

TECHNICAL

GLASS GUIDE

3.1

ENGINEERING THE FUTURE OF GLASS

CARDINAL 
Glass Industries



ENGINEERING

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 9,000 employees serve a broad domestic and international customer base.



Plant #45 BEIG, Buckeye, AZ, 2020



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.

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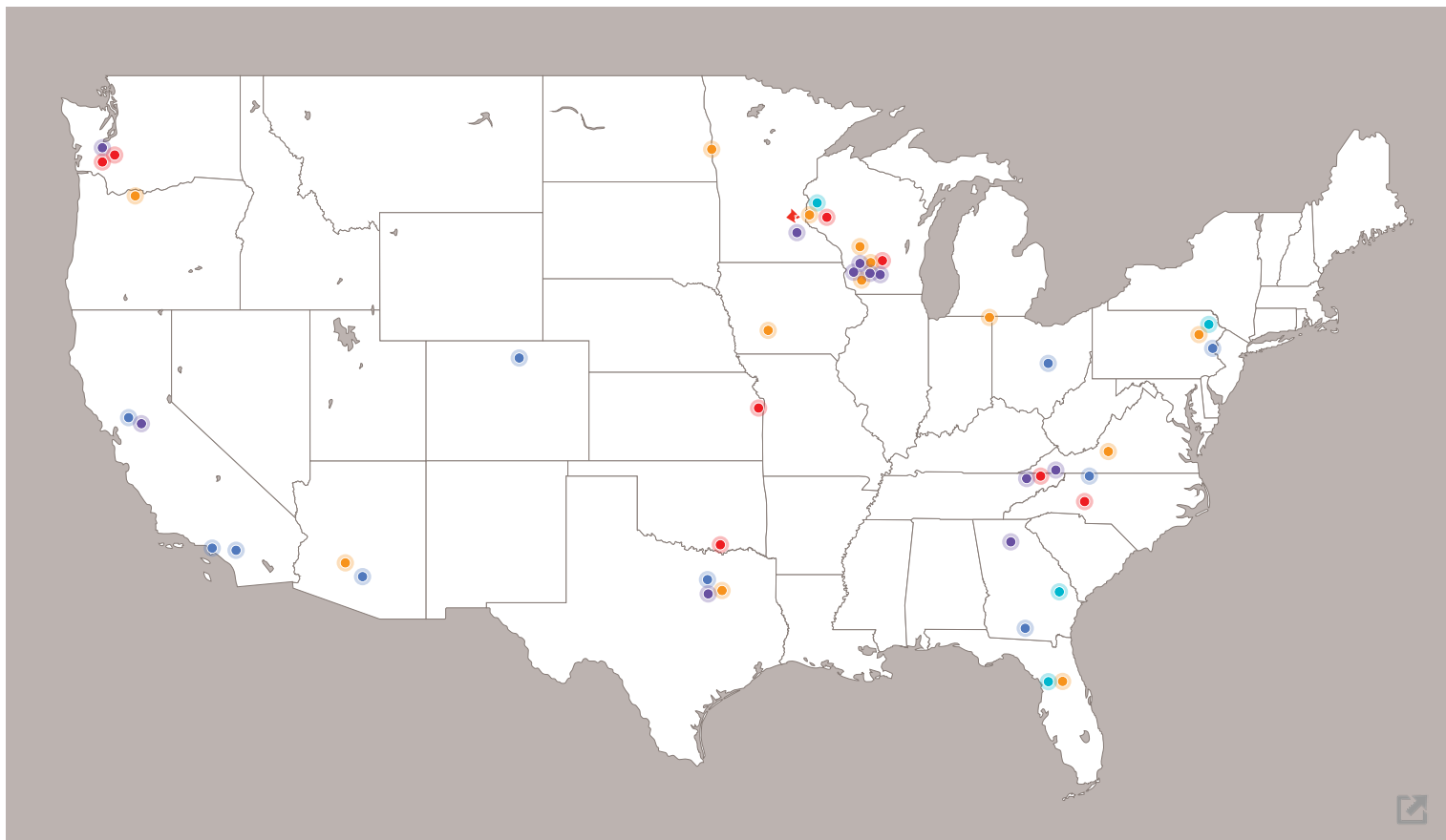
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With Cardinal facilities and service teams nationwide, you'll receive the products and support you need, when you need it.

<p> Cardinal CG® Co. [Coated Glass] Church Hill, TN Spring Green, WI Northfield, MN Buford, GA Waxahachie, TX Tumwater, WA Galt, CA Abingdon, VA [Tempered Only Production] Mazomanie, WI</p>	<p> Cardinal IG® Co. [Insulating Glass] Buckeye, AZ Greenfield, IA Spring Green, WI Tomah, WI Fremont, IN Fargo, ND Waxahachie, TX Hood River, OR Vinton, VA Mountain Top, PA Ocala, FL</p>	<p> Cardinal FG® Co. [Float Glass] Church Hill, TN Menomonie, WI Portage, WI Mooresville, NC Durant, OK Winlock, WA Spring Hill, KS [Tempered Only Production] Chehalis, WA</p>	<p> Cardinal LG® Co. [Laminated Glass] Amery, WI Jessup, PA Ocala, FL Statesboro, GA</p>	<p> Cardinal CT® Co. [Custom Tempering] Casa Grande, AZ Moreno Valley, CA Loveland, CO Fort Worth, TX Mt. Airy, NC Utica, OH Easton, PA Adel, GA Dixon, CA</p>
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 **Cardinal Glass Industries Headquarters**
Eden Prairie, MN

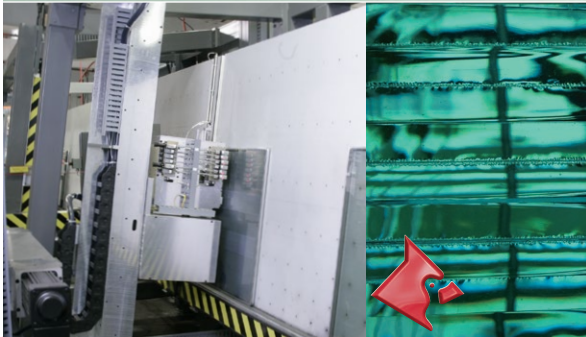
Cardinal IG® Technology Center
Minneapolis, MN

Cardinal CG® Technology Center
Cardinal AG® Automation Group
Cardinal CG® Rotar
Spring Green, WI

Cardinal LG® Technology Center
Ocala, FL

LoE Coated Glass
Laminated Glass
Insulating Glass
Float Glass
Tempered Glass
CLiC®
Neat+® Glass
Preserve® Film

From LoE 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.



Far Beyond Ordinary
Low-E Glass

CARDINAL LoE COATED GLASS

Cardinal LoE glass sets the industry standard for energy-efficient coated glass. Our patented, world-class sputtered LoE 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 LoE glass options includes one, two, three and now even four layers of silver, resulting in 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 LoE-452+® has superior solar control with an 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]

LoE³-366® 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.

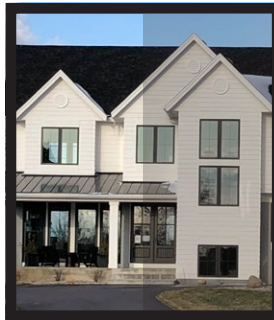


LOW SOLAR GAIN GLASS

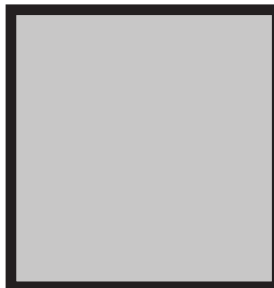
[Three silver layers]

Solar radiation and glare control (three silver layers), designed to be on surface #2 in a double-pane or triple-pane insulating glass unit. LoE³-340® provides an industry-leading SHGC of 0.18 in a double-pane insulating glass unit. It also blocks 98% of UV light infiltration.

CLEAR | Quad LoE-452+

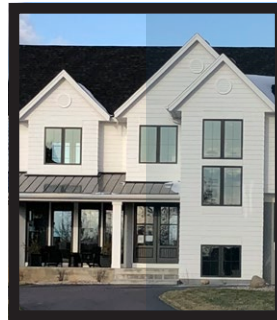


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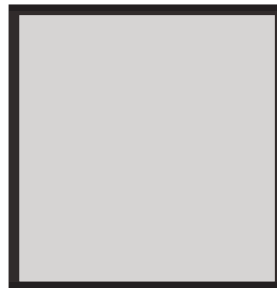


EXTERIOR APPEARANCE

CLEAR | LoE³-366



TRANSMITTED APPEARANCE



EXTERIOR APPEARANCE

CLEAR | LoE³-340



TRANSMITTED APPEARANCE



EXTERIOR APPEARANCE

Transmitted and exterior appearance images are for reference only.



**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 LoE²-272® coating, which provides a slightly better SHGC value. Designed to be on surface #2 in a double-pane or triple-pane insulating glass unit.



LOW SOLAR GAIN GLASS
[Two silver layers]

LoE²-240 is an excellent overall performer for climates where the sun is constantly on the offensive. As a specially formulated two-layer coating, many opt for LoE²-240 for its great solar performance and gentle gray hue.



HIGH SOLAR GAIN GLASS
[One silver layer]

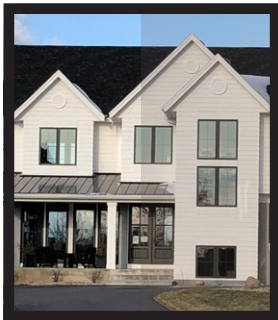
LoE-180® and 180 ESC®: High solar gain coating (one silver layer), LoE-180 and LoE-180 ESC are ideal for passive solar applications. They allow the sun's radiant heat to pass into the home while providing a thermal insulating quality to prevent conductive heat loss to the outside. Both coatings are designed 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. LoE-180 ESC was specifically engineered to meet the Energy Star Canada performance requirements.



**MOISTURE CONTROL
GLASS**
[One indium tin oxide layer]

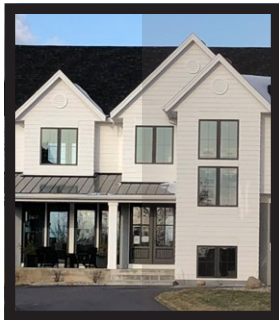
LoE-x89® is a near colorless exterior glass surface coating (indium tin oxide) that reduces outdoor glass condensation. Designed for surface #1 in a double-pane insulating glass unit to reduce heat loss and the occurrence of the glass falling below the dew point. This reduces the opportunity for exterior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

CLEAR | LoE²-272



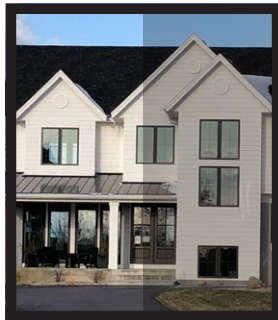
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CLEAR | LoE²-270



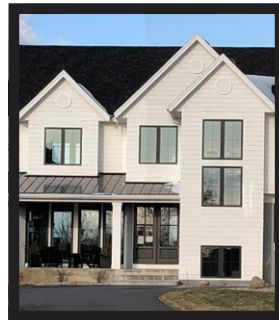
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CLEAR | LoE²-240



TRANSMITTED APPEARANCE

CLEAR | LoE-180



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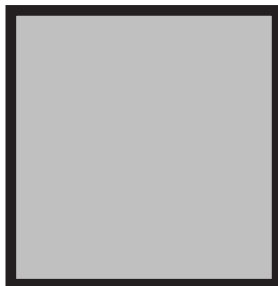
LoE-x89, LoE-i89 AND LoE-Di89 HAVE MINIMAL TO NO EFFECT ON REFLECTED AND TRANSMITTED COLOR. THE ACCOMPANYING LoE GLASS SPECIFIED WILL DOMINATE THE COLOR PROFILE OF THE IG UNIT.



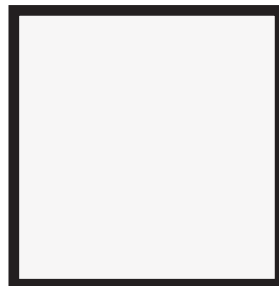
EXTERIOR APPEARANCE



EXTERIOR APPEARANCE



EXTERIOR APPEARANCE



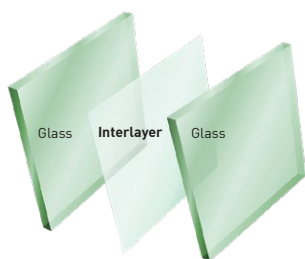
EXTERIOR APPEARANCE

Transmitted and exterior appearance images are for reference only.

CARDINAL LAMINATED GLASS

Laminated glass remains a highly 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



SAFETY

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.



SOUND

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 from exposure to solar energy entering the 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.

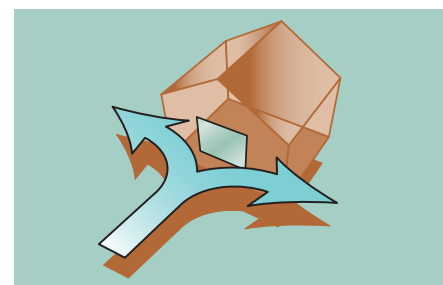
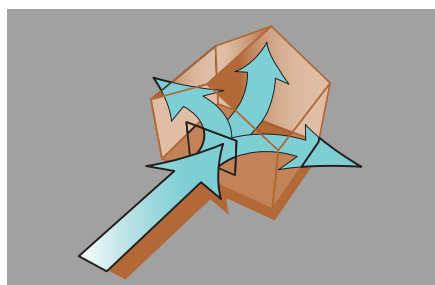


UV PROTECTION

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. Investing in windows and doors made with Sea-Storm laminated glass could save a home or even a life.



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.

Figure 1-1

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 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 0.10% over 20 years, allowing us to offer

the industry's leading comprehensive 20-year factory warranty. More than 400,000,000 Cardinal IG units are currently under warranty.

Endur IG units are all constructed with dual seal construction of a polyisobutylene (PIB) primary sealant and silicone secondary sealant. In this

combination, the PIB provides ultra-low argon permeation, and the inorganic silicone seal provides a structural seal that is durable and highly resistant to heat, moisture and UV.

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

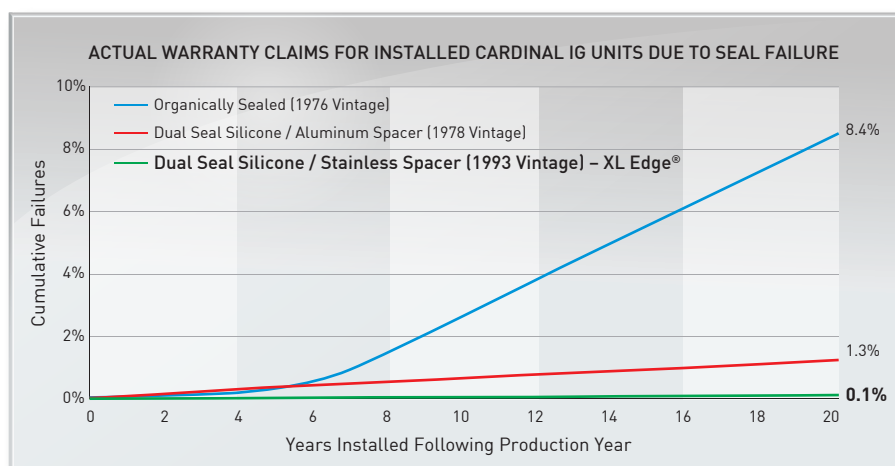
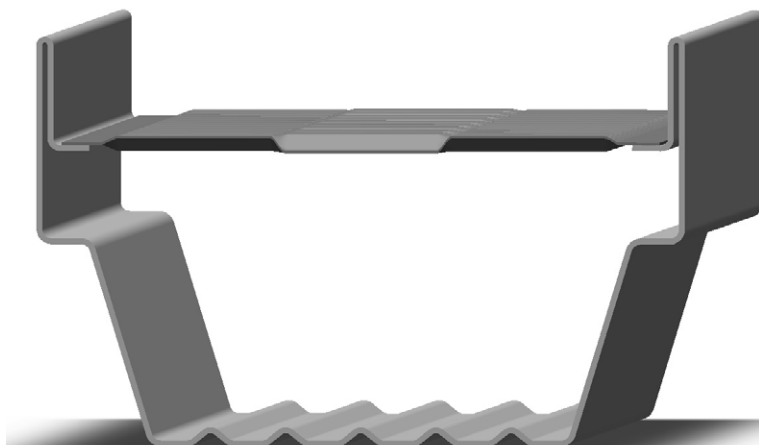


Figure 1-2

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.





Naturally Cleaner Glass

Since 2006, millions of 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 original 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 LoE coatings, reducing the amount of energy needed to coat both glass surfaces.

LoE Comfort and Efficiency

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

Conductive Surface = 40% Less Dust

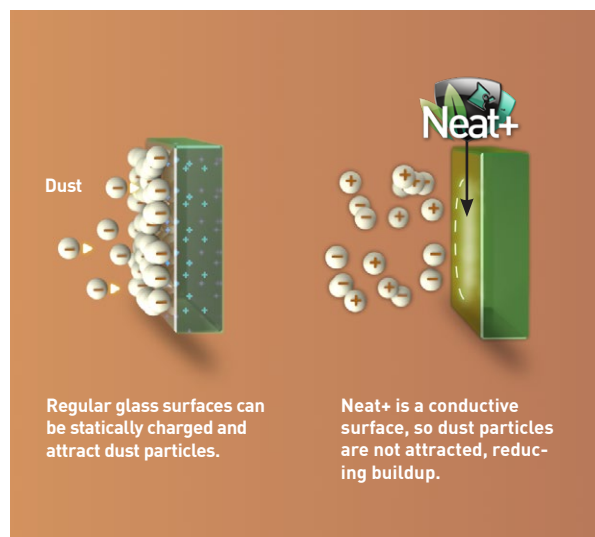


Figure 1-3

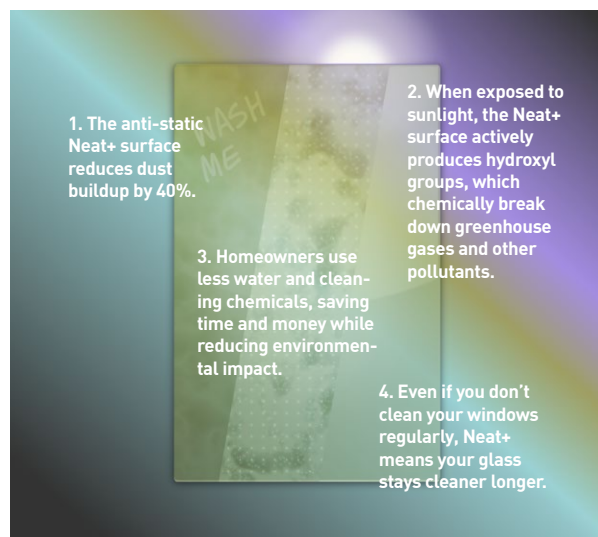


Figure 1-4



Protective Film

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. It should be removed within six 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.

