All about GLASS

Flat Glass Industry Literature

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HISTORY OF GLASS

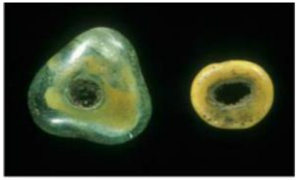
Timeline throughout history:

- 3,000 B.C. (Stone Age Beads and Tools)
- 1400 B.C. (Late Bronze Age Colored Glass Vessels
- 900 B.C. (Iron Age Colorless Glass)
- 250 B.C. (Glassblowing)
- 300 A.D. (Window Glass)
- 700 – 800 (Murano Glassware)
- 400 – 1500 (Middle Ages Stained Glass)
- 1500 – 1600 (Clear Windows)
- 1688 (Plate Glass)
- 1800s (Large Lites of Glass)
- 1900s (Float Glass)

3,000 B.C. (Stone Age) Beads and Tools

Experts believe that the ancient Syrians accidentally discovered glassmaking in about 3,000 BC.

Glass was used by many Stone Age societies across the globe for the production of sharp cutting tools and was extensively traded.



The earliest known man-made glass objects were beads – probably by-products of another trade.

Obsidian was commonly used to create sharp weapons.

HISTORY OF GLASS

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1400 B.C. (Late Bronze Age) Colored Glass Vessels

Glass-making technology increased in Egypt during the Late Bronze Age.

Early Syrian and Egyptian glass were a simple melted mixture of soda ash, lime, and sand that was sculpted into final shapes while it was still hot.

The earliest vessels and vases were produced by twisting glass around a sand core with a metal rod in the middle.

The glassware was decorated by adding molten colored glass to the final layer.

The metal rod then cooled as the glass annealed.

Once cool, the metal rod was removed so that the sand core could be scraped out.

Early glass work consisted of methods learned from other trades, such as stone working. This meant that cooled glass was often ground and carved.

Discoveries from the Late Bronze Age include colored glass vessels.

900 B.C. (Iron Age) Colorless Glass

Glass was a luxury item through the Bronze Age and beyond. Because it was not made in many locations, it was a prized export item.

In Egypt, vessels were still being produced with sand cores. However, around the world, other glassmaking techniques were discovered with experimentation and technological advancements.

New methods that were introduced during the Iron Age meant that larger glass pieces could be made.

The new techniques also allowed for production of glass dishes and mosaic glass materials.

Colorless glass was also becoming more popular.

Photo by Luis García
[GFDL (http://www.gnu.org/copyleft/fdl.html),

250 B.C. Glassblowing

Glassblowing was discovered when glassmakers switched to hollow metal rods to hold the sand cores and found that molten glass could be blown into shapes.

Glassblowing paved the way for the increase in glass production that occurred throughout the Roman world.

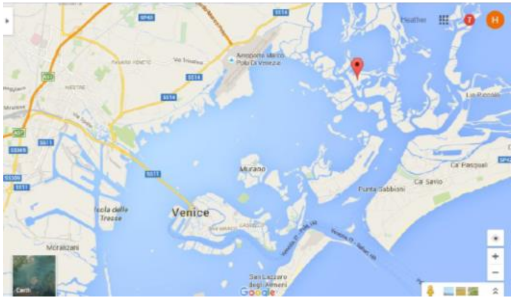
After this discovery, which dates to about 250 B.C., glass vessels suddenly became easy and inexpensive to produce.

300 A.D. (Window Glass)

Window glass originated in Rome at the end of the third century. The window glass was thick and translucent - it let light in but people couldn't see out. Romans began to use glass windows in their most important buildings.

With the breakdown of the Roman Empire, glassmaking technology stagnated in Europe.

700 – 800 (Murano Glassware)



Glass objects from the 7th and 8th centuries were discovered on the Venetian island of Torcello (pinned on map above). These objects reflect the importance of Torcello in glass production during medieval Roman times.

Glassblowers on another Venetian Island, Murano, developed a clear, almost transparent glass called cristallo, which helped Italy build a thriving glass export trade when Murano glass became popular throughout Europe.

Murano Glassware

HISTORY OF GLASS

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400 – 1500 (Middle Ages) Stained Glass

In the Middle Ages, glass was still made by hand.

Window glass was made by blowing the molten glass into a flat disc which was spun so that it would thin out and flatten. The discs were then cut into small panes of glass, usually limited to 18 square inches.

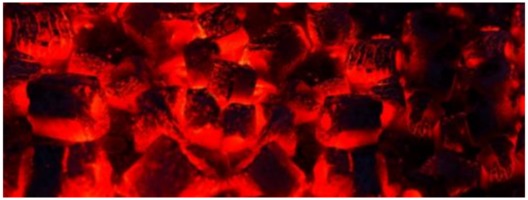
Interestingly, stained glass is still made the same way today!

Photo by Neal Sanche (Shared via Creative Commons 2.0) https://www.flickr.com/photos/thorinside/2481381346Flickr

1500 – 1600 Clear Windows

In the 16th and 17th centuries, due to a shortage of trees, the English discovered that burning coal instead of wood in furnaces produced a clearer glass.

Although the panes were wavy, full of bubbles, and sometimes light amethyst or amber in color, people could see through the windows made on coal-burning fires.

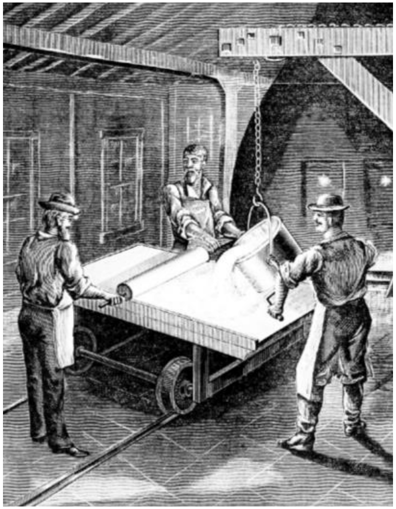


1688 Plate Glass

Frenchman Louis Lucas de Nehou developed a cumbersome process for making plate glass in 1688.

The process took 16 days from start to finish and produced glass so expensive that only the very rich could afford it.

Over the next 200 years, the process was improved, but the French plate glass method remained the basic technique.



HISTORY OF GLASS
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1800s Large Lites of Glass

Great strides were made during the 19th century.

Compressed air technology led to flatter panes. Controlled amounts of air were used to blow a large glass cylinder, which was slit lengthwise, reheated, and allowed to flatten.

Using this method, large lites of glass were produced.

Photo by Stephen Nyran

1900s Float Glass (Present)

Plate glass became more common by the end of the 19th century. Improved forms of heating the glass and the use of electricity made the grinding and polishing of glass faster.

In the 20th century, machines were developed that perfected glass manufacturing. These machines began to produce float glass on a bed of molten tin.

The 20th century also saw great improvements in processes to strengthen glass, such as tempering.

The float glass process, which is used to manufacture more than 90 percent of flat glass for today's construction and automotive applications, was invented by Sir Alastair Pilkington in 1952. To manufacture float glass, raw materials are combined in a furnace to form molten glass, which is then poured continuously over a bath of molten tin, forming a flat, level "ribbon" of glass. The speed at which the glass ribbon is pulled from the tin bath determines its thickness.

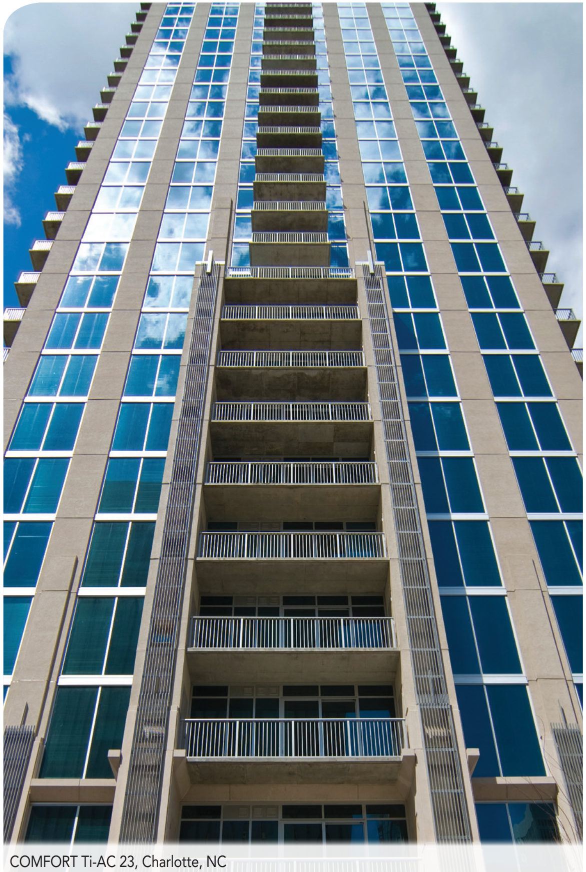
A float glass line will operate continuously for 10 to 20 years, producing 6,000 kilometers (3,728 miles) of glass annually. Most float lines are designed to allow for several "lifetimes," after major repairs and upgrades.

Today, between 350 and 400 float glass lines are in operation worldwide, with an output of about 1,000,000 tons of glass per week.

Photo by Saint-Gobain

HISTORY OF GLASS
ALL ABOUT GLASS

1 GLASS PRODUCTS



COMFORT Ti-AC 23, Charlotte, NC

1.1 COMPOSITION

Flat glass used in buildings is a soda lime (soda + lime) silicate (silica or sand) obtained by melting the mixture at a high temperature.

