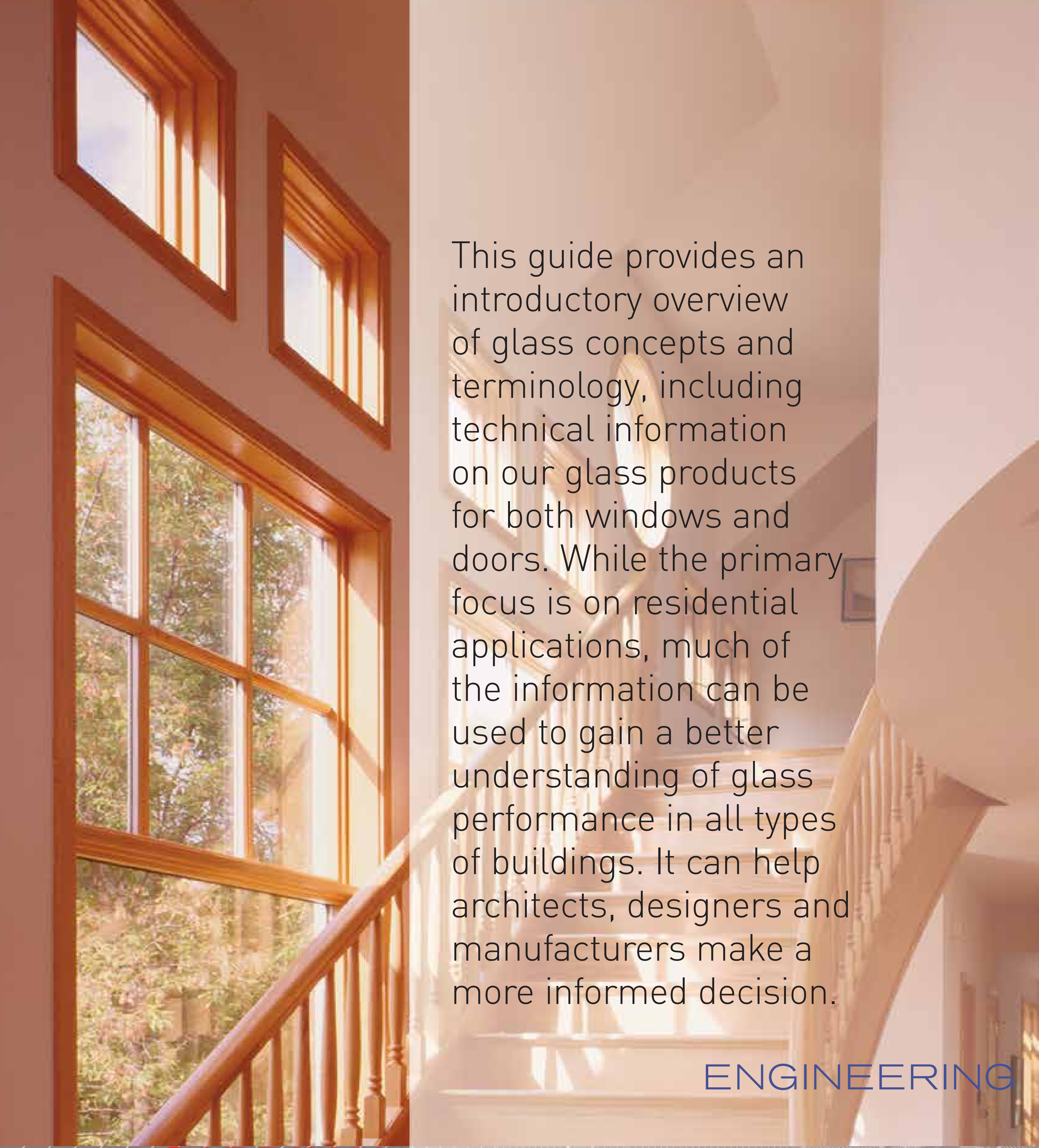
CARDINAL Glass Industries

ENGINEERING THE FUTURE OF GLASS

Technical Glass Guide

Version2.0



This guide provides an introductory overview of glass concepts and terminology, including technical information on our glass products for both windows and doors. While the primary focus is on residential applications, much of the information can be used to gain a better understanding of glass performance in all types of buildings. It can help architects, designers and manufacturers make a more informed decision.

ENGINEERING

CARDINAL Glass Industries

Cardinal Glass Industries is considered one of the world's leading providers of superior quality glass products. From the melting of sand to produce clear float glass to the vacuum sputtering of silver to produce low-emissivity coatings, Cardinal manufactures the quality components and finished insulating glass products used in top-of-the-line residential windows and doors around the world.

Cardinal is a management-owned company leading the industry in the development of long-lasting, energy-efficient glass products. We began fabricating insulating glass products in 1962. Since then, we have produced billions of square feet of insulating glass.

At Cardinal, we try to maintain a clear vision: design and fabricate the most advanced glass products in the industry. To sustain that vision, we invest heavily in research and development. Our twin R&D centers in Minnesota and Wisconsin provide the basis for new advances in glazing fenestration.

Cardinal turns fresh ideas into functional products that our customers can use. We provide a turnkey solution to our customers whether it includes insulating glass, coated, laminated, tempered or just plain float glass. In every case, our solutions always incorporate the latest applied glass science.

THE FUTURE OF GLASS

With Cardinal facilities all across the U.S.,

Company Structure

Cardinal Glass Industries is a corporation with five wholly-owned subsidiaries and more than 6,000 employees located at 40 locations around the United States. We enjoy a broad base of domestic and foreign customers.

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

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

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

Cardinal CT® Company
(Custom Tempering)
Adel, GA
Easton, PA
Irving, TX
Los Angeles, CA
Mount Airy, NC
Utica, OH

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

Cardinal Glass Industries
Eden Prairie, MN, USA

Cardinal IG® Technology Center
Minneapolis, MN, USA

Cardinal CG® Technology Center
Spring Green, WI, USA

Cardinal AG® Automation Group
Spring Green, WI, USA

ROTAR Rotation Cathodes
Spring Green, WI, USA

you’re assured of getting what you need when you need it.

Cardinal Coated Energy-Efficient Glass Goes Far Beyond Ordinary Low-E Glass

For years, Cardinal LoĒ® glass has been setting the standard for energy-efficient glass. Our patented, state-of-the-art sputtered coatings are unmatched by any other glass manufacturer. Our high transmission coatings are virtually clear, blocking the heat and reducing solar gain, while optimizing light transmission. In fact, our LoĒ^{2}® and LoĒ^{3}® coatings actually outperform the tinted glass often used in warm climates. In addition, because our coated glass transmits more natural light and reduces solar gain, you may be able to reduce both lighting and air-conditioning electrical loads.

LoĒ Coating Terminology

LoĒ^{2}-272 Equals two layers of silver, 72% light transmission for a double-pane IG unit

LoĒ-i89 Equals Indium Tin Oxide coating with monolithic transmission of 89%

Product Emissivity (unit-less):

LoĒ-i89®	0.149
LoĒ-x89™	0.192
LoĒ-180®	0.068
LoĒ^{2}-272®	0.042
LoĒ^{2}-270®	0.037
LoĒ^{3}-366®	0.022
LoĒ^{3}-340™	0.028

LoĒ Aesthetics

Aesthetics of glass products – such as color, transmittance, reflectivity, etc. – are very subjective. Cardinal LoĒ glass is virtually non-reflective and its transmitted and exterior appearance covers a range of neutral earth tones. Viewing angle, sky conditions (blue sky vs. overcast), colors of objects being reflected, colors of materials behind the glass (e.g., blinds, draperies) and viewing distance away from the glass will have a dramatic impact on the perceived glass aesthetics. Using clear glass as a basis, the depiction to the right shows the transmitted appearance and the exterior appearance of Cardinal's LoĒ products.

ENHANCED PERFORMANCE GLASS

LoĒ-i89 glass features an Indium Tin Oxide coating sputtered onto the indoor lite of an insulating glass (IG) unit, thus reflecting escaping heat back into the room and lowering U-Factors.

MOISTURE CONTROL GLASS

LoĒ-x89 glass reduces outdoor glass condensation. It features an Indium Tin Oxide coating that reduces heat loss and reduces the chance of the glass temperature falling below the dew point, thus decreasing the days with condensation. In addition, LoĒ-x89 has a titanium dioxide coating that becomes hydrophilic when exposed to UV radiation. So if condensation forms, the water will sheet, allowing visibility.

CLEAR | LoĒ-i89

TRANSMITTED APPEARANCE

EXTERIOR APPEARANCE

CLEAR | LoĒ-x89

TRANSMITTED APPEARANCE

EXTERIOR APPEARANCE

HIGH SOLAR GAIN GLASS
[One silver layer]

Cardinal LoĒ-180 is the perfect cold remedy. Ideal for passive solar applications, it allows winter sun's heat to pass into the home while blocking heat loss to the outside.

CLEAR | LoĒ-180

TRANSMITTED APPEARANCE

EXTERIOR APPEARANCE

ADVANCED PERFORMANCE GLASS FOR MOST CLIMATES
[Two silver layers]

Cardinal LoĒ^2-272 glass delivers year-round performance and comfort, whether it's -20° F (-29° C) or 110° F (43° C) in the shade. In winter, it reflects heat back into the room. In summer, it rejects the sun's heat and damaging UV rays.

CLEAR | LoĒ^2-272

TRANSMITTED APPEARANCE

EXTERIOR APPEARANCE

ADVANCED PERFORMANCE GLASS FOR MOST CLIMATES
[Two silver layers]

Where additional solar control is required, with very little sacrifice in visibility, LoĒ^2-270 is the ideal choice. Its patented coating blocks 86% of the sun's infrared heat and 86% of the sun's harmful UV rays.

CLEAR | LoĒ^2-270

TRANSMITTED APPEARANCE

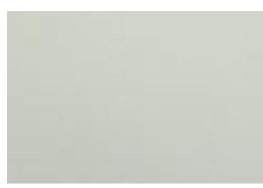
EXTERIOR APPEARANCE

ULTIMATE PERFORMANCE GLASS FOR ALL CLIMATES
[Three silver layers]

The new standard, LoĒ^3-366 delivers the perfect balance of solar control and high visibility – with no room-darkening tints and virtually no exterior reflectance. It provides the highest levels of year-round comfort and energy savings, making it the perfect glass for any location. The secret? An unprecedented three layers of silver.

CLEAR | LoĒ^3-366

TRANSMITTED APPEARANCE



EXTERIOR APPEARANCE

LOW SOLAR GAIN GLASS
[Three silver layers]

LoĒ^3-340 provides an industry-leading Solar Heat Gain Coefficient (SHGC) of 0.18 in a double-pane unit without the use of tinted glass. There's no need to sacrifice significant visible light transmission with a Light to Solar Gain (LSG) ratio of 2.17.

In addition to providing solar heat gain control, LoĒ^3-340 provides excellent glare control and will meet the requirements for turtle code glass.

CLEAR | LoĒ^3-340

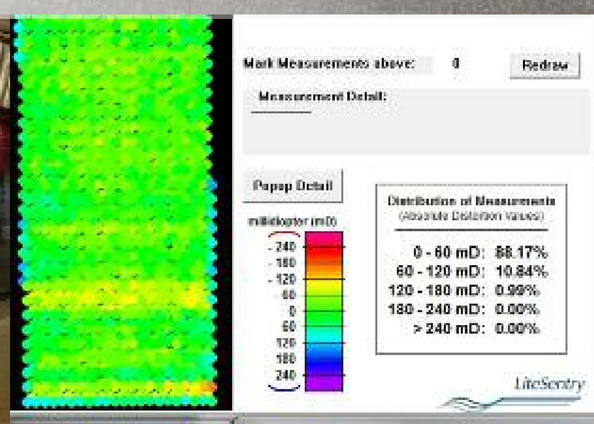
TRANSMITTED APPEARANCE

EXTERIOR APPEARANCE

Intelligent Quality
Assurance Program

Count on Cardinal Glass to Always Meet or Exceed Your Specifications

Cardinal IQ – our Intelligent Quality Assurance Program – ensures the quality of every piece of glass. Using state-of-the-art and our own patented inspection systems, we thoroughly examine the glass from start to finish.



Float Glass IQ

Float glass is the foundation of all Cardinal products.

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

Strain Measurements
Three different strain measurements are taken, so we can 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 mark and distortion.

Optimization System
This process arbitrates the best cut for the ribbon, which helps maximize production and efficiency in order to keep costs down.

Emissions Conformance
Cardinal is committed to the environment, and all facilities are equipped with the latest technologies to reduce emissions.

Coated Glass IQ

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 provides analysis based on how the complete product will appear in its final installation. Production measurements enable us to statistically control the existing process and use the data as benchmarks for continuous improvement efforts.

Room-Side Color and Visible Transmission/Reflection
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.

Edge Deletion
Statistically managing this process ensures that customers will not incur edge delete issues such as sealing an unprepared surface.

Performance Testing
R&D conducted evaluations to look at 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.

Tempered Glass IQ

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

Hawkeye Camera
This high-resolution, high-speed camera is used to detect scratches, coating faults and debris on the surface.

Tempered Distortion
Our state-of-the-art camera system measures the entire glass, focusing on a series of circles (similar to pixels). The results represent what the human eye sees. Competitive inspection systems read the peaks and valleys that develop as part of the tempering process but they report only an average. And not all lites are measured.

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

Tempered Conformance
In some Cardinal tempering facilities, a photoelastic stress measuring system identifies areas of non-uniform stress in the glass. The system highlights any area where there is inadequate tempering. The system also allows us to reconfigure procedures as necessary to obtain better heating and quenching – further assuring you of high-quality tempered glass every time.

Insulating Glass IQ

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

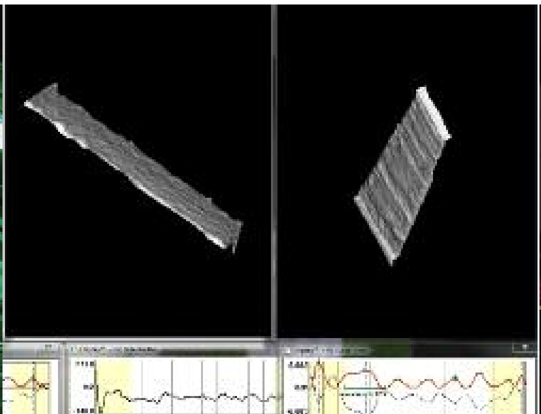
Vision Scope and Hawkeye Cameras
Similar to the systems incorporated on our tempering lines, this is where scratches, coating faults and debris on the glass surface are detected. The systems accurately characterize defects by size and sort them according to specifications to help prevent defective glass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

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

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

Coating Color
A spectrophotometer checks color intensity and hue. To avoid rejection of the unit, each different coating must meet specific color values.

Center of Glass Unit Thickness
Where possible, we do a 100% sort inspection of all important attributes, including center of glass thickness.



Naturally Clean Glass

Windows clean easier and stay cleaner.
Neat® coated glass harnesses the power of the sun's UV rays to loosen dirt so water can rinse it away, leaving windows virtually spotless. Windows clean easier and stay cleaner. Because Neat coated glass is available with any of our LoĒ® coatings, you get all of the LoĒ coating performance benefits as well.

The science of Neat coated glass.
A variety of different technologies go into manufacturing Neat coated glass. But the key technology – the one that helps windows stay clean longer – is the super-thin coating we apply.

Using our patented double sputtering process, we apply an invisible, durable and permanent coating of silicon dioxide and titanium dioxide to the bottom surface, and in the same pass apply the LoĒ coating to the top surface.

The titanium dioxide layer of Neat coated glass reacts chemically with the sun's UV rays and causes organic materials that are on the glass to decompose. It works even on cloudy days.

Neat coated glass is also extra smooth thanks to a thin layer of silicon dioxide. This makes the glass hydrophilic, much smoother than ordinary hydrophobic glass, allowing water to disperse evenly or "sheet off" and evaporate quickly, greatly reducing water spotting.

The sun and rain finish the job.
Then when it rains, the decomposed dirt caused by the titanium dioxide reaction is rinsed away, leaving the glass almost spotless. Builders and homeowners spend less time washing windows.

Clear advantages over competitive products.
Neat coated glass allows more visible light transmittance than any comparable competitive product and is also less reflective.

Preserve

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 IG units.

After the job's 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 by-products, it can be recycled or disposed of with the rest of normal construction site debris. Preserve film saves you time, money...and a lot of hassle.

4 LDPE

Facts About Preserve Film

- Preserve film incorporates a water-based adhesive and is rated as a low-density polyethylene.
- Preserve film should be removed within nine months of installation.
- Preserve film should not be pressure washed.
- Do not affix permanent grilles or external fixtures directly to Preserve film.
- Acid should not be used on Preserve film.
- 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.

Indoor

Outdoor

LoĒ Perfo

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

ormance

Energy Terminology

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

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

Shading Coefficient
The ratio of solar heat gain through a window to the solar heat gain through a single light of 1/8" (3 mm) clear glass under the same set of conditions. Dimensionless and varying between 0 and 1, the smaller the number, the better the window is at stopping the entry of solar heat.

Solar Heat Gain Coefficient (SHGC)
The fraction of incident solar radiation which enters a building as heat. It is based on the sum of the solar energy transmittance plus the inwardly flowing fraction of absorbed solar energy on all lites of the glazing. Dimensionless and varying between 0 and 1, the smaller the number, the better the glazing is at preventing solar gain. It is preferred over the shading coefficient since it can be used for solar incidence angles other than normal to the glass surface.

Relative-Heat Gain (RHG)
The total amount of heat gain through a glazing system at NFRC/ASHRAE-specified summer conditions, incorporating the U-Factor and the Solar Heat Gain Coefficient. The conditions are 230 BTU/hr/ft^2 (726 W/m^2) outdoor temperature of 89° F (32° C), indoor temperature of 75° F (24° C) and 6.2 mph (2.8 m/s) wind. [RHG = U_{summer} x (89-75) + SHGC x (230)]. Expressed in terms of BTU/hr/ft^2.

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

ISO-CIE Damage Function
In a portion of the solar spectrum (300 to 700 nm), the International Standards Organization (ISO) developed a weighting function, recommended by the International Commission on Illumination (CIE) that takes into account not only the UV transmission but also a portion of the visible light spectrum that can cause fading of materials and furnishings.

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

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

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

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

Solar Energy Reflectance
In the solar spectrum, the percentage of solar energy that is reflected from the glass surface(s).

Light to Solar Gain
The ratio of visible transmittance to solar heat gain coefficient (LSG ratio).

TO CONVERT INCH-POUND	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 11-1

Optical Properties of IG Units

The Optical Properties data shown below (Figure 12-1) can be used to compare performance data on the insulating glass constructions listed.

The visible data given below indicate the amount of visible light transmitted and reflected by the insulating glass construction relative to the CIE Standard Observer. The Solar Heat Gain Coefficient, Shading Coefficient and Relative Heat Gain data indicate the amount of solar gain obtained with the insulating glass construction. The lower the Solar Heat Gain Coefficient, Shading Coefficient and Relative Heat Gain, the better the product is at reducing solar gain, resulting in greater summer comfort and reduced cooling costs.