PROTECTIVE FILM

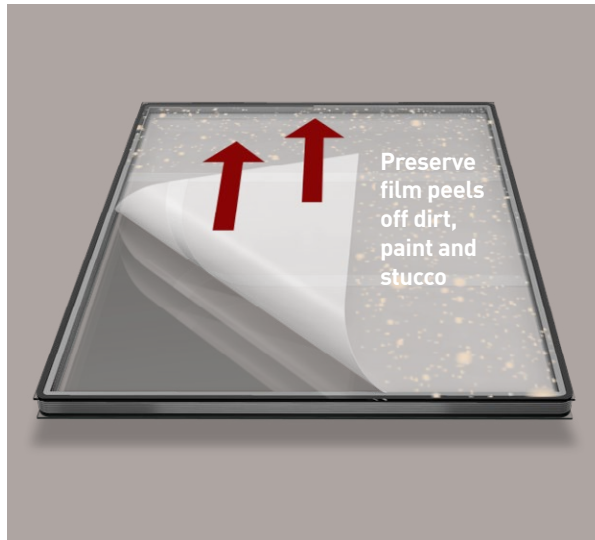


Figure 1-5

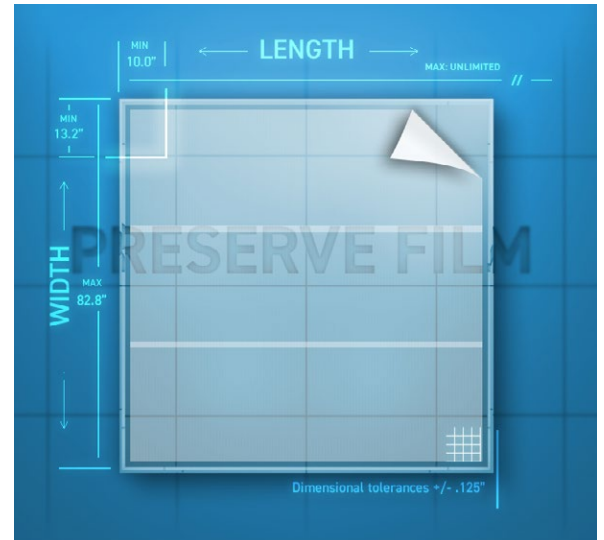


Figure 1-6



CLiC® glass fulfills the need for a dependable IG solution that switches between total privacy and crystal-clear views, instantly and on demand.

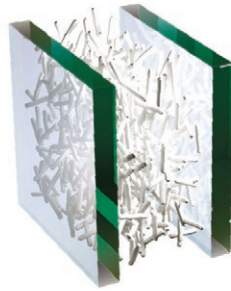
This next-generation glass is integrated with Cardinal IG and LoE™ coatings to meet the thermal and solar performance requirements of exterior applications, while reducing noise and protecting from storms and forced entry. CLiC can also be used monolithically in a variety of interior design applications.

Haze-Free Clarity

CLiC provides privacy with abundant light transmission in private mode. When in clear mode, the glass produces crystal-clear views from any angle with minimal off-axis haze, foggy or distortion, making it appear like regular glass. This clarity is maintained on even the largest glass panels.

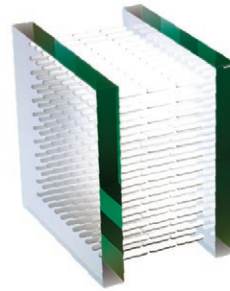
Fast Switching

CLiC glass eliminates the waiting for either privacy or clarity. It features a transition time of less than 100 milliseconds so that room occupants experience a near-instantaneous mode change whenever one is initiated.



Privacy

When electricity is off, the liquid crystal forms into a light scatter layer for instant privacy while diffusing the light into a soft, even glow.



Haze-Free Clarity

When electricity is applied, the liquid crystal layer aligns itself for a crystal-clear view.



Figure 1-7



Figure 1-8

CLiC® for Exteriors

CLiC PRIVACY GLASS

Reliable Performance

CLiC electronics deliver carefully tuned power management for consistent performance. Unlike other privacy products that require glass to be in private mode up to four hours per day to maintain warranty coverage, CLiC operates without such limitations and is backed by a comprehensive, industry-leading warranty.

In addition to durability and performance, CLiC electronics have been designed with flexibility in mind. CLiC offers different electronics to fit any size installation. CLiC offers a small, easily concealable, single-channel controller for smaller installations and a powerful, rack-mount multi-channel, network-enabled controller for even the largest projects.



Easy Integration

CLiC operates on NEC class 3 low-voltage power, is UL and FCC certified, and allows for easy integration with third-party control systems for seamless installation into buildings and homes.



Patented Construction

The CLiC glass design is based on polymer stabilized cholesteric texture (PSCT) liquid crystal technology. By using PSCT technology in a direct-to-glass application, Cardinal IG sets a new standard for switchable privacy glass performance and reliability.

Film-free application

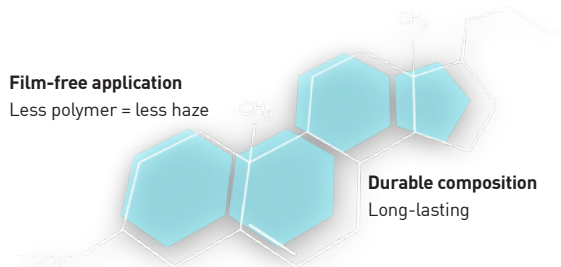
Less polymer = less haze

Future-proof

The right platform for new features

Durable composition

Long-lasting



Also Available for Interior Applications

CLiC monolithic glass creates new possibilities for the versatility, functionality and uncluttered beauty of commercial and residential interior spaces.

The options are virtually limitless for architects and interior designers who incorporate CLiC into their projects. For example, the glass can be used for privacy partitions or on-demand whiteboarding surfaces in modern offices. It is also the ideal maintenance-free replacement for privacy curtains in hospital rooms.



Figure 1-9



Figure 1-10

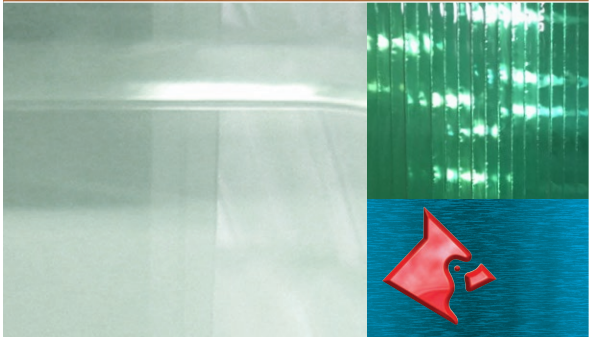
CLiC® for Interiors



CARDINAL PRODUCTS



From thermal performance to solar energy transmission to fading protection and more, this section contains technical data of Cardinal Glass insulating glass products.



IG PERFOR- MANCE SECTION



Terminology

Center of Glass (COG)

These values are the properties of the glass or insulating glass unit only and do not include the effects of the IG spacer system, window frame or window sash.

Condensation Resistance (CR)

Measures how well a window resists the formation of condensation on the indoor-facing glass surface. CR is expressed as a number between 1 and 100. The higher the number, the better a product resists condensation. CR compares window products and their potential for condensation formation.

Energy Rating (ER)

ER is a window measure that weighs Solar Heat Gain Coefficient (SHGC), U-factor and air leakage into one unitless performance number. This calculation favors windows with high solar heat gains, low U-factors and low air leakage. ER is most useful in buildings designed to utilize passive solar heating in cold environments like Canada.

Glass Surfaces

The industry convention is to label the outdoor-facing glass surface as #1 and then work sequentially toward the final indoor-facing glass surface (i.e., surface #4 in a double-pane IG unit).

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.

R-Value

The thermal resistance of a glazing system expressed in $\text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}/\text{BTU}$. 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.

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 $^\circ\text{F}$ (32 $^\circ\text{C}$), indoor temperature of 75 $^\circ\text{F}$ (24 $^\circ\text{C}$) and 6.2 mph (2.8 m/s) wind ($\text{RHG} = U_{\text{summer}} \times (89-75) + \text{SHGC} \times (230)$). Expressed in terms of BTU/hr/ft^2 .

Sightline (IG)

The area of the IG unit where the sealants and spacer systems are blocking the visible light transmission through the glass.

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 Transmittance

In the solar spectrum (300 to 2,500 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 ranging from 0 to 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 $\text{BTU/hr/ft}^2/^\circ\text{F}$ ($\text{W/m}^2/^\circ\text{C}$). The lower the U-factor, the less heat is transmitted through the glazing material.

Winter Nighttime

U-factors are calculated using outside air temperature of 0 $^\circ\text{F}$ (-18 $^\circ\text{C}$), outside air velocity of 12.3 mph (5.5 m/s) and a solar intensity of 0 BTU/hr/ft^2 (0 W/m^2).

Summer Daytime

U-factors are calculated using outside air temperature of 89 $^\circ\text{F}$ (32 $^\circ\text{C}$), outside air velocity of 6.2 mph (2.8 m/s), inside air temperature of 75 $^\circ\text{F}$ (24 $^\circ\text{C}$) and a solar intensity of 248 BTU/hr/ft^2 (783 W/m^2). Unless otherwise noted, all U-factors provided use winter nighttime conditions.

Ultraviolet (UV) Light

Represents the solar spectrum from 300 to 380 nm. This transmitted light contributes to the fading of materials and furnishings.

Visible Indoor Reflectance

In the visible spectrum (380 to 780 nm), the percentage of visible light that is reflected from the glass surface(s) to the inside of the building.

Visible Light Transmittance

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

Visible Outdoor Reflection

In the visible spectrum (380 to 780 nm), the percentage of visible light that is reflected outward from the glass surface(s) 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

Performance Data

The performance data shown in the adjacent tables can be used to compare different insulating glass constructions and LoE coatings.

U-Value: Thermal performance of IGU. The lower the number, the more thermally insulating the IG unit is.

SHGC (Solar Heat Gain Coefficient): The higher the value, the more solar energy is passed through the IG unit.

Visible Light Transmittance and Reflectance: Light that is transmitted through the glass and reflected off the glass surfaces. Higher light transmission values indicate more natural light coming through the glass.

UV Light Transmittance:

Amount of ultraviolet radiation transmitted through the glass. As this value decreases, the amount of UV transmission decreases. In turn, this will reduce the effects of fading.

(3 MM / 13.0 MM / 3 MM) DOUBLE-PANE IGU PERFORMANCE DATA							
IG Configuration Outboard Lite / Inboard Lite	U-Factor (Argon)		SHGC	Visible Light			UV Light
	(BTU/hr-ft ² ·°F)	(W/m ² ·°K)		Trans. (%)	Refl. Out (%)	Refl. In (%)	Trans. (%)
Clear / Clear	0.48	2.59	0.78	82	15	15	58
Clear / LoE-180® (#3)	0.26	1.49	0.69	79	15	15	29
Clear / LoE-180 ESC® (#3)	0.27	1.51	0.71	79	15	15	25
LoE-180® (#2) / Clear	0.26	1.49	0.64	79	15	15	29
LoE ² -240® (#2) / Clear	0.26	1.46	0.25	40	14	11	16
LoE ² -270® (#2) / Clear	0.25	1.42	0.37	70	12	13	14
LoE ² -272® (#2) / Clear	0.25	1.43	0.41	72	11	12	16
LoE ³ -340® (#2) / Clear	0.25	1.39	0.18	39	13	16	2
LoE ³ -366® (#2) / Clear	0.24	1.38	0.27	65	11	12	5
Quad LoE-452+® (#2) / Clear	0.24	1.37	0.22	52	10	15	1
LoE-180® (#2) / LoE-i89® (#4)	0.21	1.19	0.62	77	15	14	27
LoE-180 ESC® (#2) / LoE-i89® (#4)	0.21	1.21	0.64	78	15	14	24
LoE ² -240® (#2) / LoE-i89® (#4)	0.21	1.17	0.24	39	14	10	15
LoE ² -270® (#2) / LoE-i89® (#4)	0.20	1.14	0.36	69	12	12	14
LoE ² -272® (#2) / LoE-i89® (#4)	0.20	1.15	0.41	70	11	11	16
LoE ³ -340® (#2) / LoE-i89® (#4)	0.20	1.13	0.17	38	13	15	2
LoE ³ -366® (#2) / LoE-i89® (#4)	0.20	1.12	0.27	63	11	11	5
Quad LoE-452+® (#2) / LoE-i89® (#4)	0.20	1.11	0.21	51	10	14	1

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 LoE products, otherwise air-filled cavity. Coatings on surfaces #2, #3 and/or #4.

Figure 2-2

(6 MM / 13.0 MM / 6 MM) DOUBLE-PANE IGU PERFORMANCE DATA							
IG Configuration Outboard Lite / Inboard Lite	U-Factor (Argon)		SHGC	Visible Light			UV Light
	(BTU/hr-ft ² ·°F)	(W/m ² ·°K)		Trans. (%)	Refl. Out (%)	Refl. In (%)	Trans. (%)
Clear / Clear	0.47	2.55	0.72	80	14	14	47
Clear / LoE-180® (#3)	0.26	1.47	0.64	77	14	15	24
Clear / LoE-180 ESC® (#3)	0.26	1.50	0.66	77	14	15	21
LoE-180® (#2) / Clear	0.26	1.47	0.60	77	15	14	24
LoE ² -240® (#2) / Clear	0.25	1.45	0.24	37	13	10	13
LoE ² -270® (#2) / Clear	0.25	1.40	0.36	68	12	12	13
LoE ² -272® (#2) / Clear	0.25	1.42	0.40	70	11	11	14
LoE ³ -340® (#2) / Clear	0.24	1.38	0.18	38	13	15	2
LoE ³ -366® (#2) / Clear	0.24	1.37	0.27	63	11	11	4
Quad LoE-452+® (#2) / Clear	0.24	1.36	0.22	51	9	15	1
LoE-180® (#2) / LoE-i89® (#4)	0.21	1.18	0.58	75	15	13	23
LoE-180 ESC® (#2) / LoE-i89® (#4)	0.21	1.20	0.60	75	15	14	20
LoE ² -240® (#2) / LoE-i89® (#4)	0.21	1.16	0.23	37	13	9	13
LoE ² -270® (#2) / LoE-i89® (#4)	0.20	1.13	0.35	66	12	12	12
LoE ² -272® (#2) / LoE-i89® (#4)	0.20	1.14	0.39	68	10	11	14
LoE ³ -340® (#2) / LoE-i89® (#4)	0.20	1.12	0.17	37	13	14	2
LoE ³ -366® (#2) / LoE-i89® (#4)	0.20	1.11	0.26	61	10	11	4
Quad LoE-452+® (#2) / LoE-i89® (#4)	0.19	1.10	0.21	50	9	14	1

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 LoE products, otherwise air-filled cavity. Coatings on surfaces #2, #3 and/or #4.

Figure 2-3



(3 MM / 13.0 MM / 3 MM / 13.0 MM / 3 MM) TRIPLE-PANE IGU PERFORMANCE DATA

IG Configuration Exterior Lite / Center Lite / Inboard Lite	U-Factor (Argon)		SHGC	Visible Light			UV Light
	(BTU/hr-ft ² ·°F)	(W/m ² ·°K)		Trans. (%)	Refl. Out (%)	Refl. In (%)	Trans. (%)
Clear / Clear / Clear	0.31	1.63	0.70	75	21	21	48
Clear / Clear / LoE-180® (#5)	0.18	1.04	0.61	73	20	21	24
Clear / Clear / LoE-180 ESC® (#5)	0.19	1.06	0.63	73	21	21	21
LoE-180® (#2) / Clear / LoE-180® (#5)	0.13	0.75	0.56	70	20	20	13
LoE-180 ESC® (#2) / Clear / LoE-180 ESC® (#5)	0.14	0.77	0.58	70	21	21	10
LoE ² -240® (#2) / Clear / LoE-180® (#5)	0.13	0.74	0.22	35	16	17	7
LoE ² -270® (#2) / Clear / LoE-180® (#5)	0.13	0.73	0.33	62	16	19	7
LoE ² -272® (#2) / Clear / LoE-180® (#5)	0.13	0.73	0.37	63	15	18	8
LoE ³ -340® (#2) / Clear / LoE-180® (#5)	0.13	0.72	0.16	34	15	21	1
LoE ³ -366® (#2) / Clear / LoE-180® (#5)	0.13	0.71	0.24	57	14	18	2
Quad LoE-452+® (#2) / Clear / LoE-180® (#5)	0.13	0.72	0.19	46	12	21	1
LoE-180® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.12	0.66	0.53	68	21	19	13
LoE-180 ESC® (#2) / LoE-180 ESC® (#4) / LoE-i89® (#6)	0.12	0.68	0.56	69	21	19	9
LoE ² -240® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11	0.65	0.21	34	16	15	7
LoE ² -270® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11	0.64	0.32	60	16	17	7
LoE ² -272® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11	0.64	0.36	62	15	16	8
LoE ³ -340® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11	0.64	0.15	33	15	19	1
LoE ³ -366® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11	0.63	0.24	56	14	16	2
Quad LoE-452+® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11	0.63	0.19	45	12	19	1

1. Calculated values using LBNL Window computer program per NFRC environmental conditions.

Figure 2-4

2. Triple-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoE products, otherwise air-filled cavity. Coatings on surfaces #2, #4, #5 and/or #6.

