



II.

ALL ABOUT GLASS

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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

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

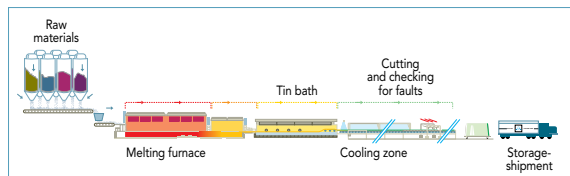
Maximum dimensions are 130" by 204".

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

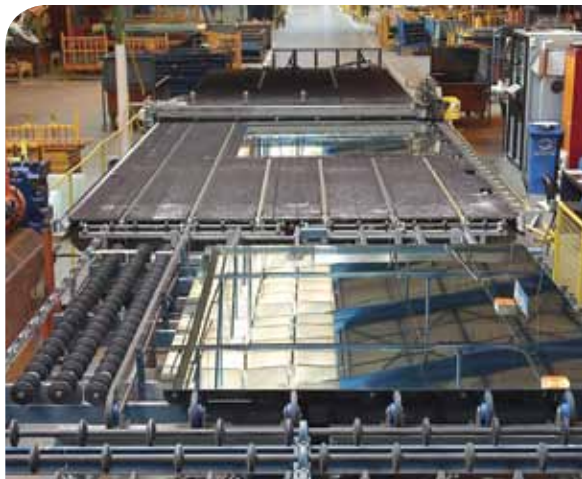
1.3.3. PROCESSED PRODUCTS

▼ 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

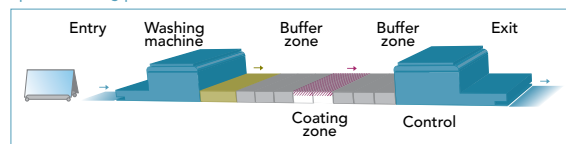
Sputter or “soft” glass coatings are applied through the bombardment of metal atoms onto cooled float glass. This process, which takes place in a low-pressure chamber, is known as magnetic sputter vapor deposition (MSVD). Because it takes place after float manufacturing is complete, sputter coating is 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 enamelled to meet specialized applications
- > There is no need for edge deletion when incorporating pyrolytic 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.

▼ 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 sandblasting treatment—i.e., abrasive etching at high pressures. This process can be used to obtain uniform or multi-relief motifs.

> 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.

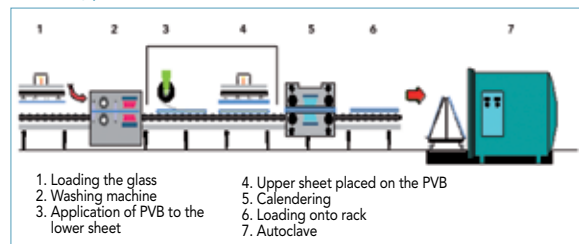
The high performance level of laminated products may provide one or more of these functions:

- > 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.

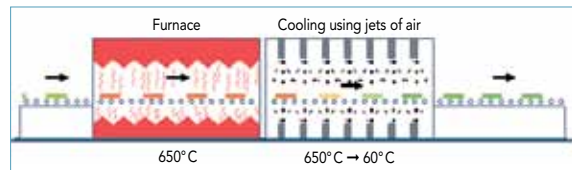
Specific properties provided by laminated products include enhanced UV protection, as well as protection from unwanted noise. In fact, the use of laminated glass can significantly improve the sound transmission class (STC) rating for windows in noisy areas. Compared to traditional single- and double-glazed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

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

▼ 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.

▼ 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.

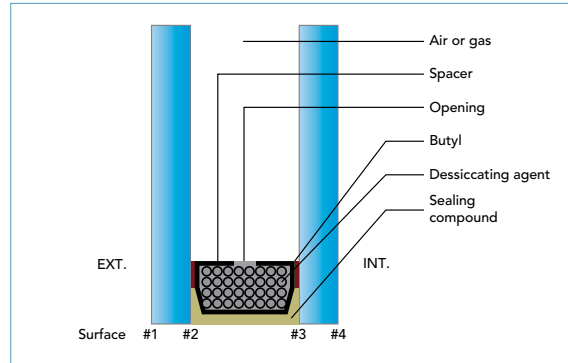
The main purpose of double glazing or triple glazing is to provide a higher level of thermal insulation than single glazing.

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

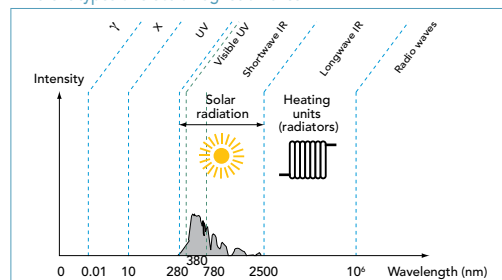
Every day we are subjected to different types of radiation, including radiation from the sun. The table and figure below show how these different types of radiation are classified according to their wavelengths.

Classification of electromagnetic radiation by wavelength

Type of radiation	Wavelengths (nm)*
Gamma rays	0 to 0.01
X-rays	0.01 to 10
Ultraviolet (UV) rays	10 to 380
UV C	10 to 280
UV B	280 to 315
UV A	315 to 380
Visible rays	380 to 780
Infrared (IR) rays	780 to 10 ⁶
Shortwave IR A	780 to 1,400
Shortwave IR B	1,400 to 2,500
Longwave IR C	2,500 to 10 ⁶
Radio waves	10 ⁶ to several km

* 1nm = 1 nanometer = 10⁻⁹m.

Different types of electromagnetic waves



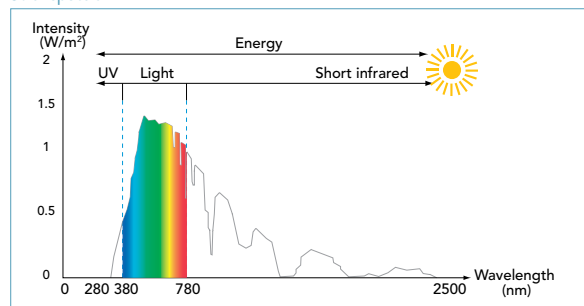
2.2.2 THE SOLAR SPECTRUM

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

Type of radiation	Wavelength (nm)	Percentage of total solar energy
UV	280 to 380	Approx. 5 %
Visible	380 to 780	Approx. 50 %
IR	780 to 2,500	Approx. 45 %

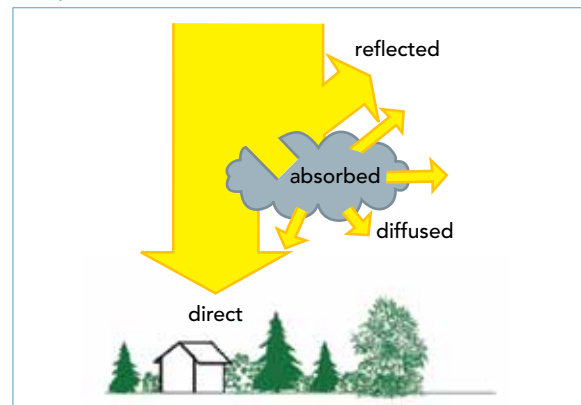
Solar spectrum



The sun is the basis for the solar spectrum. It gives off 66 million W/m² of energy produced by nuclear chain reactions. Only a fraction of this energy ends up anywhere near our atmosphere. This fraction—1,353 W/m²—is called the solar constant.

The energy we receive from the sun is less than the solar constant, since our atmosphere absorbs approximately 15% of solar radiation and reflects another 6% back into space. Total solar radiation is therefore defined as the sum of direct and diffused radiation.

Atmospheric influence on solar radiation



The energy we receive also depends on the season, which changes the angle of incidence of the sun in relation to the earth, as well as latitude, weather conditions (cloud coverage), geographic contours, pollution, the direction our buildings are facing, and other factors.

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.

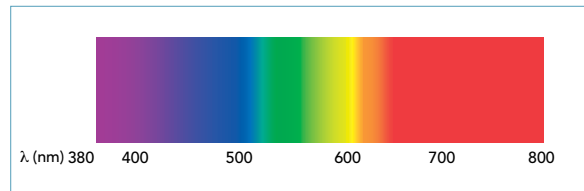
The table and figure below show the composition of light.

Composition of light

Color	Wavelengths (nm*)
Violet	380 to 462
Blue	462 to 500
Green	500 to 577
Yellow	577 to 600
Orange	600 to 625
Red	625 to 780

* 1nm = 1 nanometer = 10^{-9} m

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.

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

▼ 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 thickness. Bronze, grey, blue, and green float glasses reduce the amount of solar energy and therefore the level of light transmission.

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

2.3 THERMAL INSULATION

2.3.1 TRANSMISSION OF HEAT THROUGH A GLAZING

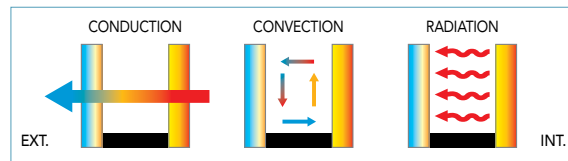
A difference in temperature between two points within any material will result in heat being transferred from the hot point to the cold point.

Heat may be transferred in various ways:

- > By conduction within the material itself: the heat is transferred from one molecule to the next when heated. For example, a metal rod with one end heated up will transfer this heat throughout the rod.
- > By convection in liquids and gases: temperature variations within a liquid prompt differences in density, which cause the molecules to move around. This occurs because the hot parts have a smaller mass and rise, while the opposite is true for the cold parts. These movements balance out temperatures—for example, when heating a saucepan of water, the temperature eventually becomes constant.
- > By radiation: any heated body gives off energy in the form of electromagnetic radiation. This radiation crosses physical spaces more easily and effectively than light waves. By contrast, when light waves meet an obstacle, they release part of their energy to the obstacle—which, in turn, emits heat. This method of heat transmission requires no area and can also take place in a vacuum—for example, in the case of solar radiation or an electric light bulb.

Double glazing is designed to limit heat lost through conduction within the glass by inserting an insulating space of air or gas between the two sheets of glass.

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



2.3.2 THERMAL CONDUCTIVITY AND THERMAL TRANSMITTANCE

▼ Introduction

The heat flow density q (W/m^2) per second passing through the glazing from the warm atmosphere to the cold atmosphere can be expressed by the equation:

$$q = \frac{(\theta_i - \theta_e)}{R} = U (\theta_i - \theta_e)$$

where

θ_i and θ_e are the temperatures of the internal and external atmospheres

R is the thermal resistance of the glazing ($\text{m}^2 \cdot \text{K}/\text{W}$)

$U = 1/R$ is the thermal transmittance of the glazing ($\text{W}/(\text{m}^2 \cdot \text{K})$)

▼ Thermal Transmittance U (Formerly k)

Thermal transmittance is defined as the amount of heat passing through the glazing, in a steady state, per unit of surface area, for a difference in temperature of 1.8°F (1°C) on each side of the glass between the atmospheres.

The amount of heat per second Q (W) passing through a glazing with surface area S (m^2) from the hot atmosphere to the cold atmosphere is therefore:

$$Q = S U (\theta_i - \theta_e)$$

For a solid isotropic material, thermal resistance R is defined as the relationship between its thickness e (m) and its thermal conductivity λ ($\text{W}/(\text{m} \cdot \text{K})$):

$$R = \frac{e}{\lambda}$$

▼ 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 insulating 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 ($\epsilon = 0.04$) (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).