OPTICAL PROPERTIES OF INSULATING GLASS UNITS

IG Configuration Outboard Lite / Inboard Lite	Glass Thickness		Visible Light			Fading			
	mm	inches	Trans. (%)	Refl. Out (%)	Refl. In (%)	UV Trans. (300 to 380 nm)	ISO-CIE Trans. (300 to 700 nm)	SHGC	LSG
Clear / Clear	3.0	1/8	82	15	15	58%	75%	0.78	1.05
	5.7	1/4	80	15	15	48%	70%	0.72	1.11
Clear / LoĒ-180®	3.0	1/8	79	15	15	29%	63%	0.69	1.14
	5.7	1/4	77	14	15	24%	60%	0.64	1.20
LoĒ^2-272® / Clear	3.0	1/8	72	11	12	16%	55%	0.41	1.76
	5.7	1/4	70	10	11	14%	53%	0.40	1.75
LoĒ^2-270® / Clear	3.0	1/8	70	12	13	14%	53%	0.37	1.89
	5.7	1/4	68	12	12	13%	50%	0.36	1.89
LoĒ^3-366® / Clear	3.0	1/8	65	11	12	5%	43%	0.27	2.41
	5.7	1/4	63	11	11	4%	41%	0.27	2.33
LoĒ^3-340™ / Clear	3.0	1/8	39	11	13	2%	27%	0.18	2.17
	5.7	1/4	38	11	13	2%	26%	0.18	2.11
LoĒ-180® / LoĒ-i89® (#4)	3.0	1/8	77	15	14	27%	61%	0.62	1.24
	5.7	1/4	75	15	13	23%	58%	0.58	1.29
LoĒ^2-272® / LoĒ-i89® (#4)	3.0	1/8	70	11	11	16%	53%	0.41	1.71
	5.7	1/4	68	10	11	14%	51%	0.39	1.74
LoĒ^2-270® / LoĒ-i89® (#4)	3.0	1/8	69	12	12	14%	51%	0.36	1.92
	5.7	1/4	66	12	12	12%	49%	0.35	1.89
LoĒ^3-366® / LoĒ-i89® (#4)	3.0	1/8	63	11	11	5%	41%	0.27	2.33
	5.7	1/4	61	10	11	4%	40%	0.26	2.35
LoĒ^3-340™ / LoĒ-i89® (#4)	3.0	1/8	38	11	12	2%	26%	0.17	2.24
	5.7	1/4	37	11	12	2%	25%	0.17	2.18
Triple-Pane Clear / Clear / Clear	3.0	1/8	75	21	21	48%	67%	0.70	1.07
	5.7	1/4	72	20	20	37%	62%	0.63	1.14
Triple-Pane LoĒ-180® / Clear / LoĒ-180®	3.0	1/8	70	20	20	13%	50%	0.56	1.25
	5.7	1/4	67	20	20	11%	47%	0.51	1.31
Triple-Pane LoĒ^2-272® / Clear / LoĒ-180®	3.0	1/8	63	15	18	8%	44%	0.37	1.70
	5.7	1/4	60	14	17	7%	42%	0.35	1.71
Triple-Pane LoĒ^2-270® / Clear / LoĒ-180®	3.0	1/8	62	16	19	7%	43%	0.33	1.88
	5.7	1/4	59	15	18	6%	41%	0.32	1.84
Triple-Pane LoĒ^3-366® / Clear / LoĒ-180®	3.0	1/8	57	14	18	2%	36%	0.25	2.28
	5.7	1/4	54	14	17	2%	34%	0.24	2.25
Triple-Pane LoĒ-180® / LoĒ-180® / LoĒ-i89®	3.0	1/8	68	21	19	13%	49%	0.53	1.28
	5.7	1/4	65	20	18	10%	46%	0.48	1.35
Triple-Pane LoĒ^2-272® / LoĒ-180® / LoĒ-i89®	3.0	1/8	62	15	16	8%	43%	0.36	1.72
	5.7	1/4	59	15	16	6%	41%	0.34	1.74
Triple-Pane LoĒ^3-366® / LoĒ-180® / LoĒ-i89®	3.0	1/8	56	14	16	2%	35%	0.24	2.33
	5.7	1/4	53	14	16	2%	33%	0.23	2.30

1) Calculated values using LBNL WINDOW computer program per NFRC environmental conditions.
2) Double-pane IG construction: 1/2" (13.0 mm) airspace, 90% argon filled for LoĒ products, otherwise air-filled cavity. Coatings on surfaces #2, #3, and/or #4.
3) Triple-pane IG construction: 5/16" (8.0 mm) airspace, 90% argon filled for LoĒ products. Coatings on surfaces #2 and #5, or #2, #4, and #6.
4) Please see Cardinal's TSB for Heat Treatment Guidelines.

Figure 12-1

Fading

Energy from the sun which is transmitted through glass can be categorized into three main regions (see Figure 13-1):

- Ultraviolet (UV) energy spans from 300 to 380 nm.
- Visible (seen by the eye) spans from 380 to 780 nm.
- Near infrared radiation (or heat energy) spans from 780 to 2500 nm.

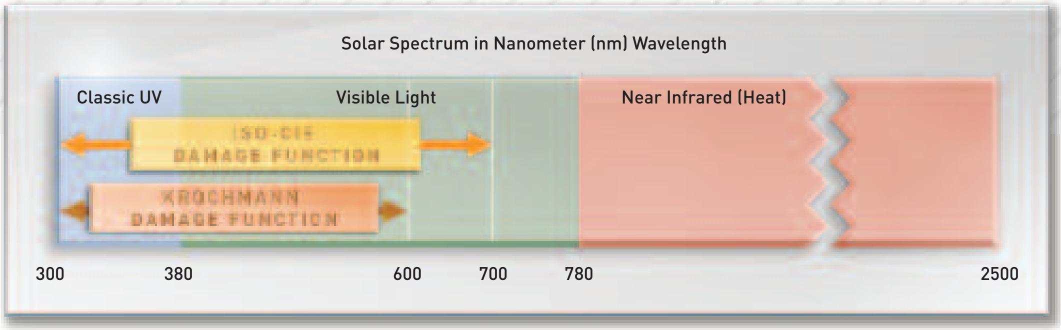


Figure 13-1

There is more energy below 300 nm, but this is effectively blocked-out by all glass products.

Conventionally, it is considered that UV energy accounts for the majority of fading. As a result, many people use the classical UV transmittance (300 to 380 nm) to indicate fading potential and compare products. It has been shown experimentally that fading damage can also occur in the visible light region up to approximately 600 nm (see Figure 13-1). For this reason, a damage weighted function was developed in Europe by Krochmann.

Krochmann Damage Function
This function attempts to account for the fading potential of all damaging radiation which can be transmitted through glass. It covers a spectral range from about 300 to 600 nm and weights each wavelength in relation to the potential damage it can cause to typical materials.

ISO-CIE Function
Another method to calculate damage weighted transmittance was 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.

Cardinal manufactures LoĒ® products which reduce the potential for fading of fabrics and materials by blocking out damaging solar radiation. It is important to consider the sensitivity of the materials or fabrics to be protected. Some materials are only sensitive in the UV region while others display greater sensitivity to the visible spectrum. Knowing the sensitivity of the material to be protected helps determine how well a particular glass product will protect against fading.

Center of Glass U-Factors of IG Units

These tables (Figures 13-2, 14-1, 14-2 and 14-3) show how Cardinal LoĒ coatings and argon filling improve center of glass U-Factors.

U-Factor vs. Airspace Thickness
In addition to showing the benefit of LoĒ coatings and argon filling, this table shows that the optimum airspace thickness can range between 7/16" (11.5 mm) and 5/8" (16 mm). The optimum airspace means that the winter U-Factor does not appreciably change when the width changes, for example, from 1/2" to 5/8".

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

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

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

Figure 13-2

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

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

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

Figure 14-1

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

Nominal Airspace		Clear / Clear / Clear BTU/(hr-ft^2-°F) (W/m^2-K)	LoĒ-180® LoĒ-180® BTU/(hr-ft^2-°F) (W/m^2-K)		LoĒ^2-272® LoĒ-180® BTU/(hr-ft^2-°F) (W/m^2-K)		LoĒ^2-270® LoĒ-180® BTU/(hr-ft^2-°F) (W/m^2-K)		LoĒ^3-366® LoĒ-180® BTU/(hr-ft^2-°F) (W/m^2-K)	
mm	inches	air	air	argon	air	argon	air	argon	air	argon
6.5	1/4	**0.37** (2.10)	**0.25** (1.42)	**0.20** (1.14)	**0.25** (1.42)	**0.19** (1.08)	**0.25** (1.42)	**0.19** (1.08)	**0.25** (1.42)	**0.19** (1.08)
8.0	5/16	**0.35** (1.99)	**0.22** (1.25)	**0.17** (0.97)	**0.22** (1.25)	**0.17** (0.97)	**0.21** (1.19)	**0.17** (0.97)	**0.21** (1.19)	**0.17** (0.97)
9.8	3/8	**0.33** (1.87)	**0.19** (1.08)	**0.15** (0.85)	**0.19** (1.08)	**0.15** (0.85)	**0.19** (1.08)	**0.15** (0.85)	**0.19** (1.08)	**0.14** (0.79)
11.5	7/16	**0.32** (1.82)	**0.17** (0.97)	**0.14** (0.79)	**0.17** (0.97)	**0.13** (0.74)	**0.17** (0.97)	**0.13** (0.74)	**0.17** (0.97)	**0.13** (0.74)
13.0	1/2	**0.31** (1.76)	**0.16** (0.91)	**0.13** (0.74)	**0.16** (0.91)	**0.13** (0.74)	**0.16** (0.91)	**0.13** (0.74)	**0.16** (0.91)	**0.13** (0.74)

1) Calculated values using LBNL WINDOW computer program per NFRC environmental conditions.
2) For triple-pane IG units, the LoĒ® coatings are on surfaces #2 and #5.
3) U-Factors calculated at center of glass
4) Glass thickness is 3 mm
5) Argon fill is 90%

Figure 14-2

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

Airspace		LoĒ-180® LoĒ-180® LoĒ-i89® (#6) BTU/(hr-ft^2-°F) (W/m^2-K)		LoĒ^2-272® LoĒ-180® LoĒ-i89® (#6) BTU/(hr-ft^2-°F) (W/m^2-K)		LoĒ^3-366® LoĒ-180® LoĒ-i89® (#6) BTU/(hr-ft^2-°F) (W/m^2-K)	
mm	inches	air	argon	air	argon	air	argon
6.5	1/4	**0.21** (1.19)	**0.17** (0.97)	**0.21** (1.19)	**0.17** (0.97)	**0.20** (1.14)	**0.16** (0.91)
8.0	5/16	**0.18** (1.02)	**0.15** (0.85)	**0.18** (1.02)	**0.15** (0.85)	**0.18** (1.02)	**0.14** (0.79)
9.8	3/8	**0.16** (0.91)	**0.13** (0.74)	**0.16** (0.91)	**0.13** (0.74)	**0.16** (0.91)	**0.13** (0.74)
11.5	7/16	**0.15** (0.85)	**0.12** (0.68)	**0.15** (0.85)	**0.12** (0.68)	**0.15** (0.85)	**0.12** (0.68)
13.0	1/2	**0.14** (0.79)	**0.12** (0.68)	**0.14** (0.79)	**0.11** (0.62)	**0.14** (0.79)	**0.11** (0.62)

1) Calculated values using LBNL WINDOW computer program per NFRC environmental conditions.
2) For triple-pane IG units, the LoĒ® coatings are on surfaces #2, #4, and #6.
3) U-Factors calculated at center of glass
4) Glass thickness is 3 mm
5) Argon fill is 90%

Figure 14-3

Overall Window U-Factors

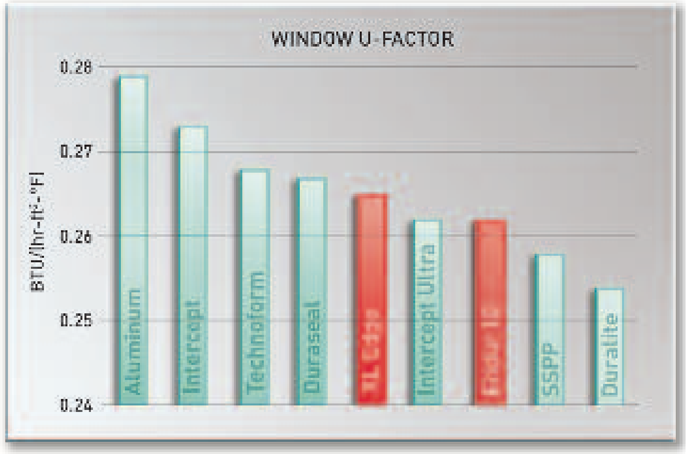
U-Factor and Glass Frame Interface Temperatures
The data below (Figures 15-1, 15-2, 15-3 and 15-4) compare various spacer types in the industry and their effect on the overall window U-Factor, NFRC CR rating, and sightline temperature. The simulations were made by a Certified NFRC Simulator, using a wood or vinyl frame with sightlines of the spacer system equal in all cases.

LoĒ^{3}-366 DOUBLE-GLAZED UNIT

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

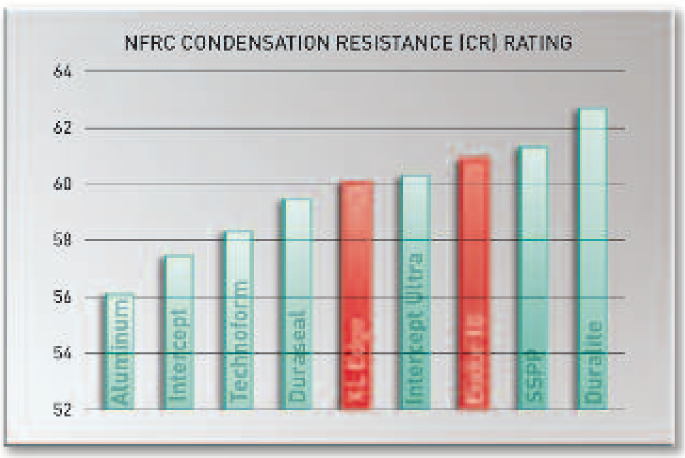
1) 3.1 mm LoĒ^{3}-366® / 0.5" Argon / 3.1 mm Clear

Figure 15-1



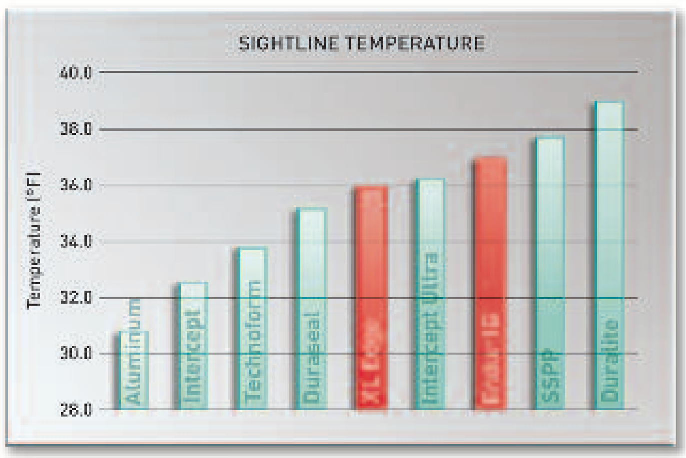
1) 3.1 mm LoĒ^{3}-366 / 0.5" Argon / 3.1 mm Clear
2) Generic Wood / Vinyl Frame

Figure 15-2



1) 3.1 mm LoĒ^{3}-366 / 0.5" Argon / 3.1 mm Clear
2) Generic Wood / Vinyl Frame

Figure 15-3



1) 3.1 mm LoĒ^{3}-366 / 0.5" Argon / 3.1 mm Clear
2) Generic Wood / Vinyl Frame

Figure 15-4

Effect of Spacer Systems on Overall U-Factors
In most windows that exist today, the rate of heat flow through the frame and the 2 1/2" band of glass near the frame is greater than the heat flow through the center of an argon-filled, LoĒ^{2}® or LoĒ^{3}® insulating glass unit. In addition, the U-Factor of the edge, frame and overall window are improved when using Cardinal's stainless steel spacer over the typical aluminum spacer (Figure 15-2).

The Endur spacer will also increase the glass/frame interface temperature resulting in less opportunity for indoor condensation around the periphery of the glass (Figures 15-3 and 15-4).

Comparative Analysis of Window U-Factor

To comply with energy codes, window manufacturers must label and rate their windows per the U.S. NFRC program (www.nfrc.org) and/or the Canadian CSA A440.2 standard. The latest energy code versions in both the U.S. and Canada specify window U-Factors that will require the use of a Non-Metal frame type to comply (metal frame U-Factors are too high). Non-Metal frames would include these sub-categories:

A. Clad Wood

B. Wood/Vinyl/Fiberglass

C. Insulated Wood/Vinyl/Fiberglass

In general, category B will have lower U-Factors than sub-category A, and C will be better than B. In practice, however, there are examples within each category that comply with code given the right glass package.

The tabulation to follow presents overall window U-Factor as a function of glass type using a comparative analysis. Three "classes" of window U-Factor are used to describe the effect of frame and edge-of-glass against incremental changes in center-of-glass performance. As formatted there is a 0.02 U-Factor increment between classes 1 to 2, and 2 to 3. Jumping from one class to another is mostly a function of the window design, moving down the list of glazing options shows the impact of glass changes within a basic window design.

Note that all the U-Factors shown are representative. Code compliance will require an NFRC rating and simulation.

To use this format, find an option that you currently build to define your frame class and compare the impacts of other glazing options.

Example: Current window uses LoĒ^2-270® and achieves a 0.32 U-Factor.

This window would fall into Class 1. Double-pane options shown would change the U by +0.01 or -0.04. A 1 1/8" triple-pane could be 0.07 to 0.08 lower U.

For a more comprehensive list of glazing options, go to www.cardinalcorp.com.

WINDOW U-FACTOR

Glazing	Class 1		Class 2		Class 3	
	BTU/(hr-ft^2-°F)	(W/m^2-K)	**BTU/(hr-ft^2-°F)**	(W/m^2-K)	**BTU/(hr-ft^2-°F)**	(W/m^2-K)
Clear / Clear	Code Default for Double-Pane & Non-Metal Frame is **0.55** (3.12)					
Clear / LoĒ-180®	**0.33**	1.87	**0.31**	1.76	**0.29**	1.65
LoĒ^2-272® or 270® / Clear	**0.32**	1.82	**0.30**	1.70	**0.28**	1.59
LoĒ^3-366® / Clear	**0.31**	1.76	**0.29**	1.65	**0.27**	1.53
LoĒ^3-340™ / Clear	**0.31**	1.76	**0.29**	1.65	**0.27**	1.53
LoĒ-180® / LoĒ-i89® (#4)	**0.29**	1.65	**0.27**	1.53	**0.25**	1.42
LoĒ^2-272® or 270® / LoĒ-i89® (#4)	**0.29**	1.65	**0.27**	1.53	**0.25**	1.42
LoĒ^3-366® / LoĒ-i89® (#4)	**0.28**	1.59	**0.26**	1.48	**0.24**	1.36
LoĒ^3-340™ / LoĒ-i89® (#4)	**0.28**	1.59	**0.26**	1.48	**0.24**	1.36
Clear / Clear / Clear	**0.38**	2.16	**0.36**	2.04	**0.34**	1.93
LoĒ-180® / Clear / LoĒ-180®	**0.25**	1.42	**0.23**	1.31	**0.21**	1.19
LoĒ^2-272® / Clear / LoĒ-180®	**0.25**	1.42	**0.23**	1.31	**0.21**	1.19
LoĒ^2-270® / Clear / LoĒ-180®	**0.25**	1.42	**0.23**	1.31	**0.21**	1.19
LoĒ^3-366® / Clear / LoĒ-180®	**0.24**	1.36	**0.22**	1.25	**0.20**	1.14
LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)	**0.24**	1.36	**0.22**	1.25	**0.20**	1.14
LoĒ^2-272® / LoĒ-180® / LoĒ-i89® (#6)	**0.24**	1.36	**0.22**	1.25	**0.20**	1.14
LoĒ^2-270® / LoĒ-180® / LoĒ-i89® (#6)	**0.24**	1.36	**0.22**	1.25	**0.20**	1.14
LoĒ^3-366® / LoĒ-180® / LoĒ-i89® (#6)	**0.24**	1.36	**0.22**	1.25	**0.20**	1.14

Figure 16-1

1) All LoĒ options are argon filled
2) 3/4" Double Pane (1) 13.0 mm gap
3) 1 1/8" Triple Pane (2) 9.8 mm gaps
4) Calculated values using LBNL WINDOW computer program per NFRC environmental conditions.
5) Double-pane IG units: 1/8" (3 mm) glass thickness and ½" (13 mm) airspace with 90% argon gas fill. Clear/Clear values based on an air-filled cavity.
6) Triple-pane IG units: 1/8" (3 mm) glass thickness and 3/8" (9.8 mm) airspace with 90% argon gas fill. Clear/Clear/Clear values based on an air-filled cavity.
7) For double-pane IG units, the LoĒ coatings are on surfaces #2 and/or #4.
8) For triple-pane IG units, the LoĒ coatings are on surfaces #2 and #5; or #2, #4, and #6.

Heat Transfer: Winter Heat Loss

Heat transfer across the cavity of insulating glass units 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 (see Figure 17-1 at right), 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/ft^2. By adding the low emissivity coating, the heat loss by thermal radiation is now reduced to only 12% of the total heat transfer. The LoĒ^3-366® unit with argon illustration (Figure 17-3) shows this effect.

The heat transfer characteristics of the LoĒ^3-366 products with argon airspace vs. double-pane clear with air are shown at right (Figures 17-2 and 17-3). The lower thermal conductivity of argon lowers conductive heat transfer and reduces the heat loss to 17 BTU/hr/ft^2, double the performance of standard double-pane insulating glass with air.

