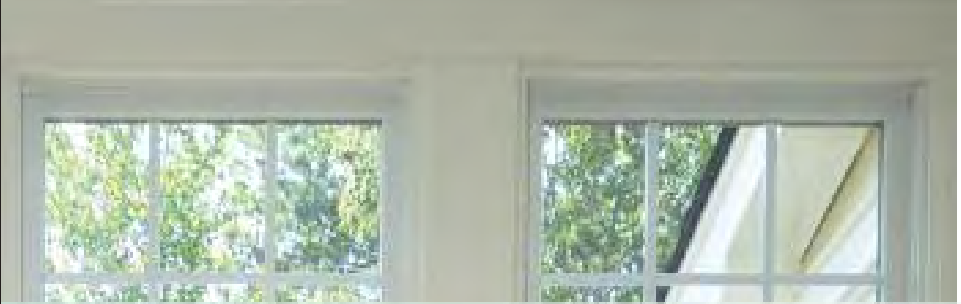
Residential Glass Technical Guide

Cardinal Glass Industries

Superior glass products for residential windows and doors

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.

Cardinal Sets



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 hundreds of millions 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 Standard

Cardinal offers you and your customers a variety of products to choose

LoĒ Glass
Patented, state-of-the-art sputtered coatings deliver optimal energy efficiency.

XL Edge®
Outstanding thermal performance and extremely low failure rates.

Neat® Naturally Clean Glass
For windows that clean easier and stay clean longer.

Preserve® Protective Film
Protects glass in transit and on the construction site.

How to Select Insulating Glass

In today's homes, the selection of a glass involves questions of aesthetics, performance and comfort. In addition, the type of home and its location must be considered. Each of these attributes is discussed in this technical guide and measured values of Cardinal's products are included throughout the brochure.

During selection, trade-offs or compromises may be necessary since some properties may conflict with each other. Suppose a homeowner wants high visibility through the window but also wants good solar control. A tinted product might meet the solar control needs but not offer enough visible light. Cardinal's LoĒ products, especially LoĒ³-366™, offer an excellent combination of high visible light transmittance, neutral color, low solar transmission and low U-Value.

When choosing insulating glass products, several variables should be considered:

- Longevity of the IG unit construction
- Price of the IG unit
- Thermal performance of the IG unit (includes window U-Factor, NFRC condensation resistance, sightline temperature)
- Ability to make custom units, i.e. shapes, internal grilles, etc.
- Ability to put inert gases into the airspace and retain the gas

The selection process is complicated by some manufacturers laying claim to performance values which are not tested to industry standards. This makes it difficult to make specific performance comparisons.

The National Fenestration Rating Council (NFRC) is helping to make the process of glass selection easier by standardizing and enforcing performance measurement procedures. NFRC has been mandated by Congress to offer a credible rating system for windows and their components. Cardinal has subscribed to NFRC procedures in all performance data presented in this brochure.

from within a wide range of aesthetic and performance characteristics.

SeaStorm®
The ultimate hurricane-resistant glass and safety glazing.

Company Structure

Cardinal Glass Industries is a corporation with five wholly-owned subsidiaries and more than 5,500 employees located at 27 manufacturing 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 & Optical Mirrors)
Buford, GA
Casa Grande, AZ
Northfield, MN
Spring Green, WI
Waxahachie, TX
Galt, CA (Coated)
Moreno Valley, CA (Tempered)
Tumwater, WA (Coated)
N. Salt Lake City, UT (Tempered)

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

Cardinal ST® Company
(Solar Technologies)
Spring Green, WI

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

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.

Low Emissivity Coatings (LoĒ) Coatings applied to glass which reflect long wave room side infrared energy back into the room reducing the U-Value. Emissivity varies from 0 to 1 and the lower the emissivity, the lower the resultant U-Value.

LoĒ^{2}®
Second generation of LoĒ coatings which provide a high visible light transmission while offering a significant decrease in solar heat gain coefficient and shading coefficient. These products have two silver layers in the coating stack.

LoĒ^{3}™
Third generation of LoĒ coatings which provide the best solar heat gain coefficient and shading coefficient with a high visible light transmission. These products have three silver layers in the coating stack.

ALL CLIMATE GLASS
[One silver layer]

Cardinal LoĒ-179™ provides excellent insulating capability in cooler weather and is well-suited for passive solar applications.

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.

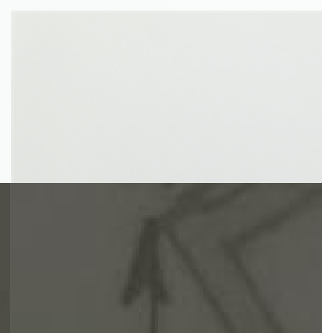
CLEAR GLASS

TRANSMITTED APPEARANCE

EXTERIOR APPEARANCE

CLEAR | LoĒ-179™

TRANSMITTED APPEARANCE



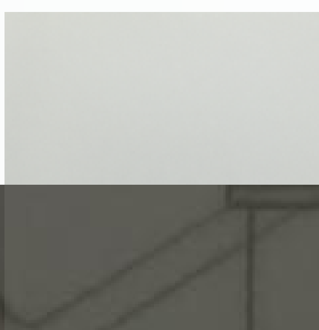
EXTERIOR APPEARANCE

ALL CLIMATE GLASS
[Two silver layers]

Cardinal LoĒ^2-272™ glass (pronounced low-e squared 272) 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



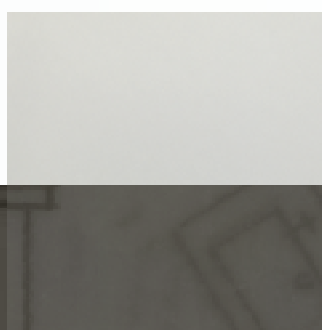
EXTERIOR APPEARANCE

ALL CLIMATE SOLAR CONTROL GLASS
[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



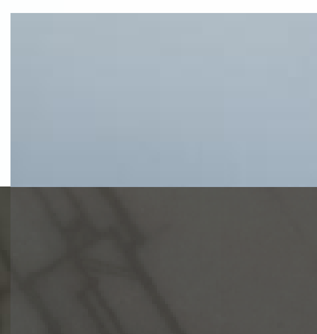
EXTERIOR APPEARANCE

GLARE CONTROL GLASS
[Two silver layers]

Wherever glare is a problem, LoĒ^2-240™ is an ideal solution. It's a specially treated version of our LoĒ^2 glass so it not only controls glare but also blocks oppressive solar heat gain and maintains cool indoor glass temperatures. Regular tinted glass works by absorbing sunlight, so the glass color changes with the thickness and the glass becomes hot in sunlight. However, LoĒ^2-240™ maintains its appearance and performance regardless of the glass thickness. It can be used for turtle glass codes.

CLEAR | LoĒ^2-240™

TRANSMITTED APPEARANCE



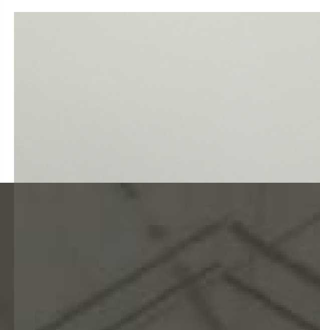
EXTERIOR APPEARANCE

ULTIMATE PERFORMANCE GLASS
[Three silver layers]

The new standard, LoĒ^3-366™ (pronounced low-e cubed 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



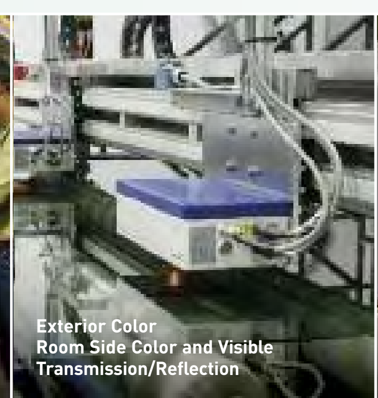
EXTERIOR APPEARANCE

Count on Cardinal Glass to Always Meet or Exceed Your Specifications

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


Argon-Fill Levels


Strain Measurement


Exterior Color
Room Side Color and Visible Transmission/Reflection


Coating Color

Float Glass I.Q.

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 I.Q.

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 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 I.Q.

Cardinal tempering increases the glass strength to nearly 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
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. 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.

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 I.Q.

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

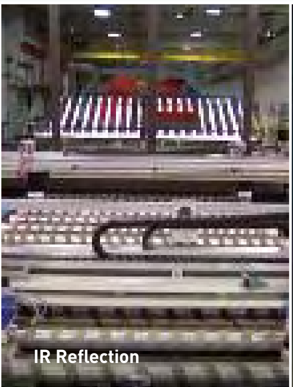
Vision Scope and Hawkeye Cameras
This is where scratches, coating faults and debris on the glass surface are detected. The systems accurately characterize defects by size and sort them according to specifications to help prevent defective glass from proceeding to high-value operations.

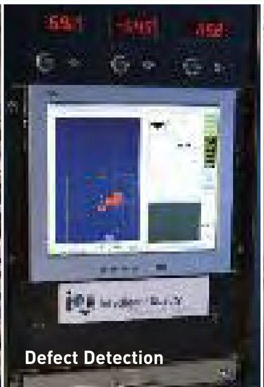
Edge Thickness
Our Press Master ensures the precise thickness of each IG unit to within thousandths of an inch.

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 on average meet European standards for argon loss of less than 1% per annum.

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

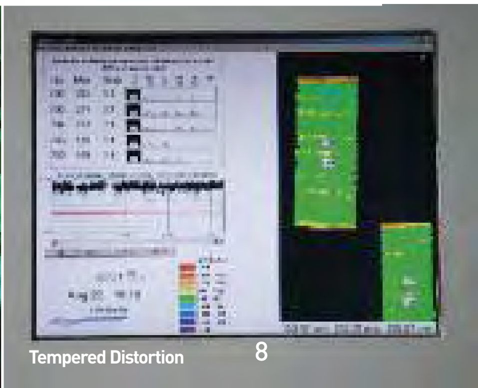
Center of Glass Thickness
Where possible, we do a 100% sort inspection of all important attributes, including center of glass thickness.


IR Reflection


Defect Detection

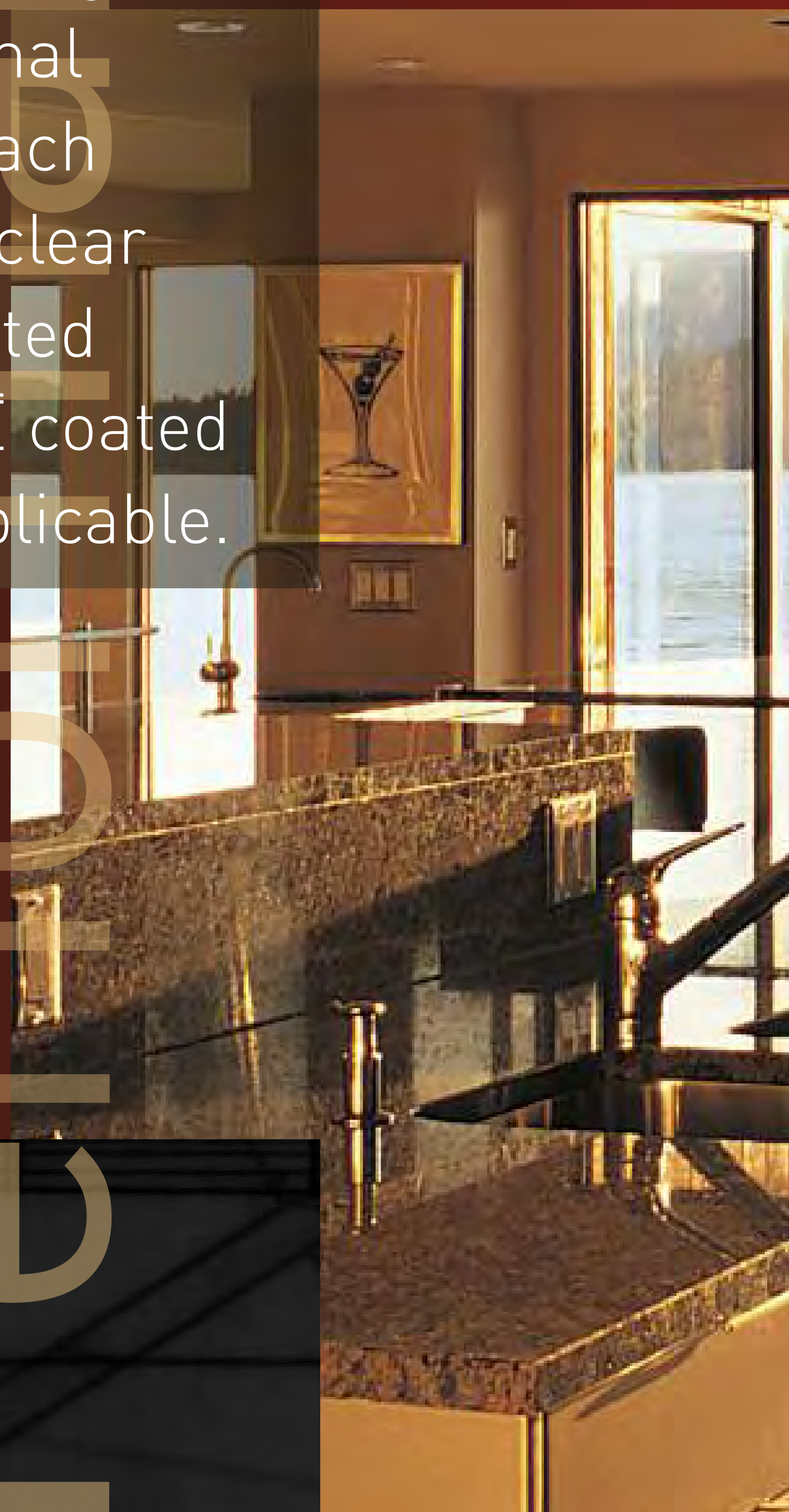

Vision Scope and Hawkeye Cameras


Hawkeye Camera


Tempered Distortion

Performance

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.



Energy Terminology

U-Value
The heat flow rate through a given construction is expressed in Btu/hr/ft²/°F (W/m²/°C). The lower the U-Value, 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/ft² (783 W/m²). Winter nighttime U-Values 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/ft² (0 W/m²).

R-Value
Thermal resistance of a glazing system expressed in hr•ft²•°F/Btu. It is the reciprocal of U-Value, 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" (3mm) 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-Value and the Solar Heat Gain Coefficient. The conditions are 230 Btu/hr/ft² (726 W/m²) 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/ft².

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 (C.I.E.) 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 C.I.E. 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 C.I.E. 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).

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

TO CONVERT INCH-POUND	TO METRIC	MULTIPLY BY
Inches (in)	Millimeters (mm)	25.4
Feet (ft)	Meters (m)	0.305
Square inches (in²)	Square millimeters (mm²)	645
Square feet (ft²)	Square meters (m²)	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/inch² (lbf/in²)	Kilopascals (kPa)	6.89
Pounds force/feet² (lbf/ft²)	Kilopascals (kPa)	0.048
Btu/hr	Watts (W)	0.293
Btu/hr/ft²/°F	W/m²/°C	5.678
Btu/hr/ft²	W/m²	3.15

Figure 11-1

Solar/Optical Properties of IG Units

The Solar/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 C.I.E. 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 for reducing solar gains with a resultant better summer comfort and reduced cooling costs.

SOLAR/OPTICAL PROPERTIES OF IG UNITS

IG Configuration Outboard lite / Inboard lite	Glass Thickness		Visible Light			Solar Energy		SHGC	SC	LSG	Rel. Ht. Gain
	mm	inches	Trans. (%)	Refl. Out (%)	Refl. In (%)	Trans. (%)	Refl. Out (%)				Btu/hr/ft^2
Clear / Clear	2.2	3/32	83	15	15	75	14	0.79	0.91	1.05	189
	3.0	1/8	82	15	15	73	13	0.78	0.89	1.05	186
	3.9	5/32	82	15	15	69	13	0.75	0.87	1.09	180
	4.7	3/16	81	15	15	67	12	0.74	0.85	1.09	178
	5.7	1/4	80	15	15	63	12	0.72	0.83	1.11	172
Clear / LoĒ-179™	2.2	3/32	80	14	14	62	21	0.71	0.82	1.13	167
	3.0	1/8	79	14	14	60	20	0.70	0.80	1.13	164
	3.9	5/32	78	13	14	57	19	0.68	0.78	1.15	160
	4.7	3/16	78	13	14	55	18	0.67	0.77	1.16	158
	5.7	1/4	77	13	14	52	17	0.65	0.75	1.18	153
LoĒ^2-272™ / Clear	2.2	3/32	73	11	12	39	36	0.42	0.48	1.74	99
	3.0	1/8	72	11	12	38	35	0.41	0.48	1.76	98
	3.9	5/32	71	11	12	37	32	0.41	0.47	1.73	97
	4.7	3/16	71	11	11	36	31	0.41	0.47	1.73	96
	5.7	1/4	70	10	11	35	29	0.40	0.46	1.75	95
LoĒ^2-270™ / Clear	2.2	3/32	71	12	13	35	42	0.37	0.43	1.92	88
	3.0	1/8	70	12	13	34	39	0.37	0.42	1.89	88
	3.9	5/32	69	12	13	33	36	0.36	0.42	1.92	86
	4.7	3/16	69	12	12	32	33	0.36	0.41	1.92	86
	5.7	1/4	68	12	12	31	32	0.36	0.41	1.89	85
LoĒ^3-366™ / Clear	2.2	3/32	65	11	12	25	47	0.27	0.31	2.41	66
	3.0	1/8	65	11	12	25	44	0.27	0.31	2.41	66
	3.9	5/32	64	11	12	24	41	0.27	0.31	2.37	66
	4.7	3/16	64	11	11	24	39	0.27	0.31	2.37	66
	5.7	1/4	63	11	11	24	36	0.27	0.31	2.33	65
LoĒ^2-240™ / Clear	2.2	3/32	40	14	10	22	32	0.25	0.29	1.60	62
	3.0	1/8	40	14	10	21	31	0.25	0.29	1.60	61
	3.9	5/32	39	14	10	20	27	0.25	0.28	1.56	60
	4.7	3/16	39	14	10	20	27	0.25	0.28	1.56	60
	5.7	1/4	37	13	10	19	27	0.24	0.28	1.54	59
Triple-Pane LoĒ-179™	2.2	3/32	71	19	19	49	24	0.58	0.67	1.22	136
	3.0	1/8	69	18	18	47	23	0.57	0.65	1.21	133
	3.9	5/32	68	18	18	44	21	0.55	0.63	1.24	129
	4.7	3/16	67	18	18	42	20	0.54	0.62	1.24	127
	5.7	1/4	66	18	18	39	19	0.52	0.60	1.27	122
Triple-Pane LoĒ^2-272™	2.2	3/32	58	13	13	27	39	0.36	0.41	1.61	84
	3.0	1/8	57	13	13	26	37	0.35	0.41	1.63	83
	3.9	5/32	57	13	13	25	34	0.35	0.40	1.63	82
	4.7	3/16	56	13	13	24	33	0.34	0.40	1.65	82
	5.7	1/4	55	13	13	23	30	0.34	0.39	1.62	80

Figure 12-1

1) Calculated values using LBNL Window 5.2 computer program per NFRC 100-2001:

- Dual-pane IG construction: 1/8" (3 mm) glass thickness, 1/2" (13.0 mm) airspace, 90% argon filled for LoĒ products, otherwise air filled cavity. Coatings on surface #2 (except for LoĒ-179™ coating is on surface #3).
- Triple-pane IG construction: 1/8" (3 mm) glass thickness, 5/16" (8.0 mm) airspace, 90% argon filled for LoĒ products. Coatings on surfaces #2 and #5.

