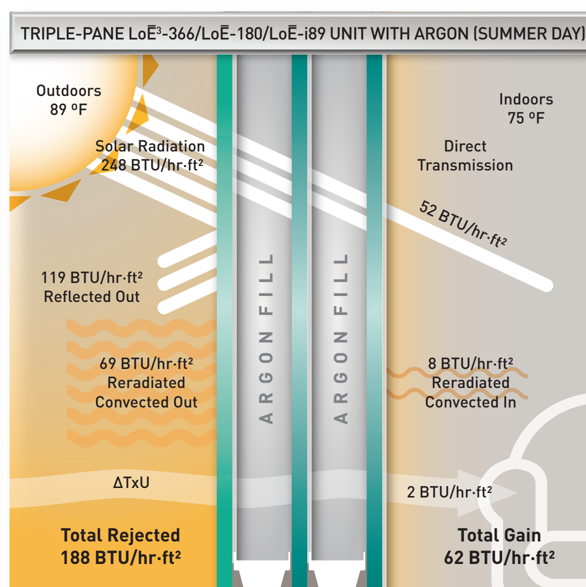


Figure 2-26

Heat Transfer: Summer Night

Relatively small amounts of heat transfer occur in summer night conditions due to the lack of solar gain and the relatively small indoor to outdoor temperature difference.

One phenomenon that is commonly observed in summer time night conditions is condensation forming on the outside surface of the glass. This condensation forms when the outside glass radiates heat to the night time sky reducing its temperature below the air's dew point. When this occurs dew will form on the glass surface. Reducing the emissivity on the surface of one of the insulating glass (IG) units minimizes heat transfer to the sky, which reduces the likelihood of outdoor condensation forming.

SUMMER NIGHT TIME AIRSPACE HEAT TRANSFER

Insulating Glass Unit	Exterior Glass Temperature (Surface #1) °F (°C)	U summer BTU/hr·ft²·°F (W/m²·K)	Radiative Heat Gain BTU/hr·ft² (W/m²)	Conductive Heat Gain BTU/hr·ft² (W/m²)	Total Heat Gain BTU/hr·ft² (W/m²)
Clear / Clear	**82.8** (79.6)	**0.51** (2.90)	**3** (9)	**4** (13)	**7** (22)
Clear / LoĒ-180® (#3)	**83.2** (28.4)	**0.24** (1.36)	**0** (0)	**3** (9)	**3** (9)
LoĒ^3-366® / Clear	**83.2** (31.7)	**0.21** (1.19)	**0** (0)	**3** (9)	**3** (9)
LoĒ-180® (#2) / LoĒ-i89® (#4)	**83.3** (31.7)	**0.18** (1.02)	**0** (0)	**3** (9)	**3** (9)
LoĒ^3-366® (#2) / LoĒ-i89® (#4)	**83.3** (31.7)	**0.16** (0.91)	**0** (0)	**2** (6)	**2** (6)
LoĒ-x89® (#1) / LoĒ-180® (#3)	**87.2** (30.7)	**0.21** (1.19)	**1** (3)	**2** (6)	**3** (9)
LoĒ-180® / Clear / LoĒ-180® (#5)	**83.3** (31.7)	**0.18** (1.02)	**0** (0)	**3** (9)	**3** (9)
LoĒ^3-366® / Clear / LoĒ-180® (#5)	**83.3** (31.7)	**0.18** (1.02)	**0** (0)	**3** (9)	**3** (9)
LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)	**83.3** (79.8)	**0.15** (0.85)	**0** (0)	**2** (6)	**2** (6)
LoĒ^3-366® / LoĒ-180® / LoĒ-i89® (#6)	**83.3** (79.6)	**0.14** (0.79)	**0** (0)	**2** (6)	**2** (6)

1. Calculated values using LBNL Window computer program per NFRC environmental conditions.
2. Double-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoĒ products, otherwise air-filled cavity. Coatings on surfaces #2, #3 and/or #4.
3. Triple-pane IG construction: 5/16" (8.0 mm) airspace, 90% argon filled for LoĒ products. Coatings on surfaces #2 and #5, or #2, #4 and #6.
4. All insulating glass systems contain 1/8" (3 mm) glass.

Figure 2-27

DOUBLE-PANE CLEAR UNIT WITH AIR (SUMMER NIGHT)

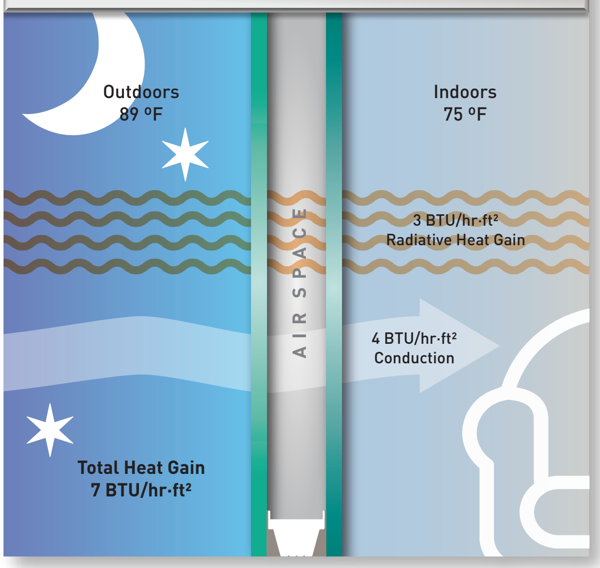


Figure 2-28

DOUBLE-PANE LoĒ^3-366/CLEAR UNIT WITH ARGON (SUMMER NIGHT)

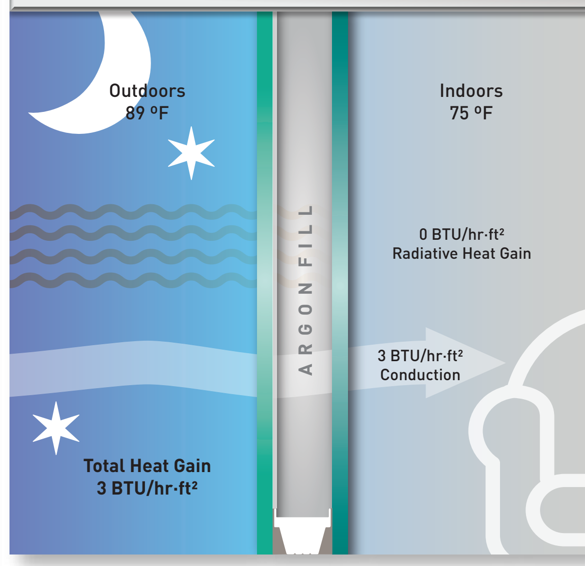


Figure 2-29

DOUBLE-PANE LoĒ-x89/LoĒ-180 UNIT WITH ARGON (SUMMER NIGHT)

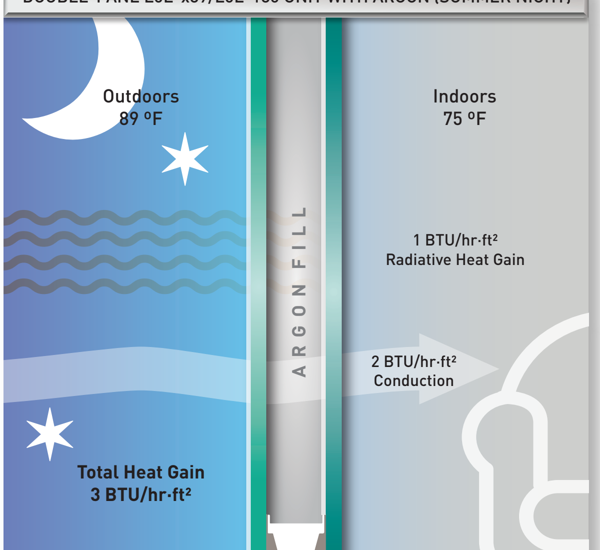


Figure 2-30

TRIPLE-PANE LoĒ-180/LoĒ-180/LoĒ-i89 UNIT WITH ARGON (SUMMER NIGHT)

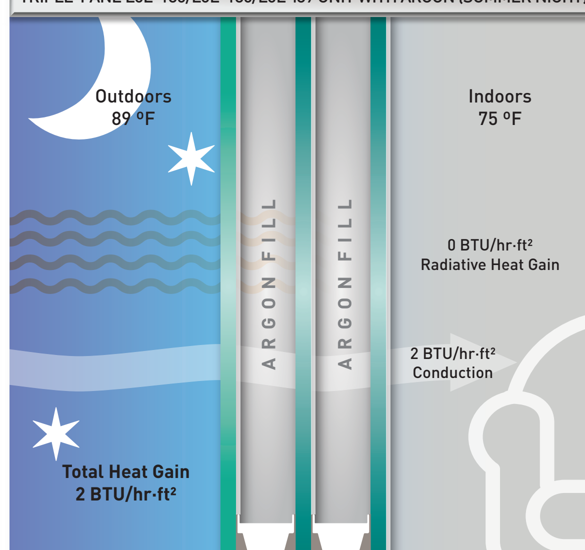


Figure 2-31

Outdoor Condensation

Condensation on the outdoor surface of an insulating glass unit (IG) is not an indication that the insulating glass unit is defective. Under the right set of atmospheric conditions, it is possible to get condensation on the exterior glass surface of an IG unit. Specifically, these conditions are as follows:

- Glass temperature below dew point temperature
- Clear night sky
- Still air
- High relative humidity
- Well-insulating glazings

Exposed to these conditions, the outdoor surface of the glass can radiate heat away to the night sky such that the glass temperature falls below the dew point of the ambient air. When this occurs, moisture from the air condenses on the glass surface. Only when the glass temperature rises above the dew point will the condensation evaporate back into the air. Dew formation on grass, car hoods and roofs, building roofs and walls is common and accepted as a fact of nature.

The presence of moisture indicates that a specific set of atmospheric conditions exists and the insulating glass unit is indeed doing its job of insulating the building from the environment. In this case, that insulation capability is what retards the flow of building heat through the glass and prevents warming of the outdoor glass surface above the dew point.

If outdoor condensation occurs on an IG unit, there is little or nothing that can be done to prevent its recurrence.

Here are some measures that may help:

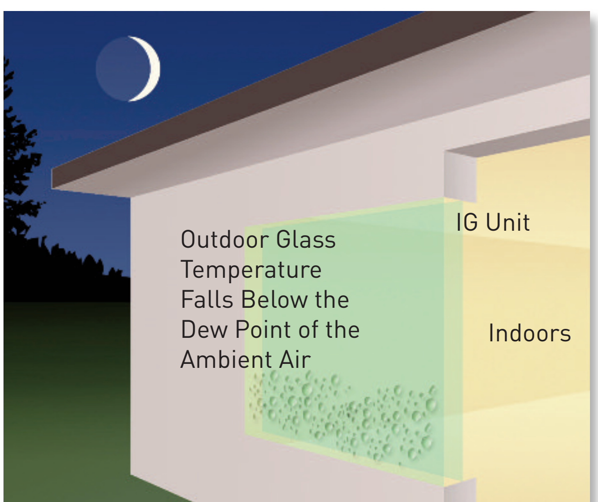


Figure 2-32

- Open drapes to maximize heat transfer through the glass.
- Plant trees to block the radiation view to the sky.
- Remove shrubbery immediately adjacent to the glass.
- Add exterior solar screens, insect screens and/or awnings.

The outdoor surface of the IG unit will warm and the condensation will evaporate when the wind picks up or sunlight is absorbed on the glass surface.

If condensation on the exterior of the window is a concern, the use of Cardinal's LoĒ-x89® coating should be considered. The LoĒ-x89 coating is an indium tin oxide based coating sputtered onto the outdoor surface of the IG unit designed specifically for the reduction of outdoor condensation. This coating reduces the heat loss from the outboard keeping it warmer and reducing the chance of the glass temperature falling below the outside dew point. In addition, the LoĒ-x89 coating has all the same "stay clean longer" properties of the Neat+™ coating.

Indoor Condensation

Maintaining a Desirable Humidity Level

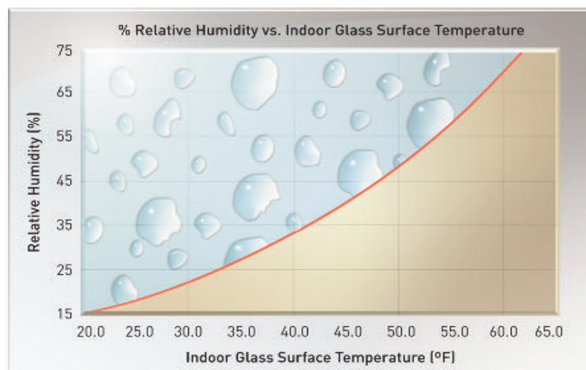
People are most comfortable when relative humidity ranges between 20% and 60%. In the home, an average relative humidity of 35% to 40% is appropriate when the outside temperature is 20 °F (-7 °C) or above. However, during cold weather, higher humidity ranges may cause indoor condensation on windows.

The table below shows recommended indoor humidity levels in relation to outdoor temperatures.

Outdoor Temperature °F	Recommended Relative Humidity
20° and Above	35% to 40%
+10°	30%
0°	25%
-10°	20%
-20°	15%

Figure 2-33

Figure 2-34 shows the relationship of condensation to indoor glass and room relative humidity. If glass conditions are above the red line in the chart, expect to see condensation. If they are below the line, you won't see condensation.



1. Indoor Air Temperature = 70°F (21° C)

Figure 2-34

INDOOR CONDENSATION PREDICTABILITY FOR DOUBLE-PANE IG UNITS

Outdoor Glass	Airspace inches	Airspace mm	U-Factor BTU/hr·ft²·°F (W/m²·K)	-20 °F (-29 °C) Outdoor Air Temperature T_{cog} °F (°C)	-20 °F RH %	0 °F (-18 °C) Outdoor Air Temperature T_{cog} °F (°C)	0 °F RH %	+20° F (7 °C) Outdoor Air Temperature T_{cog} °F (°C)	+20 °F RH %
Clear / Clear	1/4	6.5	**0.54** (3.07)	**34** (1)	26	**41** (5)	34	**48** (9)	46
	3/8	9.8	**0.50** (2.84)	**36** (2)	29	**43** (6)	38	**50** (10)	49
	1/2	13.0	**0.48** (2.73)	**37** (3)	30	**44** (7)	39	**51** (11)	51
	5/8	16.0	**0.48** (2.73)	**37** (3)	29	**44** (7)	39	**51** (11)	51
Clear / LoĒ-Di89™ (#3 & #4)	1/4	6.5	**0.28** (1.59)	**33** (1)	26	**40** (4)	34	**45** (7)	45
	3/8	9.8	**0.24** (1.36)	**37** (3)	30	**44** (7)	39	**50** (10)	50
	1/2	13.0	**0.23** (1.31)	**37** (3)	30	**44** (7)	40	**52** (11)	53
	5/8	16.0	**0.24** (1.36)	**36** (2)	29	**44** (7)	39	**52** (11)	53
Clear / LoĒ-180® (#3)	1/4	6.5	**0.33** (1.87)	**47** (8)	44	**52** (11)	52	**56** (13)	62
	3/8	9.8	**0.27** (1.53)	**51** (11)	50	**55** (13)	59	**59** (15)	69
	1/2	13.0	**0.26** (1.48)	**50** (10)	49	**55** (13)	60	**60** (16)	71
	5/8	16.0	**0.27** (1.53)	**50** (10)	48	**55** (13)	59	**60** (16)	71
Clear / LoĒ-180 ESC™ (#3)	1/4	6.5	**0.33** (1.87)	**47** (8)	44	**51** (11)	52	**56** (13)	62
	3/8	9.8	**0.27** (1.53)	**50** (10)	44	**55** (13)	59	**59** (15)	68
	1/2	13.0	**0.27** (1.53)	**50** (10)	49	**55** (13)	59	**60** (16)	71
	5/8	16.0	**0.27** (1.53)	**50** (10)	48	**55** (13)	58	**60** (16)	70
LoĒ²-272® / Clear	1/4	6.5	**0.32** (1.82)	**48** (9)	45	**52** (11)	53	**57** (14)	63
	3/8	9.8	**0.26** (1.48)	**51** (11)	50	**55** (13)	59	**59** (15)	70
	1/2	13.0	**0.25** (1.42)	**51** (11)	51	**56** (13)	61	**60** (16)	72
	5/8	16.0	**0.26** (1.48)	**50** (10)	49	**55** (13)	60	**60** (16)	71
LoĒ²-270® / Clear	1/4	6.5	**0.32** (1.82)	**48** (9)	45	**52** (11)	53	**57** (14)	64
	3/8	9.8	**0.25** (1.42)	**51** (11)	52	**56** (13)	61	**60** (16)	70
	1/2	13.0	**0.25** (1.42)	**51** (11)	51	**56** (13)	61	**61** (16)	73
	5/8	16.0	**0.26** (1.48)	**50** (10)	50	**55** (13)	60	**61** (16)	72
LoĒ³-366® / Clear	1/4	6.5	**0.31** (1.76)	**48** (9)	46	**52** (11)	54	**57** (14)	64
	3/8	9.8	**0.25** (1.42)	**52** (11)	55	**56** (13)	61	**60** (16)	71
	1/2	13.0	**0.24** (1.36)	**51** (11)	51	**56** (13)	62	**61** (16)	73
	5/8	16.0	**0.25** (1.42)	**51** (11)	51	**56** (13)	61	**61** (16)	73
Quad LoĒ-452+™ / Clear	1/4	6.5	**0.31** (1.76)	**48** (9)	46	**53** (12)	54	**57** (14)	64
	3/8	9.8	**0.25** (1.42)	**52** (11)	53	**56** (13)	61	**60** (16)	71
	1/2	13.0	**0.24** (1.36)	**51** (11)	52	**56** (13)	62	**61** (16)	73
	5/8	16.0	**0.25** (1.42)	**51** (11)	51	**56** (13)	61	**61** (16)	73
LoĒ³-340® / Clear	1/4	6.5	**0.32** (1.82)	**48** (9)	46	**52** (11)	54	**57** (14)	64
	3/8	9.8	**0.25** (1.42)	**52** (11)	52	**56** (13)	61	**60** (16)	70
	1/2	13.0	**0.25** (1.42)	**51** (11)	51	**56** (13)	61	**61** (16)	73
	5/8	16.0	**0.25** (1.42)	**50** (10)	51	**56** (13)	60	**61** (16)	72
LoĒ²-240® / Clear	1/4	6.5	**0.33** (1.87)	**47** (8)	45	**52** (11)	53	**57** (14)	63
	3/8	9.8	**0.26** (1.48)	**51** (11)	51	**55** (13)	60	**60** (16)	69
	1/2	13.0	**0.26** (1.48)	**50** (10)	50	**55** (13)	60	**60** (16)	60
	5/8	16.0	**0.27** (1.53)	**50** (10)	49	**55** (13)	59	**60** (16)	71
LoĒ-180® / LoĒ-i89® (#4)	1/4	6.5	**0.26** (1.48)	**35** (2)	28	**42** (6)	36	**49** (9)	47
	3/8	9.8	**0.22** (1.25)	**39** (4)	33	**46** (8)	42	**52** (11)	53
	1/2	13.0	**0.21** (1.19)	**39** (4)	33	**46** (8)	43	**54** (12)	56
	5/8	16.0	**0.21** (1.19)	**39** (4)	32	**46** (8)	42	**53** (12)	56
LoĒ-180 ESC™ / LoĒ-i89® (#4)	1/4	6.5	**0.27** (1.53)	**35** (2)	27	**41** (5)	35	**49** (9)	47
	3/8	9.8	**0.22** (1.25)	**39** (4)	33	**45** (7)	41	**52** (11)	53
	1/2	13.0	**0.21** (1.19)	**39** (4)	32	**46** (8)	43	**53** (12)	55
	5/8	16.0	**0.22** (1.25)	**38** (3)	32	**46** (8)	42	**53** (12)	55
LoĒ²-272® / LoĒ-i89® (#4)	1/4	6.5	**0.26** (1.48)	**36** (2)	28	**42** (6)	37	**49** (9)	48
	3/8	9.8	**0.21** (1.19)	**40** (4)	34	**46** (8)	43	**53** (12)	54
	1/2	13.0	**0.20** (1.14)	**40** (4)	34	**47** (8)	44	**54** (12)	57
	5/8	16.0	**0.21** (1.19)	**39** (4)	33	**47** (8)	43	**54** (12)	57
LoĒ-270® / LoĒ-i89® (#4)	1/4	6.5	**0.25** (1.42)	**36** (2)	29	**42** (6)	37	**49** (9)	48
	3/8	9.8	**0.21** (1.19)	**40** (4)	35	**47** (8)	43	**53** (12)	55
	1/2	13.0	**0.20** (1.14)	**40** (4)	34	**47** (8)	44	**54** (12)	58
	5/8	16.0	**0.21** (1.19)	**39** (4)	33	**47** (8)	44	**54** (12)	57
LoĒ³-366® / LoĒ-i89® (#4)	1/4	6.5	**0.25** (1.42)	**36** (2)	29	**43** (6)	37	**50** (10)	48
	3/8	9.8	**0.20** (1.14)	**41** (5)	35	**47** (8)	44	**53** (12)	55
	1/2	13.0	**0.20** (1.14)	**41** (5)	34	**48** (9)	45	**55** (13)	59
	5/8	16.0	**0.20** (1.14)	**40** (4)	34	**47** (8)	44	**54** (12)	58
Quad LoĒ-452+™ / LoĒ-i89® (#4)	1/4	6.5	**0.25** (1.42)	**36** (2)	29	**43** (6)	37	**50** (10)	48
	3/8	9.8	**0.20** (1.14)	**41** (5)	34	**48** (9)	44	**53** (12)	55
	1/2	13.0	**0.20** (1.14)	**40** (4)	34	**47** (8)	45	**55** (13)	59
	5/8	16.0	**0.20** (1.14)	**40** (4)	34	**47** (8)	44	**55** (13)	58
LoĒ³-340® / LoĒ-i89® (#4)	1/4	6.5	**0.25** (1.42)	**36** (2)	29	**42** (6)	37	**49** (9)	48
	3/8	9.8	**0.21** (1.19)	**41** (5)	35	**47** (8)	44	**53** (12)	55
	1/2	13.0	**0.20** (1.14)	**40** (4)	34	**47** (8)	45	**54** (12)	58
	5/8	16.0	**0.20** (1.14)	**39** (4)	32	**47** (8)	44	**54** (12)	58
LoĒ²-240® / LoĒ-i89® (#4)	1/4	6.5	**0.26** (1.48)	**35** (2)	28	**42** (6)	36	**49** (9)	47
	3/8	9.8	**0.21** (1.19)	**40** (4)	34	**46** (8)	42	**52** (11)	54
	1/2	13.0	**0.21** (1.19)	**39** (4)	33	**47** (8)	44	**54** (12)	57
	5/8	16.0	**0.21** (1.19)	**39** (4)	32	**46** (8)	43	**54** (12)	56