(6 MM / 13.0 MM / 6 MM / 13.0 MM / 6 MM) TRIPLE-PANE IGU PERFORMANCE DATA

IG Configuration Exterior Lite / Center Lite / Inboard Lite	U-Factor (Argon)		SHGC	Visible Light			UV Light
	(BTU/hr-ft ² ·°F)	(W/m ² ·°K)		Trans. (%)	Refl. Out (%)	Refl. In (%)	Trans. (%)
Clear / Clear / Clear	0.30	1.62	0.64	72	20	20	37
Clear / Clear / LoE-180® (#5)	0.18	1.03	0.56	69	19	20	19
Clear / Clear / LoE-180 ESC® (#5)	0.18	1.05	0.57	69	20	20	17
LoE-180® (#2) / Clear / LoE-180® (#5)	0.13	0.75	0.51	67	20	20	11
LoE-180 ESC® (#2) / Clear / LoE-180 ESC® (#5)	0.13	0.77	0.54	67	20	20	8
LoE ² -240® (#2) / Clear / LoE-180® (#5)	0.13	0.74	0.20	33	15	17	5
LoE ² -270® (#2) / Clear / LoE-180® (#5)	0.13	0.72	0.32	58	15	19	5
LoE ² -272® (#2) / Clear / LoE-180® (#5)	0.13	0.73	0.35	60	14	17	7
LoE ³ -340® (#2) / Clear / LoE-180® (#5)	0.13	0.72	0.15	33	14	20	1
LoE ³ -366® (#2) / Clear / LoE-180® (#5)	0.13	0.71	0.24	54	14	18	2
Quad LoE-452+® (#2) / Clear / LoE-180® (#5)	0.13	0.71	0.19	44	11	20	1
LoE-180® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.12	0.66	0.49	65	20	18	10
LoE-180 ESC® (#2) / LoE-180 ESC® (#4) / LoE-i89® (#6)	0.12	0.67	0.51	65	20	18	8
LoE ² -240® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11	0.65	0.19	32	15	15	5
LoE ² -270® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11	0.64	0.30	57	16	17	5
LoE ² -272® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11	0.64	0.34	59	15	16	6
LoE ³ -340® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11	0.63	0.15	32	14	19	1
LoE ³ -366® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11	0.63	0.23	53	14	16	2
Quad LoE-452+® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11	0.63	0.18	43	12	18	1

1. Calculated values using LBNL Window computer program per NFRC environmental conditions.

Figure 2-5

2. Triple-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoE products, otherwise air-filled cavity. Coatings on surfaces #2, #4, #5 and/or #6.



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 (see Figure 2-37). It has been shown that fading damage can also occur from light in nearly the entire visible light spectrum.

The IC0-CIE Damage Function attempts to quantify the risk of damage from the full spectrum of light (UV and visible). It uses a system of weighting the amount of light transmitted at

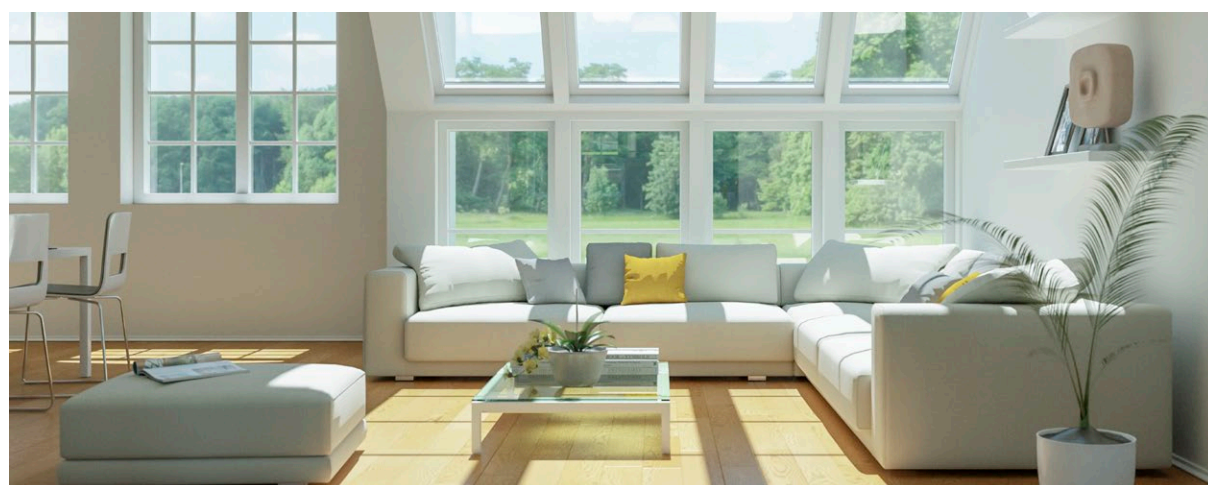
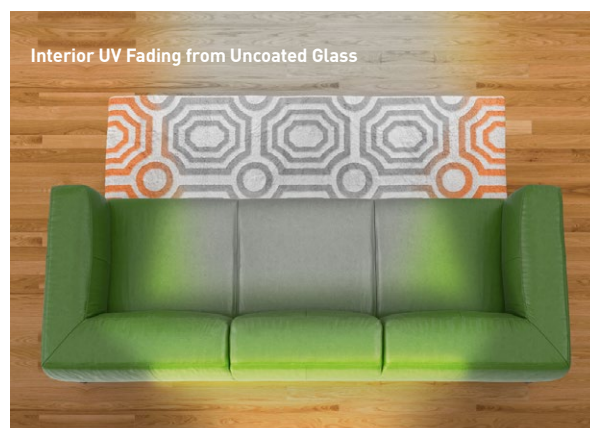
a wavelength based on its contribution to fading of materials such as fabrics. It should also be noted that all materials fade at different rates and no glass choice will completely eliminate fading effects.

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 (interior lighting) may also contribute to fading in a significant way.

In addition to the light sources, the materials themselves will have different resistances to fading. Some fabrics, woods, paints and other interior finishes are significantly more susceptible to fading. Manufacturers of interior finishes should be consulted for fading potential as it relates to their products.

Laminated glass is often used in situations where a minimal 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 light transmission, the visible light that is transmitted will contribute to fading of finishes within a building. In glass constructions where the LoE already blocks the vast majority of UV light, the addition of the laminate glass will only provide a small increase in fading protection.



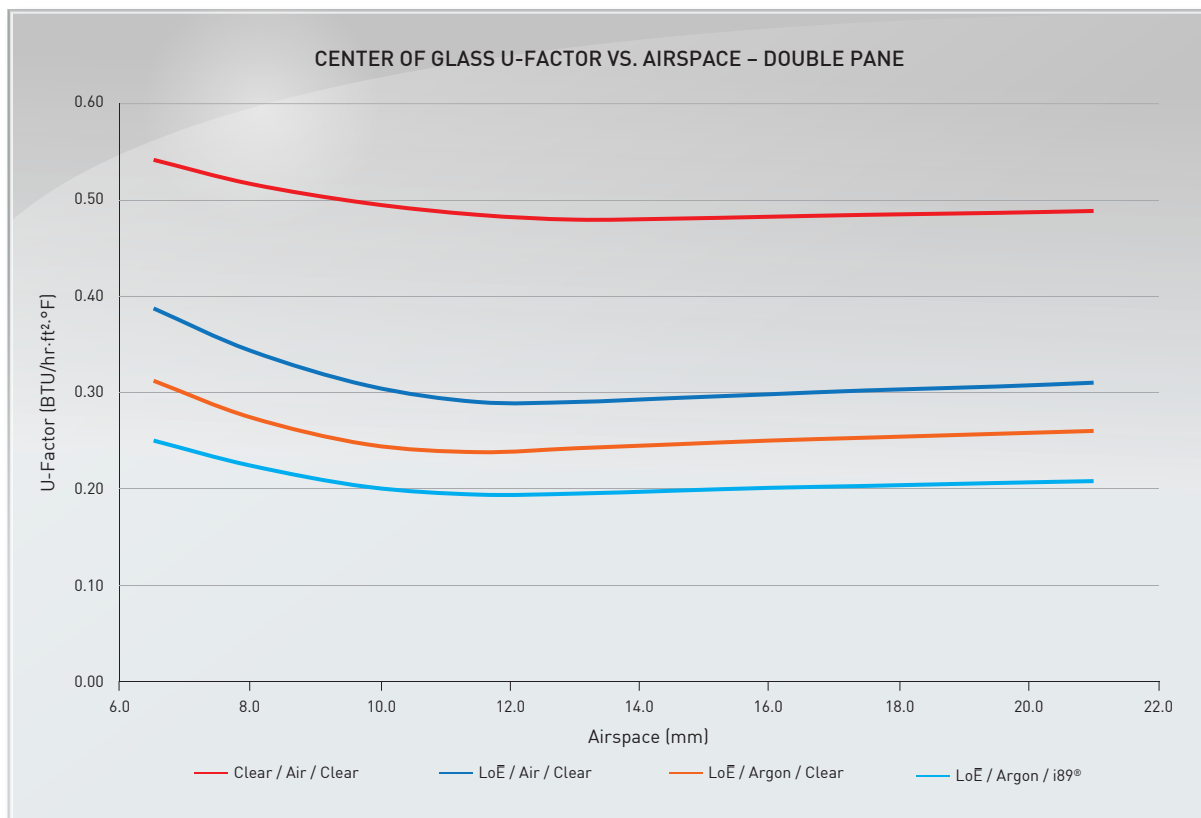
Uncoated glass allows abundant amounts of UV light to reach a home's interior, which may damage furniture, carpets, wood floors and artwork. Laminated glass blocks most of this UV radiation, helping to protect interior furnishings from fading.

Center of Glass U-Factors of IG Units

These graphs illustrate how Cardinal LoE coatings and argon filling improve center of glass U-factors.

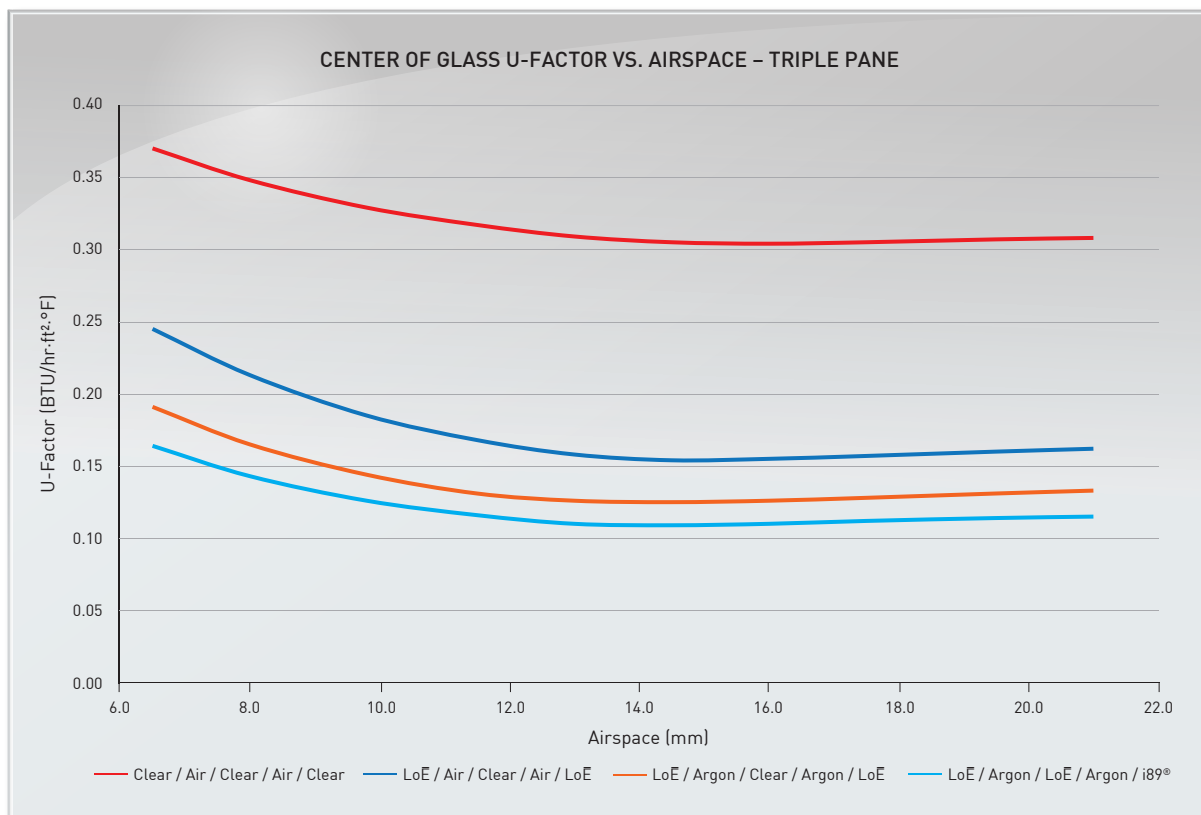
U-Factor vs. Airspace Thickness

In addition to showing the benefit of LoE coatings and argon filling, these graphs show that the optimum airspace thickness for a double-pane argon-filled IGU is approximately 12 mm and for a triple-pane IGU, is approximately 14 mm. They also illustrate larger airspaces will increase the U-factor, and thereby decrease thermal performance.



1. Calculated values using LBNL Window program per NFRC environmental conditions. 2. LoE³-366® (#2) & LoE-i89® (#4).
3. 3.0 mm thick glass, 13.0 mm airspace. 4. Argon fill = 90%.

Figure 2-6



1. Calculated values using LBNL Window program per NFRC environmental conditions. 2. LoE³-366® (#2), LoE-180® (#4 or #5), & LoE-i89® (#6).
3. 3.0 mm thick glass, 13.0 mm airspace. 4. Argon fill = 90%.

Figure 2-7

Overall Window U-Factors

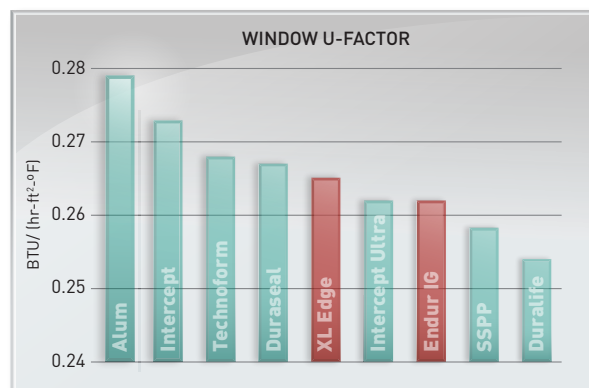
U-Factor and Glass Frame Interface Temperatures

The tables here compare various spacer types in the industry and their effect on the overall window U-factor, NFRC Condensation Resistance (CR) rating and sightline temperature. The simulations were made by a Certified NFRC Simulator using a wood or vinyl frame with sightlines equal in all cases.

WINDOW PERFORMANCE			
Spacer Type	Window 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

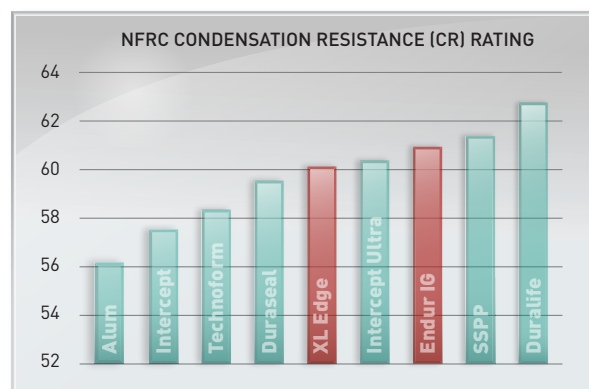
1. 3.1 mm LoE²-366® / 0.5" Argon / 3.1 mm Clear

Figure 2-8



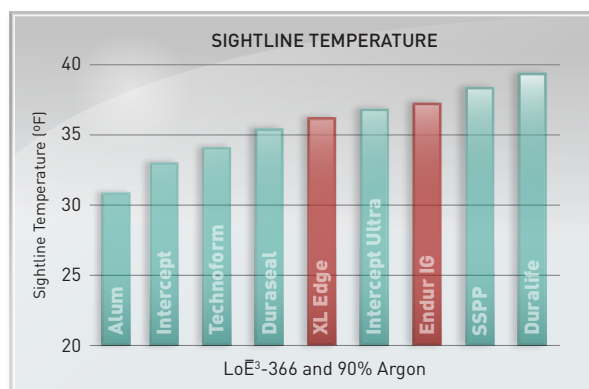
1. 3.1 mm LoE²-366 / 0.5" Argon / 3.1 mm Clear
2. Generic Wood / Vinyl Frame

Figure 2-9



1. 3.1 mm LoE²-366 / 0.5" Argon / 3.1 mm Clear
2. Generic Wood / Vinyl Frame

Figure 2-10



1. 3.1 mm LoE²-366 / 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 approximately 2.5" band of glass near the frame is greater than the heat flow through the center of an argon-filled, LoE 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 aluminum spacers (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 (Figure 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 LoE-180® and LoE-i89® while maintaining very low U-factors.