Soda lime silicate glass is composed of:

> Silicate sand, which gives the glass its texture—it is known as the glass former, or SiO_2 network former

> Calcium carbonate, used as a melting agent to lower the melting temperature of the silica and as a fining agent to homogenize the melting mixture and eliminate bubbles

> Lime, used as a stabilizer, which gives the glass its chemical resistance

> Fining agents, which are designed to agitate the melting mixture, release gases and standardize quality

> Various metal oxides, which enhance the mechanical characteristics of the glass, increase its resistance to atmospheric agents, and provide any color it might have

There are also other types of glass, for example:

> Borosilicates, which are used, for example, for laboratory glazing because of their low expansion coefficient

> Glass ceramics made up of a crystalline phase and a residual glassy phase; they have a linear expansion coefficient of virtually zero and are used, among other applications, in the manufacture of ceramic cook tops

> Alkaline earth glasses

> Glasses with a high lead content (approximately 70%), which substantially reduces the transmission of X-rays; these are used for glazed walls in medical or industrial radiology areas

> Crystal, which is glass containing a minimum of 24% lead oxide, offering special features of clarity and resonance

ALL ABOUT GLASS

1.2 PROPERTIES

Main properties of soda lime silicate glass

Density @ Room Temperature	156 lb/ft^3 2,500 kg/m^3
Modulus of Elasticity	10 x 10^6 psi 69 GPa
Poisson's ratio	0.23
Mohs' hardness	5.5
Melting temperature	≈ 2,700°F ≈1,500°C
Softening point	(1,319-1,345)°F (715-729)°C
Coefficient of thermal expansion	5.0 x 10^{-6} (°F) 9.0 x 10-6 (°C)
Thermal conductivity	1.0 Btu/ft-h-°F 1.7 W/m-K
Specific heat capacity	0.2 Btu/lb$_m$-°F 840 J/kg-K
Characteristic bending strength***	
Annealed glass	6,000 psi 41.4 MPa
Heat-strengthened glass	12,000 psi 82.7 MPa
Tempered glass	24,000 psi 165.5 MPa
Compressive Strength	1,000 N/mm^2 145 x 10^3 psi
Refraction index	1.5
Emissivity of uncoated glass	0.84
Values below are for 3mm clear	
Total solar transmission	86%
Total visible light transmission	90%
Solar heat gain coefficient	0.88

***The above are generally accepted values. Glass does not behave like a standard building material, use appropriate safety coefficient and FEA program when performing mechanical calculations.

1.3 GLASS PRODUCTS

1.3.1 INTRODUCTION

Finished glass is obtained by bringing the soda lime silica mixture to its melting point (approximately 1,600°C), then cooling and processing it. Several types of glass can be made, depending on the process used.

In describing glass products, a distinction is drawn between two types:

> Base products—i.e., soda lime silicate glass products that undergo no additional processing after leaving the furnace

> Processed products—i.e., those products obtained by processing base glasses. Among processed glass solutions, a further distinction is made between two types of processing:

- Primary processing of large sizes (sheets) or, where necessary, standard sizes
- Secondary processing of standard sizes

These products are described briefly in sections **1.3.2** and **1.3.3** of this chapter.

Base and processed products

Base products		Float glass - Patterned glass - Wired glass - Polished wired glass
Processed products	**Primary processing**	Low-e coated glass - Surface treated glass (etched, sandblasted, etc.)
	Secondary processing	Tempered glass - Heat-strengthened glass - Laminated glass - Enameled and silk-screen printed glass - Bent glass - Mirror glass - Insulating glass - Spandrel glass

1.3.2 BASE PRODUCTS

▼ Float Glass (ASTM C-1036)

The float glass product category includes flat, transparent, clear, and colored (e.g., green, grey, bronze, blue) soda lime silicate glass.

Standard thicknesses for architectural applications are:

in.	SGL	LAMI	DSG	1/8	5/32	3/16	1/4	5/16	3/8	1/2	5/8	3/4
mm	2.5	2.7	3	3.1	4	5	6	8	10	12	15	19

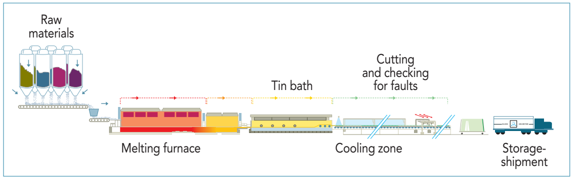
Maximum dimensions are 130" by 204".

Float glass is the base glass used in all subsequent glass processing operations.

The production line for float glass is composed of the following key areas:

- Area for storing and weighing raw materials
- The melting and refining furnace, where materials are melted at a temperature of approximately 1,600˚C; this process refines and homogenizes the mixture, eliminates gas bubbles, and ensures good thermal conditioning of the molten glass
- The tin bath, where the molten glass is “floated” to form the sheet of glass; regulating the flow rate of the mixture determines the thickness of the sheet of glass
- The annealing zone, where the glass is cooled under controlled conditions to eliminate internal stresses
- Equipment area, where flaws are detected and the continuous strip of glass is cut into smaller sizes
- Area for storing and shipping end products

Float process



AGC float products: Clear and Solarshield™ tinted glasses, Linea Azzurra (blue tinted) and low-iron Krystal Klear™

▼ Patterned Rolled Glass (ASTM C-1036)

Patterned rolled glass features a design on one or both sides, obtained by passing the sheet of glass between textured rollers during the manufacturing process.

The production line for patterned glass is similar to a float line, except that the stage of floating on a tin bath is replaced by shaping the glass between two rollers. The distance between the rollers determines the ultimate thickness of the glass. Afterward, patterned glass is annealed, or placed in a cooling zone.

AGC patterned product: low-iron Krystal Patterns™

▼ Wired Glass (ASTM C-1036)

Wired glass products consist of patterned glass into which a wire mesh is incorporated. This product is laminated between rollers to form a glass “sandwich.” The internal wire mesh is designed to hold pieces of glass in place in the event of breakage, but has no impact on mechanical strength.

▼ Polished Wired Glass (ASTM C-1036)

Polished wired glass is a wired glass patterned with a very faint design; this surface design is then softened and polished to achieve the transparency and clarity of float glass. Like wired glass, this product protects against injury in the event of glass breakage; it can also provide fire resistance in certain applications.

AGC polished wired products: Diamond, Square, Kasumi Obscure

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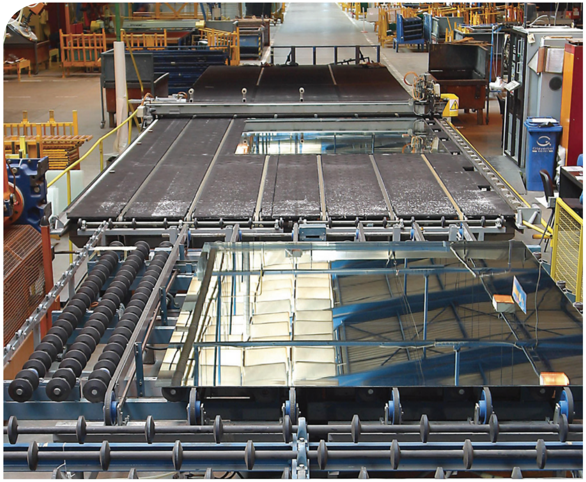
1.3.3. PROCESSED PRODUCTS

▼ Coated Glass (ASTM C-1376)

This popular glass solution is created by applying one or more coatings of inorganic materials to alter the physical properties of the glass—including its solar heat gain coefficient (SHGC), emissivity, color, light transmission, light reflection, and other properties. (See Section 2 in this chapter, called "Properties and Functions.")

Coated glass products can be categorized by three main characteristics:

1. The method used to apply the coating (pyrolytic or sputter-coated)
2. The position of the coated side of the glass when installed in an insulating unit (e.g., position 1, 2, 3, 4)
3. The application for which the glass is used (e.g., thermal control or solar control)



▼ Sputter-Coated Glass

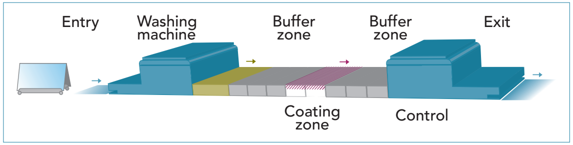
Sputter or "soft" glass coatings are applied through the bombardment of metal atoms onto cooled float glass. This process, which takes place in a low-pressure chamber, is known as magnetic sputter vapor deposition (MSVD). Because it takes place after float manufacturing is complete, sputter coating is often referred to as an "offline" coating method.

In the sputter-coating process, a sheet of annealed glass is placed under a magnetic sputter ring, as well as a plate of the specific metallic material that will be used to coat the glass with a microscopically thin layer. This plate is negatively charged, then bombarded with gas particles that disturb its outermost molecules—depositing them, in a "sputter" pattern, onto the annealed glass surface beneath.

The specific metal atoms deposited on the glass surface will determine its ultimate performance properties.

In order to protect the integrity of the coating, "soft-coat" products should be installed in position 2 or 3 in a double glazed unit and 4 or 5 in a triple glazed unit.

Sputter-coating process



AGC sputter-coated products: Comfort Ti-PS™, Comfort Ti-AC™, Comfort Ti-AC 40™, Comfort Ti-AC 36™, Comfort Ti-AC 28™, and Comfort Ti-AC 23™

▼ Glass With Pyrolytic Coatings

Pyrolytic coatings are metallic oxides applied during the float manufacturing process, while glass is still in a semi-molten state—when it has cooled to a temperature of about 1,112˚F or 600˚C. Because these coatings become a permanent part of the glass itself, they are extremely durable and tough—hence the common name "hard coat."

After the molten glass has moved through the tin bath—floating on its surface to form a perfectly flat, consistently shaped ribbon—specialized metallic oxide coatings can be applied to the "atmosphere" surface of the glass in order to improve its performance or enhance its appearance. This "online" coating process is known as chemical vapor deposition (CVD).

Glass products that feature a pyrolytic coating have a number of advantages:
> They offer a high level of solar control
> They are easy to handle, transport, stack, and store
>They can be heat-treated, laminated, bent, silk screened, and enameled to meet specialized applications
>There is no need for edge deletion when incorporating pyro- lytic glass in an insulating unit. "Edge deletion" means removing a portion of the coating at the perimeter of the glass to ensure a tight seal
>Pyrolytic products are durable enough to be used monolithically, though this is seldom recommended by AGC
Pyrolytic reflective coatings can be exposed to weather positioned on the #1 surface—but this is never recommended by AGC Flat Glass North America because of increased potential for damage and staining of the coating.
AGC hard-coated products: Comfort E-PS®, Stopsol®, Sunergy®

▼ Mirror Glass (ASTM C-1503)

Mirror is glass to which a coating is applied to reflect images; this coating is then protected by a second coating of paint. The process of manufacturing mirrors is called silvering.

▼ Copper-Free Mirror

The copper free Mirror is proven to be superior to conventional mirrors in all accelerated test including: CASS (copper accelerated salt spray), humidity, salt fog, ferric chloride and ammonia tests.

>Applications

Typical applications include wardrobe doors, bathrooms mirrors, furniture, TV projection screens, display cases, vehicle mirrors, decorative walls, ceiling and pillar covers, exercise rooms and mirrors for dance studios.

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>Composition and methods:

Guardian mirrors are produced on the latest state-of-the-art equipment. A four-layer patented process to create copper-free mirror involves an initial application of tin as a super sensitizer to the glass, followed by a layer of sensitizing palladium providing the ultimate foundation for silver-to-glass adhesion. A layer of silver is applied for reflectivity with a fourth layer of GMP to protect the silver. The mirror is further protected and encapsulated with organic paints, giving the mirror mechanical and chemical durability.