1. U-Factor: Winter night time conditions with outdoor air temperatures shown. 12.3 mph (19.8 kph) outdoor wind velocity with indoor air temperature = 70 °F (21° C). 2. Tcog: Indoor center of glass surface temperature (rounded to nearest degree). Calculated using LBNL Window program. 3. %RH: Percent relative humidity at indoor temperature of 70 °F (21 °C). Maximum indoor relative humidity before condensation starts to appear. 4. Double-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon-filled for LoĒ products, otherwise air-filled cavity. Coatings on surfaces #2, #3 and/or #4. 5. All insulating glass systems contain 1/8" (3 mm) glass. 6. U-Factors are based on a 0 °F (-18 °C) outdoor air temperature.

Figure 2-35

INDOOR CONDENSATION PREDICTABILITY FOR TRIPLE-PANE IG UNITS

Outdoor Glass	Airspace inches	Airspace mm	U-Factor BTU/hr·ft²·°F (W/m²·K)	-20 °F (-29 °C) Outdoor Air Temperature T_{cog} °F (°C)	-20 °F (-29 °C) RH %	0 °F (-18 °C) Outdoor Air Temperature T_{cog} °F (°C)	0 °F (-18 °C) RH %	+20 °F (7 °C) Outdoor Air Temperature T_{cog} °F (°C)	+20 °F (7 °C) RH %
Clear / Clear / Clear	5/16	8.0	**0.35** (1.99)	**46** (8)	43	**51** (11)	51	**56** (13)	61
	7/16	11.5	**0.32** (1.82)	**48** (9)	46	**52** (11)	54	**57** (14)	63
LoĒ-180® / Clear / LoĒ-180®	5/16	8.0	**0.17** (0.97)	**58** (14)	65	**60** (16)	71	**63** (17)	78
	7/16	11.5	**0.14** (0.79)	**60** (16)	70	**62** (17)	76	**64** (18)	82
LoĒ^2-272® / Clear / LoĒ-180®	5/16	8.0	**0.17** (0.97)	**58** (14)	66	**60** (16)	71	**63** (17)	78
	7/16	11.5	**0.13** (0.74)	**60** (16)	70	**62** (17)	76	**64** (18)	82
LoĒ^2-270® / Clear / LoĒ-180®	5/16	8.0	**0.17** (0.97)	**58** (14)	66	**60** (16)	73	**63** (17)	78
	7/16	11.5	**0.13** (0.74)	**60** (16)	71	**62** (17)	76	**64** (18)	82
LoĒ^3-366® / Clear / LoĒ-180®	5/16	8.0	**0.17** (0.97)	**58** (14)	66	**60** (16)	72	**63** (17)	78
	7/16	11.5	**0.13** (0.74)	**60** (16)	71	**62** (17)	77	**64** (18)	83
Quad LoĒ-452+™ / Clear / LoĒ-180®	5/16	8.0	**0.16** (0.91)	**58** (14)	66	**60** (16)	72	**63** (17)	78
	7/16	11.5	**0.13** (0.74)	**60** (16)	71	**62** (17)	76	**65** (18)	83
LoĒ^3-340® / Clear / LoĒ-180®	5/16	8.0	**0.17** (0.97)	**58** (14)	66	**60** (16)	72	**63** (17)	78
	7/16	11.5	**0.13** (0.74)	**60** (16)	71	**62** (17)	77	**64** (18)	82
LoĒ^2-240® / Clear / LoĒ-180®	5/16	8.0	**0.17** (0.97)	**58** (14)	65	**60** (16)	71	**63** (17)	78
	7/16	11.5	**0.14** (0.79)	**60** (16)	70	**62** (17)	76	**64** (18)	82
LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)	5/16	8.0	**0.15** (0.85)	**48** (9)	47	**52** (11)	54	**57** (14)	63
	7/16	11.5	**0.12** (0.68)	**51** (11)	51	**55** (13)	60	**59** (15)	68
LoĒ^2-272® / LoĒ-180® / LoĒ-i89® (#6)	5/16	8.0	**0.15** (0.85)	**49** (9)	47	**53** (12)	54	**57** (14)	64
	7/16	11.5	**0.12** (0.68)	**52** (11)	53	**55** (13)	60	**59** (15)	63
LoĒ^2-270® / LoĒ-180® / LoĒ-i89® (#6)	5/16	8.0	**0.15** (0.85)	**49** (9)	47	**53** (12)	55	**57** (14)	64
	7/16	11.5	**0.15** (0.85)	**49** (9)	47	**53** (12)	55	**60** (16)	64
LoĒ^3-366® / LoĒ-180® / LoĒ-i89® (#6)	5/16	8.0	**0.14** (0.79)	**49** (9)	48	**53** (12)	55	**57** (14)	64
	7/16	11.5	**0.12** (0.68)	**52** (11)	53	**56** (13)	61	**59** (15)	69
Quad LoĒ-452+™ / LoĒ-180® / LoĒ-i89® (#6)	5/16	8.0	**0.14** (0.79)	**49** (9)	48	**53** (12)	55	**57** (14)	64
	7/16	11.5	**0.12** (0.68)	**52** (11)	53	**55** (13)	61	**59** (15)	70

Figure 2-36

1. U-Factor: Winter night time conditions with outdoor air temperatures shown. 12.3 mph (19.8 kph) outdoor wind velocity with indoor air temperature = 70 °F (21 °C).
2. Tcog: Indoor center of glass surface temperature (rounded to nearest degree). Calculated using LBNL Window program.
3. %RH: Percent relative humidity at indoor temperature of 70 °F (21 °C). Maximum indoor relative humidity before condensation starts to appear.
4. Triple-pane IG construction: 5/16" (8.0 mm) airspace, 90% argon filled for LoĒ products. Otherwise air-filled cavity. Coatings on surfaces #2 and #5, or #2, #4 and #6.
5. All insulating glass systems contain 1/8" (3 mm) glass.
6. U-Factors are based on a 0 °F (-18 °C) outdoor air temperature.

Thermal Comfort

ASHRAE Standard 55 suggests that thermal conditions are acceptable until more than 10% of the room occupants are uncomfortable. This can be somewhat subjective as it depends on the person's activity and clothing insulation levels, but most building comparisons assume sedentary with seasonally appropriate attire.

Comfort near a window varies with season of the year. Winter comfort depends on where the building is located: northern latitudes have more extreme cold temperatures and the winter season is longer. Summer locations have little impact on comfort; the primary issue for summertime is exposure orientation (east/west versus north/south). Spring and fall comfort problems stem from building design: Too much solar gain without a call for heat or cool can lead to building overheat.

Winter Cold Weather Comfort

In general, the lower the U-Factor the more comfortable the glass will be on a cold winter night. Double- to triple-pane glass, LoĒ coatings, gas fill and LoĒ-i89® all lower the U-Factor and improve winter comfort. The other consideration for cold is window size: The larger the window the more it dominates the comfort space and the more important U-Factor improvements are.

In most instances, the roomside glass surface temperature can be used for guidance on comfort expectations (warmer = better). LoĒ-i89 is a special case, because the infrared reflectance of LoĒ-i89 will generate comfort conditions more like that of an insulated wall. Mean Radiant Temperature (MRT) is used to account for roomside glass surface temperature, window size and the IR reflectivity. MRT is a better overall comparator than roomside temperature for decisions relating to glass and comfort.

COLD WEATHER COMFORT

<table>
<tr><th rowspan="2">Insulating Glass Unit</th><th rowspan="2">Gap</th><th rowspan="2">Approximate Window U-Factor</th><th colspan="2">Northern U.S.</th><th colspan="2">Central U.S.</th><th colspan="2">Southern U.S.</th></tr>
<tr><th>Typical Window Area</th><th>Large Window Area</th><th>Typical Window Area</th><th>Large Window Area</th><th>Typical Window Area</th><th>Large Window Area</th></tr>
<tr><td>Clear / Clear</td><td>9.8 mm, Air</td><td>0.50</td><td rowspan="2">NR</td><td rowspan="2">NR</td><td rowspan="2">NR</td><td rowspan="2">NR</td><td rowspan="2">NR</td><td rowspan="2">NR</td></tr>
<tr><td>Clear / Clear / Clear</td><td>8.0 mm, Air</td><td>0.50</td></tr>
<tr><td>Clear / LoĒ-180®</td><td>13.0 mm, Argon</td><td>0.50</td><td rowspan="6">+2</td><td rowspan="6">+3</td><td rowspan="6">+1</td><td rowspan="6">+2</td><td rowspan="6">Okay</td><td rowspan="6">+1</td></tr>
<tr><td>LoĒ^2-272® / Clear</td><td>13.0 mm, Argon</td><td>0.50</td></tr>
<tr><td>LoĒ^2-270® / Clear</td><td>13.0 mm, Argon</td><td>0.50</td></tr>
<tr><td>LoĒ^3-366® / Clear</td><td>13.0 mm, Argon</td><td>0.50</td></tr>
<tr><td>Quad LoĒ-452+™ / Clear</td><td>13.0 mm, Argon</td><td>0.50</td></tr>
<tr><td>LoĒ^3-340® / Clear</td><td>13.0 mm, Argon</td><td>0.50</td></tr>
<tr><td>LoĒ-180® / LoĒ-i89® (#4)</td><td>13.0 mm, Argon</td><td>0.27</td><td rowspan="6">+1</td><td rowspan="6">+2</td><td rowspan="6">Okay</td><td rowspan="6">+1</td><td rowspan="6" colspan="2">Okay</td></tr>
<tr><td>LoĒ^2-272® / LoĒ-i89® (#4)</td><td>13.0 mm, Argon</td><td>0.27</td></tr>
<tr><td>LoĒ^2-270® / LoĒ-i89® (#4)</td><td>13.0 mm, Argon</td><td>0.27</td></tr>
<tr><td>LoĒ^3-366® / LoĒ-i89® (#4)</td><td>13.0 mm, Argon</td><td>0.27</td></tr>
<tr><td>Quad LoĒ-452+™ / LoĒ-i89® (#4)</td><td>13.0 mm, Argon</td><td>0.27</td></tr>
<tr><td>LoĒ^3-340® / LoĒ-i89® (#4)</td><td>13.0 mm, Argon</td><td>0.27</td></tr>
<tr><td>LoĒ-180® / Clear / LoĒ-180®</td><td>8.0 mm, Argon</td><td>0.20</td><td rowspan="4">Okay</td><td rowspan="4">+1</td><td rowspan="4" colspan="2">Okay</td><td rowspan="4" colspan="2">Okay</td></tr>
<tr><td>LoĒ^2-272® / Clear / LoĒ-180®</td><td>8.0 mm, Argon</td><td>0.20</td></tr>
<tr><td>LoĒ^2-270® / Clear / LoĒ-180®</td><td>8.0 mm, Argon</td><td>0.20</td></tr>
<tr><td>LoĒ^3-366® / Clear / LoĒ-180®</td><td>8.0 mm, Argon</td><td>0.20</td></tr>
<tr><td>LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)</td><td>8.0 mm, Argon</td><td>0.18</td><td rowspan="4" colspan="2">Okay</td><td rowspan="4" colspan="2">Okay</td><td rowspan="4" colspan="2">Okay</td></tr>
<tr><td>LoĒ^2-272® / LoĒ-180® / LoĒ-i89® (#6)</td><td>8.0 mm, Argon</td><td>0.18</td></tr>
<tr><td>LoĒ^2-270® / LoĒ-180® / LoĒ-i89® (#6)</td><td>8.0 mm, Argon</td><td>0.18</td></tr>
<tr><td>LoĒ^3-366® / LoĒ-180® / LoĒ-i89® (#6)</td><td>8.0 mm, Argon</td><td>0.18</td></tr>
</table>

Figure 2-37

NR	Not recommended
+1	Raise Heating by 1°
+2	Raise Heating by 2°
+3	Raise Heating by 3°

North America can be considered to have approximately 3 zones in terms of cold weather window discomfort.

- North. Winter design temperatures are below 0 °F (-20 °C).
- Central. Winter design temps are about 10 °F (-10 °C)
- South. Winter design temps are near freezing (30 °F, 0 ° C)

Figure 2-37 shows what product options will deliver acceptable comfort as a function of geographic location and window to room size ratio. The plus values (e.g., +1, +2, +3) indicate an increase in heating thermostat needed for acceptable comfort per ASHRAE Standard 55.

When it comes to winter comfort, look to the best regional selection of Cardinal's insulating glass products with a glass.

HOT WEATHER COMFORT

Insulating Glass Type	LoĒ Type	Approximate Window SHGC	Typical Window Area	Large Window Area
Double Pane	Clear / Clear	0.60	NR	NR
	Clear / LoĒ-180®	0.50	NR*	NR*
	LoĒ^2-272® / Clear	0.30	-1	-2
	LoĒ^2-270® / Clear	0.30		
	LoĒ^3-366® / Clear	0.20	Okay	
	Quad LoĒ-452+™ / Clear	0.16		
	LoĒ^3-340® / Clear	0.16		
Double Pane w/i89®	Clear / LoĒ-180®	0.50	NR*	NR*
	LoĒ^2-272® / Clear	0.30	-1	-2
	LoĒ^2-270® / Clear	0.30		
	LoĒ^3-366® / Clear	0.20	Okay	
	Quad LoĒ-452+™ / Clear	0.16		
	LoĒ^3-340® / Clear	0.16		
Triple Pane	LoĒ-180® / Clear / LoĒ-180®	0.45	NR*	NR*
	LoĒ^2-272® / Clear / LoĒ-180®	0.27	-1	-2
	LoĒ^2-270® / Clear / LoĒ-180®	0.27		
	LoĒ^3-366® / Clear / LoĒ-180®	0.18	Okay	
Triple Pane w/i89®	LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)	0.45	NR*	NR*
	LoĒ^2-272® / LoĒ-180® / LoĒ-i89® (#6)	0.27	-1	-2
	LoĒ^2-270® / LoĒ-180® / LoĒ-i89® (#6)	0.27		
	LoĒ^3-366® / LoĒ-180® / LoĒ-i89® (#6)	0.18	Okay	

Figure 2-38

NR	Not recommended
NR*	Requires design guidance
-1	Lower cooling by 1°
-2	Lower cooling by 2°

Hot Weather Comfort
Direct solar gain onto the occupant is the primary concern for hot weather discomfort. Across North America, this means east-facing windows in the morning and west-facing windows in the afternoon will be of concern. Of the two, west is the biggest concern as max solar gain is coincident with max temperature. Summer sun exposure on north and south elevations are minimal. If the occupant is in direct sun, the window size does not really affect discomfort (presuming air conditioner is adequately sized to handle window area load).

