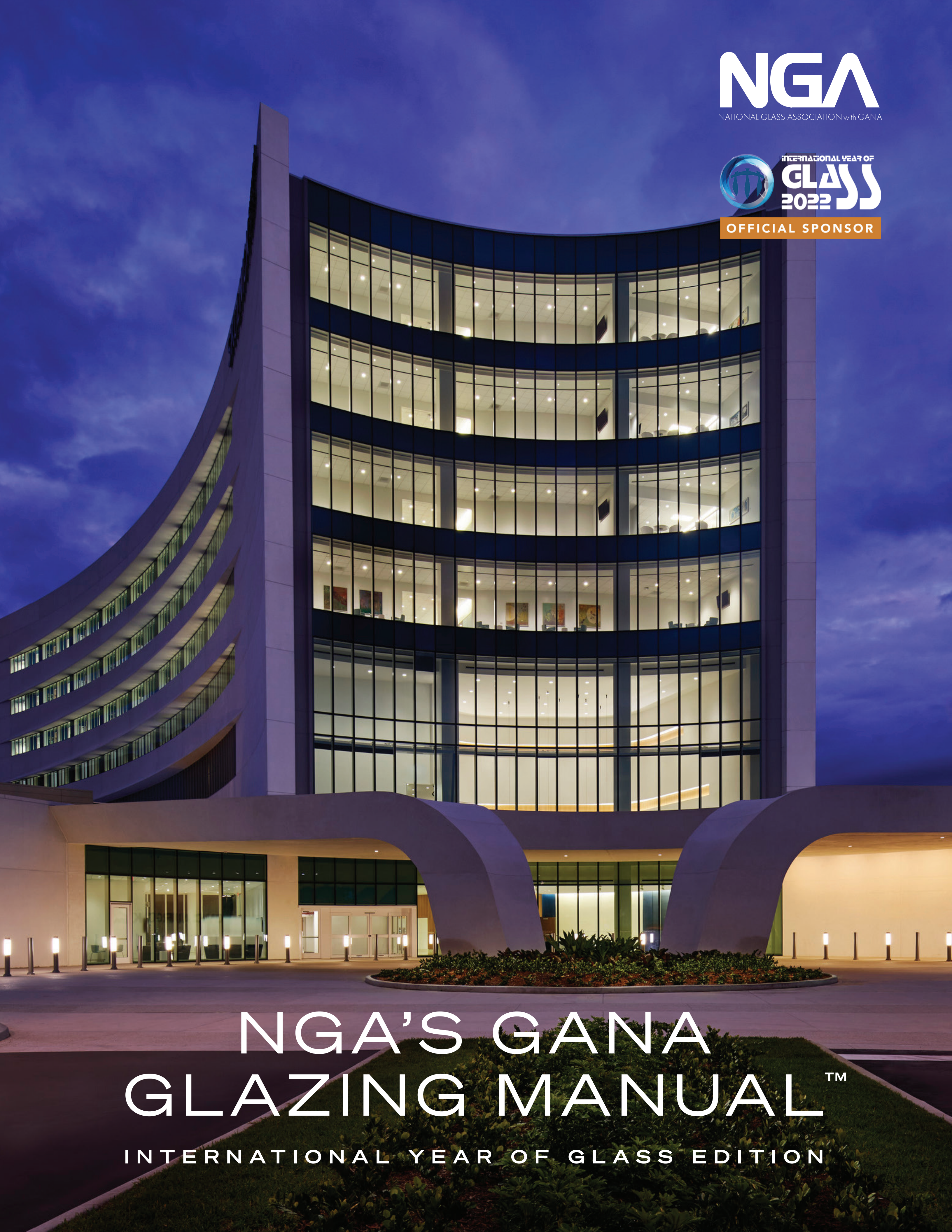

NGA

NATIONAL GLASS ASSOCIATION with GANA

INTERNATIONAL YEAR OF GLASS 2022

OFFICIAL SPONSOR

NGA'S GANA GLAZING MANUAL™

INTERNATIONAL YEAR OF GLASS EDITION

Dedication

This edition of the *NGA's GANA Glazing Manual* is dedicated to the International Year of Glass 2022.