WINTER DAYTIME SOLAR HEAT GAIN COMPARISONS							
Insulating Glass Unit	U _{winter} Btu/(hr-ft ² -°F) (W/m ² -K)	SHGC	Solar Radiation Reflected Btu/(hr-ft ²) (W/m ²)	Solar Radiation Transmitted Btu/(hr-ft ²) (W/m ²)	Total Energy Rejected Btu/(hr-ft ²) (W/m ²)	Total Energy Gained Btu/(hr-ft ²) (W/m ²)	
Clear / Clear	0.48 [2.73]	0.78	32 [102]	181 [571]	89 [281]	193 [609]	
Clear / LoE-180® (#3)	0.26 [1.48]	0.69	52 [164]	149 [470]	95 [300]	171 [540]	
Quad LoE-452+® (#2) / Clear	0.24 [1.36]	0.22	104 [329]	47 [148]	210 [663]	55 [174]	
LoE-180® (#2) / LoE-i89® (#4)	0.21 [1.19]	0.62	52 [164]	136 [429]	109 [344]	154 [486]	
Quad LoE-452+® (#2) / LoE-i89® (#4)	0.20 [1.14]	0.21	104 [329]	47 [148]	210 [663]	52 [164]	
LoE-180® (#2) / Clear / LoE-180® (#5)	0.13 [0.74]	0.56	62 [196]	117 [369]	118 [372]	139 [439]	
Quad LoE-452+® (#2) / Clear / LoE-180® (#5)	0.13 [0.74]	0.19	107 [336]	42 [133]	210 [663]	47 [148]	
LoE-180® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.12 [0.68]	0.53	62 [196]	109 [344]	125 [394]	131 [413]	
Quad LoE-452+® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11 [0.62]	0.19	107 [336]	40 [126]	209 [659]	47 [148]	

Notes:

1. Calculated values using LBNL Window computer program.

2. Double-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoE™ products, otherwise air-filled cavity. Coatings on surfaces #2, #3 and/or #4.

3. Triple-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoE™ products. Coatings on surfaces #2 and #5, or #2, #4 and #6.

4. All insulating glass systems contain 1/8" (3 mm) glass.

5. Environmental conditions: -0.4°F outdoor, 69.8°F indoor, 248.2 BTU/hr/ft² solar radiation, NFRC/ASHRAE standard wind speeds and convection coef.

Figure 2-12

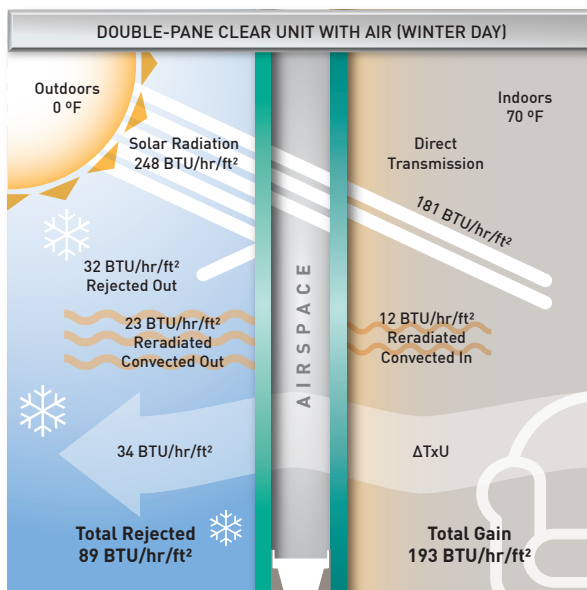


Figure 2-13

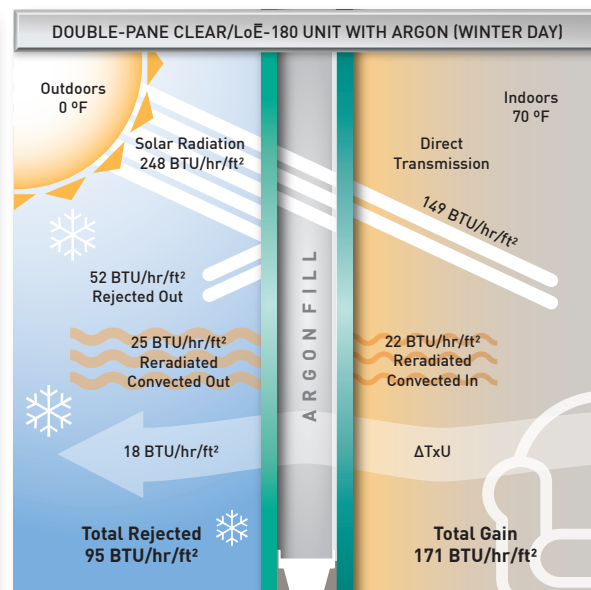


Figure 2-14

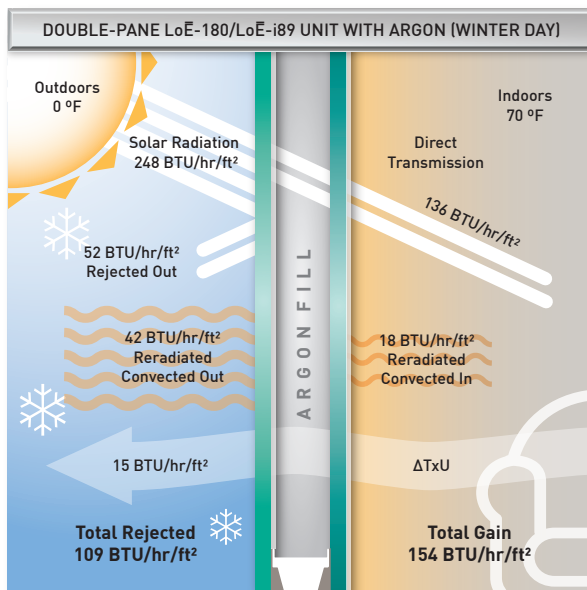


Figure 2-15

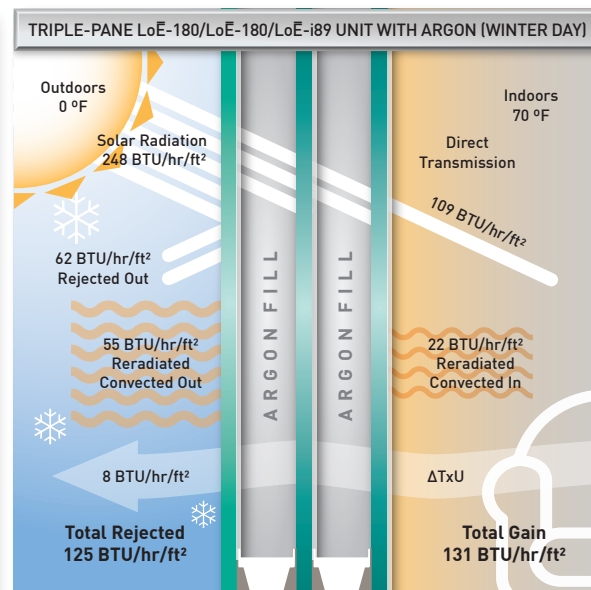


Figure 2-16

Heat Transfer: Winter Heat Loss

Heat transfer across the cavities 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 LoE³-366® unit with argon in figure 2-17 shows this effect

The heat transfer characteristics of the LoE-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 NIGHTTIME AIRSPACE HEAT TRANSFER						
Insulating Glass Unit	U _{winter} Btu/(hr-ft ² -°F) [W/m ² -K]	Radiative Heat Loss Btu/(hr-ft ²) [W/m ²]	Conductive Heat Loss Btu/(hr-ft ²) [W/m ²]	Total Heat Loss Btu/(hr-ft ²) [W/m ²]		
Clear / Clear	0.48 [2.73]	21 [66]	13 [41]	34	[107]	
Clear / LoE-180® (#3)	0.26 [1.48]	3 [9]	15 [47]	18	[57]	
Quad LoE-452+® (#2) / Clear	0.24 [1.36]	1 [3]	16 [50]	17	[54]	
LoE-180® (#2) / LoE-i89® (#4)	0.21 [1.19]	2 [6]	13 [41]	15	[47]	
Quad LoE-452+® (#2) / LoE-i89® (#4)	0.20 [1.14]	1 [3]	13 [41]	14	[44]	
LoE-180® (#2) / Clear / LoE-180® (#5)	0.13 [0.74]	2 [6]	7 [22]	9	[28]	
Quad LoE-452+® (#2) / Clear / LoE-180® (#5)	0.13 [0.74]	1 [3]	8 [25]	9	[28]	
LoE-180® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.12 [0.68]	1 [3]	7 [22]	8	[25]	
Quad LoE-452+® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11 [0.62]	1 [3]	7 [22]	8	[25]	

Notes:

1. Calculated values using LBNL Window computer program.
2. Double-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoE™ products, otherwise air-filled cavity. Coatings on surfaces #2, #3 and/or #4.
3. Triple-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoE™ products. Coatings on surfaces #2 and #5, or #2, #4 and #6.
4. All insulating glass systems contain 1/8" (3 mm) glass.
5. Environmental conditions: -0.4°F outdoor, 69.8°F indoor, 0 BTU/hr-ft² solar radiation, NFRC/ASHRAE standard wind speeds and convection coef.

Figure 2-17

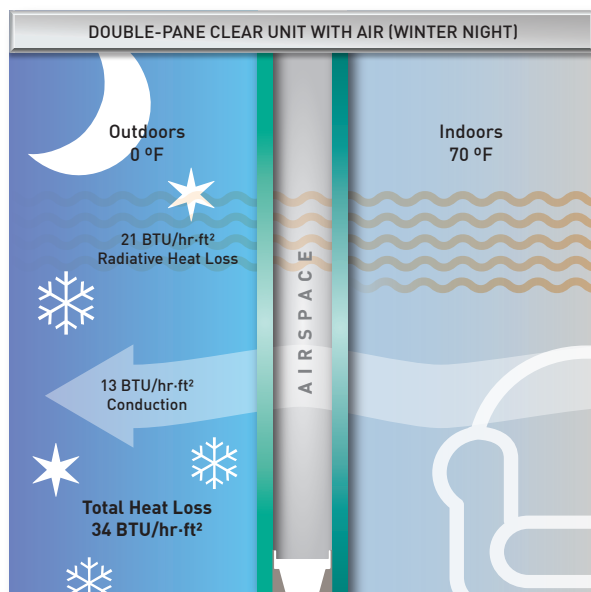


Figure 2-18

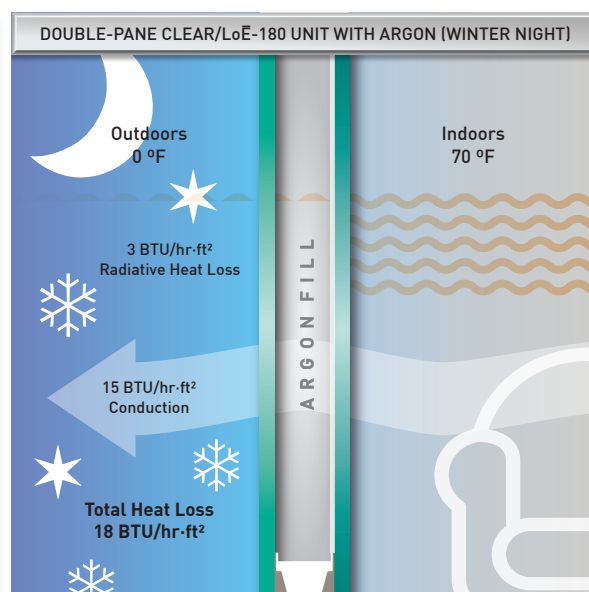


Figure 2-19

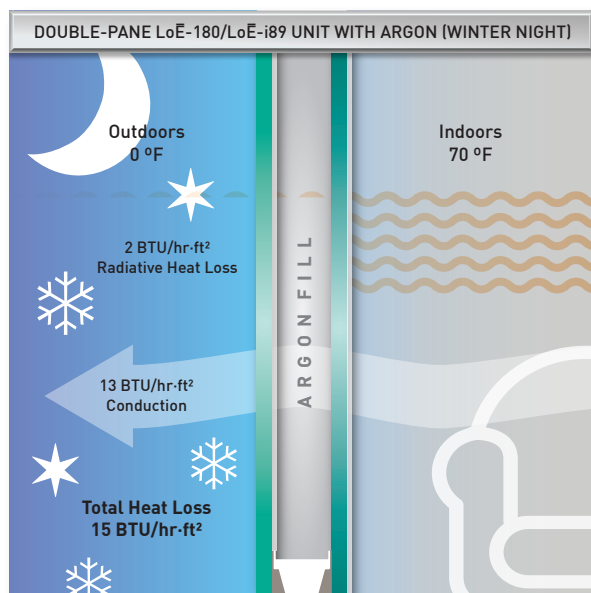


Figure 2-20

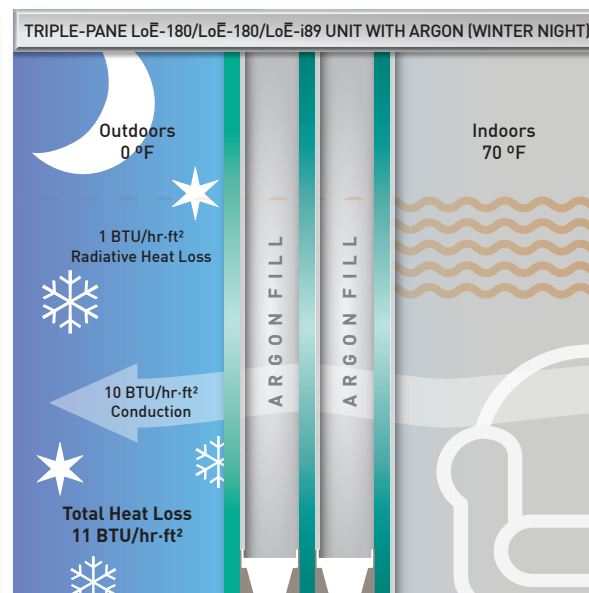


Figure 2-21

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 LoE³-366® products. In using the LoE³-366 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 DAYTIME SOLAR HEAT GAIN COMPARISONS								
Insulating Glass Unit	U _{summer} Btu/(hr-ft ² -°F) (W/m ² -K)	SHGC	Solar Radiation Reflected Btu/(hr-ft ²) (W/m ²)	Solar Radiation Transmitted Btu/(hr-ft ²) (W/m ²)	Total Energy Rejected Btu/(hr-ft ²) (W/m ²)	Total Energy Gained Btu/(hr-ft ²) (W/m ²)		
Clear / Clear	0.50 [2.84]	0.78	32 [101]	181 [571]	55 [174]	200 [631]		
Clear / LoE-180® (#3)	0.23 [1.31]	0.69	52 [164]	149 [470]	77 [243]	174 [549]		
Quad LoE-452+® (#2) / Clear	0.20 [1.14]	0.22	104 [328]	47 [148]	193 [609]	58 [183]		
LoE-180® (#2) / LoE-i89® (#4)	0.18 [1.02]	0.62	52 [164]	136 [429]	94 [297]	157 [495]		
Quad LoE-452+® (#2) / LoE-i89® (#4)	0.16 [0.91]	0.21	104 [328]	47 [148]	196 [618]	54 [170]		
LoE-180® (#2) / Clear / LoE-180® (#5)	0.13 [0.74]	0.56	62 [196]	117 [369]	109 [344]	141 [445]		
Quad LoE-452+® (#2) / Clear / LoE-180® (#5)	0.12 [0.68]	0.19	107 [338]	42 [133]	201 [634]	49 [155]		
LoE-180® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11 [0.62]	0.53	62 [196]	109 [344]	117 [369]	133 [420]		
Quad LoE-452+® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.11 [0.62]	0.19	107 [338]	40 [126]	201 [634]	49 [155]		

Notes:
1. Calculated values using LBNL Window computer program.
2. Double-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoE™ products, otherwise air-filled cavity. Coatings on surfaces #2, #3 and/or #4.
3. Triple-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoE™ products. Coatings on surfaces #2 and #5, or #2, #4 and #6.
4. All insulating glass systems contain 1/8" (3 mm) glass.
5. Environmental conditions: 89.6°F outdoor, 75.2°F indoor, 248.2 BTU/hr/ft² solar radiation, NFRC/ASHRAE standard wind speeds and convection coef.