▼ Painted Glass

Painted glass products are coated on one side with a high-quality, durable paint in a range of colors. Painted glass products are for interior use only and should not be used outdoors.

For special applications where personal safety is a concern, painted products can be backed by a polypropylene film, which is applied to the painted side of the glass. This backing minimizes injury and damage if the glass breaks, because splinters adhere to the film. This backing has the added benefit of protecting the painted surface from scratches.

AGC painted products: Krystal Kolours™

▼ Matte-Finish Glass

Acid-etched glass may be wholly or partially matte in appearance. This innovative product is created by applying acid to one or both sides of clear or colored float glass. The acid attacks the surface of the glass, giving it a translucent appearance and a smooth, satin feel.

AGC acid-etched products: Matelux®

▼ Sandblasted Glass

This decorative product is flat glass which undergoes a sand-blasting treatment— i.e., abrasive etching at high pressures. This process can be used to obtain uniform or multi-relief motifs.

GLASS PRODUCTS 1.3

ALL ABOUT GLASS

> Laminated Glass (ASTM C-1172)

Laminated glass solutions consist of at least two sheets of glass bonded into a "sandwich" configuration by a full-surface plastic interlayer. The plastic interlayer may be one or more plastic films (PVB, EVA, etc.), as well as resin, silicate, or gel. These materials are designed to bond the sheets of glass together while further enhancing the performance of the end product.

The high performance level of laminated products may provide one or more of these functions:

> Safety and security of people and property (limiting the risk of injury in the event of glass breakage, or providing protection against hurricanes, defenestration, vandalism, burglary, etc.)

> Protection against bullets and explosions

> Protection against fire

> Sound insulation

> Decoration

Producing laminated glass solutions with PVB interlayers involves the following processing steps:

> The glass is loaded and cleaned

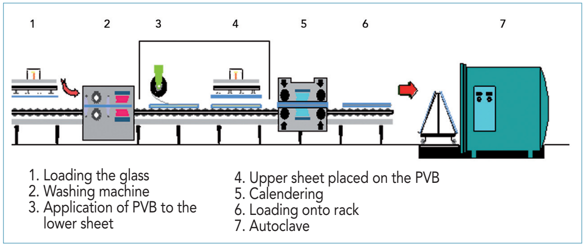
> The PVB film is applied to the first glass, and the second glass is then applied onto the film

> The glass moves into an oven, where a roller passes over it at a very high temperature to eliminate any air bubbles—as well as ensure preliminary bonding of the glass to the PVB

> The laminated glasses (not yet transparent) are then stored on racks

> The racks are placed in a high-pressure, high-temperature autoclave to achieve the product's ultimate adhesion and transparency properties

Laminating process

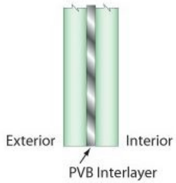


Laminated products—which can be visually indistinguishable from monolithic glass—can be fabricated with a variety of annealed, heat-treated, and coated products to create custom-tailored solutions.

In commercial applications, building codes often require the use of laminated safety glass in overhead glazings such as atriums and skylights, and laminated glass can be used as a safety glazing in storefronts and entrance doors.

Specific properties provided by laminated products include enhanced UV protection, as well as protection from unwanted noise. In fact, the use of laminated glass can significantly improve the sound transmission class (STC) rating for windows in noisy areas. Compared to traditional single- and double-glazed systems, the difference in STC rating can be dramatic.

See Section 2 in this chapter, called "Properties and Functions."

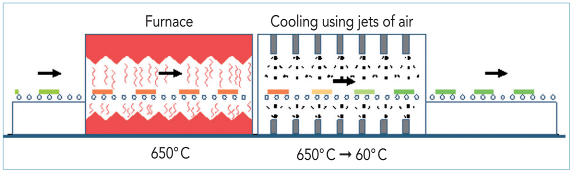


GLASS PRODUCTS 1.3
ALL ABOUT GLASS

▼ Tempered Glass (ASTM C-1048, ANSI Z97.1 & CPSC 16 CFR 1201)

Tempered glass is a flat glass product which has undergone heat treatment; it is heated to approximately 1,112˚F (600˚C), then cooled rapidly using jets of air.

Tempering process



This rapid cooling locks the surface of the glass in a state of compression. This makes it more resistant to mechanical and thermal stresses and gives it the required fragmentation characteristics.

If the glass breaks, it fragments into small pebble-sized pieces, limiting the risk of personal injury. Tempered glass is considered a safety glass that protects against injury, and it can be used for specific applications where safety is a concern (shower enclosures, skylights, glass doors, display cases, etc.). Tempered glass has a small risk of spontaneous breakage, due to nickel sulfide inclusions.

Many of AGC's high-quality flat glass products can be tempered; consult the AGC Technical Services team for details

▼ Heat-Strengthened Glass (ASTM C-1048)

Heat-strengthened solutions have undergone heat treatment during which they have been heated to approximately 1,112˚F (600˚C), and then cooled in a controlled manner using jets of air. In this case, the cooling process is slower than it is for tempered glass.

The surface of the glass is then locked in a state of compression, making it more resistant to mechanical and thermal stresses. However, when broken, heat-strengthened glass splits into large sharp pieces like float glass. For this reason, it is not considered a safety glass.

AGC heat-strengthened products: Many of AGC's flat glass solutions can be heat-strengthened; consult the AGC Technical Services team for details

▼ Ceramic Frit

To produce high-quality enamelled solutions, the entire surface of the flat glass is covered with a coating of vitreous enamel during the strengthening or tempering process. Enamelled glass is often used in spandrel panels.

▼ Silk-Screen Printed Glass

This decorative product is manufactured in a process similar to enamelling. An enamel coating is applied to part of the glass using a screen and is vitrified during the tempering or strengthening process.

▼ Curved Glass

Curved glass is obtained by bending flat glass—at a high temperature—to fit the shape of a mold on which it is resting.

GLASS PRODUCTS 1.3
ALL ABOUT GLASS

▼ Insulating Glass (ASTM E-2190)

An insulating glass unit is a glazing which is factory sealed and made up of multiple sheets of glass separated by a spacer and filled with dehydrated air and/or gas.

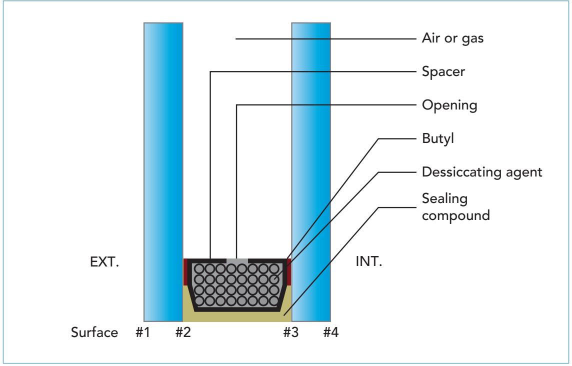
The main purpose of double glazing or triple glazing is to provide a higher level of thermal insulation than single glazing.

The thermal insulation characteristics of insulating glazing can be combined with properties such as solar control, sound insulation, and safety by using the appropriate glass products as components of insulated glazing.

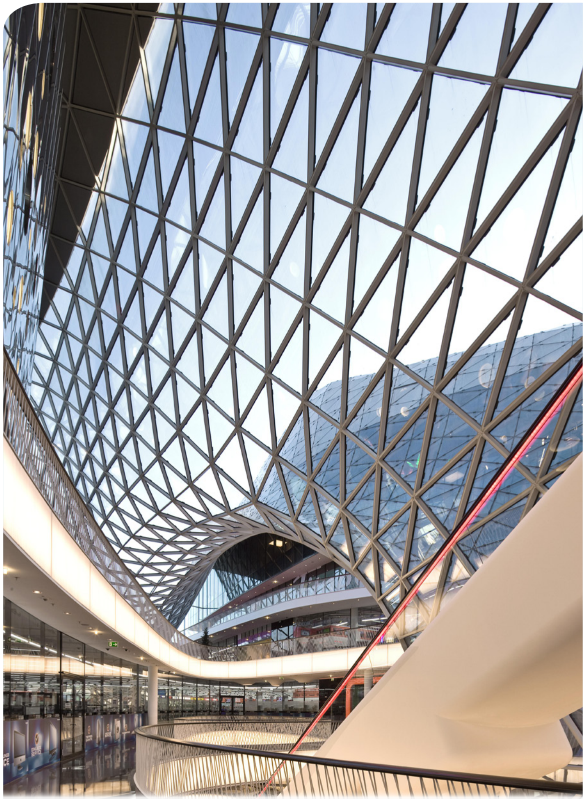
See Section 2 in this chapter, called "Properties and Functions."

The sides of the components in double glazing (including non-laminated glass products) are generally numbered from 1 to 4 (exterior to interior). Units which include laminated glass solutions may be numbered 1 through 8, because they include more individual glass surfaces.

Insulating glazing: components, direction, and numbering of sides



2 PROPERTIES AND FUNCTIONS



MyZeil, Frankfurt, Germany - Architect: Fuksas

2.1 INTRODUCTION

The first glass appeared a little over 2,000 years ago. It was used to seal off entrances to structures and to perform the main function of glass: letting in light while also providing a minimum level of protection against wind, cold, and rain.

However, the use of glass in buildings did not become widespread until a few centuries ago, and it was not until the 20th century that glass performance began to evolve significantly. In the late 1940s, the concept of double glazing to enhance thermal insulation began to develop, but its real growth came about in the wake of the global energy crisis of the 1970s.

Since then, the development of coated glass, laminated glass, and other innovative products has provided high-quality solutions for functions such as solar energy and luminosity control—while coated glass, laminated glass, tempered and heat-treated glass, and other products have proven effective solutions for sound insulation and safety.

Today, there is increasing demand for all these functions to be combined in a single type of glass.

To provide an insight into the many functions of glass, this chapter of *Your Glass Pocket* describes the following areas of glass performance in detail:

> Introduction to radiation, light, and color

> Thermal insulation

> Solar control

> Light control

> Sound insulation

> Safety

> Protection against fire

These glass functions are then linked to specific glass types, as well as the product range of AGC Flat Glass North America.

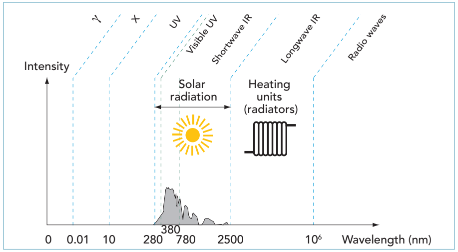
2.2 RADIATION, LIGHT, AND COLOR

The concepts of radiation, light, and color are key to understanding the following sections on thermal insulation, solar control, and light control.