2.3.3 DIFFERENT TYPES OF INSULATING GLAZING

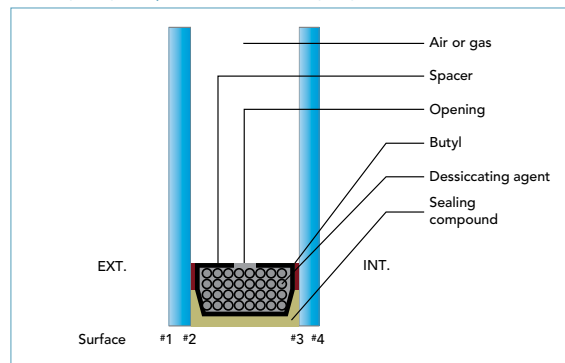
▼ Introduction

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

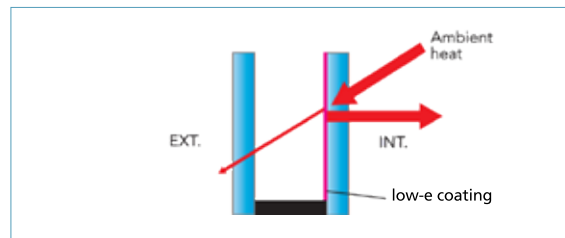
The development of techniques for applying metallic coatings to glass has been a decisive step forward in improving the thermal insulation of glazings. Applying a metallic coating to a glass makes it “high-performance” (also called “low-emissivity” or “low-e”).

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

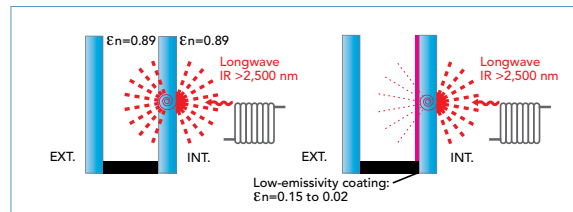
Objects located inside buildings radiate heat in the form of longwave infrared radiation (over 2,500 nm). Since glass transmits virtually none of this type of radiation, it will absorb longwave infrared radiation, heat up, and then emit this heat back.

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.

The mathematical formula is:

$$\epsilon = AE = 1 - TR - RE = 1 - RE \text{ (because } TR = 0\text{)}$$

In scientific terms, emissivity is defined as the relationship between the energy emitted by a given surface at a given temperature and that of a perfect emitter (i.e., a black body which has an emissivity of 1, at the same temperature).

Standard NFRC 300 describes the method used to measure normal emissivity ϵ_n ; in practice, the corrected emissivity value ϵ is used in heat transfer calculations. This corrected value is achieved by multiplying normal emissivity by a numerical factor that considers the angular distribution of the emissivity.

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.

2.3.4 AGC FLAT GLASS NORTH AMERICA BRANDS: BASE GLASSES

AGC Flat Glass North America offers a complete range of Low-Emissivity coated glass—both hard-coat pyrolytic and soft-coat sputter solutions—to provide excellent thermal insulation.

Some of these coatings are used solely for thermal insulation and are ideal for passive solar applications where it is important to capture the “free” energy of the sun to reduce annual heating costs. Comfort E-PS™ and Comfort Ti-PS™ are two types of AGC coated products that deliver these thermal benefits.

Other Low-Emissivity solar control solutions are engineered to combine high levels of solar control with outstanding thermal insulation. AGC's Comfort Ti™ family of soft-coat glasses is perfect for applications where a high level of solar-blocking performance is required—but thermal insulation is also important.

The table on page 46 summarizes the different coatings available from AGC Flat Glass North America.

AGC brands of high-performance glass

	"Soft" or sputter coatings	"Hard" or pyrolytic coatings
Passive solar low-e glass	Comfort Ti-PS™	Comfort E-PS™
Solar control low-e glass	Comfort Ti-AC™ Comfort Ti-AC 23™ Comfort Ti-AC 28™ Comfort Ti-AC 36™ Comfort Ti-AC 40™	Sunergy®
Solar control glass		Stopsol® (used in combination with a low-e coated glass)

Note: Sputter or "soft" glass coatings must always be positioned inside a double glazing unit on surface #2 or #3.

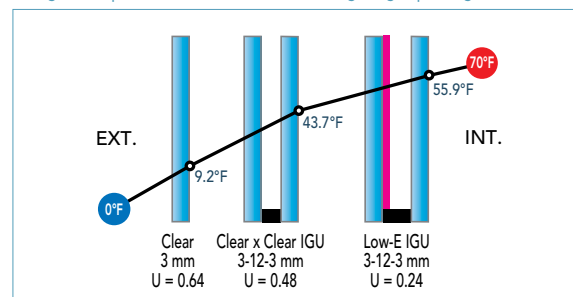
2.3.5 TEMPERATURE OF GLAZINGS AND COMFORT

Feeling comfortable in any given location depends not only on the ambient air temperature, but also on the proximity of cold surfaces. The human body—with a skin temperature of approximately 82.4°F (28°C)—acts as a "radiator" when, for example, it is placed near a window which provides little thermal insulation from low outdoor temperatures. The heat energy dissipated from the skin results in an uncomfortable feeling of coldness.

The figure on page 47 shows the temperature of the internal side of a single glazed unit, as well as various other insulating glazings, under internal and external temperature conditions ranging from 20°F to 68°F (0°C to 32°C) in a steady state.

This demonstrates that using high-performance glazings can help limit energy loss, lower U-factor, and reduce overall cost associated with heating.

Change in temperature of the internal side of the glazing depending on the U Factor



2.3.6 CONDENSATION

Condensation is the process by which atmospheric water vapor liquefies to form fog, clouds, or water droplets on objects. Three types of condensation are likely to occur on glazings (all surface positions are for a dual-glazed, non-laminated unit):

- > Surface condensation on the internal side (position 4): this occurs if internal relative humidity is high and/or the temperature of the internal side of the glazing is low. Under normal internal conditions (e.g., heated buildings with no specific source of humidity), this type of condensation very rarely occurs with high-performance double glazings.
- > Surface condensation on the external side (position 1): this can sometimes occur at dawn on high-performance double glazings, but only following clear, still nights. Under these conditions, given the high-performance thermal insulation of double glazing, the external pane cools to the point that condensation forms on the outside. This is temporary and only proves the insulating efficiency of the glazing.
- > Condensation inside the double glazing unit (position 2 or 3): this can be caused by a failed window seal. How effectively the desiccant and the waterproof barriers work determines the lifespan of the glazing. If the desiccant becomes ineffective or if the seal is no longer hermetic, condensation will form inside the glazing unit and it will need to be replaced.

2.4 SOLAR CONTROL

2.4.1 ENERGY AND LIGHT FACTORS

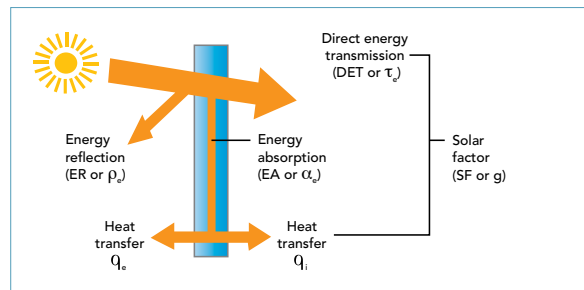
Energy and light factors (or spectrophotometric factors) determine the transmission, absorption, and light and energy reflection properties of glazings.

▼ Energy factors

When the sun's rays hit a glazing, the total incident solar radiation (between 300 nm and 2,500 nm) ϕ_e is split up into:

- > A fraction $\rho_e \phi_e$ reflected outward, where ρ_e (or ER) is the direct energy reflection of the glazing
- > A fraction $\tau_e \phi_e$ transmitted through the glazing, where τ_e (or DET) is the direct energy transmission of the glazing
- > A fraction $\alpha_e \phi_e$ absorbed by the glazing, where α_e (or EA) is the direct energy absorption of the glazing; the energy absorbed by the glazing is then divided up into:
 - A fraction $q_i \phi_e$ emitted back to the inside, where q_i is the secondary internal heat transfer factor
 - A fraction $q_e \phi_e$ emitted back to the outside, where q_e is the secondary external heat transfer factor

Energy factors



These different factors are linked by the formulae:

$$\rho_e + \tau_e + \alpha_e = 1 \quad \text{or} \quad ER + DET + EA = 100$$

and

$$\alpha_e = q_i + q_e$$

The SHGC represents the total energy transmitted through the glazing; it is therefore the sum of the radiation transmitted directly and that which is absorbed and emitted back to the inside:

$$SHGC = \tau_e + q_i$$

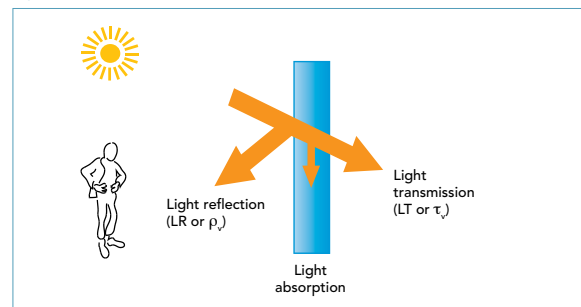
▼ Light Factors

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

The National Fenestration Rating Council (NFRC) has developed a uniform national rating system for the energy performance characteristics of fenestration products. NFRC 100, NFRC 200, NFRC 303, NFRC 304, and NFRC 500 are guidelines developed by the NFRC to meet the need for a uniform and accurate means of rating the thermal and related performance of fenestration systems.

▼ 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.

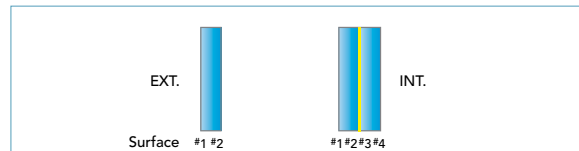
In the United States, the Department of Energy defines a spectrally selective glazing as a glazing with a Light to Solar Heat Gain Ratio (LSG) of 1.25 or greater.

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

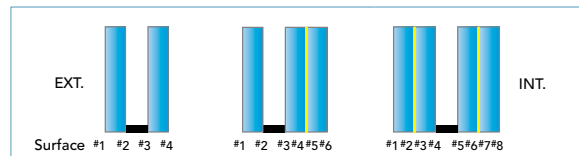
▼ Conventions in Coating Positions

The North American conventions are shown below.

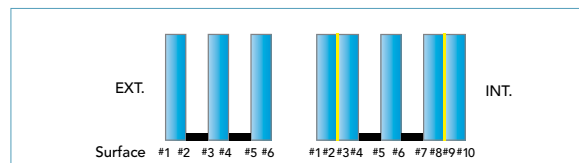
- > Monolithic glass (numbered 1 and 2 for non-laminated glass, numbered 1 through 4 for laminated)



- > 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)



2.4.2 SOLAR CONTROL

▼ Introduction

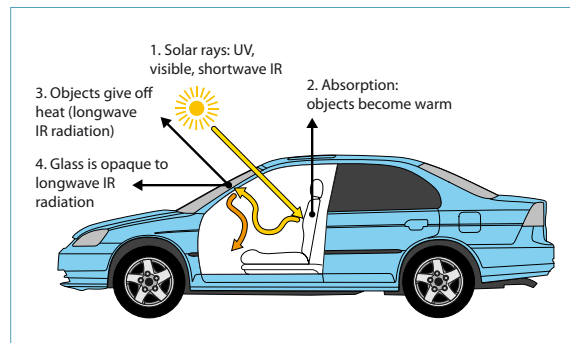
> Heating rooms: the greenhouse effect

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.