What is the International Year of Glass?
The United Nations declared 2022 the International Year of Glass (IYOG). IYOG 2022 celebrates the essential role glass has and will continue to have in society. The vision is to celebrate the past, present and future of this transformative material following the United Nations' goals in Agenda 2030:

- Demonstrate the role of glass in advancing civilization throughout recorded history.
- Organize international glass science and art festivals, with workshops to excite and inform the public of this rich history, and highlight links between glass, art and culture.
- Stimulate research on glass amongst organizations in education, industry, research and the public domain, including museums, to address the great challenges the world faces: achieving sustainable and equitable growth, and improving the quality of life everywhere.
- Build worldwide alliances focused on science and engineering for young people, while addressing gender balance and the needs of developing countries/emerging economies.

NGA'S Role in The International Year of Glass
The National Glass Association (NGA) supports the vision of IYOG 2022 as an official sponsor. NGA's IYOG activities are organized under two themes, Glass Can Save the World, highlighting the sustainability, recyclability and protective attributes of glass and glazing products, and Build the World with Glass, showcasing the career paths available in the glass industry.

FIGURE 1 *The National Glass Association themes for International Year of Glass 2022*

NGA Glass & Glazing Advocacy Day Event
Industry leaders from NGA member companies, congressional members and agency officials convened in Washington, DC, on April 4–5, 2022, for the association's first Glass & Glazing Advocacy Day featuring meetings face-to-face with legislative leaders from all over the United States.

Policy priorities important to the architectural glass and glazing industry were at the forefront of the event: high-performance glazing and building resiliency; bird-friendly glazing; recycling and circular economy; school security; and registered apprenticeship programs.

The event was held just prior to the American Ceramic Society's National Day of Glass, which took place April 5–7, to build upon the spotlight on the glass industry in Washington, DC.

NGA Glossary of Architectural Glass & Glazing

NGA published the first edition of the *NGA Glossary of Architectural Glass & Glazing* as a special gift to its member companies to commemorate 2022 as the International Year of Glass. The NGA Glossary includes 1,800 terms used in the architectural glass and glazing industry and will serve as an invaluable resource for industry veterans and new hires alike.

The National Glass Association thanks the following member companies for sponsoring its IYOG 2022 activities:

FIGURE 2 *NGA member companies that sponsored activities during the International Year of Glass*

Acknowledgements

On behalf of the members of the National Glass Association (NGA) and the glass and glazing industry, we would like to express our appreciation to the many individuals, manufacturers, fabricators, installers, architects, specifiers and industry associations who have given freely of their time and resources to make possible the continued publication of the GANA Glazing Manual. We especially wish to thank the following for their contributions and critical reviews of the drafts that led to the final publication of the 2022 IYOG Edition:

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Cover photo by Christopher Barrett Photograph/CannonDesign. The Mount Sinai Medical Center, Skolnick Surgical Tower and Hildebrandt Emergency Center is located in Miami Beach, FL. The segmented Pro-tech system resulted in a smooth concave design for the façade of the tower. Architect: Cannon Design; General Contractor: Robins & Morton; Glass Fabricator: Viracon; Glazing Contractor: Crawford-Tracey Corporation.

Introduction

The purpose of *NGA's GANA Glazing Manual* is to educate architects, engineers, builders, fabricators, installers and the general public about the constantly increasing wonders of glass, the benefits to be derived from its use and to provide general guidelines for proper installation techniques.

The 1973 Arab oil embargo and continued dramatic fluctuations in oil costs forced national and local agencies to legislate new energy conservation standards. The glass industry responded to the challenge by developing an assortment of coated and spectrally selective glass products, which control, to a known degree, the passage of visible light, infra-red heat energy and ultraviolet energy into all structures. Insulating glass units utilizing warm-edge spacer technology, insulating gas between the glazing lites and advanced low-emissivity (low-e) coatings have greatly improved the ability of glass to keep our buildings warmer in the winter and cooler in the summer.

Glass allows the architect and engineer to design structures to get the full benefits of daylighting while controlling heat transfer. The glass industry has become a major energy conservation industry.