WINTER NIGHT 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 / LoĒ-180®	**0.26** (1.48)	**3** (9)	**15** (47)	**18** (57)
LoĒ^2-272® / Clear	**0.25** (1.42)	**2** (6)	**16** (50)	**18** (57)
LoĒ^2-270® / Clear	**0.25** (1.42)	**2** (6)	**16** (50)	**18** (57)
LoĒ^3-366® / Clear	**0.24** (1.36)	**1** (3)	**16** (50)	**17** (54)
LoĒ^3-340™ / Clear	**0.25** (1.42)	**1** (3)	**17** (54)	**18** (57)
LoĒ-180® / LoĒ-i89® (#4)	**0.21** (1.19)	**2** (6)	**13** (41)	**15** (47)
LoĒ^2-272® / LoĒ-i89® (#4)	**0.20** (1.14)	**1** (3)	**13** (41)	**14** (44)
LoĒ^2-270® / LoĒ-i89® (#4)	**0.20** (1.14)	**1** (3)	**13** (41)	**14** (44)
LoĒ^3-366® / LoĒ-i89® (#4)	**0.20** (1.14)	**1** (3)	**13** (41)	**14** (44)
LoĒ^3-340™ / LoĒ-i89® (#4)	**0.20** (1.14)	**1** (3)	**13** (41)	**14** (44)
Clear / Clear / Clear	**0.35** (1.99)	**14** (44)	**11** (35)	**25** (79)
LoĒ-180® / Clear / LoĒ-180®	**0.17** (0.97)	**2** (6)	**10** (32)	**12** (38)
LoĒ^2-272® / Clear / LoĒ-180®	**0.17** (0.97)	**1** (3)	**11** (35)	**12** (38)
LoĒ^2-270® / Clear / LoĒ-180®	**0.17** (0.97)	**1** (3)	**11** (35)	**12** (38)
LoĒ^3-366® / Clear / LoĒ-180®	**0.17** (0.97)	**1** (3)	**11** (35)	**12** (38)
LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)	**0.15** (0.85)	**1** (3)	**10** (32)	**11** (35)
LoĒ^2-272® / LoĒ-180® / LoĒ-i89® (#6)	**0.15** (0.85)	**1** (3)	**10** (32)	**11** (35)
LoĒ^3-366® / LoĒ-180® / LoĒ-i89® (#6)	**0.14** (0.79)	**1** (3)	**9** (28)	**10** (32)

1) Calculated values using Vision and LBNL WINDOW computer program per NFRC environmental conditions.
2) Double-pane IG construction: 1/2" (13 mm) airspace, 90% argon filled for LoĒ® products, otherwise air-filled cavity. Coatings on surfaces #2, #3, and/or #4.
3) Triple-pane IG construction: 5/16" (8.0 mm) airspace, 90% argon filled for LoĒ products. Coatings on surfaces #2 and #5, or #2, #4, and #6.
4) All insulating glass systems contain 1/8" (3 mm) glass.

Figure 17-1

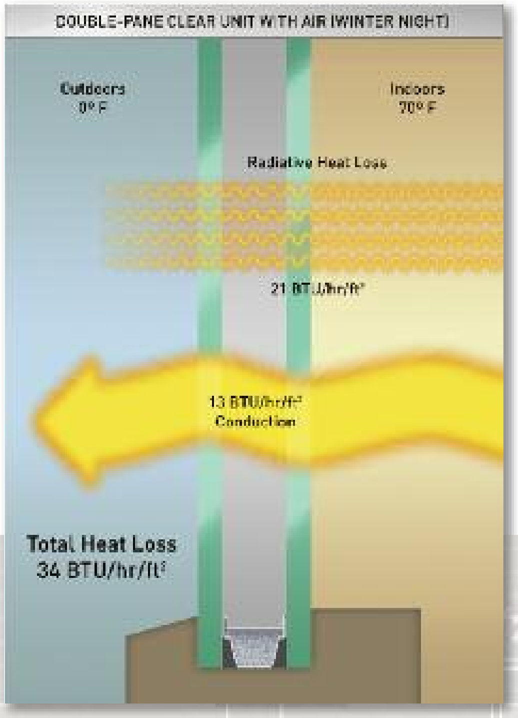


Figure 17-2

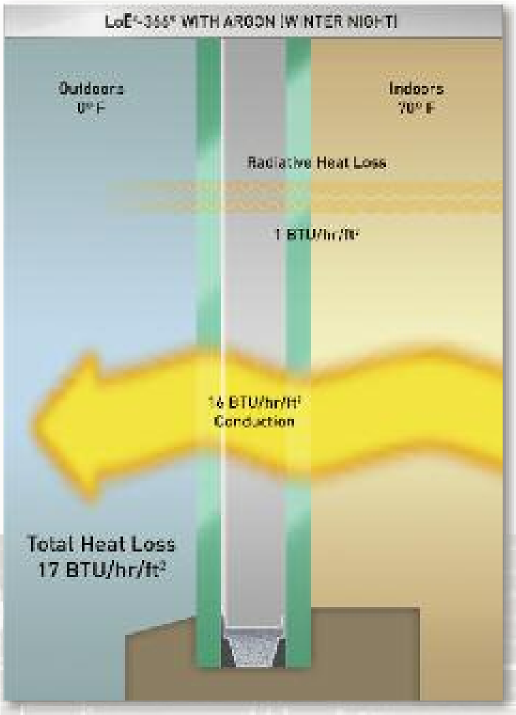


Figure 17-3

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 (Figures 18-1, 18-2 and 18-3) show the heat gain characteristics of double-pane clear and LoĒ^3-366® products. In using the LoĒ^3-366 product, the heat gain is reduced 65% compared with a double-pane clear insulating glass unit.

The data and figures show that LoĒ® products have a distinct advantage for summertime performance over clear insulating glass.

SUMMER DAY SOLAR HEAT GAIN COMPARISONS

Insulating Glass Unit	U_{summer} BTU/(hr-ft^2) (W/m^2)	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 / LoĒ-180®	**0.23** (1.31)	0.68	**52** (164)	**149** (470)	**79** (249)	**172** (543)
LoĒ^2-272® / Clear	**0.22** (1.25)	0.41	**87** (274)	**94** (297)	**146** (461)	**105** (331)
LoĒ^2-270® / Clear	**0.22** (1.25)	0.37	**97** (306)	**84** (265)	**157** (495)	**94** (297)
LoĒ^3-366® / Clear	**0.21** (1.19)	0.27	**109** (344)	**62** (196)	**181** (571)	**70** (221)
LoĒ^3-340™ / Clear	**0.21** (1.19)	0.18	**99** (312)	**35** (110)	**203** (640)	**48** (151)
LoĒ-180® / LoĒ-i89® (#4)	**0.18** (1.02)	0.62	**52** (164)	**136** (429)	**94** (297)	**157** (495)
LoĒ^2-272® / LoĒ-i89® (#4)	**0.17** (0.97)	0.40	**87** (274)	**92** (290)	**149** (470)	**101** (319)
LoĒ^2-270® / LoĒ-i89® (#4)	**0.17** (0.97)	0.36	**97** (306)	**82** (259)	**159** (502)	**91** (287)
LoĒ^3-366® / LoĒ-i89® (#4)	**0.17** (0.97)	0.27	**109** (344)	**60** (189)	**181** (571)	**69** (218)
LoĒ^3-340™ / LoĒ-i89® (#4)	**0.17** (0.97)	0.17	**99** (312)	**35** (110)	**206** (650)	**44** (139)
Clear / Clear / Clear	**0.38** (2.16)	0.70	**42** (132)	**156** (492)	**74** (233)	**179** (565)
LoĒ-180® / Clear / LoĒ-180®	**0.18** (1.02)	0.56	**62** (196)	**117** (369)	**109** (344)	**142** (448)
LoĒ^2-272® / Clear / LoĒ-180®	**0.18** (1.02)	0.37	**92** (290)	**79** (249)	**156** (492)	**95** (300)
LoĒ^2-270® / Clear / LoĒ-180®	**0.18** (1.02)	0.33	**99** (312)	**72** (227)	**166** (524)	**85** (268)
LoĒ^3-366® / Clear / LoĒ-180®	**0.18** (1.02)	0.25	**114** (360)	**52** (164)	**186** (587)	**65** (205)
LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)	**0.15** (0.85)	0.53	**62** (196)	**109** (344)	**117** (369)	**133** (420)
LoĒ^2-272® / LoĒ-180® / LoĒ-i89® (#6)	**0.15** (0.85)	0.36	**92** (290)	**77** (243)	**159** (502)	**91** (287)
LoĒ^3-366® / LoĒ-180® / LoĒ-i89® (#6)	**0.14** (0.79)	0.24	**114** (360)	**52** (164)	**188** (593)	**62** (196)

1) Calculated values using Vision and LBNL WINDOW computer program per NFRC environmental conditions.
2) Double-pane IG construction: 1/2" (13 mm) airspace, 90% argon filled for LoĒ products, otherwise air-filled cavity. Coatings on surfaces #2, #3, and/or #4.
3) Triple-pane IG construction: 5/16" (8.0 mm) airspace, 90% argon filled for LoĒ products. Coatings on surfaces #2 and #5, or #2, #4, and #6.
4) All insulating glass systems contain 1/8" (3 mm) glass.

Figure 18-1

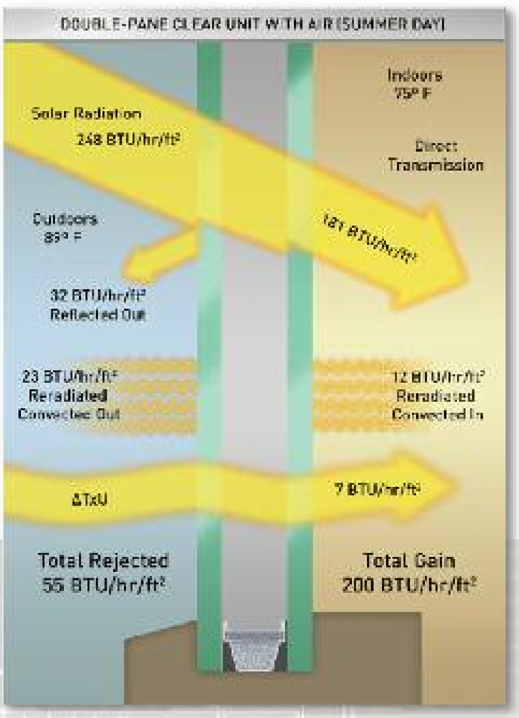


Figure 18-2

Figure 18-3

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 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.

Figure 19-1 illustrates the high solar heat gain of products utilizing Cardinal LoĒ-180® and LoĒ-i89® while maintaining very low U-Factors.

WINTER DAY SOLAR HEAT GAIN COMPARISONS

Insulating Glass Unit	U_{winter} BTU/(hr-ft²) (W/m²)	SHGC	Solar Radiation Reflected BTU/(hr-ft²) (W/m²)	Solar Radiation Transmitted BTU/(hr-ft²) (W/m²)	Total Energy Rejected BTU/(hr-ft²) (W/m²)	Total Energy Gained BTU/(hr-ft²) (W/m²)
Clear / Clear	**0.48** (2.73)	0.77	**32** (101)	**181** (571)	**91** (287)	**191** (603)
Clear / LoĒ-180®	**0.26** (1.48)	0.68	**52** (164)	**149** (470)	**97** (306)	**169** (533)
LoĒ²-272® / Clear	**0.25** (1.42)	0.41	**87** (274)	**94** (297)	**164** (517)	**102** (322)
LoĒ²-270® / Clear	**0.25** (1.42)	0.36	**97** (306)	**84** (265)	**177** (558)	**89** (281)
LoĒ³-366® / Clear	**0.24** (1.36)	0.27	**109** (344)	**62** (196)	**198** (625)	**67** (211)
LoĒ³-340™ / Clear	**0.25** (1.42)	0.17	**99** (312)	**35** (110)	**220** (694)	**42** (132)
LoĒ-180® / LoĒ-i89® (#4)	**0.21** (1.19)	0.60	**52** (164)	**136** (429)	**114** (360)	**149** (470)
LoĒ²-272® / LoĒ-i89® (#4)	**0.20** (1.14)	0.40	**87** (274)	**92** (290)	**163** (514)	**99** (312)
LoĒ²-270® / LoĒ-i89® (#4)	**0.20** (1.14)	0.35	**97** (306)	**82** (259)	**175** (552)	**87** (274)
LoĒ³-366® / LoĒ-i89® (#4)	**0.20** (1.14)	0.26	**109** (344)	**60** (189)	**198** (625)	**64** (202)
LoĒ³-340™ / LoĒ-i89® (#4)	**0.20** (1.14)	0.17	**99** (312)	**35** (110)	**220** (694)	**42** (132)
Clear / Clear / Clear	**0.35** (1.99)	0.70	**42** (132)	**156** (492)	**99** (312)	**174** (549)
LoĒ-180® / Clear / LoĒ-180®	**0.17** (0.97)	0.56	**62** (196)	**117** (369)	**121** (382)	**139** (438)
LoĒ²-272® / Clear / LoĒ-180®	**0.17** (0.97)	0.37	**92** (290)	**79** (249)	**168** (530)	**92** (290)
LoĒ²-270® / Clear / LoĒ-180®	**0.17** (0.97)	0.33	**99** (312)	**72** (227)	**178** (562)	**82** (259)
LoĒ³-366® / Clear / LoĒ-180®	**0.17** (0.97)	0.24	**114** (360)	**52** (164)	**200** (631)	**60** (189)
LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)	**0.15** (0.85)	0.52	**62** (196)	**109** (344)	**130** (410)	**129** (407)
LoĒ²-272® / LoĒ-180® / LoĒ-i89® (#6)	**0.15** (0.85)	0.35	**92** (290)	**77** (243)	**172** (543)	**87** (274)
LoĒ³-366® / LoĒ-180® / LoĒ-i89® (#6)	**0.14** (0.79)	0.23	**114** (360)	**52** (164)	**201** (634)	**57** (180)

1) Calculated values using Vision and LBNL WINDOW computer program per NFRC environmental conditions.
2) Double-pane IG construction: 1/2" (13 mm) airspace, 90% argon filled for LoĒ® products, otherwise air-filled cavity. Coatings on surfaces #2, #3, and/or #4.
3) Triple-pane IG construction: 5/16" (8.0 mm) airspace, 90% argon filled for LoĒ products. Coatings on surfaces #2 and #5, or #2, #4, and #6.
4) All insulating glass systems contain 1/8" (3 mm) glass.

Figure 19-1

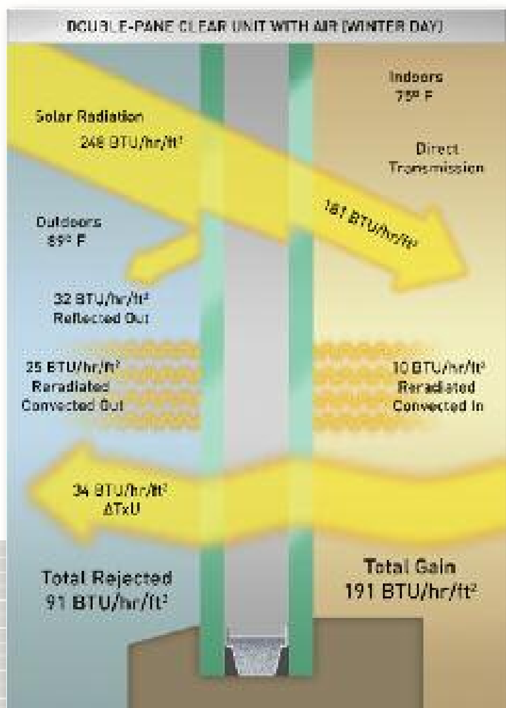


Figure 19-2

Figure 19-3

Thermal Comfort

Traditionally, the thermal comfort near a window could be represented by a comparison of center-of-glass (COG) surface temperatures for different products. Warmer nighttime COG temperatures during the winter and cooler summer day temps were used as an indicator of a more comfortable glass product.

With the introduction of LoĒ-i89® (a roomside low-E coating), the radiant interchange to the room and the occupant is significantly reduced. To compare the comfort aspects of uncoated and low-E coated roomside glass surfaces, it's best to use Mean Radiant Temperature (MRT). MRT can be thought of as a "feels like" temperature; the closer the MRT is to the thermostat setting the better the comfort will be.

A determination of MRT requires knowledge of the window size and occupant position relative to the window. The MRT column shown in the following table assumes a larger size window (e.g., patio door) with the occupant about 3 ft. away. This creates a view factor of 0.40 that is used to calculate MRT at standard winter/summer conditions. The combination of extreme (but not worst-case) geometry and temperature conditions gives an MRT comparison point that should cover the vast majority of situations expected in most residential structures.

Cold Weather Comfort
In general the lower the U-Factor the more comfortable the glass will be. Adding low-E to double- or triple-pane glass improves (lowers) U-Factor and improves the comfort (Figure 20-1). Use of LoĒ-i89 will have a positive effect on MRT. In fact the MRT of a double-pane with LoĒ-i89 is better than the triple-pane with uncoated glass to the roomside.

Hot Weather Comfort
Two glass attributes affect hot weather comfort: MRT and solar heat gain coefficient (SHGC). In hot weather a lower MRT (closer to the thermostat) and a lower solar heat gain provides the best combination for glass comfort. LoĒ-i89 can provide some relief from the absorption heating that's typical of high solar gain products, but it does little to limit solar gain and the risk of overheat during the air-conditioning season.

Figure 20-1 illustrates the winter and summer comfort characteristics of insulating glass (IG) products. All low-E products improve cold weather comfort and the addition of LoĒ-i89 moves all these glass products closer to the comfort of an insulated wall. When it comes to summer comfort, look for Cardinal's solar control low-E coatings: LoĒ^2-272®, LoĒ^2-270®, LoĒ^3-366®, and LoĒ^3-340™.

INDOOR GLASS TEMPERATURES AND RELATIVE HEAT GAINS

Insulating Glass Product	Winter: Center of Glass °F (°C)	Winter: MRT °F (°C)	Summer: MRT °F (°C)	Summer: SHGC
Clear / Clear	**44** (7)	**60** (16)	**81** (27)	**0.78**
Clear / LoĒ-180®	**55** (13)	**64** (18)	**83** (28)	**0.69**
LoĒ^2-272® / Clear	**56** (13)	**65** (18)	**79** (26)	**0.41**
LoĒ^2-270® / Clear	**56** (13)	**65** (18)	**78** (26)	**0.37**
LoĒ^3-366® / Clear	**56** (13)	**65** (18)	**78** (26)	**0.27**
LoĒ^3-340™ / Clear	**56** (13)	**65** (18)	**79** (26)	**0.18**
LoĒ-180® / LoĒ-i89® (#4)	**46** (8)	**68** (20)	**78** (26)	**0.62**
LoĒ^2-272® / LoĒ-i89® (#4)	**47** (8)	**68** (20)	**77** (25)	**0.41**
LoĒ^2-270® / LoĒ-i89® (#4)	**47** (8)	**68** (20)	**77** (25)	**0.36**
LoĒ^3-366® / LoĒ-i89® (#4)	**48** (9)	**68** (20)	**77** (25)	**0.27**
LoĒ^3-340™ / LoĒ-i89® (#4)	**47** (8)	**68** (20)	**77** (25)	**0.17**
Clear / Clear / Clear	**51** (11)	**63** (17)	**82** (28)	**0.70**
LoĒ-180® / Clear / LoĒ-180®	**60** (16)	**66** (19)	**83** (28)	**0.56**
LoĒ^2-272® / Clear / LoĒ-180®	**60** (16)	**66** (19)	**80** (27)	**0.37**
LoĒ^2-270® / Clear / LoĒ-180®	**60** (16)	**66** (19)	**79** (26)	**0.33**
LoĒ^3-366® / Clear / LoĒ-180®	**60** (16)	**66** (19)	**79** (26)	**0.25**
LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)	**52** (11)	**68** (20)	**79** (26)	**0.53**
LoĒ^2-272® / LoĒ-180® / LoĒ-i89® (#6)	**53** (12)	**68** (20)	**78** (26)	**0.36**
LoĒ^2-270® / LoĒ-180® / LoĒ-i89® (#6)	**53** (12)	**68** (20)	**78** (26)	**0.32**
LoĒ^3-366® / LoĒ-180® / LoĒ-i89® (#6)	**53** (12)	**68** (20)	**77** (25)	**0.22**

1) Standard weather conditions used for winter/summer temperature calculations.
2) Assumes occupant near a large window (0.40 view factor).
3) MRT calculated with ASHRAE Standard 55 Thermal Comfort Tool, version 2.0.03.

Figure 20-1

Outdoor Condensation

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

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

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

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

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

- Draperies can be opened to allow as much heat transfer through the glass as possible.
- Trees or buildings can block the radiation view to the sky reducing the chance for outdoor condensation.
- Shrubbery immediately adjacent to the glass can increase the local humidity increasing the chance for outdoor condensation.