Figure 2-22

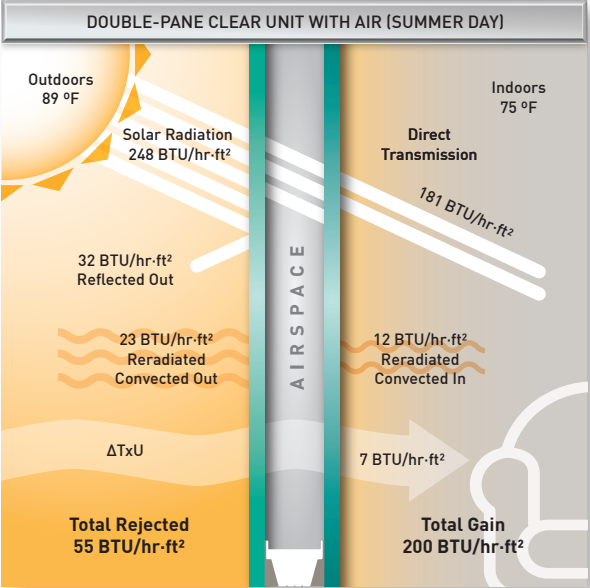


Figure 2-23

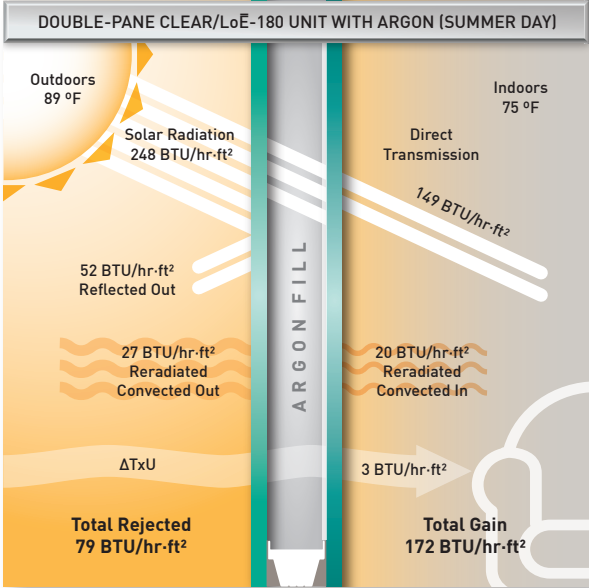


Figure 2-24

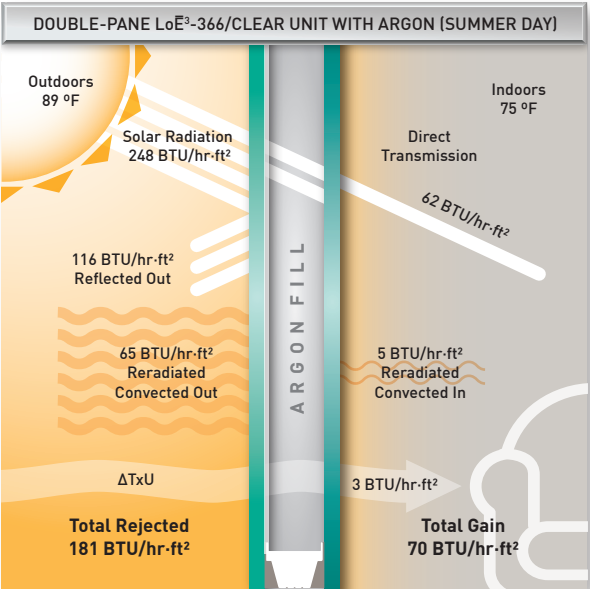


Figure 2-25

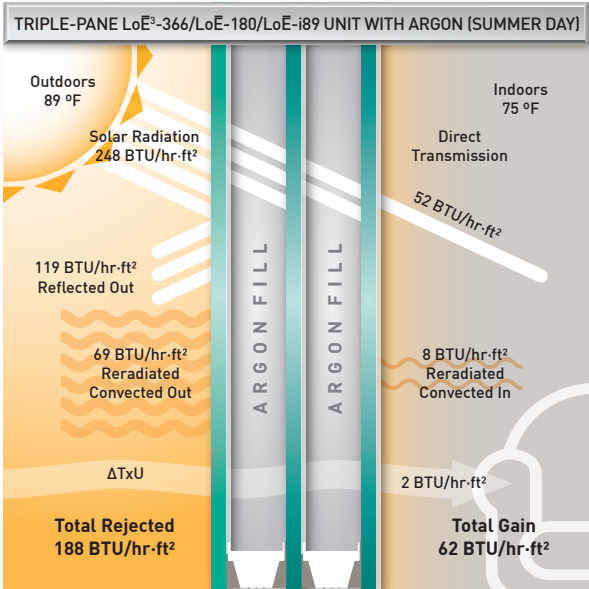


Figure 2-26

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 summertime night conditions is condensation forming on the outside surface of the glass. This condensation forms when the outside glass radiates heat to the nighttime 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 NIGHTTIME AIRSPACE HEAT TRANSFER					
Insulating Glass Unit	Exterior Glass Temperature (Surface #1) °F (°C)	U _{summer} BTU/hr-ft ² ·°F (W/m ² ·K)	Radiative Heat Gain BTU/hr-ft ² (W/m ²)	Conductive Heat Gain BTU/hr-ft ² (W/m ²)	Total Heat Gain BTU/hr-ft ² (W/m ²)
Clear / Clear	82.8 (79.6)	0.51 (2.90)	3 (9)	4 (13)	7 (22)
Clear / LoE-180® (#3)	83.2 (28.4)	0.24 (1.36)	0 (0)	3 (9)	3 (9)
LoE ³ -366® / Clear	83.2 (31.7)	0.21 (1.19)	0 (0)	3 (9)	3 (9)
LoE-180® (#2) / LoE-i89® (#4)	83.3 (31.7)	0.18 (1.02)	0 (0)	3 (9)	3 (9)
LoE ³ -366® (#2) / LoE-i89® (#4)	83.3 (31.7)	0.16 (0.91)	0 (0)	2 (6)	2 (6)
LoE-x89® (#1) / LoE-180® (#3)	87.2 (30.7)	0.21 (1.19)	1 (3)	2 (6)	3 (9)
LoE-180® / Clear / LoE-180® (#5)	83.3 (31.7)	0.18 (1.02)	0 (0)	3 (9)	3 (9)
LoE ³ -366® / Clear / LoE-180® (#5)	83.3 (31.7)	0.18 (1.02)	0 (0)	3 (9)	3 (9)
LoE-180® / LoE-180® / LoE-i89® (#6)	83.3 (79.8)	0.15 (0.85)	0 (0)	2 (6)	2 (6)
LoE ³ -366® / LoE-180® / LoE-i89® (#6)	83.3 (79.6)	0.14 (0.79)	0 (0)	2 (6)	2 (6)

1. Calculated values using LBNL Window computer program.

2. Double-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoE 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 LoE products. Coatings on surfaces #2 and #5, or #2, #4 and #6.

4. All insulating glass systems contain 1/8" (3 mm) glass.

5. Environmental conditions: 89.6°F exterior temperature, 75.2°F interior temperature, 0 BTU/hr-ft² solar radiation, NFRC/ASHRAE standard wind speeds and convection coef.

Figure 2-27

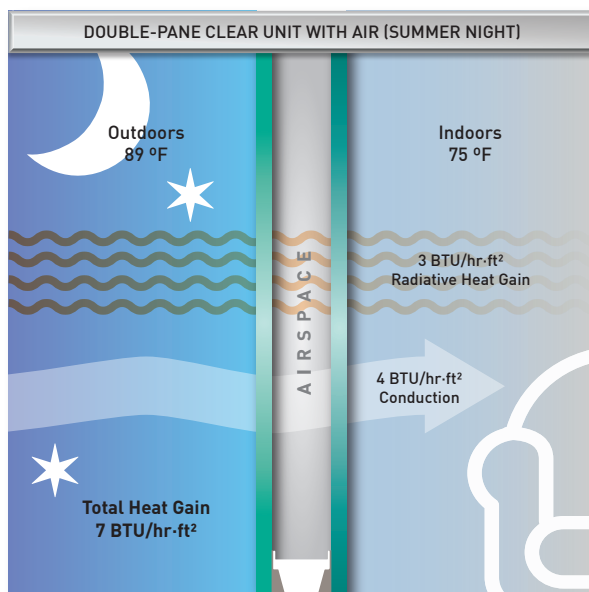


Figure 2-28

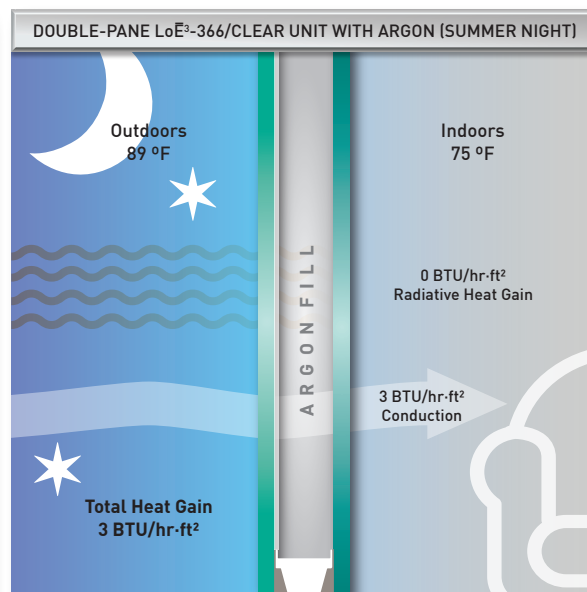


Figure 2-29

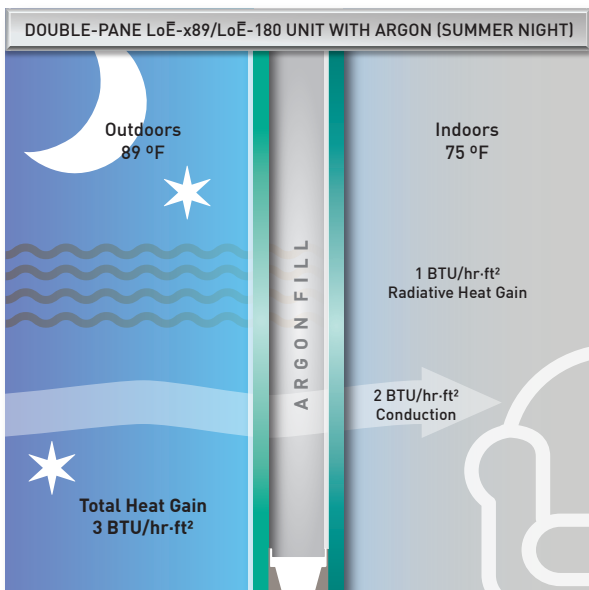


Figure 2-30

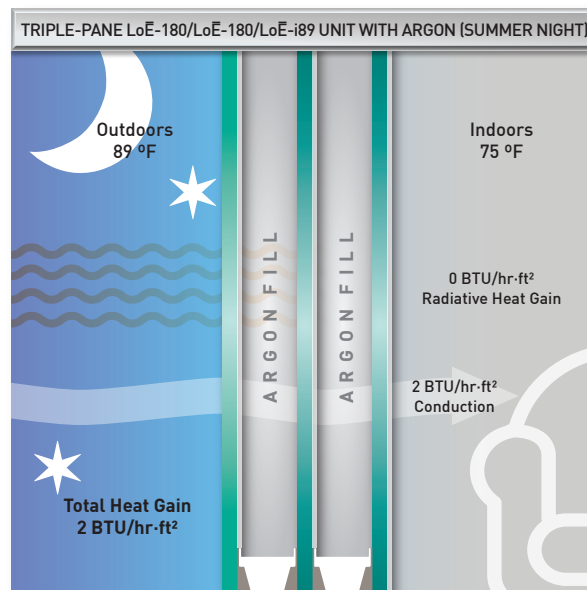


Figure 2-31

Outdoor Condensation



Condensation on the outdoor surface of an insulating glass (IG) unit is not an indication that the IG 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.

Here are some measures that may help:

- 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 LoE-x89® coating should be considered. The LoE-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 LoE-x89 coating has all the same "stay clean longer" properties of the Neat+® coating.



Figure 2-32

Indoor Condensation

Maintaining a Desirable Humidity Level

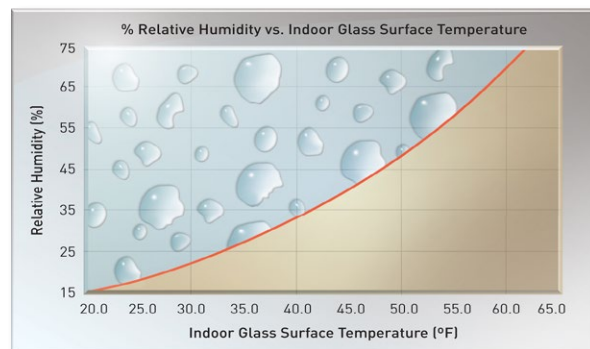
People are most comfortable when relative humidity ranges between 20% and 60%. In the home, an average relative humidity of 35% to 40% is appropriate when the outside temperature is 20 °F (-7 °C) or above. However, during cold weather, higher humidity ranges may cause indoor condensation on windows.

Figure 2-33 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

Insulating Glass Unit Exterior Glass / Interior Glass	-20 °F [-29 °C] Outdoor Air Temperature			0 °F [-18 °C] Outdoor Air Temperature			+20° F [7 °C] Outdoor Air Temperature		
	BTU/hr·ft²·°F (W/m²·K)	T _{cog} °F [°C]	RH %	BTU/hr·ft²·°F (W/m²·K)	T _{cog} °F [°C]	RH %	BTU/hr·ft²·°F (W/m²·K)	T _{cog} °F [°C]	RH %
Clear / Clear	0.48 [2.73]	37 [3]	30	0.48 [2.73]	44 [7]	39	0.48 [2.73]	51 [11]	51
Clear / LoE-i89® (#3)	0.31 [1.76]	48 [9]	46	0.29 [1.65]	54 [12]	57	0.27 [1.53]	59 [15]	68
Clear / LoE-180® (#3)	0.28 [1.59]	50 [10]	49	0.26 [1.48]	55 [13]	59	0.24 [1.36]	60 [16]	71
Clear / LoE-180 ESC® (#3)	0.28 [1.59]	50 [10]	49	0.27 [1.53]	55 [13]	59	0.25 [1.42]	60 [16]	71
LoE²-272® / Clear	0.27 [1.53]	51 [11]	51	0.25 [1.42]	56 [13]	61	0.23 [1.31]	60 [16]	71
LoE²-270® / Clear	0.27 [1.53]	51 [11]	51	0.25 [1.42]	56 [13]	61	0.23 [1.31]	61 [16]	73
LoE³-366® / Clear	0.26 [1.48]	51 [11]	51	0.24 [1.36]	56 [13]	61	0.22 [1.25]	61 [16]	73
Quad LoE-452+® / Clear	0.26 [1.48]	51 [11]	51	0.24 [1.36]	56 [13]	61	0.22 [1.25]	61 [16]	73
LoE²-240® / Clear	0.28 [1.59]	50 [10]	49	0.26 [1.48]	55 [13]	59	0.24 [1.36]	60 [16]	71
LoE³-340® / Clear	0.27 [1.53]	51 [11]	51	0.25 [1.42]	56 [13]	61	0.22 [1.25]	61 [16]	73
LoE-180® / LoE-i89® (#4)	0.23 [1.31]	39 [4]	32	0.21 [1.19]	46 [8]	42	0.19 [1.08]	53 [12]	55
LoE-180 ESC® / LoE-i89® (#4)	0.23 [1.31]	39 [4]	32	0.21 [1.19]	46 [8]	42	0.20 [1.14]	53 [12]	55
LoE²-272® / LoE-i89® (#4)	0.22 [1.25]	40 [4]	34	0.20 [1.14]	47 [8]	44	0.19 [1.08]	54 [12]	57
LoE-270® / LoE-i89® (#4)	0.22 [1.25]	40 [4]	34	0.20 [1.14]	47 [8]	44	0.18 [1.02]	54 [12]	57
LoE³-366® / LoE-i89® (#4)	0.21 [1.19]	41 [5]	35	0.20 [1.14]	48 [9]	46	0.18 [1.02]	55 [13]	59
Quad LoE-452+® / LoE-i89® (#4)	0.21 [1.19]	41 [5]	35	0.20 [1.14]	48 [9]	46	0.18 [1.02]	55 [13]	59
LoE²-240® / LoE-i89® (#4)	0.22 [1.25]	39 [4]	32	0.21 [1.19]	47 [8]	44	0.19 [1.08]	54 [12]	57
LoE³-340® / LoE-i89® (#4)	0.22 [1.25]	40 [4]	34	0.20 [1.14]	47 [8]	44	0.18 [1.02]	54 [12]	57

1. U-factor: Winter nighttime conditions with outdoor air temperatures shown. 12.3 mph (19.8 kph) outdoor wind velocity with indoor air temperature = 70 °F (21° C).

2. T_{cog}: 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 LoE 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

Insulating Glass Unit Exterior Glass / Center Glass / Interior Glass	-20 °F [-29 °C] Outdoor Air Temperature			0 °F [-18 °C] Outdoor Air Temperature			+20° F [7 °C] Outdoor Air Temperature		
	BTU/hr-ft²·°F (W/m²·K)	T _{cog} °F [°C]	RH %	BTU/hr-ft²·°F (W/m²·K)	T _{cog} °F [°C]	RH %	BTU/hr-ft²·°F (W/m²·K)	T _{cog} °F [°C]	RH %
Clear / Clear / Clear	0.30 [1.70]	48 [9]	46	0.31 [1.76]	53 [12]	55	0.32 [1.82]	57 [14]	63
Clear / Clear / LoE-180® (#5)	0.19 [1.08]	56 [13]	61	0.18 [1.02]	59 [15]	68	0.18 [1.02]	62 [17]	76
Clear / Clear / LoE-180 ESC® (#5)	0.19 [1.08]	56 [13]	61	0.19 [1.08]	59 [15]	68	0.18 [1.02]	62 [17]	76
LoE-180® (#2) / Clear / LoE-180® (#5)	0.14 [0.79]	60 [16]	71	0.13 [0.74]	62 [17]	76	0.13 [0.74]	64 [18]	81
LoE-180 ESC® (#2) / Clear / LoE-180 ESC® (#5)	0.14 [0.79]	59 [15]	68	0.14 [0.79]	62 [17]	76	0.13 [0.74]	64 [18]	81
LoE²-240® (#2) / Clear / LoE-180® (#5)	0.14 [0.79]	60 [16]	71	0.13 [0.74]	62 [17]	76	0.13 [0.74]	64 [18]	81
LoE²-270® (#2) / Clear / LoE-180® (#5)	0.14 [0.79]	60 [16]	71	0.13 [0.74]	62 [17]	76	0.12 [0.68]	65 [18]	84
LoE²-272® (#2) / Clear / LoE-180® (#5)	0.14 [0.79]	60 [16]	71	0.13 [0.74]	62 [17]	76	0.12 [0.68]	65 [18]	84
LoE³-340® (#2) / Clear / LoE-180® (#5)	0.13 [0.74]	60 [16]	71	0.13 [0.74]	62 [17]	76	0.12 [0.68]	65 [18]	84
LoE³-366® (#2) / Clear / LoE-180® (#5)	0.13 [0.74]	60 [16]	71	0.13 [0.74]	63 [17]	78	0.12 [0.68]	65 [18]	84
Quad LoE-452+® (#2) / Clear / LoE-180® (#5)	0.13 [0.74]	60 [16]	71	0.13 [0.74]	63 [17]	78	0.12 [0.68]	65 [18]	84
LoE-180® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.12 [0.68]	52 [11]	53	0.12 [0.68]	56 [13]	61	0.11 [0.62]	60 [16]	71
LoE-180 ESC® (#2) / LoE-180 ESC® (#4) / LoE-i89® (#6)	0.12 [0.68]	51 [11]	51	0.12 [0.68]	55 [13]	59	0.12 [0.68]	59 [15]	68
LoE²-240® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.12 [0.68]	52 [11]	53	0.11 [0.62]	56 [13]	61	0.11 [0.62]	60 [16]	71
LoE²-270® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.12 [0.68]	52 [11]	53	0.11 [0.62]	56 [13]	61	0.11 [0.62]	60 [16]	71
LoE²-272® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.12 [0.68]	52 [11]	53	0.11 [0.62]	56 [13]	61	0.11 [0.62]	60 [16]	71
LoE³-340® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.12 [0.68]	52 [11]	53	0.11 [0.62]	56 [13]	61	0.11 [0.62]	60 [16]	71
LoE³-366® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.12 [0.68]	52 [11]	53	0.11 [0.62]	56 [13]	61	0.11 [0.62]	60 [16]	71
Quad LoE-452+® (#2) / LoE-180® (#4) / LoE-i89® (#6)	0.12 [0.68]	52 [11]	53	0.11 [0.62]	56 [13]	61	0.11 [0.62]	60 [16]	71

1. U-factor: Winter nighttime conditions with outdoor air temperatures shown. 12.3 mph [19.8 kph] outdoor wind velocity with indoor air temperature = 70 °F [21 °C].
2. T_{cog}: 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 LoE 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.