Solar heat gain coefficient (SHGC) includes both direct gain and re-radiated gain from hot glass. A lower SHGC value implies less gain and/or less impact from mean radiant temperature (MRT). While LoĒ-i89® can provide some relief from the absorption heating that is typical of high solar gain products, it does little to limit solar gain and the risk of overheat discomfort. Figure 2-38 illustrates the summer comfort characteristics of insulating glass (IG) products. Like the cold weather chart, it relates glass choice and SHGC to the needed adjustment to the thermostat to maintain comfort based on window area. Clear double or triple pane is not recommended anywhere as the solar gain is too high for comfort. The required design guidance (NR*) assigned to LoĒ-180® options covers questions surrounding passive solar building designs. While LoĒ-180 can provide winter passive solar energy saving on the south façade, there is substantial risk of swing season overheat unless overhang shading or massive thermal mass is included in the building design.

Solar Energy Transmittance Comparison

Solar energy can be broken down into the UV, Visible and Near Infrared spectrums. Characteristics of these energy spectrums are as follows:

- UV, 300 to 380 nm – Can cause fading of furnishings
- Visible, 380 to 780 nm – Visible light
- Near Infrared, 780 to 2500 nm – Solar energy that we feel as heat

A comparison of the performance of Cardinal's LoĒ products is shown below.

Depending on the application, the best glass product would have a low UV transmission, a high visible light transmission and a low near infrared transmission. Considerations of outdoor aesthetics, color, glare, solar heat gain coefficient (SHGC), heat loss (U-Factor), comfort, visible light transmission, etc., should be taken into account on any application.

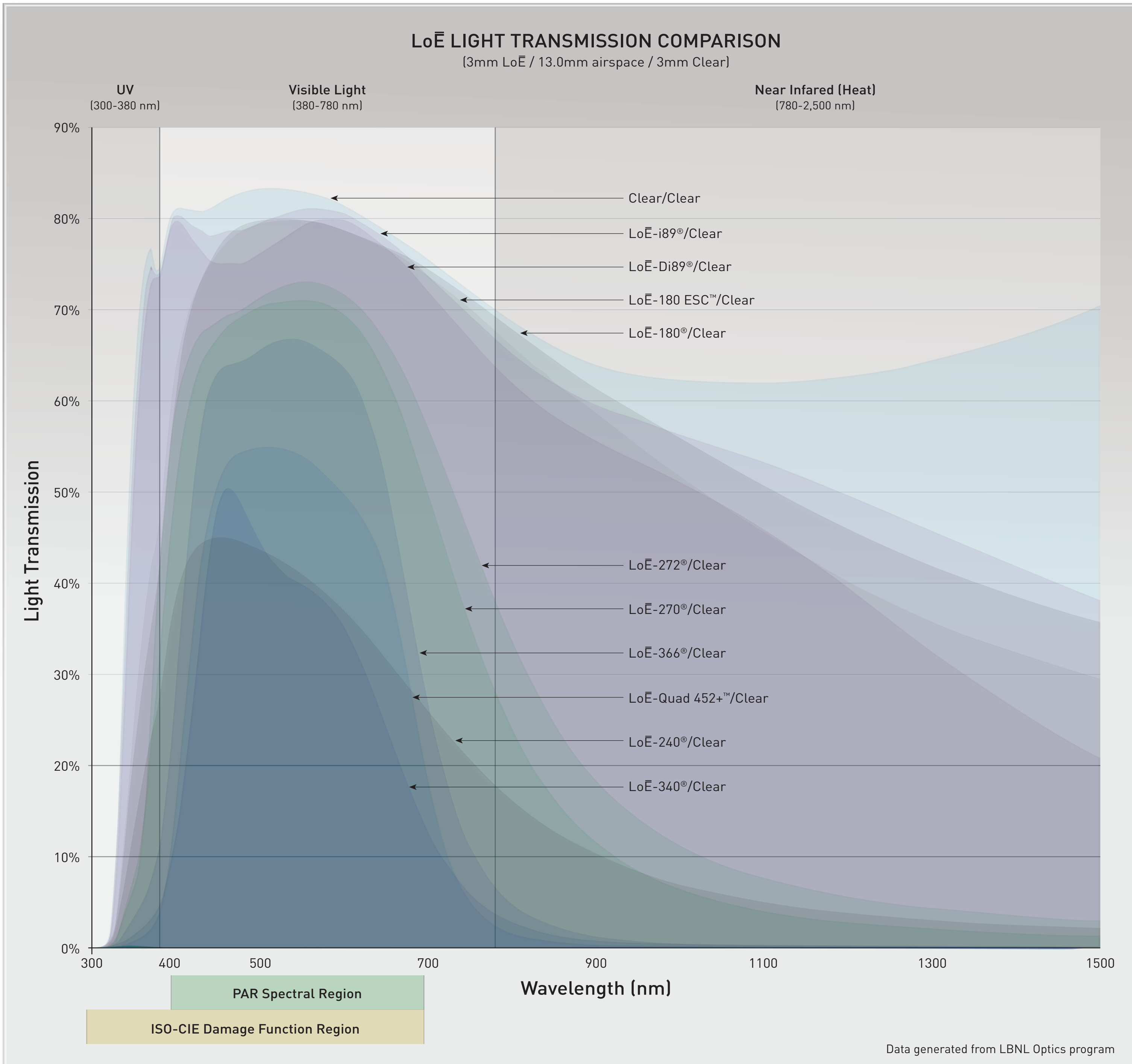


Figure 2-39

Effects of Glass and Coatings on Plant Growth

The most important effect of a glazing system on plant growth is its influence on photosynthesis. Light which drives photosynthesis is called photosynthetically active radiation (PAR) and falls in the spectral range from 400 nm to 700 nm (see Figure 2-39). In essence, the higher the light transmission in the spectral range from 400 to 700 nm, the better the glass product is for plant growth.

House plants often grow under conditions which are marginal for adequate growth, and are primarily selected because of their ability to grow in relatively low light. Not all house plants are equally well adapted to low light conditions; however, some will be stressed by reduced light environments. Factors such as distance from windows, length of exposure to direct sunlight, time of day of direct exposure, light reflection from interior and exterior surfaces, average ambient temperature, temperature fluctuations, relative humidity, air circulation patterns, watering, and perhaps most important of all, the cleanliness of the windows, all have potential impact on plant growth. Dirty windows can be a significant problem in greenhouses due to the reduction in light transmission. The same is undoubtedly true for other buildings in which plants are grown. Light supply problems are most apt to be observed in November, December and January, when the days are short and cloud cover is prevalent.

Unlike field crop plants, house plants have the ability to grow in relatively low light conditions.

Figure 2-40 below lists the percentage of photons transmitted in the PAR region per Cardinal LoĒ coating. The majority of the listed coatings will have minimal effects on plant growth. A small number of coatings cause the level of photons in the PAR spectrum to fall to or below 50% of the light to be transmitted through an insulating glass IG unit, which is equivalent to the amount of light produced during a bright overcast day. Therefore, on cloudy days the rate of photosynthesis could fall to levels which would noticeably slow plant growth. If internal light intensities are marginal, then the use of this coating in an (IG) unit could result in the inability to grow some house plants.

IG Unit (3 mm glass)	Percentage of Photons Transmitted in PAR Spectral Region
Clear / Clear	83%
Clear / LoĒ-i89®	81%
Clear / LoĒ-Di89™	80%
Clear / LoĒ-180 ESC™	80%
Clear / LoĒ-180®	80%
LoĒ²-272® / Clear	73%
LoĒ²-270® / Clear	71%
LoĒ³-366® / Clear	67%
Quad LoĒ-452+™ / Clear	55%
LoĒ³-340® / Clear	50%
LoĒ²-240® / Clear	45%

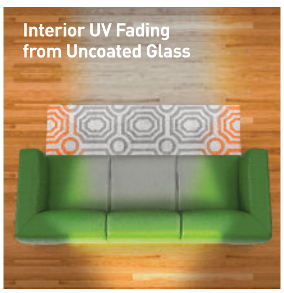
Figure 2-40

UV Fading

The energy from UV light causes most fading damage. As a result, many people use the classical UV transmittance (300 to 380 nm) as an indicator of fading potential to compare glass products. It has been shown that experimentally fading damage can also occur from light in nearly the entire visible light spectrum. The ICO-CIE Damage Function attempts to quantify the risk of damage from the full spectrum of light (UV and visible). It uses system of weighting the amount of light transmitted at a wavelength based on its contribution to fading of materials such as fabrics. See table below for more detail. It should be noted all materials fade at different rates and no glass choice will completely eliminate fading. In order to see through the window, all glass options will allow some visible light through the glass and therefore cause some level of fading. Additionally, in the absence of natural light, artificial light will be used within the building that will also contribute to fading in a significant way.

The way a particular object may fade is highly variable. In addition to the light sources, the materials themselves will have different resistance to fading. Some fabrics, woods, paints and other interior finishes are significantly more susceptible to fading. Manufacturers of the interior finishes should be consulted for both recommendations and expectations as it relates their products and fading caused by sunlight and interior lighting.

Laminated glass is often used in situations where a low amount of fading is desired. Most glass laminates have very low levels of UV transmission. This will contribute to relatively low weighted damage functions as well. As noted above, even though most laminated glass allows virtually no UV transmission, the visible light that is transmitted will contribute to fading of finishes within a building. In glass constructions where the LoĒ already blocks the vast majority of UV, the addition of the laminate will only provide a small increase in fading protection.



Uncoated glass allows abundant amounts of UV light to reach a home's interior, which can damage furniture, carpets, wood floors and artwork. Laminated glass blocks most of this UV radiation, helping to protect interior furnishings from fading.

GLASS UV FADING PROTECTION COMPARISON

Glass	SHGC	UV-Trans	ISO-CIE
Clear / Clear	0.78	58%	75%
Clear / Lami	0.75	<1%	56%
Clear / LoĒ-180®	0.79	29%	63%
Lami / LoĒ-180®	0.64	<1%	52%
LoĒ^2-272® / Clear	0.41	16%	55%
LoĒ^2-272® / Lami	0.41	<1%	47%
LoĒ^3-366®/ Clear	0.27	5%	43%
LoĒ^3-366® / Lami	0.27	<1%	40%
Quad LoĒ-452+™ / Clear	0.22	1%	33%
Quad LoĒ-452+™ / Lami	0.22	<1%	31%
LoĒ^3-340® / Clear	0.18	2%	27%
LoĒ^3-340® / Lami	0.18	<1%	26%

Figure 2-41

1. Data was calculated using the LBNL Window computer program per NFRC environmental conditions.
2. 90% argon/10% air fill is used for insulated glass (IG) units with LoĒ coated glass, otherwise 100% air fill is used for uncoated units.
3. The UV Transmittance is determined as an average for wavelengths 300 - 380 nm.
4. UV Damage Weighted Transmittance (ISO-CIE) is the weighted average for wavelengths 300 - 700 nm (based on CIE 89/3).
5. UV transmittance is never 0%, but for any construction with a laminated layer, it is very close to 0%.
6. Airspaces are 1/2" (13.0 mm) wide.

In laboratory testing for durability and long-term performance, our results exceed industry standards. Our experience in the field provides the ultimate proof: Cardinal IG® units have the lowest failure rates in the industry. We also offer an industry-leading 20-year comprehensive warranty. Cardinal IG units stand the test of time.

3

Intelligent Quality
Assurance Program

Ensuring Quality from Start to Finish

Cardinal maintains the highest quality standards through industry-leading inspection processes. Our Intelligent Quality (IQ) Assurance Program is our signature seal for quality, with every piece of glass thoroughly checked from start to finish. IQ systems are in place for everything from float glass manufacturing to producing all types of coated, tempered and insulating glass.

FLOAT GLASS

Float glass is the foundation of all Cardinal products, and it is where our quality commitment begins.

Annealing - By providing a uniform glass temperature, this cooling process helps create the inherent uniformity of the glass and maximizes the ability to cut the finished product.

Strain Measurements - Three different strain measurements are taken to precisely control the strain on the ribbon which also affects the cuttability of the glass.

Thickness Profile - By gauging the thickness across the entire ribbon, we can determine if any portion is out of specification.

Defect Detection - Our laser system inspects 100% of the glass, detecting defects as well as ribbon edges, knurl marks and distortion.

Optimization System - This process arbitrates the best cut for the ribbon, which helps maximize production and efficiency to reduce waste.

Emissions Conformance - The Cardinal environmental commitment includes equipping all facilities with the latest technologies to reduce emissions.

COATED GLASS

Cardinal employs patented, state-of-the-art sputter coating processes that are unmatched by any other glass manufacturer.

Exterior Color - Exterior color is validated in process as well as off-line. This specific technology analyzes how the final product will appear in its final installation. Production measurements enable us to statistically control the existing process and use the data as benchmarks for continuous improvement efforts.

Room-Side Color and Visible Transmission/ Reflection - This Cardinal-specific technology provides continuous load-to-load monitoring to validate film stack construction.

IR Reflection - This measurement validates and ensures coating performance by measuring infrared reflection.

Performance Testing - R&D conducted evaluations consider every potential variable that can arise along the way. Customized for production, in-process testing is continuous and recorded into our electronic Quality Management System.

CUSTOM TEMPERED GLASS

Cardinal tempering increases the glass strength to at least four times that of ordinary glass, while distortion remains minimal and color is virtually unnoticeable.

Vision Inspection Systems
These high-resolution, high-speed camera systems are used to detec scratches, coating faults and debris on the surface.

Tempered Distortion
Our state-of-the-art camera systems measure the entire glass, focusing on a series of circles (similar to pixels). The results represent what the human eye sees.

Defect Detection - This system accurately characterizes defects by size and sorts them according to our specifications, helping to prevent defective glass from proceeding to high-value operations.

Tempered Conformance - In some Cardinal tempering facilities, a photoelastic stress measuring system identifies areas of non-uniform stress in the glass, highlighting areas with inadequate tempering. The system also allows us to reconfigure procedures as necessary to obtain better heating and quenching, further ensuring high-quality tempered glass every time.

INSULATING GLASS

Cardinal IG® units deliver outstanding thermal performance and extremely low failure rates.

Vision-Based Inspections - Similar to the systems incorporated on our tempering lines, this is where scratches, coating faults and debris on the glass surface are detected. The systems accurately characterize defects by size and sort them according to specifications to help prevent defective glass from proceeding to high-value operations.

Edge Thickness - Our press equipment ensures the precise thickness of each IG unit to within thousandths of an inch.

Argon-Fill Levels - Our unique inline system measures the argon-fill levels of Cardinal IG units and verifies initial fill rates. Our IG units have been tested to meet the U.S. standards for argon total fill and argon loss per ASTM E2190.

Coating Color - A spectrophotometer checks color intensity and hue. Each unit must meet specific color values prior to being accepted.

Center of Glass Unit Thickness - We measure all units for center dimension online. This is a critical parameter for reducing unit stress and reducing distortion in the glass.

Essentials of Manufacturing Long-Lasting IG Units

What makes a long-lasting IG unit?

Material Selection
The sealant(s) used to bond glass to the spacer system is the most important material used in IG unit construction. The sealant(s) must resist temperature extremes, UV radiation, moisture ingress into the airspace and retain any inert gas in the airspace; i.e., argon. Cardinal has chosen a dual seal system with polyisobutylene [PIB] as the primary seal and silicone as the secondary seal.

In addition to sealant choice, spacer design and processing are also important. Cardinal uses four bent corners in our construction which requires only one joint in the spacer. Many other IG units use notched corners. Each notch is a potential leak into the system, significantly increasing the potential for moisture ingress or argon loss from the IG unit.

Workmanship
Critical to IG unit longevity is fabrication consistency. Cardinal's unique Intelligent Quality Assurance Program virtually eliminates anomalies in the fabrication process. All inspections rely on carefully calibrated instrumentation, so results are objective. In addition, Cardinal manufactures its own production equipment to ensure that units are fabricated with consistent high quality.

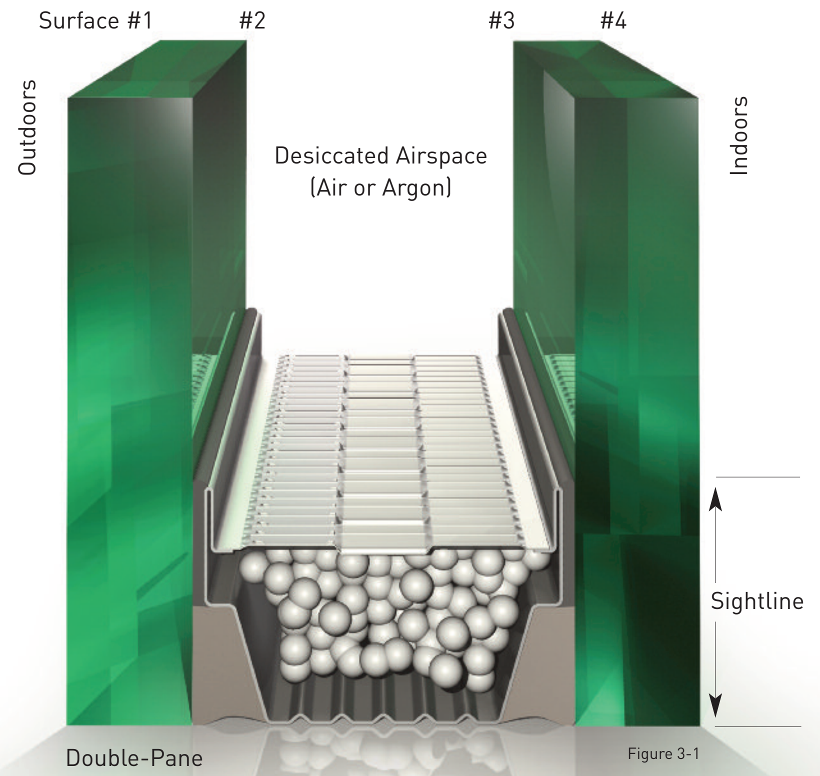


Figure 3-1

Surfaces: The industry convention for labeling of glass surface is to start with the outdoor surface and count the surface toward the inside of the structure.

Sightline: The industry convention for labeling of glass surface is to start with the outdoor surface and count the surface toward the inside of the structure.

How the Units Are Glazed
If an IG unit sits in water or the seal system is overstressed, there is no unit construction that will deliver long-term performance. Cardinal believes our dual seal construction is the most versatile IG seal system because of its excellent weatherability. In fact, in both real-world and simulated weathering conditions, Cardinal's dual seal system outperforms other IG unit constructions.

Compatibility
Extra care must be taken in choosing window sealants and glazing materials that will be in direct contact with the IG unit. These material interactions with the IG unit can potentially degrade unit longevity to a significant degree. Cardinal offers its customers expert guidance on assessing the risk of material incompatibility with Cardinal's products.