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

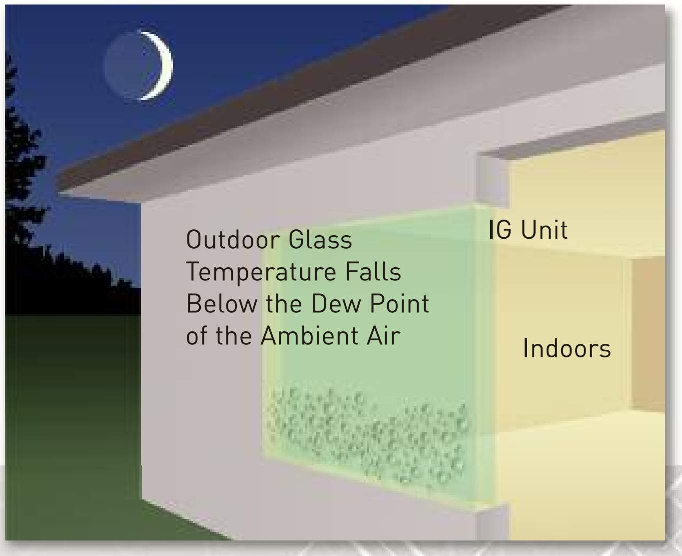


Figure 21-1

If condensation on the exterior of the window is a concern, the use of Cardinal's LoĒ-x89™ coating should be considered. The LoĒ-x89 coating is an Indium Tin Oxide based coating sputtered onto the outdoor surface of an insulating glass (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. This decreases the hours and days with condensa-tion. In addition, this coating has a titanium dioxide coating that becomes hydrophilic when exposed to UV radiation so if condensation forms, the water will sheet allowing better visibility through the water layer.

Indoor Condensation

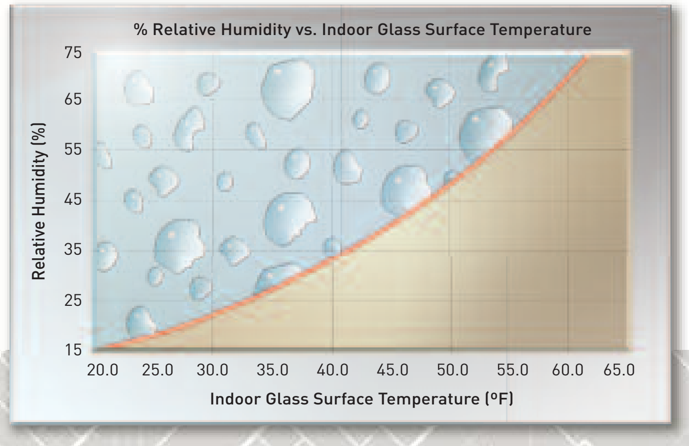
Maintaining a Desirable Humidity Level
People are most comfortable when relative humidity ranges between 20 and 60%. In the home, an average relative humidity of 35 to 40% is appropriate when the outside temperature is 20° F (-7° C) or above. However, during cold weather, higher humidity ranges may cause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

This table (Figure 21-2) 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 21-2

The chart in Figure 21-3 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 21-3

INDOOR CONDENSATION PREDICTABILITY

Outdoor Glass	Airspace mm	Airspace inches	-20° F (-29° C) Outdoor Air Temperature: U-Factor BTU/hr-ft²-°F (W/m²-K)	T_{cog} °F (°C)	%RH	0° F (-18° C) Outdoor Air Temperature: U-Factor BTU/hr-ft²-°F (W/m²-K)	T_{cog} °F (°C)	%RH	+20° F (7° C) Outdoor Air Temperature: U-Factor BTU/hr-ft²-°F (W/m²-K)	T_{cog} °F (°C)	%RH
Clear / Clear	6.5	1/4	**0.53** (3.01)	**34** (1)	26	**0.54** (3.07)	**41** (5)	35	**0.55** (3.12)	**48** (9)	45
	9.8	3/8	**0.49** (2.78)	**35** (2)	28	**0.50** (2.84)	**43** (6)	38	**0.51** (2.90)	**50** (10)	49
	13.0	1/2	**0.48** (2.73)	**37** (3)	30	**0.48** (2.73)	**44** (7)	39	**0.48** (2.73)	**51** (11)	51
	16.0	5/8	**0.49** (2.78)	**37** (3)	30	**0.48** (2.73)	**44** (7)	39	**0.48** (2.73)	**51** (11)	51
Clear / LoĒ-180® (#3)	6.5	1/4	**0.33** (1.87)	**47** (8)	44	**0.33** (1.87)	**52** (11)	53	**0.33** (1.87)	**57** (14)	63
	9.8	3/8	**0.27** (1.53)	**51** (11)	51	**0.27** (1.53)	**55** (13)	59	**0.27** (1.53)	**59** (15)	68
	13.0	1/2	**0.28** (1.59)	**50** (10)	49	**0.26** (1.48)	**55** (13)	59	**0.24** (1.36)	**60** (16)	71
	16.0	5/8	**0.29** (1.65)	**50** (10)	49	**0.27** (1.53)	**55** (13)	59	**0.25** (1.42)	**60** (16)	71
LoĒ²-272® / Clear	6.5	1/4	**0.32** (1.82)	**48** (9)	45	**0.32** (1.82)	**52** (11)	53	**0.32** (1.82)	**57** (14)	63
	9.8	3/8	**0.26** (1.48)	**51** (11)	51	**0.26** (1.48)	**55** (13)	59	**0.25** (1.42)	**60** (16)	71
	13.0	1/2	**0.27** (1.53)	**51** (11)	51	**0.25** (1.42)	**56** (13)	61	**0.23** (1.31)	**61** (16)	73
	16.0	5/8	**0.28** (1.59)	**50** (10)	49	**0.26** (1.48)	**55** (13)	59	**0.23** (1.31)	**60** (16)	71
LoĒ²-270® / Clear	6.5	1/4	**0.32** (1.82)	**48** (9)	45	**0.32** (1.82)	**52** (11)	53	**0.32** (1.82)	**57** (14)	63
	9.8	3/8	**0.26** (1.48)	**51** (11)	51	**0.25** (1.42)	**56** (13)	61	**0.25** (1.42)	**60** (16)	71
	13.0	1/2	**0.27** (1.53)	**51** (11)	51	**0.25** (1.42)	**56** (13)	61	**0.23** (1.31)	**61** (16)	73
	16.0	5/8	**0.28** (1.59)	**50** (10)	49	**0.26** (1.48)	**55** (13)	59	**0.23** (1.31)	**61** (16)	73
LoĒ³-340™ / Clear	6.5	1/4	**0.31** (1.76)	**48** (9)	45	**0.32** (1.82)	**52** (11)	53	**0.32** (1.82)	**57** (14)	63
	9.8	3/8	**0.26** (1.48)	**52** (11)	53	**0.25** (1.42)	**56** (13)	61	**0.25** (1.42)	**60** (16)	71
	13.0	1/2	**0.27** (1.53)	**51** (11)	51	**0.25** (1.42)	**56** (13)	61	**0.22** (1.25)	**61** (16)	73
	16.0	5/8	**0.28** (1.59)	**51** (11)	51	**0.25** (1.42)	**56** (13)	61	**0.23** (1.31)	**61** (16)	73
LoĒ³-366® / Clear	6.5	1/4	**0.31** (1.76)	**48** (9)	45	**0.31** (1.76)	**52** (11)	53	**0.32** (1.82)	**57** (14)	63
	9.8	3/8	**0.26** (1.48)	**52** (11)	53	**0.25** (1.42)	**56** (13)	61	**0.24** (1.36)	**60** (16)	71
	13.0	1/2	**0.26** (1.48)	**51** (11)	51	**0.24** (1.36)	**56** (13)	61	**0.22** (1.25)	**61** (16)	73
	16.0	5/8	**0.27** (1.53)	**51** (11)	51	**0.25** (1.42)	**56** (13)	61	**0.23** (1.31)	**61** (16)	73
LoĒ-180® / LoĒ-i89® (#4)	6.5	1/4	**0.26** (1.48)	**35** (2)	28	**0.26** (1.48)	**42** (6)	36	**0.26** (1.48)	**49** (9)	47
	9.8	3/8	**0.22** (1.25)	**40** (4)	34	**0.22** (1.25)	**46** (8)	42	**0.21** (1.19)	**52** (11)	53
	13.0	1/2	**0.23** (1.31)	**39** (4)	32	**0.21** (1.19)	**46** (8)	42	**0.19** (1.08)	**54** (12)	57
	16.0	5/8	**0.23** (1.31)	**39** (4)	32	**0.21** (1.19)	**46** (8)	42	**0.20** (1.14)	**53** (12)	55
LoĒ²-272® / LoĒ-i89® (#4)	6.5	1/4	**0.26** (1.48)	**36** (2)	29	**0.26** (1.48)	**42** (6)	36	**0.25** (1.42)	**49** (9)	47
	9.8	3/8	**0.22** (1.25)	**40** (4)	34	**0.21** (1.19)	**46** (8)	42	**0.21** (1.19)	**53** (12)	55
	13.0	1/2	**0.22** (1.25)	**40** (4)	34	**0.20** (1.14)	**47** (8)	44	**0.19** (1.08)	**54** (12)	57
	16.0	5/8	**0.23** (1.31)	**39** (4)	32	**0.21** (1.19)	**47** (8)	44	**0.19** (1.08)	**54** (12)	57
LoĒ²-270® / LoĒ-i89® (#4)	6.5	1/4	**0.26** (1.48)	**36** (2)	29	**0.26** (1.48)	**42** (6)	36	**0.25** (1.42)	**49** (9)	47
	9.8	3/8	**0.21** (1.19)	**41** (5)	35	**0.21** (1.19)	**47** (8)	44	**0.21** (1.19)	**53** (12)	55
	13.0	1/2	**0.22** (1.25)	**40** (4)	34	**0.20** (1.14)	**47** (8)	44	**0.18** (1.02)	**54** (12)	57
	16.0	5/8	**0.22** (1.25)	**39** (4)	32	**0.21** (1.19)	**47** (8)	44	**0.19** (1.08)	**54** (12)	57
LoĒ³-340™ / LoĒ-i89® (#4)	6.5	1/4	**0.25** (1.42)	**36** (2)	29	**0.25** (1.42)	**42** (6)	36	**0.25** (1.42)	**50** (10)	49
	9.8	3/8	**0.21** (1.19)	**41** (5)	35	**0.21** (1.19)	**47** (8)	44	**0.18** (1.02)	**55** (13)	59
	13.0	1/2	**0.22** (1.25)	**40** (4)	34	**0.20** (1.14)	**47** (8)	44	**0.18** (1.02)	**55** (13)	59
	16.0	5/8	**0.22** (1.25)	**40** (4)	34	**0.20** (1.14)	**47** (8)	44	**0.18** (1.02)	**54** (12)	57
LoĒ³-366® / LoĒ-i89® (#4)	6.5	1/4	**0.25** (1.42)	**36** (2)	29	**0.25** (1.42)	**42** (6)	36	**0.25** (1.42)	**50** (10)	49
	9.8	3/8	**0.21** (1.19)	**41** (5)	35	**0.20** (1.14)	**47** (8)	44	**0.20** (1.14)	**53** (12)	55
	13.0	1/2	**0.21** (1.19)	**41** (5)	35	**0.20** (1.14)	**48** (9)	45	**0.18** (1.02)	**55** (13)	59
	16.0	5/8	**0.22** (1.25)	**40** (4)	34	**0.20** (1.14)	**47** (8)	44	**0.18** (1.02)	**55** (13)	59
Clear / Clear / Clear	8.0	5/16	**0.34** (1.93)	**46** (8)	42	**0.35** (1.99)	**51** (11)	51	**0.36** (2.04)	**56** (13)	61
	11.5	7/16	**0.31** (1.76)	**48** (9)	45	**0.32** (1.82)	**52** (11)	53	**0.33** (1.87)	**57** (14)	63
LoĒ-180® / Clear / LoĒ-180®	8.0	5/16	**0.17** (0.97)	**58** (14)	66	**0.17** (0.97)	**60** (16)	71	**0.17** (0.97)	**63** (17)	78
	11.5	7/16	**0.14** (0.79)	**60** (16)	71	**0.14** (0.79)	**62** (17)	76	**0.14** (0.79)	**64** (18)	81
LoĒ²-272® / Clear / LoĒ-180®	8.0	5/16	**0.17** (0.97)	**58** (14)	66	**0.17** (0.97)	**60** (16)	71	**0.17** (0.97)	**63** (17)	78
	11.5	7/16	**0.14** (0.79)	**60** (16)	71	**0.13** (0.74)	**62** (17)	76	**0.13** (0.74)	**64** (18)	81
LoĒ²-270® / Clear / LoĒ-180®	8.0	5/16	**0.17** (0.97)	**58** (14)	66	**0.17** (0.97)	**60** (16)	71	**0.17** (0.97)	**63** (17)	78
	11.5	7/16	**0.14** (0.79)	**60** (16)	71	**0.13** (0.74)	**62** (17)	76	**0.13** (0.74)	**64** (18)	81
LoĒ³-366® / Clear / LoĒ-180®	8.0	5/16	**0.16** (0.91)	**58** (14)	66	**0.17** (0.97)	**60** (16)	71	**0.17** (0.97)	**63** (17)	78
	11.5	7/16	**0.14** (0.79)	**60** (16)	71	**0.13** (0.74)	**62** (17)	76	**0.13** (0.74)	**65** (18)	84
LoĒ-180® / LoĒ-180® / LoĒ-i89® (#6)	8.0	5/16	**0.15** (0.85)	**49** (9)	47	**0.15** (0.85)	**52** (11)	53	**0.15** (0.85)	**57** (14)	63
	11.5	7/16	**0.12** (0.68)	**52** (11)	53	**0.12** (0.68)	**55** (13)	59	**0.12** (0.68)	**59** (15)	68
LoĒ²-272® / LoĒ-180® / LoĒ-i89® (#6)	8.0	5/16	**0.14** (0.79)	**49** (9)	47	**0.15** (0.85)	**53** (12)	55	**0.15** (0.74)	**57** (14)	63
	11.5	7/16	**0.12** (0.68)	**52** (11)	53	**0.12** (0.68)	**55** (13)	59	**0.12** (0.68)	**59** (15)	68
LoĒ³-366® / LoĒ-180® / LoĒ-i89® (#6)	8.0	5/16	**0.14** (0.79)	**49** (9)	47	**0.14** (0.79)	**53** (12)	55	**0.14** (0.79)	**57** (14)	63
	11.5	7/16	**0.12** (0.68)	**52** (11)	53	**0.12** (0.68)	**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).

Figure 22-1

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 mm) airspace, 90% argon filled for LoĒ® products, otherwise air-filled cavity. Coatings on surfaces #2, #3, and/or #4.
5) Triple-pane IG construction: 5/16" (8.0 mm) airspace, 90% argon filled for LoĒ® products, otherwise air-filled cavity. Coatings on surfaces #2 and #5, or #2, #4, and #6.
6) All insulating glass systems contain 1/8" (3 mm) glass.
7) COG Values, does not include frame effects.

Solar Energy Transmittance Comparison

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

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

A comparison of the performance of Cardinal's LoĒ® products is shown (Figure 23-1).

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

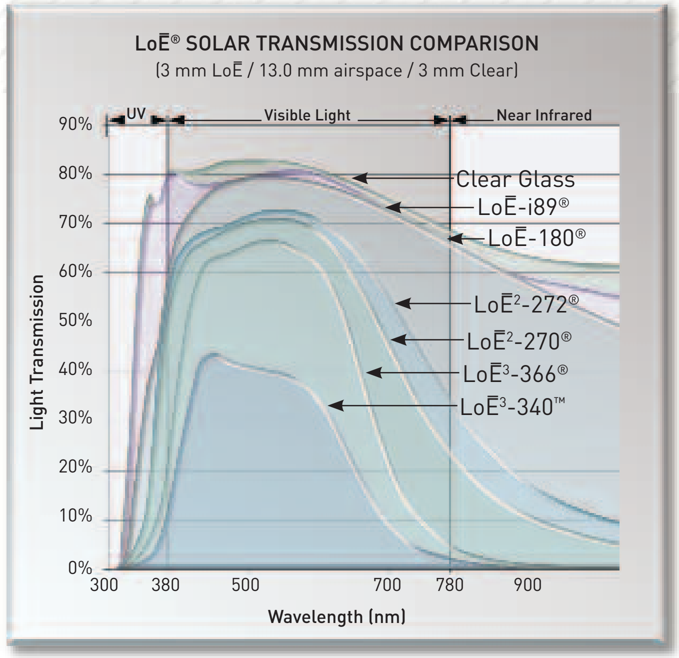


Figure 23-1

Acoustics

The acoustical performance of windows and doors is affected by:

- Glass size
- Glass thickness
- Airspace gap
- Presence of laminated products
- Framing members
- Gaskets, sealants, weather stripping
- Window design

Sound transmission class (STC) measured in decibels (dB) is the standard method for rating sound attenuation characteristics of glass products and window assemblies. The higher the STC rating, the higher the sound attenuation properties of the window. To determine the specific STC rating of a window or door, ASTM E90-09 "Standard Method for Laboratory Airborne Sound Transmission Loss of Building Partitions" should be used.

Using published industry data, Cardinal has developed this table (Figure 23-2) which gives rough estimates on the STC ratings of various glass products. It should be noted that these are only estimates of glass STC ratings, and the final STC rating of the window assembly could vary because of the influence of the acoustical performance of the framing members and the construction of the window assembly.

Estimating STC ratings: To approximate the STC rating of a glass assembly, add the change in STC rating in dB for the property in question to the base line construction condition of 28. For example, increasing the airspace from 6.5 mm to 13.0 mm and increasing the glass thickness of both lites from 3.0 mm to 6.0 mm results in an approximate STC rating of 34 (28 + 2 + 4 = 34).

ACOUSTICAL PROPERTIES

Base line unit construction: STC rating 28
3.0 mm (⅛") Glass/6.5 mm (¼") Airspace/3.0 mm (⅛") Glass

Property	Change in STC rating (dB)	
Increase airspace thickness		
6.5 mm to 13.0 mm	+ 2 dB	
13.0 mm to 25.0 mm	+ 3 dB	
Change glass thickness	**One lite**	**Both lites**
3.0 mm to 6.0 mm	+ 2 dB	+ 4 dB
6.0 mm to 12.0 mm	+ 2 dB	+ 5 dB
3.0 mm to 2.2 mm	- 2 dB	- 3 dB
Mismatch glass thickness increased from 2:1 to 3:1	+ 1 dB	
PVB Laminate addition of 0.8 mm (0.030")	+ 4 dB	
Increase PVB thickness – 0.8 mm to 1.5 mm (0.030" to 0.060")	+ 2 dB	
Replace air with argon	No change	

1) Some of the data above was obtained from the Solutia "Acoustical Glazing Design Guide." For additional information on Acoustics, it is recommended that this Design Guide be used as a reference.

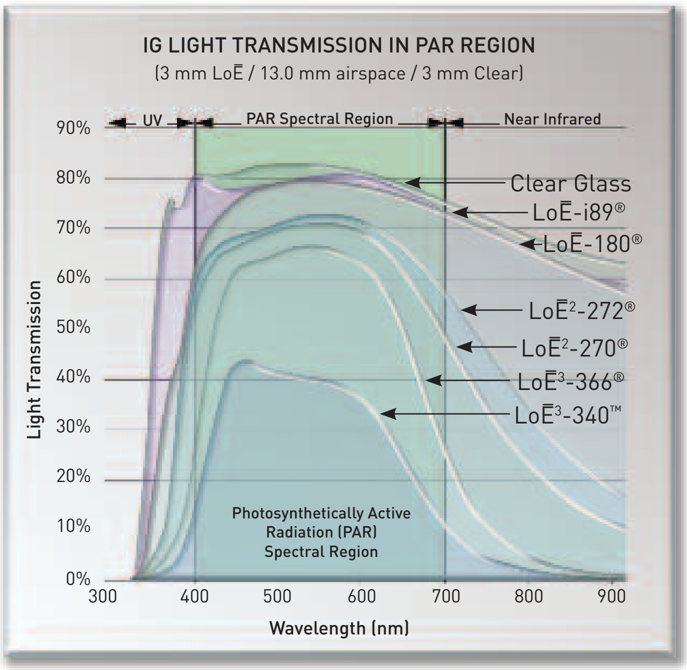
Figure 23-2

Effects of Glass and Coatings on Plant Growth

The most important effect of a glazing system on plant growth is its influence on photosynthesis. Light which drives photosynthesis is called photosynthetically active radiation (PAR) and falls in the spectral range from 400 nm to 700 nm (see Figure 24-1). In essence, the higher the light transmission in the spectral range from 400 to 700 nanometers, the better the glass product is for plant growth.

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

Unlike field crop plants, house plants have the ability to grow in relatively low light conditions. Figure 24-2 below lists the percentage of photons transmitted in the PAR region per Cardinal LoĒ® coating. The majority of the listed coatings will have minimal effects on plant growths, except for LoĒ³-340™. This coating allows only 44% of light to be transmitted through an insulating glass unit, which is equivalent to the amount of light produced during a bright overcast day. Therefore, on cloudy days the rate of photosynthesis could fall to levels which would noticeably slow plant growth. If internal light intensities are marginal, then the use of this coating in an insulating glass unit could result in the inability to grow some house plants.