Center of Glass U-Values of IG Units

This table (Figure 13-1) shows how Cardinal LoĒ coatings and argon filling improve center of glass U-Values.

U-Value 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" (11.3mm) and 5/8" (16mm). The optimum airspace means that the winter U-Value does not appreciably change by increasing the width, such as 1/2" to 5/8".

CENTER OF GLASS U-VALUES OF IG UNITS

Airspace		Clear / Clear	Clear / LoĒ-179™		LoĒ^2-272™ / Clear, or LoĒ^2-270™ / Clear		LoĒ^3-366™ / Clear		LoĒ^2-240™ / Clear		LoĒ-179™ Triple-Pane (#2 & #5)		LoĒ^2-272™ Triple-Pane (#2 & #5)	
mm	inches	air	air	argon	air	argon	air	argon	air	argon	air	argon	air	argon
6.5	1/4	0.55	0.42	0.35	0.41	0.33	0.40	0.33	0.41	0.34	0.27	0.21	0.26	0.20
8.0	5/16	0.52	0.38	0.31	0.36	0.29	0.35	0.28	0.36	0.30	0.23	0.19	0.22	0.17
9.8	3/8	0.50	0.34	0.29	0.33	0.26	0.32	0.25	0.33	0.27	0.20	0.16	0.19	0.15
11.5	7/16	0.49	0.32	0.27	0.30	0.25	0.30	0.24	0.31	0.26	0.19	0.15	0.17	0.13
13.0	1/2	0.48	0.32	0.28	0.30	0.25	0.29	0.24	0.30	0.26	0.18	0.14	0.16	0.13
14.5	9/16	0.48	0.32	0.28	0.30	0.26	0.29	0.25	0.31	0.26	0.17	0.14	0.15	0.12
16.0	5/8	0.48	0.33	0.28	0.31	0.26	0.30	0.25	0.31	0.26	0.17	0.14	0.15	0.13
17.5	11/16	0.48	0.33	0.29	0.31	0.26	0.30	0.25	0.31	0.27	0.17	0.15	0.16	0.13
19.5	3/4	0.49	0.34	0.29	0.31	0.27	0.31	0.26	0.32	0.27	0.18	0.15	0.16	0.13

1) Calculated values using LBNL Window 5.2 computer program:
- LoĒ on surface #2 for double-pane IG products, except for LoĒ-179™ IG the coating is on surface #3.
- U-Values calculated at center of glass.
- Glass thickness is 3.0 mm.
- Argon fill is 90%.

Figure 13-1

Overall Window U-Factors

When evaluating the U-Value for window systems, U-Values for the frame, glass edge (2 1/2" from frame) and center of glass must be considered. The LNBL Window 5.2 computer program uses a modeled window to calculate the overall window U-Factor.

OVERALL WINDOW U-FACTORS FOR VARIOUS FRAMES

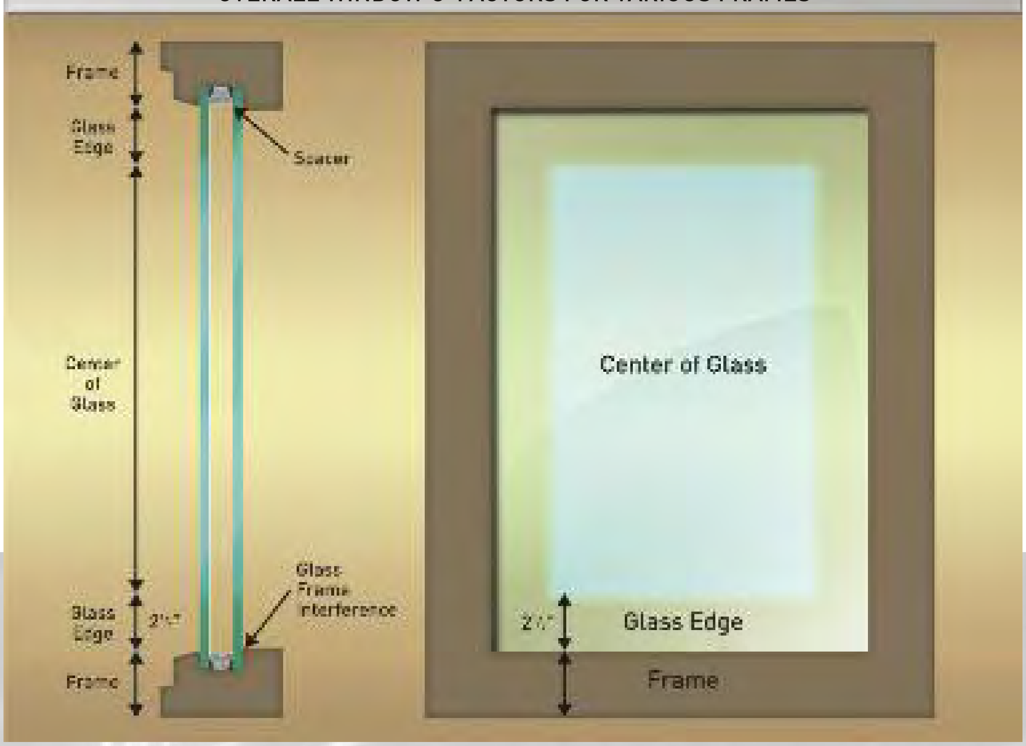


Figure 13-2

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, LoĒ²® or LoĒ³™ insulating glass unit. In addition, the U-Value of the edge, frame and overall window is improved when using Cardinal's XL Edge® spacer over the typical aluminum spacer.

The XL Edge spacer will also increase the glass/frame interface temperature resulting in less opportunity for indoor condensation around the periphery of the glass.

Effect of Frames on Overall U-Factors

The chart below (Figure 14-1) shows a window's overall U-Factor for aluminum, wood, vinyl and clad wood sash. Values incorporate edge conductance of Cardinal's XL Edge spacer.

The data clearly show that the overall U-Factor and in turn heat loss are significantly reduced with Cardinal LoĒ²® and LoĒ³™ products over clear IG units.

WINDOW U-FACTOR

Glazing	Center of Glass U-Value (Btu/hr/ft²/°F)	Aluminum Window (No Thermal Break) U-Factor (Btu/hr/ft²/°F)	Aluminum Window (Thermally Broken) U-Factor (Btu/hr/ft²/°F)	Alum. Clad Wood or Reinforced Vinyl Window U-Factor (Btu/hr/ft²/°F)	Wood or Vinyl Window U-Factor (Btu/hr/ft²/°F)
Clear / Clear	0.47	0.85	0.58	0.48	0.44
Clear / LoĒ-179™	0.28	0.71	0.44	0.35	0.30
LoĒ²-272™ / Clear	0.25	0.69	0.42	0.34	0.29
LoĒ²-270™ / Clear	0.25	0.69	0.42	0.34	0.29
LoĒ³-366™ / Clear	0.24	0.69	0.42	0.33	0.28
LoĒ²-240™ / Clear	0.26	0.69	0.43	0.34	0.29
Triple-Pane LoĒ-179™/Clear/LoĒ-179™	0.17	0.64	0.37	0.29	0.24
Triple-Pane LoĒ²-272™/Clear/LoĒ²-272™	0.15	0.63	0.36	0.28	0.23

Figure 14-1

1. All double-pane insulating glass units are constructed with 1/8" glass and 1/2" airspace. All LoĒ IG units calculated with 90% argon gas fill. Clear/clear values based on an air filled cavity. Triple-pane units constructed with 1/8" glass and 3/8" airspace.
2. For double-pane IG units the LoĒ coating is on surface #2, except for LoĒ-179™ the coating is on surface #3.
3. For triple-pane IG units the LoĒ coating is on surfaces #2 and #5.
4. Window U-Factors are calculated using the Window 5.2 program with a NFRC Casement Single operable window and the following defaults for frame performances:
   a. Class 3 edge correlation (spacer similar to Cardinal's XL Edge®)
   b. Frame material absorption = 0.90
   c. Frame U-Value (Btu/hr/ft²/°F): Al (1.90), Al T. B (0.88), Al Clad Wood/Reinf Vinyl (0.46), Wood/Vinyl (0.30)
   d. Projected Frame Dimensions: Al (2.25"), Al T. B (2.10"), Al Clad Wood/Reinf Vinyl (2.80"), Wood/Vinyl (2.75")
5. This data does not represent all window manufacturers' performance values due to the different frame sizes and materials.

PERFORMANCE

U-Factor and Glass Frame Interface Temperatures

The data below (Figures 14-2 and 14-3) compares 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.

As can be seen by the data, Cardinal's XL Edge stainless steel spacer system is equivalent to others sold in the market for the properties listed.

WINDOW PERFORMANCE WITH LoĒ³-366 DOUBLE-GLAZED UNIT

Spacer Type	NFRC U-Factor	NFRC CR	Sightline Temp °F
Aluminum	0.29	55.4	32.8
U-Steel Spacer	0.28	57.0	35.5
Butyl Spacer	0.28	61.4	39.2
XL Edge®	0.27	58.5	39.2
Plastic/Stainless Composite Spacer	0.27	60.3	41.1
Plastic Spacer	0.27	60.7	41.8
Foam Spacer	0.27	60.8	42.0

1) 3.1E / 0.5" Argon (90%) / 3.1
2) Wood or vinyl frame.

Figure 14-2

WINDOW PERFORMANCE WITH LoĒ³-366 TRIPLE-GLAZED UNIT

Spacer Type	NFRC U-Factor	NFRC CR	Sightline Temp °F
XL Edge® – Argon	0.22	67.1	43.4
XL Edge® – Krypton	0.19	71.4	44.7
Foam Spacer – Argon	0.21	69.1	45.9
Foam Spacer – Krypton	0.18	73.6	47.1

1) 3.1E / 8.0 90% Gas / 3.1 / 8.0 90% Gas / E3.1
2) Wood or vinyl frame.

Figure 14-3

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 15-1 at right), over 60% of the total heat transfer is by thermal radiation. Incorporating a low emissivity coating on one surface facing the air space 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 15-3) shows this effect.

The heat transfer characteristics of the LoĒ^3-366™ products with argon airspace vs. double-pane clear with air are shown below (Figures 15-2 and 15-3). The lower thermal conductivity of argon lowers conductive heat transfer and reduces the heat loss to 17 Btu/hr/ft^2. This is now double the performance of standard double-pane insulating glass with air.

WINTER TIME AIRSPACE HEAT TRANSFER

IG Products	Radiative Heat Loss (Btu/hr/ft^2)	Conductive Heat Loss (Btu/hr/ft^2)	Total Heat Loss (Btu/hr/ft^2)	Heat Loss Reduction Compared To Standard Double-Pane Unit	Indoor Glass Temp (°F)
Double-Pane Clear	21	13	34	----	44
Double-Pane LoĒ-179™	5	15	20	41%	54
Double-Pane LoĒ^2-272™, LoĒ^2-270™	2	16	18	47%	56
Double-Pane LoĒ^3-366™	1	16	17	50%	56
Triple-Pane LoĒ-179™	2	11	13	62%	59
Triple-Pane LoĒ^2-272™	1	11	12	65%	60
Triple-Pane LoĒ^3-366™	1	10	11	68%	60

1) Double-Pane IG Construction: 3.0mm (1/8") thick glass with a 13.0mm (1/2") airspace, 90% argon filled for LoĒ products, otherwise air-filled cavity. Coatings are on surface #2, except for LoĒ-179™ coating is on surface #3.
2) Triple-Pane IG Construction: 3.0mm (1/8") thick glass with two 8.0mm (5/16") airspace, 90% argon filled for LoĒ products, otherwise air-filled cavity. Coatings are on surfaces #2 and #5.

Figure 15-1

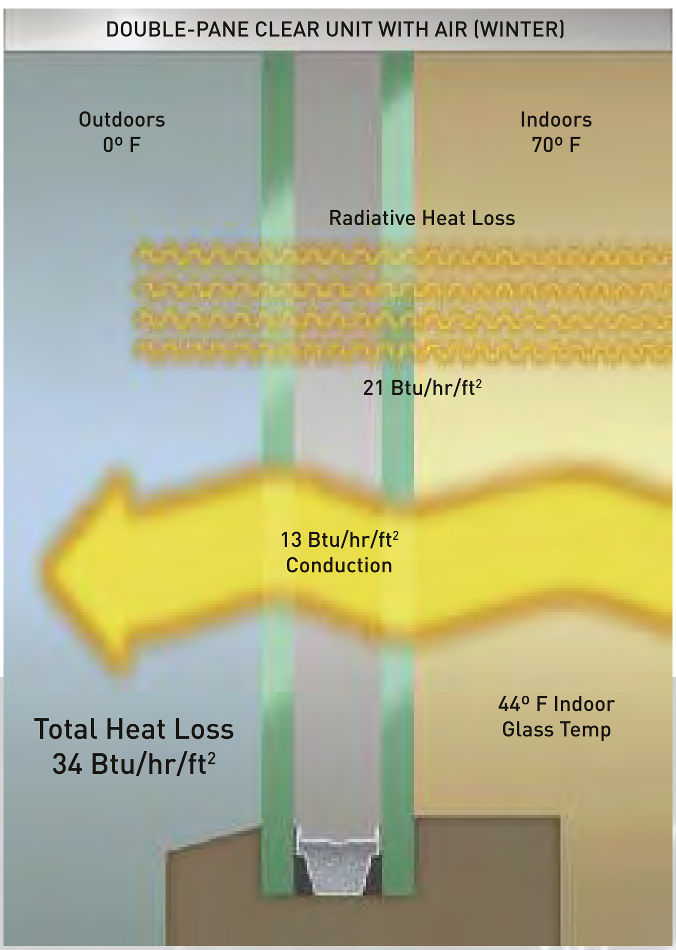


Figure 15-2

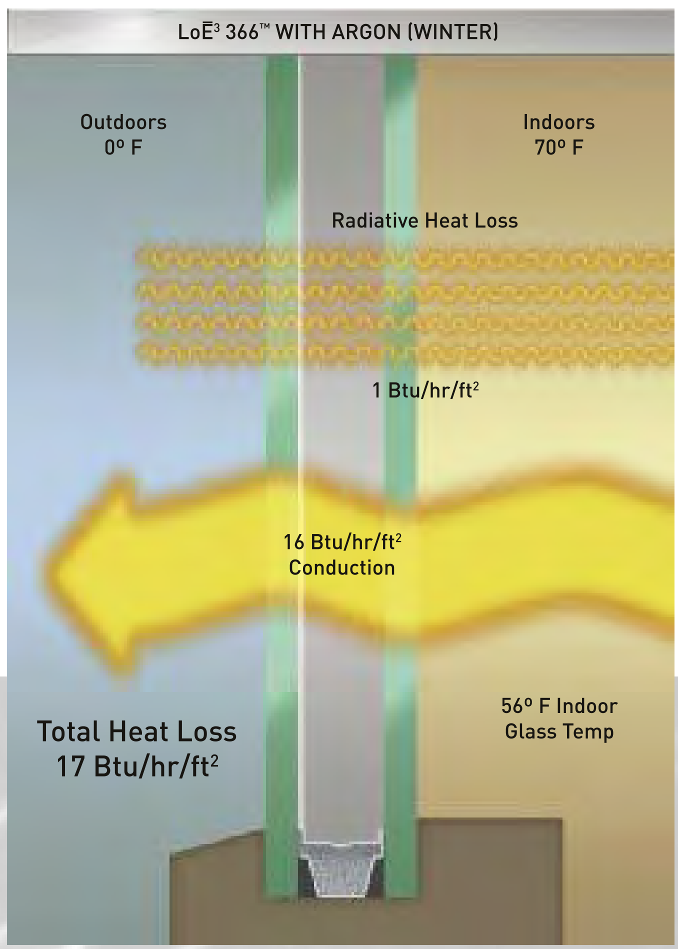


Figure 15-3

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 here (Figures 16-1, 16-2 and 16-3) 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 TIME SOLAR HEAT GAIN COMPARISONS

Product	Total Energy Rejected (Btu/hr/ft^2)	Total Energy Gained (Btu/hr/ft^2)	Heat Gain Reduction Compared To Standard Double-Pane Unit	Shading Coefficient	SHGC	Indoor Glass Temp °F
Double-Pane Clear	51	186	----	0.90	0.78	90
Double-Pane LoĒ-179™	73	160	13%	0.80	0.70	86
Double-Pane LoĒ^2-272™	136	98	47%	0.48	0.41	84
Double-Pane LoĒ^2-270™	146	88	53%	0.42	0.37	83
Double-Pane LoĒ^3-366™	167	66	65%	0.31	0.27	82
Triple-Pane LoĒ-179™	100	133	28%	0.65	0.57	95
Triple-Pane LoĒ^2-272™	149	83	55%	0.40	0.35	94
Triple-Pane LoĒ^3-366™	175	57	69%	0.27	0.24	92

1) Double-Pane IG Construction: 3.0mm (1/8") thick glass with a 13.0mm (1/2") airspace, 90% argon filled for LoĒ products, otherwise air-filled cavity. Coatings are on surface #2, except for LoĒ-179™ coating is on surface #3.
2) Triple-Pane IG Construction: 3.0mm (1/8") thick glass with two 8.0mm (5/16") airspace, 90% argon filled for LoĒ products, otherwise air-filled cavity. Coatings are on surfaces #2 and #5.