Cardinal IG® Unit Construction
Cardinal IG units consist of two or three lites of glass separated by an inorganic metal spacer (Figures 3-1 and 3-2). Spacer corners are bent to be air/gas tight. The spacer contains desiccant which adsorb the moisture vapor within the airspace.

The dual seal construction has a primary seal of polyisobutylene (PIB) and a secondary seal of silicone. Cardinal certifies all units through the IGCC (Insulating Glass Certification Council) Program, and has met the requirements of the IGMA (Insulating Glass Manufacturers Alliance) Certification Program.

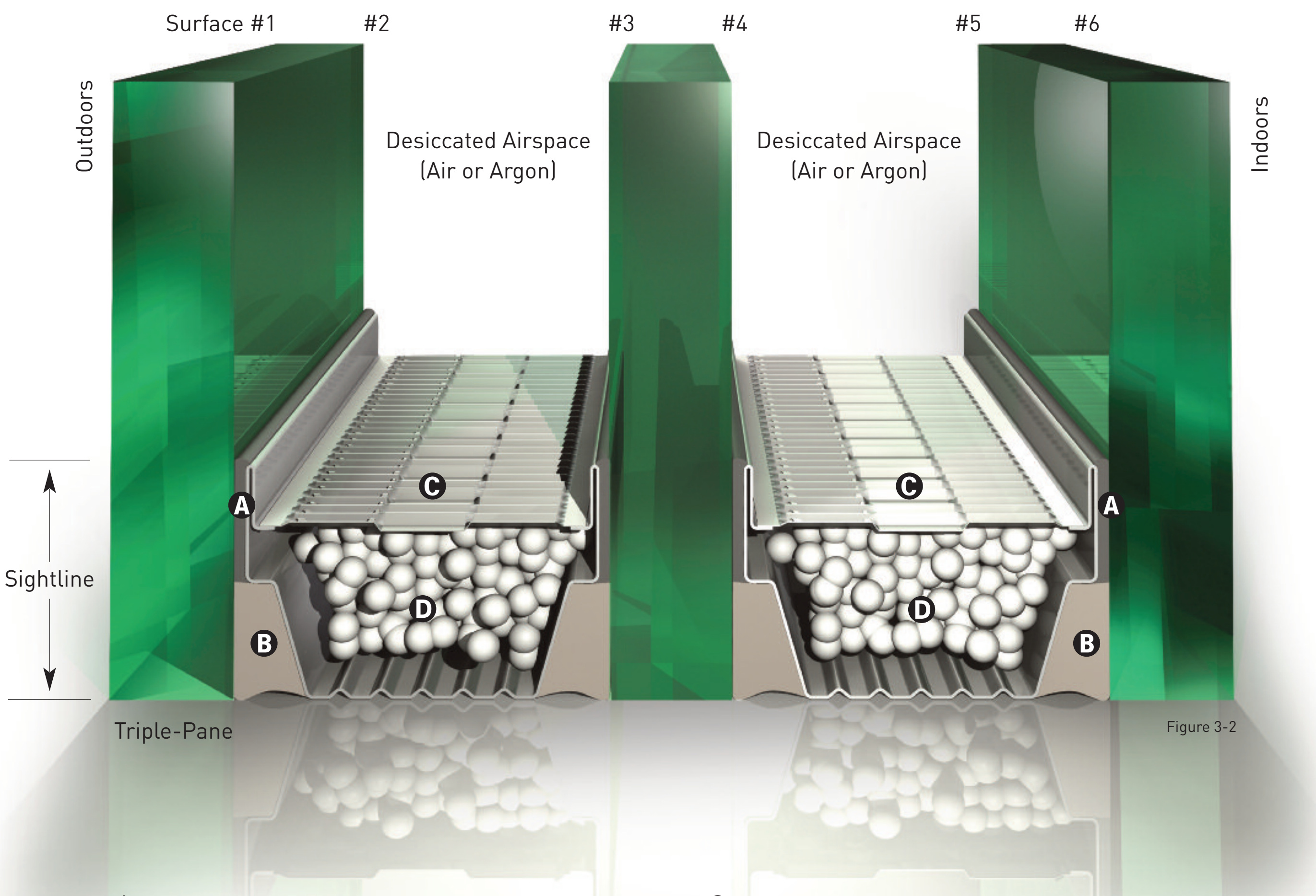


Figure 3-2

A **Primary Seal:** Polyisobutylene (PIB) minimizes moisture permeation and provides one of the lowest argon permeation rates of all known sealants.

B **Secondary Seal:** Specially formulated silicone for IG units provides long-term adhesion. Silicones, due to their non-organic nature, are the most resistant sealants in the window industry to the negative effects of UV and moisture. Silicone is recognized as the best sealant for resisting weathering and adhering to glass substrates. Because of its structural properties, silicone provides the structural integrity of the IG units.

C **Spacer:** Our stainless steel spacer features a roll formed design providing maximum area for primary and secondary sealant coverage. It provides increased resistance to condensation and less stress on IG seal system. Bent corners completely seal the spacer periphery to eliminate moisture vapor transmission into the airspace through joints and notches.

D **Desiccant:** Molecular sieve creates a low frost point below -85 °F. Cardinal's 3 angstrom desiccant assures optimum moisture adsorption while minimizing the effects of temperature-related pressure changes.

Testing and Field Experience Confirm Cardinal IG® Durability

Cardinal Exceeds Industry Standards

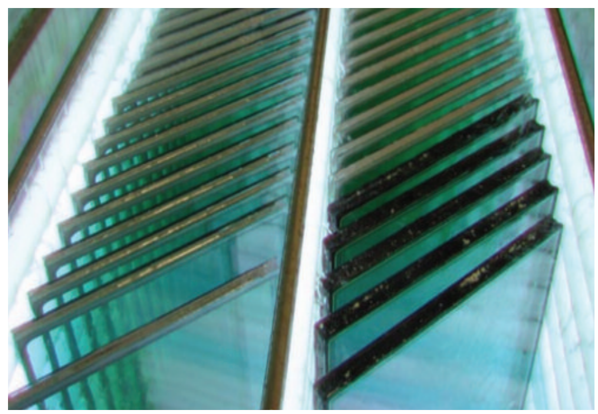
ASTM International has developed a testing protocol (E2190 Standard Specification for Insulating Glass Unit Performance and Evaluation) to determine the weather-ability of insulating glass constructions. Passing this standard is considered a minimum requirement for insulating glass durability. This protocol exposes the samples to high humidity, thermal cycling and UV. The samples are evaluated for chemical fogging, elevated dew points and argon fill/retention. The standard is used as the basis for IGCC/IGMA certification. All Cardinal IG production facilities are IGCC/IGMA certified.

Thermal Cycling

Cardinal subjects IG units to more severe thermal cycling exposures than the E2188/2190. Our testing immerses the entire sample in an environment that cycles from -27 ºF to +160 ºF (-32 ºC to +71 ºC) five times per day. Full immersion, as opposed to single-sided exposure of the ASTM test, along with the wider temperature range, significantly increases the severity of the test. Although the ASTM 2188/2190 standard requires only 250 cycles while maintaining a low unit dew point in this environment, Cardinal units are built to last more than 1,000 cycles.

Cardinal IG Units Excel in Rigorous P-1 Test

Cardinal subjects IG units to the more demanding and industry-accepted P-1 test, which determines long-term seal durability. Test conditions simulate worst-case, real-world scenarios: 140 ºF (60 ºC), constant UV exposure and 100% humidity. Results show that competitive seal systems fail within eight to 22 weeks of testing. However, Cardinal IG units still have a dew point below 0 ºF (-18 ºC) after 80 weeks of the test.



P-1 Test Chamber: 140°F, constant UV, 100% humidity

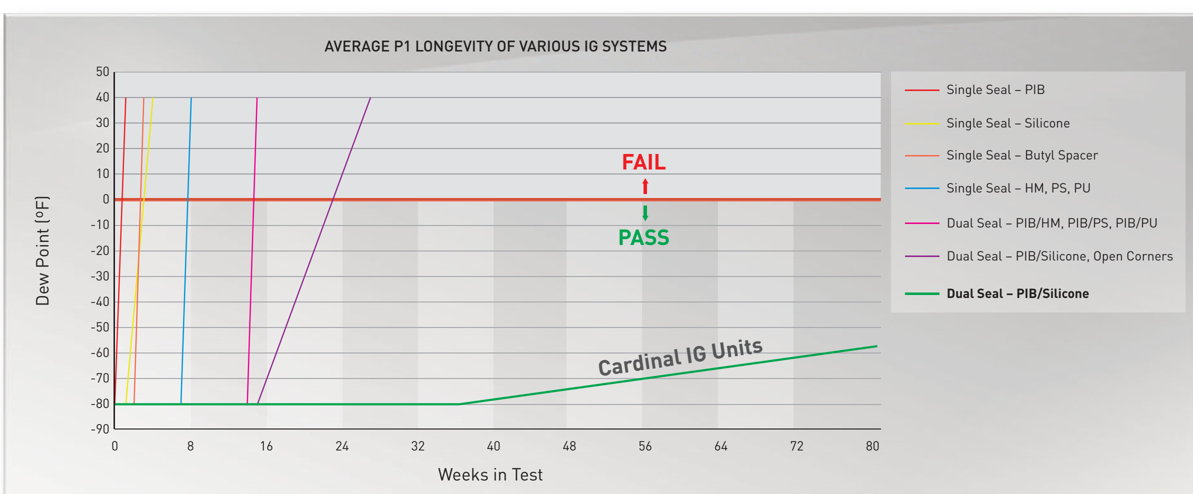


Figure 3-3

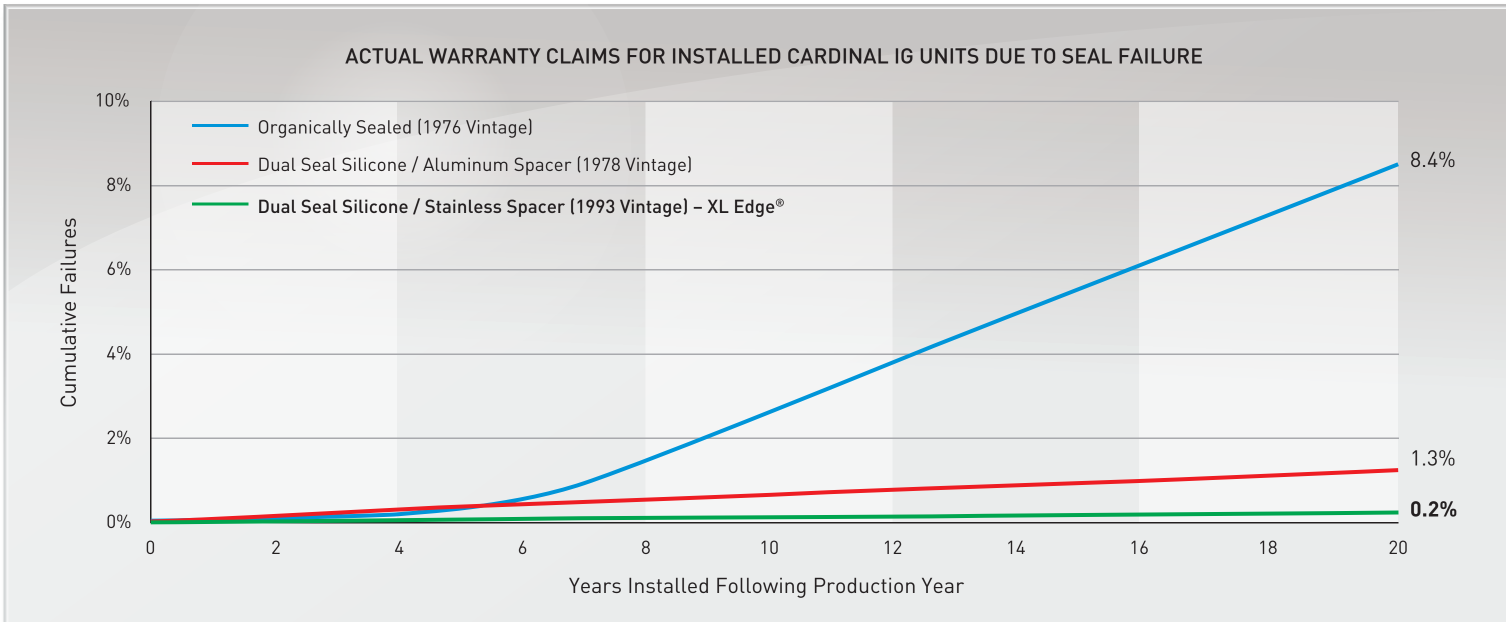


Figure 3-4

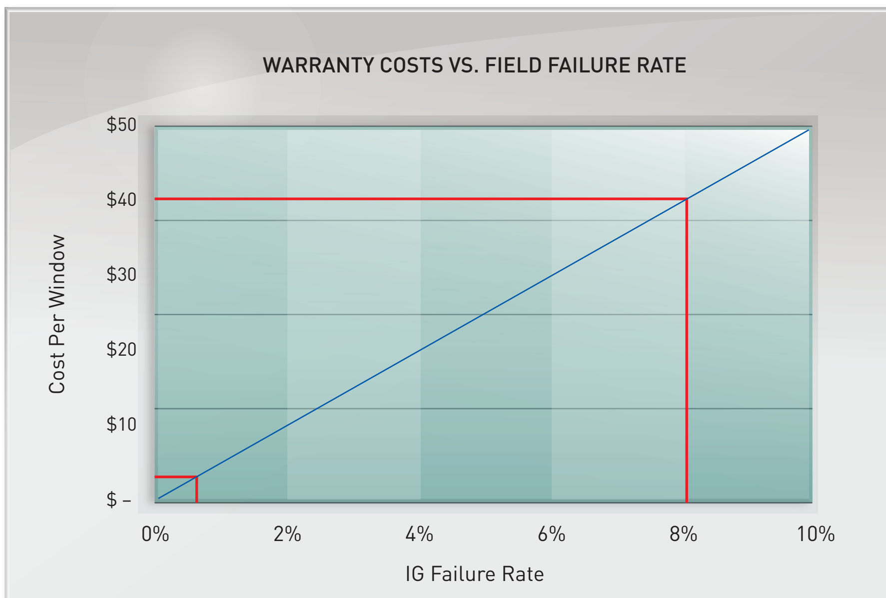
Cardinal Seal Failure Experience

Figure 3-4 shows Cardinal field failure rate comparing failures to industry-wide failure rates, Cardinal Dual Organic Seals with Aluminum Spacers, Dual Seal Silicone with Aluminum Spacers and Dual Seal Silicone with Stainless Steel Spacers. Cardinal's 20-year failure rate with our products are as follows:

- Dual Organic Seal/ Aluminum Spacer – 8.4%
- Dual Seal Silicone/ Aluminum Spacer – 1.3%
- Dual Seal Silicone/XL Edge (SS Spacer) – 0.2%

The graph shows Cardinal's actual failure rates for three different IG unit constructions. In 1993, Cardinal introduced a stainless steel spacer with a polyisobutylene (PIB)/Silicone seal system and four bent corners. We produced approximately 8 million IG units that year. As can be seen by the data, the cumulative seal failure rate of the stainless steel spacer product is 0.2% after 20 years of field service. Currently, Cardinal has approximately 500 million IG units under warranty.

What this means to the window manufacturer is shown in Figure 3-5. Assuming a $500 service call to replace a failed IG unit under warranty, and with an 8% seal failure rate, the window manufacturer would need to add $40 to the cost of the window to cover warranty costs. With a 0.2% seal failure rate, the window manufacturer would only need to add $1.00 to the window to cover warranty claims.



1. $500 Replacement Costs
2. 100,000 Units/Year

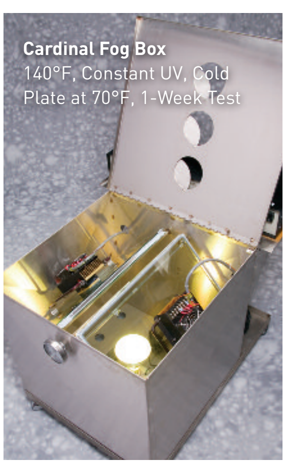
Figure 3-5

Edge Deletion Assures Proper Sealant-to-Glass Bonding

By deleting the edge of LoĒ coatings, Cardinal provides the added safety that the IG unit sealants are bonded to glass rather than a coating. Without edge deletion, all LoĒ coatings extend to the edge of the glass, and corrosion of the coatings can propagate past the seal system when the IG unit is exposed to high humidity conditions or is sitting in water.

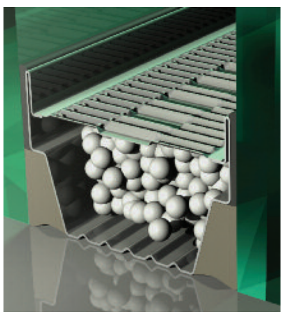
Chemical Fog

Any material used in an insulating glass unit; e.g., sealants, grilles, spacer systems, desiccant, etc., can produce a fog in the unit. ASTM International test E2189 (Standard Test Method for Testing Resistance to Fogging in Insulating Glass Units) was designed to screen for this potential. Cardinal has developed its own more rigorous version of this test. Cardinal's chemical fog test exposes units to higher temperatures and utilizes a more demanding inspection criteria. Cardinal's test is approximately four times more demanding than the ASTM test.



Cardinal Fog Box
140°F, Constant UV, Cold Plate at 70°F, 1-Week Test

Desiccant



Cardinal fills all four legs of its spacer with pure 3A molecular sieve beaded desiccant. The use of only 3A molecular sieve ensures the desiccant only absorbs moisture, not nitrogen gas. Desiccant with pores larger than 3A can absorb nitrogen and other gases, causing the glass to be nonparallel and stressing the seals. This can potentially decrease unit longevity. Cardinal's four-side fill means Cardinal IG units will have twice the desiccant capacity of most metal spacers, and up to four times as much desiccant as a typical flexible spacer system. Desiccant amount can be directly related to IG unit longevity.

Stainless Steel Spacer Minimizes Seal Stress and Argon Loss

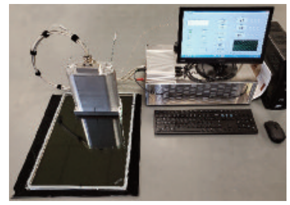
Using computerized finite element analysis (FEA), Cardinal determined that the stainless steel spacer introduced in the early 1990s did not stress the IG seal system to the same degree as previously used aluminum spacers. Excessive stress on the polyisobutylene (PIB) sealant can cause argon loss. The analysis showed that the stainless steel spacer system reduces PIB shear strain (parallel to glass surface) anywhere from 1.5 to 10 times depending on outdoor conditions. PIB extensional strain (perpendicular to glass surface) was one to three times less compared to the aluminum spacer system, depending on the conditions studied.