1) Data calculated using Optics computer program.
2) IG configuration: 1/8" (3 mm) LoĒ® (#2) - 1/2" (13 mm) airspace - 1/8" (3 mm) clear, except for LoĒ-180® coating is on surface #3 and LoĒ-i89® is on surface #4.

Figure 24-1

IG Unit (3 mm / 13.0 / 3 mm)	Percentage of Photons Transmitted in PAR Spectral Region
Clear / Clear	83%
Clear / LoĒ-180®	80%
Clear / LoĒ-i89®	81%
LoĒ²-272® / Clear	73%
LoĒ²-270® / Clear	71%
LoĒ³-366® / Clear	67%
LoĒ³-340™ / Clear	44%

Figure 24-2

Durability

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

Essentials of Manufacturing Long-Lasting IG Units

What makes a long-lasting IG unit?

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

In addition to sealant choice, spacer design and processing are also important. Cardinal uses four bent corners in our construction which requires only one joint in the spacer. Many other IG manufacturers use corner keys to attach the four spacer pieces together. Four joints instead of one significantly increases the potential for moisture ingress into the IG unit.

2. Workmanship
Critical to IG unit longevity is fabrication consistency. There must be no voids allowed in the seal system. Cardinal's unique Intelligent Quality Assurance Program virtually eliminates anomalies in the fabrication process. All inspections rely on carefully calibrated scientific instrumentation, so results are objective. In addition, Cardinal manufactures its own production equipment to ensure that units are fabricated with consistent high quality.

3. 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 that 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.

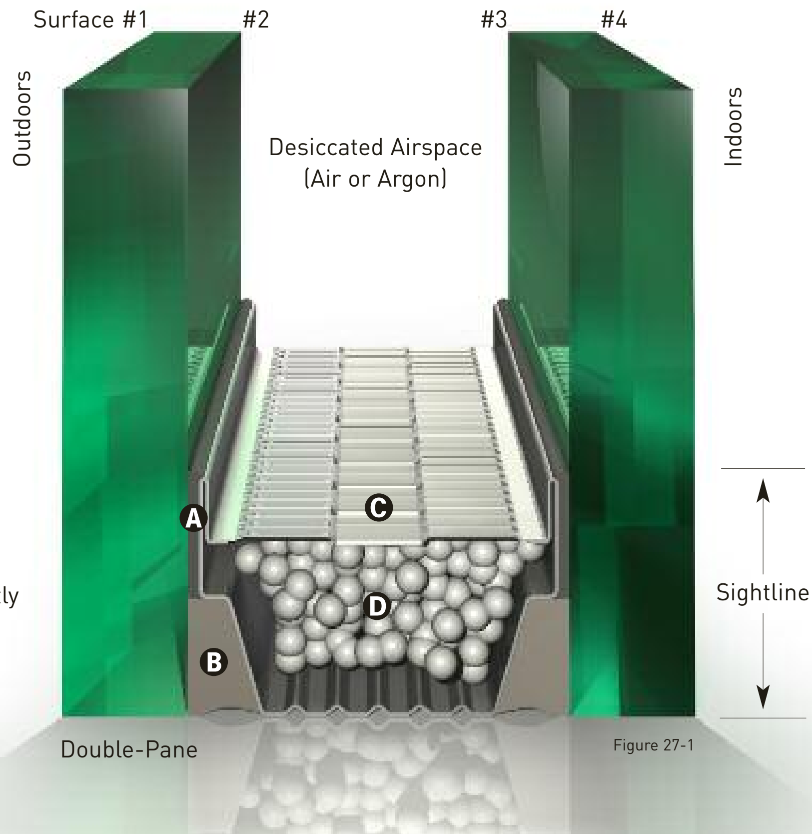


Figure 27-1

Cardinal IG® Unit Construction
Cardinal IG units consist of two or three lites of glass separated by an inorganic metal spacer (Figures 27-1 and 28-1). Spacer corners are bent to be air/gas tight. The spacer contains desiccant which adsorb the moisture vapor within the airspace.

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

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

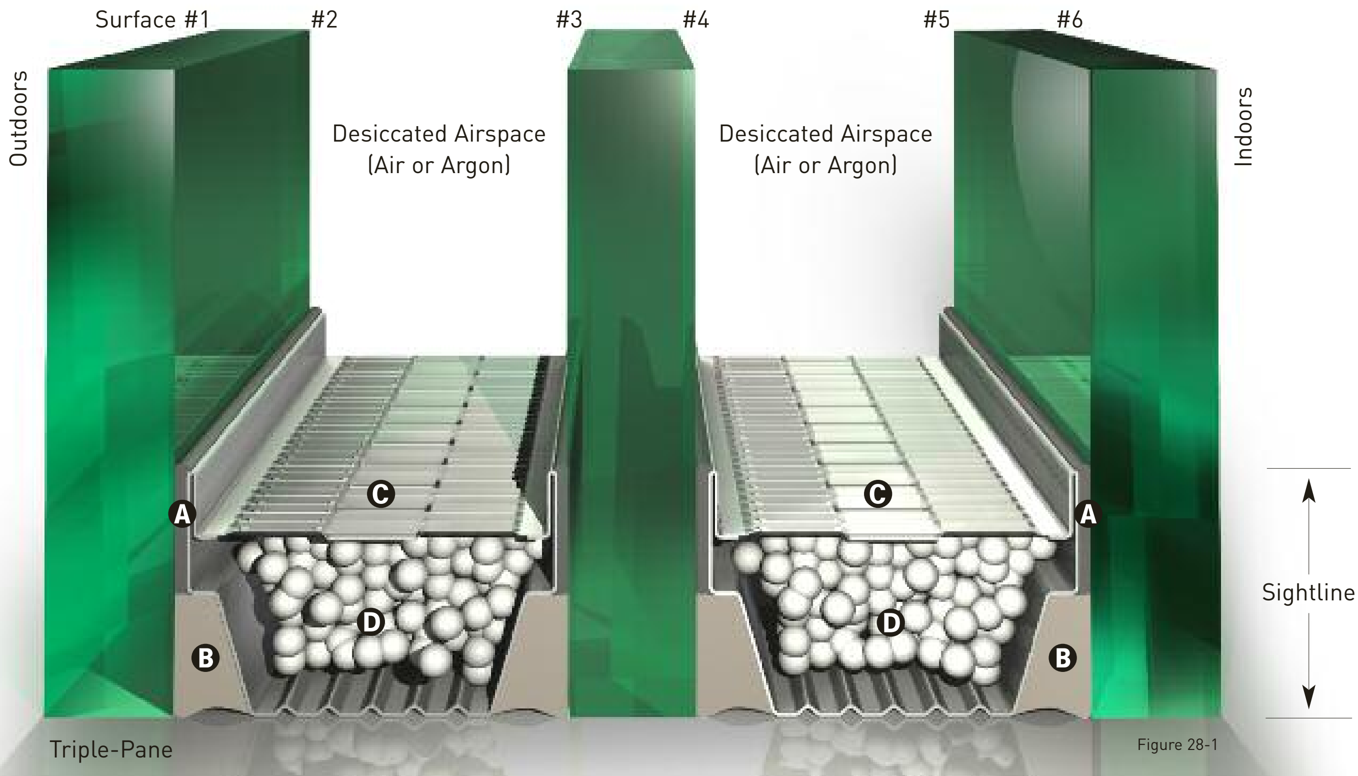


Figure 28-1

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 structural integrity of the IG units.

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

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

Insulating Glass Guide Specifications

The following guide specification is recommended for specifying insulating glass units:

A. Glass

- Float glass. Specify clear, heat absorbing, or LoĒ®, LoĒ^2® or LoĒ^3®.

B. Dual Seal

- PIB Primary Seal
- Silicone Secondary Seal
- Bent Corners

C. Argon Fill

D. Certified in accordance with ASTM Specification E-2190 through:

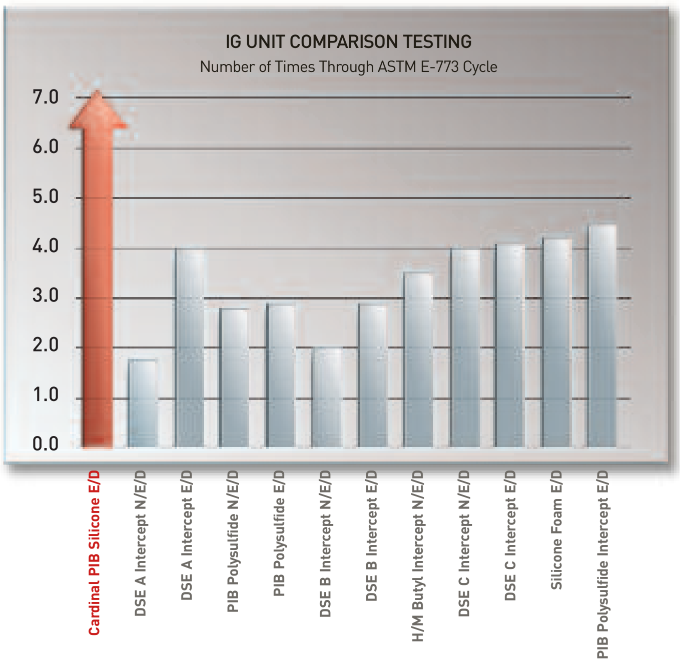
- Insulating Glass Certification Council (IGCC)
- Insulating Glass Manufacturers Alliance (IGMA)

Testing and Field Experience Confirm Cardinal IG® Durability

Cardinal Exceeds Industry Standards

The 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 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. IGCC/IGMA have certified all of Cardinal IG's production facilities for passing this standard.

Cardinal previously tested samples to the industry accepted ASTM E773/774 durability test. This test was a simplified version of E2190. In the graph below (Figure 29-1) it can be seen that Cardinal IG units passed the 15-week test seven times (105 weeks) without failure. All other completive constructions had failed prior to five times through the test. All testing then and today is performed by independent test labs.



1) Cardinal seal had not failed – tests were stopped
2) DSE – Dual Seal Equivalent
3) N/E/D – Non-Edge Deleted
4) E/D – Edge Deleted

Figure 29-1

Cardinal IG Units Excel in Rigorous P-1 Test

Cardinal also subjects IG units to the more demanding P-1 test – an industry accepted test – to determine long-term seal durability. Test conditions simulate worst-case, real-world scenarios: 140° F (60° C), constant UV exposure and 100% humidity. Results show that competitive seal systems fail within eight to 22 weeks of testing (Figure 29-2). However, Cardinal IG units still have a dew point below 0° F (-18° C) after 80 weeks of the test.

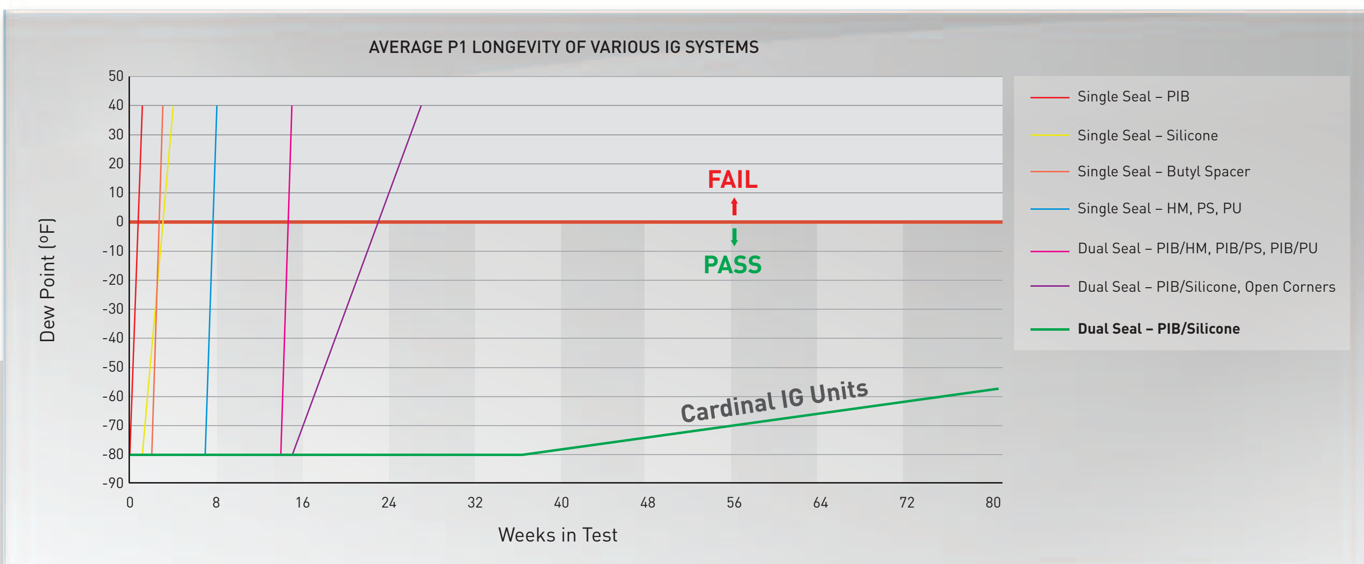


Figure 29-2

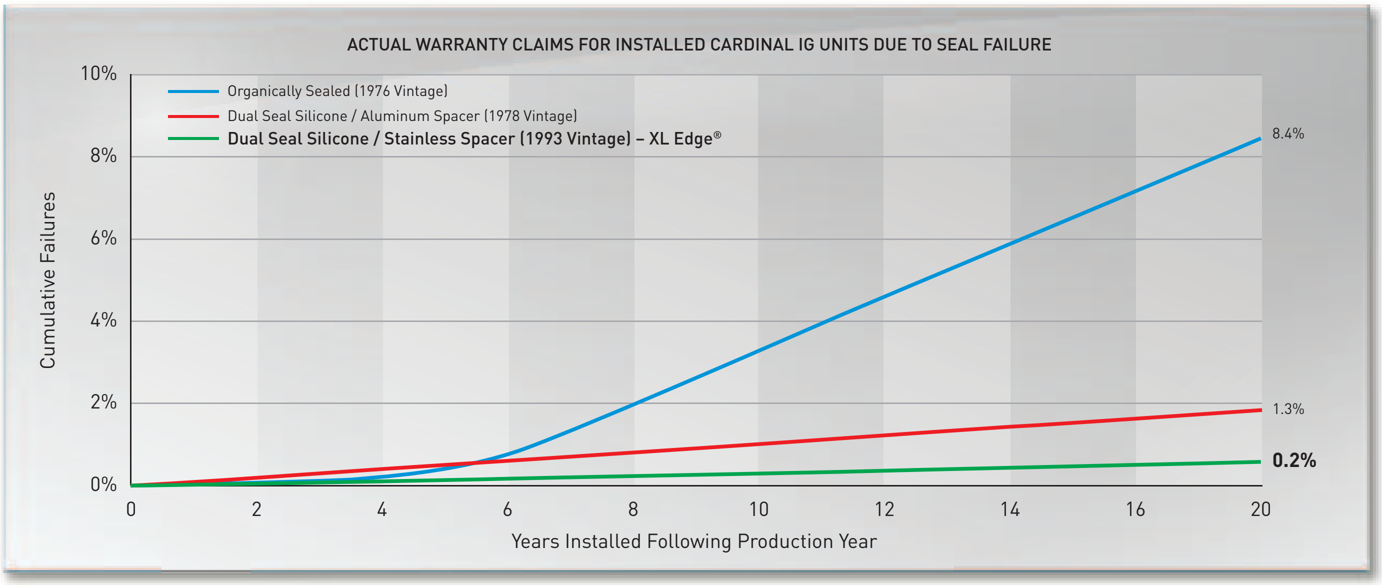


Figure 30-1

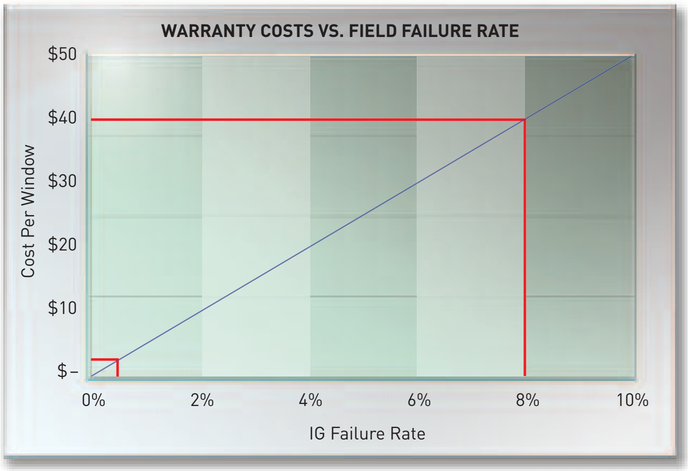
Thermal Cycling
Cardinal subjects their units to more severe thermal cycling exposures than the E2188/2190. Our testing immerses the entire sample in an environment that cycles from -30º F to +177º F (-34° C to 81° C) five times per day. Full immersion, as opposed to single-sided exposure of the ASTM test, along with the wider temperature range significantly increases the severity of the test. Cardinal units last greater than 1000 cycles (ASTM 2188/2190 250 cycles) in this environment while maintaining a low dew point in the unit.

Cardinal's Seal Failure Experience
Figure 30-1 shows Cardinal's field failure rate comparing failures to industry-wide failure rates, Cardinal Dual Organic Seals with Aluminum Spacers, Dual Seal Silicone with Aluminum Spacers and Dual Seal Silicone with Stainless Steel Spacers. Cardinal's 20-year failure rate with our products are as follows:

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

The graph shows Cardinal's actual failure rates for three different IG unit constructions. In 1993, Cardinal introduced a stainless steel spacer with a 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 seal failure rate of the stainless steel spacer product is 0.2% after 20 years of field service. Cardinal has hundreds of millions of IG units under warranty.

What this means to the window manufacturer is shown in Figure 30-2. Assuming a $500 service call to replace a failed IG unit under warranty, and with an 8% seal failure rate, the window manufacturer would need to add $40 to the cost of the window to cover warranty costs. With a 0.2% seal failure rate, the window manufacturer would need to add $1.25 to the window to cover warranty claims.



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

Figure 30-2

Edge Deletion Assures Proper Sealant-to-Glass Bonding

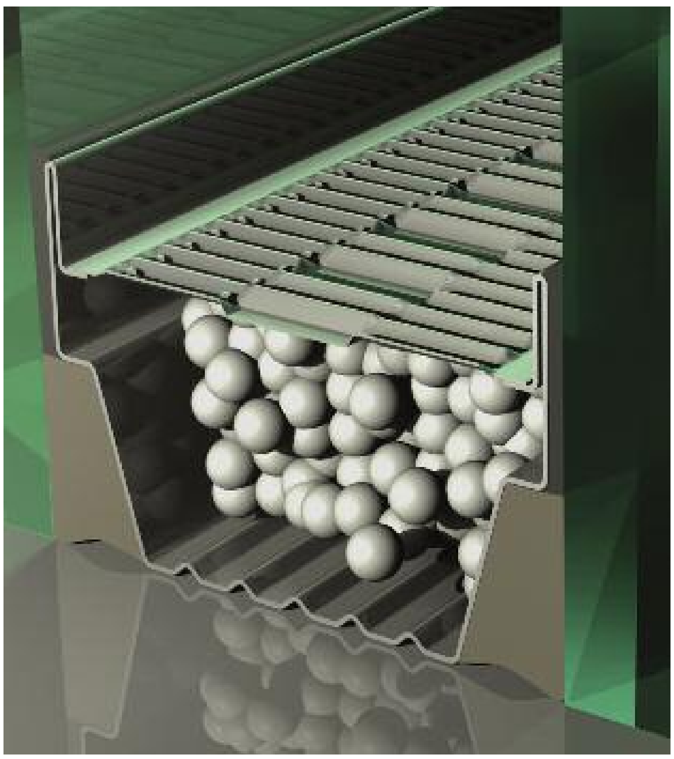
By deleting the edge of LoĒ® coatings, Cardinal provides the added safety that the IG unit sealants are bonded to glass rather than a coating. Without edge deletion all low-E coatings extend to the edge of the glass, and corrosion of the coatings can propagate past the seal system when the IG unit is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

Chemical Fog

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


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


Chemical Fog



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. It will later desorb with temperature causing an exaggerated expansion and contraction of the IG unit with temperature, decreasing 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.

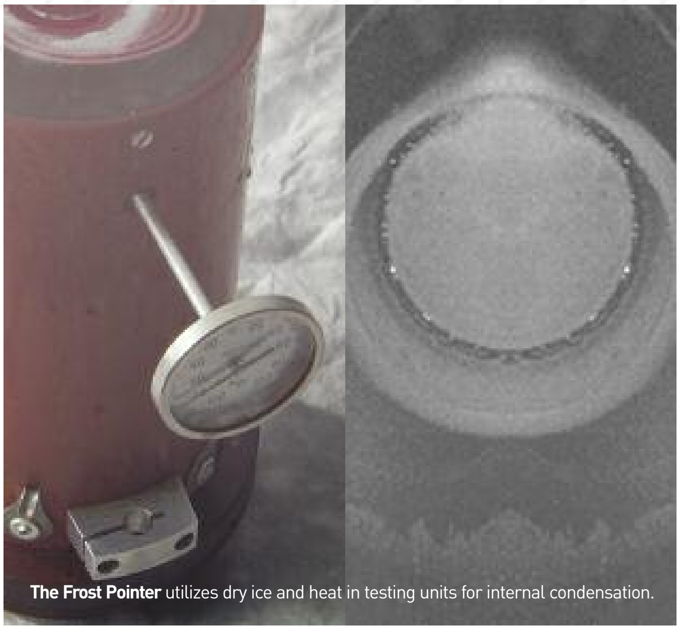
Stainless Steel Spacer Minimizes Seal Stress and Argon Loss

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 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.