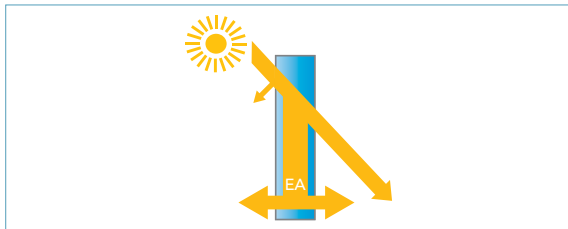
> Absorbent (tinted) glass

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



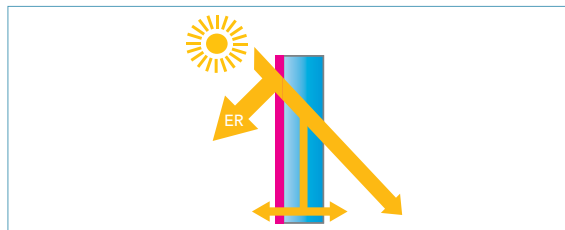
The amount of energy emitted to the outside and the inside depends on the wind speed, as well as external and internal air temperatures. To dispatch the heat radiated to the outside as efficiently as possible, the absorbent tinted glass must be installed as close to the front of the facade as possible. 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®).

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.

▼ Risk of Breakage Due to Thermal Stresses

Breakage caused by thermal stresses occurs if the temperature difference between two areas of annealed glass is too great. If the temperature of the glass rises, the glass expands—which causes no problems if the temperature remains uniform throughout the glazing. However, if part of the glazing remains cool, it will prevent the warm section from expanding freely. This creates tensile stress, which can exceed the permitted level of stress in the glass. If there is any risk of this happening, the glass must be tempered or heat strengthened.

Except where a preliminary study is carried out, spandrels must be tempered or heat strengthened.

2.4.3. AGC BRANDS

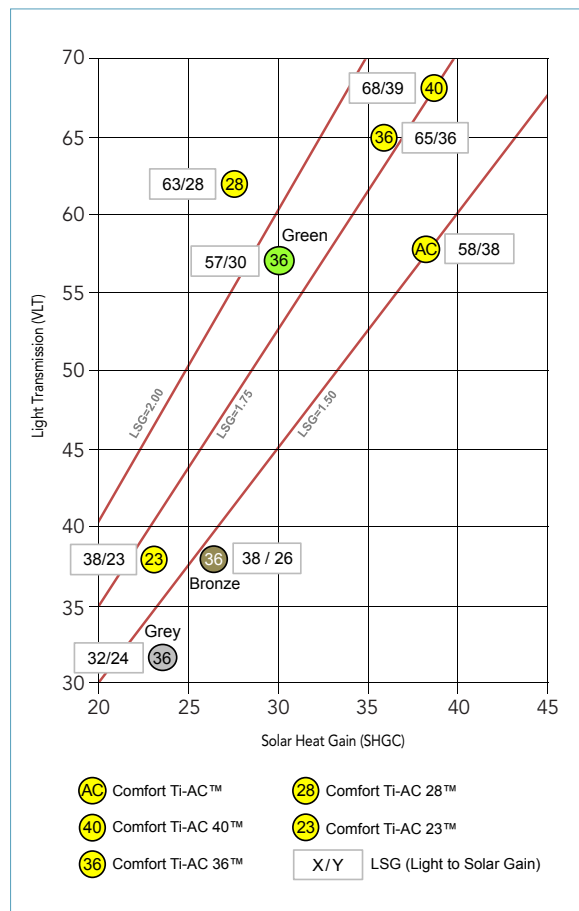
AGC offers a full range of solar control glass: colored glass, glass with pyrolytic (hard) coatings, and glass with sputter (soft) coatings. The table below sums up the range.

AGC solar control glass brands

Type	Pyrolytic coatings	Sputter coatings	Uncoated
Reflective	Stopsol®	Comfort Ti-AC™	—
Solar Control	Sunergy®	Comfort Ti-AC 23™ Comfort Ti-AC 28™ Comfort Ti-AC 36™ Comfort Ti-AC 40™	Solarshield™ Tinted Glass
Passive Solar	Comfort E-PS™	Comfort Ti-PS™	Clear Float

The graph on page 59 gives an overview of the position of the different families of AGC solar control glass in double glazings (6-12-6 configuration). Passive solar products can be combined with reflective or tinted glass to achieve solar control properties.

Performance ranges of AGC solar control glazings in double-glazed units



The table below and on page 59 show the various processing options and the properties of AGC's solar-control coated glasses.

Use and processing of solar control glass

Options	Pyrolytic		Sputter
	Stopsol®	Comfort E-PS™/Sunergy®	Comfort Ti™
Single Glazing	#1 or #2	—	—
Double Glazing	#1 or #2	#2 or #3	#2 or #3**
Edge Deletion Required	No	No	Yes
Processing Options	Laminating	Laminating	Laminating*
	Tempering	Tempering	Tempering
	Spandrel	Spandrel	
	Bending	Bending	

* Under certain conditions, AGC's Comfort Ti products can be fabricated into a laminated solution when solar control is required in a laminated product. Please consult AGC Technical Services for more information.

** Only certain AGC Sputter coated products can be used in surface #3 applications. Please consult AGC Technical Services for more information.

AGC Glass by usage

Usage		Pyrolytic coatings	Sputter coatings	Uncoated
Passive Solar		Comfort E-PS™	Comfort Ti-PS™	—
Solar Control	Low-E	Sunergy®	Comfort Ti-AC 23™ Comfort Ti-AC 28™ Comfort Ti-AC 36™ Comfort Ti-AC 40™	
	Reflective	Stopsol®	Ti-AC™	
	Absorbing			Tints

Coating	Reflective	Pyrolytic	Sputter
Product	Stopsol	Comfort E-PS/ Sunergy	Comfort Ti-AC, Comfort Ti-AC 23, Comfort Ti-AC 36 and Comfort Ti-AC 40*
Light reflection	High (#1) Medium (#2)	Low	Low to high
Thermal insulation	Low	Medium	High
Light to Solar Gain	Low	Medium	High
Neutrality	Low	Medium	High

* The Comfort Ti product family also includes Comfort Ti-PS, a sputter-coated product with higher passive solar gains, for applications where a soft-coat passive solar product is desirable.

2.5 LIGHT CONTROL

2.5.1 LIGHT CONTROL

The location of a building has a substantial impact on its requirements in terms of light control. In very sunny regions, the general aim is to limit light transmission (and solar heat gain). By contrast, in regions with less sunshine, it is important to make the most of the natural light available.

Modern glazings are designed to meet all these requirements, since light transmission levels ranging between a very low percentage (for applications designed to reduce glare) and 90% (for extra clear glass) can be achieved.

Moreover, depending on the type of coating or glass used, these levels of light transmission can be combined with more or less equivalent (low selectivity) or more high-performance (high selectivity) SHGC ratings.

While light transmission is an important consideration, in specifying a glazing—determined through SHGC levels, which impact a building's HVAC requirement—is typically the decisive factor.

2.5.2 LIGHTING ROOMS

▼ Introduction

When designing a building, the surface of glazings and their level of light transmission have a direct impact on the level of artificial lighting required.

Natural lighting of rooms is a complex process. In *Your Glass Pocket*, AGC Flat Glass North America discusses only a few general rules in relation to private homes rather than office buildings—where artificial lighting is always present.

For each project, the architect must adapt the position and the size of the openings to the direction the building faces, as well as its location—and must choose the appropriate glazing based on these considerations.

To learn more about how specific glazing choices can impact natural lighting levels, please consult AGC Technical Services.

▼ Natural Lighting

The amount of natural light available depends on weather conditions, the season, the time of day, and any physical obstacles close to the building's openings (e.g., trees).

As with energy transmission, light transmission depends on the direction each window is facing. In the northern hemisphere, north-facing windows receive virtually no sun, and most of the light available there is natural light. By contrast, east- and west-facing windows receive direct transmission of light; this is also true of south-facing windows during winter months.

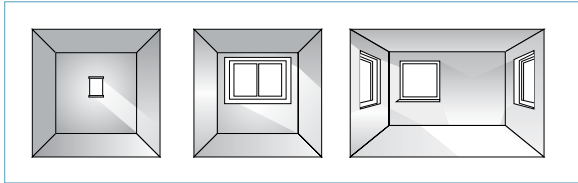
▼ Position of Openings

Since light travels in a straight line, the upper parts of openings are a room's main light source. It is advisable to position glazings so that their upper edge is at least halfway up the wall. Roof openings are also a good idea.

Even distribution of light is also the key to high-quality lighting. It is not enough to allow light into interior spaces; it also has to be distributed harmoniously. Since light is reflected by ceilings, floors, and walls, care should be taken to avoid dark colors which absorb light and cause "dark corners."

Where this is not possible, reflective surfaces should be used inside rooms, which act as secondary light sources. An imbalance between the intensity of several light sources can also be offset by an appropriate choice of light transmission levels.

Distribution of light depending on the size and position of windows



Finally, although it is nice to have plenty of light, care should be taken to ensure that the intensity is not so great that it causes glare. Glare is caused by the presence of overly intense light sources in the field of vision. Reducing the surface area of openings is not a viable solution since this accentuates the contrast between the window and the wall in which it is set, thereby further increasing discomfort. On the other hand, glare can be lessened by using coated glass with reduced levels of light transmission.

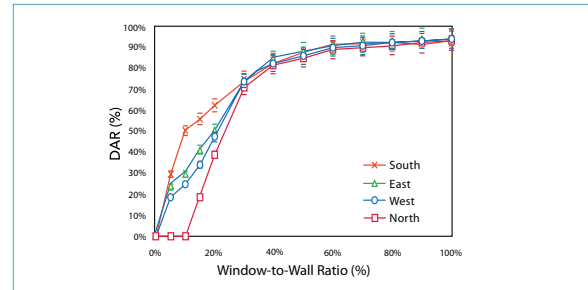
▼ Surface Area of Glazings

To provide good natural lighting in rooms, the surface area of the openings must be large enough and the proportion of non-transparent elements (for example, frame subdivisions) must be limited. In fact, the glazed surface area is always smaller than the surface area of the opening.

2.5.3 DAYLIGHTING AND VISIBLE TRANSMITTANCE

The emphasis on daylighting (the practice of designing structures to maximize the use of natural light) continues to increase in step with the movement toward greater sustainability. The benefits of daylighting include reduced energy consumption and increased indoor environmental quality. As such, the merits of daylighting are recognized by the USGBC and its LEED® certification program. Studies have shown that daylighting can also increase the productivity of building occupants and improve the test scores of students.

Daylighting Availability Ratio vs. Window to Wall Ratio



It's natural to assume that the more sunlight, the better. But this isn't entirely true. Research by A. Tzempelikos indicates that window to wall ratios in excess of 60% provide very little additional daylighting benefits. The ideal upper limit ratio is in the 40%–50% range.

The reason for the diminishing benefits of daylight is the issue of sunlight glare. The fact is, poor glare control can completely defeat the intended purpose of daylighting. As a result, it is critical to account for proper glare control when designing structures with daylighting in mind.