Figure 16-1

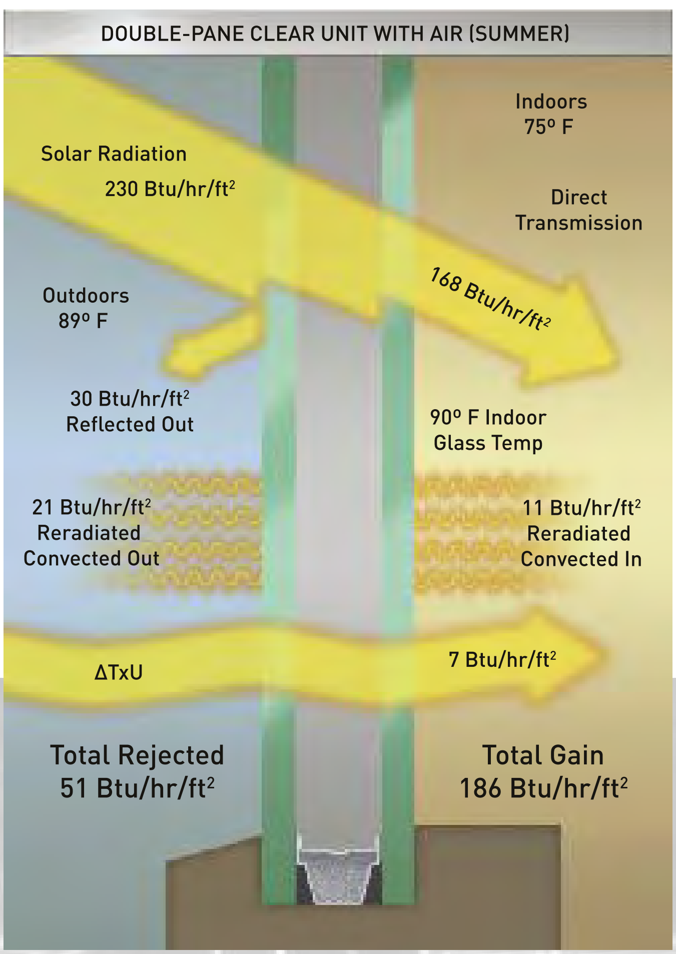


Figure 16-2

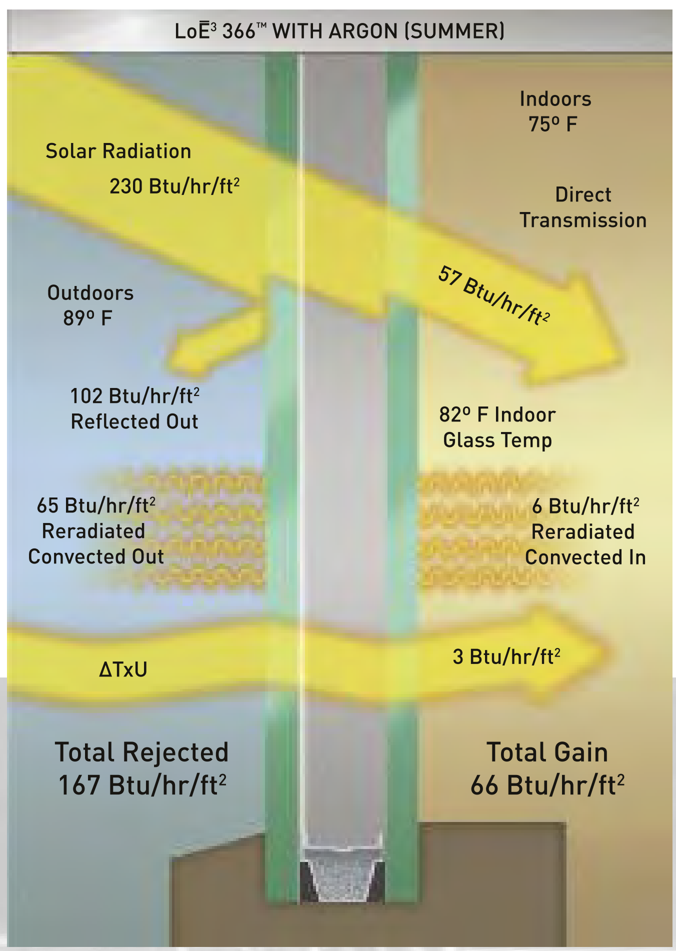


Figure 16-3

LoĒ^2® and LoĒ^3™ Glass Improves Comfort Year Around

LoĒ^2® and LoĒ^3™ insulating glass units improve comfort year round. The following tables (Figures 17-1 and 17-2) illustrate the winter and summer comfort characteristics of insulating glass (IG) products. When it comes to comfort, Cardinal's LoĒ-179™, LoĒ^2-272™, LoĒ^2-270™, LoĒ^3-366™ and LoĒ^2-240™ IG units outperform clear glass IG units.

Cold weather comfort

The higher the indoor glass temperature, the better the product is for comfort. In controlled test projects (see House Studies, page 31, for protocol and corresponding energy-saving information), LoĒ^2® and LoĒ^3™ glass maintained acceptable comfort in winter conditions with a lower thermostat setting than would be necessary in a house with clear glass.

WINTER CONDITIONS: INDOOR GLASS TEMPERATURES

Insulating Glass Product	Temperature (°F)
Double-Pane Clear	44
Cardinal LoĒ-179™, LoĒ^2-272™, LoĒ^2-270™, LoĒ^3-366™, LoĒ^2-240™	56
Triple-Pane LoĒ-179™ (#2 and #5)	60
Triple-Pane LoĒ^2-272™ (#2 and #5)	60

1) Temperatures calculated per ASHRAE-NFRC winter time design condition
2) All LoĒ products calculated with 90% argon fill, and clear glass products are air filled
3) Glass temperatures were computed using LBNL Window 5.2 computer program
4) Glass temperatures are for central portion of glass
5) Double-pane configuration: 1/8" (3 mm) glass, 1/2" (13.0 mm) airspace
6) Triple-pane configuration: 1/8" (3 mm) glass, 5/16" (8.0 mm) airspace

Figure 17-1

Hot weather comfort

The lower the indoor glass temperature and relative heat gain, the better the product is for comfort. In the controlled test projects, data proved that acceptable comfort with LoĒ^2® and LoĒ^3™ windows could be accomplished with a 78° F thermostat setting. To develop a comparable comfort level in a clear glass house, the thermostat would have to be lowered by 4° F or more. There was less overheating during sunny, mild days and more uniform temperatures from room to room with the use of LoĒ^2® and LoĒ^3™ products.

SUMMER CONDITIONS: INDOOR GLASS TEMPERATURES AND RELATIVE HEAT GAINS

IG Product	Temperature (°F)	Relative Heat Gain (Btu/hr/ft^2)
Double-Pane Clear	90	186
LoĒ-179™	86	138
LoĒ^2-272™	84	98
LoĒ^2-270™	83	88
LoĒ^3-366™	82	66
LoĒ^2-240™	86	61
Triple-Pane LoĒ-179™ (#2 and #5)	94	117
Triple-Pane LoĒ^2-272™ (#2 and #5)	94	83

Reference Figure 17-1 for footnotes.

Figure 17-2

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-insulated 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.

Condensation means the IG unit is working

The presence of moisture indicates that the 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 should be open 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.

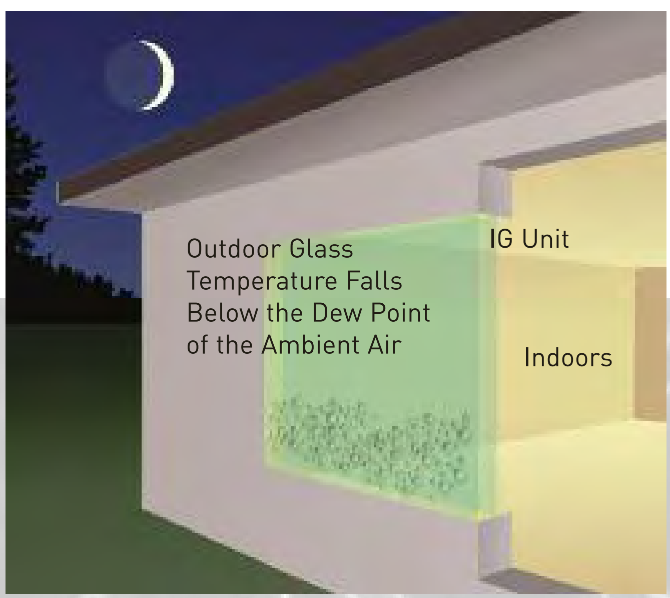


Figure 17-3

Indoor Condensation

Maintaining a desirable humidity level

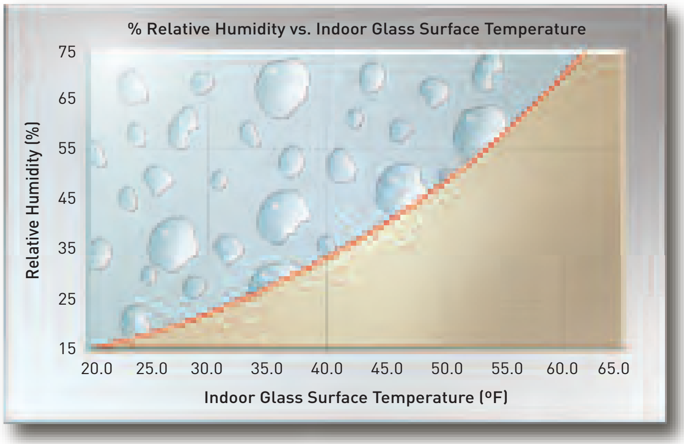
People are most comfortable when relative humidity ranges between 20 and 60 percent. In the home, an average relative humidity of 35 to 40 percent is appropriate when the outside temperature is 20° F or above. However, during cold weather, higher humidity ranges may cause indoor condensation on windows.

This table (Figure 18-1) 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 18-1

If glass conditions are above the line (Figure 18-2), expect to see condensation. If they are below the line, you won't see condensation.



1) Indoor Air Temperature = 70° F

Figure 18-2

INDOOR CONDENSATION PREDICTABILITY

Outdoor Glass	Air Space		-20° F Outdoor Air Temperature			0° F Outdoor Air Temperature			+20° F Outdoor Air Temperature		
	mm	inches	U-Value	T_{cog}	%RH	U-Value	T_{cog}	%RH	U-Value	T_{cog}	%RH
Clear / Clear	6.5	1/4	0.55	33	25	0.56	40	34	0.57	48	45
	9.8	3/8	0.50	36	29	0.51	43	38	0.52	50	49
	13.0	1/2	0.49	37	30	0.49	44	39	0.49	51	51
	16.0	5/8	0.49	36	29	0.49	44	39	0.48	51	51
Clear / LoĒ-179™	6.5	1/4	0.35	46	42	0.35	51	51	0.36	56	61
	9.8	3/8	0.29	49	47	0.29	54	57	0.29	58	66
	13.0	1/2	0.30	49	47	0.28	54	57	0.26	59	68
	16.0	5/8	0.31	49	47	0.29	54	57	0.27	59	68
LoĒ²-272™ / Clear	6.5	1/4	0.33	47	44	0.34	51	51	0.34	56	61
	9.8	3/8	0.27	51	51	0.27	55	59	0.26	59	68
	13.0	1/2	0.27	51	51	0.25	56	61	0.23	61	73
	16.0	5/8	0.28	50	49	0.26	55	59	0.24	60	71
LoĒ²-270™ / Clear	6.5	1/4	0.33	47	44	0.33	52	53	0.34	56	61
	9.8	3/8	0.27	51	51	0.26	55	59	0.26	59	68
	13.0	1/2	0.27	51	51	0.25	56	61	0.23	61	73
	16.0	5/8	0.28	50	49	0.26	56	61	0.23	60	71
LoĒ²-240™ / Clear	6.5	1/4	0.34	46	42	0.34	51	51	0.35	56	61
	9.8	3/8	0.28	51	51	0.27	55	59	0.27	59	68
	13.0	1/2	0.28	50	49	0.26	56	61	0.24	60	71
	16.0	5/8	0.29	50	49	0.27	55	59	0.24	60	71
LoĒ³-366™ / Clear	6.5	1/4	0.33	47	44	0.33	52	53	0.33	57	63
	9.8	3/8	0.26	51	51	0.26	56	61	0.26	60	71
	13.0	1/2	0.27	51	51	0.24	56	61	0.22	61	73
	16.0	5/8	0.28	51	51	0.25	56	61	0.23	61	73
Triple-pane clear	6.5	1/4	0.37	44	39	0.38	49	47	0.39	54	57
	13.0	1/2	0.31	48	45	0.31	53	55	0.32	57	63
Triple-pane LoĒ-179™	6.5	1/4	0.21	55	59	0.21	58	66	0.22	61	73
	13.0	1/2	0.15	59	68	0.14	62	76	0.14	64	81
Triple-pane LoĒ³-366™	6.5	1/4	0.19	56	61	0.20	59	68	0.20	62	76
	13.0	1/2	0.13	61	73	0.12	63	79	0.12	65	84

Figure 18-3

1) U-Value: Winter night time conditions with outdoor air temperatures shown. 12.3 mph outdoor wind velocity with indoor air temperature = 70° F.
2) T_{cog}: Indoor center of glass surface temperature (rounded to nearest degree). Calculated using Window 5.2 program from LBNL.
3) %RH: Percent relative humidity at indoor temperature of 70° F. Maximum indoor relative humidity before condensation starts to appear.
4) LoĒ coatings on surface #2 for double-pane construction (except LoĒ-179™ coating is on surface #3).
5) LoĒ coatings on surface #2 and #5 for triple-pane construction.
6) 90% argon filled airspace for coated insulating glass units, otherwise air filled airspace unless noted.
7) All insulating glass systems contain 1/8" (3 mm) glass.

Solar Energy Transmittance Comparison

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

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

A comparison of the performance of Cardinal's LoĒ products is shown below (Figure 19-1).

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 gain (SHGC), heat loss (U-Factor), comfort, visible light transmission, etc., should be taken into account on any application.

All Cardinal LoĒ glass products can be supplied in stock sheets and can be tempered, bent and laminated for stock delivery. Maximum stock sheet size: 96" x 144" (2.43 meters x 3.65 meters).

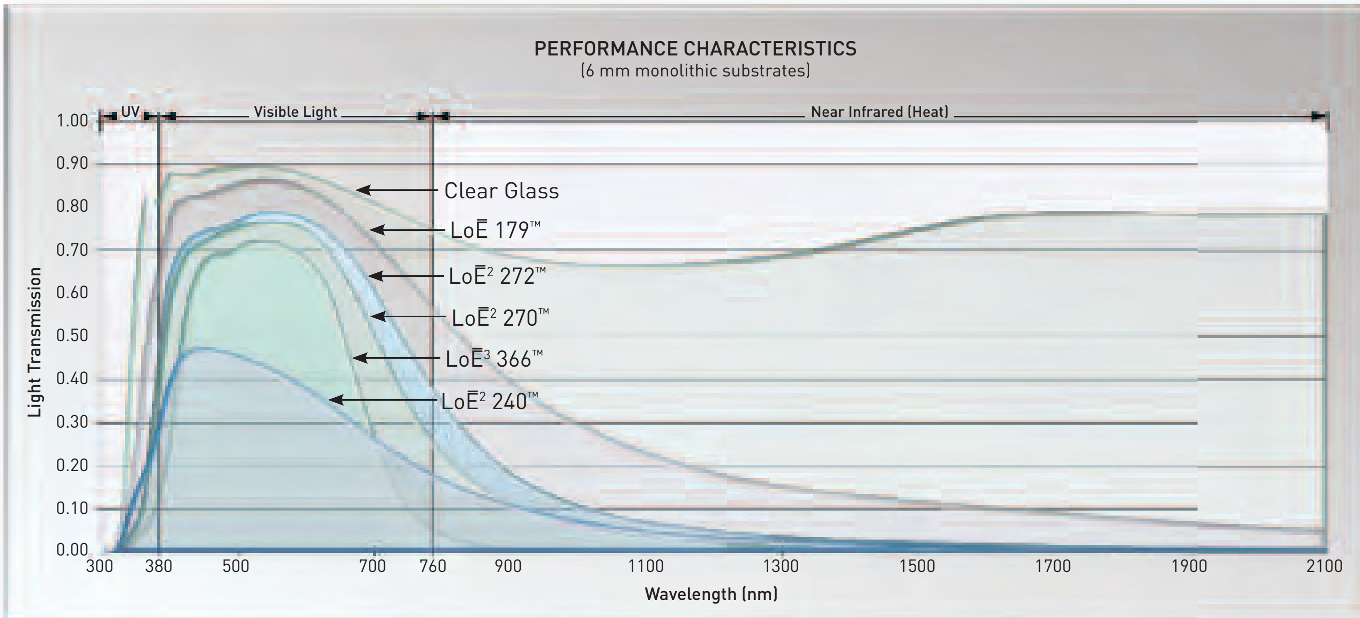


Figure 19-1

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 Test Standard E 90-85 "Standard Method for Laboratory Airborne Sound Transmission Loss of Building Partitions" should be used.

Using published industry data, Cardinal has developed this table (Figure 19-2) 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 (1/8") Glass/6.5 mm (1/4") Airspace/3.0 mm (1/8") Glass

Property	Change in STC Rating (dB)	
Increase air space 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 19-2

Fading

Energy from the sun which is transmitted through glass can be categorized into three main regions:

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

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 (Solar Spectrum graphic above). For this reason, a damage weighted function was developed in Europe by Krochmann. (Solar Spectrum graphic above, Figure 20-1).

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.

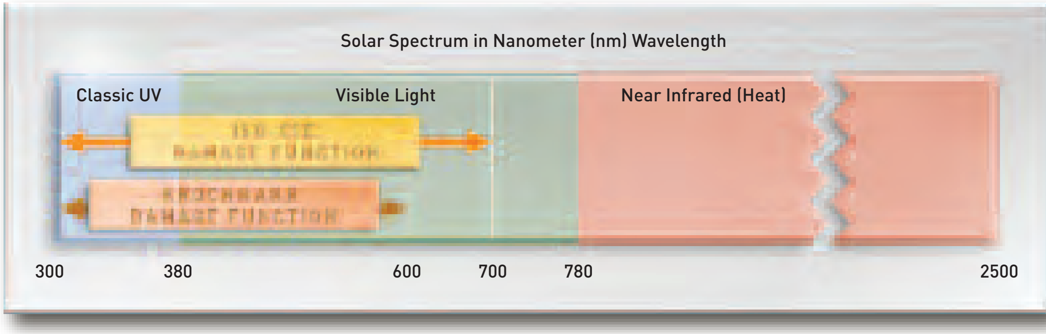


Figure 20-1

FADING COMPARISONS

IG Product	UV Transmission (300 to 380 nm)	Krochmann Damage Weighted Transmission (300 to 600 nm)	ISO-CIE Damage Weighted Transmission (300 to 700 nm)
Single Pane 3 mm Clear	73%	74%	85%
Single Pane 3 mm Bronze	36%	43%	57%
Single Pane 3 mm Pyrolytic	49%	56%	71%
Single Pane 7.8L Laminate	2%	30%	61%
Clear / Clear	58%	61%	75%
Clear / Pyrolytic	46%	51%	65%
Clear / LoĒ-179™	24%	39%	61%
LoĒ^2-272™ / Clear	16%	33%	55%
LoĒ^2-270™ / Clear	14%	31%	53%
LoĒ^3-366™ / Clear	5%	21%	43%
LoĒ^2-240™ / Clear	16%	24%	35%
Bronze / Clear	31%	37%	51%
Bronze / LoĒ-179™	14%	26%	43%
Bronze / LoĒ^2-272™	10%	23%	39%
Bronze / LoĒ^2-270™	9%	22%	37%
Clear / 7.8L Laminate	<1%	27%	55%
LoĒ-179™ / 7.8L Laminate	<1%	23%	50%
LoĒ^2-272™ / 7.8L Laminate	<1%	22%	46%
LoĒ^2-270™ / 7.8L Laminate	<1%	21%	45%
LoĒ^3-366™ / 7.8L Laminate	<1%	16%	39%
LoĒ^2-240™ / 7.8L Laminate	<1%	14%	28%
Triple-Pane: LoĒ-179™ / Clear / LoĒ-179™	10%	26%	48%

Figure 20-2

1) Calculations were done using Window 5.2 program with NFRC 100-2001 environmental conditions.
2) Pyrolytic product: 3 mm Pilkington/LOF Energy Advantage Low-E.
3) Laminated configuration: 7.8L (3 mm / 0.060" PVB / 3 mm).
4) IG configurations: 3 mm glass thickness, 12.7 mm airspace dimension. For double-pane IG units, the LoĒ coatings were located on surface #2; except when configured with a tinted lite then the LoĒ coating is located on surface #3. For triple-pane IG units, the LoĒ coatings were located on surfaces #2 and #5.