2.2.1 DIFFERENT TYPES OF RADIATION

Every day we are subjected to different types of radiation, including radiation from the sun. The table and figure below show how these different types of radiation are classified according to their wavelengths.

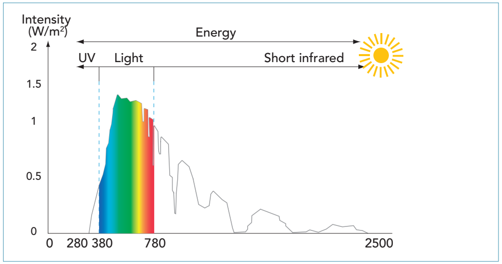
Different types of electromagnetic waves



2.2.2 THE SOLAR SPECTRUM

Solar radiation accounts for only a small portion of the spectrum of electromagnetic waves. Its composition is shown in the table and figure below. The spectrum of visible light forms part of the solar spectrum.

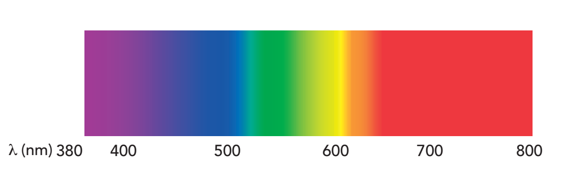
Composition of the solar spectrum



2.2.3 LIGHT

Light is the part of the solar spectrum—from 380 nm to 780 nm—which is visible to the human eye.

Light



We perceive light visually, but light can also be perceived in the form of heat. Light comprises approximately half of the heat we receive from the sun.

2.2.4 HEAT

The heat we feel comes from two sources:

> Heat from the solar spectrum and generated by UV rays, light, and short infrared waves

> Heat emitted by objects (lamps, radiators, etc.) in the form of long infrared waves

2.2.5 PROTECTION PROVIDED BY GLASS AGAINST DIFFERENT WAVELENGTHS OF THE SOLAR SPECTRUM

▼ Introduction

Glass can be used to control most types of radiation; the sections below give a brief outline of the glass solutions available for different types of solar control.

▼ Protection Against UV Radiation

In certain situations, solar radiation can damage the color of objects exposed to it. This change in color is due to the gradual degradation of molecular links caused by high-energy photons. Such damage is caused by ultraviolet radiation and, to a lesser extent, shortwave visible light (in the violet and blue range). Solar radiation also causes the temperature to increase, thus accelerating this process.

Some glass products can combat this discoloration:

> Laminated glass with PVB interlayers absorbs over 99% of UV radiation up to 380 nm

> Colored glass with a predominantly yellow-orange tint partially absorbs violet and blue light

> Glass with a low solar factor limits temperature increases

That said, no glass product can completely eliminate discoloration. In fact, in some cases, interior artificial lighting can also cause discoloration.

Various indices are used to quantify the protection against UV radiation provided by glass products, as well as the risk of discoloration:

> UV transmission index (TrUV)

> The Damage Weighted Index (LBNL Window 5.2=TDW-ISO): this index is defined in ISO 9050 and pertains to the transmission of radiation for wavelengths in the range of 300 nm to 600 nm—i.e., those wavelengths causing objects to discolor

▼ Light Control

Light can be controlled by using tinted, coated, or translucent glass.

For further details, see the section of this chapter entitled "Light Control."

▼ Protection Against Shortwave Infrared Radiation and Heat

Solar control glass with an appropriate SHGC provides protection against shortwave infrared radiation and heat in general.

When designing a building, it is important to remember that the surface of the glazings and their SHGC have a direct impact on the ventilation system used.

RADIATION, LIGHT, AND COLOR 2.2
ALL ABOUT GLASS

▼ Control of Longwave Infrared Radiation

Controlling longwave infrared radiation involves preventing longwaves—i.e., the heat emitted by objects—from leaving buildings in order to enhance thermal insulation.

Low-emissivity coated glass can be used to control longwave infrared radiation.

When designing buildings, it is important to remember that the thermal insulation of the glazings (and of the building in general) will directly affect the heating system used.

For further details, see the section of this chapter entitled "Thermal Insulation."

2.2.6 COLOR

Objects we can see—whether they are transparent, translucent, or opaque—all have a specific color.

The color depends on several parameters, such as:

> Incident light (type of illumination)
> The reflection and transmission properties of the object
> The sensitivity of the eye of the observer
> The environment surrounding the object and the contrast between the object and those around it

The color of an object depends on all these factors, and an observer will not always see the object in the same way, depending, for example, on the time of day or the level of natural light.

Clear glass has a slightly green transmission color. The optical qualities of colored glass vary widely depending on their thick ness. Bronze, grey, blue, and green float glasses reduce the amount of solar energy and therefore the level of light transmis sion.

The view through colored glazings is therefore influenced by the color of the glass itself.

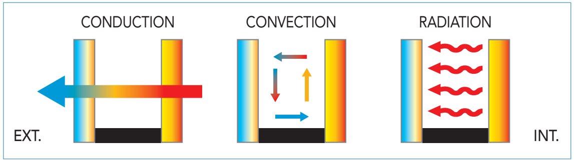
2.2 RADIATION, LIGHT, AND COLOR
ALL ABOUT GLASS

2.3 THERMAL INSULATION

2.3.1 TRANSMISSION OF HEAT THROUGH A GLAZING

A difference in temperature between two points within any material will result in heat being transferred from the hot point to the cold point.

Methods of heat transmission through a glazing
(where the outside temperature is lower than the inside temperature)



▼ Thermal Conductivity λ

Thermal conductivity is defined as the amount of heat passing per second through a pane 1 m thick, and with a surface area of 1 m² where there is a temperature difference of 1˚C between two surfaces.

The thermal conductivity of the glass is 1 W/(m.K). It is therefore not an insulating material, since insulating materials are those with a thermal conductivity of less than 0.065 W/(m.K).

To minimize energy loss and therefore ensure maximum thermal insulation, the thermal transmittance or U Factor of the glazing must be as low as possible (i.e., the thermal resistance R of the glazing must be as great as possible).

NFRC 100 Standard details the method used to calculate the U Factor of glazings. The value obtained using this calculation is the U Factor at the center point of glazings—i.e., excluding edge effects due to the presence of the spacer.

The table below shows the U Factor for different types of insu lating glazings. The most widely used spacers are between 1/4 inch (6 mm) and 1/2 inch (12 mm) thick.

U Factor (thermal transmittance values) for different types of glazings

Space mm (inches)	Standard IGU 3 mm x 3 mm (1/8" clear x 1/8" clear)			low-e IGU* 3 mm x 3 mm (ε = 0.04) (1/8" TiAC 36 x 1/8" clear)		
	Air	90% Argon	90% Krypton	Air	90% Argon	90% Krypton
6 (1/4 in.)	0.550	0.503	0.447	0.406	0.321	0.216
10 (3/8 in.)	0.502	0.465	0.439	0.322	0.252	0.214
12 (1/2 in.)	0.480	0.452	0.443	0.294	0.241	0.224
15 (5/8 in.)	0.482	0.455	0.447	0.303	0.249	0.228
19 (3/4 in.)	0.486	0.459	0.447	0.310	0.256	0.228

* coating on surface #2 of IGU

As a comparison, an uninsulated cavity wall has a U Factor of approximately 1.5 W/(m².K); that of an insulated wall is less than 0.6 W/(m².K).

THERMAL INSULATION 2.3

ALL ABOUT GLASS

2.3.3 DIFFERENT TYPES OF INSULATING GLAZING

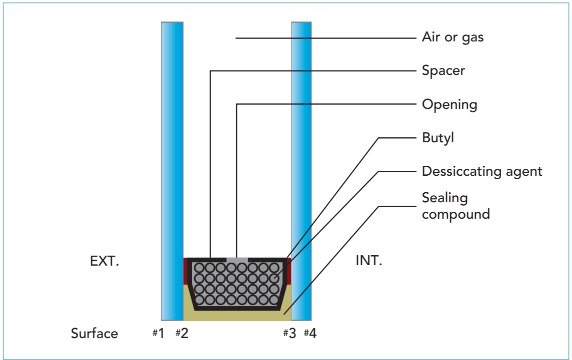
▼ Introduction

Single-pane glazing is not a high-performance solution in terms of thermal insulation. Various solutions have been developed to enhance the insulating properties of glazings, primarily in the wake of the energy crisis of the 1970s.

▼ Double Glazing

The first type of thermally insulating glazing was double glazing, which is composed of two sheets of glass separated by a spacer to provide a space filled with dry air. Since the air has a thermal conductivity of 0.025 W/(m.K) (at 50˚F or 10˚C), while that of glass is 1 W/(m.K), the layer of air enhances the insulating properties and reduces the U Factor of the glazing.

Double glazing: components and numbering of glass surfaces



The glass surfaces in double glazings are generally numbered from 1 to 4 (outside to inside). For laminated glass products, the surfaces may be numbered 1 to 8.

▼ Noble Gases

Another improvement in thermal insulation was achieved by replacing air with noble gases—which have both a lower thermal conductivity, to limit heat conduction, and a greater volumic mass, to restrict convection and make molecular movement more difficult.

Noble gases lower the U Factor and are only used in coated insulating glazings. In practice, argon and krypton are generally used.

▼ High-Performance Double Glazings

> Principle

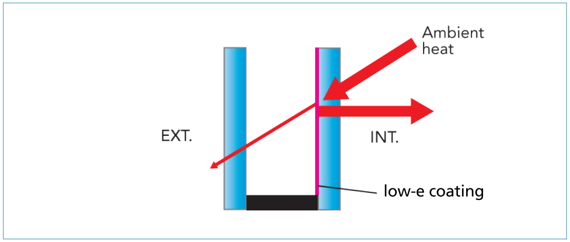
The development of techniques for applying metallic coatings to glass has been a decisive step forward in improving the thermal insulation of glazings. Applying a metallic coating to a glass makes it “high-performance” (also called “low-emissivity” or “low-e”).

These coatings are generally:

- Sputter coatings applied inside a vacuum chamber, which must be positioned inside a double glazing unit (“soft” coatings)
- Pyrolytic coatings, which are applied as part of the float manufacturing process (“hard” coatings)

In a typical dual glazing with surfaces numbered 1 through 4, low-emissivity coatings are generally applied in position 2 or 3. Placing them in position 2 does not affect their insulation properties, but rather their reflection properties—and therefore the overall solar heat gain and look of the glazing.