For more information on how to maximize the benefits of daylighting in your design, contact the AGC Technical Services department at 1-800-251-0441.

2.5.4 VISION PROTECTION

In some specific instances, it is important to maintain privacy by preventing people from looking into a room. Several types of glass products offer solutions to this:

- > Coated glass: this partially obscures a room from prying eyes, provided that the room in question has a lower light level than the environment outside
- > Translucent and/or colored glass: patterned glass, laminated glass with translucent or colored PVB, acid-etched or sand-blasted glass, or glass blocks can provide privacy and obscurity
- > Silk-screen printed or enameled glass also offers vision protection
- > Two-way mirrors: these are glazings which allow vision in one direction only, to enable those inside to see out while preventing those outside from seeing in (appropriate in airports, large retail stores, etc.). Two conditions are required for high-quality two-way mirrors:
 - A coated glass must be used, which has a low level of light transmission
 - The glass used must have a much lower level of luminosity on the viewing side than on the viewed side.

Please see the “Brands and Products” section of *Your Glass Pocket* for many AGC products which can provide visual protection and privacy—including Krystal Patterns™ glasses, Matelux® acid-etched glasses, and Krystal Kolours™ premium painted glass.

2.6 SOUND INSULATION

2.6.1 SOUND CONCEPTS

▼ Sound, Pressure, and Frequency

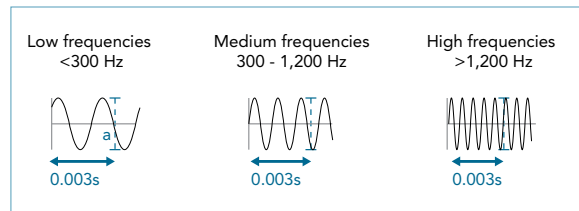
The movements of a vibrating body disturb the environment around it. These disturbances gradually spread in all directions from the source to the reception body—for example, the ear. The speed at which they move depends on the physical properties of the environment. In air at a temperature of 68°F (20°C), this speed is 1,115 feet/second (340 m/s). They do not spread in a vacuum.

Under certain conditions, these disturbances can be perceived by the ear causing what we call “sound.” The sound heard by the ear is a variation in pressure on the eardrum transmitted by movement in an environment, generally the air. The eardrum harnesses this change in pressure, and the ear’s neuro-acoustic system transforms it into a sound sensation.

Two values are required to measure a sound:

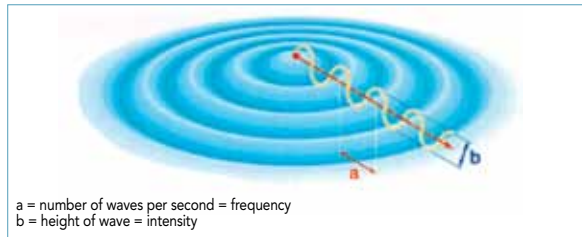
- > Its level of pressure, expressed in Pascal—or, more generally, the level of sound pressure, expressed in decibels
- > Its frequency, which depends on the duration of a complete vibration, measured by taking the number of vibrations per second expressed in Hertz (Hz). The higher the frequency, the more high-pitched the sound.

Frequency ranges



The movement of sound through the air can be likened to waves on the surface of water.

Frequency and intensity



The hearing threshold for the human ear is a pressure of 2.10^{-5} Pa; it can withstand pressures of up to 20 Pa undamaged, while the pain threshold is approximately 200 Pa. The human ear is therefore so sensitive that the minimum audible change in pressure is over 10 million times less than that of its pain threshold.

In terms of frequencies, the ear can, on average, hear sounds ranging from approximately 20 Hz up to 16,000–20,000 Hz.

▼ Acoustic Pressure

In practice, acoustic pressure is not used to measure the intensity of a sound because:

- > The pressure range is too great: from 2.10^{-5} to 20, or even 100 Pa
- > The relationship between the human ear and acoustic pressure is not linear, but logarithmic. The level of acoustic pressure L_p of a sound is therefore calculated using the formula:

$$L_p = 10 \log \frac{p^2}{p_0^2} = 20 \log \frac{p}{p_0} \text{ (dB)}$$

where: p is the sound pressure (Pa) of the sound wave in question, and

p_0 is the reference pressure equivalent to the hearing threshold of 2.10^{-5} Pa

This value is expressed in decibels (dB).

Example: if a sound has a sound pressure of 10 Pa, its acoustic pressure will be:

$$L_p = 10 \log \frac{10^2}{(2.10^{-5})^2} = 114 \text{ dB}$$

The table below shows the correlation between acoustic pressure (Pa), levels of acoustic pressure (dB), and details of physiological effects and examples of corresponding sounds.

Sound pressure and level of acoustic pressure

Effect	Example	Sound pressure p (Pa)	Acoustic pressure L_p (dB)
Blackout		200,000	200
		20,000	180
		2,000	160
Pain threshold		200	140
	Aircraft engine		130
Danger	Klaxon horn	20	120
	Lawn mower		110
	Metro train arriving	2	100
	Heavy traffic	0.2	80
	Loud voices	0.02	60
	Normal voices	0.002	40
	Whispers	0.0002	20
Hearing threshold	Total silence	0.00002	0

▼ Decibels in Practice

When several independent sources produce sound pressures p_1 , p_2 , p_3 , ..., at the same time, the resulting pressure p is calculated using the formula $p^2 = p_1^2 + p_2^2 + p_3^2 + \dots$, and the resulting acoustic pressure using the formula:

$$L_p = 10 \log \frac{p_1^2 + p_2^2 + p_3^2 + \dots}{p_0^2}$$

This means that it is incorrect to add together all acoustic pressure values expressed in dB.

Two sounds with the same acoustic pressure combine to produce a noise measuring 3 dB higher than that of each constituent part.

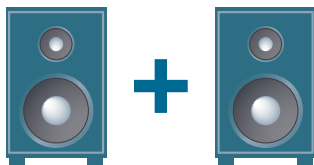
For example, if a noise has a sound pressure of 0.2 Pa, its acoustic pressure is calculated using the formula:

$$L_p = 10 \log \frac{0.2^2}{(2 \cdot 10^{-5})^2} = 60 \text{ dB}$$

If two sounds measuring 60 Pa are combined, the acoustic pressure is calculated using the formula:

$$L_p = 10 \log \frac{0.2^2 + 0.2^2}{(2 \cdot 10^{-5})^2} = 63 \text{ dB}$$

Example of combining acoustic pressure



$$60 \text{ dB} + 60 \text{ dB} \\ = 63 \text{ dB}$$

An important note: even if a difference of 3 dB in the insulation between two products is equivalent to a 50% reduction in sound intensity, the same does not apply to the sound heard by the ear. In this way, to the ear, a difference of:

- > 1 dB is virtually inaudible
- > 3 dB is barely audible
- > 5 dB is clearly audible
- > 10 dB is equivalent to a 50% reduction in the perception the sound intensity
- > 20 dB is equivalent to a 75% reduction in the perception of sound intensity

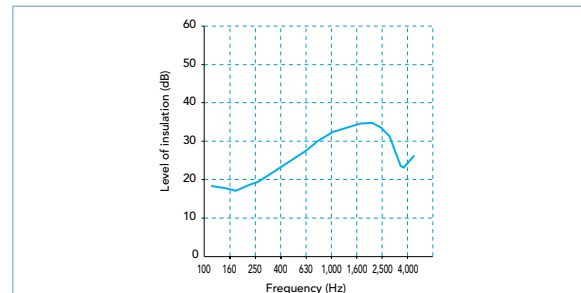
▼ Sound Spectrum

In reality, the sounds we hear are not made up of repeated

frequency cycles and identical pressure levels, but of different frequencies and sound pressures superimposed on each other, which create a continuous spectrum containing all the frequencies.

To represent a sound comprehensively, it is therefore necessary to show it in a diagram called a sound spectrum, which expresses the level of pressure (or sound insulation) depending on the frequency. The table below gives an example of a sound spectrum.

Example of a sound spectrum



▼ Sound Reduction Index

> Sound Transmission Loss (TL) and Sound Transmission Class (STC)

In North America, the sound resistance of a building material is referred to as Sound Transmission Loss (TL). The Sound Transmission Class (STC) performance of materials is a single number which rates the materials' airborne sound transmission loss across 16 one-third octave bands between 125 Hz and 4,000 Hz, as measured in an acoustical laboratory under carefully controlled conditions.

TL measures the ability of a building material to resist the transmission of sounds at different frequencies (Hz). While TL is a measured value, the STC is a single number rating a given material's calculated value. Both these parameters are determined in accordance to ASTM E90 "Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements."

TL and STC performance data for many glazing configurations is available to architects and designers, to help them in selecting the

best sound reduction glazing for a given application. While STC is a good parameter to use in selecting a glazing, the designer must also examine the TL performance of the glazing at the frequency of the noise that needs to be isolated.

2.6.2 SOUND INSULATION OF GLAZINGS

▼ Single-Pane (Float) Glass

In terms of sound insulation, single-pane glass acts as a simple partition and, as such, it respects two acoustical laws that apply to all single-pane partitions, regardless of the material they are made out of:

- > The law of frequencies
- > The law of masses

The law of frequencies states that, in theory, for thin partitions of any size, sound insulation increases by 6 dB by doubling the average frequency.

In practice, this law is not always respected, and there are three frequency zones within a sound spectrum:

- > In the first zone, the law of frequencies is respected in most cases, and insulation increases with frequency. However, partitions are of a specific size and have a muffling effect, which means that the insulation gains achieved are only as much as 4 or 5 dB at most when the average frequency is doubled—i.e., up to approximately 800 Hz.
- > In the second zone, the level of sound insulation drops due to the critical frequency of the pane of glass. The critical frequency f_{cr} of a thin pane of glass is the frequency at which the free-bend speed on the partition and the air speed are equal—i.e., the frequency at which a pane of glass spontaneously vibrates following a wave.

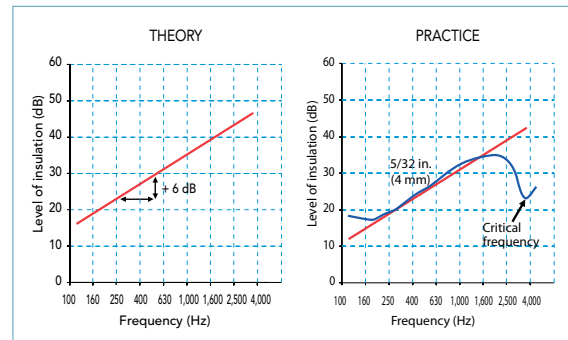
At ambient temperature, critical frequency is equivalent to approximately

$$f_{cr} = \frac{12,800}{e}$$

where e is the thickness of the pane of glass expressed in mm. The site of this zone depends on the elasticity of the material; the more rigid it is, the closer the coincidence zone is to the low frequencies.

- > In the third zone, following coincidence, insulation increases rapidly by doubling the frequency—in theory, by 9 dB, but in practice the increase is less.