Glass in windows, curtain walls and skylights produces important energy-saving benefits when properly designed and managed. The use of daylighting in commercial buildings reduces the demand for artificial lighting. Artificial lighting is the largest single user of energy in typical office buildings; daylighting is free. Energy costs to overcome heat gain and loss through glass are much less than for artificial lighting. Arbitrarily limiting glass area to a small percentage of exterior wall or roof area can produce higher operating costs than larger, well-designed and well-managed glass areas.

Glass on sun-facing orientations of residences acts as a passive solar collector to offset a portion of winter heating costs. When double or triple glazing is used, especially in conjunction with a low-e coating, the net effect is energy conservation comparable to that of many opaque walls. When used with awnings, overhangs or indoor shading devices to reject summer sun, windows can be even more energy-efficient and cost-effective.

Beyond energy efficiency, glass in buildings can serve many purposes, often simultaneously, to enhance the comfort and protection of occupants. Figure 3 illustrates many of the attributes of architectural glass.

FIGURE 3 *The functions of glass in buildings*

Safety and security glass doors, windows and railings provide protection during natural and manmade events. Glass enhances the safety and security of buildings, provides an enhanced sense of connection to the community outside, and allows occupants to identify approaching threats. Fire-rated glass prevents the spread of flames and smoke to allow occupant egress. Windstorm-rated glass helps protect people and buildings from extreme weather.

Interrupting reflections by creating visual markers or patterns on glass at a specific spacing and geometry can significantly reduce bird collisions. Architects are specifying this type of glass, termed Bird-Friendly Glass, as high as the mature tree canopy for the building site. The use of tinted glass on the beachfront in coastal regions can help reduce unnecessary light from reaching the beach at night. Lower light levels can help prevent sea turtle hatchlings from becoming disoriented as they make their way to the water.

Biophilic design with glass connects people and nature within built environments. Glass contributes to health and productivity as proven by many studies correlating access to daylight and views with occupant well-being in schools, workplaces and healthcare facilities.

Glass is infinitely recyclable, which supports a circular economy and reduces waste and landfill. Many industries can use recycled glass, such as containers (jars and bottles), fiberglass, reflective highway paint and landscaping products.

Previous publication dates: 1958, 1965, 1971, 1974, 1980, 1986, 1990, 1997, 2004, 2008

About NGA
The National Glass Association (NGA) was founded in 1948 and combined with the Glass Association of North America (GANA) in 2018 to create the largest trade association serving our industry. NGA is an advocacy and technical powerhouse that brings the best minds to the table to create technical resources, and to promote and advocate for glass in buildings.

The NGA member community is 1,700 companies strong. We are contract glaziers and full-service glass companies. We are manufacturers and suppliers. We are fabricators of insulating, laminating, tempering, decorative/mirror, fire-rated, protective glazing and high-performance glass products

NGA's technical papers and manuals, and business resources help guide you and your company to success. Our online training courses at MyGlassClass.com, plus NGA Glazier Apprentice Curriculum, teach job skills and knowledge that will complement your company's on-the-job training.

NGA brings news, product announcements and financial insights directly to you through our official magazines Glass Magazine and Window + Door.

Our many events throughout the year—GlassBuild America, the Building Envelope Contractors (BEC) Conference, NGA Glass Conferences, Glazing Executives Forum, GPAD (Glass Processing Automation Days) and Thirsty Thursday webinars—provide a gathering place for you to learn, share, engage, and make connections.

Learn more at glass.org.

Disclaimer
This edition of the Manual was developed by the National Glass Association (NGA) and this disclaimer is made by the NGA (the Provider). Neither the Provider nor its officers, directors, members, employees, contractors or agents shall be held liable for any improper or incorrect use of the materials or information described and/or contained in this Manual and assume no responsibility for any user's use of them. The Provider expressly disclaims any responsibility for any specific results related to the use or non-use of the Manual, for any omissions or errors contained in it, and for any liability for loss or damage of any kind arising out of the use of the Manual.

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Nor is this Manual intended to provide legal advice. If legal advice or other expert assistance is required, you should seek the services of legal counsel or other competent professional.