Quick and Easy IG Unit Identification

Laser Logo shows certification

Knowing the IG unit manufacturer is essential for any warranty claim. But not all insulating glass manufacturers identify their units. Cardinal laser engraves a logo and date code on all units so the homeowner, window manufacturer and Cardinal know when and where the IG unit was fabricated.

Argon Gas Measurement



Cardinal maintains a state-of-the-art facility for the measurement of IG argon and krypton gas concentration and permeation. Cardinal has developed and patented methods to assure that the spark emission spectroscopy used to measure argon gas concentration is accurate and repeatable. All of Cardinal's production lines have the ability to measure online the units produced for argon or krypton fill level.

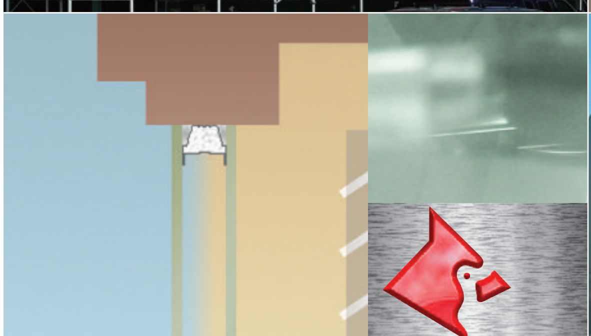
Material Compatibility

Cardinal has devoted a significant amount of research to identify materials that are compatible with our IG system. We work with component suppliers to help ensure their products work with our design. We can offer input into customers' material choices to help them get the longest life out of a Cardinal IG unit.

Technical Service Bulletins

Cardinal provides an extensive library of Technical Service Bulletins (TSBs) at cardinalcorp.com. These TSBs describe in great detail use and performance of Cardinal IG units.

This section is designed to assist in the design of windows, offering data and information to help design professionals make the best decisions possible for their intended applications.



4

DESIGN CRITE-RIA

Glass Types

Annealed Glass

Annealed glass can be used for vision applications where clear, tinted and LoĒ glasses are specified, provided they meet the windload, thermal stress and building code requirements of the project.

Heat-Strengthened Glass

Heat-strengthened glass is approximately two times as strong as annealed glass of the same thickness in resisting windload. If it fractures, it usually breaks into large sections (similar to annealed glass) and usually remains in the opening. If it meets all requirements, codes and specifications, heat-strengthened glass should be used in all applications where annealed glass will not meet thermal or windload requirements. Heat-strengthened glass can be used for all tinted, LoĒ and reflective vision applications. It is the recommended choice for all spandrel applications.

Tempered Glass

Tempered glass is at least four times as strong as annealed glass of the same thickness in resisting windload. If fracture occurs, it will break into very small particles which usually will evacuate the opening and could cause damage or injury to people below. Because of this, Cardinal recommends that the use of tempered glass in commercial construction be restricted to applications where codes require safety glazing, fire knockout panels or in non-hazardous applications where glass fallout potential is not a concern.

Heat-Strengthened and Tempered Glass Manufacturing

Heat-strengthening and glass tempering are processes of heating annealed glass to approximately 1,200 °F (650 °C) and then rapidly cooling it with air. The resultant piece of glass is approximately two to four times stronger than a piece of annealed glass. This increased strength is the result of permanently locking the outer surface molecules of the glass in compression and the center portion in compensating tension.

Bow/Warp

Since the glass is reheated to its softening point and then rapidly cooled, a certain amount of warp or bow is normally associated with each piece of heat-treated glass. Generally this warp or bow is not a significant factor to the design professional. On occasion, it shows up as distorted reflected images under certain viewing conditions and will be more noticeable as the outdoor reflectance of the glass increases.

Strain/Pattern

A visible phenomenon of tempered and heat-strengthened glass is a strain pattern that might appear under certain lighting conditions, especially if it is viewed through polarized lenses. The strain pattern can appear as faint spots, blotches or lines; this is the result of the air quenching (cooling) of the glass during the strengthening process and is not a glass defect.

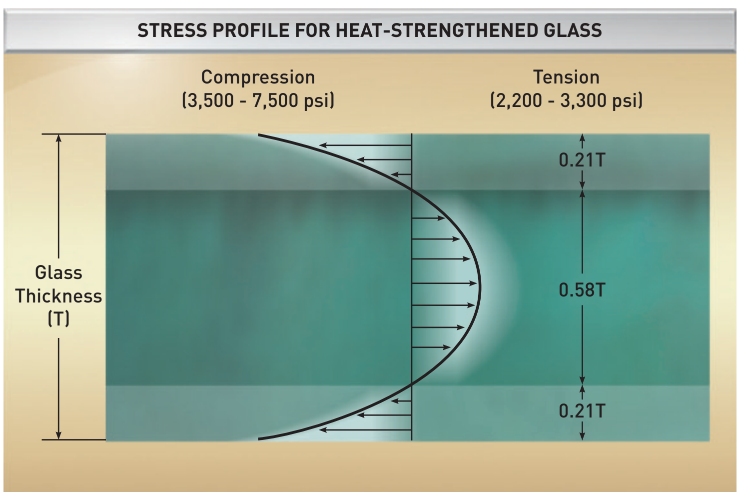


Figure 4-1

Figure 4-2

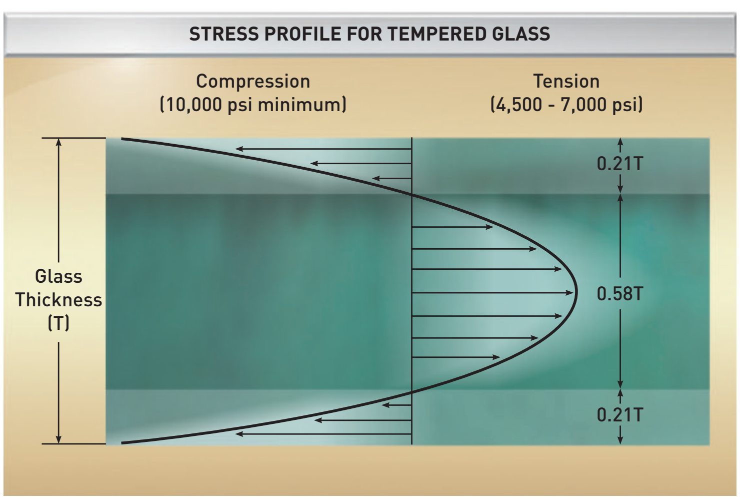


Figure 4-3

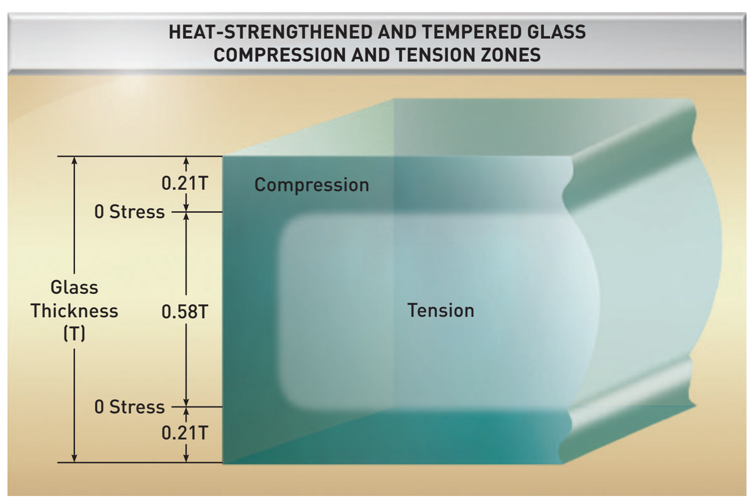


Figure 4-4

Distortion
Distortion can occur in all glass products (i.e., annealed, heat-treated, monolithic, insulating, coated or non-coated). These sometimes visible phenomena are the direct result of light being reflected and refracted at different angles and speeds through uneven glass surfaces.

Mirror-like images should not be expected from glass that has been tempered or heat-strengthened. Quality standards for various sizes and thicknesses of heat-treated glasses are detailed in ASTM Specification C1048. Some glass products will tend to accentuate distortion levels if they have a relatively high outdoor reflectance. Viewing angle, glass type, sky condition, time of day, glass orientation and the type and amount of reflected images all affect the perceived degrees of distortion in any glass product. Causes of distortion can be attributable to one or a combination of the following factors:

1. Roll Ripple
   a. Heat treatment process for heat-strengthened and tempered glass
2. Bow or Warp (either positive or negative)
   a. Heat treatment process
   b. Differences between insulating glass air-space pressure and barometric pressures caused by weather or altitude
   c. Difference between insulating glass air-space temperature and outdoor temperature
   d. Static or dynamic pressure differences from indoors to outdoors (i.e., windload, building's internal pressure, etc.)
   e. Glazing stop pressure
   f. Framing manufacturing and erection tolerance
   g. Insulating glass air-space fabrication pressures

In every process under our control, we always strive to control and minimize distortion levels as much as possible. The glazing system, temperatures and pressures greatly influence the amount of distortion. It is recommended the design professional responsible for glass selection view a mock-up of the intended glass choice in an environment as close as possible to the actual building site to determine if the glass product meets the aesthetic objectives of the project.

Soft Center Glass
Tempered and heat-strengthened glass can exhibit conditions known as soft-centered, bistable and oil canning.

Bistable glass exhibits two stable bow positions. If you press on the glass, it can move and stay in another stable position until acted upon and it moves back to its original stable position.

Oil-canned glass is very similar to bistable glass, but has one stable and one semi-stable position. The glass can be moved from its stable bow position to its less stable position, before it pops back to its stable position after a period of time, similar to an oil can.

Centered glass is glass that feels softer than expected, sometimes described as wobbly glass.

All of these conditions are more prevalent on larger pieces of glass, thinner glass substrates and units with small aspect ratios (nearer to square). Cardinal limits them by enforcing our size guidelines, specifically the short side dimension limits. However, the presence of any of these conditions does not affect glass safety rating, strength or wind resistance.

Glazing Considerations

The glazing system should provide recommended face and edge clearances and bite to retain the glass in place under windload. It also should thermally and mechanically isolate the glass from the framing members to prevent glass to metal contact. Sealants or gaskets should provide a watershed with an approximate height of 1/16" (1.6 mm) above the edge or sightline of the glass framing members. The bite plus watershed should be large enough to cover the insulating glass sightline.

Setting Blocks
Setting blocks are required for successful glazing of insulating glass units into the window frame. When properly used, setting blocks provide the necessary weight distribution, cushioning, and clearance needed for long-term durability of the IG unit. Glass lites should be set on two silicone or other compatible elastomeric setting blocks having a Shore A Durometer hardness of 85 +10/-10. Setting blocks should be positioned at the quarter points. When this is not practical, setting blocks can be installed to within 6" (152 mm) of the vertical glass edge. Length of the setting blocks should be 0.1" (2.5 mm) in length for each square foot of glass area, but no less than 2" (51 mm) in length. Setting blocks need to be of sufficient width to fully support both lites of the insulating glass unit, yet still allow water to pass by and drain from the glazing channel. Setting block thickness is recommended to be 1/8" (3 mm) or greater to provide sufficient glass edge clearance.

Setting blocks should be low in or free of migrating organic plasticizers, which should be confirmed with the block supplier. Some organic plasticizers have the potential to migrate into and damage the insulating glass sealants. Some block materials can discolor other insulating glass components. If discoloration is a concern, ASTM C1087 can be used to screen components. The compatibility of the setting block should be verified with the block supplier and Cardinal IG.

Weep Systems
Water should not be permitted to remain in the glazing rabbet. A weep system should incorporate enough weep holes to ensure adequate drainage; usually this consists of three 3/8" (9.5 mm) diameter holes or equivalent, equally spaced at the sill.

Framing Recommendations
The framing system should provide structural support for the glass and under design loads must not exceed the length of the span divided by 175. Horizontal member deflection due to the glass weight should be limited to 1/8" (3 mm) or 25% of the design edge clearance of the glass or panel below, whichever is less. In dry glazed gasket systems, compressive pressure exerted at the glass edge should be 4 to 10 pounds per lineal inch (700 to 1750 N/m).

Glass Thickness Nomenclature
The glass industry has used a soft conversion method to designate flat glass product thickness in metric. To more accurately describe the actual glass thickness for products presented in this brochure, the specific metric thickness will be used. This does not represent a change in glass thickness, but a more accurate depiction of the thickness traditionally used. Listed below (Figure 4-5) is a comparison of specific metric thickness, the nominal glass thickness in inches and the traditional designation.

Specific Metric Thickness	Target Glass Thickness	ASTM Designation	Traditional Designation
2.2 mm	0.087 inches	2.5 mm	Single-Strength
3.0 mm	0.117 inches	3 mm	Double-Strength, ⅛ inch
3.1 mm	0.122 inches	3 mm	Double-Strength, DST, ⅛ inch
3.9 mm	0.152 inches	4 mm	5/32 inch
4.7 mm	0.182 inches	5 mm	3/16 inch
5.7 mm	0.221 inches	6 mm	¼ inch
8.0 mm	0.310 inches	8 mm	5/16 inch

Figure 4-5

Thermal Stress and Glass Breakage

When window glass is warmer at the center relative to the edge as shown below (Figure 4-9), the expansion of the central zone places a tensile stress on the glass edge. Based upon the coefficient of thermal expansion for soda lime glass, a 1 °F (0.5 °C) temperature difference creates 50 psi (345 kPa) mechanical stress in the glass edge. When the stress exceeds the strength of the glass edge, a thermal fracture can occur. Low stress fractures; i.e., less than 1,500 psi (10,335 kPa) stress, can be characterized by a single fracture line perpendicular to the glass edge. Typically, a flaw or chip can be found at the edge (origin) of this type of fracture. Higher stress fractures can be characterized as having multiple vent lines running into the daylight opening. Please see Cardinal's TSB for Thermal Breakage Prediction.

There are three worst case conditions in which to evaluate the stresses in glass and the impact on breakage expectations. The conditions are: cold winter night, cold winter day with high solar load, hot summer day with high solar load. Each of these conditions creates the following responses in a sealed, double glazing unit.

1. Cold Winter Night
Under these conditions, the interior lite of glass will be exposed to the maximum thermal stress. The thermal resistance of the IG unit keeps the central glass region relatively warm. At the edge of glass, however, the thermal conductivity of the IG edge seal and the frame design will reduce this glass edge temperature significantly. This warm center/cold edge condition now creates tensile stresses and increased breakage potential.

2. Cold Winter Day with High Solar Load
Solar absorptance in the interior lite of glass will increase its central temperature and the resulting thermal stresses. In addition, any shading devices used on the inside of the window will trap and/or reflect heat back at the glass, further increasing the glass temperatures. In either case, the effect of solar loads on the edge temperatures is minimal. This may lead to higher stress potentials than the winter nighttime conditions if the solar absorptance of the interior lite is greater than that of clear glass.

3. Hot Summer Day with High Solar Load
Clear glass with its low solar absorptance is not affected by these conditions. Absorbing glasses (i.e., LoĒ coated and/or tinted) can see a greater heat buildup under these conditions. If the glass edge is shaded due to a window or building projection, the non-uniform heating of the glass surface then can lead to thermal stresses. Factors that can affect thermal stress on glass are:

- Glass type (thickness, tint, coating type)
- Glass edge quality
- Shadow patterns on glass
- Heat trap caused by closed blinds or draperies
- Amount of solar radiation
- Outdoor-indoor temperatures
- Framing material
- Glass size
- Solar absorptance of the glass

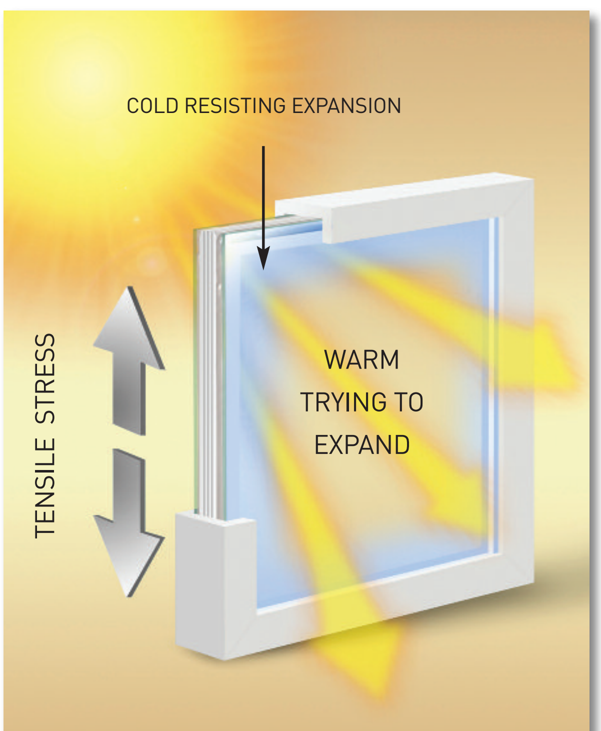


Figure 4-6

Outdoor Shading
Static and moving shadow patterns on glass from building overhangs, columns, trees and shrubbery and other buildings create varying degrees of thermal edge stress on the glass. The glass type (clear, tinted, LoĒ), glass size and thickness, degree and type of shadow pattern, outdoor temperature extremes and time of the year all influence the amount of thermal edge stress. If thermally induced stress is high enough, glass fracture could occur. In most applications, thermal stresses caused by the above are not high enough to cause breakage of heat-treated glasses but could cause breakage of annealed glass. Cardinal offers a glazing review on projects to recommend specific glass types and treatment to reduce the potential of thermal breakage.

Indoor Shading
Draperies, venetian blinds or other interior shading devices must be hung to provide space at the top and bottom or one side and bottom to permit natural air movement over the room-side of the glass. The following criteria must be met to avoid formation of a heat trap:

1. Minimum 1.5" (38 mm) clearance required at the top and bottom or one side and bottom between shading device and surrounding construction, or a closure stop of 60° from horizontal for horizontal blinds.
2. Minimum 2" (51 mm) clearance between glass and shading device.
3. Heating/cooling outlets must be to roomside of shading device.

Heat-strengthening or tempering of the glass may be necessary to offset the effects of a lack of adequate ventilation.

The following are recommendations for blinds and draperies to reduce glass thermal stress:

1. Vertical blinds are recommended over horizontal blinds.
2. Dark blinds are recommended over light blinds.
3. Open weave draperies are recommended over continuous material.
4. A closure stop is recommended on horizontal or vertical blinds to prevent them from closing completely.
5. A natural air vent is recommended across the head of the horizontal detail.

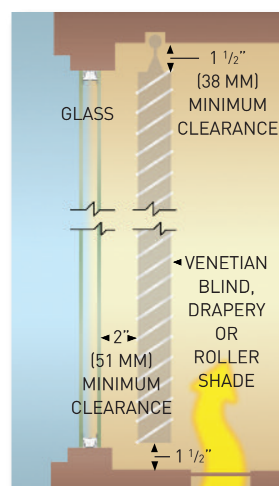


Figure 4-7

Windloads and Insulating Glass Size Guidelines

The windload data presented below is based on ASTM Standard E1300 (Standard Practice for Determining Load Resistance of Glass in Buildings).