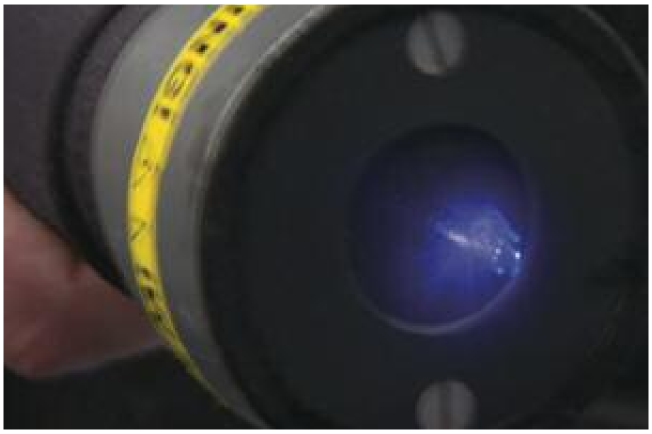
Laser Logo shows certification



The Frost Pointer utilizes dry ice and heat in testing units for internal condensation.

Argon Gas Measurement

Cardinal maintains a state-of-the-art facility for measurement of IG argon gas concentration. Cardinal has developed and patented methods to assure that the spark emission spectroscopy used to measure argon gas concentration is accurate and repeatable.



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 (TSB) at www.cardinalcorp.com. These TSBs describe in great detail use and performance of Cardinal IG units.

Energy Sa

Cardinal LoĒ® energy-efficient glass can significantly reduce energy consumption in both hot and cold climates, saving homeowners money on heating and cooling. Reduced energy consumption is also good for the environment – it reduces greenhouse gas emissions by millions of tons each year.

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Test House Studies Confirm that LoĒ^{2}® Glass Reduced Heating and Cooling Energy Usage by 20%

HOUSE A (Clear IG)

HOUSE B (LoĒ^{2}®)

Figure 35-1

To obtain this proof, Cardinal authorized three long-term studies in locations across the country – California, Texas and Indiana. Identical new houses (Figure 35-1) were purchased in each location, and the effects of different glazings on heating and cooling energy usage were scientifically measured and monitored by outside experts.*

Test House Protocol
All houses were new, identical and unoccupied

- Energy attributes inspected during construction
- Fully commissioned to ensure equivalency:

  Blower door tests
  Co-heat tests
  Sealed ducts
  Air conditioner
  baseline studies

Complete monitoring

- 24 hours a day, 365 days a year
- On-site weather stations including solar radiation
- Room-by-room temperatures
- HVAC performance and energy consumption

Occupant simulation

- Internal heat gain
- Moisture generation
- Ventilation

In every case, the test projects demonstrated conclusively that LoĒ^{2}® IG products can reduce energy consumption, saving homeowners money on heating and cooling bills while making homes more comfortable year-round. Builders can save money on the cost of heating and cooling equipment.

Projections from these results show that LoĒ^{3}-366® will expand on these savings.

Energy Savings of Up to 20%
When compared with various glass types – such as high solar gain low-E (HSLE), tinted and clear glass – LoĒ^{2}® saved energy on combined heating and cooling in every test site. Total annual savings ranged from 15 to 20% (Figure 35-2).

See www.cardinalcorp.com for more information on these studies and information on the energy savings provided by Cardinal products.

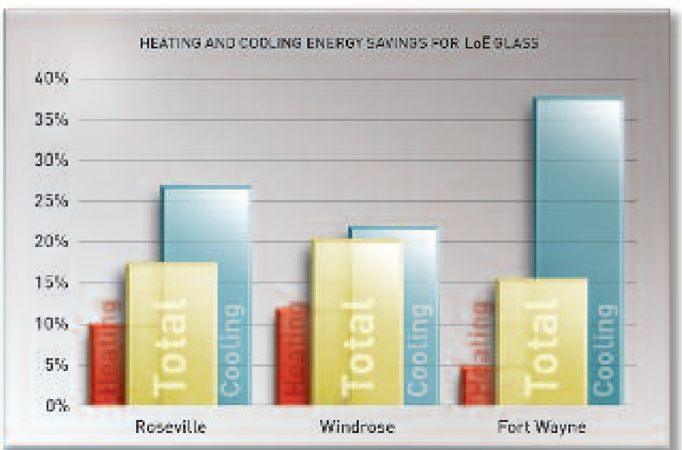


Figure 35-2

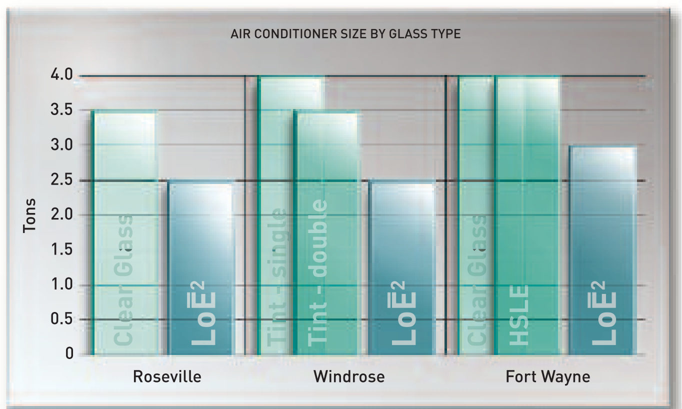
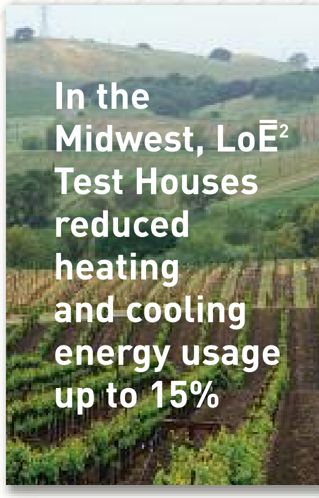


Figure 35-3

* All three projects were managed by Bruce A. Wilcox, P.E. In addition to project management, Wilcox was responsible for the experimental design and analysis of the data collected. Ken Nittler of Enercomp assisted in the data analysis with window modeling and Micropas simulations of the home designs. Chip Barnaby of Wrightsoft assisted in sizing calculations for the heating and cooling equipment. John Proctor of the Proctor Engineering Group verified the air-conditioning system performance. Rick Chitwood of Chitwood Energy Management did additional HVAC and envelope commissioning. Ed Hancock and Greg Barker of Mountain Energy Partners installed the data collection systems. Aeroseal tested and sealed the ductwork. Ren Anderson of the National Renewable Energy Laboratory (NREL) provided assistance on the infrared thermographs. Building America partners, Building Science Corporation and IBACOS, have documented construction details and provided comfort measurements. Energy Sense of Houston provided site assistance for the Windrose project. Joe Driver of Fremont, Indiana, managed the site operations for the Fort Wayne project. All comparisons made to a baseline of a double-paned IG unit with clear glass, air fill and no LoĒ coatings.



Significant HVAC Savings

Clear or tinted glass creates 50 to 60% of the cooling load. But because LoĒ^2 glass cuts solar heat gain in half, project houses were able to utilize smaller air-conditioning units and maintain proper temperatures (Figure 35-3). All tests validated the A/C sizing calculations. The equipment savings realized – typically one ton or up to $1,000 per house – would normally be enough to more than offset the increased cost of LoĒ^2 glass.

Solar control windows can cut air-conditioning peak loads in all climates, and in all house sizes. For example, in a 4,000-square-foot home, LoĒ^2 can reduce the cooling load by nearly 2.5 tons, compared with clear glass. Our next generation product, LoĒ^3-366®, can save nearly one additional ton in this house compared to LoĒ^2.

With the air conditioner now properly sized, better dehumidification was also achieved throughout the cooling season. And a smaller A/C unit running full time is more efficient – it uses less energy and improves comfort.

Improved Comfort Year-Round

The energy savings aspect of LoĒ^2 glass is only part of the story. Comfort is equally important, and LoĒ^2 glass improved comfort year-round.

- Warmer glass in winter
- Cooler rooms during the "swing" seasons
- More comfortable rooms in direct sun

Residential Building Energy Codes, ENERGY STAR® for Windows and Green Building Programs

Building Codes

Building codes define residential as: detached one- and two-family houses and multi-family dwellings not more than three stories above grade in height. A high-rise apartment or condominium falls under the purview of the commercial construction codes.

Model residential building codes are used in both the U.S. and Canada as templates for local jurisdictions (states or provinces). The International Code Council (www.iccsafe.org) oversees U.S. model codes; the latest iteration of the U.S. energy code is the 2012 International Energy Conservation Code (IECC). A committee of the National Research Council sets the standards for Canada (see http://www.nationalcodes.nrc.gc.ca). Canada's energy code was last updated in 2010.

Code adoption at the state, province or local levels usually lags behind the updates to model codes. Window manufacturers should look to the latest code to understand and prepare for upcoming design changes needed for code compliance. This website gives an overview of current code levels across the U.S.: http://www.energycodes.gov/adoption/states.

Canada allows for two compliance options: meet the prescriptive U-Factor or minimum Energy Rating (ER). For the heating dominated climates represented by most of Canada, ER combines the benefit of passive solar gain as a trade-off against insulating value. Note that this doesn't account for air-conditioning nor does it consider the potential for thermal discomfort associated with poorer U-Factors and high solar gain.

ENERGY STAR®

ENERGY STAR® for Windows is a voluntary program for manufacturers and looks to the latest version of the model code to set stringency levels for residential windows that are "better than code." Version 6 of U.S. ENERGY STAR is scheduled to be effective in January of 2015 and Version 4 of the Canadian program will be effective in February of 2015.

The energy code defines eight different climate zones across the North American continent (Zone 1 = south, Zone 8 = north). U.S. ENERGY STAR combines the zones within the lower 48 states into four zones. Canada ENERGY STAR calls out three zones. Note that the climate zones at the U.S.-Canada border are "mixed." The same window may not be compliant on both sides of the border.

U.S. ENERGY STAR Climate Zones

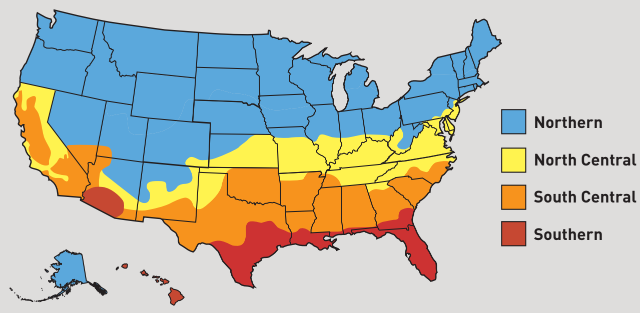


Figure 37-1

U.S. ENERGY STAR REQUIREMENTS FOR WINDOWS		
Zone	U-Factor (IP)	SHGC
Northern	≤ 0.27	any
North Central	≤ 0.30	≤ 0.40
South Central	≤ 0.30	≤ 0.25
Southern	≤ 0.40	≤ 0.25

1) U and SHGC must be rated per NFRC (www.nfrc.org).
2) Criteria per Version 6, Draft 2.
3) Marine 4 (Pacific coast) uses Zone 5 criteria.
4) Trade-up to a U-Factor of 0.30 is allowed with high solar heat gain.

Figure 37-2

GENERIC MINIMUM COMPLIANCE GUIDELINES FOR THE U.S. ENERGY STAR WINDOWS	
Zone	Compliance Guideline
Northern	Class 2 or 3 window with any LoĒ plus LoĒ-i89
North Central	Class 2 or 3 w/LoĒ^2 or LoĒ^3
South Central	Class 2 or 3 w/LoĒ^3
Southern	Class 1 or better w/LoĒ^3

1) See Page 16 for Cardinal window class definitions.

Figure 37-3

Canada ENERGY STAR Climate Zones

Figure 38-1

CANADA ENERGY STAR REQUIREMENTS FOR WINDOWS		
Zone	U-Factor (SI)	or ER
3	≤ 1.2	≥ 34
2	≤ 1.4	≥ 29
1	≤ 1.6	≥ 25

1) U and SHGC must be rated per NFRC (www.nfrc.org) or CSA A440.2 (www.csagroup.org).
2) Criteria per Version 4.

Figure 38-2

GENERIC MINIMUM COMPLIANCE GUIDELINES FOR CANADA ENERGY STAR WINDOWS	
Zone	Compliance Guideline
3	Class 3 (3-Pane) w/any LoĒ
2	Class 3 (2-Pane) w/LoĒ-180
1	Class 3 (2-Pane) w/any LoĒ **or** Class 2 or 3 (2-Pane) w/LoĒ-180

1) See Page 16 for Cardinal window class definitions.

Figure 38-3

Both ENERGY STAR programs call out U-Factors consistent with better frame designs and double- or triple-pane IG with low-E and argon fill (see window U-Factor discussions on page 16). Solar heat gain (SHGC) requirements in North Central, South Central and Southern zones can be satisfied with LoĒ^3-366®. In most instances Northern U.S. windows will require the addition of a 4th surface low-E product like LoĒ-i89®, or triple-pane glass. In Canada's furthest north, better performing triple-panes will be needed, while the most populous sections of the country can utilize better performing double-panes with a high solar gain low-E such as LoĒ-180®. Canada's ER protocol does not provide credit to LoĒ-i89® (despite a U-Factor reduction, the slight reduction in SHGC with a 4th surface low-E negates any rating improvement when heating is the only attribute).

Green Building Programs

Programs such as LEED for Homes and the NAHB National Green Building Standard set criteria in three areas of building design and construction practice:

- Sustainable building designs (materials resourcing and site plans)
- Energy efficiency
- Water efficiency

One tenet of all green programs is that the building must first comply with energy code. Additional credit is awarded for better energy efficiency, but as this is tied to whole building performance, it's difficult to make a specific statement as to what level of additional window performance is desired. In general the credit available for energy efficiency in windows is small compared to the other categories.

In the past these green programs allowed the glass industry to claim credit for internal recycling efforts (cullet) in the production of float glass. Cullet is now considered a pre-consumer industrial reuse that no longer qualifies for much of a recycling credit.

ENERGY STAR® Homes and the Passive House Institute are two examples of advocacy programs that push for building efficiency levels significantly beyond the model energy code. Most "above code" building programs will require a home energy rating (HERS score) from an independent home energy rater. The scores are developed using computer simulation of energy consumption specific to the particular design, location and orientation. Beyond improved windows these programs emphasize excellent air sealing, advanced insulation for walls, ceilings and foundations, and high-efficiency HVAC equipment.

Design C

The criteria in this section should be considered when designing windows. The data presented should help the design professional make a more informed decision for his or her particular circumstances.

riteria

Glass Types

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

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

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

Heat-Strengthened and Tempered Glass Manufacturing

Heat-strengthening and glass tempering are processes of heating annealed glass to approximately 1200° 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.

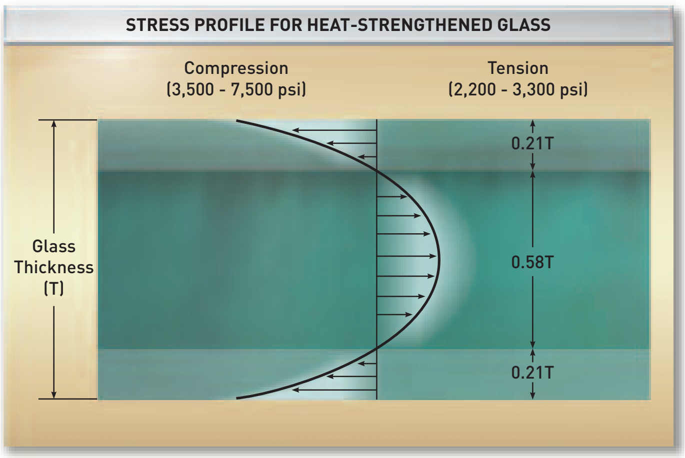


Figure 41-1

Figure 41-3

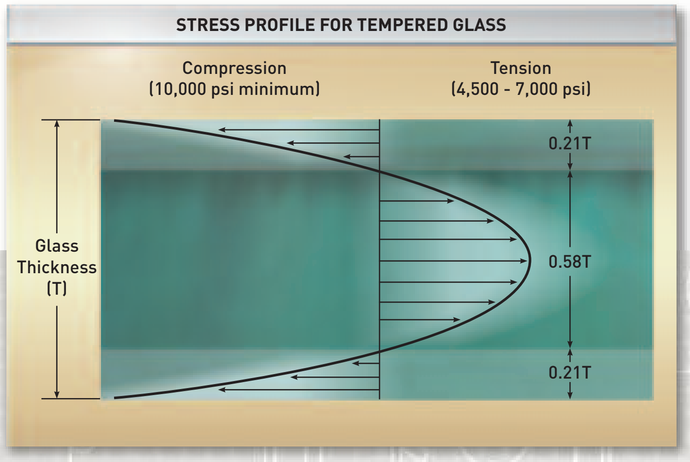


Figure 41-2

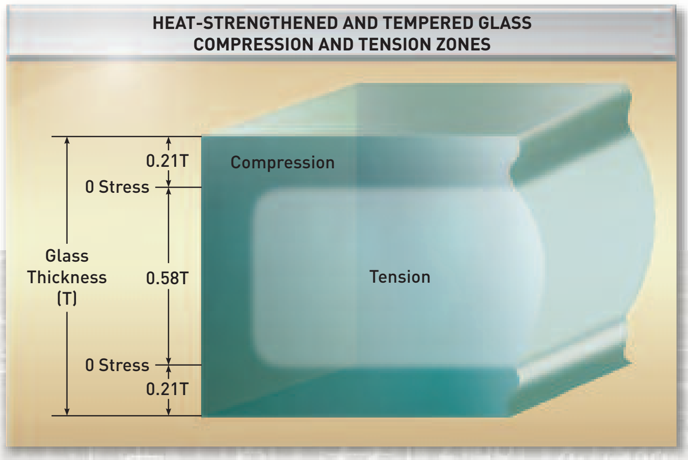


Figure 41-4

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 C1048-12. 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

It is Cardinal's intent to control and minimize distortion levels in processes under our control. The glazing system, temperatures and pressures greatly influence the amount of distortion. It is recommended that 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.

Glazing Considerations

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

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

Setting blocks should be low in or free of migrating organic plasticizers, which should be confirmed with the block supplier. Some organic plasticizers have the potential to migrate into and damage the insulating glass sealants. Some block materials can discolor other insulating glass components. If discoloration is a concern, ASTM C-1087 can be used to screen components. The compatibility of the setting block should be verified with the block supplier and Cardinal IG.

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

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

Glass Thickness Nomenclature
The glass industry has used a soft conversion method to designate flat glass product thickness in metric. To more accurately describe the actual glass thickness for products presented in this brochure, the specific metric thickness will be used. This does not represent a change in glass thickness, but a more accurate depiction of the thickness traditionally used. Listed below (Figure 42-1) is a comparison of specific metric thickness, the nominal glass thickness in inches and the traditional designation.