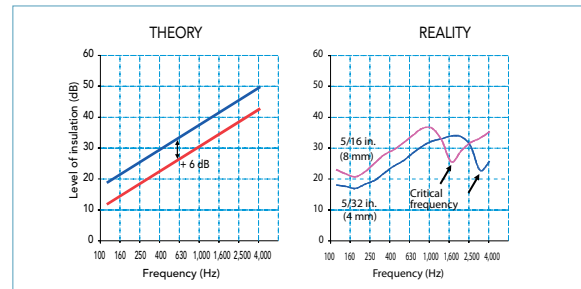
The law of frequencies: in theory and in practice



The law of masses states that, in theory, if the mass of a partition is doubled, then the sound insulation it provides increases by 6 dB at a constant frequency.

In practice, this law is respected in most cases, except in the coincidence zone. However, increasing the thickness of a single-pane glazing also pushes the critical frequency into a lower frequency area (per the law of frequencies).

The law of masses: in theory and practice



The table below shows the critical frequency of single-pane glazings according to their thickness.

Critical frequency (coincidence) of single-pane glazings

Thickness in. (mm)	Critical frequency (Hz)
5/32 in. (4)	3,200
3/16 in. (5)	2,560
1/4 in. (6)	2,133
5/16 in. (8)	1,600
5/8 in. (10)	1,280
1/2 in. (12)	1,067

Conclusions:

- > In light of the law of frequencies, all materials naturally provide better sound insulation against high frequencies than against low ones. However, the noise against which buildings require sound insulation often contains low frequencies.
- > Increasing the thickness of a single-pane glass—which, in theory, enhances the glass's sound insulation—has the disadvantage of shifting the critical-frequency trough toward lower frequencies, thereby weakening the insulation provided against low-pitched sounds. However, for low frequencies, increasing the thickness of the glass can improve performance to some extent.

▼ Laminated Glass

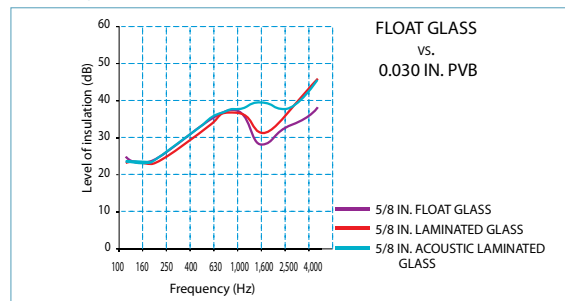
In terms of sound insulation, there are two types of laminated glass:

- > Glazings with a PVB (polyvinyl butyral) interlayer: the main function of this type of glazing is to protect against burglary and to ensure safety; however, such glazings also offer enhanced sound insulation.
- > Glazings with acoustic PVB: this type of PVB interlayer is more supple than the "safety" PVB described above. It was developed to provide better sound insulation—while providing the same level in terms of safety and burglary-resistance properties.

Given their elasticity, acoustic PVBs can separate the two glasses making up the laminated glass and prevent it from acting as a monolithic glass. The critical-frequency trough is less and is shifted toward the high frequencies.

The table below shows the spectra for float glass, as well as these two types of laminated glass, with the same total thickness.

Spectra of sound insulation for a single-pane glass and laminated glass of the same thickness



Conclusions:

- > For a laminated glass of equal mass, sound insulation generally increases in the zone in which it coincides with the critical frequency. The sound-insulation trough is restricted by the muffling of the vibrations by the interlayer. This effect is more marked for acoustic PVB. In addition, in some cases the resonance trough is shifted toward the high frequencies.
- > Laminated glasses have STC performance levels of approximately 34 dB for 1/4" up to 39 dB for 1/2"
- > Laminated glass with acoustic PVB typically improve STC performance by 1 dB regardless of glass thickness

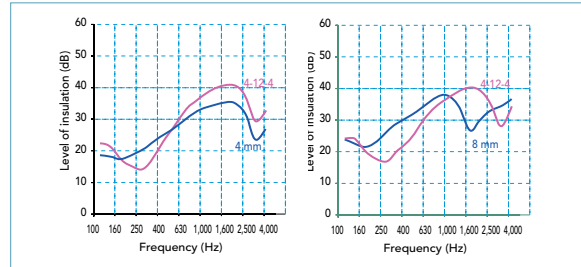
Note: Dissymmetrical laminated glass does not improve the sound insulation.

▼ Double glazing

The performance levels of symmetrical double glazings are often lower than those of a single-pane glazing with the same total glass thickness.

The table below shows the sound insulation spectra of a 4 mm/12 mm/4 mm (5/32"/1/2"/5/32") double glazing as compared with that of single-pane glazings with a thickness of 4 mm (5/32") and 8 mm (5/16").

Spectra of sound insulation for a single-pane glass and laminated glass of the same thickness



This table demonstrates:

- > A logical reduction in sound insulation of approximately 3,200 Hz for double glazing equivalent to the critical frequency of 4 mm (5/32") panes of glass
- > In relation to single-pane glazing, a lower level of insulation at low frequencies. This trend can be explained by the fact that double glazing acts as a mass-spring-mass (m-r-m) system. This mass-spring-mass system has a resonant frequency (entire system) located in the low-frequency zone of approximately 200 to 300 Hz, depending on the thickness involved. Sound insulation is significantly reduced in this zone.
- > Between the resonance trough due to the mass-spring-mass system and the critical-frequency trough of the individual panes of glass, the sound insulation increases sharply (in theory, increases of 18 dB by doubling the frequency).

To provide the building with efficient sound insulation, the resonant frequency of the mass-spring-mass system must be below 100 Hz. This condition is not met by double glazing made up of two panes of glass of the same thickness and air space of 12 or 15 mm, and the sound insulation of double glazing in the low- and medium-frequency zone is limited.

To eliminate the mass-spring-mass effect, the air space between the panes of glass must be widened, in order to make the spring

created by the air space more flexible. However, this could result in glazings which are too thick and which require equally wide frames, which would add significant weight to the unit. This would also increase convection within the air or gas space, which would be detrimental in terms of thermal insulation. For these reasons, insulating glazing is not widely used in practice for sound reduction.

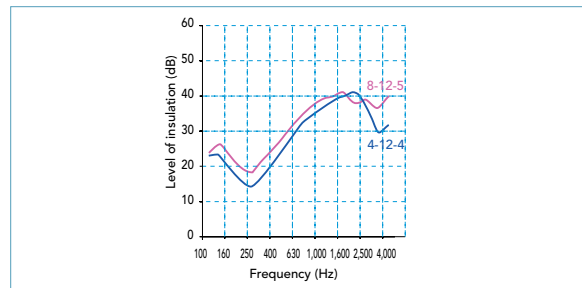
Conclusions:

- > The acoustic performance of symmetrical double glazing is limited.
- > One might draw the conclusion that when renovating an older building, replacing single-pane glazing with double glazing is not a viable option. This is an incorrect assumption for two reasons:
 - Replacing a single-pane glazing with double glazing generally also means replacing the frame, which will also provide a greater level of sound insulation than the old frame. The level of sound insulation provided by the entire window unit will therefore be higher.
 - In terms of thermal insulation, the gain afforded by double glazing in relation to single-pane glazing means that it is the only viable solution.
- > The level of sound insulation provided by double glazing can easily be enhanced (see next sections) by using dissymmetrical forms or laminated glass.

▼ Dissymmetrical Double Glazing

To enhance the level of sound insulation provided by double glazing, the first step is to use glasses with sufficiently different thicknesses, in order to ensure that each can compensate for the weaknesses in the other when the unit reaches its critical frequency. This produces a coincidence trough in a broader frequency zone—but one in which the peaks are less marked. (In the figure below, the trough around 3,200 Hz disappears). In this case, the increase in mass in relation to 4 mm/12 mm/4 mm (5/32"/1/2"/5/32") double glazing also helps to reduce the trough at low frequencies.

Sound insulation spectra for 4mm/12mm/4mm (5/32" /1/2" /5/32") and 8mm/12mm/5mm (5/16" /1/2" /3/16") double glazings



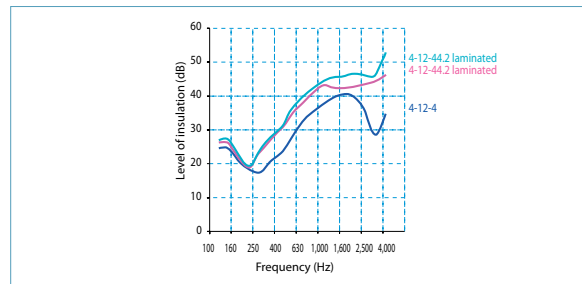
Conclusion:

- > Using two glasses of different thicknesses in a double glazing unit significantly improves performance in relation to symmetrical solution

▼ Double Glazing Units With Laminated Glass

Laminated glass can also be used in double glazing. The figure below shows the improvement in performance when laminated glass is used. The gain can be seen primarily in the high-frequency zone, since it flattens out the critical-frequency trough.

Sound insulation spectrum for conventional 4-12-4, double glazing, a double glazing with laminated glass, and a double glazing with acoustic laminated glass



The direction in which dissymmetrical double glazings and/or double glazings with laminated glass are installed has no effect on the acoustical performance of the glazing. It is advisable to position any laminated glazing with PVB on the inside to ensure safety in the event of any breakage.

Conclusions:

- > If the performance levels of dissymmetrical double glazings are insufficient, better results can be achieved by replacing one or both of the two single panes with a laminated glass or an acoustic laminated glass
- > Improvements are generally seen at the high-frequency level

▼ Triple glazings

Triple glazings are of no particular value in terms of sound insulation, because of the multiple resonance which occurs in the cavities between the glass panes.

▼ Conclusion

The factors that affect the levels of sound insulation provided by various glazings can be summarized as follows:

- > Single-pane glazing:
 - Increased thickness provides slight improvement
 - Using laminated glass and acoustic laminated glass provides significant improvement in performance levels
- > Double glazing:
 - Always use dissymmetrical glazing
 - Use a substantial air space
 - Use thick glass in most instances
 - Use a laminated glass (conventional PVB or safety) in place of one of the two monolithic glasses
 - Use a laminated glass with acoustic PVB for high levels of sound disturbance

2.7 SAFETY

2.7.1 SAFETY GLASS PRODUCTS

▼ 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

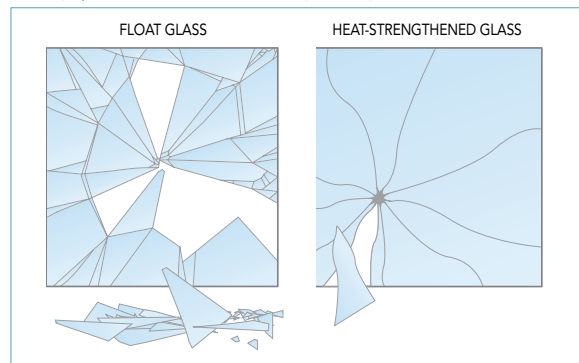
Only a small number of glass products meet the breakage pattern, defenestration, and resistance criteria described above: these are tempered and laminated glass. Other glass products—including float, heat-strengthened, and wired glass, among others—are not considered safety glasses.

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.

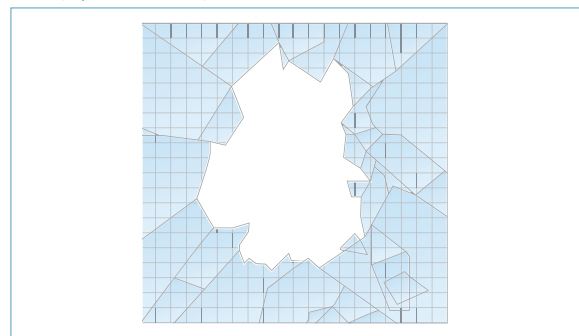
Breakage patterns of float and heat-strengthened glass



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.