The tables may be used by the design professional to choose the appropriate glass product to meet the windload criteria specified. The tables are for insulating glass (IG) units and assume four-sided support with support deflections not greater than L/175 of the span at design load, and a uniform 3-second load duration.

Breakage probability for IG is 8/1,000 units. By definition, breakage of either lite in an IG unit constitutes unit breakage. The 8/1,000 unit breakage probability is the combined probability for both lites when the unit is exposed to design load.

Using the Tables

The user of the attached tables needs to first know the design pressure (DP) rating required. Then choose either Annealed Glass or Heat Treated Glass table (fully tempered or heat-strengthened glass) depending on the glass type. Determine the square footage and Aspect Ratio. The Aspect Ratio is the long dimension divided by the short dimension. In the table, find the glass thickness which is less than or equal to the square footage listed under the appropriate column for DP and Aspect Ratio. Example: A two-pane IG with a dimension of 24" x 48" (8 square feet) with annealed 3.0 mm glass will meet a DP60 design pressure rating.

DOUBLE-PANE DESIGN PRESSURE LIMITS – ANNEALED GLASS

Glass Thickness (mm)	Maximum Area in Square Footage										Recommended Maximum Length (inches)
	DP80		DP60		DP50		DP40		DP30		
	Aspect ratio ≤2	Aspect ratio >2	Aspect ratio ≤2	Aspect ratio >2	Aspect ratio ≤2	Aspect ratio >2	Aspect ratio ≤2	Aspect ratio >2	Aspect ratio ≤2	Aspect ratio >2	
2.2	4	3	7	5	9	6	10[6]	8	10[6]	10[6]	70
3.0	7	6	11	8	15	10	15[6]	13	15[6]	15[6]	80
3.9	10	9	16	13	21	15	24[6]	20	24[6]	24[6]	90
4.7	14	13	20	18	27	21	33[6]	27	33[6]	33[6]	100
5.7	18	18	27	24	35	29	45	37	50[6]	50[6]	120
8.0	29	28	41	39	52	47	72	72[6]	72[6]	72[6]	144

Figure 4-8

DOUBLE-PANE DESIGN PRESSURE LIMITS – HEAT TREATED GLASS

Glass Thickness (mm)	Maximum Area in Square Footage										Recommended Maximum Length (inches)
	DP80		DP60		DP50		DP40		DP30		
	HS/HS	FT/FT	HS/HS	FT/FT	HS/HS	FT/FT	HS/HS	FT/FT	HS/HS	FT/FT	
2.2	8	NA	15[6]	NA	15[6]	NA	15[6]	NA	15[6]	NA	70
3.0	13	20[4]	20[6]	20[6]	20[6]	20[6]	20[6]	20[6]	20[6]	20[6]	80
3.9	20	30[6]	30[6]	30[6]	30[6]	30[6]	30[6]	30[6]	30[6]	30[6]	90
4.7	27	50[6]	37	50[6]	50[6]	50[6]	50[6]	50[6]	50[6]	50[6]	100
5.7	37	60[6]	60[6]	60[6]	60[6]	60[6]	60[6]	60[6]	60[6]	60[6]	144
8.0	83	96[6]	96[6]	96[6]	96[6]	96[6]	96[6]	96[6]	96[6]	96[6]	144

Figure 4-9

1. Limitations are based on wind load, manufacturing and safe handling limits.
2. The ASTM E1300 "Standard Practice for Determining the Minimum Thickness and Type of Glass Required to Resist a Specified Load" was used for determining the design allowance.
3. DP Rating-Design Pressure in pounds/ft^2.
4. Limits shown do not apply to the IG units fabricated with mismatched glass.
5. Limitations on square footage are based on design pressure and the maximum length factors. Both factors must be considered. The maximum length tolerance cannot be exceeded regardless of the square footage. Exceeding maximum tolerance could result in design pressures less than the values shown.
6. Limitations based on safe handling and manufacturing tolerances.
7. Weight limits may restrict square foot limits. Check with Cardinal IG fabricator for possible weight limit restrictions.
8. Tables do not restrict dimensions for glass deflection. Center glass deflections may exceed 1 inch at maximum wind load.
9. HS = Heat Strengthened and FT = Fully Tempered.

TRIPLE-PANE DESIGN PRESSURE LIMITS – ANNEALED GLASS

Glass Thickness (mm)	Maximum Area in Square Footage: DP80 Aspect ratio ≤2	DP80 Aspect ratio >2	DP60 Aspect ratio ≤2	DP60 Aspect ratio >2	DP50 Aspect ratio ≤2	DP50 Aspect ratio >2	DP40 Aspect ratio ≤2	DP40 Aspect ratio >2	DP30 Aspect ratio ≤2	DP30 Aspect ratio >2	Recommended Maximum Length (inches)
2.2	7	5	10[6]	7[5]	10[6]	9[5]	10[6]	10[6]	10[6]	10[6]	70
3.0	11	8[5]	15[6]	12[5]	15[6]	14[5]	15[6]	15[6]	15[6]	15[6]	80
3.9	16	13[5]	24[6]	19[5]	24[6]	24[6]	24[6]	24[6]	24[6]	24[6]	90
4.7	20	18[5]	32	25[5]	33[6]	33[5]	33[6]	33[5]	33[6]	33[6]	100
5.7	27	24[5]	41[6]	33[5]	50[6]	40[6]	50[6]	50[6]	50[6]	50[6]	144
8.0	41	39	60	53	72[6]	72[5]	72[6]	72[5]	72[6]	72[5]	144

Figure 4-10

TRIPLE-PANE DESIGN PRESSURE LIMITS – HEAT TREATED GLASS

Glass Thickness (mm)	Maximum Area in Square Footage: DP80 HS/HS/HS	DP80 FT/FT/FT	DP60 HS/HS/HS	DP60 FT/FT/FT	DP50 HS/HS/HS	DP50 FT/FT/FT	DP40 HS/HS/HS	DP40 FT/FT/FT	DP30 HS/HS/HS	DP30 FT/FT/FT	Recommended Maximum Length (inches)
2.2	15[6]	NA	15[6]	NA	15[6]	NA	15[6]	NA	15[6]	NA	70
3.0	20[6]	20[6]	20[6]	20[6]	20[6]	20[6]	20[6]	20[6]	20[6]	20[6]	80
3.9	30[6]	30[6]	30[6]	30[6]	30[6]	30[6]	30[6]	30[6]	30[6]	30[6]	90
4.7	50[6]	50[6]	50[6]	50[6]	50[6]	50[6]	50[6]	50[6]	50[6]	50[6]	100
5.7	60[6]	60[6]	60[6]	60[6]	60[6]	60[6]	60[6]	60[6]	60[6]	60[6]	144
8.0	96[5]	96[6]	96[6]	96[6]	96[6]	96[6]	96[6]	96[6]	96[6]	96[6]	144

Figure 4-11

1. Limitations are based on wind load, manufacturing and safe handling limits. Heat Treated Triple Panes wind load values assumes all three lites are Heat Treated.
2. The ASTM E1300 "Standard Practice for Determining the Minimum Thickness and Type of Glass Required to Resist a Specified Load" was used for determining the design allowance.
3. DP Rating-Design Pressure in pounds/ft².
4. Limits shown do not apply to the IG units fabricated with mismatched glass.
5. Limitations on square footage are based on design pressure and the maximum length factors. Both factors must be considered. The maximum length tolerance cannot be exceeded regardless of the square footage. Exceeding maximum tolerance could result in design pressures less than the values shown.
6. Limitations based on safe handling and manufacturing tolerances.
7. Weight limits may restrict square footage limits. Check with Cardinal IG fabricator for possible weight restrictions.
8. Tables do not restrict dimensions for glass deflection. Center glass deflections may exceed 1 inch at maximum wind load.

IG UNIT SIZE LIMIT GUIDELINES

Glass Thickness (mm)	Annealed Max Size (ft^2)	Weight at Max Annealed Size Dual / Triple (lb)	Annealed Max Length (in)	HS Max size (ft^2)	Tempered Max Size (ft^2)	Weight at Max Tempered Size Dual / Triple (lb)	HS and Temp Max Length (in)	Max Short Side Dimension Temp (in)
2.2	10	24 / 36	70	15	NA	36 / 54	70	36
3.0	15	47 / 72	80	20	20	62 / 96	80	36
3.9	24	98 / 146	90	30	30	123 / 183	90	48
4.7	33	161 / 241	100	50	50	245 / 365	100	60
5.7	50	295 / 445	120	60	60	354 / 534	144	72
8.0	72	598 / 907	144	96	96	797 / 1210	144	96

Figure 4-12

1. Not all glass thicknesses, unit sizes, and coating options are available from all Cardinal IG locations.
2. Glass sizes do not take into consideration windload requirements; see TSB IG03 for more information.
3. Use of 8 mm glass may be limited to use as the clear/interior lite of a IG unit due to the availability of LoĒ coated 8 mm glass.
4. Not all production facilities have the capability of producing maximum sizes listed above.
5. Some sizes may be further limited due to weight limitations of particular plants and/or production equipment.
6. Weight assumes 0.1 lb/ft^2 for spacer, sealant, and desiccant per airspace, and equal thickness lites of glass.
7. Production of all unit sizes may not be practical or possible in all airspaces.
8. Further restrictions on size may be needed for particular applications.

Inert Gas Filling

Inert gases; i.e., argon and krypton, have been used in insulating glass (IG) units to enhance the thermal performance of the IG unit and window by reducing the U-Factor. Argon and krypton are colorless, odorless, non-toxic, non-corrosive, nonflammable, chemically inactive gases and are parts of the atmosphere. Argon is approximately 1% of the atmosphere and krypton is approximately 0.000001% or 1 part per million of the atmosphere.

Improved Thermal Conductivity

The principal reason for using argon or krypton in the airspace of an IG unit is because the thermal conductivity of these inert gases is significantly lower than that of air. This lowers the conductive heat transfer across the cavity of the IG unit, improving the center of glass U-Factor and overall window U-Factor. The lower conductance of these gases is due to the fact that their molecular mass is greater than that of air. With a larger mass, these inert gases move slower than air, and there are fewer molecular collisions per unit of time. Fewer collisions result in less heat transfer.

IG UNIT MAXIMUM DIMENSION PER AIRSPACE

Airspace Dimension inches (mm)	Maximum Long Dimension inches (mm)	Maximum Area ft^2 (m^2)
¼ (6.5)	**80** (2032)	**20** (1.9)
5⁄16 (8.0)	**90** (2286)	**30** (2.8)
⅜ (9.8)	**100** (2540)	**50** (4.6)
≥7⁄16 (≥11.5)	**144** (3658)	**60** (5.6)

Figure 4-13

Argon and Krypton

Because of its large natural abundance, argon is inexpensive compared to krypton. Krypton is approximately 600 times the price of argon and fluctuates significantly with market conditions. That is the main reason why krypton is used sparingly compared to argon. Since argon and krypton gases are inert and very pure in commercial grades, there is no concern over chemical reactions with other materials used in an insulating glass unit or window.

In 1988, Cardinal developed and patented a state-of-the-art process for argon filling of insulating glass units. Recognizing the need to determine the specific argon fill levels in IG units, Cardinal has also installed online argon measuring equipment using Spark Emission Spectroscopy (SES) or Tunable Diode Laser absorption spectroscopy on all our production lines.

Gas Fill Levels

The insulating glass (IG) unit size, geometry and addition of internal grilles, etc., influence the effectiveness of the argon filling process. For instance, grilles inside the airspace contain air, and the air in the grilles will reduce the overall initial argon percent fill level. Based on 20 years of argon filling, testing and manufacturing experience, we can confidently assert that Cardinal IG units will have an average initial argon fill level of 90% or greater.

Cardinal certifies that its insulating glass products are constructed similarly to specimens that were audited, tested and found to pass the stated requirements of the IGCC (Insulating Glass Certification Council). To certify that it meets argon fill level requirements, a manufacturer must have an average initial argon fill level of 90% for test specimens, along with an average of 80% after exposure to the ASTM E2190 weathering cycle. Cardinal meets these requirements as listed in the IGCC Certified Products Directory.

Since argon is approximately 1% of the earth's atmosphere, there is a driving force for the argon to permeate through all IG edge seals to the ambient atmosphere. Likewise, there is a similar driving force for air (oxygen and nitrogen) to permeate into the IG unit.

In Europe, EN1279 part 3 is the governing standard on gas filling. This specification requires that tested specimens demonstrate a leakage rate of <1% per year after weather cycling. Cardinal's IG units have been independently tested by European labs and meet this requirement.

Safety Glazing

Safety glazing may be required to meet local and/or national building codes. The Safety Glazing Certification Council (SGCC) provides for the certification of safety glazing materials found to be in compliance with one or more of the following requirements: ANSI Z-97.1, CPSC 16CFR 1201 cat. I and CPSC 16CFR 1201 cat. II, as listed below (Figure 4-8).

SAFETY GLAZING STANDARDS

	ANSI Z97.1 Class B/ CPSC 16 CFR 1201 Cat I	ANSI Z97.1 Class A CPSC 16 CFR 1201 Cat II
Use of Standard	To test and identify glasses as safety glazing materials which will be used in locations that are subject to human impact resistance and as required by building codes. **Limited to glass no greater than 9 ft².**	To test and identify glasses as safety glazing materials which will be used in locations that are subject to human impact resistance and as required by building codes.
Impact Test Requirements	Class B/Cat I; 100 pound bag drop from height of 18 inches.	Class A /Cat II; 100 pound bag drop from height of 48 inches.
Evaluation Criteria for Tempered Glass to Pass Standard	a. If fracture occurs at the specified class drop height, the 10 largest particles shall not weigh more than 10 square inches of the glass tested. b. If no fracture occurs from the bag drop test, then the glass shall be broken using either a spring loaded center punch or a sharp impactor such as a pointed hammer. The criteria described in (a) above is used for pass/fail criteria. Certain additional criteria may apply when using the spring loaded punch for pass/fail. Refer to ANSI standard for additional details.	
Evaluation Criteria for Laminated Glass to Pass Standard	a. No fracture at the respective drop height. b. If fracture occurs at the specified drop height, there shall be no hole through which a 3 inch diameter sphere will freely pass. c. If particles are detached from the test specimen, they shall in total weigh no more than a mass equivalent to 15.5 in² of the original test specimen. Detached individual particles less than the mass equivalent of 1 in² are to be excluded from the fragment analysis. The single largest particle shall weigh less than a mass equivalent to 6.82 in² of the original test specimen.	

Figure 4-14

High Altitude

When insulating glass (IG) units are installed at altitudes above where they were manufactured, they will bow outward, creating stress in the glass and IG edge seal. Depending on unit size, airspace and glass thickness, this stress can be enough to cause glass breakage and unit failure.

The conventional approach to alleviate these problems is to install a capillary tube. The tube permits the IG unit to pressure-equalize with the local atmosphere, relieving the altitude pressure differential created by the difference in manufacturing altitude and installation altitude. When argon gas is used in the airspace, capillary tubes will permit the argon gas to escape. U-Factors should be based on an air-filled IG unit construction.

Pressure Imbalance Problems

When an IG unit is exposed to windloads, local barometric fluctuations, temperature swings or an altitude change, a pressure imbalance is created. Depending on the glass stiffness, there are four potential issues associated with these pressure loads:

- Damage to the insulating glass seal
- Glass breakage
- Excessive deflection and clearance problems for operating windows
- Complaints about unacceptable distortion resulting from glass deflection

Glass deflection, edge seal loads and breakage probability can be quantified if the IG unit construction, glass size and a magnitude of the initial pressure imbalance is known. The perceived distortion for a given deflection is subjective. Objections to glass deflection generally occur when the unit is viewed from the exterior at some distance away from the building. Distortion complaints are greatest for concave surfaces such as a negative IG unit.

The addition of heat-strengthened or tempered glass in one lite of the IG unit will not change the glass deflection, but will reduce the glass breakage probability. If heat-strengthened or tempered glass were used in both lites of an IG unit, the breakage probability due to altitude changes will be significantly reduced.

Ideal IG Unit Construction

If IG units are being considered for installation in high-altitude applications, consideration for breakage, deflection, damage to the insulating glass seal and distortion should be made. If any of these parameters are beyond acceptable levels, air-filled capillary tube IG units should be considered.

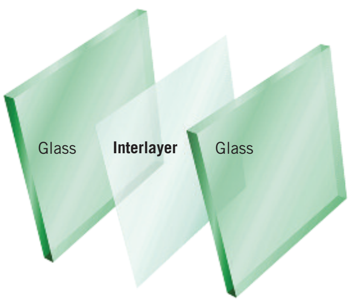
Whether you need to meet hurricane codes, provide home security or reduce noise, Cardinal offers a laminated glass to meet your requirements, delivering a level of security and serenity that can't be realized with ordinary glass.

LAMI-NATED GLASS

BENEFITS AND APPLICATIONS

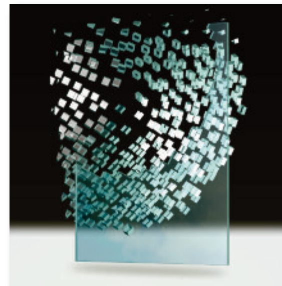
What is Laminated Glass?

Laminated glass is constructed with two or more plies of glass permanently bonded together with one or more polymeric interlayers. The primary feature of laminated glass is superior safety. Although it will break on impact, unlike annealed or tempered glass, the glass fragments will adhere to the interlayer to keep the glass intact and resist penetration.

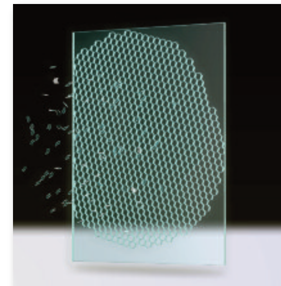


The layered nature of laminated glass also offers superior sound control and limits the amount of harmful UV radiation infiltration that can fade interior furnishings. In addition, laminated glass provides greater aesthetic flexibility than monolithic glass, and annealed laminated glass can be used instead of monolithic tempered glass to avoid the risk of visible distortions that can occur during heat treatment. Cardinal offers a wide array of design options to meet various building codes, performance levels and aesthetic requirements.

ANNEALED GLASS breaks easily, producing long, sharp splinters.



TEMPERED GLASS shatters completely under higher levels of impact energy, and few pieces remain in the frame.



LAMINATED GLASS may crack under impact but tends to remain integral, adhering to the interlayer.