Specific Metric Thickness	Target Glass Thickness	ASTM Designation	Traditional Designation
2.2 mm	0.087 inches	2.5 mm	Single-Strength
2.3 mm	0.092 inches	2.5 mm	Single-Strength
3.0 mm	0.117 inches	3 mm	Double-Strength, ⅛ inch
3.1 mm	0.122 inches	3 mm	Double-Strength, DST, ⅛ inch
3.9 mm	0.153 inches	4 mm	5/32 inch
4.0 mm	0.160 inches	4 mm	5/32 inch
4.7 mm	0.187 inches	5 mm	3/16 inch
5.7 mm	0.223 inches	6 mm	¼ inch

Figure 42-1

IG UNIT SIZE LIMITS

Glass Thickness inches (mm)	Minimum Recommended Short Side Dimension for Argon Filled Unit[2] inches (mm)	Annealed Glass: Maximum Long Dimension inches (mm)	Annealed Glass: Maximum Area[3] (ft^2) (m^2): Aspect Ratio Less than 2	Annealed Glass: Maximum Area[3] (ft^2) (m^2): Aspect Ratio Greater than 2	Heat-Treated Glass: Maximum Short Dimension inches (mm)	Heat-Treated Glass: Maximum Long Dimension inches (mm)	Heat-Treated Glass: Maximum Area[3] ft^2 (m^2)	Weight: IG Unit Weight Approximation lbs/ft^2 (kg/m^2)
3/32 (2.2)	10 (254)	70 (1778)	10 (0.9)	8 (0.7)	36 (914)	70 (1778)	15 (1.4)	2.4 (11.7)
1/8 (3.0)	12 (305)	80 (2032)	15 (1.4)	13 (1.2)	36 (914)	80 (2032)	20 (1.9)	3.2 (15.6)
5/32 (3.9)	14 (356)	90 (2286)	24 (2.2)	20 (1.9)	48 (1219)	90 (2286)	30 (2.8)	4.2 (20.5)
3/16 (4.7)	18 (457)	100 (2540)	33 (3.1)	27 (2.5)	60 (1524)	100 (2540)	50 (4.6)	5.0 (24.4)
1/4 (5.7)	24 (610)	120 (3048)	45 (4.2)	37 (3.3)	84 (2134)	144 (3658)	60 (5.6)	6.5 (31.7)

1) Limits shown do not apply to shapes or units fabricated with mismatched glass thickness.
2) Minimum dimensions do not apply to breather tube units.
3) Maximum area based on 40 psf (1.92 kPa) design windload (3-second duration), manufacturing, and/or safe handling limit.
4) This chart applies to double-pane IGUs.
5) The suggested limit on maximum short dimension for heat-treated glass is based on reducing the potential of bi-stable glass (oil canning and soft centered).
6) The maximum short and long dimension for 1/4" (5.7 mm) glass is based on the size of the tempering line.
7) These are guidelines only and are not a substitute for the ASTM standard E1300.
8) Revised 7-18-14.

Figure 43-1

Inert Gas Filling

Inert gases; i.e., argon and krypton, have been used in 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 approximately 600 times the price of argon, and that is the main reason why krypton is used sparingly compared to argon. Since argon and krypton gases are inert and very pure in commercial grades, there should not be a concern over chemical reactions with other materials used in an insulating glass unit or window.

IG UNIT MAXIMUM DIMENSION PER AIRSPACE

Airspace Dimension inches (mm)	Maximum Long Dimension inches (mm)	Maximum Area ft^2 (m^2)
1/4 (6.5)	80 (2032)	20 (1.9)
5/16 (8.0)	90 (2286)	30 (2.8)
3/8 (9.8)	100 (2540)	50 (4.6)
≥7/16 (≥11.5)	144 (3658)	60 (5.6)

Figure 43-2

In 1988, Cardinal developed and patented a state-of-the-art process for argon filling of insulating glass units. Recognizing the need to determine the specific argon fill levels in IG units, Cardinal has installed on-line argon measuring equipment using spark emission spectroscopy (SES) technology from Sparklike, Ltd.

Gas Fill Levels

The insulating glass 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. With close to 20 years of argon filling testing and manufacturing experience, Cardinal believes that its IG units will have an initial average argon fill level of 90% or greater.

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.

Cardinal certifies its insulating glass products affirming that they are constructed similarly to specimens that were audited, tested and found to pass the stated requirements of IGMA (Insulating Glass Manufacturers Alliance) and IGCC (Insulating Glass Certification Council). To indicate that a manufacturer meets the argon fill level requirements, a manufacturer must have an average initial argon fill level of 90% for test specimens and an average of 80% after exposure to the ASTM E-2190 weathering cycle. Cardinal meets these requirements as listed in the IGCC Certified Products Directory.

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

Safety Glazing

Safety glazing may be required to meet any 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-97.1-2009, CPSC 16CFR 1201 cat. I and CPSC 16CFR 1201 cat. II, as listed below (Figure 44-1).

SAFETY GLAZING STANDARDS

	ANSI Z-97.1-2009	CPSC 16CFR 1201 cat. I	CPSC 16CFR 1201 cat. II
Use of Standard	To test and identify glasses as safety glazing materials which will be used in locations where required in building codes. Monolithic annealed glass in any thickness is not considered a safety glazing material under this standard.	To test and identify glasses as safety glazing materials which will be used in any location that is subject to human impact resistance requirements (limited to products having an area not greater than 9 sq. ft.)	To test and identify glasses as safety glazing materials which will be used in any location that is subject to human impact resistance requirements (unlimited size)
Impact Test Requirements	Class A: 100# bag dropped from height of 48" Class B: 100# bag dropped from height of 18" Class C: 100# bag dropped from height of 12"	100# bag dropped from height of 18"	100# bag dropped from height of 48"
Evaluation Criteria for Tempered Glass to Pass Standard	a. If fracture occurs at the specified Class drop height, the 10 largest crack-free particles shall not weigh more than 10 square inches of the glass tested, b. If no fracture occurs from the standard bag drop test, then the glass shall be broken using either 1) sharp impactor such as a pointed hammer or 2) using a spring loaded center punch. The criteria described in (a) above is used for pass/fail criteria	a. No fracture at 18 inches or, b. If fracture occurs, the 10 largest crack-free particles shall not weigh more than 10 square inches of the glass tested	a. No fracture at 48 inches or, b. If fracture occurs, the 10 largest crack-free particles shall not weigh more than 10 square inches of the glass tested
Evaluation Criteria for Laminated Glass to Pass Standard	a. No fracture at specified Class drop height or, b. If fracture occurs at the specified Class height, no hole through which a 3-inch diameter sphere will freely pass is allowed	a. No fracture at 18 inches or, b. If fracture occurs, no hole through which a 3-inch diameter sphere will freely pass is allowed	a. No fracture at 48 inches or, b. If fracture occurs, no hole through which a 3-inch diameter sphere will freely pass is allowed

Figure 44-1

Thermal Stress and Glass Breakage

When window glass is warmer at the center relative to the edge as shown below (Figure 45-1), 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 Heat Transfer Guidelines.

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

1. Cold Winter Night

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

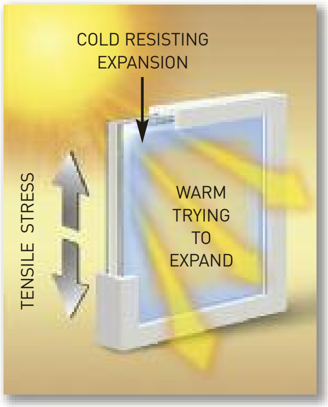


Figure 45-1

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 tend to trap and/or reflect heat back at the glass, further increasing the glass temperatures. In either case, the effect of solar loads on the edge temperatures is minimal. This may lead to higher stress potentials than the winter nighttime conditions if the solar absorptance of the interior lite is greater than that of clear glass.

3. Hot Summer Day with High Solar Load

Clear glass with its low solar absorptance is not affected by these conditions. Absorbing glasses (i.e., LoĒ® coated and/or tinted) can see a greater heat build-up 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, LoĒ), glass size and thickness, degree and type of shadow pattern, outdoor temperature extremes and time of the year all influence the amount of thermal edge stress. If thermally induced stress is high enough, glass fracture could occur. In most applications, thermal stresses caused by the above are not high enough to cause breakage of heat-treated glasses but could cause breakage of annealed glass. Cardinal offers a glazing review on projects to recommend specific glass types and treatment to reduce the potential of thermal breakage.

Indoor Shading

Draperies, venetian blinds or other interior shading devices must be hung so as 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 outlets must be to roomside of shading device.

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

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

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

Figure 45-2

Windloads and Insulating Glass Size Limits

The windload data presented (Figures 46-2, 46-3, 46-4, 46-5 and 46-6) is based on ASTM Standard E1300 (Standard Practice for Determining Load Resistance of Glass in Buildings) for annealed glass.

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

Breakage probability for insulating glass is 8/1000 units. By definition, breakage of either lite in an insulating glass unit constitutes unit breakage. The 8/1000 unit breakage probability is the combined probability for both lites when the unit is exposed to design load.

How to use the windload chart and design factors:

- Locate the long dimension and short dimension on the chart.
- Draw a vertical line from the long dimension and a horizontal line from the short dimension.
- At the point where these lines intersect, interpolate between the windload (kPa) contours to determine the allowable windload. For windload in PSF, use the conversion factor in chart.
- If an IG construction other than annealed-annealed is to be used, determine the windload for the annealed-annealed glass with the appropriate glass thickness, and multiply this windload by the appropriate load factor (see Load Factors Figure 46-1 below).

Load Factors	
Annealed / Annealed	1.00
Heat-Strengthened / Annealed	1.11
Heat-Strengthened / Heat-Strengthened	2.00
Heat-Strengthened / Tempered	2.11
Tempered / Tempered	4.00

1) Heat-strengthened glass to have a surface compression between 24.1 MPa (3,500 psi) and 51.7 MPa (7,500 psi).
2) Tempered glass to have a surface compression of 69 MPa (10,000 psi) minimum.
3) Duration of load is three seconds.
4) 8/1000 probability of failure.

Figure 46-1

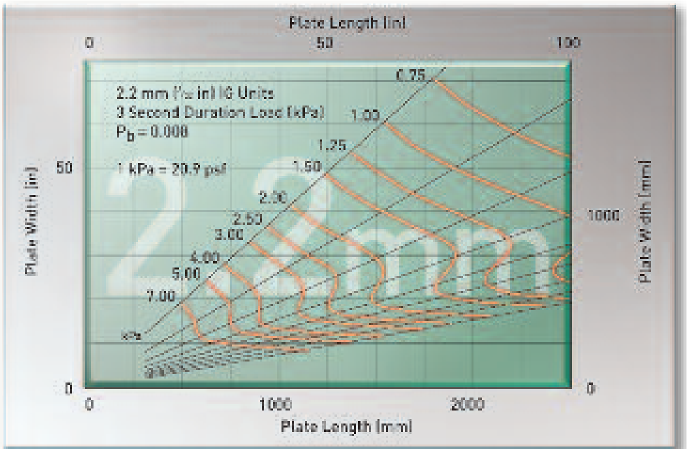


Figure 46-2

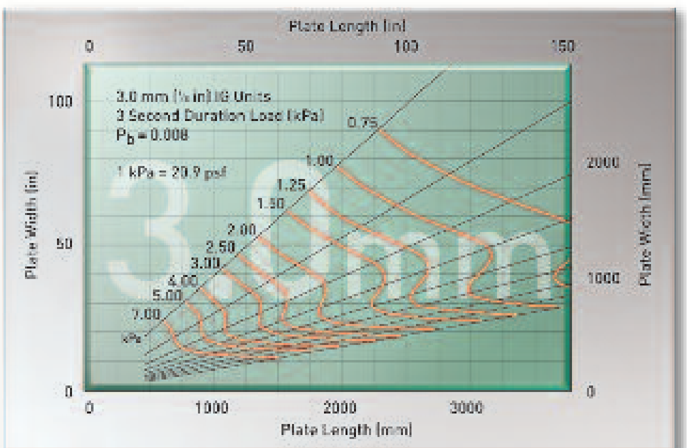


Figure 46-3

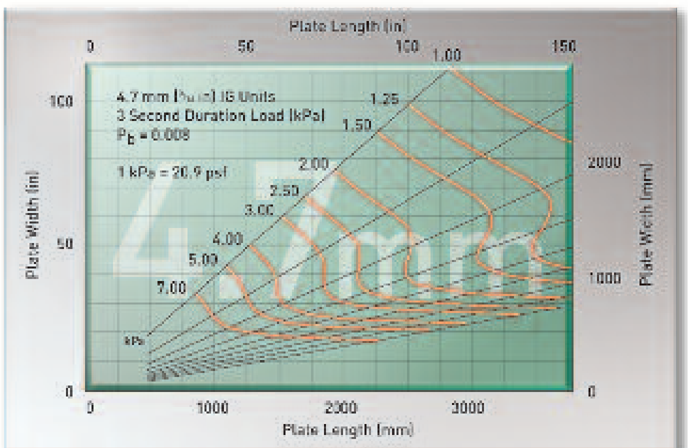


Figure 46-5

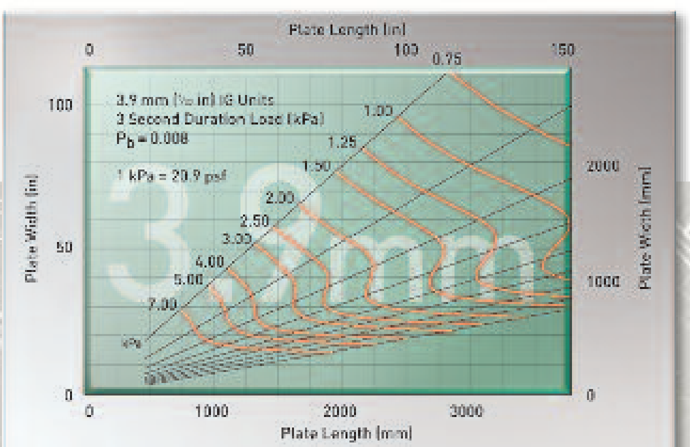


Figure 46-4

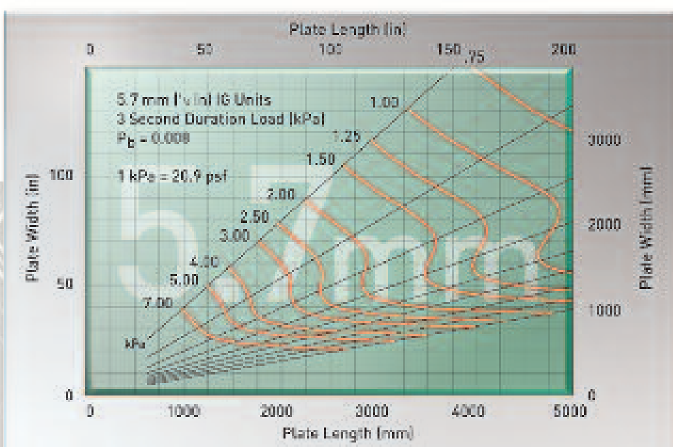


Figure 46-6

High Altitude

When insulating glass units are installed at altitudes of approximately 5,000 feet above the manufacturing altitude, the conventional approach has been to install a capillary tube. The tube permits the insulating glass unit to pressure equalize with the local atmosphere and relieve the altitude pressure differential across the unit 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, and U-Factors should be based on an air-filled IG unit construction.

Pressure Imbalance Problems

When an insulating glass 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 insulating glass 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 insulating glass 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 insulating glass unit, the breakage probability due to altitude changes would be essentially eliminated.

Ideal IG Unit Construction

The best construction alternatives for high-altitude installations of insulating glass units would be to use the thinnest glass possible in combination with the smallest possible airspace gap width. If insulating glass units are being considered to be installed 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.

Figures 47-1, 47-2, 48-1, 48-2 and 48-3 were developed for insulating glass units installed at high altitudes.

Note: These high-altitude charts are only to be used for Cardinal IG insulating glass units.

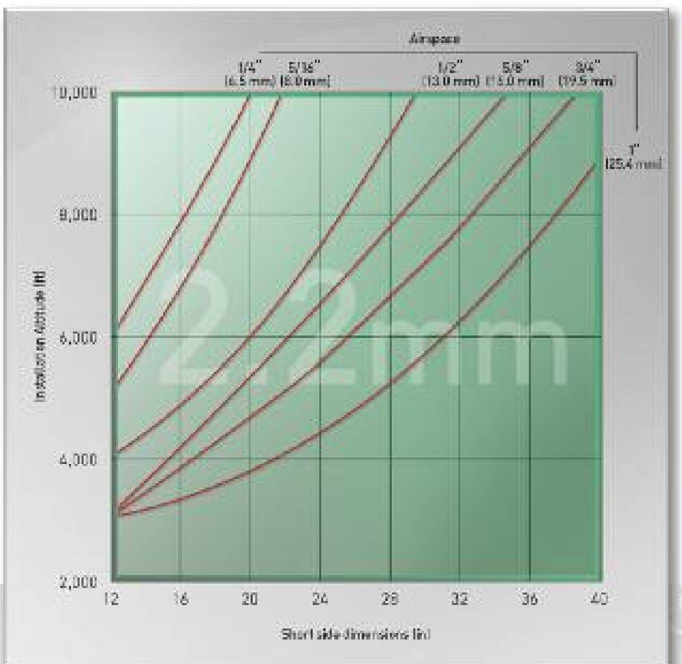


Figure 47-1

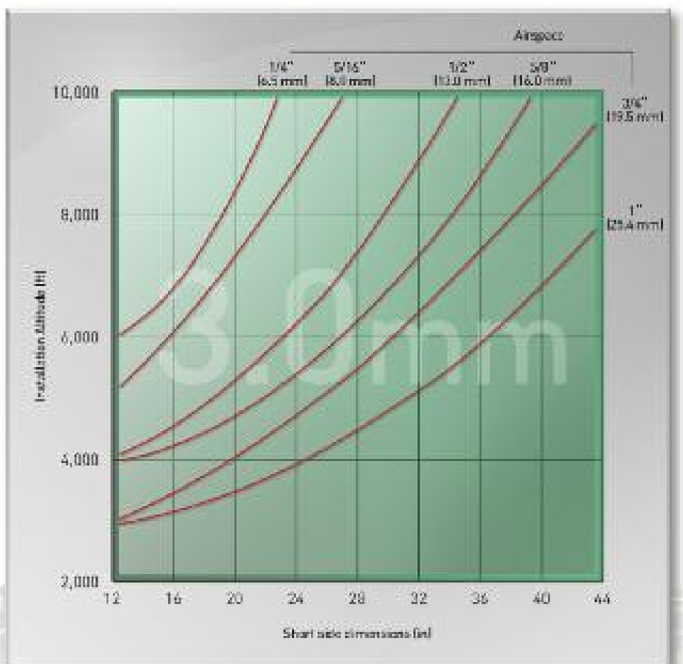


Figure 47-2

Assumptions Used in High Altitude Charts

- Load duration (installation time) is based on 1 month.
- Curves are based on a 1% glass breakage or 5 pounds/lineal inch edge stress, whichever occurs first.
- Insulating glass unit assumed to be fabricated at an altitude of 850 feet (259 meters) at 70° F (21° C).
- Both lites of the IG unit are annealed glass. If one or both lites of glass are heat-strengthened or tempered, the charts will yield conservative results.
- No consideration is given to aesthetics and glass distortion.

How to Use High Altitude Charts

- Determine installation altitude (altitude where units are installed).
- Locate glass thickness chart, short side dimension, installation altitude and gap width.
- At the point where the short side dimension meets the installation altitude, determine if the point is above or below the gap width line. If the point is below the line, the insulating glass unit should give satisfactory service without capillary tubes. If the point is above the gap width line, the IG unit is not suitable for the given conditions, and capillary tubes, a change in glass thickness or gap width should be considered.
- For triple-pane units with equal airspaces and matched glass thicknesses, use the appropriate glass thickness chart and the line equal to the sum of the two airspaces.