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.

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 (C.I.E.). 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. The Fading Comparisons table above (Figure 20-2) lists Cardinal's products and their relationships to the three different fading interpretations: UV, Krochmann and ISO-C.I.E.

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 21-2). 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 they 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.

Other factors affecting plant growth include:

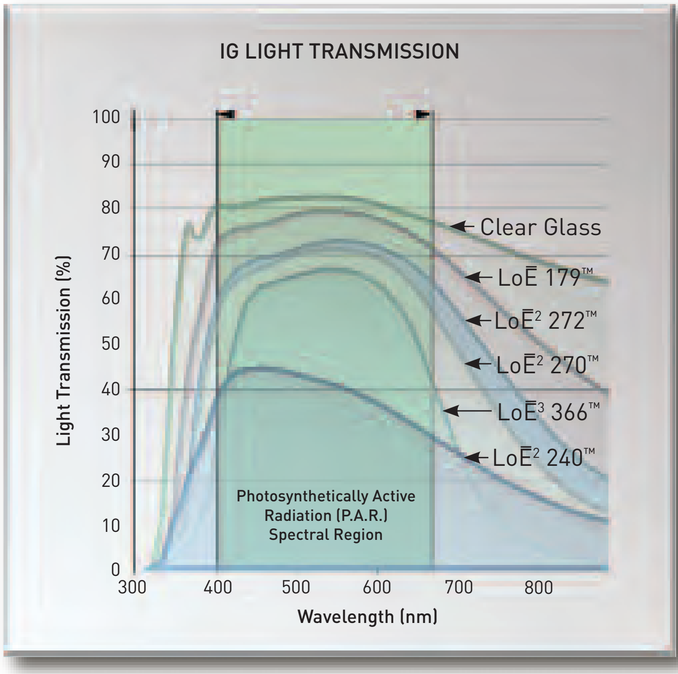
- Distance from windows
- Length of exposure to direct sunlight
- Time of day of direct exposure
- Light reflection from interior and exterior surfaces
- Average ambient temperature
- Temperature fluctuations
- Relative humidity
- Air circulation patterns
- Watering
- Perhaps most important of all, the cleanliness of the windows

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. The table below (Figure 21-1) 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 LoĒ²-240™. This coating allows only 45% 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.

IG Unit (3 mm glass)	Percentage of Photons Transmitted in P.A.R. Spectral Region
Clear / Clear	83%
Clear / LoĒ-179™	80%
LoĒ²-272™ / Clear	73%
LoĒ²-270™ / Clear	71%
LoĒ³-366™ / Clear	67%
LoĒ²-240™ / Clear	45%

Figure 21-1



1) Data calculated using Optics 5.
2) IG Configuration: 3 mm LoĒ / 13.0 mm airspace / 3 mm clear, except for LoĒ-179™ coating is on surface #3.

Figure 21-2

Roof Windows

Glass products used in roof window applications are exposed to higher levels of thermal loads, snow loads and possibly impact loads. In addition, because the glass is used in a non-vertical application, the potential for fall-out due to glass breakage should be considered.

Thermal stress

Because the glass is used in a sloped application, it is exposed more directly to solar loads compared with a glass product that is used in a vertical application. Glass thermal stress is usually higher when glass products are used in a sloped glazing application. (Also see Thermal Stress on page 41.)

Snow loads

Snow loads need to be considered when designing glass products for roof windows. Fresh, light, powdery snow weighs approximately 5 to 10 pounds per cubic foot, while wet snow weighs between 20 and 25 pounds per cubic foot. The breaking stress of glass is a function of the load duration on the glass. For windload, breakage probabilities are usually chosen based on a three-second uniform windload duration. However, snow loads can exist for days or weeks on end. An increase in sustained loading will decrease the average breaking stress of glass.

For instance, based on an 8 lite per 1,000 breakage probability, the chart below (Figure 22-1) lists the reduction strength for monolithic annealed, heat-strengthened and tempered glasses when exposed to a one-week duration versus a 60-second duration load.

Product	% Reduction in Strength
Annealed	50%
Heat-Strengthened	33%
Tempered	17%

Figure 22-1

Code requirements

The major model building codes have published specific requirements for glass products as used in a sloped glazing application. Tempered safety glass and laminated glass, when used in accordance with building code requirements, have been successfully used in roof windows. Sloped glazing, as defined by the codes, is designated as any installation of glass products glazed at a slope of 15 degrees or more from the vertical plane. It is strongly recommended that when considering roof windows, all local and national codes be reviewed to make certain that the products being considered will meet the applicable codes for windload, snow load and fall-out potential.

The following is from the International Residential Code for one- and two-family dwellings.

"For Skylights and Sloped Glazing which is at a slope of 15 degrees or more from the vertical, the following types of glazing may be used:

- Laminated glass with a minimum of 0.015" (0.38 mm) PVB interlayer for glass panes 16 ft^2 (1.49 m^2) or less in area located such that the highest point of the glass is not more that 12 feet (3,658 mm) above a walking surface. For higher or larger glass sizes, the minimum interlayer thickness shall be 0.030" (0.76 mm)
- Fully tempered glass with a glass area of 16 ft^2 (1.49 m^2) or less with the highest point of glass not more than 12 feet (3,658 mm) above a walking surface. Nominal glass thickness not more than 3/16 inch (4.7 mm).

If tempered glass products are greater in area or installed higher than 12 feet, a retaining screen shall be installed below the glass for fall-out protection."

Thermal performance of roof windows

For roof windows, the winter nighttime U-Value will increase as the slope of the window changes from vertical to horizontal. This increase in U-Value occurs due to air space gas convection flow changes which increase the heat flow rate.

The solar heat gain coefficient (SHGC) for a sloped window remains unchanged from the vertical position. This is because the SHGC is always based on normal solar incidence. This is not to say that the total heat gain is unchanged with slope. Total heat gain is a complex calculation, based on inputs of angle of sun, time of day, time of year, slope, glass type, latitude, etc. While it is not possible to calculate total heat gain unless all of these factors are known, in most cases a sloped window will experience more heat gain than a vertical window.

The percent change in Center of Glass U-Values compared to vertical glazing (Figure 22-2) at 1/2" gap width are:

Product	45° Slope	Horizontal
Clear IG	+12%	+22%
LoĒ^2-272™	+33%	+54%
LoĒ^2-272™ (triple-glazing)	+23%	+54%

Figure 22-2

The specific data for Center of Glass U-Value vs. airspace and tilt is tabulated below (Figure 22-3).

CENTER OF GLASS U-VALUE VS. AIRSPACE VS. TILT

Airspace	6.5 mm (¼")	8.0 mm (5/16")	9.8 mm (⅜")	11.5 mm (7/16")	13.0 mm (½")
Clear / Air			**U-Value**		
90° Tilt	0.55	0.52	0.50	0.49	0.48
45° Tilt	0.59	0.56	0.54	0.54	0.55
0° Tilt	0.60	0.56	0.59	0.60	0.60
LoĒ^2-272™, LoĒ^2-270™, LoĒ^3-366™			**U-Value**		
90° Tilt	0.33	0.28	0.25	0.24	0.24
45° Tilt	0.33	0.29	0.30	0.31	0.32
0° Tilt	0.34	0.36	0.38	0.37	0.37
LoĒ-179™			**U-Value**		
90° Tilt	0.35	0.31	0.29	0.27	0.28
45° Tilt	0.35	0.31	0.31	0.33	0.34
0° Tilt	0.35	0.37	0.39	0.39	0.39
LoĒ^2-272™, Triple, #2 & #5			**U-Value**		
90° Tilt	0.20	0.17	0.15	0.13	0.13
45° Tilt	0.20	0.20	0.15	0.15	0.16
0° Tilt	0.20	0.20	0.19	0.19	0.20

Figure 22-3

1) 90° Tilt = Vertical. 0° Tilt = Horizontal. Data Based on 3.0 mm Glass.
2) Triple-Pane IG Construction: 3.0mm (1/8") thick glass with two 8.0mm (5/16") airspace, 90% argon filled for LoĒ products, otherwise air-filled cavity. Coatings are on surfaces #2 and #5.
3) For more information on roof windows, it is recommended that the following documents be reviewed:
   - GANA (Glass Association of North America) 2004 Glazing Manual
   - SIGMA (Sealed Insulating Glass Manufacturers Association) "Voluntary Guidelines for Sloped Glazing of Organically Sealed Insulating Glass Units" Document A-2801-77 (86)
   - AAMA (American Architectural Manufacturers Association) "Sloped Glazing Guidelines" Document AAMA T IR-A7-83
   - NWWDA (National Wood Window and Door Association) "Industry Standard for Wood Skylights/Roof Window Units" Document IS-7 (87)

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 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.

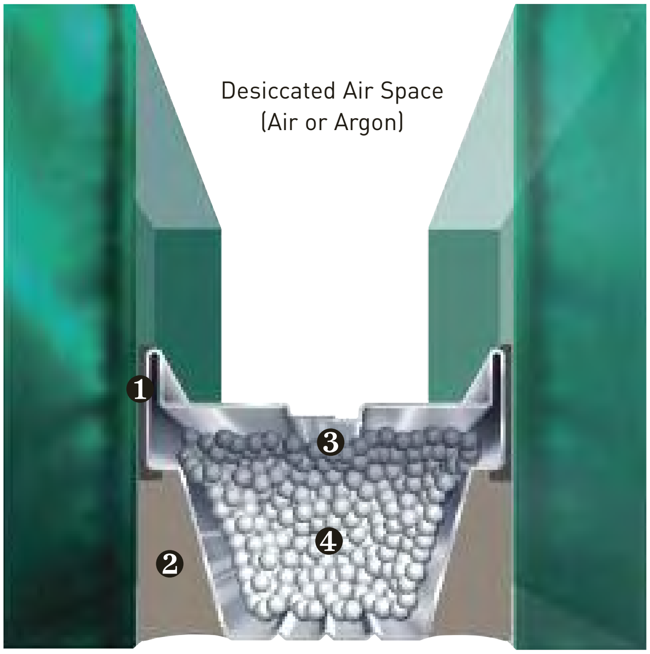
In addition to sealant choice, spacer design and processing are also important. Cardinal uses four bent corners in our construction which requires only one joint in the spacer. Many other IG manufacturers use corner keys to attach the four spacer pieces together. Four joints instead of one significantly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



Double-Pane

Figure 25-1

Cardinal IG® Unit Construction

Cardinal IG units consist of two or three lites of glass separated by an inorganic metal spacer (Figures 25-1 and 26-1). Spacer corners are bent to be air/gas tight. The spacer contains desiccants 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.

Glass: Float glass. Specify clear, heat absorbing, or LoĒ, LoĒ²® or LoĒ³™.

❶ **Primary Seal:** Polyisobutylene (PIB) minimizes moisture permeation, increases UV resistance, reduces the potential for chemical fog in airspace, and provides the lowest argon permeation of all known sealants.

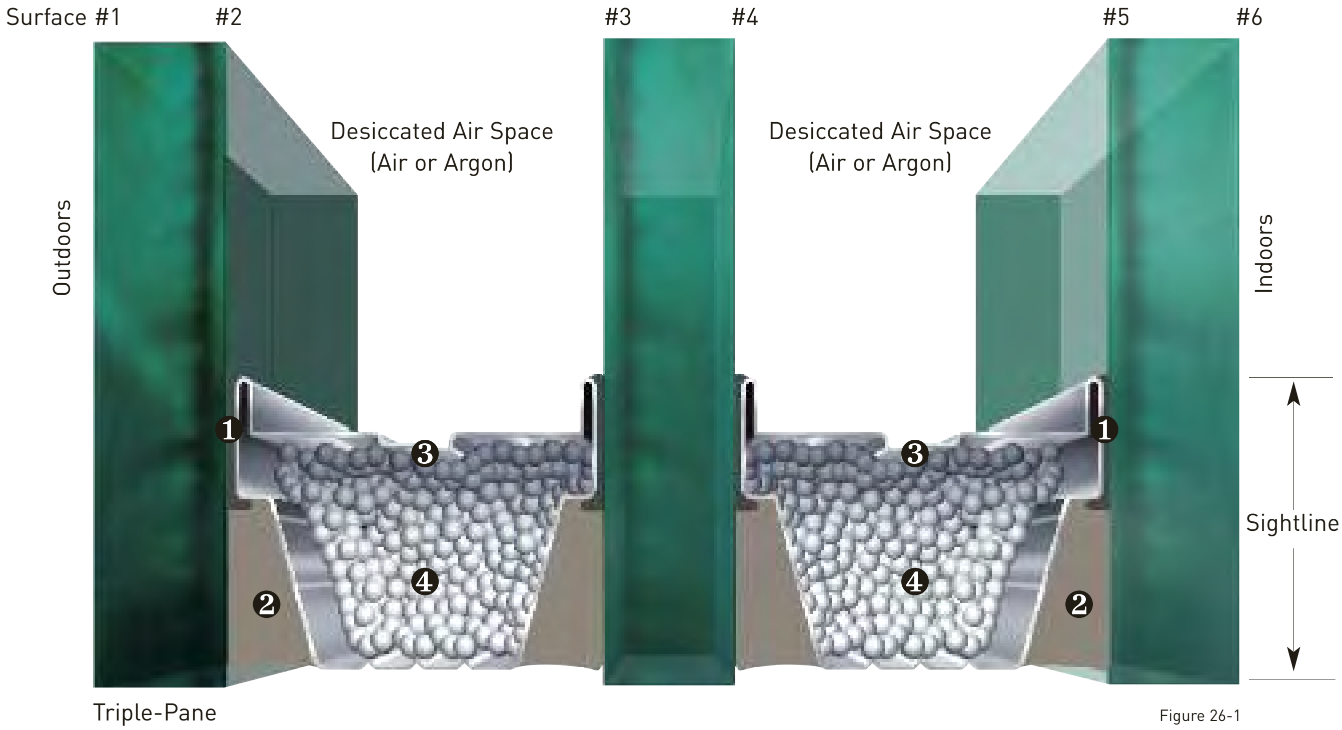


Figure 26-1

❷ **Secondary Seal**: Specially formulated silicone for IG units provides long-term adhesion, UV protection, and greater resistance to the effects of solvents, oils and short-term water immersion. 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.

❸ **Spacer:** Stainless steel spacer (XL Edge®) features a roll form design to provide 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.

❹ Desiccants: Molecular sieve provides initial frost points below – 85° F. 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. Dual Seal

- PIB Primary Seal
- Silicone Secondary Seal
- Bent Corners

B. Argon Fill

C. 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 standard by 7 times – or more
The American Society of Testing and Materials (ASTM) has developed a testing protocol to determine the weatherability of insulating glass constructions. Passing this standard is considered to be the minimum requirement for insulating glass units. A failure is when the dew point of the unit is 0º F or higher.

As shown below (Figure 27-1), Cardinal's dual-seal system passed this 15-week test 7 times (105 weeks) without failure. It would have gone longer, but the tests were halted. All tests were performed at an independent test lab.

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 weatherability. Test criteria simulate worst-case, real-world scenarios: 140º F, constant UV exposure and 100% humidity.

Results showed that competitive seal systems failed within 8 to 22 weeks of testing. However, Cardinal IG units still had a dew point below 0º F after 80 weeks of the test.

Cardinal's Seal Failure Experience
Figure 27-2 shows Cardinal's field failure rate comparing single seal organic failure rates to 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 – 6.53% -
- Dual Seal Silicone/ Aluminum Spacer – 1.3%
- Dual Seal Silicone/ XL Edge (SS Spacer) – 0.20%

This is compared to Single Seal Organic Seals which we believe will have a 15.54% failure rate in 20 years.

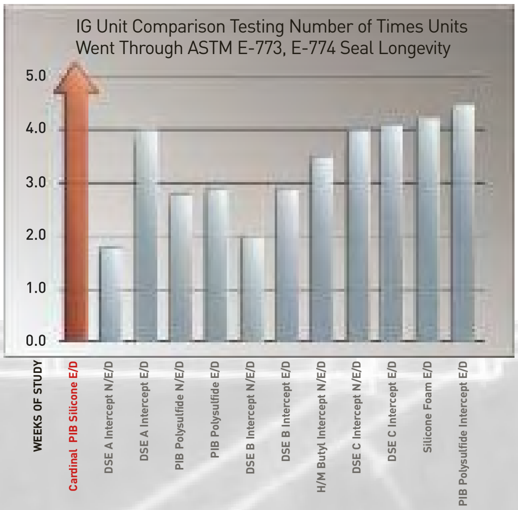
The graph shows Cardinal actual failure rates for three different IG unit constructions. In 1993, Cardinal introduced a stainless steel spacer with a PIB/Silicone seal system and four bent corners. We produced approximately 8 million IG units that year.

As can be seen by the data, the seal failure rate of the XL Edge product is 0.20% after 20 years of field service.