Safety

Safety glazing refers to glazing with additional safety features that make it less likely to break, or less likely to pose a threat when broken. It is used in applications where it is subject to accidental human impact, and may be required to meet any local and/or national building codes. Cardinal certifies its laminated safety glass products through the Safety Glazing Certification Council (SGCC) sampling and testing program. The SGCC is an independent agency which confirms that safety glass meets the following industry safety standards for glazing materials:

- ANSI Z97.1 Class "A" and CPSC 16CFR 1201 Cat II – laminated glass with 0.030" interlayer and thicker
- ANSI Z97.1 Class "B" and CPSC 16 CFR 1201 Cat I – laminated glass with 0.015" interlayer

SAFETY GLAZING STANDARDS

	ANSI Z97.1 Class B/ CPSC 16 CFR 1201 Cat I	ANSI Z97.1 Class A CPSC 16 CFR 1201 Cat II
Use of Standard	To test and identify glasses as safety glazing materials which will be used in locations that are subject to human impact resistance and as required by building codes. **Limited to glass no greater than 9 ft².**	To test and identify glasses as safety glazing materials which will be used in locations that are subject to human impact resistance and as required by building codes.
Impact Test Requirements	Class B/Cat I; 100 pound bag drop from height of 18 inches.	Class A /Cat II; 100 pound bag drop from height of 48 inches.
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Evaluation Criteria for Laminated Glass to Pass Standard	a. No fracture at the respective drop height. b. If fracture occurs at the specified drop height, there shall be no hole through which a 3 inch diameter sphere will freely pass. c. If particles are detached from the test specimen, they shall in total weigh no more than a mass equivalent to 15.5 in² of the original test specimen. Detached individual particles less than the mass equivalent of 1 in² are to be excluded from the fragment analysis. The single largest particle shall weigh less than a mass equivalent to 6.82 in² of the original test specimen.	

Figure 5-1

House still standing after Hurricane Michael 2018, Mexico Beach, Florida. See Trosifol Case Study: Sand Palace for more information.

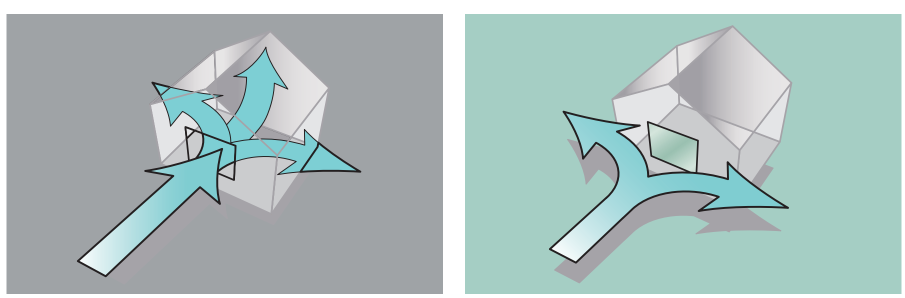
Windborne Debris Resistance

Windows and glazed portions of doors are critical components of a building's envelope. They are, however, vulnerable to damage from wind forces and windborne debris, particularly in geographic regions prone to hurricanes. Once broken, wind can enter the building and cause internal pressurization that can lead to catastrophic structural failure. Sea-Storm® impact-resistant laminated glass products help prevent this from happening.

In order to meet hurricane building codes, commercial and residential window and door systems have to meet tough testing requirements for impact resistance. Cardinal's Sea-Storm products have been successfully tested in many glazing systems that meet the requirements of Miami-Dade County TAS 201, TAS 203, ASTM E1886 and ASTM E1996. The Miami-Dade County testing protocols are regarded as some of the most rigorous product performance testing currently available. In this testing, the glazing system must withstand a large missile impact from a 9-pound 2x4 traveling at 50 feet per second (34 miles/hr.) and then complete 9000 positive and negative pressure cycles equating to wind gusts of up to 150 mph or more.

Depending on the location, size of the glazing area, and design pressures, the recommended interlayer used in Sea-Storm® products may be of different thicknesses or types. For example, glass with an 0.060" PVB interlayer is typically adequate to meet small missile performance. For large missile performance up to about 30 ft^2 and 80 PSF design pressure, 0.090" PVB is normally adequate. SentryGlas® in thicknesses of 0.090" and 0.100" is typically used for glazing sizes beyond 30 ft^2 and design pressures greater than 80 PSF. It is critical to remember that hurricane testing is conducted on the whole system and elements other than the glazing infill, such as the framing system and sealant, have a direct effect on the performance during impact and cycling loads.

Windborne debris protection requirements have expanded beyond Florida as states have adopted the International Building Codes. Because the International Codes serve as models for the states or local jurisdictions, there are often differences in requirements from one region to another. Design professionals are encouraged to research the local building codes when beginning new projects.



When a building envelope is breached through a broken window, wind can enter the building and create a sudden pressure increase that lifts the roof and pushes the walls outward, causing the building to collapse. Sea-Storm® Impact-Rated laminated glass helps preserve the building envelope, minimizing the damage from wind, rain and other elements.

Fallout Protection (Post-Breakage Performance)

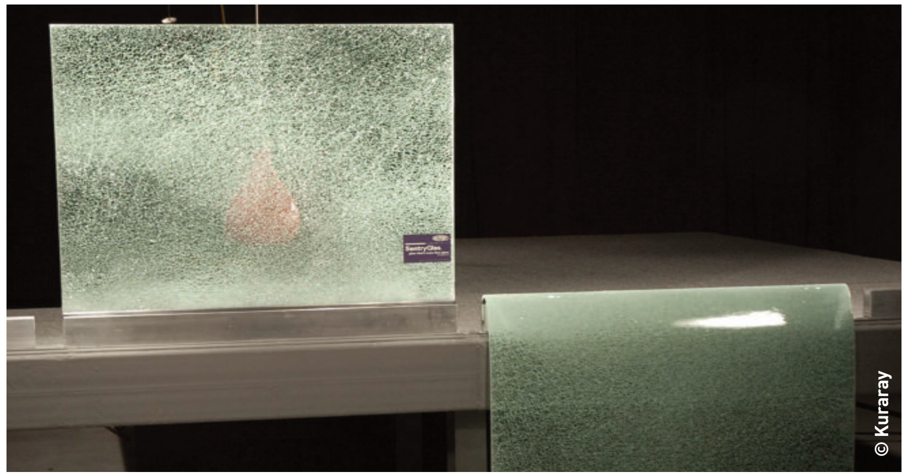
Glass has long been used as an architectural element for railing and guard systems, in both residential and commercial settings. However, several high-profile incidents of tempered glass breakage in recent years have raised concern over the safety of glass railings and guard systems. In order to address the issue of glass fallout, the International Building Code has required the use of fully tempered laminated or heat-strengthened laminated glass in most railing applications.

High-performance structural interlayers such as SentryGlas® and structural PVB are ideal choices for structural glass applications, exposed edge laminates, floors, stairs, balconies and many other architectural applications. This is due to their post-breakage strength, high film shear modulus, and outstanding clarity and edge stability.

INTERLAYER PERFORMANCE COMPARISON

Properties	Standard PVB	Structural PVB	SentryGlas
Post Breakage Performance at Room Temperature	🔴	🟢	🟢
Post Breakage Performance at Elevated Temperature	🔴	🔴	🟢
Structural Properties at Room Temperature	🔴	🟢	🟢
Structural Properties at Elevated Temperature	🔴	🔴	🟢
Edge Stability	🔴	🟡	🟢

Figure 5-2



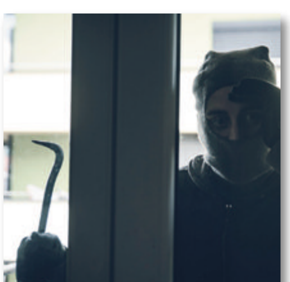
Blast Resistance

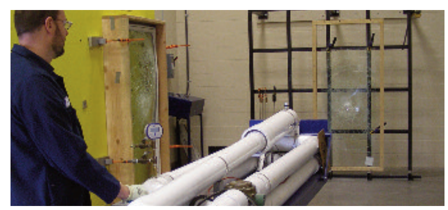
The use of blast-resistant glazing can mitigate the number and severity of glass-related injuries if bomb blasts occur. Cardinal laminated glass can be used to meet blast performance levels specified by the General Services Administration, Department of State and Department of Defense. It is important to note that much like a hurricane-resistant window, a blast-resistant window operates as a system, so the performance will vary based on the frame design, anchorage, glazing details, glass and interlayer type and thickness.

Security

Security glazing is used as a means of keeping people and property safe for a considerable time during a security threat. Security glazing generally falls into five broad categories based on the level of penetration resistance and threat type:

- Basic
- Enhanced
- Forced Entry
- Forced Entry + Ballistics
- Ballistic Protection





SECURITY GLAZING

Glass Penetration Resistance	Basic Safety Glazing	Enhanced	Forced Entry	Forced Entry + Ballistics	Ballistic Protection
Threat to Glazing	Accidental human impact	Simulated weapon impact by 2 x 4	Repeated assaults	Ballistic assault followed by forced entry impact to gain entry	Ballistic assault using various ammunition classes
Typical Application	Minimum requirements for lobby, entry, first floor windows and doors	Burglary risk areas	Non-monitored areas; high-risk glazing; detention facilities	Very high-risk areas	Ballistic risk areas
Typical Laminate	Two glass layers with interlayer	Two glass layers with minimum 0.060 in interlayer	Multiple plies of glass and/or polycarbonate with poly-urethane interlayer	Multiple layers of glass, interlayers, resins and/or plastic materials such as polycarbonate or acrylic	Multiple layers of glass, interlayers, resins and/or plastic materials such as polycarbonate or acrylic
Test Standards	ANSI Z97.1	ASTM E2395 UL972 ASTM F3006	ASTM F3038 ASTM F1915	ASTM F1233	UL 752 NIJ 0108.01
Test Criteria	Glass containment upon breakage	Extended deterrence to entry	Longer duration deterrence	Deterrence time extended	No penetration of witness panel from glass or plastic spall

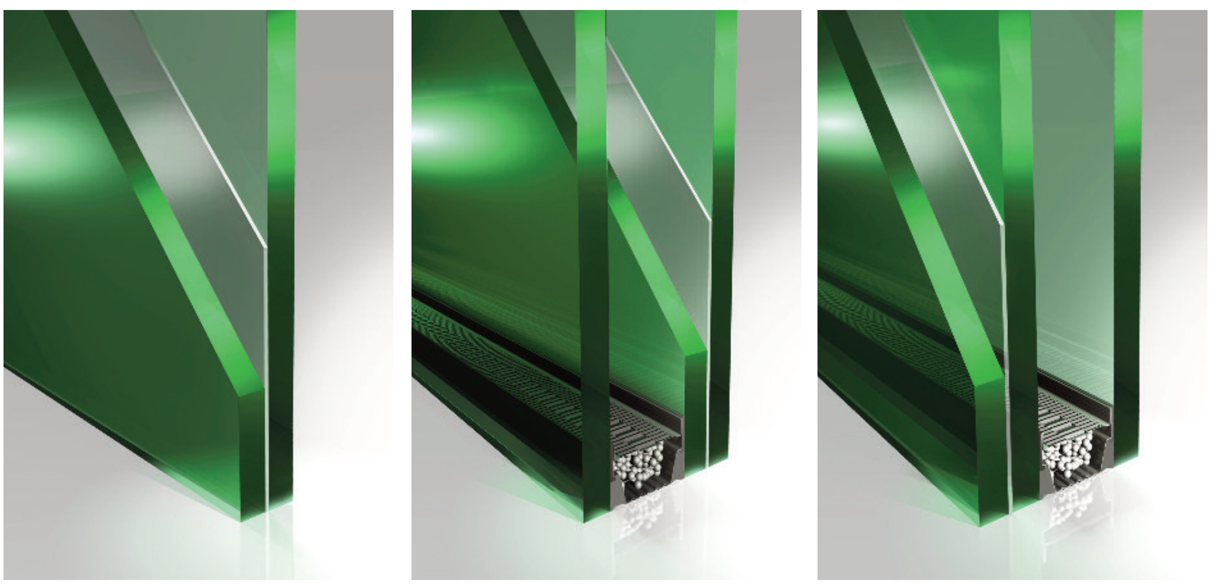
Figure 5-3

Decorative

The use of laminated glass in decorative applications provides designers with considerable artistic freedom. Cardinal decorative laminated glass can be made with unique textiles, meshes, wood veneers, rice papers, prints, metals, mirrors and more. Additional fabrication such as polished edges, notching, and hole drilling is also available for use in glass railings, interior partitions, office furniture and other design uses.

Energy Efficiency

Cardinal laminated glass can be supplied incorporating Cardinal low emissivity glass to reduce heat loss from the building and thus save on energy costs. LoĒ, LoĒ^2, LoĒ^3 and Quad LoĒ coatings can be used when in an insulating glass unit with the coating facing the airspace. These coatings can be used monolithically with the coating facing the interlayer (embedded) and edge deleted to minimize risk of corrosion. However, there will be a color shift when the LoĒ coating is embedded, and not all LoĒ products have a desirable appearance when embedded. LoĒ^3 and Quad LoĒ coatings have the most desirable appearance when embedded.



Monolithic Laminated **Insulating Laminated** **Laminated Insulating**

Figure 5-4

Sound Control

Laminated glass reduces the level of noise with considerably greater efficiency than monolithic glass of the same thickness. This is achieved through the sound dampening properties of the interlayer, which will vary with the type and thickness of the interlayer.

In cases where increased noise attenuation is desired, special acoustic PVB interlayers with increased sound reduction performance are available.

An STC rating is calculated in accordance with ASTM E413 over the frequency range of 125 to 4000 HZ. The OITC rating is calculated in accordance to ASTM E1332 over the frequency range of 80 to 4000 HZ.

SOUND PERFORMANCE COMPARISONS

Glass Product	Nominal Thickness	STC	OITC
1/4" Monolithic Glass	1/4"	31	29
7.0 PVB (3.0-0.030" PVB-3.0)	1/4"	35	31
7.0 PVB (3.0-0.030" Acoustic PVB-3.0)	1/4"	36	32
12.8 PVB (5.7-0.060" PVB-5.7)	9/16"	37	34
12.8 SG (5.7-0.060" SG-5.7)	9/16"	35	33
Double-Pane: 3.0 Clear / 13.0 / 3.0 Clear	3/4"	31	26
Double-Pane: 5.7 Clear / 13.0 / 5.7 Clear	1"	35	28
Double-Pane: 7.0 PVB / 6.5 / 3.1 Clear	5/8"	35	31
Double-Pane: 7.0 PVB / 13.0 / 5.7 Clear	1"	39	31
Double-Pane: 10.0 PVB / 13.0 / 5.7 Clear	1-1/8"	40	31
Double-Pane Laminate: 7.0 PVB / 13.0 / 7.0 PVB	1-1/16"	42	33
Triple-Pane: 5.7 Clear / 13.0 / 5.7 Clear / 13.0 / 5.7 Clear	1-11/16"	39	31
Triple-Pane Laminate: 7.0 PVB / 13.0 / 7.0 PVB / 13.0 / 7.0 PVB	1-27/32"	44	33

Figure 5-5

UV and Solar Control

PVB and SG laminated glass products absorb the sun's UV radiation while allowing important visible light to pass through. Consequently, the glass helps protect curtains, furnishings and carpets from fading caused by the damaging effects of short-wave ultraviolet radiation. Laminated glass can incorporate tinted interlayer, tinted or reflective glass, or embedded LoĒ coatings to reduce glare and heat gain in a building.

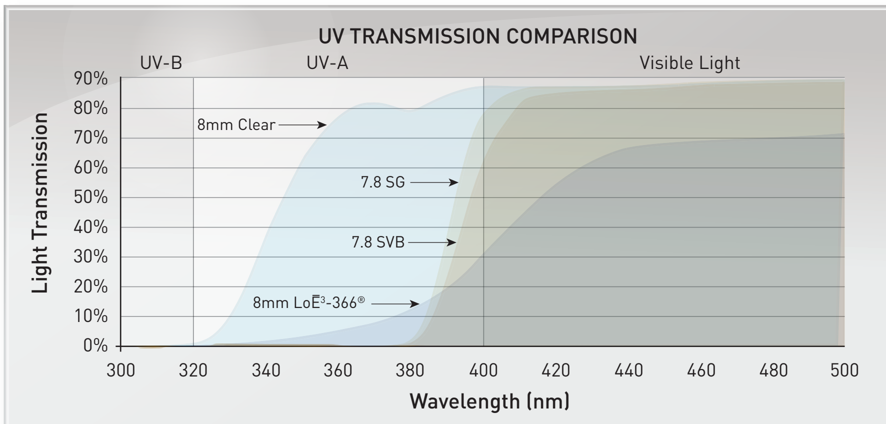


Figure 5-6

Turtle Glass

Turtle glass is glass that is tinted to reduce light projection and has a visible light transmittance of 45% or less in order to meet lighting ordinances for coastline areas. This table shows some examples of laminate constructions that will meet or exceed the requirements of the "Turtle Code."

TURTLE GLASS COMPARISONS

Thickness	Laminate Configuration	Visible Light Transmittance
9/32"	3mm Grey / 0.038" SG / 3mm LoE³-366® (#3)	41%
19/64"	3mm Grey / 0.060" PVB / 3mm LoE³-366® (#3)	42%
5/16"	3mm Grey / 0.090" PVB / 3mm LoE³-366® (#3)	41%
5/16"	3mm Clear / 0.030" Grey PVB + 0.060" PVB / 3mm LoE³-366® (#3)	31%
5/16"	3mm Clear / 0.030" Grey PVB + 0.060" PVB / 3mm Clear	45%
9/16"	6mm Grey / 0.090" PVB / 6mm Clear	43%
9/32"	3mm Grey / 0.035" SG / 3mm Quad 452+™ (#3)	38%
5/16"	3mm Grey / 0.090" PVB / 3mm Quad 452+™ (#3)	38%
5/16"	3mm Grey / 0.090" PVB / 3mm Quad 452+™ (#3)	38%

Figure 5-7

INTERLAYERS

Interlayer Options

Polymeric interlayers are used to permanently bond two plies of glass in a laminated configuration. Cardinal LG offers a wide variety of interlayer options to meet your specific requirements.

Polyvinyl Butyral (PVB) is a standard architectural interlayer available in five different thicknesses:

- 0.015" (0.38 mm)
- 0.030" (0.76 mm)
- 0.045" (1.14 mm)
- 0.060" (1.52 mm)
- 0.090" (2.28 mm)

The most commonly used thicknesses include 0.030", 0.060" and 0.090".

Trosifol® UltraClear is a specialized PVB with high adhesion and a low yellowness index available in three thicknesses:

- 0.030" (0.76 mm)
- 0.045" (1.14 mm)
- 0.060" (1.52 mm)

Structural PVB is a specialized PVB capable of providing superior structural performance compared with standard PVB. Interlayer available in 0.030" (0.76 mm) thickness by Kuraray (Trosifol® Extra Stiff) and Eastman (Saflex® DG).