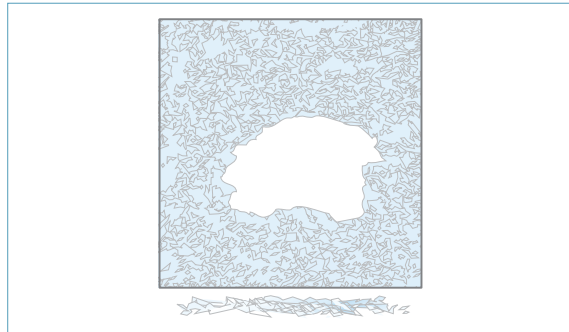
Breakage pattern of wired glass



▼ 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

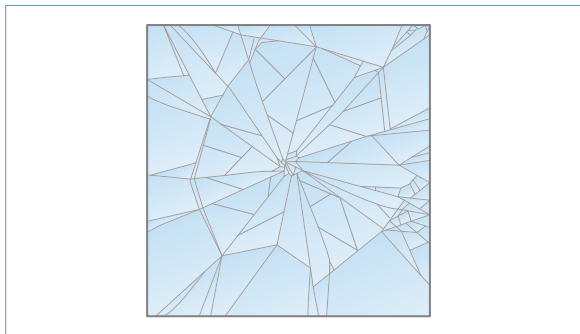
Comparing the impact resistance of a 11.8 inches by 11.8 inches (30 cm x 30 cm) piece of float glass to a similar-sized piece of tempered glass:

- > 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.

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.

2.7.2 STANDARDS AND TESTS

▼ 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

In the event that breakage occurs, the two fragmentation methods accepted by the ANSI Z-97.1 standard for these criteria are:

- > Numerous cracks appear, but no shear or opening is allowed within the test piece through which a 3-inch (76 mm) diameter sphere can pass when a maximum force of (18 N) is applied (in accordance with annex A). In addition, if particles are detached from the test piece up to 5 minutes after impact, they shall, in total, weigh no more than a mass equivalent to 10 square inches (640 mm²) of the original test piece.
- > When breakage occurs, the 10 largest crack-free particles shall be selected within 5 minutes subsequent to the impact and shall weigh no more than the equivalent weight of 10 square inches (640 mm²) of the original specimen. For purposes of impact test evaluation when breakage occurs, the average thickness of a tempered glass specimen containing grooves, bevels, or other thickness-altering fabrication shall be considered the average of the thinnest measurement of each of the 10 geometrically largest crack-free particles. This average thickness will then be used to determine the maximum allowable weight of the 10 largest crack-free particles.

NOTE: The weight in ounces of 10 square inches of glass is equal to 14.5 times the glass thickness in inches. The weight in grams of 10 square inches of glass is equal to 412 times the glass thickness in inches (16.18 grams/mm). (From ANSI Z-97.1)

> 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 Missile 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.

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.

- All test specimens must resist the large or small missile impacts, or both, without penetrating the pane of glass
- 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 security. 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.

ANSI/UL 972 test requirements for burglary-resistant glazings*

Test Requirements Burglary-Resistant Glazing Material					
UL 972 Tests ¹	Impacts per Sample	Impact Energy		Temperature	
		ft.-lb.	Joules	°F	°C
Multiple Impact	5	50	68	70-80	21-27
Outdoor Use	5	40	54	14	-10
Indoor Use ²	5	40	54	120	49
	5	50	68	95	35
High Energy Impact ³	5	50	68	55	13
	1	200	271	70-80	21-27

*Charts provided by Solutia Saflex in its "Security Design Guide"

Note:

1. Tests consist of dropping 3-1/4 inches (82 mm) 5-pound (2.26 kg) steel ball through a designated vertical distance; sample size 24 inches x 24 inches (610 mm x 610 mm).
2. The steel ball shall not penetrate the laminate on any five impacts for nine of the 10 samples tested.
3. The steel ball shall not penetrate the laminate on any of the three samples tested.

▼ Bullet Resistance—ASTM F-1233 and UL-752

There are many standards used in North America for the testing and classification of bullet-resistant glasses. These standards make a distinction between the resistance that glazings demonstrate against various types of weapons and ammunition. There are various classes or levels reflecting various weapon and ammunition types. For each category of weapons that are tested, glass products are considered bullet-resistant if they stop all the bullets on a set of different rounds fired from a specified distance.

The various classes and levels of bullet-resistant glass may include products that offer a number of levels of protection. A glass meeting the requirements stipulated for a given class of weapons also meets those of the classes below it. However, there is no correlation between classes/levels for different weapon types.

The table below and on page 92 provide more detail about the weapons, ammunition, and test conditions for the different classes of bullet-resistant glazings under ASTM F-1233 and UL-752.

Classes of bullet-resistance according to standard ASTM F-1233*

ASTM F1233 Ballistic Criteria				
Class/Level	Weapon Description	Caliber	Bullet Mass ¹ /Type ²	Velocity ³ (ft./sec.)
HG1	Handgun - Low	.38 Special	158 gr/lead	875 (± 25)
HG2	Handgun - Medium, Soft Point	.357 Magnum	158 gr/JSP	1,400 (± 50)
HG3	Handgun - Medium, Jacketed	9 mm	124 gr/FMC	1,250 (± 50)
HG4	Handgun - High	.44 Magnum	240 gr/FMC	1,425 (± 25)
SMG	Submachine-gun	9 mm	124 gr/FMC	1,450 (± 50)
R1	Rifle - Light	.223 (5.56 mm)	55 gr/M193 ball	3,100 (± 100)
R2	Rifle - Heavy, Soft Point	0.30'-06	180 gr/SP	2,925 (± 75)
R3	Rifle - Heavy, Jacketed	.308 Winchester (7.62 mm)	147 gr/M80 ball, FMC	2,750 (± 50)
R4-AP	Rifle - Armor Piercing	.30'-06	164 gr/M2-AP	2,800 (± 50)
SH1 ⁴	Shotgun - Buckshot	12-gauge, 3 in. Magnum	OO buckshot, 15 pellets	1,200 (± 50)
SH2	Shotgun - Slug	12-gauge	1 oz. rifle slug	1,650 (± 50)

*Charts provided by Solutia Saflex in its "Security Design Guide"

Notes:

1. gr denotes grain as a unit of mass; 1gr = 1.426 x 10⁻⁴ pound (0.0647981 g)
2. FMC = Full Metal Coating, JSP = Jacketed Soft Point, LGC = Lead Gas Check, and SP = Soft Point
3. Velocity measured at a distance of 10 feet (3 m) from the strike face of the sample. Muzzle of the barrel is positioned at a distance of the 25 feet (7.6 m) from the strike face of the sample.
4. This ammunition is to be used as an adjunct to the primary test to further evaluate the ability of designed assembly details to resist fragmentary threats.
5. The shotgun load includes 15 pellets of 59 grains each. Each pellet has an energy of approximately 227 foot-pound (308 joules).

- This test standard requires the sample to resist three (3) rounds fired at 25 feet (7.6 m) range and 120° spacing around an 8-inch diameter (203 mm) target circle. Spall is measured using a 0.001 inch (0.03 mm) = thick aluminum foil witness panel 6 inches (152 mm) behind the glazing.
- The small differences between the weapon characteristics defined in Figure 2.8 for UL 752 and those presented for ASTM F1233, as well as the differences in required shot patterns and methods for measuring spall, can make a difference in whether a specimen will pass or fail.

Classes of bullet-resistance according to standard ASTM F-1233*

Rating	Typical Weapon	Ammunition	Bullet Mass ¹ / Type ²	Velocity ³ (ft./sec.)
Level 1	9 mm Gun	Full metal copper jacket with lead core	1,175/124	3
Level 2	.357 Magnum Revolver	Jacketed lead soft point	1,250/158	3
Level 3	.44 Magnum Revolver	Lead semi-wadcutter gas checked	1,350/240	3
Level 4	.30 Rifle	Lead core soft point	2,540/180	1
Level 5	7.62 mm Rifle	Lead core full metal copper jacket, military ball	2,750/150	1
Level 6	9 mm Gun	Full metal copper jacket with lead core	1,400/124	5
Level 7	5.56 mm Rifle	Full metal copper jacket with lead core	3,080/55	5
Level 8	7.62 mm Rifle	Lead core full metal copper jacket, military ball	2,750/150	5
Supplementary	12-Gauge Shotgun	12-gauge rifled lead slug	1,585/437	3
Supplementary	12-Gauge Shotgun	12-gauge lead buck-shot (12 pellets)	1,200/650	3

*Charts provided by Solutia Saflex in its "Security Design Guide"

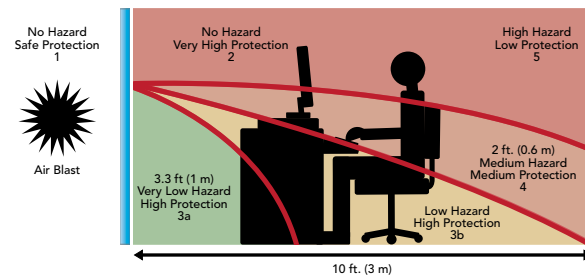
▼ Explosion Resistance—GSA "Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings" and ASTM F-1642

To resist explosions, laminated glass products can be designed to meet the requirements of the U.S. General Services Administration (GSA) "Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings" as well as ASTM F-1642 "Standard Test Method for Glazing and Glazing Systems Subject to Air Blast Loadings." These test methods are designed to measure the performance criteria of glazings subjected to air blast loads similar to those of an explosion.

Both the GSA and ASTM F-1642 test standards can be performed using shock tube or field arena blasts to create overpressure. When glass is exposed to a blast event, broken glass shards fly into the inhabited space, potentially causing personal injury and loss of life. These tests methods measure the performance of the glazings in their ability to retain the broken shards of glass—and restrain them from flying into the inhabited space.

The levels of explosion protection range from a "no break" safety level to a low protection level, where the glazing cracks and the window system fails catastrophically. Glass fragments enter the inhabited space, impacting a vertical witness panel located 9.8 feet (3 m) from the window at a height of 2 feet (0.6 m) above the floor.

Performance conditions for explosion-resistant glazings



Department of Defense Criteria

The United States Department of Defense (DoD) Unified Facilities Criteria UFC 4-010-01 “DoD Minimum Antiterrorism Standards for Buildings” sets minimum design guidelines for windows and doors designed to resist explosions. This standard requires that a 1/4 inch (6 mm) nominal laminated glass be used, at a minimum. The 1/4 inch (6 mm) laminated glass should consist of two nominal 1/8 inch (3 mm) annealed glass panes bonded together with a minimum of a 0.03 inch (0.75 mm) polyvinyl-butylal (PVB) interlayer.

For insulating glass units, the DoD design criteria requires the use of 1/4 inch (6 mm) laminated glass for the inboard pane, at a minimum. The required thickness for the laminated glass and PVB interlayer is determined based on the appropriate explosive weight and standoff distance defined in ASTM F-2248, “Standard Practice for Specifying an Equivalent 3-Second Duration Design Loading for Blast Resistant Glazing Fabricated With Laminated Glass,” as well as ASTM E-1300 “Standard Practice for Determining Load Resistance of Glass in Buildings.”