What this means to the window manufacture is shown in Figure 27–3. Assuming a $200 service call to reglaze a failed IG unit under warranty, and with an 8% seal failure rate, the window

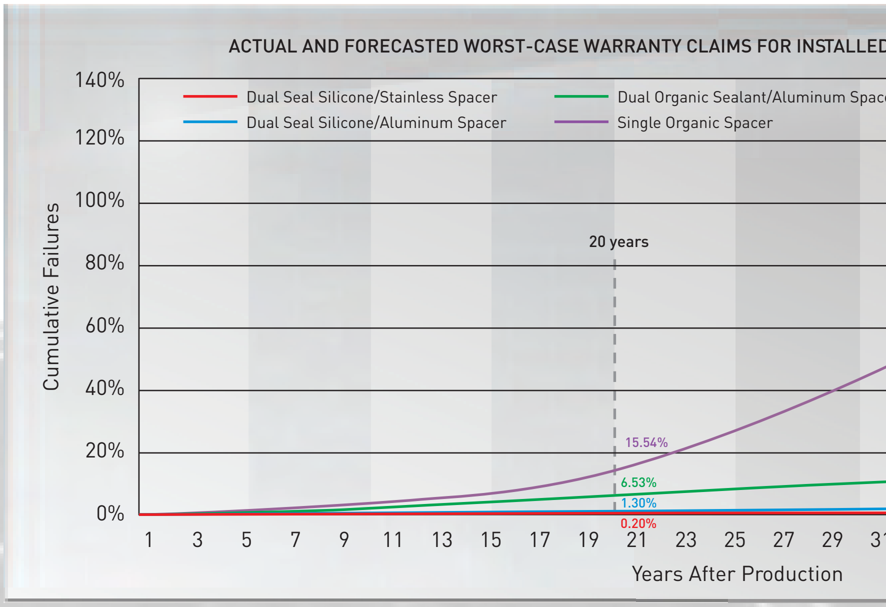
P-1 Test Chamber:
140° F, constant UV,
100% humidity

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



(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 27-1



manufacturer would need to add $16 to the cost of the window to cover warranty costs. With a 0.20% seal failure rate, the window manufacturer would need to add $0.50 to the window to cover warranty claims.

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, the LoĒ coatings extend to the edge of the glass, and corrosion of the coatings can propagate past the seal system when the IG unit is exposed to high humidity conditions or is sitting in water.

IG unit clarity

Cardinal's insulating glass unit warranty covers "obstruction of vision." The obstruction may be either internal condensation or chemical fog. Cardinal tests IG units for both.

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. An industry-accepted test called the Canadian Fog Box Test is used to determine the fogging potential of these materials. Cardinal has developed its own rigorous rating system for this test.

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 1990's 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 1 to 3 times less compared to the aluminum spacer system depending on the conditions studied.

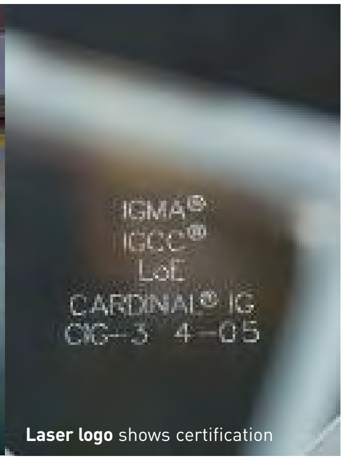
Quick and easy IG unit identification

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 the IG unit was fabricated.


Internal (air space) condensation


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


Chemical fog



Laser logo shows certification

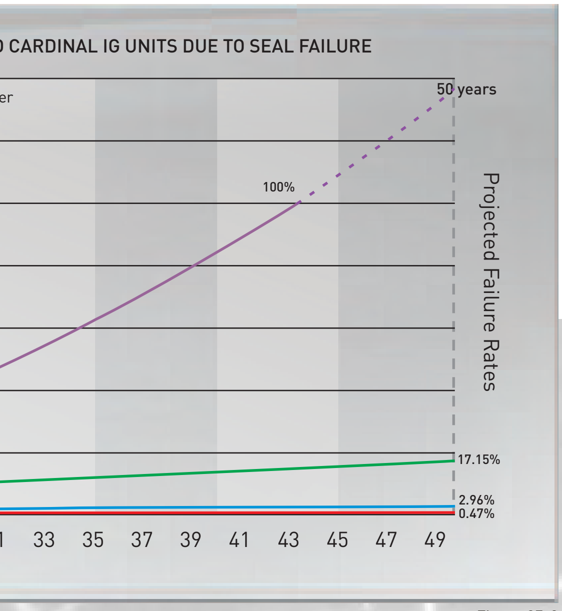
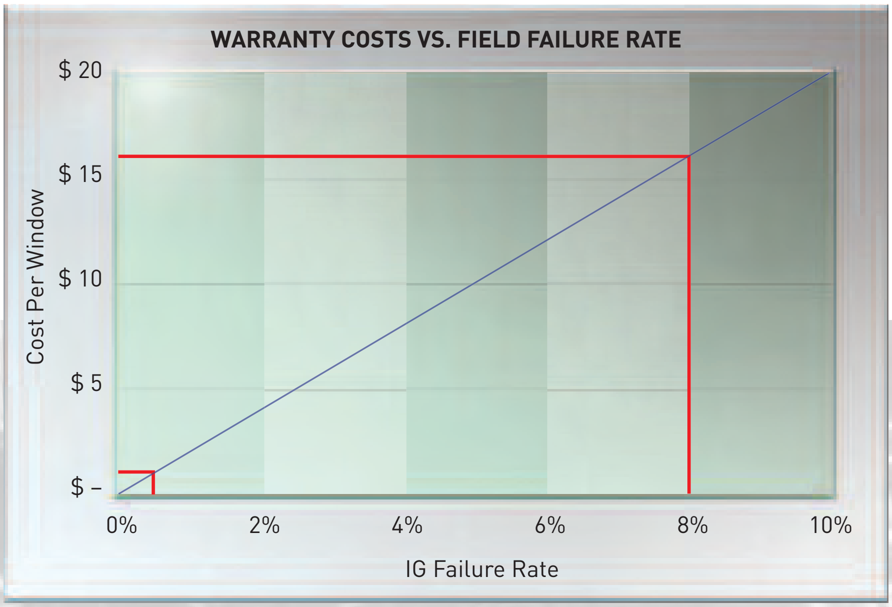


Figure 27-2

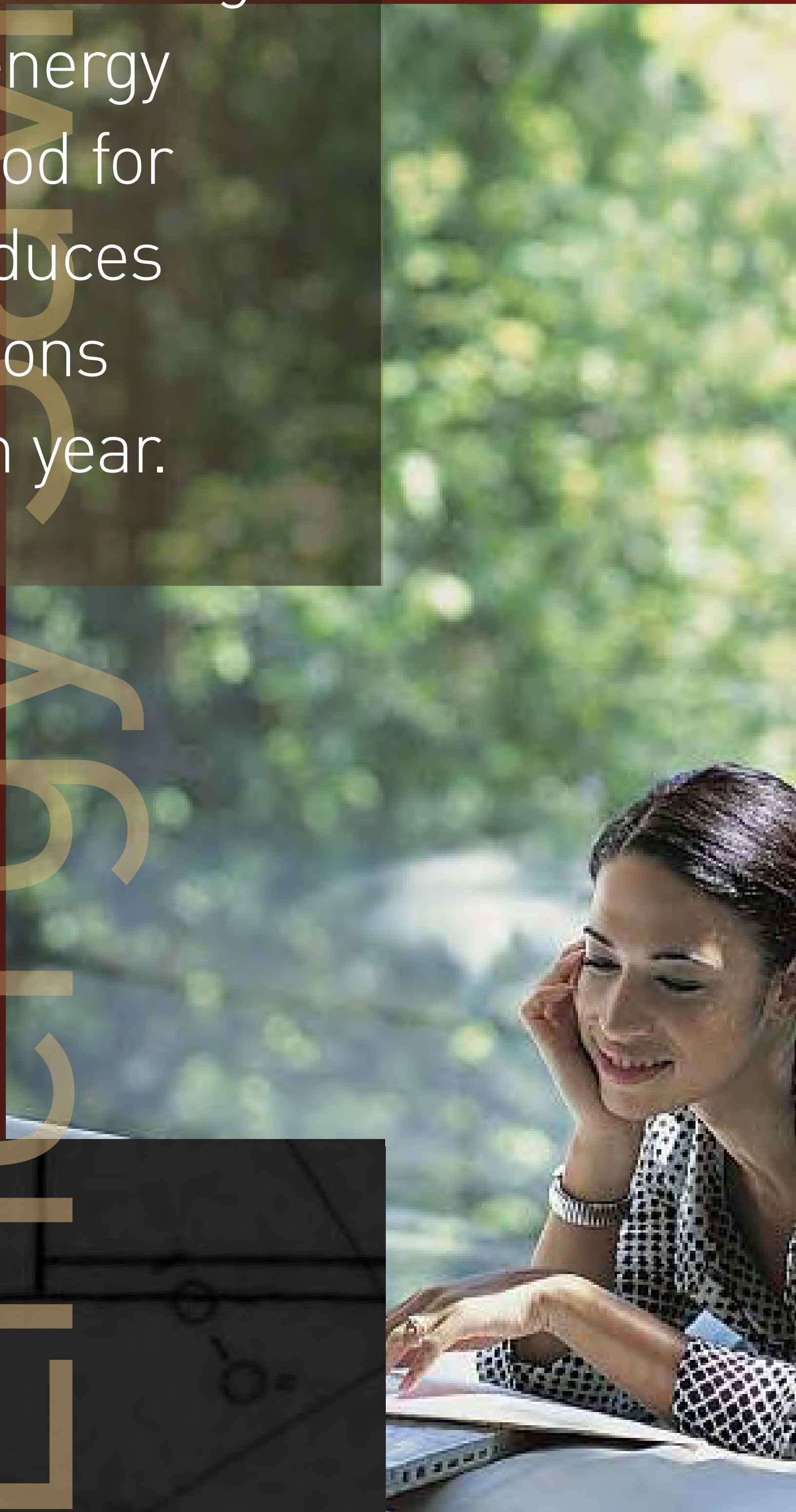


1) $200 Replacement Costs
2) 100,000 Units/Year

Figure 28-1

Energy Savings

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.



Test House Studies Confirm that LoĒ²® Glass Reduces Energy Usage by 20%

To obtain this proof, Cardinal authorized three long-term studies in locations across the country – California, Texas and Indiana. Identical new houses (Figure 31-1) were purchased in each location, and the effects of different glazings on energy usage were scientifically measured and monitored by outside experts.

HOUSE A (Clear IG)

HOUSE B (LoĒ²®)

Figure 31-1

In every case, the test projects demonstrated conclusively that LoĒ²® IG products can reduce energy consumption, saving homeowners money on heating and cooling bills while making homes more comfortable year around. Builders can save money on the cost of heating and cooling equipment.

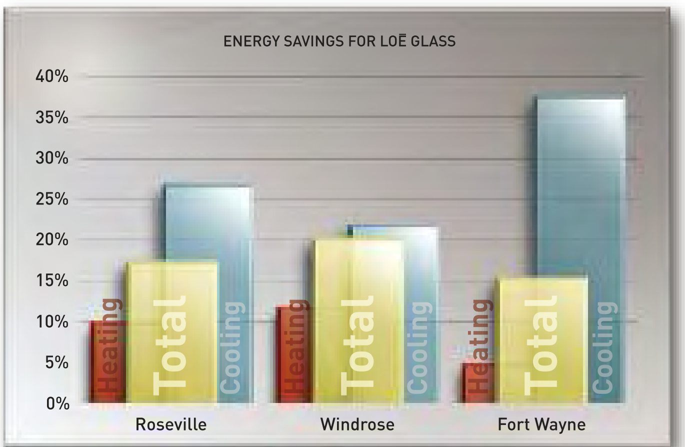


Figure 31-2

Projections from these results show that LoĒ³-366™ 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 – LoĒ²® saved energy on combined heating and cooling in every test site. Total annual savings ranged from 15 to 20% (Figure 31-2).

Significant HVAC savings
Clear or tinted glass creates 50-60% of the cooling load. But because LoĒ²® glass cuts solar heat gain in half, project houses were able to utilize smaller air conditioning units and maintain proper temperatures (Figure 31-3). 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 LoĒ²® glass.

Solar control windows can cut air-conditioning peak loads in all climates, and in all house sizes. A larger house, 4,000 square feet, can reduce the cooling load by nearly 2.5 tons for LoĒ²® vs. clear glass. Our next generation product, LoĒ³-366™, can save nearly one additional ton in this house compared to LoĒ²®.

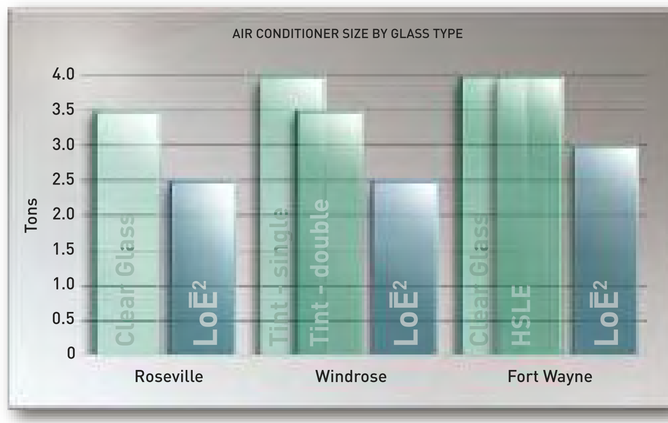


Figure 31-3

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 around
The energy savings aspect of LoĒ²® glass is only part of the story. Comfort is equally important, and LoĒ²® glass improved comfort year-round.

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

Reduced Energy Usage Means Reduced Greenhouse Gas Emissions as Well

Yet the cost is minimal. Energy-efficient LoĒ windows cost only about $15 more per window than clear double-pane windows.

So builders experience an additional cost of about $350 per average house (2,500 ft^2 of floor space, 22 windows). But with proper engineering, builders would save up to $1,000 in first-time HVAC costs. The savings would be significant, considering that over 91% of new homes built in America have mechanical air conditioning, according to the U.S. Census Bureau.

Less energy usage, fewer greenhouse gases
Currently, the residential windows and doors sold with energy-efficient glass (58%) are reducing peak energy demand enough to eliminate the need for eight new 200 MW coal-fired power plants each year.

If the remaining inefficient windows and doors (42%) sold each year were required to have LoĒ^2® glass:

- Peak U.S. energy demands would be reduced sufficiently to eliminate the need to construct six additional new 200 MW coal-fired power plants each year.
- Greenhouse gas emissions (CO_2) from heating and cooling U.S. homes would be reduced by 2.5 million tons each year.
- The annual CO_2 emissions prevented by converting an average house to energy-efficient LoĒ^2® windows and doors equate to the difference between the volume of CO_2 emitted by driving an SUV versus a small hybrid vehicle.
- More than 50% of all windows manufactured in the United States are installed as remodeling or replacement windows in older homes. If these were energy-efficient windows, the improved energy performance would create actual reductions in total U.S. energy consumption.

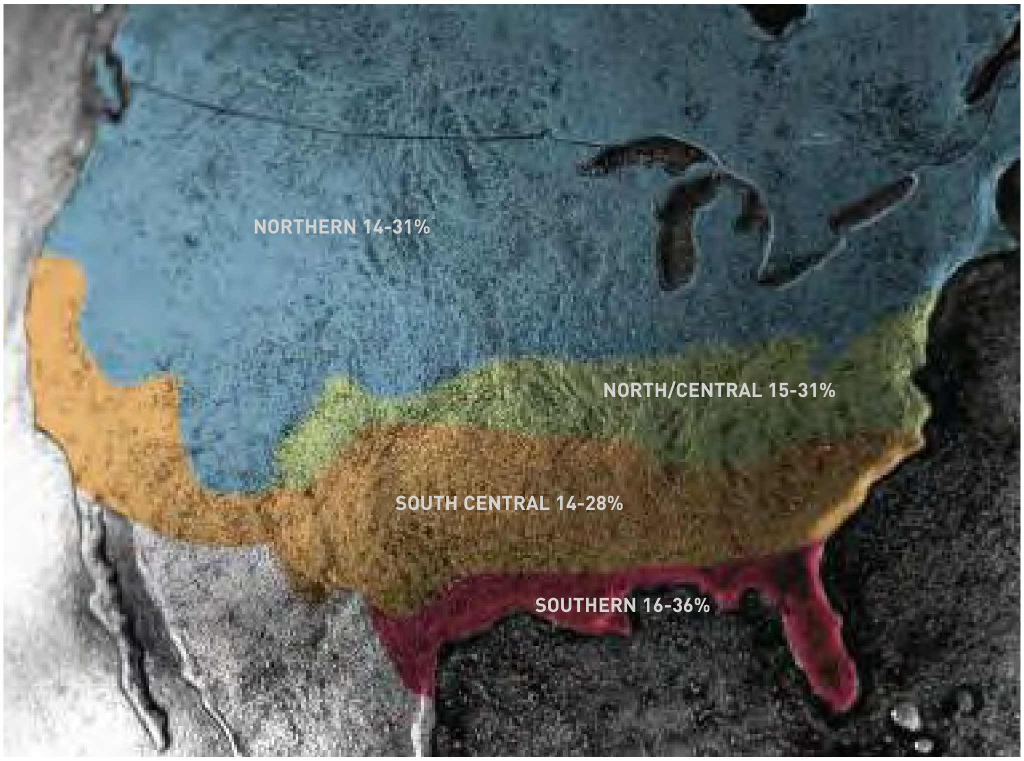
The future appears even brighter

- If all windows and patio doors in the U.S. were required to use LoĒ^3-366™ (the third generation of LoĒ products), greenhouse gas emissions (CO_2) from heating and cooling U.S. homes would be reduced by 7.0 million tons each year.
- This would amount to eliminating two new coal-fired power plants per year, or a total elimination of eight new coal-fired power plants per year.

What about emissions from Cardinal plants in manufacturing these products? In fact, the energy saved by Cardinal glass products neutralizes our entire carbon footprint within twelve months. What's more, the windows continue conserving energy for many years to come.

Heating and Cooling Energy Savings

Figure 33-1 shows total energy costs (heating + cooling) comparing clear double-pane glass to LoĒ$^{2®}$ and LoĒ$^{3™}$ glass for a house with 15% window-to-wall ratio uniformly distributed on all four sides of the house. The smaller savings value assumes identical occupancy patterns. The larger value shows the potential savings when the improvement in occupant comfort is included. A home with LoĒ$^{2®}$ or LoĒ$^{3™}$ glass can deliver equivalent comfort with a lower heating setpoint in the winter and a higher cooling setpoint in the summer.



Percentage of dollars saved over Clear IG

Figure 33-1

LEED Rating System

Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ is recognized around the world as a standard for measuring building design, construction and operation of a high performance green building. LEED certification, which requires the involvement of an independent third party, offers four certification levels for new construction: Certified, Silver, Gold and Platinum.

The level of certification is related to the number of credits acquired at five levels of "green design" categories:

1. Sustainable Sites
2. Water Efficiency
3. Energy and Atmosphere
4. Materials and Resources
5. Indoor Environmental Quality

Cardinal's LoĒ insulating glass products offer builders excellent thermal performances, high transmissions of daylight and are environmentally friendly.