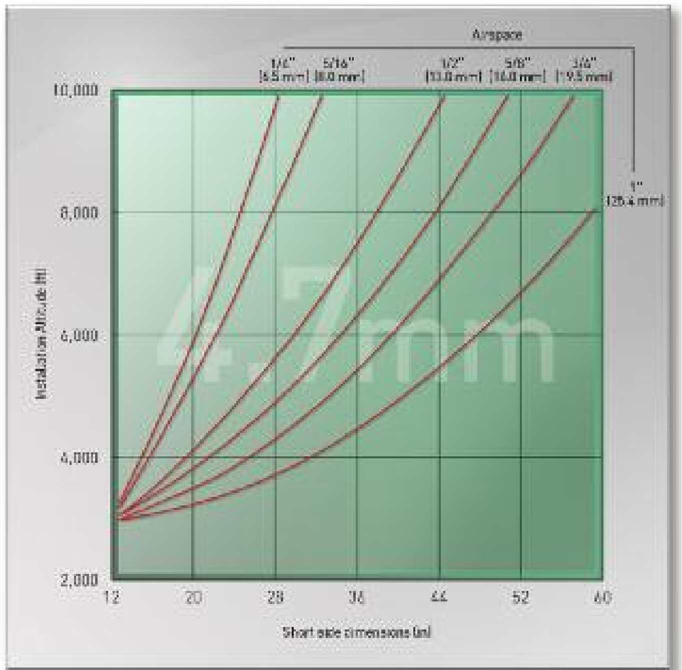


Figure 48-2

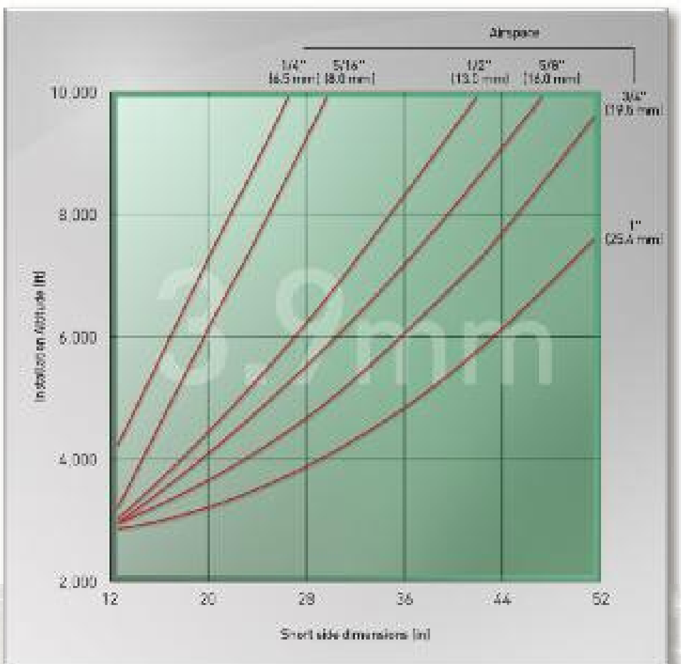


Figure 48-1

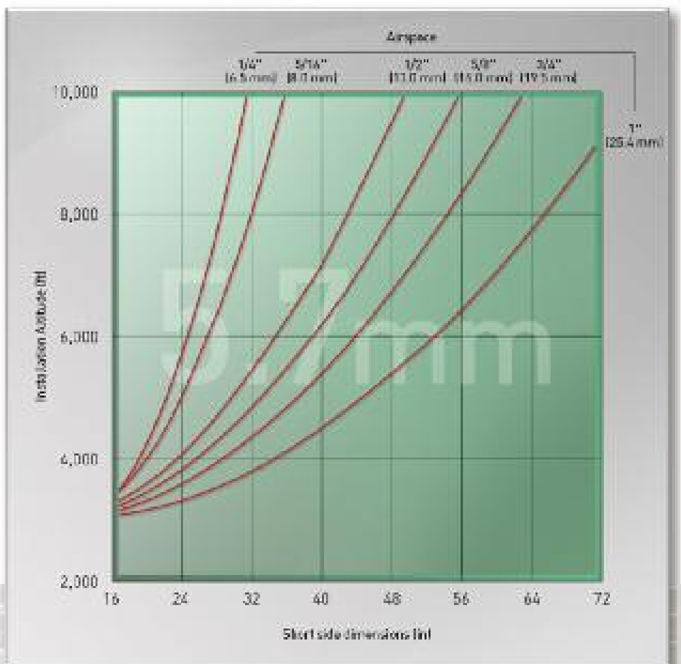


Figure 48-3

Laminate

Whether you want laminated glass 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.

ed Glass

Laminated Glass

Cardinal laminated glass is available in annealed, heat-strengthened, or tempered glass options with one or more transparent to opaque interlayers sandwiched together to create a stronger, sturdier glass unit.

We offer multiple interlayer options to meet various codes, security, and aesthetic requirements.

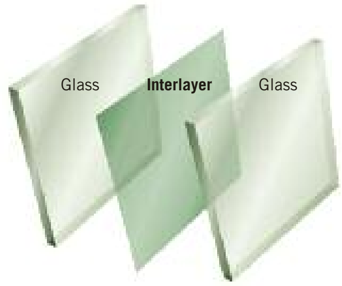


Figure 51-1

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 pressure, but tends to remain integral, adhering to the interlayer.

Figure 51-2

Unlike annealed or tempered glass, if laminated glass is broken, the glass fragments remain adhered to the interlayer and securely in the frame. This provides a strong barrier against forced entry or wind-blown debris. Since laminated glass can be cut from only one side, glass cutters are rendered useless in the hands of would-be intruders.

Characteristics of Cardinal's Laminated Glass
- Enhances security and resists forced entry
- Blocks over 95% of harmful UV rays
- Optional LoĒ^{3}-366® coating for improved SHGC
- Monolithic or insulating glass application
- Clear, tinted or colored interlayer and/or glass options available
- Optional Neat® coating (easy clean)
- Optional Preserve® protective film available

Cardinal laminated glass meets rigorous industry codes and standards including ASTM International's standard for preventing forced entry (ASTM F1233). It is also certified through the Safety Glazing Certification Council.

Laminated Glass Applications
- Safety Glazing
- Wind-borne Debris Resistance (SeaStorm®)
- Forced Entry Resistance
- Blast Resistance
- Acoustical Performance (noise reduction)
- Fading Protection
- Architectural

Available Laminate Interlayers
- Polyvinyl Butyral (PVB)
- DuPont SentryGlas® (SG)
- PVB / Polyester (PET)
- Ethylene Vinyl Acetate (EVA)

Laminated Glass Coatings
- LoĒ®, LoĒ^{2}®, and LoĒ^{3}® coatings when used in an insulating glass unit. Coating faces airspace.
- LoĒ^{3}-366® coating when used monolithically. Coating faces interlayer.

Safety Glazing
Cardinal certifies their laminated glass products through the Safety Glazing Certification Council (SGCC) sampling and testing program. The SGCC is an independent agency which confirms the laminate products meet the following requirements:
- ANSI Z97.1-2009 Class "A" (0.030" interlayer and thicker)
- ANSI Z97.1-2009 Class "B" (0.015" interlayer)
- CPSC 16CFR 1201 Cat II (0.030" interlayer and thicker)
- CPSC 16CFR 1201 Cat I (0.015" interlayer)

SeaStorm® Laminated Glass

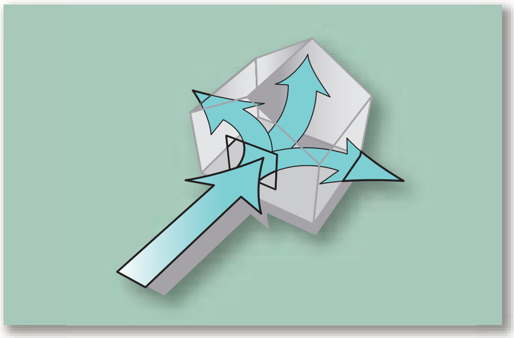
During hurricanes and windstorms, wind-borne debris is common. Debris slams into windows that are being subjected to sustained and gusting hurricane force winds. SeaStorm® laminated glass is designed to withstand high levels of impact and remain integral in the window system even if glass breakage has occurred.

Cardinal laminated glass products are currently being used in glazing assemblies that meet the requirements of Miami-Dade County TAS201, TAS202, and TAS203, as well as ASTM E1886 and E1996. In this testing, the door or window laminated glass must withstand an impact from a nine-pound 2x4 traveling at 50 feet per second (34 miles/hr), and then complete 9000 positive and negative pressure cycles equating to wind gusts of up to 200 mph or more. This is regarded as some of the most rigorous product performance testing anywhere.

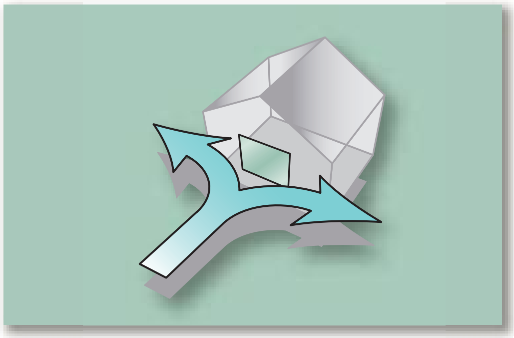
The most recent Dade County NOAs (notification of acceptance) for Cardinal laminated glass products are available on the Miami-Dade County website (http://www.miamidade.gov/building/pc-search_app.asp).

Figure 52-1

SeaStorm protection



If the building envelope is breached through a broken window, wind may enter the building, creating an increase in pressure that could lift the roof and push the walls outward causing the building to collapse.



SeaStorm laminated glass helps preserve the building envelope, minimizing damage from wind, rain and other elements.

Figure 52-2

Blast Resistance
Cardinal laminated glass can qualify for the Department of Defense Unified Facilities Criteria for blast resistance.

Acoustical Performance
The ASTM International developed the sound transmission class (STC) and outdoor/indoor transmission class (OITC) to describe the sound isolation performance of materials. A higher rating indicates a greater sound-dampening effect.

Cardinal laminated glass incorporating PVB interlayer increases the STC or OITC rating of a window system by diminishing undesired noise levels.

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	STC	OITC
1/4" Monolithic Glass	31	29
7.0L (3.0-0.030" PVB-3.0)	35	31
10.0L (4.7-0.030" PVB-4.7)	36	33
12.0L (5.7-0.030" PVB-5.7)	38	34
12.8L (5.7-0.060" PVB-5.7)	39	34
Double-Pane: 5.7 Clear / 13.0 / 5.7 Clear	35	28
Double-Pane: 7.0L / 6.5 / 3.1 Clear	35	31
Double-Pane: 7.0L / 13.0 / 5.7 Clear	39	31
Double-Pane: 10.0L / 13.0 / 5.7 Clear	40	31
Double-Pane: Double-Pane Laminate: 7.0L / 13.0 / 7.0L	42	33
Triple-Pane: 5.7 Clear / 13.0 / 5.7 Clear / 13.0 / 5.7 Clear	39	31
Triple-Pane Laminate: 7.0L / 13.0 / 7.0L / 13.0 / 7.0L	44	33

1) "L" indicates laminated glass. Data from Solutia Acoustic Guide and Riverbank Acoustical Laboratories

Figure 53-1

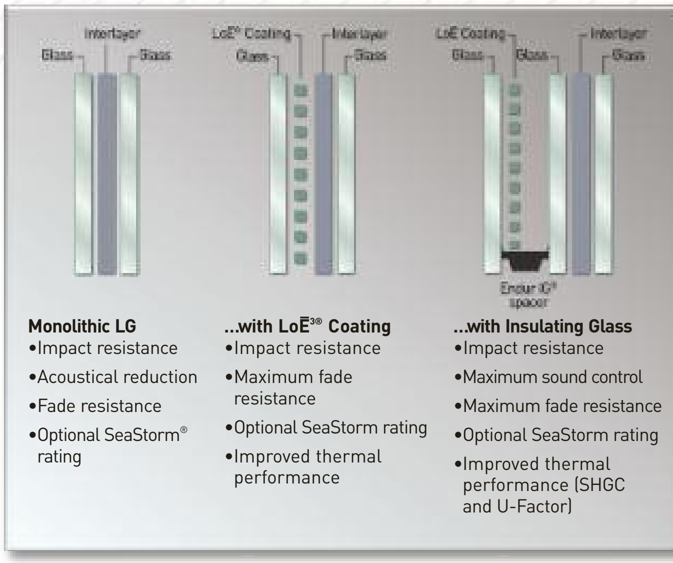


Figure 53-2

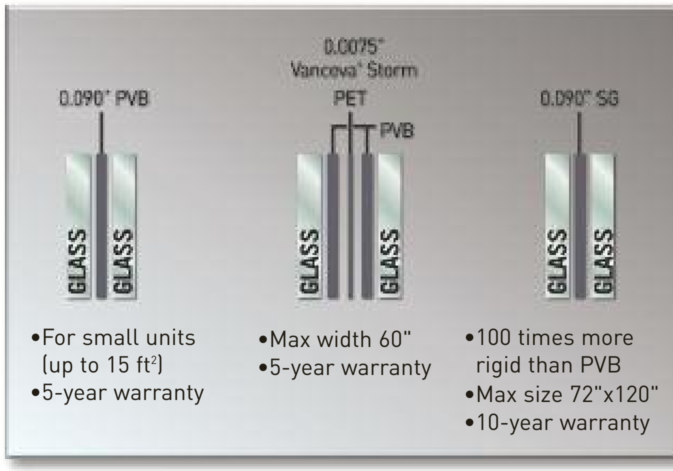


Figure 53-3

Performance Specifications

Cardinal laminated glass provides design flexibility to meet industry requirements. The performance tables below show characteristics of SG and PVB Laminates. This represents a sample of possible laminate configurations and merely reflects some of the major elements in glass selection.

SGP (SENTRYGLASPLUS)

Laminate Configuration	Visible Light Transmittance	Visible Light Reflectance Out	Visible Light Reflectance In	Solar Heat Gain Coefficient (SC = SHGC/0.87)	U-Factor (BTU/hr/ft²/°F) (W/m²)	UV Transmission	Fading (T_{uv}) ISO CIE
3.0 / 0.090" SG / 3.0	88%	8%	8%	0.78	**0.97** (5.51)	< 1%	60%
3.0 LoĒ^3-366® / 0.090" SG / 3.0	62%	13%	13%	0.34	**0.97** (5.51)	< 1%	40%
3.0 LoĒ^3-366® / 0.090" SG / 3.0 LoĒ-i89® (#4)	60%	12%	12%	0.30	**0.61** (3.46)	< 1%	39%
3.0 LoĒ^3-340™ / 0.090" SG / 3.0	37%	15%	14%	0.28	**0.97** (5.51)	< 1%	25%
3.0 LoĒ^3-340™ / 0.090" SG / 3.0 LoĒ-i89® (#4)	37%	15%	14%	0.22	**0.62** (3.52)	< 1%	25%
3.9 / 0.090" SG / 3.9	88%	9%	9%	0.78	**0.96** (5.45)	< 1%	62%
3.9 LoĒ^3-366® / 0.090" SG / 3.9	60%	13%	13%	0.34	**0.96** (5.45)	< 1%	39%
4.7 / 0.090" SG / 4.7	86%	9%	9%	0.74	**0.95** (5.39)	< 1%	60%
4.7 LoĒ^3-366® / 0.090" SG / 4.7	60%	11%	11%	0.35	**0.95** (5.39)	< 1%	38%
4.7 LoĒ^3-366® / 0.090" SG / 4.7 LoĒ-i89® (#4)	59%	13%	12%	0.30	**0.61** (3.46)	< 1%	38%
4.7 LoĒ^3-340™ / 0.090" SG / 4.7	37%	14%	14%	0.29	**0.96** (5.45)	< 1%	26%
4.7 LoĒ^3-340™ / 0.090" SG / 4.7 LoĒ-i89® (#4)	37%	13%	12%	0.23	**0.61** (3.46)	< 1%	26%
5.7 / 0.090" SG / 5.7	84%	7%	7%	0.71	**0.94** (5.34)	< 1%	59%
5.7 LoĒ^3-366® / 0.090" SG / 5.7	57%	11%	12%	0.35	**0.94** (5.34)	< 1%	36%
5.7 LoĒ^3-366® / 0.090" SG / 5.7 LoĒ-i89® (#4)	59%	13%	11%	0.31	**0.60** (3.41)	< 1%	37%
5.7 LoĒ^3-340™ / 0.090" SG / 5.7	37%	14%	13%	0.30	**0.95** (5.39)	< 1%	26%
5.7 LoĒ^3-340™ / 0.090" SG / 5.7 LoĒ-i89® (#4)	36%	14%	13%	0.23	**0.60** (3.41)	< 1%	25%

1) Calculated values using LBNL WINDOW computer program with NFRC 100-2010 environmental conditions;
2) Name Code: G = Gray glass, B = Bronze glass, N = Green glass, L = PVB interlayer, M = SG interlayer, X = LoĒ^3-366®

Figure 54-1

PVB (POLYVINYL BUTYRAL)

Laminate Configuration	Visible Light Transmittance	Visible Light Reflectance Out	Visible Light Reflectance In	Solar Heat Gain Coefficient (SC = SHGC/0.87)	U-Factor (BTU/hr/ft²/°F) (W/m²)	UV Transmission	Fading (T_{uv}) ISO CIE
2.7 / 0.030" PVB / 2.7	88%	10%	10%	0.78	**0.96** (5.45)	<1%	60%
3.0 / 0.090" PVB / 3.0	88%	9%	9%	0.78	**0.96** (5.45)	<1%	60%
3.0 LoĒ^3-366® / 0.090" PVB / 3.0	61%	13%	13%	0.34	**0.96** (5.45)	<1%	39%
3.0 LoĒ^3-366® / 0.090" PVB / 3.0 LoĒ-i89® (#4)	60%	12%	12%	0.30	**0.61** (3.46)	<1%	39%
3.0 LoĒ^3-340™ / 0.090" PVB / 3.0	37%	15%	14%	0.28	**0.96** (5.45)	<1%	26%
3.0 LoĒ^3-340™ / 0.090" PVB / 3.0 LoĒ-i89® (#4)	37%	15%	13%	0.23	**0.61** (3.46)	<1%	25%
4.7 / 0.090" PVB / 4.7	87%	9%	9%	0.73	**0.90** (5.34)	<1%	56%
4.7 LoĒ^3-366® / 0.090" PVB / 4.7	61%	13%	12%	0.35	**0.95** 5.39)	<1%	39%
4.7 LoĒ^3-366® / 0.090" PVB / 4.7 LoĒ-i89® (#4)	60%	13%	11%	0.30	**0.60** (3.41)	<1%	38%
4.7 LoĒ^3-340™ / 0.090" PVB / 4.7	37%	14%	14%	0.29	**0.95** (5.39)	<1%	26%
4.7 LoĒ^3-340™ / 0.090" PVB / 4.7 LoĒ-i89® (#4)	37%	13%	12%	0.23	**0.60** (3.41)	<1%	26%
5.7 / 0.090" PVB / 5.7	86%	9%	9%	0.72	**0.93** (5.28)	<1%	54%
5.7 LoĒ^3-366® / 0.090" PVB / 5.7	60%	13%	12%	0.36	**0.94** (5.34)	<1%	39%
5.7 LoĒ^3-366® / 0.090" PVB / 5.7 LoĒ-i89® (#4)	59%	12%	11%	0.31	**0.60** (3.41)	<1%	38%
5.7 LoĒ^3-340™ / 0.090" PVB / 5.7	37%	14%	14%	0.30	**0.94** (5.34)	<1%	26%
5.7 LoĒ^3-340™ / 0.090" PVB / 5.7 LoĒ-i89® (#4)	36%	14%	13%	0.23	**0.60** (3.41)	<1%	25%

1) Calculated values using LBNL WINDOW computer program with NFRC 100-2010 environmental conditions;
2) PVB green is the same as PVB blue-green;
3) Name Code: G = Gray glass, B = Bronze glass, N = Green glass, L = PVB interlayer

Figure 54-2

Websites You May Find Helpful

Cardinal Glass Industries
www.cardinalcorp.com

American Architectural Manufacturers Association (AAMA)
www.aamanet.org

ASHRAE
www.ashrae.org

ASTM International
www.astm.org

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

Consumer Product Safety Commission
www.cpsc.gov

ENERGY STAR
www.energystar.gov

Glass Association of North America (GANA)
www.glasswebsite.com

Insulating Glass Certification Council
www.igcc.org

Insulating Glass Manufacturers Alliance
www.igmaonline.org

International Code Council
www.iccsafe.org

National Fenestration Rating Council
www.nfrc.org

Safety Glazing Certification Council
www.sgcc.org

Society of Vacuum Coaters
www.svc.org

Window & Door Manufacturers Association (WDMA)
www.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)
- Insulating Glass Manufacturers Alliance (IGMA)
- National Fenestration Rating Council (NFRC)
- Safety Glazing Certification Council (SGCC)
- Conformity to CEN (European Committee for Standardization) Program Requirements

Standards and Codes

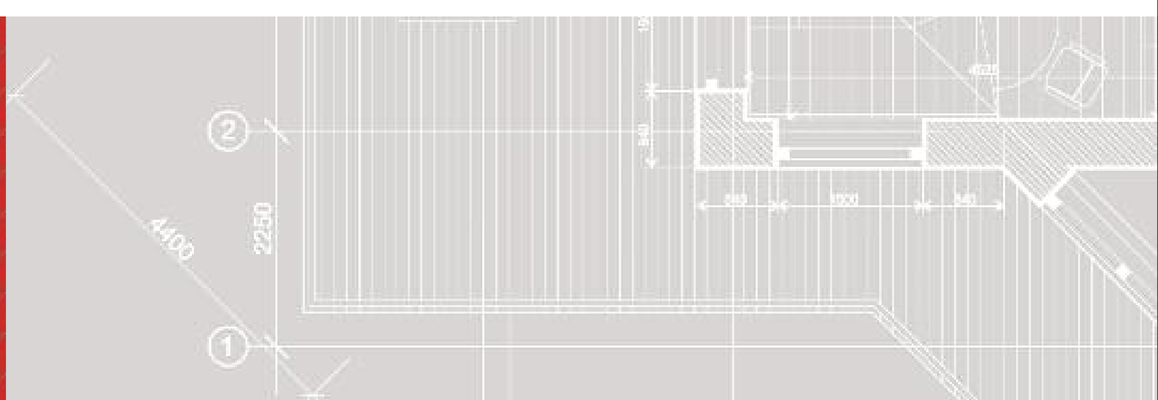
By complying with established standards, our inherent quality and product performance are fully recognized.

- 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.

- American Architectural Manufacturers Association (AAMA)
- Center for Glass Research
- Insulating Glass Manufacturers Alliance (IGMA)
- Society of Vacuum Coaters
- Window & Door Manufacturers Association (WDMA)



Index

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

CARDINAL Glass Industries

775 Prairie Center Drive
Eden Prairie, MN 55344
www.cardinalcorp.com