Saflex® High Protection (HP) is a specialized PVB which provides high glass adhesion and improved performance for large missile hurricane-resistant applications relative to conventional PVB. Interlayer available in 0.100" (2.54 mm) thickness.

SentryGlas® is an ionoplast interlayer. It is a high strength and high stiffness interlayer that is the least vulnerable to moisture exposure or yellowing over time. Available thicknesses:

- 0.038"
- 0.060"
- 0.090"
- 0.100"

Saflex® Storm is a composite interlayer composed of PVB and PET. This interlayer provides the impact resistance of PVB and the tear resistance of polyethylene terephthalate (PET) film. Interlayer is available in 0.077" (1.96 mm) thickness.

Acoustic Interlayers:

- Saflex® Acoustic
- Trosifol® SC Monolayer
- Trosifol® SC Multilayer

UV Selective Interlayers:

- Saflex® SG
- Trosifol® Natural UV
- SentryGlas® Natural UV
- Trosifol® UV Extra Protect

Tinted PVB Interlayers:

- Vanceva®
- Trosifol® Color
- Trosifol® Tints
- Trosifol® Black & White

LAMINATED GLASS INTERLAYER APPLICATIONS

Interlayer Material	Safety	Structural	Impact Resistant (small missile)	Impact Resistant (large missile)	Security	Blast Mitigating	Acoustic	UV Control	Decorative
PVB 0.030"	●				●	●			
PVB 0.060"	●		●		●	●			
PVB 0.090"	●			●	●	●			
Trosifol® UltraClear	●								●
Structural PVB		●							
Saflex® HP				●					
SentryGlas®				●	●	●			
Saflex® Storm				●					
Acoustic Interlayers							●		
UV Selective								●	
Tinted PVB									●

†This chart is a general reference to represent the primary use for each type of interlayer. For example, while the primary application for tinted PVB is decorative, it could still be used in a safety application.
‡This chart does not indicate compliance for a specific application. Laminated glass is a component of the overall glazing system; therefore, the performance in a specific application is dependent upon other factors.

Figure 5-8

SG (SENTRYGLAS®)

Laminate ID	Laminate Configuration	Nominal Fractional Inches	Target Thickness in	(mm)	Visible Light Transmittance	Visible Light Reflectance Out	Visible Light Reflectance In	SHGC	U-Factor BTU/hr·ft²·°F	(W/m²·K)	UV Transmission
6.0 SG	2.7 – 0.038" SG – 2.7	1/4	**0.246**	(6.25)	89%	9%	9%	0.81	**1.00**	(5.70)	1%
6.8 SG	2.7 – 0.060" SG – 2.7	9/32	**0.271**	(6.88)	89%	9%	9%	0.80	**0.98**	(5.57)	<1%
7.0 SG	3.0 – 0.038" SG – 3.0	9/32	**0.272**	(6.91)	89%	8%	8%	0.80	**1.00**	(5.66)	<1%
7.8 SG	3.0 – 0.060" SG – 3.0	5/16	**0.297**	(7.54)	89%	8%	8%	0.79	**0.98**	(5.60)	<1%
8.6 SG	3.0 – 0.090" SG – 3.0	11/32	**0.329**	(8.36)	88%	8%	8%	0.78	**0.96**	(5.51)	<1%
8.7 SG	3.9 – 0.038" SG – 3.9	11/32	**0.342**	(8.69)	88%	8%	8%	0.77	**0.99**	(5.61)	<1%
9.3 SG	3.9 – 0.060" SG – 3.9	3/8	**0.367**	(9.32)	88%	8%	8%	0.76	**0.97**	(5.50)	<1%
10.0 SG	4.7 – 0.038" SG – 4.7	13/32	**0.404**	(10.26)	87%	8%	8%	0.76	**0.98**	(5.55)	<1%
10.1 SG	3.9 – 0.090" SG – 3.9	13/32	**0.399**	(10.13)	87%	8%	8%	0.75	**0.95**	(5.44)	<1%
10.8 SG	4.7 – 0.060" SG – 4.7	7/16	**0.429**	(10.9)	88%	8%	8%	0.75	**0.96**	(5.45)	<1%
11.7 SG	4.7 – 0.090" SG – 4.7	15/32	**0.461**	(11.71)	86%	8%	8%	0.74	**0.94**	(5.40)	<1%
12.0 SG	5.7 – 0.038" SG – 5.7	15/32	**0.484**	(12.29)	86%	8%	8%	0.73	**0.97**	(5.49)	<1%
12.8 SG	5.7 – 0.060" SG – 5.7	1/2	**0.509**	(12.93)	87%	8%	8%	0.73	**0.95**	(5.43)	<1%
13.6 SG	5.7 – 0.090" SG – 5.7	1/2	**0.541**	(13.74)	85%	8%	8%	0.72	**0.93**	(5.35)	<1%

1. Calcualted using LBNL WINDOW and Optics comptuer modeling programs using NFRC standard conditions.

Figure 5-9

PVB (POLYVINYL BUTYRAL)

Laminate ID	Laminate Configuration	Nominal Fractional Inches	Target Thickness in	(mm)	Visible Light Transmittance	Visible Light Reflectance Out	Visible Light Reflectance In	SHGC	U-Factor BTU/hr·ft²·°F	(W/m²·K)	UV Transmission
6.0 PVB	2.7 – 0.030" PVB – 2.7	1/4	**0.238**	(6.05)	89%	9%	9%	0.80	**1.01**	(5.71)	<1%
6.8 PVB	2.7 – 0.060" PVB – 2.7	17/64	**0.268**	(6.82)	88%	9%	9%	0.79	**0.98**	(5.59)	<1%
7.0 PVB	3.0 – 0.030" PVB – 3.0	1/4	**0.264**	(6.72)	89%	8%	8%	0.81	**1.01**	(5.76)	<1%
7.8 PVB	3.0 – 0.060" PVB – 3.0	19/64	**0.294**	(7.48)	88%	9%	9%	0.78	**0.98**	(5.56)	<1%
8.6 PVB	3.0 – 0.090" PVB – 3.0	5/16	**0.324**	(8.24)	88%	9%	9%	0.78	**0.98**	(5.56)	<1%
8.7 PVB	3.9 – 0.030" PVB – 3.9	5/16	**0.334**	(8.45)	88%	8%	8%	0.78	**1.00**	(5.70)	<1%
9.3 PVB	3.9 – 0.060" PVB – 3.9	3/8	**0.364**	(9.21)	87%	9%	9%	0.76	**0.97**	(5.51)	<1%
10.0 PVB	4.7 – 0.030" PVB – 4.7	3/8	**0.396**	(10.02)	87%	8%	8%	0.76	**0.98**	(5.58)	<1%
10.1 PVB	3.9 – 0.090" PVB – 3.9	3/8	**0.394**	(9.97)	87%	9%	9%	0.76	**0.95**	(5.40)	<1%
10.8 PVB	4.7 – 0.060" PVB – 4.7	7/16	**0.426**	(10.79)	87%	8%	8%	0.75	**0.96**	(5.47)	<1%
11.7 PVB	4.7 – 0.090" PVB – 4.7	7/16	**0.456**	(11.55)	87%	9%	9%	0.74	**0.94**	(5.36)	<1%
12.0 PVB	5.7 – 0.030" PVB – 5.7	15/32	**0.476**	(12.01)	86%	8%	8%	0.74	**0.98**	(5.58)	<1%
12.8 PVB	5.7 – 0.060" PVB – 5.7	1/2	**0.506**	(12.77)	86%	8%	8%	0.72	**0.96**	(5.42)	<1%
13.6 PVB	5.7 – 0.090" PVB – 5.7	1/2	**0.536**	(13.53)	86%	9%	9%	0.72	**0.93**	(5.30)	<1%

1. Calcualted using LBNL WINDOW and Optics comptuer modeling programs using NFRC standard conditions.

Figure 5-10

SG EMBEDDED LoĒ COATING

Laminate Configuration	Nominal Fractional Inches	Target Thickness in	(mm)	Visible Light Transmittance	Visible Light Reflectance Out	Visible Light Reflectance In	SHGC	U-Factor BTU/hr·ft^2·°F	(W/m^2·K)	UV Transmission
3.0 LoĒ-180® (#2) – 0.090" SG – 3.0	11/32	**0.329**	(8.36)	83%	9%	9%	0.66	**0.98**	(5.58)	<1%
4.7 LoĒ-180® (#2) – 0.090" SG – 4.7	15/32	**0.461**	(11.71)	82%	9%	9%	0.66	**0.94**	(5.33)	<1%
5.7 LoĒ-180® (#2) – 0.090" SG – 5.7	1/2	**0.541**	(13.74)	81%	9%	9%	0.63	**0.91**	(5.16)	<1%
3.0 LoĒ^2-270® (#2) – 0.090" SG – 3.0	11/32	**0.329**	(8.36)	73%	10%	10%	0.41	**0.97**	(5.52)	<1%
4.7 LoĒ^2-270® (#2) – 0.090" SG – 4.7	15/32	**0.461**	(11.71)	71%	10%	10%	0.42	**0.95**	(5.41)	<1%
5.7 LoĒ^2-270® (#2) – 0.090" SG – 5.7	1/2	**0.541**	(13.74)	71%	10%	9%	0.42	**0.94**	(5.36)	<1%
3.0 LoE^3-366® (#2) – 0.090" SG – 3.0	11/32	**0.329**	(8.36)	62%	13%	13%	0.34	**0.97**	(5.51)	<1%
3.9 LoE^3-366® (#2) – 0.090" SG – 3.9	13/32	**0.399**	(10.13)	61%	12%	12%	0.34	**0.96**	(5.46)	<1%
4.7 LoE^3-366® (#2) – 0.090" SG – 4.7	15/32	**0.461**	(11.71)	60%	11%	11%	0.35	**0.95**	(5.42)	<1%
5.7 LoE^3-366® (#2) – 0.090" SG – 5.7	1/2	**0.541**	(13.74)	57%	11%	12%	0.35	**0.94**	(5.36)	<1%
3.0 LoE^3-340® (#2) – 0.035" SG – 3.0	9/32	**0.272**	(6.91)	37%	15%	14%	0.28	**1.00**	(5.70)	<1%
3.0 LoE^3-340® (#2) – 0.090" SG – 3.0	11/32	**0.329**	(8.36)	37%	15%	14%	0.28	**0.98**	(5.53)	<1%
4.7 LoE^3-340® (#2) – 0.035" SG – 4.7	9/32	**0.272**	(6.91)	37%	14%	14%	0.29	**0.99**	(5.59)	<1%
4.7 LoE^3-340® (#2) – 0.090" SG – 4.7	15/32	**0.461**	(11.71)	37%	14%	14%	0.29	**0.96**	(5.44)	<1%
5.7 LoE^3-340® (#2) – 0.035" SG – 5.7	9/32	**0.272**	(6.91)	37%	14%	13%	0.30	**0.97**	(5.53)	<1%
5.7 LoE^3-340® (#2) – 0.090" SG – 5.7	1/2	**0.541**	(13.74)	37%	14%	13%	0.30	**0.95**	(5.38)	<1%
3.0 Quad LoĒ-452+™ (#2) – 0.035" SG – 3.0	9/32	**0.272**	(6.91)	55%	9%	13%	0.31	**1.00**	(5.68)	<1%
3.0 Quad LoĒ-452+™ (#2) – 0.090" SG – 3.0	11/32	**0.329**	(8.36)	55%	9%	13%	0.31	**0.97**	(5.51)	<1%
4.7 Quad LoĒ-452+™ (#2) – 0.035" SG – 4.7	9/32	**0.272**	(6.91)	54%	9%	12%	0.33	**0.98**	(5.56)	<1%
4.7 Quad LoĒ-452+™ (#2) – 0.090" SG – 4.7	15/32	**0.461**	(11.71)	54%	9%	13%	0.33	**0.95**	(5.39)	<1%
5.7 Quad LoĒ-452+™ (#2) – 0.035" SG – 5.7	9/32	**0.272**	(6.91)	54%	9%	12%	0.33	**0.97**	(5.51)	<1%
5.7 Quad LoĒ-452+™ (#2) – 0.090" SG – 5.7	1/2	**0.541**	(13.74)	54%	9%	12%	0.33	**0.94**	(5.34)	<1%

1. Calcualted using LBNL WINDOW and Optics comptuer modeling programs using NFRC standard conditions.

Figure 5-11

PVB EMBEDDED LoĒ COATING

Laminate Configuration	Nominal Fractional Inches	Target Thickness in	(mm)	Visible Light Transmittance	Visible Light Reflectance Out	In	SHGC	U-Factor BTU/hr·ft^2·°F	(W/m^2·K)	UV Transmission
3.0 LoE^2-270® (#2) – 0.090" PVB – 3.0	5/16	**0.324**	(8.24)	73%	10%	10%	0.42	**0.96**	(5.46)	<1%
3.9 LoE^2-270® (#2) – 0.090" PVB – 3.9	3/8	**0.394**	(9.97)	72%	10%	9%	0.42	**0.95**	(5.40)	<1%
4.7 LoE^2-270® (#2) – 0.090" PVB – 4.7	7/16	**0.456**	(11.55)	71%	10%	10%	0.42	**0.94**	(5.36)	<1%
5.7 LoE^2-270® (#2) – 0.090" PVB – 5.7	1/2	**0.536**	(13.53)	71%	10%	10%	0.42	**0.93**	(5.30)	<1%
3.0 LoE^3-366® (#2) – 0.060" PVB – 3.0	19/64	**0.294**	(7.48)	61%	13%	13%	0.34	**0.98**	(5.58)	<1%
3.0 LoE^3-366® (#2) – 0.090" PVB – 3.0	5/16	**0.324**	(8.24)	61%	13%	13%	0.34	**0.96**	(5.46)	<1%
3.9 LoE^3-366® (#2) – 0.090" PVB – 3.9	3/8	**0.394**	(9.97)	61%	14%	14%	0.34	**0.95**	(5.40)	<1%
4.7 LoE^3-366® (#2) – 0.060" PVB – 4.7	7/16	**0.426**	(10.79)	61%	13%	12%	0.35	**0.97**	(5.48)	<1%
4.7 LoE^3-366® (#2) – 0.090" PVB – 4.7	7/16	**0.456**	(11.55)	61%	13%	12%	0.35	**0.95**	(5.37)	<1%
5.7 LoE^3-366® (#2) – 0.060" PVB – 5.7	1/2	**0.506**	(12.77)	61%	13%	12%	0.36	**0.95**	(5.42)	<1%
5.7 LoE^3-366® (#2) – 0.090" PVB – 5.7	1/2	**0.536**	(13.53)	60%	13%	12%	0.36	**0.94**	(5.31)	<1%
3.0 LoE^3-340® (#2) – 0.060" PVB – 3.0	19/64	**0.294**	(7.48)	37%	15%	14%	0.28	**0.98**	(5.58)	<1%
3.0 LoE^3-340® (#2) – 0.090" PVB – 3.0	5/16	**0.324**	(8.24)	37%	15%	14%	0.28	**0.96**	(5.46)	<1%
4.7 LoE^3-340® (#2) – 0.060" PVB – 4.7	7/16	**0.426**	(10.79)	37%	14%	14%	0.29	**0.97**	(5.48)	<1%
4.7 LoE^3-340® (#2) – 0.090" PVB – 4.7	7/16	**0.456**	(11.55)	37%	14%	14%	0.29	**0.95**	(5.37)	<1%
5.7 LoE^3-340® (#2) – 0.060" PVB – 5.7	1/2	**0.506**	(12.77)	37%	14%	13%	0.30	**0.95**	(5.42)	<1%
5.7 LoE^3-340® (#2) – 0.090" PVB – 5.7	1/2	**0.536**	(13.53)	37%	14%	14%	0.30	**0.94**	(5.31)	<1%
3.0 Quad LoĒ-452+™ (#2) – 0.060" PVB – 3.0	19/64	**0.294**	(7.48)	55%	9%	13%	0.31	**0.98**	(5.56)	<1%
3.0 Quad LoĒ-452+™ (#2) – 0.090" PVB – 3.0	5/16	**0.324**	(8.24)	55%	9%	13%	0.31	**0.96**	(5.45)	<1%
4.7 Quad LoĒ-452+™ (#2) – 0.060" PVB – 4.7	7/16	**0.426**	(10.79)	54%	9%	12%	0.33	**0.96**	(5.45)	<1%
4.7 Quad LoĒ-452+™ (#2) – 0.090" PVB – 4.7	7/16	**0.456**	(11.55)	54%	9%	12%	0.33	**0.94**	(5.34)	<1%
5.7 Quad LoĒ-452+™ (#2) – 0.060" PVB – 5.7	1/2	**0.506**	(12.77)	54%	9%	12%	0.33	**0.95**	(5.39)	<1%
5.7 Quad LoĒ-452+™ (#2) – 0.090" PVB – 5.7	1/2	**0.536**	(13.53)	54%	9%	12%	0.33	**0.93**	(5.28)	<1%

1. Calcualted using LBNL WINDOW and Optics comptuer modeling programs using NFRC standard conditions.

Figure 5-12

Websites You May Find Helpful

Cardinal Glass Industries
cardinalcorp.com

ASHRAE
ashrae.org

ASTM International
astm.org

Canadian General Standards Board (CGSB)
tpsgc-pwgsc.gc.ca

Consumer Product Safety Commission
cpsc.gov

ENERGY STAR
energystar.gov

Fenestration and Glazing Industry Alliance
fgiaonline.org

Insulating Glass Certification Council
igcc.org

International Code Council
iccsafe.org

National Fenestration Rating Council
nfrc.org

National Glass Association
glass.org

Safety Glazing Certification Council
sgcc.org

Society of Vacuum Coaters
svc.org

Window & Door Manufacturers Association (WDMA)
wdma.com

LBL Windows and Daylighting
windows.lbl.gov

Certification Programs

Certification programs like these help us make sure that our product designs comply with government safety and durability.

Insulating Glass Certification Council (IGCC)
National Fenestration Rating Council (NFRC)
Safety Glazing Certification Council (SGCC)
Conformity to CEN (European Committee for Standardization) Program Requirements

Standards and Codes

By complying with established standards, our inherent quality and product performance are fully recognized.

ASHRAE
ASTM International
Canadian General Standards Board (CGSB)
International Code Council

Trade Associations

Cardinal supports industry efforts in research, education and the advancement of building science through work with these organizations.

Center for Glass Research
Society of Vacuum Coaters
Window & Door Manufacturers Association (WDMA)
National Glass Association (NGA)
Fenestration and Glazing Industry Alliance (FGIA)

Index

The following is an alphabetical index of common terms for easy reference.

CARDINAL
Glass Industries