Energy Star Criteria

The U.S. Department of Energy (DOE) has developed an ENERGY STAR® designation for windows used in new and replacement construction. The performance targets established by the program are similar to those in the latest iteration of the model energy code by the International Code Council. When the model code makes changes to the stringency requirements for windows, DOE then updates the windows program. In this manner ENERGY STAR Windows becomes a "first adopter" of new code requirements. The availability of ENERGY STAR products in the region helps set the stage for successful local adoption of improved energy codes.

The model code defines 8 different climate zones across the North American continent. From the perspective of windows and their influence on building energy performance, the U.S. breaks down into 2 basic regions: North (heating dominated) and South (cooling dominated). See figure 34-1.

DOE divides the primary regions into sub-regions labeled as North, North Central, South Central, and South. In general, the U-Factor (insulating value) criteria are more stringent to the North and the SHGC (solar control) criteria are more stringent to the South. Common practice has window manufacturers with product offerings that can comply across an entire region (e.g. North & North Central).

Combined with lower conductance framing materials (e.g. wood or vinyl), glass products like LoĒ^2® and LoĒ^3™ can achieve ENERGY STAR compliance across the entire country. These Cardinal LoĒ products offer the combination of low U-Value (better insulation) for the North with spectral selectivity that provides solar control needed in the South without sacrificing visible light transmission.

The tabulation below (Figure 34-2) shows the glass and frame combinations most likely to achieve compliance for the ENERGY STAR Windows program that is modeled after the 2006 version on the model code:

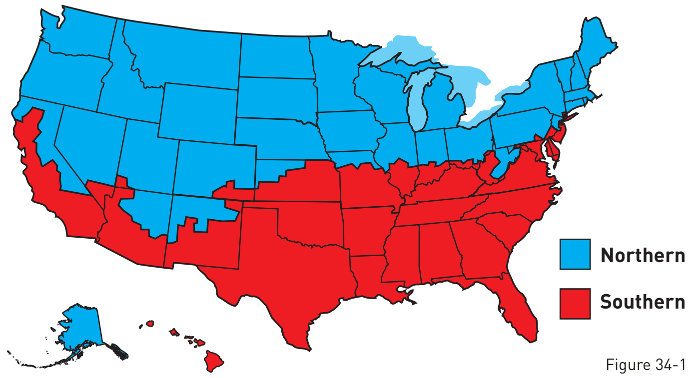


Figure 34-1

COMPLIANCE GUIDELINES FOR 2006 IECC/ENERGY STAR WINDOWS

Frame Type	Glass Layers	Glass Type	South	South Central	North Central	North
Aluminum	Double-pane	LoĒ-179				
		LoĒ^2-272, LoĒ^2-270	X			
		LoĒ^3-366, LoĒ^2-240	X			
Aluminum, Thermal Break	Double-pane	LoĒ-179				
		LoĒ^2-272, LoĒ^2-270	X	X		
		LoĒ^3-366, LoĒ^2-240	X	X		
Aluminum Clad Wood	Double-pane	LoĒ-179			X	X
		LoĒ^2-272, LoĒ^2-270	X	X	X	X
		LoĒ^3-366, LoĒ^2-240	X	X	X	X
Wood or Vinyl	Double-pane	LoĒ-179			X	X
		LoĒ^2-272, LoĒ^2-270	X	X	X	X
		LoĒ^3-366, LoĒ^2-240	X	X	X	X

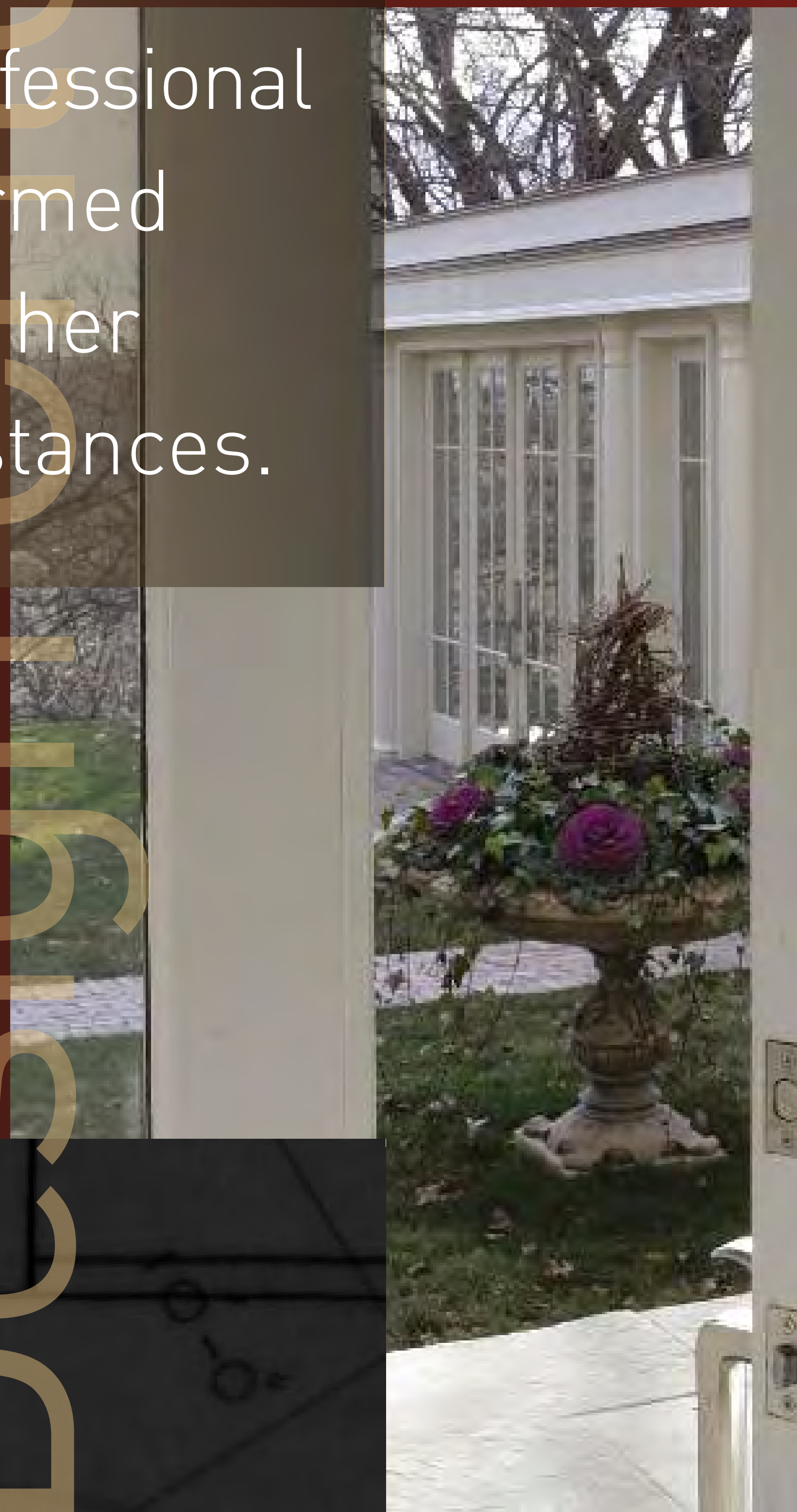
Figure 34-2

The 2009 model energy code has already adopted increased window stringency for the southern regions. These changes emphasize the importance of selecting the lowest solar gain products available in the marketplace, e.g. LoĒ^3™. To see what changes the ENERGY STAR Windows program incorporates go to this URL: http://www.energystar.gov/index.cfm?c=windows_doors.pr_windows and click on Key Product Criteria.

The Energy Star Preformance Criteria for windows continues to be debated and changed. Because of this, Cardinal has not put in this brochure the proposed Energy Star Criteria. To determine the specific Window Energy Star Criteria for Windows, please see the Department of Energy Star Web site: http://www.energystar.gov/index.cfm?c=windows_doors.pr_windows.

Design Criteria

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.



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 approximately 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 thermally strengthened resulting in it being 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 when it was heat treated and is not a glass defect.

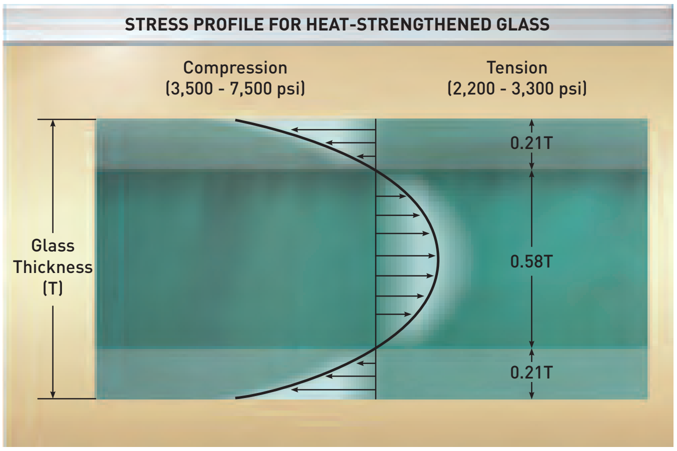


Figure 37-1

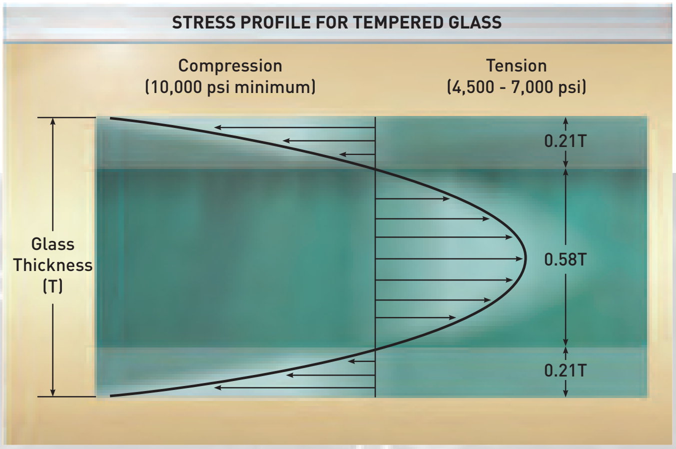


Figure 37-2

Figure 37-3

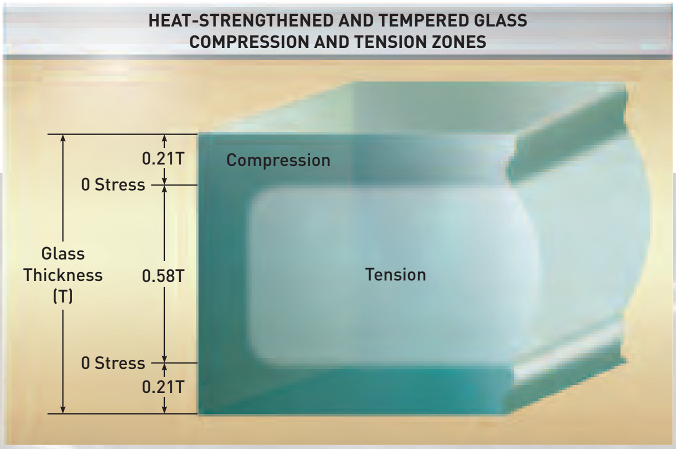


Figure 37-4

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 C1048-04. 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
   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.

Face Clearance, Edge Clearance and Bite

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

Glass lites should be set on two 80 to 90 durometer neoprene setting blocks positioned at the quarter points. When this is not practical, the setting blocks can be installed to within 6" (152 mm) of the vertical glass edge. Length of the setting block should be 0.1" (2.5 mm) in length for each square foot of glass area, but no less than 4" (102 mm) in length. The setting block should be 1/16" (1.6 mm) less than the full channel width and be of sufficient height to provide the nominal recommended bite and minimum glass edge clearance.

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 either the length of the span divided by 175 or 3/4" (19 mm) whichever is less. 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 38-1) is a comparison of specific metric thickness, the nominal glass thickness in inches and the traditional designation.

Specific Metric Thickness	Previously Used ASTM Designation	Nominal Glass Thickness	Traditional Designation
2.2 mm	2.5 mm	0.087 inches	Single-Strength
2.3 mm	2.5 mm	0.092 inches	Single-Strength
3.0 mm	3.0 mm	0.117 inches	Double-Strength, 1/8 inch
3.1 mm	3.0 mm	0.122 inches	Double-Strength, DST, 1/8 inch
3.9 mm	4.0 mm	0.153 inches	5/32 inch
4.0 mm	4.0 mm	0.160 inches	5/32 inch
4.7 mm	5.0 mm	0.187 inches	3/16 inch
5.7 mm	6.0 mm	0.223 inches	1/4 inch

Figure 38-1

DESIGN CRITERIA

IG UNIT SIZE LIMITS[1]

Glass Thickness (mm)	Minimum Recommended Short Glass Dimension for Argon Filled Unit[2] (in.)	Annealed Glass			Heat-Treated Glass			Weight
		Maximum Long Dimension (in.)	Maximum Area[3] (ft[3]) Aspect Ratio Less than 2	Maximum Area[3] (ft[3]) Aspect Ratio Greater than 2	Maximum Short Dimension (in.)	Maximum Long Dimension (in.)	Maximum Area[3] (ft[3])	IG Unit Weight Approximation (lbs/ft[2])
2.2	8	70	10	8	36	70	15	2.4
3.0	12	80	15	13	36	80	20	3.2
3.9	16	90	24	20	48	90	30	4.2
4.7	20	100	33	27	60	100	50	5.0
5.7	24	120	45	37	84	144	60	6.5

Figure 39-1

Notes:
1) Limits shown do not apply to shapes or units fabricated with mismatched glass thickness.
2) Minimum dimensions do not apply to capillary tube units.
3) Maximum area based on 40 psf design windload (3-second duration), manufacturing, and/or safe handling limit.
4) This chart applies to both double-pane IGUs and triple-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 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 6-12-08.

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 1% of the atmosphere and krypton is 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 and improves the center of glass U-Value 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 the 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 (mm)	Maximum Long Dimension (in.)	Maximum Area[3] (ft[3])
5.5	70	15
6.5 & 7.0	80	20
8.0	90	30
9.8	100	40
≥11.5	144	60

Figure 39-2

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 Gasglass technology from Sparklike, Ltd. (Figure 39-3).

Figure 39-3

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. Since there are no U.S. industry standards for argon fill levels or for argon-air exchange rates, Cardinal has used the German DIN Standard 52 293 and the European CEN Standard EN 1279 to determine the gas fill level and the argon-air exchange rate. This independent test has confirmed that Cardinal's IG product design meets or exceeds an initial 90% argon fill level, and its argon-air exchange rate is less than 1% per year.

Cardinal certifies our insulating glass products affirming that they are constructed similarly to specimens which 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.

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-97.1-2004, CPSC 16CFR 1201 cat. I and CPSC 16CFR 1201 cat. II, as listed below (Figure 40-1).

SAFETY GLAZING STANDARDS

	ANSI Z-97 .1-2004	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. No fracture at specified Class drop height or, b. if fracture occurs at the specified Class drop height, the ten largest crack free particles shall not weigh more than 10 square inches of the glass tested	a. No fracture at 18 inches or, b. if fracture occurs, the ten largest crack free particles shall not weigh more than 10 square inches of the glass tested	a. No fracture at 18 inches or, b. if fracture occurs, the ten 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 48 inches or, b. if fracture occurs, the ten largest crack free particles shall not weigh more than 10 square inches of the glass tested	a. No fracture at 48 inches or, c. if fracture occurs, no hole through which a 3 inch diameter sphere will freely pass is allowed
Evaluation Criteria for Wired Glass to Pass Standard	a. No fracture at 12 inches or, b. if fracture occurs, no hole through which a 3 inch diameter sphere will freely pass is allowed	Not Applicable	Not Applicable

Figure 40-1

Thermal Stress and Glass Breakage

When window glass is warmer at the center relative to the edge as shown below (Figure 41-1), 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.

Basically 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.

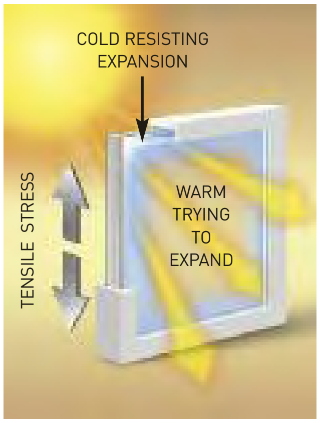


Figure 41-1

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 night-time 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.

Features that can affect thermal stress on glass are as follows:
- Glass type (thickness, tint, coating type)
- Condition of glass edges
- Shadow patterns on glass
- Heat trap caused by closed blinds or draperies
- Amount of solar radiation
- Outdoor-indoor temperatures
- Framing material
- Glass size

Outdoor Shading
Static and moving shade 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 room side of the glass. The following criteria must be met to avoid formation of a heat trap:
1. Minimum 1.5" (38 mm) clearance required at the top and bottom or one side and bottom between shading device and surrounding construction, or a closure stop of 60° from horizontal for horizontal blinds.
2. Minimum 2" (51 mm) clearance between glass and shading device.
3. Heating/cooling outlets must be to room side 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.

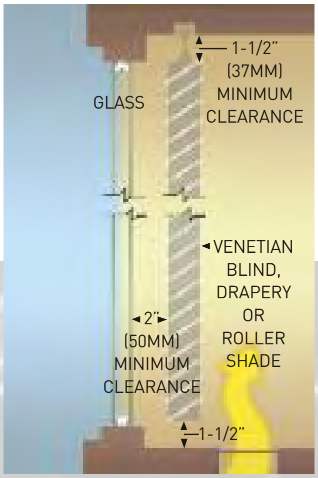


Figure 41-2

Windloads and Insulating Glass Size Limits

The windload data presented (Figures 42-2, 42-3, 42-4, 42-5 and 42-6) is based on ASTM Standard E 1300-04 (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 3-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 42-1 below).

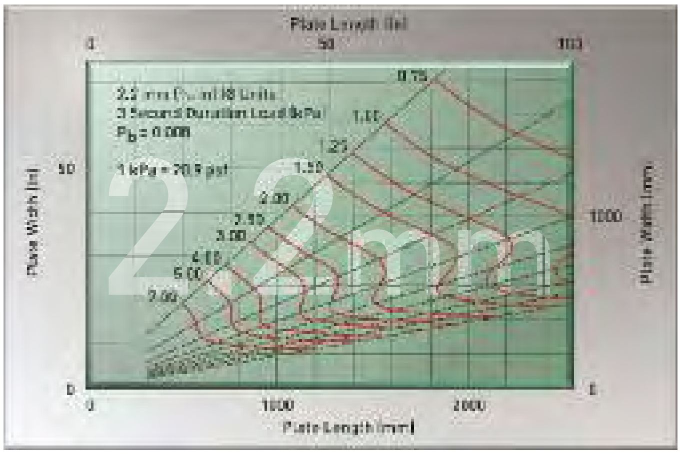


Figure 42-2

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

Assumptions:
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 3 seconds.
4) 8/1000 probability of failure.