Protection level vs. hazard level comparison

GSA Condition	Protection Level		Hazard Level	
	GSA	DoD	GSA	DoD
1	Safe	High	None	No Hazard
2	Very High	Medium	None	Minimal Hazard
3a	High	Low	Very Low	Very Low Hazard
3b and 4	High/Medium	Very Low	Low/Medium	Low Hazard
5	Low	Below AT Standards	High	High Hazard

2.7.3 SAFETY GLASS APPLICATIONS

▼ Introduction

The following section provides general information on the use of safety glass; the list of applications is not exhaustive.

While this section includes general guidelines, the application of safety glass in a specific glazing project should always be considered on a case-by-case basis according to specific site requirements and local regulations.

In all cases, the actual glass thicknesses should be adapted to the real-world glazing sizes and loads for each project—as well as the specific glazing framing system. The thicknesses corresponding to a particular safety glass class are merely a minimum level defined for testing purposes only.

AGC customers should consult the company's Technical Services team for more information about applications and requirements for safety glass products.

▼ Safety of Individuals Against Injury and Falling

> Introduction

There are two distinct aspects that must be considered when protecting the personal safety of individuals:

- > Preventing the risk of injury caused by sharp pieces of glass upon glass breakage
- > Preventing the risk of falling through glass (defenestration)

In the case of the first risk, both tempered and laminated glass products can be used. However, only laminated glass may be used for protection against defenestration.

Although it displays some impact resistance, annealed float glass is never considered to be a safety glass.

> Protection against injury

To limit the risk of personal injury resulting from shattered pieces of glass, glazings should include tempered or laminated glass with a minimum 0.015-inch (0.38 mm) PVB film interlayer for Class B, and a 0.03-inch (0.75 mm) PVB interlayer for Class A Drop Height Classification.

Such glass can be used in the following applications:

- > Retail store windows (if the bottom of the glass is close to ground level)
- > Internal partitions (if the bottom of the glass is close to ground level) where there is no difference in the level on either side
- > Doors and windows in public places
- > Street furniture: bus shelters, telephone booths, etc.
- > Shower cubicles, shelves, furniture, etc.
- > In the case of roof glazings, the use of laminated glass is vital in order to protect people standing beneath the glazed opening against the risk of injury from glass shards which have become detached—dislodged, for example, by falling objects. Since there is no guarantee that objects will not fall through the glass, roof glazings will only be completely effective if the stresses produced by such impacts are within the performance levels of the specific glazing products.

In safety applications where the edges of a glass are visible, they should be ground—and in some cases, the glass should also be tempered.

> Protection against falling

To limit the risk of injuries caused by falling through glass, laminated glass—with a minimum 0.03-inch (0.75 mm) PVB interlayer—should be used in the following applications, among others:

- > Internal windows and doors (if the bottom of the glass is close to ground level) where there is a difference in level
- > Railings and balustrades
- > Floors and staircases

> Position of safety glass

In order to protect individuals, double glazings should position the laminated glass on the side on which impacts are most likely to occur.

Two safety glasses may be used in a double glazing assembly if the impact may occur on both sides—for example, in the case of double glazings fitted in an entry door to a public place. The permissible combinations in double-glazed safety units are tempered-tempered, tempered-laminated, and laminated-laminated.

Double glazings composed of float and tempered glasses provide no safety protection. If the two glasses break at the same time, there is a risk of personal injury.

For double glazings installed in roofs, the internal glass should be laminated.

▼ Burglary Resistance

Only laminated glass may be used to protect against vandalism and burglary—or escape, e.g., in prisons or hospitals.

The fabricator of the laminated glass must determine the number of PVB films to be used, as well as the glass composition, depending on the level of protection required. Whether the aim is to provide protection against vandalism, or to protect homes and retail stores from theft, the laminated glass should be composed of two panes of glass and an increasing number of PVB films—depending on the level of security required and/or insurance requirements. For very high levels of security, multi-laminated glass should be used, potentially incorporating polycarbonate.

In the case of burglary-resistant safety glass assembled in a double glazing unit, the laminated glass should be positioned on the inside of the unit.

▼ Bullet and Explosion Resistance

Laminated or multi-laminated glasses, sometimes containing polycarbonate, are resistant to bullets and explosions.

Using glass as a source of resistance to bullets and explosions is a highly specialized field. It is the responsibility of the glazing professional to determine the level of protection required. AGC customers should contact a blast security consultant when deciding which glass products provide the level of performance required—which will depend on the specific nature of the project and the type of protection needed.

▼ Frame Quality

In all cases, safety glasses are useful only if the accompanying framing system has the same resistance qualities. The level of resistance of the weakest component determines the resistance of the assembly as a whole.

▼ Installation Instructions for Safety Glass

When fitting safety glass products, general installation instructions—as well as those specific to safety glass—should be followed.

2.8 FIRE-RATED GLAZING PRODUCTS

2.8.1 INTRODUCTION

Some of the key elements in building design and renovation are light, open environment, visual safety, and communications. Virtually all of these require the use of glass. In the past, designers had limited options under the building codes. But today with so many new fire-rated glazing systems available, design freedom is at the fingertips of the creator.

North American building fire codes are built upon the concept of compartmentalization. Thus, fire-rated glazing materials are intended to help compartmentalize a fire and smoke in a building. A fire rating is determined by the length of time a product can meet fire endurance testing to either fire-protective or fire-resistive US and Canadian building standards. The fire-protective or fire-resistive ratings mandated by most major codes are based on the application requirements. These requirements depend on how much time is necessary to maintain the structural integrity of the building, property protection, and safe egress of its occupants.

Fire-rated glazing materials carry a label on the glass that may include the manufacturer, listed fire-rating, safety standards, test standards and testing agency.

There are a number of fire-rated products that will meet all the necessary fire-rated building code requirements. These products are divided into fire-protective and/or fire-resistive categories.

2.8.2 FIRE RESISTANCE

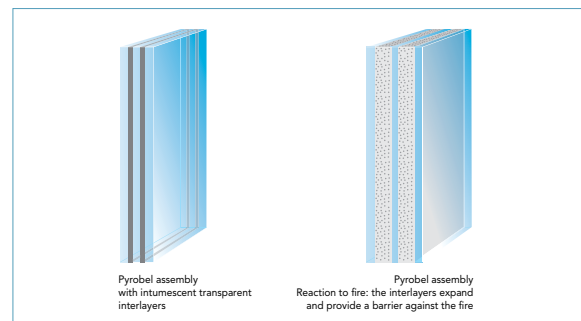
▼ Fire-Protective Glazing

This category includes polished wired glass, ceramics, specialty tempered glass, and filmed glass (both non-wired and wired). These products are generally between 1/4" and 5/8" thick. Fire ratings range from 20 minutes to 3 hours, depending on the product and application. Generally, fire protective glazing is limited to 45 minutes in interior borrowed lites. Always consult your local building code official for appropriate use of fire protective glazing.

> *Wired Glass* was the original fire-rated glass relying on embedded wires to hold the annealed glass together during a fire endurance and hose stream test. Historically it was required to meet the American National Standards Institute (ANSI) Z97.1 *American National Standard for Safety Glazing Materials Used in Buildings - Safety Performance Specifications Method of Test* impact standard (100 ft.-lbs.). In non-hazardous, fire-rated locations, traditional wired glass can be used up to the size tested and approved. Wired glass under most codes in the US today must meet the higher standard of CPSC 16CFR 1201. Filmed wired glass has been developed for safety areas by some manufacturers that meet Consumer Product Safety Commission (CPSC) 16 CFR 1201 *Safety Standard for Architectural Glazing Materials* Category I or Category II safety standards.

> *Ceramics* withstand a fire endurance and hose stream test, and when laminated or filmed, can meet CPSC 16 CFR 1201 Cat II (400 ft.-lbs.) safety requirements for use in hazardous locations. Fire-ratings range from 20 to 180 minutes depending on application. Consult your local building code official for appropriate use of protective glazing.

> *Specialty Monolithic Tempered Glass*, clear tempered glass with ratings of 20 minutes, listed for CPSC 16 CFR 1201 Category II (400 ft.-lbs.) safety for use in door locations.



> *Laminated intumescent* and gel-filled glazing may fall within the fire protective designation when either used with a traditional non-thermally broken frame or in areas where only a 45-minute rating is required. However, when a higher margin of safety is desired due to their thermal limiting characteristics (such as schools, hospitals, homes for the aged, and other areas where egress may be hampered or confused) these products may be selected.

Fire Protective Product Notes - Some of the previous products provide improved acoustical, energy performance or radiant heat transfer characteristics depending on the product selected. Contact the fire-rated glazing supplier for details on these enhanced performance characteristics.

▼ Key Questions to Ask in Selecting Fire-Protective Glazing Products

- 1) What is the minimum fire-rating required for this application?
- 2) Is an impact safety rating required?
- 3) Are there size limitations placed on the usage of a product based on code requirements?

▼ Fire-Resistant Glazing

This category includes intumescent multi-laminate and gel-filled units. These clear, transparent products contain flames, the spread of smoke, and prevent the transfer of radiant heat for 45 minutes to 2 hours. These products are listed by third party testing agencies as “non load bearing transparent walls” and are therefore not limited to the 25% glazed area restriction, when used in a temperature rise framing system of equal rating to the glazing.

Intumescent multi-laminate – These products utilize multiple sheets of annealed glass laminated together using special intumescent interlayers. The number of interlayers and overall thickness determine the fire rating. Under fire conditions the interlayers become opaque and expand to prevent the transmission of heat, smoke, and flames.

Gel-filled – These units resemble insulating glass units, however the cavity is filled with clear gel. The thickness of the gel cavity determines the fire rating. Under fire conditions the gel crystallizes into an opaque heat absorbing char that prevents the transmission of heat, smoke, and flames.

Fire-Resistive Product Notes - Intumescent multi-laminate and gel-filled products provide improved acoustical performance and are available for exterior use with energy saving make-ups. They can also be provided in special make-ups for bullet, blast, hurricane, attack resistance, and other custom protections. Contact AGC for details on these enhanced performance characteristics.

▼ Key Questions to Ask in Selecting Fire-Resistive Glazing Products

- 1) What is the minimum fire-rating required for this application?
- 2) Is the framing capable of meeting the fire-resistive rating of the glazing?
- 3) What are the size limitations of the selected fire-resistive glazing?
- 4) Is the application exterior or interior?

▼ DEFINITIONS

Fire-Protection Rating – The period of time that an opening protective assembly will maintain the ability to confine a fire as determined by tests – NFPA 252/ NFPA 257/UL 9/UL 10C/ASTM E 2010/ASTM E 2074. Canadian – CAN S 104, 105 and 106

Fire-Resistance – That property of materials or their assemblies that prevents or retards the passage of excessive heat, hot gases or flames under conditions of use.

Fire-Resistance Rating – The period of time a building element, component or assembly maintains the ability to confine a fire, continues to perform a given structural function, or both, as determined by tests – NFPA 251/ASTM E 119/UL 263 (wall assemblies). Canadian - CAN S 101, 104, 105 and 106.