Figure 2-36

Thermal Comfort

Comfort near a window varies with the seasons. Winter comfort depends on where the building is located: Northern latitudes have more extreme cold temperatures, and the winter season is longer.

In the summer, orientation (north, south, east or west) is the primary driver of comfort, with location having a smaller impact. Spring and fall comfort problems often stem from building design: Excessive solar gain can lead to building overheating.

Winter Cold Weather Comfort

In general, the lower the U-factor, the more comfortable the glass will be on a cold winter night. double- and triple-pane glass, LoE™ coatings, gas fill and LoE-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). LoE-i89® is a special case, because the infrared reflectance of LoE-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.

Summer 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 the north elevation is minimal.

During the summer, high solar heat gain coefficient (SHGC) glass products may overpower the room's air conditioning and create discomfort (presuming the air conditioner is not adequately sized to handle window area load). SHGC includes both direct heat gain and re-radiated heat gain from hot glass.

A lower SHGC value implies less heat gain and/or less impact on the MRT.

Clear double- or triple-pane IG units are not recommended anywhere as the solar gain is too high for comfort. Double-panes and triple-panes utilizing solely LoE-180® should be limited to designs intended specifically to utilize passive solar heating. While LoE-180® can provide winter passive solar energy saving on the south façade, there is substantial risk of swing season overheat without proper architectural design.



Energy + Comfort Calculator

Innovated by Cardinal, the LoEasy™ Energy + Comfort Calculator is a free app that guides users through the process of selecting glass in windows that meets energy-efficiency standards, saves on heating and cooling, and helps to maintain a comfortable home in all seasons. Homeowners and professionals can easily narrow down the best-performing LoE™ coatings for any climate zone. The Energy + Comfort Calculator can be accessed on the Cardinal website. cardinalcorp.com/technology/applications/energy-comfort-calculator-app



LoE™ Light 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 – Responsible for most fading

- Visible, 380 to 780 nm – Visible light
 - Near Infrared, 780 to 2,500 nm – Solar energy felt as heat
- A comparison of the performance of Cardinal's LoE™ products are shown

below. Depending on the application, the best glass product will 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 considered on any application.

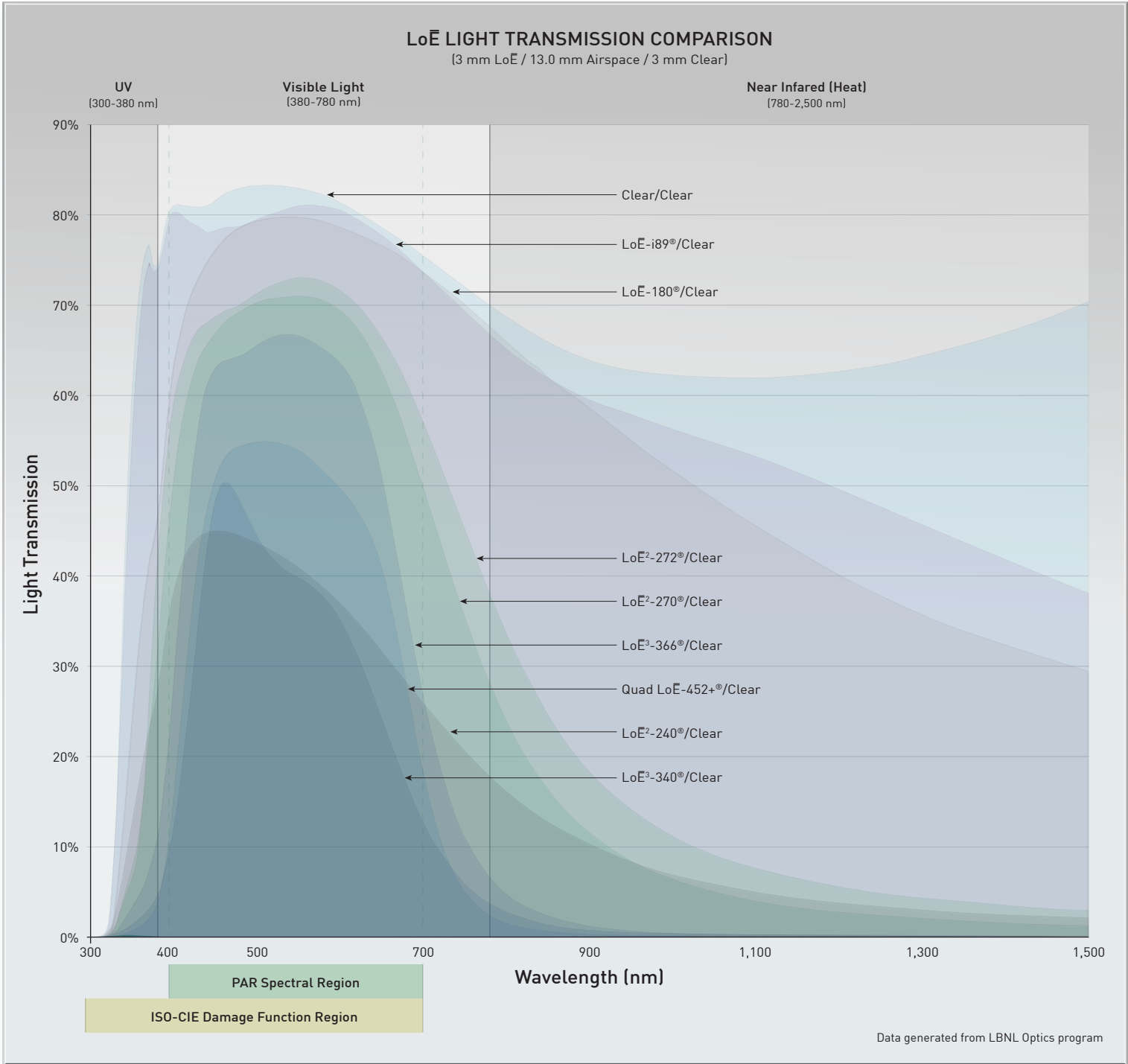


Figure 2-37

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 that drives photosynthesis is called photosynthetically active radiation (PAR) and falls in the spectral range from 400 nm to 700 nm (see Figure 2-37). 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 that are marginal for adequate growth and are often 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 where 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.

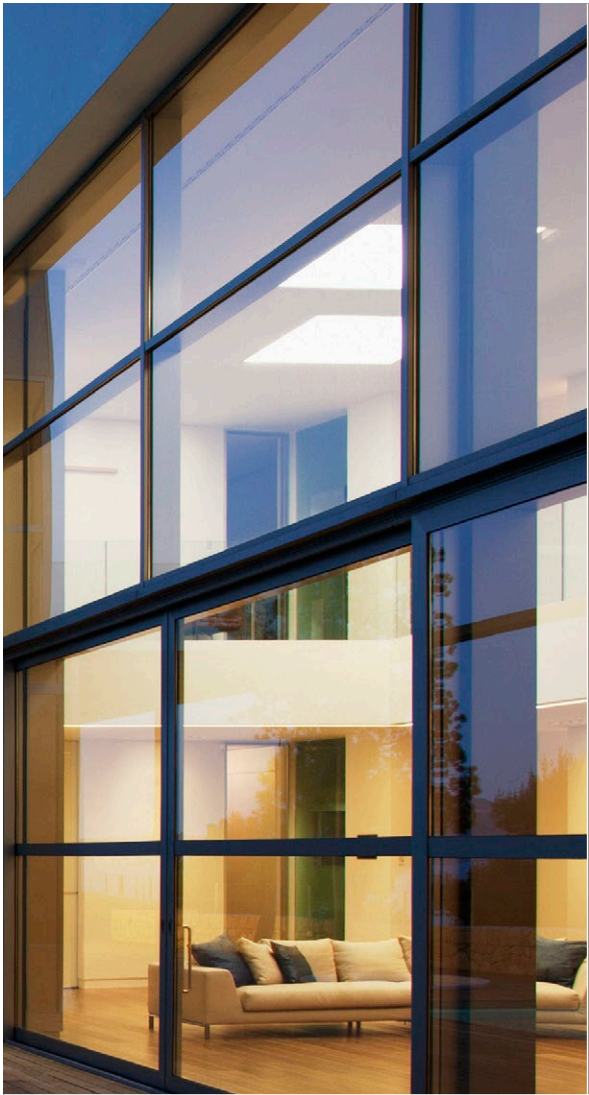
Unlike field crop plants, house plants have the ability to grow in relatively low light conditions. Figure 2-38 below lists the percentage of photons transmitted in the PAR region per Cardinal LoE™ coating. Many of the listed coatings will have minimal effects on plant growth. A small number of coatings 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 that 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.

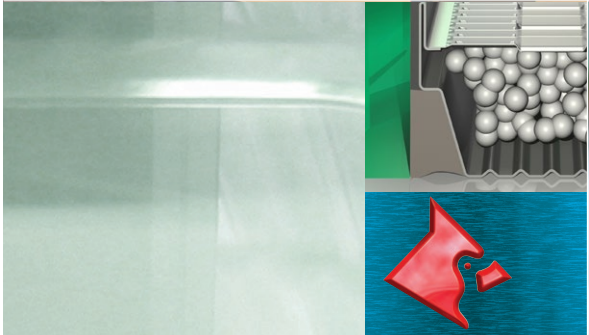
IG Unit (3 mm Thick Glass)	Photons Transmitted in PAR Spectral Region
Clear / Clear	83%
Clear / LoE-i89®	81%
Clear / LoE-Di89®	80%
Clear / LoE-180 ESC®	80%
Clear / LoE-180®	80%
LoE2-272® / Clear	73%
LoE2-270® / Clear	71%
LoE3-366® / Clear	67%
Quad LoE-452+® / Clear	55%
LoE3-340® / Clear	45%
LoE2-240® / Clear	50%

Figure 2-38





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.





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, laminated 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.

Roomside 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 approximately 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 detect scratches, coating faults and debris on the glass 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 photo-elastic 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. These 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 – Cardinal's press equipment ensures precise edge thickness of each IG unit.

Argon-Fill Levels – Our unique inline system measures the argon-fill levels of Cardinal IG units. 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.

LAMINATED GLASS

Cardinal laminated glass provides safety impact resistance, UV protection, forced entry security, and sound transmission reduction.

Vision-Based Inspections – These high-resolution, high-speed systems are used to detect a variety of defects, such as scratches, coating faults, and debris, whether it's on the glass surface or inside the laminate.

Moisture Content – Our inline system measures the moisture content of the interlayer in the finished product, a parameter critical to the performance and durability of the laminated glass.

Laminate Thickness – This system measures the overall thickness of the finished laminate, validating the construction and ensuring it's within specification.



Essentials of Manufacturing Long-Lasting IG Units

What makes a long-lasting IG unit?



Material Selection

The sealants used to bond glass to the spacer system are 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.

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

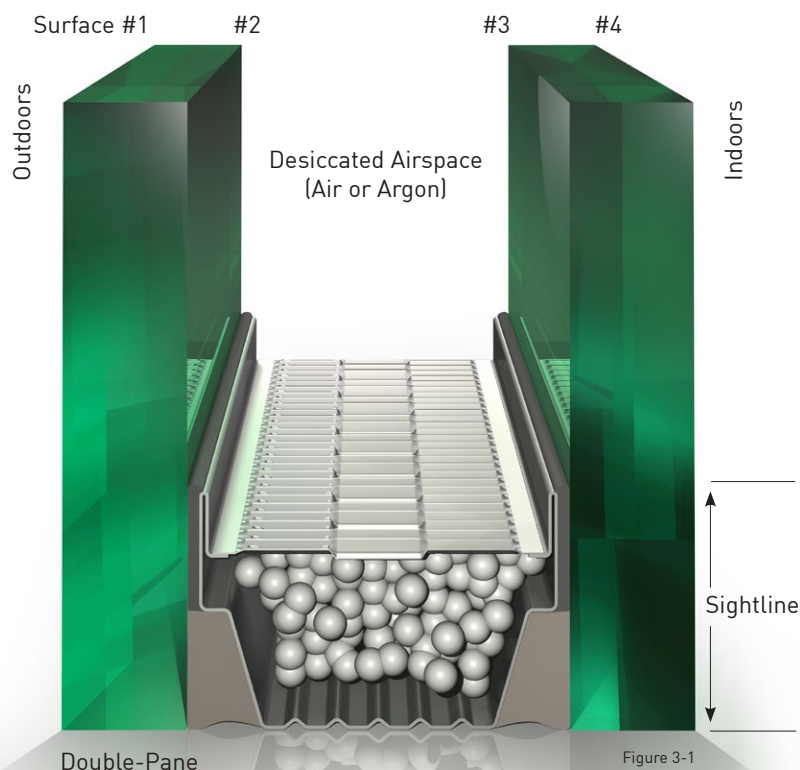
that will be in direct contact with the IG unit. These material interactions with the IG unit can potentially degrade unit longevity to a significant degree. Cardinal offers its customers expert guidance on assessing the risk of material incompatibility with Cardinal's products.

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).

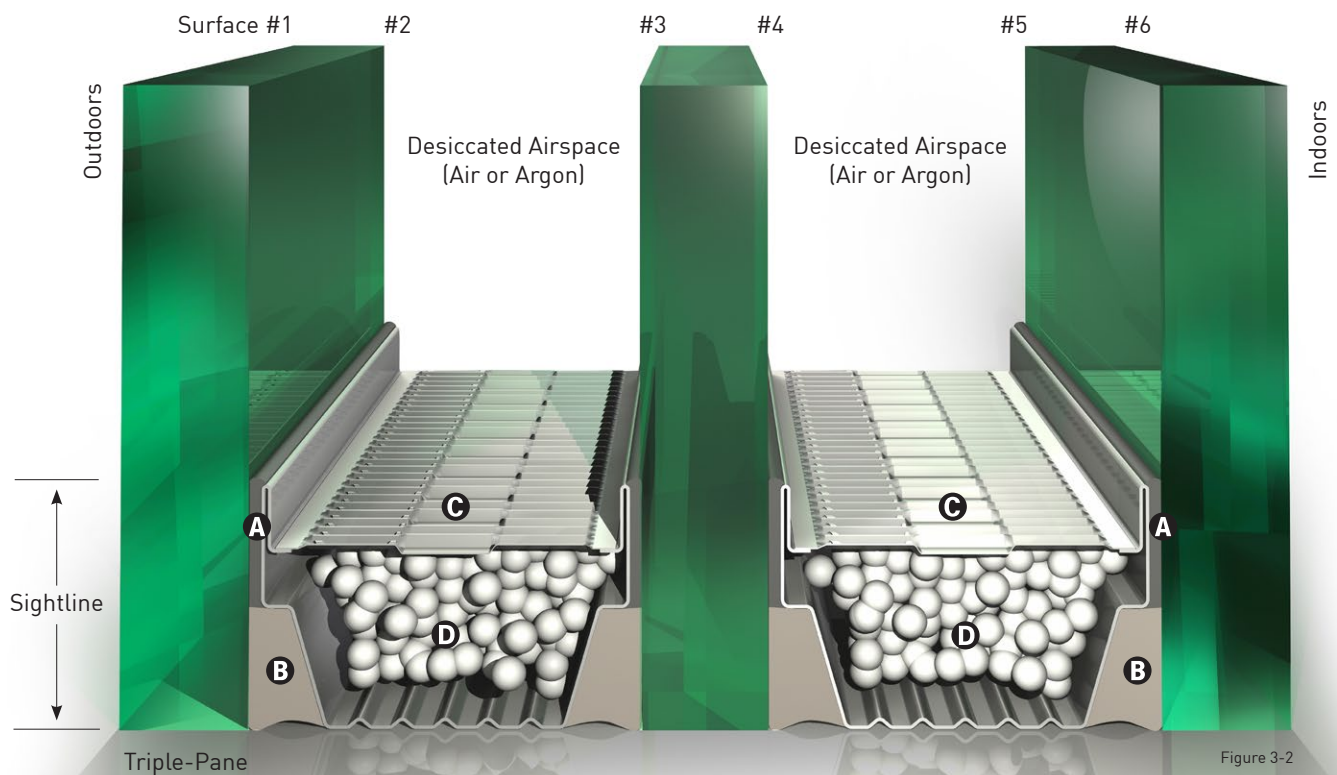
Spacer corners are bent to be air/gas tight. The spacer contains desiccant, which adsorbs the moisture vapor within the airspace.

The dual-seal construction has a primary seal of 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.



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: Distance from the edge of glass to the top of the spacer or sealant system.



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 the 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 weatherability of insulating glass constructions. Passing this standard is considered a minimum requirement for insulating glass durability. This protocol exposes the IG 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 °F to +160 °F (-32 °C to +71 °C) five times per day. Unlike the ASTM single-sided exposure test, these IG units are fully immersed with an increased temperature range that 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 °F (60 °C), constant UV exposure and water spray. Results show that competitive seal systems fail within 8 to 22 weeks of testing. However, Cardinal IG units still have a dew point below 0 °F (-18 °C) after 80 weeks of the test.