Low-emissivity glazing



> Emissivity

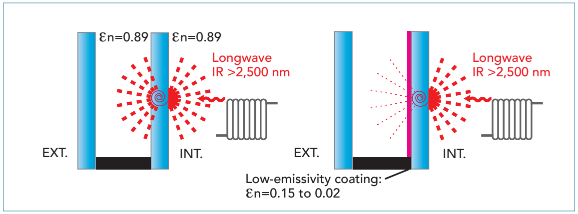
Objects located inside buildings radiate heat in the form of longwave infrared radiation (over 2,500 nm). Since glass transmits virtually none of this type of radiation, it will absorb longwave infrared radiation, heat up, and then emit this heat back.

Clear glass (with no coating) will generally emit heat to the colder side. In winter months, this heat would be emitted to the exterior of a building and lost.

Low-emissivity glass coatings are designed to increase the reflection of the heat absorbed by the glazing to the interior of the building. In contrast to clear glass, low-emissivity coated glass ensures that heat is retained in a building, enhancing thermal comfort.

The emissivity of a glass can therefore be interpreted as its heat absorption level; the lower the emissivity (absorption), the greater the reflection—and the more heat is retained.

Double glazing and high-performance double glazing



An emissivity rating of 0.2 means that 80% of the heat flow absorbed by the glazing is reflected back into the building.

A sheet of clear glass has a normal emissivity of 0.840, while "hard" or pyrolytic coatings (Comfort E-PS™ and Sunergy®) result in emissivity values of between 0.148 and 0.298 respectively. "Soft" or sputter-coated products, including the Comfort Ti™ family, result in lower emissivity values, generally between 0.06 and 0.03.

▼ Warm-Edge Spacers

The latest development to enhance thermal insulation for facades and glazing is the warm-edge spacer. The conventional metal spacer, made of aluminum or steel, is replaced with a plastic spacer—which can be reinforced by a metallic structure in some cases. The thermal conductivity of plastic materials is far superior to that of steel or aluminum, and the resulting spacer reduces heat loss around the edges of the glass—hence the name "warm edge."

Using a warm-edge spacer does not alter the U Factor in the center of the glass—but rather it improves the Uw value, which is the thermal insulation of the window as a whole (glass + spacer + frame).

▼ Triple Glazing

Since thermal insulation is increased by the presence of an air space, the next stage is triple glazing—i.e., glazings made up of three sheets of glass separated by two spaces.

This solution is used when a low Uw-Value is required by the specific application. However, there are challenges associated with triple glazings—for example, the resulting thickness and weight of the insulating unit can make it difficult to install.

▼ Notes

> Solar control

Emissivity affects longwave infrared radiation; however, it has virtually no effect on solar radiation.

To combine thermal and solar control, certain types of spectrally selective (solar control) low-e coatings must be used which combine these two functions.

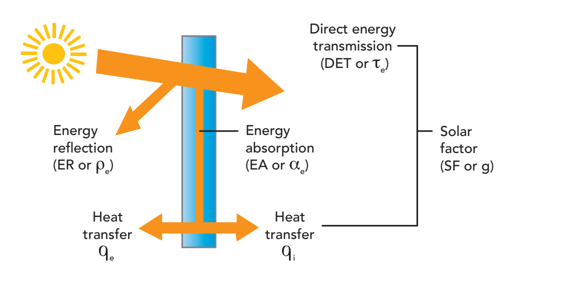
THERMAL INSULATION 2.3
ALL ABOUT GLASS

2.4 SOLAR CONTROL

2.4.1 ENERGY AND LIGHT FACTORS

Energy and light factors (or spectrophotometric factors) determine the transmission, absorption, and light and energy reflection properties of glazings.

▼



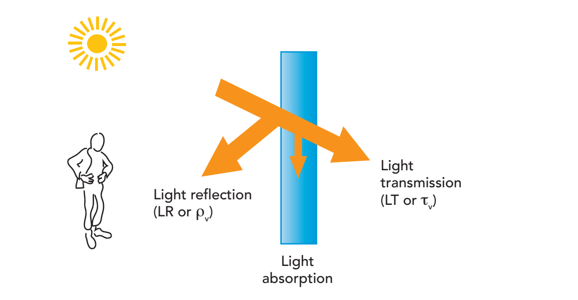
Light Factors

Similar to energy factors, light factors are defined solely on the basis of the visible part of the solar spectrum (between 380 nm and 780 nm).

Light transmission τ_v (LT) and light reflection ρ_v (LR) factors are defined, respectively, as the fractions of visible light transmitted and reflected by the glazing.

The radiation absorbed by the glazing is not visible and is not generally taken into account.

Light factors



As an example, the table below gives the SHGC and VLT values of clear single and double glazing units.

SHGC and VLT values of clear single and double glazing units

	Solar Heat Gain Coefficient	Visible Light Transmission
Clear glass: 6 mm	0.84	0.88
Clear insulating glazing: 6 mm /12 mm /6 mm	0.73	0.78

▼ Selectivity or LSG (Light-to-Solar-Gain Ratio)

The heat entering a given room comes entirely from solar radiation—i.e., visible light, ultraviolet rays, and infrared radiation.

The amount of heat entering a building can be limited without reducing light levels by using high-performance coated glass, which prevents UV and infrared radiation from passing through but allows visible light in. Such glass is called selective.

The selectivity LSG of a glazing is the relationship between its visible light transmission (VLT) and its SHGC.

The higher the value, the more selective the glazing.

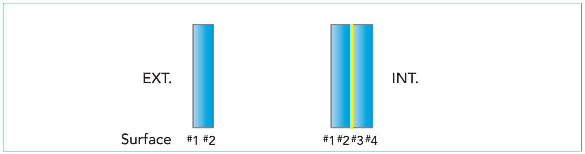
In the United States, the Department of Energy defines a spectrally selective glazing as a glazing with a Light to Solar Heat Gain Ratio (LSG) of 1.25 or greater.

Type	Configuration		VLT	SHGC	LSG
	Outboard	Inboard			
Uncoated	Bronze	CLR	0.48	0.50	0.95
Passive Solar (pyrolytic)	E-PS	CLR	0.73	0.63	1.17
Passive Solar (sputter)	Ti-PS	CLR	0.74	0.61	1.40
Solar Control (sputter)	AC36	CLR	0.65	0.36	1.81

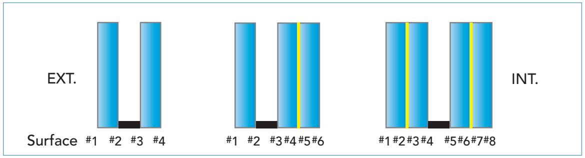
▼ Conventions in Coating Positions

The North American conventions are shown below.

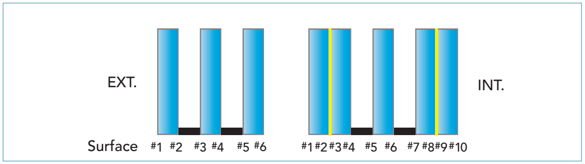
> Monolithic glass (numbered 1 and 2 for non-laminated glass, numbered 1 through 4 for laminated)



> Double glazing (1 through 4 for non-laminated, up to 8 surfaces for laminated solutions)



> Triple glazing (1 and 6 for non-laminated, up to 12 surfaces for laminated solutions)



SOLAR CONTROL 2.4

ALL ABOUT GLASS

2.4.2 SOLAR CONTROL

▼ Introduction

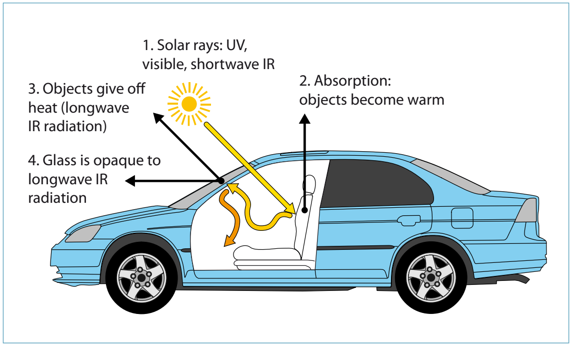
> Heating rooms: the greenhouse effect

The sun can introduce too much heat into buildings with substantial glazed areas. Heat from the sun penetrates rooms via direct or indirect transmission, after being absorbed by the glazing. This solar radiation penetrating a building reaches walls, floors, and furniture, which partially absorb it and then heat up. They then return this heat, in the form of infrared heat radiation with a wavelength in excess of 2,500 nm (longwave infrared radiation). However, glass is virtually impervious to this high-wavelength radiation—and so it is radiated back to the interior. This causes room temperatures to rise gradually; this is how the “greenhouse effect” works.

A body-tinted glass or one with solar control coatings allows less heat to pass through the glass, which reduces the level of interior warming.

The figure below shows the greenhouse effect in a car parked in the sun. The temperature inside the vehicle rises significantly, and the seats and the steering wheel also heat up considerably.

The greenhouse effect



> Passive solar: free solar energy

The greenhouse effect is desirable in homes in the northern regions of North America during cold periods of the year since it saves heating energy. By contrast, it is undesirable in office buildings in which the high numbers of employees, electrical equipment, and artificial lighting all cause interior temperatures to rise. In such cases, the greenhouse effect means increased air-conditioning costs. For these commercial buildings, protection against solar energy transmission results in lower annual energy costs.

> Direction of windows

Clearly, the amount of solar transmission depends on the direction a window faces. In the northern hemisphere, north-facing windows generate less passive solar energy. South-facing windows receive a lot of sun in the winter and little sun in the summer. West- and east-facing windows receive passive solar energy throughout the year. West-facing windows also have the disadvantage of receiving high solar energy levels toward the end of the day when the building has already had time to heat up—making west-facing windows the most critical when trying to guard against passive solar energy transmission.

> Desired performance of glazings

Solar control needs in North America are generally determined by geographic region.

Residential—In the southern region of the United States, a low SHGC is desirable. This type of high-performance window will greatly reduce the amount of solar heat energy entering the home.

In the northern region of the United States and throughout Canada, a high SHGC and a low U Factor is the best combination to allow passive solar heat in while still ensuring excellent thermal insulation to keep heat in.

Commercial—In contrast to residential, geographic region is less important than the internal heat levels generated by people and machinery. In light of this fact, throughout North America, low-SHGC glazing is generally used to reduce the amount of solar heat energy entering the building.

When choosing a glazing, it is critical to consider the energy, light transmission, and thermal insulation requirements of the overall project. For help in balancing these needs, please consult the Technical Services team at AGC Flat Glass North America.