Figure 42-1

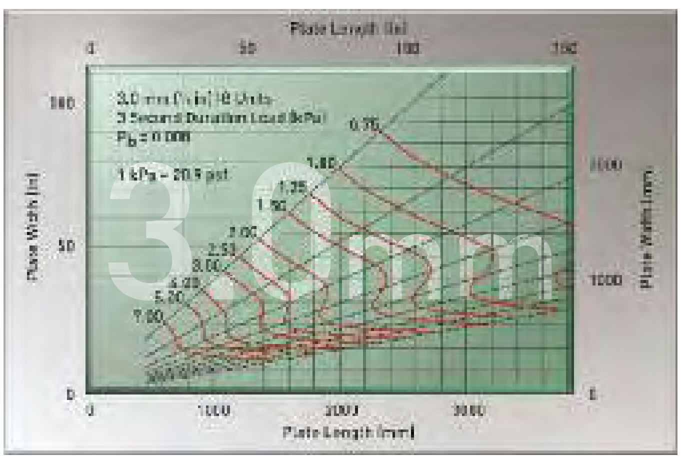


Figure 42-3

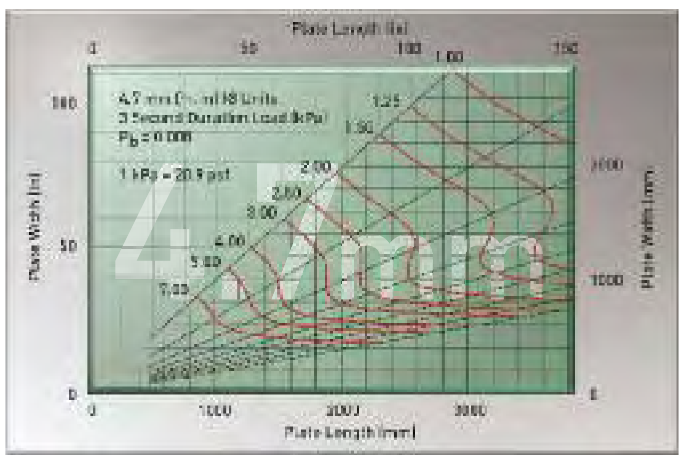


Figure 42-5

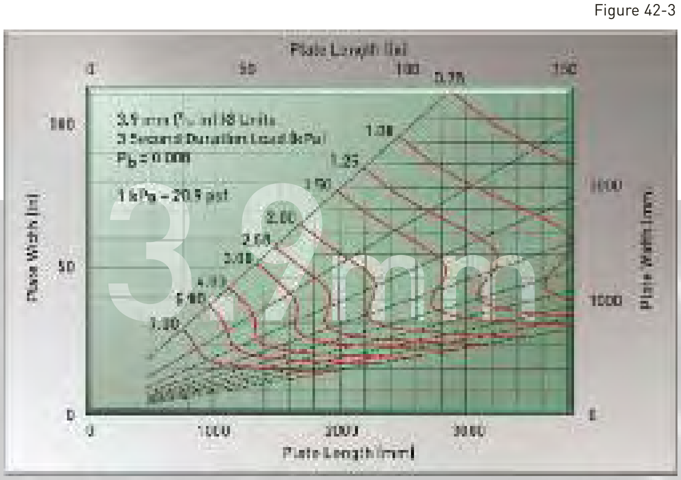


Figure 42-4

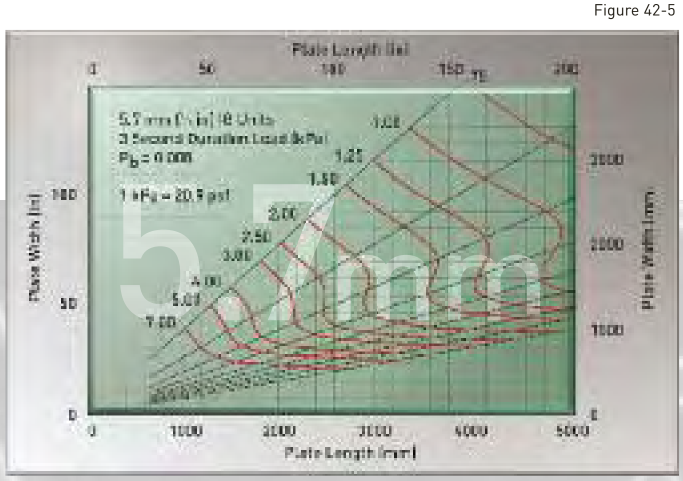


Figure 42-6

DESIGN CRITERIA

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-Values 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 problems 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 a subjective item. 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 43-1, 43-2, 44-1, 44-2 and 44-3 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.

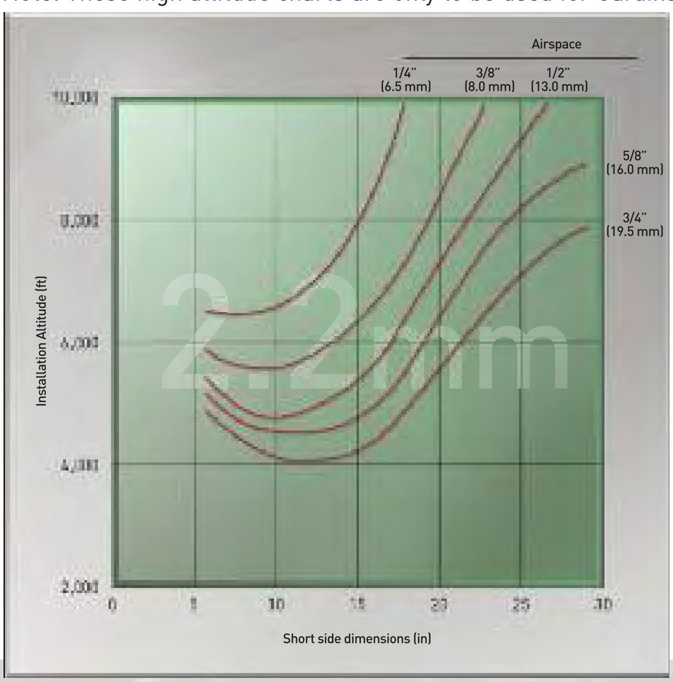


Figure 43-1

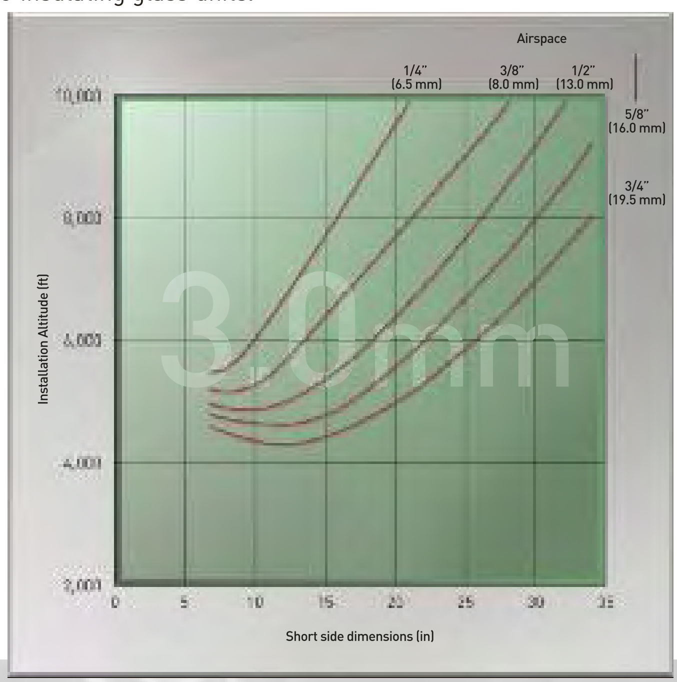


Figure 43-2

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.

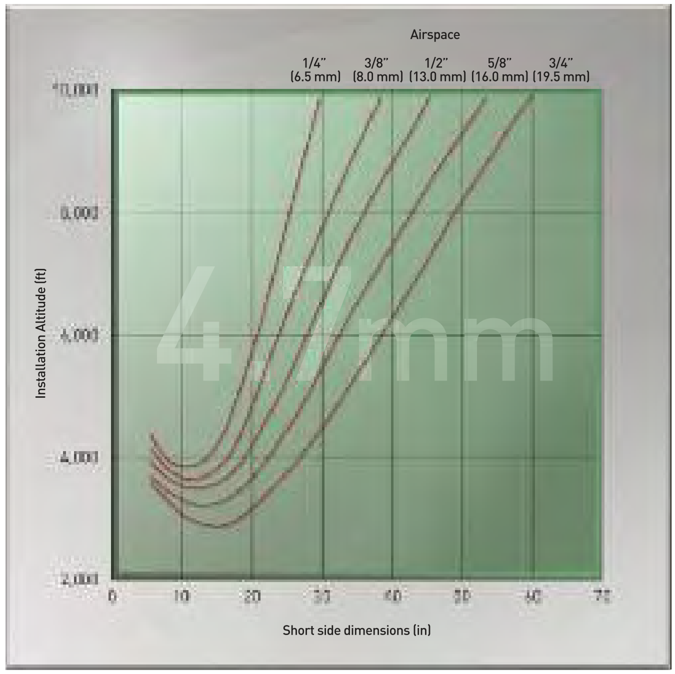


Figure 44-2

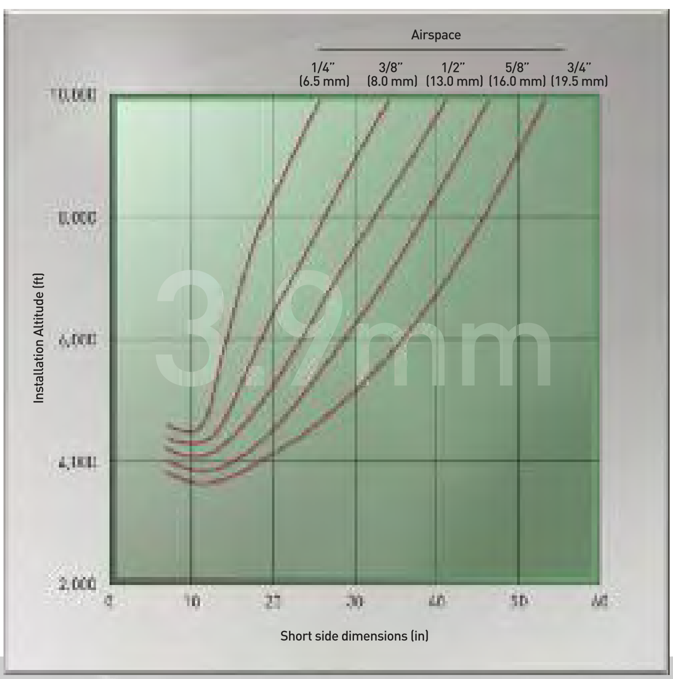


Figure 44-1

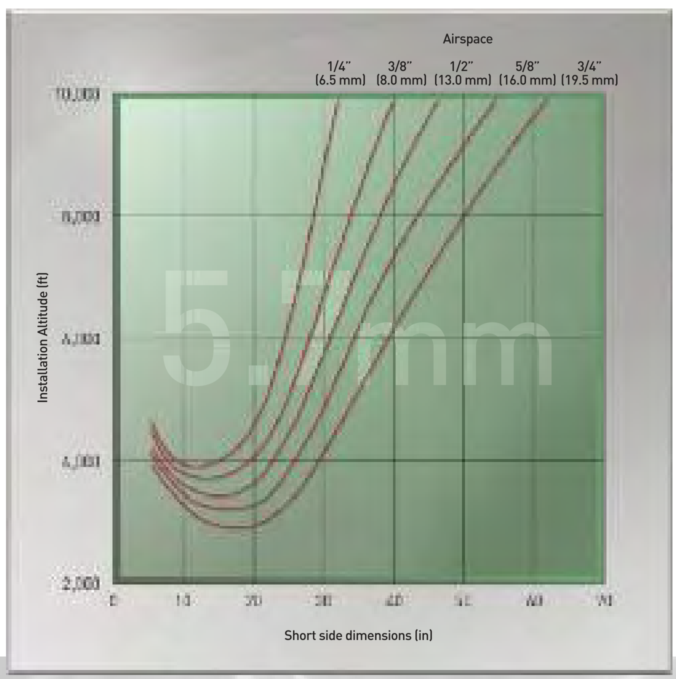
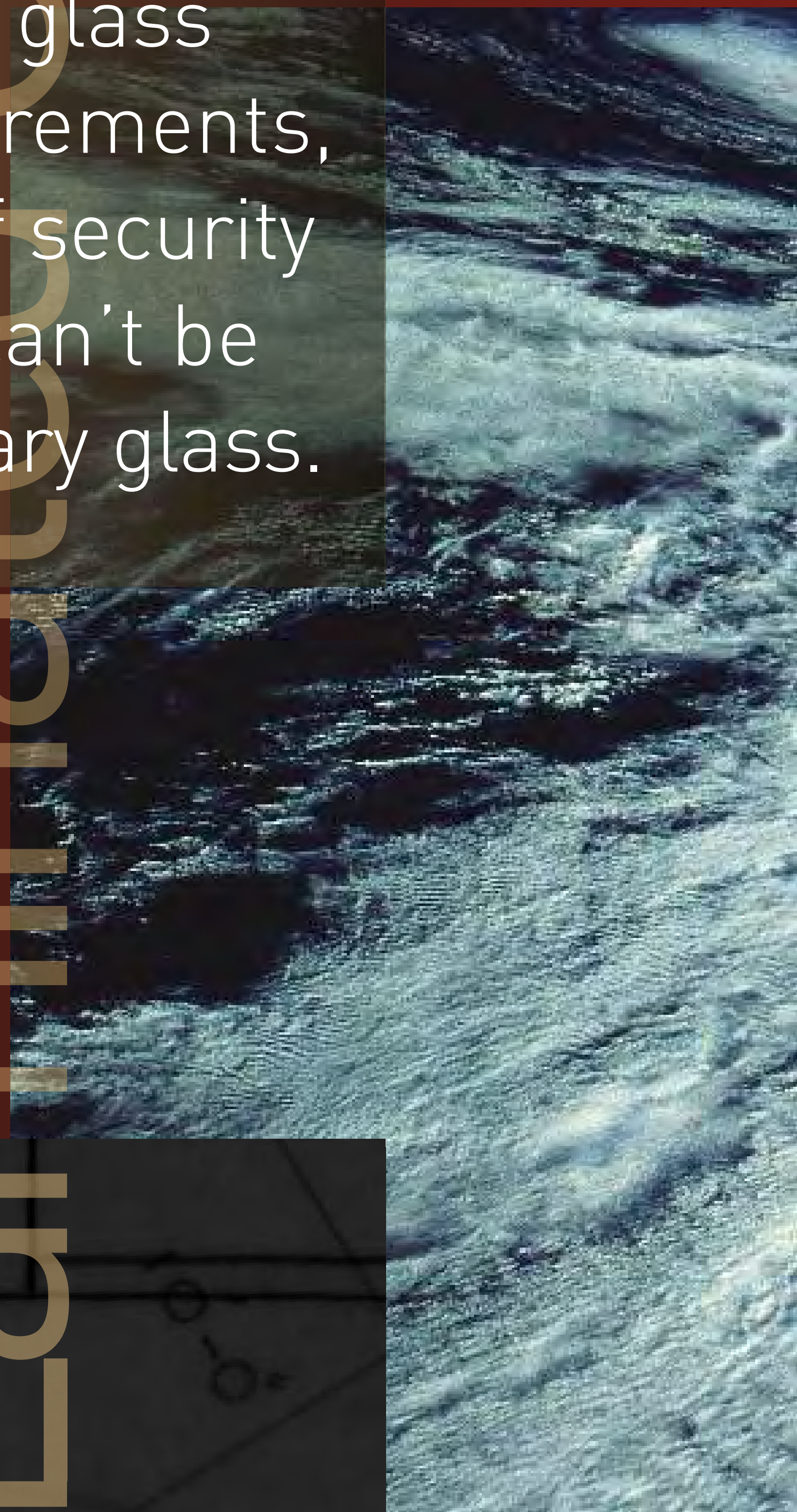
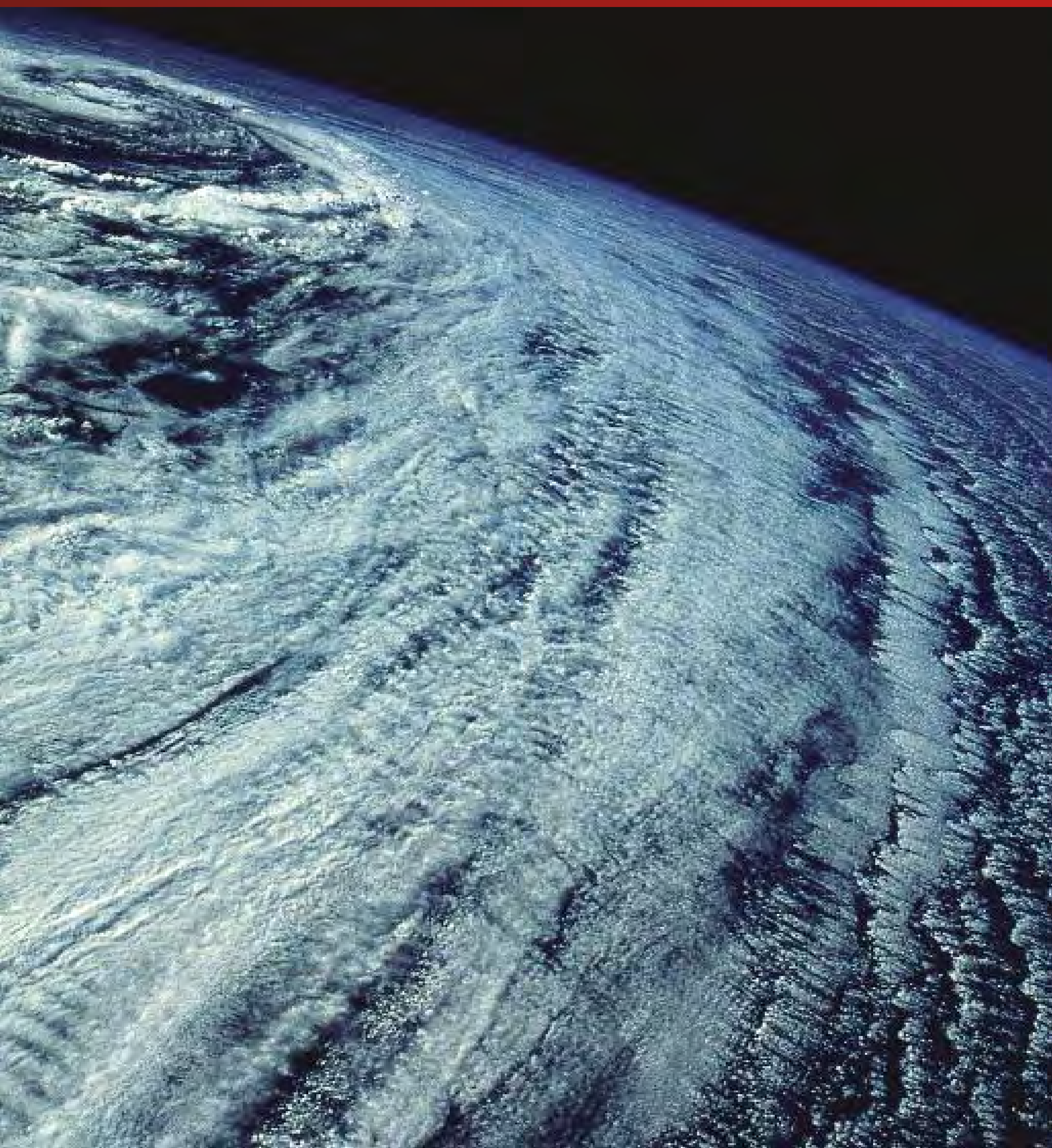


Figure 44-3

Laminated Glass

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.