P-1 Test Chamber: 140°F, constant UV, water spray

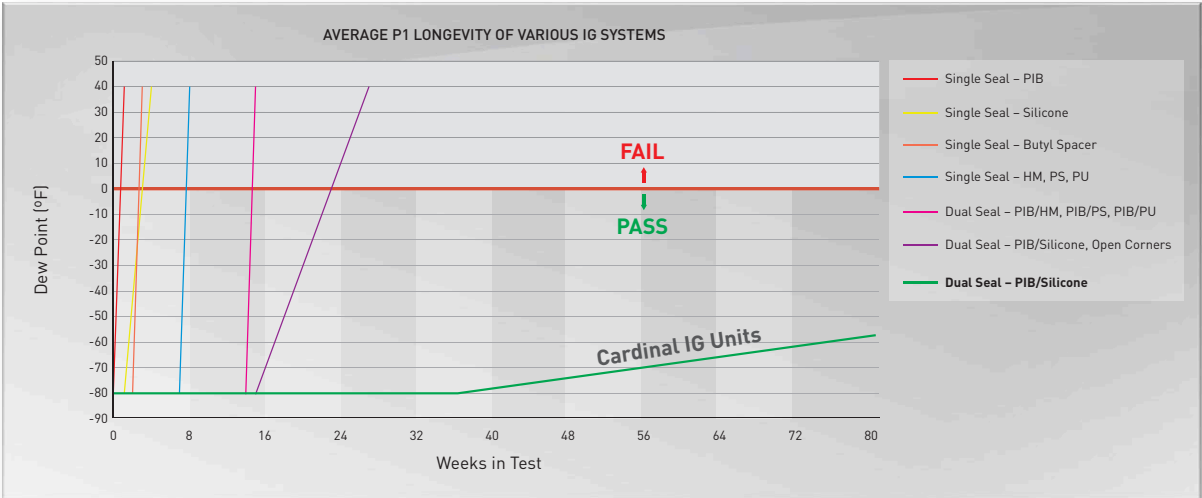


Figure 3-3

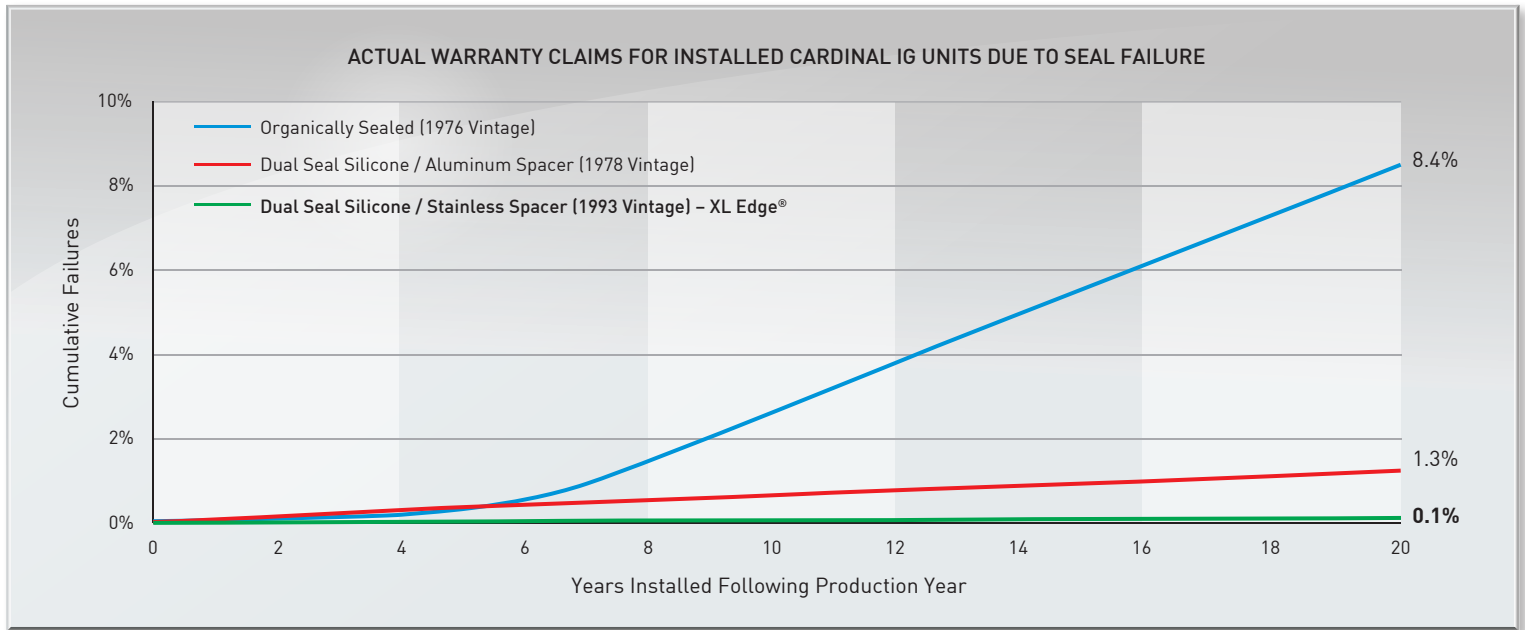


Figure 3-4

Cardinal Seal Failure Experience

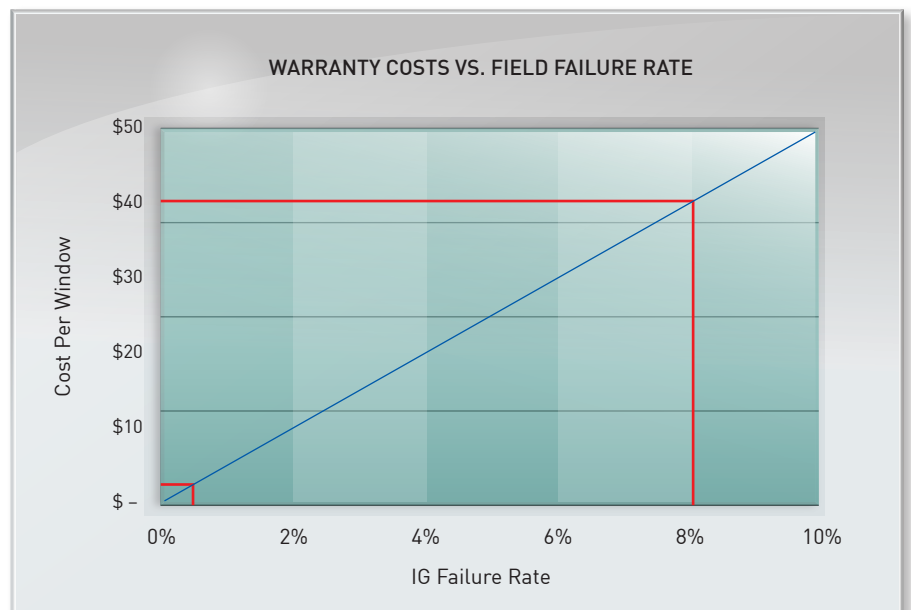
Figure 3-4 shows Cardinal field failure rate comparing failures to industry-wide failure rates, Cardinal Dual Organic Seals with Aluminum Spacers, Dual Seal Silicone with Aluminum Spacers and Dual Seal Silicone with Stainless Steel Spacers. Cardinal's 20-year failure rate with our products are as follows:

- Dual Organic Seal/ Aluminum Spacer – 8.4%
- Dual Seal Silicone/ Aluminum Spacer – 1.1%
- Dual Seal Silicone/XL Edge (SS Spacer) – 0.1%

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 0.1% after 20 years of field service. Currently, Cardinal has hundreds of millions of IG units under warranty.

The potential value of this 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 0.1% seal failure rate, the window manufacturer would only need to add \$0.50 to the window to cover warranty claims.



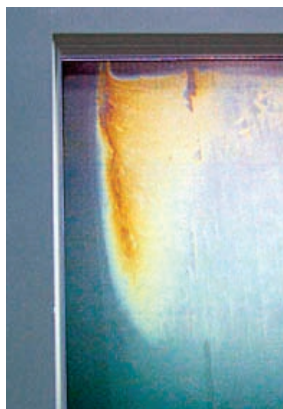
1. \$500 Replacement Costs
2. 100,000 Units/Year

Figure 3-5

Edge Deletion Assures Proper Sealant-to-Glass Bonding

By deleting the edge of LoE coatings, Cardinal provides the added safety that the IG unit sealants are bonded to glass rather than a coating. Without edge deletion, all LoE 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



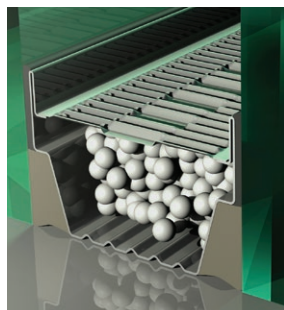
Any material used in an IG unit; e.g., sealants, grilles, spacer systems, desiccant, etc., may produce a fog in the unit.



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

ASTM International test E2189 (Standard Test Method for Testing Resistance to Fogging in Insulating Glass Units) was designed to test 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.

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

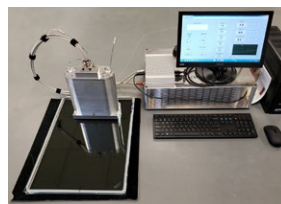
Using computerized finite element analysis (FEA), Cardinal determined that the stainless steel spacer introduced in the early 1990s did not stress the IG seal system to the same degree as previously used aluminum spacers. Excessive stress on the polyisobutylene (PIB) sealant can cause argon loss. The 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



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



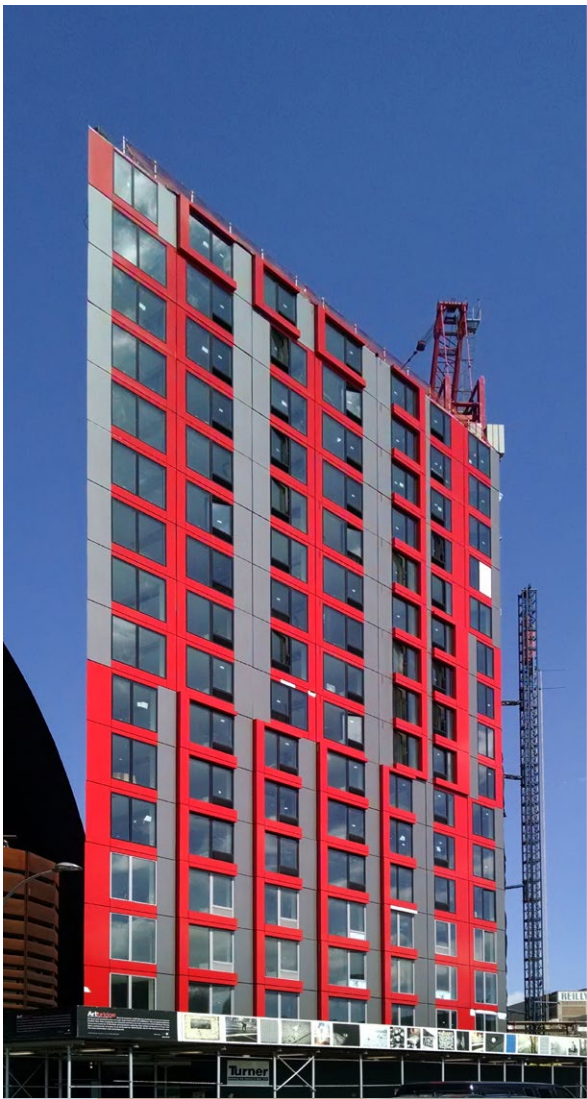
Cardinal maintains a state-of-the-art facility for the measurement of IG argon and krypton gas concentration and permeation. Cardinal has developed and patented methods to assure that the spark emission spectroscopy used to measure argon gas concentration is accurate and repeatable. All of Cardinal's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

Material Compatibility

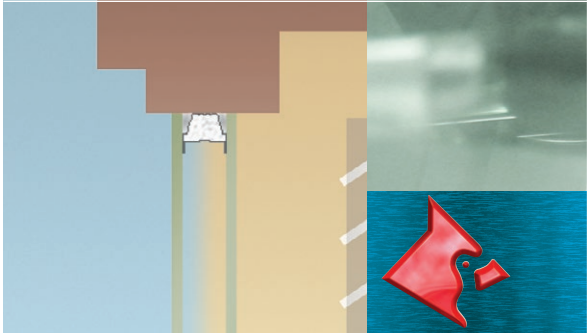
Cardinal has devoted a significant amount of research to identify materials that are compatible with our IG system. We work with component suppliers to help ensure their products work with our design. We can offer input into customers' material choices to help them get the longest life out of a Cardinal 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 selection of windows, offering data and information to help design professionals make the best decisions possible for their intended applications.



Glass Types

Annealed Glass

Annealed glass can be used for vision applications where clear, tinted and LoE 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 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, LoE and reflective vision 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

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.

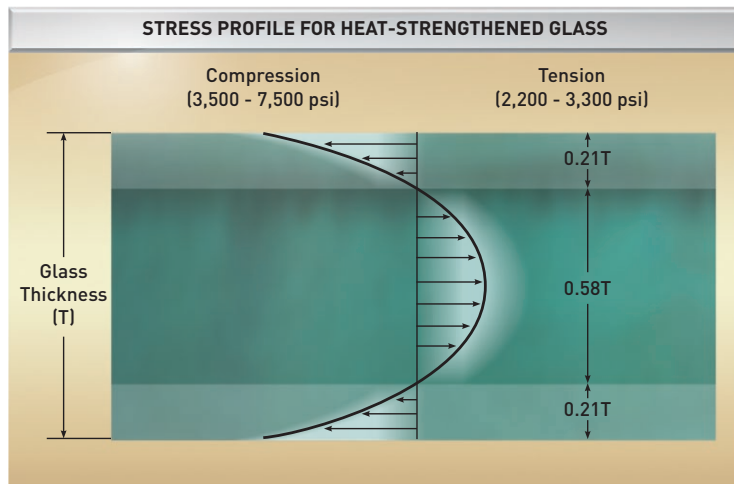


Figure 4-1



Figure 4-2

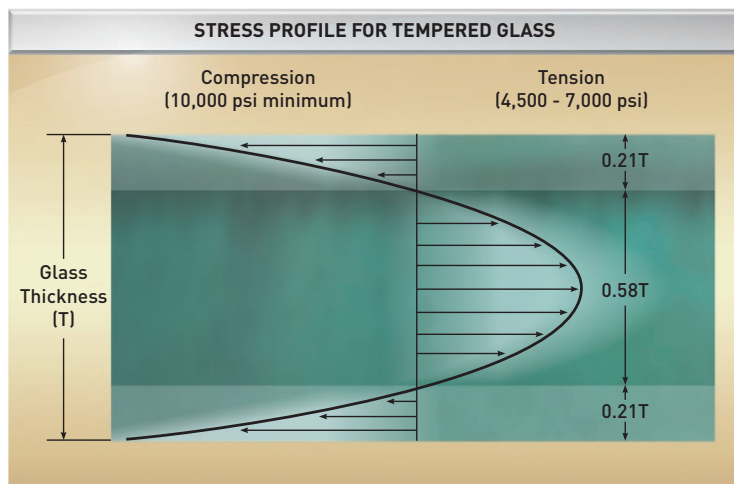


Figure 4-3

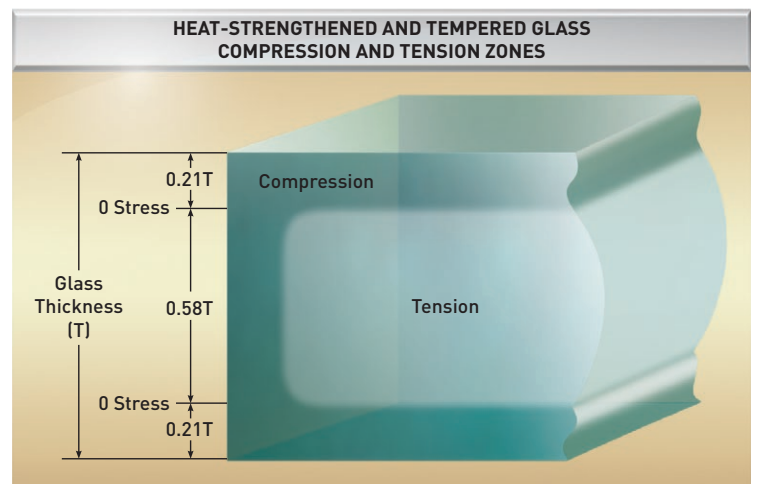


Figure 4-4

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 airspace pressure and barometric pressures caused by weather or altitude
 - c. Difference between insulating glass airspace 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 airspace 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.

Soft-centered glass 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 and does not constitute a reject.

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 supplier. Some organic plasticizers have the potential to migrate into and damage the insulating glass sealants. Some setting 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 setting 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 1,750 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. Figure 4-5 is a comparison of specific metric thickness, the nominal glass thickness in inches and the traditional designation.

Spandrel Glass
Designed to conceal structural and component elements of a building. Heat strengthening or tempering is required of spandrel glass due to its heat absorption characteristics.

GLASS THICKNESS REFERENCE			
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, 1/8 inch
3.1 mm	0.122 inches	3 mm	Double-Strength, DST, 1/8 inch
3.9 mm	0.152 inches	4 mm	3/32 inch
4.7 mm	0.182 inches	5 mm	1/16 inch
5.7 mm	0.221 inches	6 mm	1/8 inch
8.0 mm	0.310 inches	8 mm	3/16 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 4-6), 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 and hot summer day with high solar load. In addition to these weather conditions, shading of the glass (both interior and exterior) will have a notable effect on the probability of thermal glass breakage.

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., LoE 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

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, LoE), 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 roomside 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 vents 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.