▼ Solar Control Glass

Three types of solar control glass are currently available: absorbent glass, low-e coated, and reflective coated glass. These functions can also be combined in the same glazing.

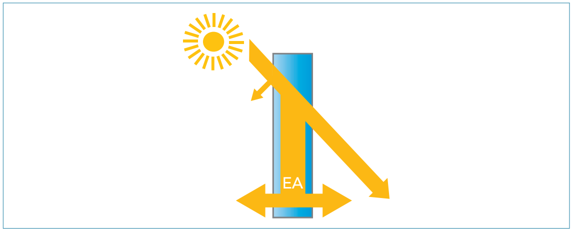
> Absorbent (tinted) glass

This type of solar control glass is body-tinted (bronze, grey, green, blue, etc.) by adding metal oxides. Depending on the color and the thickness of the glass, the SHGC varies between 40% and 80%.

AGC's Solarshield™ family of tinted products is an example of a high-performing tinted glass.

Tinted glass absorbs some of the energy from solar radiation before emitting it back inside and out.

Absorbent tinted glass



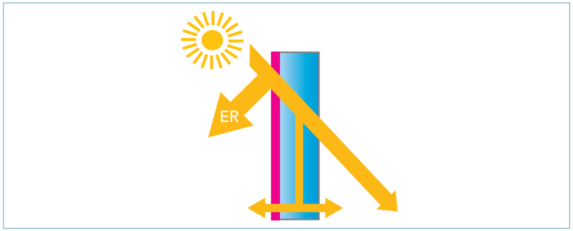
The amount of energy emitted to the outside and the inside depends on the wind speed, as well as external and internal air temperatures. To dispatch the heat radiated to the outside as efficiently as possible, the absorbent tinted glass must be installed as close to the front of the facade as possible. In flat facades, the heat absorbed can escape more easily, and the level of radiation emitted to the inside is lower.

Absorbent tinted glasses warm up more quickly than conventional clear glass. In most cases, a study should be conducted into the risk of breakage by thermal stresses prior to installing tinted glass; consult AGC Technical Services for more information.

> Low-e coated glass

Although there are many coated glass products, this section refers specifically to coated glass solutions which reflect some solar energy.

Coated glass



There are several types of coatings designed for solar control:

- Sputtered solar control low-e glasses (Comfort™ Ti family) are produced using metal- or metal oxide-based sputtered coatings on the surface of the glass. Since these coatings are placed on the surface of the glass, they should be used in position 2 or 3 (depending on the application). Soft coatings must be used on the inside of a double glazing unit.
- The sputter coating process can be used to create spectrally selective coatings to meet a wide range of aesthetic and spectrally performance needs. They can also be applied to a wide range of tinted substrates to achieve customized performance levels. (Comfort Ti glasses on Solarshield™ tints.)
- Pyrolytic solar control coated glasses are produced using metal oxide-based coatings applied to a clear or colored substrate during the float glass production process. These coatings can be either low-emissivity (Sunergy®) or reflective (Stopsol®).

SOLAR CONTROL 2.4
ALL ABOUT GLASS

Like tinted absorbent glasses, coated solutions also carry a risk of thermal breakage when subjected to high levels of solar energy. In some cases, a study should be conducted into the risk of breakage by thermal stresses before installing coated glass products. Consult AGC Technical Services to learn more.

> Notes

- It is important to always use the same type of glazing (in terms of thickness, color, coatings, etc.) side by side in order to ensure the uniform appearance of a facade.
- Coated glass with a high reflectance rating reflects light from the "brightest" area at any given time. When it is dark outside and artificial light is used to light rooms, this interior light will be reflected into the building, and it will no longer be possible to see out. For this reason, careful attention must be paid to the selection of coated glass solutions with low interior reflectance ratings.

▼ Spandrel Panels

Positioned on the exterior of commercial buildings, spandrel panels are used to mask opaque sections, as well as the structural elements of facades. Used in conjunction with vision glazings, they have given rise to "curtain wall" facades.

Depending on the products and colors used, either complete harmony or contrasting effects can be achieved when specifying spandrels and vision glass.

From an aesthetic point of view, choosing the ideal spandrel for a particular vision glazing is not always easy. AGC Flat Glass North America recommends that architects, specifiers, building owners, and glass professionals work together to choose the most appropriate solution, using actual glass samples and prototypes. AGC has an expert team of architectural and Technical Services consultants to support this decision-making process.

Spandrels can be combined with thermal insulation, sound insulation, and fire protection functions, depending on the specific customer application.

A number of different types of spandrels are available:

- Single-pane, ceramic frit enamelled glass: this is clear or colored glass which is coated with a ceramic frit, and then tempered or heat strengthened
- An insulating glazing made of the same glass as vision glass (as an external glass) and spandrel glass (as an internal glass)
- An insulating glazing enamelled in position 4
- A shadow-box: this is a spandrel made up of vision glazing combined with an opaque background (metal sheet, etc.) in order to produce an opaque glass section in harmony with the building

Except in special cases where a preliminary study has been carried out, spandrels are heat strengthened or tempered. For spandrels in insulating glazing positioned in front of a structure built out of concrete or an insulating material, a thermal study is required to ascertain the glazing's durability.

2.5 LIGHT CONTROL

2.5.1 LIGHT CONTROL

LIGHT CONTROL 2.5

ALL ABOUT GLASS

SAFETY

▼ General

Safety is a wide-reaching concept, covering many areas:

> Protecting individuals against the risk of injury from:
  - Sharp, broken glass
  - Falling glass (defenestration)

  In trying to avoid the risk of injury only, it is the breakage pattern of the glass which is significant. It is important to ensure that, if the glass breaks, it does not produce pieces which are likely to cause injury. If the aim is to provide protection against falling as well, care must be taken to ensure that the glazing is not obliterated

> Protecting people and property against burglary and vandalism of private homes, shops, and offices: in this context, the glazing should remain in place and should prevent anyone or anything penetrating it

> Protection against firearms

> Protection against explosions

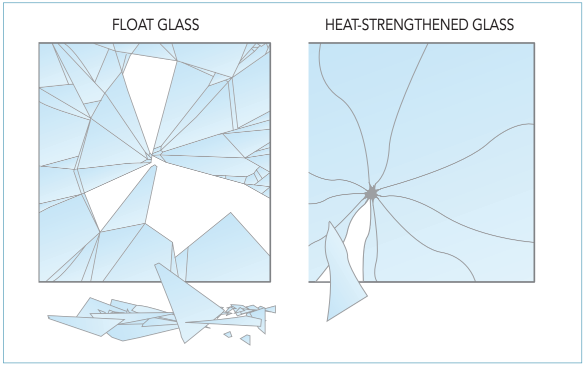
Only a small number of glass products meet the breakage pattern, defenestration, and resistance criteria described above: these are tempered and laminated glass. Other glass products—including float, heat-strengthened, and wired glass, among others—are not considered safety glasses.

The properties of these products are described briefly in this section.

▼ Float, Heat-Strengthened, and Wired Glass

In view of its breakage pattern of large sharp pieces, float glass cannot be considered a safety glass. The same applies to heat-strengthened glass, which has a similar breakage pattern.

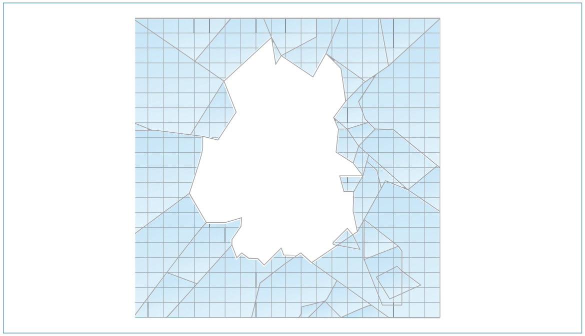
Breakage patterns of float and heat-strengthened glass



Wired glass (flat or profiled) has a metallic wire mesh built into it during the manufacturing process, designed to hold pieces of glass together in the event of breakage. However, if wired glass suffers an impact, the pieces of glass and the wire mesh may come apart, increasing the risk of injury.

For this reason, this type of glazing may not be used as a safety product, designed to prevent injury or protect people falling through it.

Breakage pattern of wired glass



▼ Tempered Glass (ASTM C-1048)

Because of the high internal stresses tempered products are subjected to during the manufacturing process, they shatter into small, blunt pieces upon impact.

Breakage pattern of tempered glass

Tempered glass is considered to be a safety glass if it meets the relevant breakage pattern criteria; these criteria are set out in the standards ANSI Z.97.1 and CPSC 16 CFR 1201—which also describes the test that must be implemented in order for a glazing to meet these safety requirements.

For reference, the main advantages of tempered glass over float glass are that tempered products:

> Exhibit much greater characteristic bending resistance: 120 N/mm² (24,000 psi) as compared with 45 N/mm² (6,000 psi)

> Have a higher level of resistance to impacts

> Are four times stronger than annealed float glass

> Have a higher level of resistance to thermal shock (approximately 392°F or 200°C)

> Break into small, blunt pieces

> Cannot be cut or processed after tempering

> Exhibit a different anisotropy of the material: in natural lighting conditions, the refraction properties vary from point to point—and the superficial aspect of the glass pane may have differently colored designs, due to interference

Comparing the impact resistance of a 11.8 inches by 11.8 inches (30 cm x 30 cm) piece of float glass to a similar-sized piece of tempered glass:

> Float glass measuring 1/4 inch (6 mm) in thickness resists a ball weighing 0.55 pound (250 g) falling from a height of 11.8 inches (30 cm)

> Tempered glass measuring 1/4 inch (6 mm) resists a ball weighing 0.55 pound (250 g) falling from a height of 9.8 feet (3 m)

> Tempered glass measuring 5/16 inch (8 mm) resists a ball weighing 1.1 pounds (500 g) falling from a height of 6.6 feet (2 m)

▼ Laminated Glass (ASTM C-1172)

A laminated glass is an assembly composed of at least two panes of glass bonded together across their entire surface by an interlayer. For laminated safety glass, the most widely used interlayer is a plastic PVB (polyvinyl butyral) film, but EVA (ethylene vinyl acetate) films or a safety resin may also be used. In the event of breakage, the bond between the glass and the interlayer ensures that the broken pieces remain in place—at least for a certain period, or up to a specified load level.

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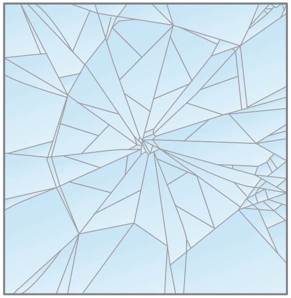
Breakage pattern of laminated glass



According to standard ANSI Z97.1, a laminated glass may be considered a safety glass if it meets the requirements of a specific resistance class following the pendulum impact test detailed in this standard.