The Manual is a "living document," and the Provider reserves the right, in its sole discretion, to update, revise and amend the Manual from time to time as it sees fit and to do so without notice to prior recipients or current users of the Manual.

The National Glass Association (NGA) has produced the *GANA Glazing Manual 2022 IYOG Edition* solely to provide general descriptions and information concerning the basics of glass. It is the responsibility of the user of this Manual to ensure that glass is selected and installed by competent professionals in compliance with all relevant laws, rules, regulations, codes, standards and other requirements.

The standards referenced in *NGA's GANA Glazing Manual 2022 IYOG Edition* are under the jurisdiction of a number of organizations and agencies and are continuously being revised. The documents referenced in this Manual were those in effect as of August 1, 2022. The most recent standards should be referenced. Full names of reference standards and publishing entities are listed in Appendices 1, 2, 3 and 4.

Specific systems are covered, describing in detail how the systems work, how they respond to either specified or design criteria, and what's involved with their design, fabrication, installation and performance once installed. Other resources, such as industry groups, manufacturers or standards organizations, can and should be consulted for specifics of how materials perform or how material is sized for specific instances.

The photographs and diagrams of products shown in the Manual have been supplied by NGA member companies and are believed to be reasonably representative of the products offered by the membership specifically and the industry generally. The publication of these photographs and diagrams is not intended as an endorsement of one product or vendor over another. There are other vendors whose products perform well and are suitable for the systems shown. Drawings in the Manual are not to scale.

NGA's GANA Glazing Manual 2022 IYOG Edition is meant to be a companion document to other industry referenced documents and standards as described throughout this document. Appendices 2 and 3 of this Manual provide a list of many of these documents for reference. Documents provided by the National Glass Association are available online at glass.org/store.

NGA's GANA Glazing Manual
2022 IYOG Edition

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Primary Glass Products

History of Flat Glass Production

In order to better understand the glass and glazing industry, a brief history of glass may be helpful.

Glass was discovered over four thousand years ago. It was considered precious and used by royalty and for religious purposes. The Romans were perhaps the first to develop flat glass for use as windows. During the Roman Empire, glass making reached a high degree of quality and use. This declined significantly during the Middle Ages, when the main achievement was “stained glass.” In the 7th century, Syrians developed the “crown” method for forming flat glass, whereby the molten glass was taken in lump form and spun on a cylindrical disc to flatten the glass. Interestingly, this represented the most common method to produce flat glass for the next one thousand years.

In the early part of the 20th century, inexpensive sheet glass was formed by drawing the glass ribbon vertically out of the molten glass pool. Unfortunately, sheet glass still suffered from distortion because of the differences in viscosity of the molten glass. In order to obtain relatively distortion-free glass for use in coach windows or mirrors, the plate glass process was developed. Plate glass was made by pouring molten glass onto a table and rolling it until flattened, then grinding and polishing it into a plate. This process eventually advanced by feeding the molten glass though continuous rollers, grinders and polishers. Sheet glass is no longer commercially produced in the United States.

Float Glass

In 1959, the float glass process was developed. This unique glass making process revolutionized the flat glass industry. In the float process, molten glass flows from the furnace onto a shallow bath of molten tin where a continuous ribbon is formed. The liquid glass floats as it hardens on the bath of liquid tin. The high temperature of the molten metal smooths out the surface, making a flat, even surface. The glass moves under toothed wheels in the hot end of the float bath to alter the thickness and width of the glass ribbon. This glass ribbon is pulled or drawn through the tin bath before being carefully lifted out of the liquid tin and onto conveyor rolls and into the annealing lehr. The job of the lehr is to further cool the glass at a controlled rate to ensure the proper stresses are put into the glass so that it can be cut easily and accurately. The glass is further cooled as it exits the lehr to essentially room temperature. The product is now flat, fire-finished and has virtually parallel surfaces. This is considered annealed glass in terms of strength. A continuous ribbon is maintained from the tin bath up to cutting, which can be ¼ mile long. Automatic cutters are used to trim the edges and cut across the width of the moving ribbon. This creates sizes, which can be shipped or handled for further processing. The float glass process accounts for almost all of the flat glass presently produced in the United States.