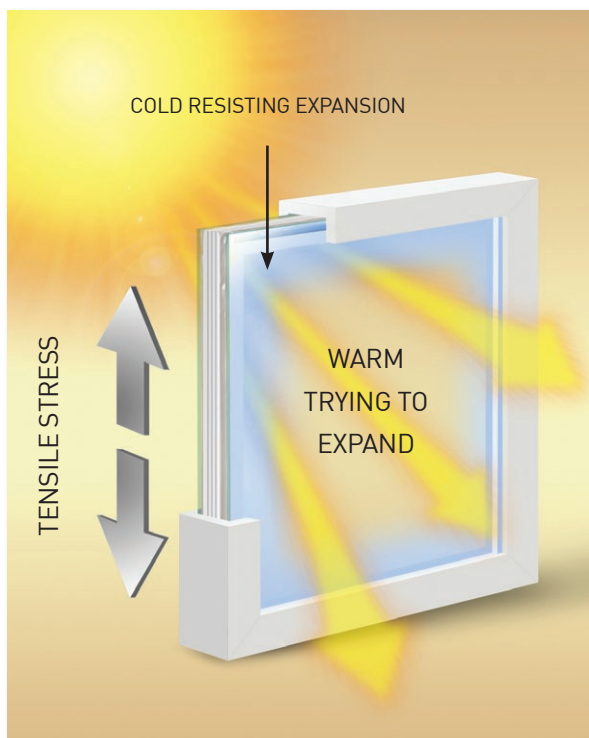


Figure 4-6

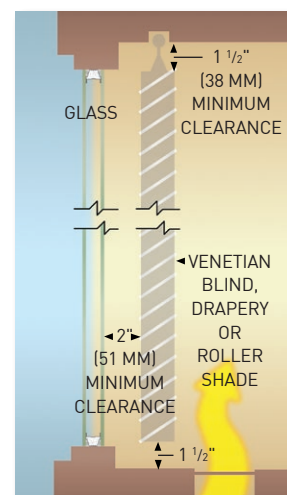


Figure 4-7

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.

The breakage probability design limit for IG units under windloading 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 that 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 DP65 design pressure rating.

DOUBLE-PANE INSULATING GLASS SIZE LIMITS – ANNEALED GLASS												
Glass Thickness (mm)	Maximum Area in Square Feet											
	DP80		DP65		DP60		DP50		DP40		DP30	
	Aspect Ratio ≤2	>2	Aspect Ratio ≤2	>2	Aspect Ratio ≤2	>2	Aspect Ratio ≤2	>2	Aspect Ratio ≤2	>2	Aspect Ratio ≤2	>2
2.2	5	4	7	5	7	5	9	6	10	8	10 ¹	10 ¹
3.0	7	6	10	8	11	8	15 ¹	10	15 ¹	13	15 ¹	15 ¹
3.9	10	10	14	12	16	13	21	15	24 ¹	20	24 ¹	24 ¹
4.7	14	14	18	16	20	18	27	21	33 ¹	27	33 ¹	33 ¹
5.7	19	19	25	24	27	26	35	30	48	37	50 ¹	50 ¹
8.0	29	32	38	39	41	40	52	48	72	61	72 ¹	72 ¹

Figure 4-8

DOUBLE-PANE INSULATING GLASS SIZE LIMITS – HEAT-TREATED GLASS												
Glass Thickness (mm)	Maximum Area in Square Feet											
	DP80		DP65		DP60		DP50		DP40		DP30	
	HS/HS	FT/FT	HS/HS	FT/FT	HS/HS	FT/FT	HS/HS	FT/FT	HS/HS	FT/FT	HS/HS	FT/FT
2.2	8	NA	12	NA	13	NA	15*	NA	15*	NA	15*	NA
3.0	13	20 ¹	18	20 ¹	20	20 ¹	20 ¹	20 ¹	20 ¹	20 ¹	20 ¹	20 ¹
3.9	20	30 ¹	26	30 ¹	29	30 ¹	30 ¹	30 ¹	30 ¹	30 ¹	30 ¹	30 ¹
4.7	27	50 ¹	35	50 ¹	38	50 ¹	50 ¹	50 ¹	50 ¹	50 ¹	50 ¹	50 ¹
5.7	37	60 ¹	48	60 ¹	50	60 ¹	60 ¹	60 ¹	60 ¹	60 ¹	60 ¹	60 ¹
8.0	61	96 ¹	76	96 ¹	83	96 ¹	96 ¹	96 ¹	96 ¹	96 ¹	96 ¹	96 ¹

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/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. Weight limits may restrict square foot limits. Check with Cardinal IG fabricator for possible weight limit restrictions.
7. Tables do not restrict dimensions for glass deflection. Center glass deflections may exceed 1 inch at maximum wind load.
8. HS = Heat Strengthened and FT = Fully Tempered.

TRIPLE-PANE INSULATING GLASS SIZE LIMITS – ANNEALED GLASS												
Glass Thickness (mm)	Maximum Area in Square Feet											
	DP80		DP65		DP60		DP50		DP40		DP30	
	Aspect Ratio ≤2 >2		Aspect Ratio ≤2 >2		Aspect Ratio ≤2 >2		Aspect Ratio ≤2 >2		Aspect Ratio ≤2 >2		Aspect Ratio ≤2 >2	
2.2	8	5	10	7	10 ¹	8	10 ¹	9	10 ¹	10 ¹	10 ¹	10 ¹
3.0	8	8	11	10	13	12	15 ¹	15 ¹	15 ¹	15 ¹	15 ¹	15 ¹
3.9	16	13	22	16	24 ¹	18	24 ¹	21	24 ¹	24 ¹	24 ¹	24 ¹
4.7	20	18	32	23	33 ¹	25	33 ¹	29	33 ¹	33 ¹	33 ¹	33 ¹
5.7	27	26	36	31	42	33	50 ¹	40	50 ¹	50 ¹	50 ¹	50 ¹
8.0	41	42	53	50	61	54	72 ¹	65	72 ¹	72 ¹	72 ¹	72 ¹
												Recommended Maximum Length (Inches)

Figure 4-10

TRIPLE-PANE INSULATING GLASS SIZE LIMITS – HEAT-TREATED GLASS												
Glass Thickness (mm)	Maximum Area in Square Feet											
	DP80		DP65		DP60		DP50		DP40		DP30	
	HS/HS	FT/FT	HS/HS	FT/FT	HS/HS	FT/FT	HS/HS	FT/FT	HS/HS	FT/FT	HS/HS	FT/FT
2.2	13	NA	15 ¹	NA	15 ¹	NA	15 ¹	NA	15 ¹	NA	15 ¹	NA
3.0	20	20 ¹	20 ¹	20 ¹	20 ¹	20 ¹	20 ¹	20 ¹	20 ¹	20 ¹	20 ¹	20 ¹
3.9	29	30 ¹	30 ¹	30 ¹	30 ¹	30 ¹	30 ¹	30 ¹	30 ¹	30 ¹	30 ¹	30 ¹
4.7	39	50 ¹	50 ¹	50 ¹	50 ¹	50 ¹	50 ¹	50 ¹	50 ¹	50 ¹	50 ¹	50 ¹
5.7	52	60 ¹	60 ¹	60 ¹	60 ¹	60 ¹	60 ¹	60 ¹	60 ¹	60 ¹	60 ¹	60 ¹
8.0	83	96 ¹	96 ¹	96 ¹	96 ¹	96 ¹	96 ¹	96 ¹	96 ¹	96 ¹	96 ¹	96 ¹
												Recommended Maximum Length (Inches)

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. Weight limits may restrict square footage limits. Check with Cardinal IG fabricator for possible weight restrictions.
7. 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 (ft²)	Weight at Max Annealed Size Dual / Triple (lb)	Annealed Max Length (in)	HS Max size (ft²)	Tempered Max Size (ft²)	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	120	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

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 LoE 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/ft² 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 airspace.
8. Further restrictions on size may be needed for particular applications.

Figure 4-12

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 4-13).

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 that will be used in locations 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 that will be used in locations 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 are 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 4-13



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, noncorrosive, 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.

Argon and Krypton

Because of its large natural abundance, argon is inexpensive compared to krypton. Krypton is hundreds of times more expensive than 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,

IG UNIT MAXIMUM DIMENSION PER AIRSPACE		
Airspace Dimension Inches (mm)	Maximum Long Dimension Inches (mm)	Maximum Area ft² (m²)
¼ (6.5)	80 (2032)	20 (1.9)
⅝ (8.0)	90 (2286)	30 (2.8)
¾ (9.8)	100 (2540)	50 (4.6)
≥7/16 (≥11.5)	144 (3658)	96 (8.9)

Figure 4-14

there is no concern over chemical reactions with other materials used in an IG unit or window.

In 1988, Cardinal developed and patented a state-of-the-art process for argon filling of IG 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 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 IG 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.

High Altitude

When 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.



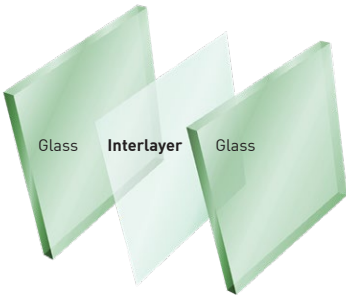


Whether you need to meet hurricane codes, provide home security or reduce noise, Cardinal offers a laminated glass to meet your requirements, delivering a level of security and serenity that can't be realized with ordinary glass.



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.

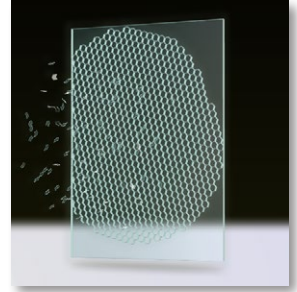
BENEFITS AND APPLICATIONS



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 that confirms 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 that will be used in locations 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 that will be used in locations 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 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 in ² of the original test specimen. Detached individual particles less than the mass equivalent of 1 in ² are to be excluded from the fragment analysis. The single largest particle shall weigh less than a mass equivalent to 6.82 in ² of the original test specimen.	

Figure 5-1



Glazing Fabricator: Custom Window Systems
Laminator: Cardinal Glass Industries
Building Owners: Dr. Lebron Lacky and Russell King

© Johnny Milano

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

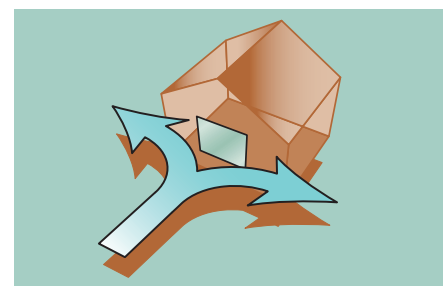
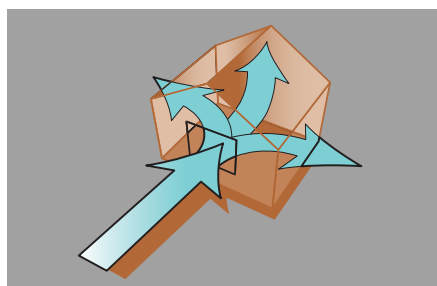
to meet tough testing requirements for impact resistance. Cardinal's Sea-Storm products have been successfully tested in many glazing systems that meet the requirements of Miami-Dade County TAS 201, TAS 203, ASTM E1886 and ASTM E1996. The Miami-Dade County testing protocols are regarded as some of the 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 9,000 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 ft² and 80 PSF design pressure, 0.090" PVB is normally adequate. SentryGlas® in thicknesses of 0.090" and 0.100" are

typically used for glazing sizes beyond 30 ft² and design pressures greater than 80 PSF. It is critical to remember that hurricane testing is conducted on the whole glazing 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 polyurethane 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

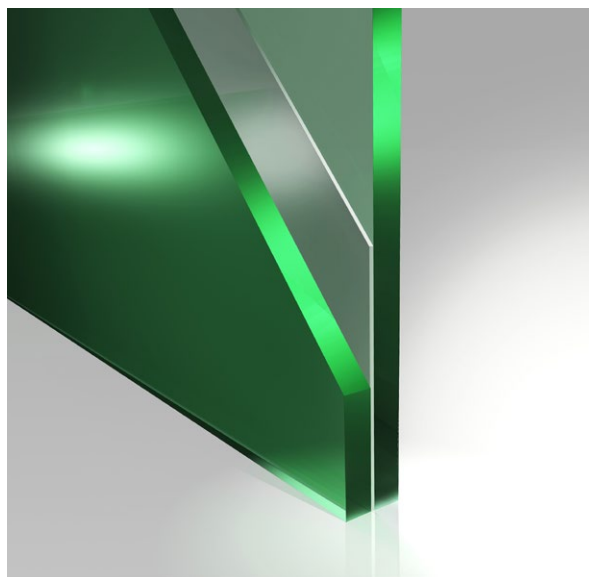
Decorative

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.

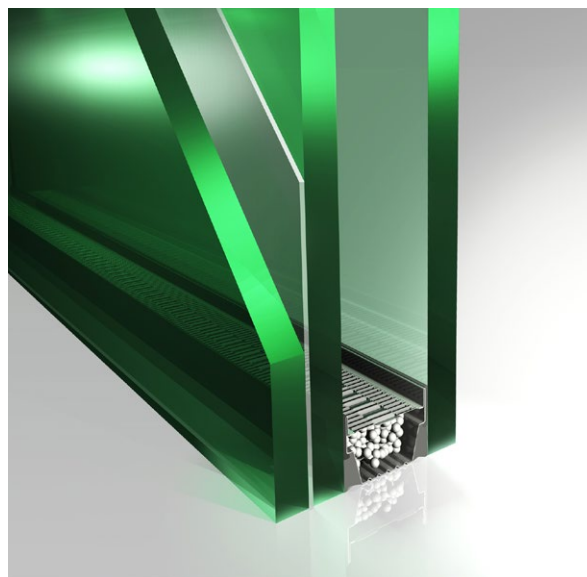


Energy Efficiency

Cardinal laminated glass can be supplied incorporating Cardinal low emissivity coated glass to reduce heat loss from the building and thus save on energy costs. LoE, LoE², LoE³ and Quad LoE coatings can be used when in an IG 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 LoE coating is embedded, and not all LoE products have a desirable appearance when embedded. LoE³ and Quad LoE coatings have the most desirable appearance when embedded.



Monolithic 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

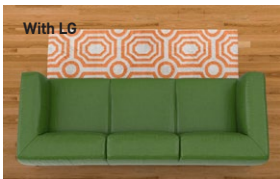
properties of the interlayer, which will vary with the type and thickness of the interlayer.

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 LoE coatings to reduce glare and heat gain in a building.

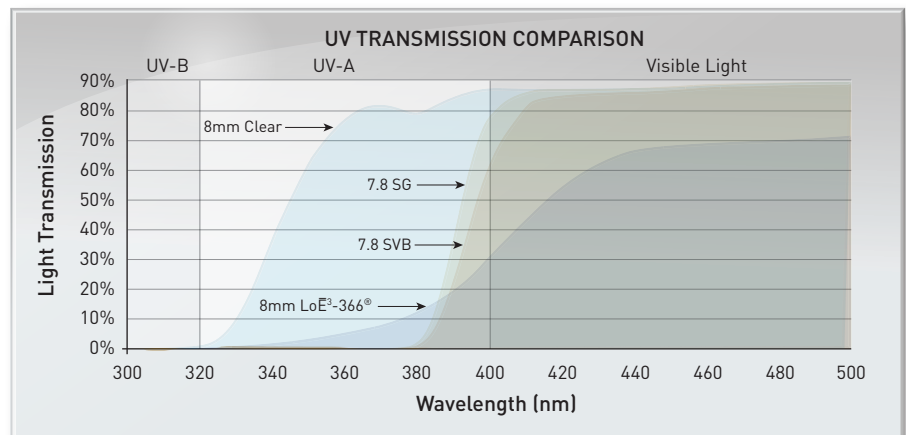


Figure 5-6

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 / 0.035" 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 / 0.038" 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 when compared with standard PVB. This interlayer is 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 that provides high glass adhesion and improved performance for large missile hurricane-resistant applications relative to

conventional PVB. This interlayer is 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:

- 0.035"
- 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									●

1. 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.

2. 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	Reflectance Out	In	SHGC	U-Factor BTU/hr-ft²·°F (W/m²·K)	UV Transmission
6.0 SG	2.7 – 0.035" 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 – 0.035" 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 – 0.035" 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 – 0.035" 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 – 0.035" 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. Calculated using LBNL WINDOW and Optics computer 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	Reflectance Out	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. Calculated using LBNL WINDOW and Optics computer modeling programs using NFRC standard conditions.

Figure 5-10

SG EMBEDDED LoE COATING								
Laminate Configuration	Nominal Fractional Inches	Target Thickness in (mm)	Visible Light Transmittance	Reflectance Out	Reflectance In	SHGC	U-Factor BTU/hr-ft ² ·°F (W/m ² ·K)	UV Transmission
3.0 LoE-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 LoE-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 LoE-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 LoE 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 LoE 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 LoE 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) – 0.038" 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) – 0.038" 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) – 0.038" 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 LoE-452+® (#2) – 0.038" SG – 3.0	9/32	0.272 [6.91]	55%	9%	13%	0.31	1.00 [5.68]	<1%
3.0 Quad LoE-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 LoE-452+® (#2) – 0.038" SG – 4.7	9/32	0.272 [6.91]	54%	9%	12%	0.33	0.98 [5.56]	<1%
4.7 Quad LoE-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 LoE-452+® (#2) – 0.038" SG – 5.7	9/32	0.272 [6.91]	54%	9%	12%	0.33	0.97 [5.51]	<1%
5.7 Quad LoE-452+® (#2) – 0.090" SG – 5.7	1/2	0.541 [13.74]	54%	9%	12%	0.33	0.94 [5.34]	<1%

1. Calculated using LBNL WINDOW and Optics computer modeling programs using NFRC standard conditions.

Figure 5-11

PVB EMBEDDED LoE COATING								
Laminate Configuration	Nominal Fractional Inches	Target Thickness in (mm)	Visible Light Transmittance	Reflectance Out	Reflectance 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 LoE-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 LoE-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 LoE-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 LoE-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 LoE-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 LoE-452+° (#2) – 0.090" PVB – 5.7	1/2	0.536 [13.53]	54%	9%	12%	0.33	0.93 [5.28]	<1%

1. Calculated using LBNL WINDOW and Optics computer 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)

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

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