In some specific cases, tempered or heat-strengthened glasses are used to manufacture laminated glass.

As such, in specific applications requiring a high level of compression, a laminated glass composed of tempered and heat-strengthened glass is sometimes used. The former provides mechanical strength, while the latter gives adequate residual stability if the glass breaks and cannot be immediately replaced.

Heat-strengthened laminated glass is sometimes used when a higher level of wind load resistance is required than that offered by annealed float glass—as well as to prevent the risk of breakage due to thermal shock.

▼ Glass With a Self-Adhesive Film

A self-adhesive film may be applied to a glass to keep fragments in place in the event of breakage.

These films are generally used for applications such as mirrors and opaque painted glass.

Please note that these films are only effective if they are applied to the glazing before it is placed in the glazing channel of the frame. Adhering a film to the visible part of a glazing already in the channel is not effective if the glass breaks. In addition, some films applied *in-situ* can cause problems in terms of breakage due to thermal shock.

▼ Introduction

In North America, there are a number of industry standards that products must meet in order to be considered safety glass solutions. These requirements are described in this section.

▼ Impact Resistance—ANSI Z97.1

Impact resistance standards for North America include both federal and voluntary standards, such as the U.S. Consumer Products Safety Commission's CPSC 16 CFR 1201 ("Glass Standard for Architectural Glazing Materials") and ANSI Z97.1 ("American National Standard for Safety Glazing Materials Used in Buildings—Safety Performance Specifications and Methods of Test").

ANSI Z97.1 establishes the test methods for safety glazing materials designed to promote safety, as well as reduce or minimize the likelihood of cutting and piercing injuries when the glazing materials are broken by human contact in their use in architectural buildings.

The related impact test utilizes a leather punching bag filled with 100 pounds (45.4 kilograms) of lead shot to simulate the impact created by a running person. The standard divides safety glazings into two groups: Category I/Class B, and Category II/Class A, as shown in the table below.

Classes and categories of safety glazings, based on impact resistance

CPSC 16 CFR 1201 Category/ ANSI Z97.1 Class	Weight of Impactor—lbs. (kg)	Height of drop—in. (cm)	Energy (ft.-lb.)	Minimum required PVB thickness—in. (mm)	Maximum Glazing Area—sq. ft. (m^2)
Cat.I / B	100 (45.4)	18 (46)	150	0.015 (3.8)	9 (2.7)
Cat.II / A	100 (45.4)	48 (122)	400	0.030 (7.6)	Unlimited

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> A tempered glass is classified as 1C2 if it resists an impact from a fall height of 17.7 inches (450 mm) without breaking and if it falls from a height of 47.25 inches (1,200 mm) and fragments in accordance with tempered glass.

▼ Hurricane Impact Resistance Glazings—ASTM E-1886/E-1996, Florida Building Code TAS 201 and 203, or AAMA 506

Building codes in the coastal counties of the United States require that, in wind-borne debris regions, glazing in buildings shall be impact-resistant or protected with an impact-resistant covering meeting the requirements of SSTD 12, ASTM E 1886 and ASTM E 1996, Florida Building Code TAS 201 and 203, or AAMA 506.

In accordance with the wind-borne debris provisions of these building codes, glazed openings located within 30 feet (9.144 m) of grade must meet the requirements of the ASTM E 1996 Large Missile Test. This test simulates the effects of large, wind-driven debris that can impact the glazing during a hurricane—such as broken roof tiles, branches, patio furniture, etc. The weight and speed of these large missiles are defined according to the basic wind speed, as per the following table.

Standards of the ASTM Large Missile Test

Large Missile			
	Basic Wind Speed	Basic Protection	Enhanced Protection
Wind Zone 1	110 to 120 mph	4.5 lb .@ 40 ft./sec.	9.0 lb. @ 50 ft./sec.
Wind Zone 2	120 to 130 mph	4.5 lb. @ 40 ft./sec.	9.0 lb. @ 50 ft./sec.
Wind Zone 3	130 to 140 mph	9.0 lb. @ 50 ft./sec.	9.0 lb. @ 80 ft./sec.
Wind Zone 4	Greater than 140 mph	9.0 lb. @ 50 ft./sec.	9.0 lb. @ 80 ft./sec.

To meet these large-missile standards, laminated glasses are offered in a variety of interlayer thicknesses and types.

Glazed openings located more than 30 feet (9.144 m) above grade must meet the provisions of the ASTM E 1996 Small Mis sile Test. This test simulates small, wind-driven debris that can impact the glazing during a hurricane—such as roof gravel and other small debris.

To meet the requirements of the ASTM E 1996 Small Missile Test, laminated glasses typically include a PVB interlayer with a thickness of 0.06 inch (1.5 mm).

Standards of the ASTM E 1996 Small Missile Test

Small Missile			
	Basic Wind Speed	Basic Protection	Enhanced Protection
Wind Zone 1	110 to 120 mph	2 g steel ball @ 130 ft./sec.	9.0 lb. @ 50 ft./sec.
Wind Zone 2	120 to 130 mph	2 g steel ball @ 130 ft./sec.	9.0 lb. @ 50 ft./sec.
Wind Zone 3	130 to 140 mph	2 g steel ball @ 130 ft./sec.	9.0 lb. @ 80 ft./sec.
Wind Zone 4	Greater than 140 mph	2 g steel ball @ 130 ft./sec.	9.0 lb. @ 80 ft./sec.

In addition to meeting the wind-borne debris requirements included in both the ASTM large and small missile tests, fenestration systems are subjected to a static cyclic pressure load test that simulates the extended force of the wind during a hurricane. Since hurricanes rotate in a counter-clockwise direction, glazings in a building structure will be subjected to both positive and negative forces. These forces are simulated at different pressure cycles, as indicated in the following table.

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Standards of the ASTM E 1996 Cyclic Static Air Pressure Loading Test

Cyclic Static Air Pressure Loading			
Loading	Basic Wind Speed	Basic Protection	Enhanced Protection
1	Positive	0.2 to 0.5 Ppos	3,500
2	Positive	0.0 to 0.6 Ppos	300
3	Positive	0.5 to 0.8 Ppos	600
4	Positive	0.3 to 1.0 Ppos	100
5	Negative	0.3 to 1.0 Pneg	50
6	Negative	0.5 to 0.8 Pneg	1,050
7	Negative	0.0 to 0.6 Pneg	50
8	Negative	0.2 to 0.5 Pneg	3,350

Pass/Fail Criteria

Window systems are certified if three similar specimens pass in accordance with the following criteria, after completion of the impact and cycling portions of the ASTM E 1996 testing.

(a) All test specimens must resist the large or small missile impacts, or both, without penetrating the pane of glass

(b) Test specimens must resist the large or small missile impacts, or both, with no tear formed longer than 5 inches (130 mm) or no opening formed through which a 3-inch (76 mm) diameter solid sphere can pass freely

▼ Burglar-Resistant Glass—ANSI/UL 972

Laminated glasses provide an element of security against "smash and grab" thefts. Whether protecting merchandise in a store display, or guarding a homeowner's porch door or window against intruders, laminated glass provides the needed secu rity. Laminated glass protects against forced entry by resisting repeated blows from hammers, bricks, or other weapons—and deterring burglars from perpetrating the crime.

ANSI/UL 972 Testing

ANSI/UL 972 test standards define the specific methods that are used to classify glasses in terms of their resistance to burglary. This testing uses the impact of a steel ball as a surrogate for a variety of burglary tools such as hammers, bricks, or crow bars.

Testing consists of dropping a 3.25-inch (82 mm), 5-pound (2.26 kg) steel ball across a designated vertical distance at glazing specimens conditioned at different temperatures. The test specimens should measure 24 inches x 24 inches (610 mm x 610 mm) in size. There are five impacts per specimen.

Pass/Fail Criteria

In order for glazings to qualify as burglary-resistant under these standards, the steel ball must not penetrate the laminate during all five impacts.

3. GLOSSARY

Annealed Glass:

Float glass (also called “flat” glass) that has not been heat-strengthened or tempered is “annealed glass.” Annealing float glass is the process of controlled cooling to prevent residual stress in the glass and is an inherent operation of the float glass manufacturing process. Annealed glass can be cut, machined, drilled, edged and polished.

Heat Gain:

Heat gain is heat added to a building interior by radiation, convection or conduction.

Heat-Strengthened Glass:

Heat-strengthened (HS) glass has been subjected to a heating and cooling cycle and is generally twice as strong as annealed glass of the same thickness and configuration.

HS glass must achieve residual surface compression between 3,500 and 7,500 PSI for 6 mm glass, according to ASTM C 1048. HS glass has greater resistance to thermal loads than annealed glass and, when broken, the fragments are typically larger than those of fully tempered glass.

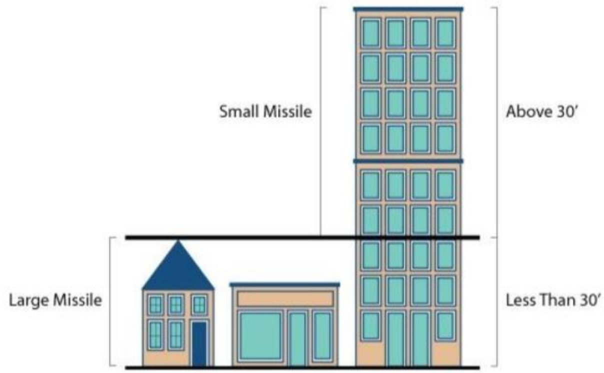
Heat-Strengthened glass is not a safety glass product as defined by the various code organizations. This type of glass is intended for general glazing, where additional strength is desired to withstand wind load and thermal stress. It does not provide the strength of fully tempered glass and is intended for applications that do not specifically require a safety glass product.

HS glass cannot be cut or drilled after heat-strengthening and any alterations, such as edge grinding, sand blasting or acid etching, can cause premature failure.

Hurricane Glass:

The coastal areas of North America have begun adopting “hurricane codes” to help prevent catastrophic building failure during hurricane conditions. Initially, Dade County, Florida, enacted requirements that have been used as a model for other areas such as Texas and the Gulf Coast, as well as up the Atlantic Seaboard.

The codes may vary regionally, so design professionals are encouraged to research the local municipality codes when beginning new projects. The following diagram indicates basic Dade County, Florida, code requirements for small and large missile glazing testing.