Physical and Mechanical Properties of Float Glass

Glass is a brittle material. It will act elastically until it fractures at ultimate load. That ultimate load will vary, depending upon the type and duration of the loads applied and the distribution, orientation and severity of the inhomogeneities and micro-flaws that exist in the surface of the glass. Because of this nature, glass cannot be engineered in the same way as other building envelope materials that have a predictable, specific strength. In those cases, factors are assigned to help assure that glass breakage does not occur at the selected design load.

Because the ultimate strength of glass does vary, its strength can best be described statistically. Architects and engineers who wish to specify a design factor for glass in buildings must choose the anticipated wind load, its duration and the probability of glass breakage (defined as x per 1000 lites of glass at the initial occurrence of the design load). The International Building Code (IBC) references ASTM International (ASTM E1300), which commonly uses a conservative factor of 8 per 1000 for vertical glazing. Refer to *Design Considerations* for further information.

Glass manufacturers can provide the appropriate data for determining the expected performance of their products. However, it remains the responsibility of the design professional to review these performance criteria and determine if they are suitable for the intended application. Table 1 summarizes the average physical and mechanical properties of soda lime float glass produced in North America. For additional values, refer to NGA Glass Technical Paper FM05-12 *Physical and Mechanical Properties of Typical Soda Lime Float Glass*. NGA Glass Technical Paper FM01-08 *Approximate Weight of Architectural Flat Glass* provides approximate weights of architectural flat glass by thickness designation as published by North American manufacturers.

TABLE 1 *Average Physical and Mechanical Properties of Soda Lime Float Glass Produced in North America*

Property	**Definition**	**Typical Value**
Modulus of Elasticity (E)	Mathematical description of an object or substance's tendency to be deformed elastically (i.e., non-permanently) when a force is applied to it. The elastic modulus of an object is defined as the slope of its stress-strain curve in the elastic deformation region.	~ 10.4 x 10^6 psi (71.7 GPa)
Modulus of Rigidity (Shear) (G)	The ratio of shear stress to the shear strain.	~ 4.3 x 10^6 psi (29.6 GPa)
Poisson's Ratio (v)	The ratio, when a sample object is stretched, of the contraction (perpendicular to the applied load), to the extension (in the direction of the applied load).	~ 0.22
Coefficient of Linear Thermal Expansion (α)	The change in the length of an object with a change in temperature. Specifically, it measures the fractional change in volume per degree change in temperature at a constant pressure.	~ 4.6 x 10^{-6} strain per °F (8.3 x 10^{-6} strain per °C)
Density (ρ)	Mass per unit volume of a material.	~ 156 lb/ft^3 (2500 kg/m^3)
Hardness	Characterizes the scratch resistance of various minerals through the ability of a harder material to scratch a softer material.	Knoop's Scale ~ 470 - 605 kg/mm^2
Specific Heat Capacity (C)	A measurable physical quantity that characterizes the amount of heat that is required to change an object's temperature by a given amount.	~ 0.20 - 0.21 Btu/(lb x °F) or ~0.84 - 0.88 J/(kg x K)
Thermal Conductivity (k)	The rate at which heat flows through a material between points at different temperatures, measured in watts per meter per degree.	~ 0.52 - 0.57 Btu/(hr x ft x °F) or ~0.9 - 1.0 W m^{-1} K^{-1}
Chemical Composition	The oxides contained in glass, represented by listing the weight percentages.	Silicon dioxide (SiO_2) 69 - 74% Calcium oxide (CaO) 5 - 12% Sodium oxide (Na_2O) 12 - 16% Magnesium oxide (MgO) 0 - 6% Aluminum oxide (Al_2O_3) 0 - 3%