Fire-Rated Products Comparison

	Fire Rating	Safety Rating	Meets Hose Stream Test	ASTM E 119 Heat Barrier (C)	Exterior/Interior Use
Traditional Wired Glass	20 – 90 minutes (A)	ANSI Z97.1 100 ft.-lbs.	Yes	No	Yes
Filmed Wired Glass	20 – 90 minutes (A)	CPSC 16 CFR 1201 Category II 400 ft.-lbs.	Yes	No	Yes
Specialty Tempered	20 minutes	CPSC 16 CFR 1201 Category II 400 ft.-lbs.	No	No	Yes
Ceramic	20 minutes – 3 hours (B)	None	Yes	No	Yes
Filmed Ceramic	20 minutes – 3 hours (B)	CPSC 16 CFR 1201 Category II 400 ft.-lbs.	Yes	No	Yes
Laminated Ceramic	20 minutes – 3 hours (B)	CPSC 16 CFR 1201 Category II 400 ft.-lbs.	Yes	No	Yes
Multi-Laminated Intumescent	45 minutes – 2 hours	CPSC 16 CFR 1201 Category II 400 ft.-lbs.	Yes	Yes	Yes (D)
Gel-Filled	45 minutes – 2 hours	CPSC 16 CFR 1201 Category II 400 ft.-lbs.	Yes	Yes	Yes (D)

IMPORTANT INFORMATION:

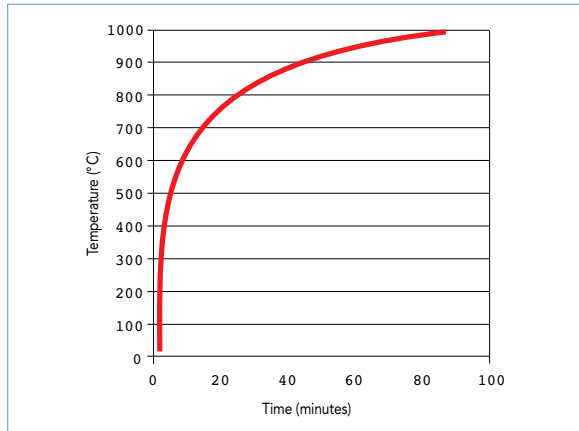
- (A) Up to 90 minutes in door applications not to exceed 100 sq. in., 45 minutes for other applications.
- (B) Up to 3 hours in door applications not to exceed 100 sq. in.
- (C) While some of the above products do not meet the requirements of the ASTM standard for barrier walls, products may offer significant heat reduction. Contact the manufacturers for detailed information.
- (D) For exterior applications, special fabrication may be needed. Advise the manufacturer of intended exterior uses of the product.

▼ TESTING AND CERTIFICATIONS BY INDEPENDENT LABORATORIES

Test standards prescribed by the building codes for fire-rated glazing and fire-rated glazing systems fall into three categories: doors, windows/borrowed lites, and “transparent wall systems.” These standards prescribe standardize fire and hose stream test procedures that apply to the assemblies intended to be used to retard the spread of fire, smoke and, in the case of wall systems, radiated and convective heat. The degree of fire protection measured in units of time is not an absolute value because all possible actual fire scenarios are not represented by the standard fire exposures. All of the standard test procedures are intended to evaluate the ability of an assembly to remain in an opening during a prescribed fire test exposure. It is then followed by the application of a prescribed hose stream.



The time-temperature fire curve, generally referred to as the ASTM E-119 curve, reflects the temperature in degrees for each segment of time the assembly is exposed.



Upon successful testing of the assembly, independent laboratories will certify and list the products and allow manufacturers to label accordingly. To assure compliance with that tested, the laboratories will inspect the manufacturing location quarterly. This inspection includes an audit of the manufacturing process and procedures in comparison to the product tested as well as the proper labeling of the glazing and glazing systems.

2.8.3 GUIDELINES FOR GLAZING IN FIRE-RATED METAL FRAMES

When setting glass in metal frames, it should be noted that many of these frames are used in fire-rated barriers. The model codes of the United States and the National Fire Protection Association Standard No. 80, Standard for Fire Doors and Fire Windows, mandate the use of labeled glass and labeled frames in fire-rated applications. This means the glass and frame must bear the mark (label) of an independent third-party agency (like Underwriters Laboratories, Factory Mutual, Warnock Hersey, etc.). The label attests to the fact that the glass and frame have been tested under the auspices of the third-party agency and shown to achieve a specified fire protection rating. Furthermore, the glass manufacturer or frame manufacturer is required, as a condition of the label, to furnish installation instructions. The glazing must be installed in accordance with the manufacturer's instructions, reflecting the manner in which the product was tested, to achieve the fire rating.

NFPA 80 should also be consulted for installation details, glass area limits and other requirements. NFPA 80 and some labeling agencies specify that the clearance between the edges of the glazing and the inside edge of the frame may not exceed 1/8". The 1/8" clearance should not be exceeded unless otherwise noted in the individual listing or the manufacturer's installation instructions.

2.8.4 GLOSSARY

NFPA-80: Standard for Fire Doors and Other Opening Protectives

This standard regulates the installation and maintenance of assemblies and devices used to protect openings in walls, floors, and ceilings against the spread of fire and smoke within, into, or out of buildings. **1.1.1** With the exception of fabric fire safety curtain assemblies, this standard addresses assemblies that have been subjected to standardized fire tests. **1.1.2** Incinerator doors, record room doors, and vault doors are not covered in this standard. **1.1.3** Requirements for horizontally sliding, vertically sliding, and swinging doors as used in this standard do not apply to hoistway doors for elevators and dumbwaiters. **1.1.4** This standard does not cover fire-resistant glazing materials and horizontally sliding accordion or folding assemblies fabricated for use as walls and tested as wall assemblies in accordance with NFPA 251, Standard Methods of Tests of Fire Resistance of Building Construction and Materials.

IBC (2003 and 2006) Sec. 700, 1000, 2400

The International Building Code (IBC) was introduced in 2000. The 2000 IBC was a culmination of three U.S. model building codes (SBCCI, BOCA and IBC), rolled into one U.S. code. The 2000 IBC was revised in 2003 and 2006 and has been adopted by virtually every state in the U.S. It is now the standard code for all construction in the U.S. and sets forth requirements for fire-rated glazing within the building envelope.

CPSC 16 CFR 1201 (Consumer Product Safety Commission): Impact Safety Rating

The CPSC standard is not only a test method and a procedure for

determining the safety performance of architectural glazing, but also a federal standard that mandates where and when safety glazing materials must be used in architectural applications and preempts any non-identical state or local standard.

ANSI Z.97 Cat. I and II (American National Standard Institute): Impact Safety Rating

ANSI Z97.1 is only a voluntary safety performance specification and test method. It does not attempt to declare when and where safety glazing materials must be used, leaving those determinations up to the building codes and to glass and fenestration specifiers. Cat. I is equivalent to a 100 ft. lb. impact. Cat. II is equivalent to a 400 ft. lb. or higher impact.

UBC

Uniform Building Code

SBCCI

Southern Building Code Congress International

BOCA

Building Officials and Code Administrators International

2.8.5 IBC LABELING REQUIREMENTS FOR FIRE-RATED GLAZING

Location Indicator

- D** denotes DOORS
- O** denotes OPENING (window, sidelite, transom, etc.)
- W** denotes WALLS (glass must meet ASTM E-119 and provide a barrier to radiant heat transfer)

Hose Stream Test

- H** denotes glazing meets **H**OSE stream test requirement (required for 45 minutes and above)
- NH** denotes the glazing does **N**OT meet the **H**OSE stream requirement (applies to 20-minute glazing only)

Temperature Rise

- T** denotes glazing meets **T**EMPERATURE rise criteria
- NT** denotes glazing does **N**OT meet **T**EMPERATURE rise criteria

Fire-Rating (Minutes)

- XX** denotes fire protection rating period in minutes

2.8.6 AGC FIRE-RATED GLAZING BRANDS

AGC has a complete range of tempered glass, ceramics, intumescent, and framing products offering a variety of levels of fire protection and fire resistance.

PyroEdge

PyroEdge is a very popular, low cost, clear, non-wired 1/4" and 3/8" tempered product offering protection from flame and smoke generally for 20 minute door assemblies.

Schott Pyran Platinum

In conjunction with Schott glass, AGC offers multiple distribution points for Pyran Platinum ceramic glazing. It is offered in three types: non-safety, filmed safety, and laminated safety glazing. Due to its unique manufacturing capability it is also classified as a green product. Fire ratings run from 20 minutes to 180 minutes depending upon the application.

Pyrobel, "Tri-Safe" Glazing

Pyrobel, manufactured in Belgium and the Czech Republic in large sheets is shipped to the AGC fabrication center in the US. There it is cut to size, labeled, boxed and shipped to the customers desired location. It is an intumescent laminated product that varies in thickness depending upon the fire exposure required. Due to its structure it can be classified as either a fire protective or fire resistant glazing. The Pyrobel glazing generally limits the temperature rise on the non fire side to a maximum of 250°F above ambient. During a fire the glazing will turn opaque and forms a rigid barrier to fire, smoke and heat radiation. Fire ratings range from 45 minutes to 120 minutes. Units exceeding 60 minutes utilize low iron glass to improve light transparency and clarity. Interestingly, Pyrobel may also be butt glazed to form a rigid non- framed "transparent wall."

Pyrobel, Vision Systems Glazing

The unique Vision glazing system is comprised of Pyrobel butt glazed units. Maximum panel sizes are 96" x 96", or 4608 sq. in., and can be combined to run virtually any length under existing U.S. and Canadian codes. The Vision system can be installed in the Quick-Frame, Series 100 and 200 discussed below to form a true, unencumbered transparent wall system. It is rated to 60 minutes.

▼ AGC Fire-rated Framing

AGC offers a range of fire-rated framing systems for all its brands of fire-rated glazing:

Hollow Metal

Standard hollow metal framing is available with listing from 45 minutes to 90 minutes. Special custom configurations are available although limited by testing standards. All framing is shipped either primed or finish painted with the appropriate laboratory fire rating certification.

Quick-Frame

Quick-Frame is a low cost framing option specifically for Pyrobel products that allows the on-site contractor to manufacture the “frameless” frame. Composed of gypsum board and steel angles, which stop in the glass, it is quick to construct. Maximum individual glazing panel sizes range to 32 sq. ft. Finishing options of wood steel or aluminum at the edge of the glass can be tailored to the designers concept and desire. The Quick-Frame has ratings from 45 minutes to 120 minutes.

StileLite 100

The StileLite 100 Series is a fully welded, modular, thermally broken frame for use in conjunction with Pyrobel 60 for 60-minute “transparent wall” applications. The profile matches that of standard hollow metal frames at 1 $\frac{7}{8}$ " and can be customized to virtually all wall thicknesses. Maximum individual glazing panel sizes range to 32 sq. ft. The StileLite 100 can be erected to virtually any size dependent upon engineering calculations. It is available primed or finish painted.

StileLite 200

The StileLite 200 Series is a fully welded, modular storefront system. It is a thermally broken frame for use in conjunction with Pyrobel 60 for 60-minute “transparent wall” applications. The profile offers a very clean sightline at 2 $\frac{1}{2}$ " and can be customized to virtually all wall thicknesses. Maximum individual glazing panel sizes range to 32 sq. ft. The StileLite 100 can be erected to virtually any size dependent upon engineering calculations. It is available primed or finish painted.

StileLite 300

The StileLite 300 Series is a fully welded, modular curtainwall system with ratings to 120 minutes utilizing Pyrobel glazing. It is available primed or finish painted.



ROC Almelo, Almelo, Netherlands - Photographer: Hans Willemsen - Pyrobel