Laminated Glass

Cardinal laminated glass consists of panes of annealed, heat-strengthened or tempered glass with one or more invisible interlayers sandwiched together to create a stronger, sturdier glass unit. We offer multiple interlayer options to meet various size and security constraints.

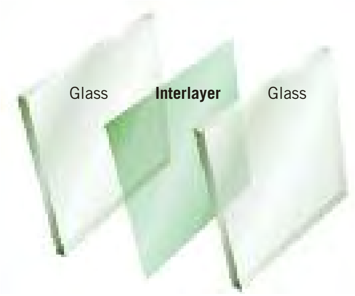


Figure 47-1

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 plastic vinyl interlayer.

Figure 47-2

If laminated glass is broken, the vinyl interlayer remains in the frame, with glass fragments adhering to the interlayer. This provides a strong barrier against forced entry or windblown debris. Furthermore, laminated glass cannot be cut from one side only, which renders glass cutters useless in the hands of would-be intruders.

Laminated glass also helps protect against fading by blocking over 99% of the sun's harmful UV rays, one of the leading causes of fading.

Cardinal laminated glass is available clear or tinted, in monolithic or insulating configurations, in custom shapes and sizes. Get increased energy efficiency by incorporating our patented X3 LoĒ coating in the laminate or used on the non laminated lite of a laminated IG unit. Neat™ is available on Cardinal's Laminated Glass Products.

Cardinal laminated glass meets rigorous industry codes, including the American Society of Testing Materials for preventing forced entry (ASTM F1233) and the burglary resistant guidelines issued by Underwriters Laboratories (UL972). It is also certified by the Safety Glazing Certification Council (SGCC).

SeaStorm® Hurricane Resistant Glass

During hurricanes and windstorms, windborne debris is common. Debris slams into windows, and following impact, windows may be subjected to sustained, gusting winds. SeaStorm hurricane-resistant glass is crafted to offer a high level of impact resistance and remain integral in the window envelope even after glass breakage.

SeaStorm meets all codes
Today, local building codes increasingly require impact protection. Windows must now be able to sustain blows from a nine-pound 2 x 4 traveling at 50 feet per second, or 34 miles per hour.

More and more coastal areas and some inland areas as well are making building codes even tougher so that homes and other buildings can withstand harsh environmental conditions.

SeaStorm offers certified, proven impact resistance – without the need for storm panels or shutters. It fulfills all code requirements.

Cardinal has the following Dade County N.O.A. (notification of acceptance) numbers for our laminated glass products:

07-0831.06 SeaStorm®

03-0415.13 Vanceva Composites®

06-0216.06 Saflex® IIIG

03-0827.08 Solutia® interlayers

05-1208.02 Dupont® Butacite® PVB

04-0818.01 Dupont® SentryGlas®

07-1116.04 Dupont® SentryGlas® Plus

Figure 48-1

SeaStorm protection

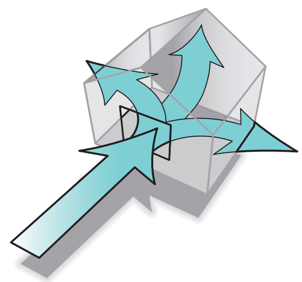


Figure 48-2

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.

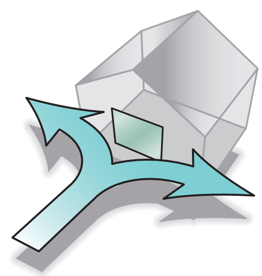


Figure 48-3

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

Performance Chart of Various Glass Configurations

The purpose of these tables (Figures 49-1 and 49-2) are to help balance the individual needs of thermal performance, safety, aesthetics and other factors. The tables show the performance characteristics of SGP and PVB Laminates. This represents a sample of possible configurations and merely reflects some of the major elements in glass selection.

SGP (SENTRYGLASPLUS)

Name	Laminate Make-up	Visible Light Transmittance	Visible Light Reflectance Out	Visible Light Reflectance In	Solar Heat Gain Coefficient (SC = SHGC/0.87)	U-Value (Btu/hr/ft²/°F)	UV Transmission	Fading (T_{dw}) Krochmann Damage Function	Fading (T_{dw}) ISO CIE
8.6M	3.1 / 0.090" SGP / 3.1	86%	8%	8%	0.76	0.97	<1%	29%	60%
8.6BM	3.1 Bronze / 0.090" SGP / 3.1	64%	6%	6%	0.66	0.97	<1%	21%	43%
8.6GM	3.1 Gray / 0.090" SGP / 3.1	59%	6%	6%	0.64	0.97	<1%	21%	42%
8.6NM	3.1 Green / 0.090" SGP / 3.1	80%	7%	7%	0.64	0.97	<1%	27%	55%
8.6MX	3.1 X3 / 0.090" SGP / 3.1	61%	13%	13%	0.36	0.97	<1%	16%	38%
8.6NMX	3.1 green / 0.090" SGP / 3.1 X3	56%	11%	12%	0.4	0.97	<1%	14%	34%
8.6GMX	3.1 gray / 0.090" SGP / 3.1 X3	41%	8%	12%	0.36	0.97	<1%	11%	26%
8.6BMX	3.1 bronze / 0.090" SGP / 3.1 X3	46%	9%	12%	0.36	0.97	<1%	11%	28%
10.1M	3.9 / 0.090" SGP / 3.9	88%	9%	9%	0.77	0.96	<1%	31%	62%
10.1MX	3.9 X3 / 0.090" SGP / 3.9	60%	13%	13%	0.35	0.96	<1%	16%	38%
10.1GMX	3.9 gray / 0.090" SGP / 3.9 X3	38%	8%	12%	0.35	0.96	<1%	10%	24%
10.1BMX	3.9 bronze / 0.090" SGP / 3.9 X3	42%	8%	12%	0.36	0.96	<1%	11%	25%
11.7M	4.7 / 0.090" SGP / 4.7	86%	9%	9%	0.73	0.95	<1%	30%	60%
11.7NMX	4.7 green / 0.090" SGP / 4.7	75%	7%	7%	0.59	0.94	<1%	25%	51%
11.7GMX	4.7 gray / 0.090" SGP / 4.7	50%	5%	5%	0.57	0.94	<1%	18%	36%
11.7BMX	4.7 bronze / 0.090" SGP / 4.7	56%	6%	6%	0.59	0.94	<1%	18%	37%
11.7MX	4.7 X3 / 0.090" SGP / 4.7	60%	13%	12%	0.37	0.95	<1%	16%	37%
11.7NMX	4.7 green / 0.090" SGP / 4.7 X3	53%	10%	11%	0.41	0.95	<1%	13%	32%
11.7GMX	4.7 gray / 0.090" SGP / 4.7 X3	34%	7%	11%	0.36	0.95	<1%	10%	22%
11.7BMX	4.7 bronze / 0.090" SGP / 4.7 X3	39%	8%	12%	0.36	0.95	<1%	10%	23%
13.6M	5.7 / 0.090" SGP / 5.7	84%	7%	7%	0.71	0.94	<1%	29%	59%
13.6GM	5.7 gray / 0.090" SGP / 5.7	43%	5%	5%	0.54	0.94	<1%	16%	31%
13.6BM	5.7 bronze / 0.090" SGP / 5.7	52%	5%	5%	0.58	0.94	<1%	16%	34%
13.6NM	5.7 green / 0.090" SGP / 5.7	72%	6%	6%	0.55	0.94	<1%	24%	49%
13.6MX	5.7 X3 / 0.090" SGP / 5.7	58%	14%	13%	0.35	0.94	<1%	16%	36%
13.6NMX	5.7 green / 0.090" SGP / 5.7 X3	54%	10%	11%	0.42	0.94	<1%	14%	33%
13.6GMX	5.7 gray / 0.090" SGP / 5.7 X3	33%	6%	9%	0.37	0.94	<1%	9%	21%
13.6BMX	5.7 bronze / 0.090" SGP / 5.7 X3	38%	7%	10%	0.37	0.94	<1%	9%	22%

Figure 49-1

PVB (POLYVINYL BUTYRAL)

Name	Laminate Make-up	Visible Light Transmittance	Visible Light Reflectance Out	Visible Light Reflectance In	Solar Heat Gain Coefficient (SC = SHGC/0.87)	U-Value (Btu/hr/ft²/°F)	UV Transmission	Fading (T_{dw}) Krochmann Damage Function	Fading (T_{dw}) ISO CIE
6.0L	2.7 / 0.030" PVB / 2.7	89%	9%	9%	0.80	1.01	<1%	27%	59%
6.0GL	2.7 / 0.030" PVB gray / 2.7	44%	6%	6%	0.63	1.01	<1%	17%	33%
11.7L	4.7 / 0.090" PVB / 4.7	87%	9%	9%	0.73	0.94	<1%	24%	56%
11.7BL	4.7 / 0.090" PVB bronze / 4.7	49%	5%	5%	0.60	0.94	<1%	13%	30%
11.7GL	4.7 gray / 0.090" PVB / 4.7	51%	5%	5%	0.58	0.94	<1%	16%	34%
13.6L	5.7 / 0.090" PVB / 5.7	86%	9%	9%	0.71	0.93	<1%	22%	54%
13.6GL	5.7 / 0.090" PVB gray / 5.7	44%	5%	5%	0.59	0.97	<1%	17%	33%
13.6GL	5.7 gray / 0.090" PVB / 5.7	45%	5%	5%	0.54	0.93	<1%	14%	30%
13.6BL	5.7 bronze / 0.090" PVB / 5.7	52%	6%	6%	0.56	0.93	<1%	14%	32%
13.6BL	5.7 / 0.090" PVB bronze / 5.7	48%	5%	5%	0.58	0.93	<1%	13%	29%
13.6NL	5.7 / 0.090" PVB green / 5.7	72%	7%	7%	0.67	0.93	<1%	22%	49%

1) PVB green is the same as PVB blue-green

2) Name Code: G = Gray glass, B = Bronze glass, N = Green glass, L = PVB interlayer, M = SGP interlayer, X = LoE^{3}™ 366 coating

Figure 49-2

Acoustical Performance of Laminated Glass

The American Society of Testing Materials (ASTM) developed the sound transmission class (STC) rating to describe the sound isolation performance of materials. A higher STC rating indicates a greater sound-dampening effect. Laminated glass increases the STC rating of a window and diminishes unwanted outside noise.

When incorporating laminated glass into an IG unit, the acoustical benefits to your windows can increase. For maximum acoustical needs, Cardinal recommends a double-laminated IG unit. This will provide the greatest acoustical performance along with the thermal efficiency of insulating glass.

Acoustic Performance	Glass Type	Threshold STC
Poor	Single-pane glass	27
Moderate	Insulating glass	31
Better	Laminated monolithic glass	33
Better	Traditional laminated glass IG with 1 laminated pane	33-35
Best	Laminated glass with 2 laminated panes	37+

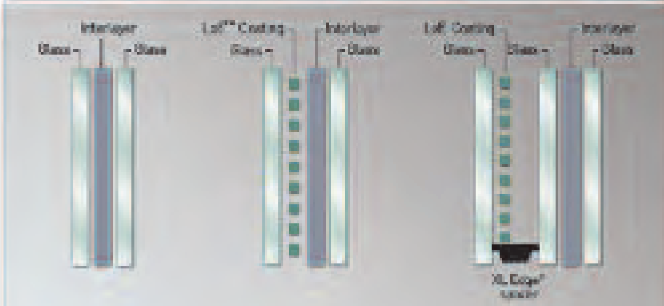
Figure 50-1

Laminated Glass Windloads

Please contact the Cardinal technical service group for information.

Laminated Glass Performance

Cardinal laminated glass provides design flexibility so you can create a unit best suited for your requirements.

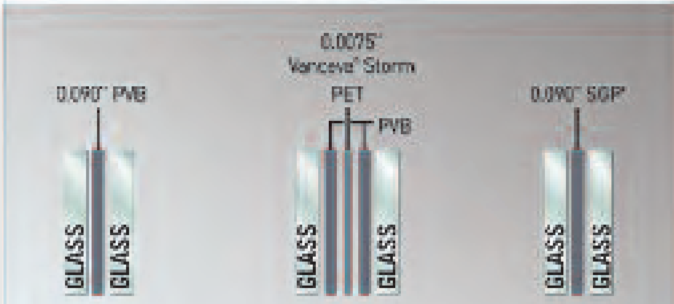


Monolithic LG
- Impact resistance
- Acoustical reduction
- Fade resistance
- Optional SeaStorm® rating

...with LoĒ³™ Coating
- Impact resistance
- Maximum fade resistance
- Optional SeaStorm rating
- Improved thermal performance

...with Insulating Glass
- Impact resistance
- Maximum sound control
- Maximum fade resistance
- Optional SeaStorm rating
- Improved thermal performance (SHGC and U-Factor)

Figure 50-2



- For small units (up to 15 ft²)
- 5-year warranty

- Max width 60"
- 5-year warranty

- 100 times as rigid as PVB
- Max size 72"x120"
- 10-year warranty

SGP® (SentryGlas® Plus) is a registered trademark of DuPont™ Company.

Figure 50-3

LAMINATED GLASS

Naturally Clean Glass

Windows stay cleaner longer and clean easier.
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 stay cleaner longer and clean easier. 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 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.The cleaning process starts with ultra-smooth glass. Silicone dioxide makes Neat glass smoother as glass ages. In fact, it's much smoother than ordinary glass. So water disperses evenly, sheets off and evaporates quickly, greatly reducing water spotting.

The sun and rain finish the job.
Titanium dioxide reacts chemically with the sun's UV rays, causing organic materials that are on the glass to decompose. It works even on cloudy days. When it rains, the decomposed dirt 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.

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 disposed of with the rest of normal construction site debris. Preserve film saves you time, money...and a lot of hassle.

Facts about Preserve film

- Preserve film incorporates a water-based adhesive and is rated as a low density polyethylene.
- Preserve film should be removed within one year of installation.
- Preserve film contains no harmful chemicals or by-products and can be disposed of with normal construction site debris.
- 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

Technical Service Bulletins (TSBs)

The following Technical Service Bulletins are available on our web site (cardinalcorp.com) to provide you with additional technical information regarding Cardinal glass products.

Cardinal IG® Company

IG01 Information on Glass Products – 05/08
IG02 Argon Filling – 05/08
IG03 Glass Windload Charts – 05/08
IG04 Use of Retrofit Films – 05/08
IG05 Low-E Performance Comparison – 05/08
IG06 Heat-Strengthened Glass – 05/08
IG07 Thermal Performance & Heat Treatment Guidelines of Cardinal LoĒ^{2}®/LoĒ^{3}™ Products – 05/08
IG08 Use of Internal Grilles – 05/08
IG09 Glass Acoustical Information – 05/08
IG10 Fogging Potential in Insulating Glass Units – 05/08
IG11 Fading – 05/08
IG12 Glass Cleaning Recommendations – 05/08
IG13 Breather Tubes/Capillary Tubes – 05/08
IG14 Vinyl Siding Distortion & Glass Reflections – 05/08
IG15 Wood Treatment Compatibility with Insulating Glass Sealants – 05/08
IG16 Cardinal Preserve® Film – 05/08
IG17 Use of Bumpers on Exposed Internal Grilles – 05/08
IG18 Distortion in Glass Products – 05/08
IG19 True Divided Lites (TDL) and Authentic Divided Lites vs. Superior Divided Lites (SDL) – 05/08
IG20 Insulating Glass Durability – 05/08
IG21 Certification and Testing for Insulating Glass ASTM 2190 – 05/08
IG22 Aluminum and SS XL Spacers – 05/08
IGWA Warranties and Terms & Conditions – 05/08

Cardinal CG Company

CG01 Edge Deletion of Sputtered Low-E Coatings – 05/08
CG02 Sealant Compatibility with Sputtered LoĒ^{2}® and LoĒ^{3}™ Coatings – 05/08
CG03 IG Unit Frost Points, Internal Condensation and LoĒ^{2}® & LoĒ^{3}™ Corrosion Potential – 05/08
CG04 Neat® Coated Glass 05/08
CGWA Warranties and Terms & Conditions – 05/08

Cardinal FG Company

FG01 Strain Pattern or Quench Pattern Characteristics – 05/08
FG02 GANA Bulletin "Heat-Treated Glass Surfaces are Different" – 05/08
FG03 Safety Glazing
FGWA Warranties and Terms & Conditions – 05/08

Cardinal LG Company

LG01 Hurricane Impact Codes – 05/08
LG02 Optical Distortion in Sea-Storm® Laminated Glass Fabricated with an Encapsulated PET Film – 05/08
LG03 Optical Distortion in Laminating Glass Fabricated with Heat Strengthened Glass Substrates – 05/08
LG04 Laminated LoĒ Glass Products – 05/08
LGWA Warranties and Terms & Conditions – 05/08

Additional Literature

The following brochures are available from Cardinal or your Cardinal representative.

Product Literature

LoĒ-179™ High Solar Gain Glass
LoĒ^{3}-366™ Ultimate Performance Glass
LoĒ^{2}-272™ All Climate Glass
LoĒ^{2}-270™ All Climate Solar Control Glass
LoĒ^{2}-240™ Glare Control Glass
Neat® Naturally Clean Glass
Preserve® Protective Film
SeaStorm® Hurricane-Resistant Glass
Cardinal LG - The Glass Choice that Protects Your World
Cardinal Architectural Glass Products

Other Literature

Cardinal I.Q. Intelligent Quality Assurance Program
Cardinal Project House Report
Cardinal Climate Change Facts
Cardinal Float Glass Plant Overview

Web Sites 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.pwgsc.gc.ca/cgsb

Center for Glass Research
www.cgr.alfred.edu

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 Assn. (WDMA)
www.wdma.com

Window 5 Software
www.windows.lbl.gov/software/window

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

Standard and Codes

With compliance 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)

Cardinal Glass Industries

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

Printed on paper containing recycled material.

5M 11/08