Insulating Glass:

Insulating glass refers to two or more lites of glass sealed around the edges with an air space between, to form a single unit. Commonly referred to as an “IG unit,” insulating glass is the most effective way to reduce air-to-air heat transfer through the glazing. When used in conjunction with low-E coatings, IG units become an effective means to conserve energy and comply with building codes. The most common residential insulating glass unit configuration is 1/8" glass / 1/2" air space / 1/8" glass.

Laminated Glass:

Laminated glass is two or more lites (pieces) of glass permanently bonded together with one or more plastic interlayers (PVB) using heat and pressure. The glass and interlayers can be a variety of colors and thicknesses designed to meet building code standards and requirements as necessary. Laminated glass can be broken, but the fragments will tend to adhere to the plastic layer and remain largely intact, reducing the risk of injury.

Laminated glass is considered "safety glass" and meets the requirements of the various code organizations that set standards for safety. Heat-strengthened and tempered glass can be incorporated into laminated glass units to further strengthen the impact resistance. Hurricane resistance, the need for bomb blast protection, sound attenuation and ballistic or forced-entry security concerns are all primary uses for laminated glass. For complete industry-accepted information about laminated glass, please review the Glass Association of North America's Laminated Glazing Reference Manual.

Low-E Coatings:

Relatively neutral in appearance, low-E coatings reduce heat gain or loss by reflecting long-wave infrared energy (heat) and, therefore, decrease the U-value and improve energy efficiency. Current sputter-coated low-E coatings are multilayered, complex designs engineered to provide high visible light transmission, low visible light reflection and reduced heat transfer.

Monolithic Glass:

Glazing construction consisting of one lite of glass.

Pyrolytic Glass:

Glass with low-E coating applied at high temperatures and fired into the glass surface during the float glass manufacturing process.

Sputter Low-E Glass:

Glass with low-E coating applied through an off-line fabrication process. Glass is put into a vacuum chamber, where ionized gas bombards the surface of a metal cathode (silver) with ions. Atoms of the desired metal are vaporized and then deposited in a thin film on the surface of the glass.

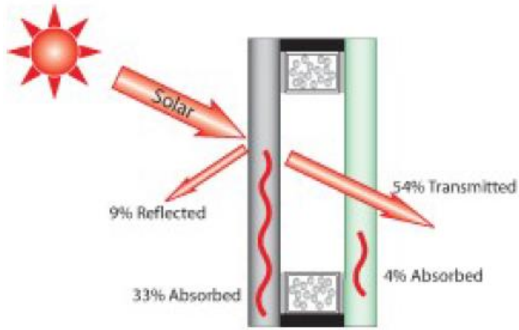
Solar Control Glass:

Tinted and / or coated glass that reduces the amount of solar heat gain transmitted through a glazed product.

Tinted Glass:

A colored glass which reduces both visual and radiant transmittances. Tinted glass may require heat-treatment to reduce potential thermal stress and breakage (when using thicker and very large pieces of glass) and tends to reradiate the absorbed heat.

Solar Heat Coefficient (SHGC)



Tinted Glass (heat-absorbing glass)
3mm gray float glass outboard / 3mm clear inboard
Tvis = 57%   SHGC =0.61

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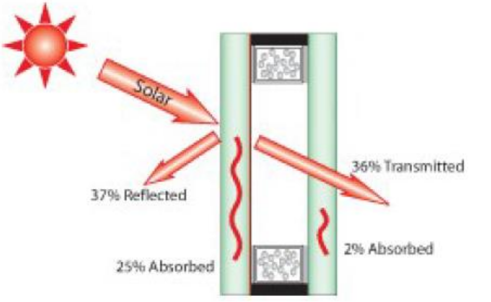
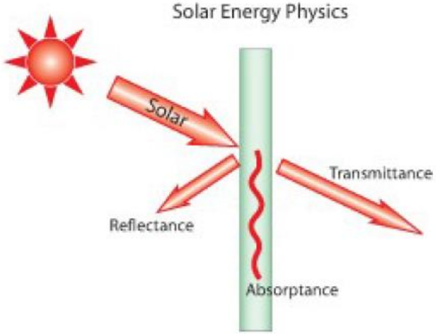


Low-E Glass (heat-reflecting glass)
3mm clear w/ClimaGuard 71/38 outboard / 3mm clear inboard
Tvis = 71% SHGC = 0.38

Solar Energy Physics



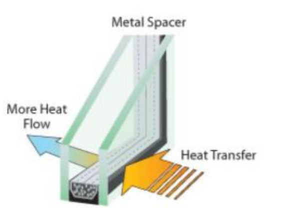
The percent of solar energy incident on the glass that is transferred indoors both directly and indirectly through the glass. The direct gain portion equals the solar energy transmittance, while the indirect is the fraction of solar energy incident on the glass that is absorbed and re-radiated or convected indoors. For example, 1/8" (3.1 mm) uncoated clear glass has an SHGC of approximately 0.86, of which 0.84 is direct gain (solar transmittance) and 0.02 is indirect gain (convection / re-radiation).

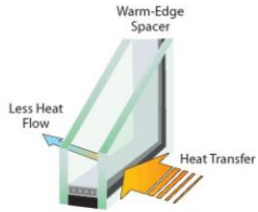
U- Value Factor:

A measure of the heat gain or loss through glass due to the difference between indoor and outdoor air temperatures. It is also referred to as the overall coefficient of heat transfer. A lower U-value indicates better insulating properties. The units are Btu/(hr)(ft2) (°F).

Spacers (for Insulating Units):

The spacer in insulating glass units is at the perimeter and keeps the two lites of glass separated at a specific gap width. The spacer material can be aluminum, stainless steel, silicone foam, etc.





Spectrally Selective Glazing:

High-performance glazing that admits as much daylight as possible, while preventing transmission of as much solar heat as possible. By controlling solar heat gains in summer, preventing loss of interior heat in winter, and allowing occupants to reduce electric lighting use by making maximum use of daylight, spectrally selective glazing significantly reduces building energy consumption. The United States Department of Energy has established a Light-to-Solar Gain Ratio of 1.25 as the minimum measurement to be classified as a "Spectrally Selective Glazing." The calculation of spectrally selective glazing follows the formula described in the "Light-to-Solar Gain" definition.

Warm-Edge Spacer:

This technology is another option for improving thermal properties, reducing condensation and reducing U-values in IG units. There are a number of warm-edge spacer designs available, all of which thermally break the metal-to-glass contact point to some degree, while offering varying levels of structural integrity that may or may not be suitable for commercial applications. Warm-edge spacers can significantly reduce heat conduction when compared to conventional metal spacers.

Tempered Glass

Fully tempered glass is approximately four times stronger than annealed glass of the same thickness and configuration. Residual surface compression must be over 10,000 PSI for 6mm glass, according to ASTM C 1048. When broken, it will break into many relatively small fragments, which are less likely to cause serious injury.

The typical process to produce tempered glass involves heating the glass to over 1,000 degrees F, then rapidly cooling to lock the glass surfaces in a state of compression and the core in a state of tension.

Tempered glass is often referred to as "safety glass," because it meets the requirements of the various code organizations. This type of glass is intended for general glazing, and safety glazing such as sliding doors, storm doors, building entrances, bath and shower enclosures, interior partitions, and other uses requiring superior strength and safety properties. Tempered glass cannot be cut or drilled after tempering, and any alterations, such as edge grinding, sand blasting or acid etching, can cause premature failure.

Fire- Rated Glass:

Specialty glass that defends against the spread of fire and smoke (fire-protective) and blocks the transfer of radiant and conductive heat (fire-resistive). Fire-rated glass has a permanent label that indicates where it should be used, what fire-protection tests it has passed, and its specific performance characteristics in terms of time and temperature resistance

Glass Terms:

Float Glass:

A sheet of glass made by floating molten glass on a bed of molten tin. Float glass is made of common raw materials: sand, soda ash, dolomite, limestone, and salt cake. During the float glass process, other materials may be used to add color, refine, or adjust the properties of the glass.

Annealed Glass:

Float glass that is slowly cooled at a specific rate to strengthen it and make it less brittle. When broken, it fractures into large, jagged pieces.

Security Glazing:

There are three main categories of security glazing products:

- Bullet-resistant laminated glass
- Glass-clad polycarbonate
    - o Glass on the exterior and interior surface o Typically used in the detention market: prisons, psychiatric hospitals, and public works buildings
    - o They offer:
        - Scratch resistance
        - Forced-entry resistance
        - A certain ballistic rating
- Laminated glass polycarbonate
    - o Glass on the exterior surface and polycarbonate on the interior surface.
    - o Ballistic rounds break the glass but are stopped by the polycarbonate and will not allow any fragmentation to enter the occupied space.

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Wall systems terms:

Curtain Wall:

An exterior, non-load bearing wall system that utilizes glass, and vertical and horizontal mullions acting as structural members to transfer wind and gravity forces to the building structure.

The system is anchored to, and supported by, the structural members of the building. There are two types of curtain wall systems: stick and unitized.

Window Wall

Factory-glazed window and door units installed between the floor slabs of multiple-story buildings. When the floor slab edges are covered on the exterior with aluminum slab covers, the resulting appearance is that of a curtain wall.

General Industry terms:

Glazing:

The work of installing glass in a frame.

Fenestration:

The arrangement, proportioning, and design of windows and doors in a building.

Inside-Glazed/Outside Glazed:

Both curtain wall and storefront systems can be interior or exterior glazed. Interior glazed systems allow for glass to be installed from the interior of the building. With exterior glazed systems, the glass must be installed from the building exterior.

Lite:

Another term for a pane or finished piece of glass.

Anodize:

A finish for metals in which the surface is coated with a layer of oxide through an electrolytic process. The coating can be for protective or decorative reasons.

Performance Values:

What performance values are most important for glass?

- U-factor: a measure of heat transfer
- Visible light transmission: the measure of visible light that passes through glazing
- Solar heat gain coefficient: the measure of heat that glazing allows into a building

The importance, or priority, of these three values changes based on the geographic location.

For a project in Seattle, with cooler temperatures and less sunlight, U-factor and VLT are most important, preventing system heat loss and maximizing natural daylight.

For a project in Kansas City, which faces all weather types, the three performance elements are equally critical.

In Miami, SHGC and VLT take top priority, as the intensity of the sun and higher temperatures can create problems with glare and heat gain if the proper glazing isn't specified.

Where can I get information about glass performance values?

Glass fabricators can provide center-of-glass performance values. From a window and wall system perspective, the system manufacturer commonly provides values. Full-system/product values, including all aspects of the framing and edge of glass, can be calculated and modeled using the center of glass and framing values.

Codes and Standards Information:

Codes provide details of where certain products are required.

Standards provide criteria upon which products can qualify.

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