Property	Definition	Typical Value
Softening Point	That temperature at which a glass fiber of uniform diameter elongates at a specific rate under its own weight when measured by ASTM Test Method C338. The viscosity at the softening point depends on the density and surface tension.	1319 - 1345 °F (715 - 729 °C)
Annealing Point	That temperature corresponding either to a specific rate of elongation of a glass fiber when measured by ASTM Test Method C336, or a specific rate of midpoint deflection of a glass beam when measured by Test Method C598. At the annealing point of glass, internal stresses are substantially relieved in a matter of minutes.	1011 - 1018 °F (544 - 548 °C)
Strain Point	That temperature corresponding to a specific rate of elongation of a glass fiber when measured by ASTM Test Method C336 or a specific rate of midpoint deflection of a glass beam when measured by Test Method 598. At the strain point internal stresses are substantially relieved in a matter of hours.	939 - 952 °F (504 - 511 °C)

Float Glass Color
Commercial clear float glass is nearly colorless, with a visible light transmittance ranging from 75 percent to 92 percent depending on thickness. Clear glass will have a faint green or blue-green color that may be noticeable in glazing applications where the glass thickness approaches or exceeds ⅜ inch (10 mm). Specialty low-iron glass has a higher visible transmittance than commercial clear float glass of the same thickness.

Float glass product quality is addressed in ASTM C1036 *Standard Specification for Flat Glass*.

Tinted/Heat-Absorbing Glass
Tinted or Heat-Absorbing Glass is made by adding various colorants to the normal, clear glass batch to create a desired color. The typical colors produced domestically include bronze, gray, dark gray, aquamarine, green, deep green, emerald green, blue, deep blue and black. Some companies in Europe produce other colors, such as rose. Visible light transmittance will vary from 14 percent to 85 percent, depending on color and thickness. The color density is also a function of thickness. As the thickness increases, visible light transmittance will decrease.

Tinting reduces the solar transmittance of glass and increases solar heat absorption. Because of this heat buildup and resulting thermal stresses, heat-treating (heat-strengthening or tempering) is sometimes required for tinted glass.

The color of tinted or heat-absorbing glass can be a major consideration for either design or aesthetic reasons. It may also be important for color matching requirements. Tinted heat-absorbing glass should always be viewed as installed for color comparison. Colors may vary among different manufacturers and from run to run. No published color standard exists, thus indicating the glass manufacturer should be consulted for color information.

Rolled Glass

Rolled glass is manufactured by passing molten glass from a furnace through a series of rollers to produce the desired thickness and pattern. The rolled glass process is used to create wired glass, figured or patterned glass, and art/opalescent/cathedral glass.

Wired Glass
Wired glass is produced by introducing a welded steel mesh into the molten glass during the rolling process. Wired glass may be further processed by grinding and polishing both surfaces, producing "polished wired glass." The manufacturing process may result in some misalignment of the wire mesh, but this minor imperfection is not generally considered a cause for rejection.

Wired glass is commercially available in two different mesh shapes. A square mesh, sometimes referred to as "Georgian" or "Baroque," has a side dimension of nominally ½ inch (12 mm), while a diamond mesh pattern, sometimes referred to as "Misco," has a side dimension of nominally ¾ inch (19 mm).

Wired glass cannot be heat-treated. For safety glazing purposes it can be laminated with PVB interlayer when the glass is going to be used for aesthetic purposes only. Laminated wired glass for use in a fire-rated application is laminated with a special composition interlayer. The use of traditional PVB or resin to laminate, however, typically voids the fire-rating due to flammability of the interlayer. Wired glass is considered to have approximately 50 percent of the strength of annealed glass of the same size and thickness. Polished wired glass is generally available as clear. Patterned wired glass is available in clear and tint. Tinted wired glass, because of the increased solar radiant heat absorptance, together with reduced edge strength from embedded wire, may produce higher rates of breakage from thermal stress, especially in non-vertical applications.

The major use of polished wired glass is in fire-rated openings. Most building codes require wired glass to meet or exceed the requirements of the National Fire Protection Association's NFPA 80 *Standard for Fire Doors and Fire Windows* standard or to be classified and listed as fire-protection-rated glazing material by an independent certification body, such as Underwriters Laboratory (UL), as a condition to its use in fire windows and fire doors. Polished wired glass is generally classified as a material that passes the 45-minute fire endurance test, as well as the required hose stream test.

Although commercially-available polished wired glass by itself does not meet the impact requirements of Consumer Products Safety Commission's (CPSC) safety standard 16 CFR Part 1201 *Safety Standard for Architectural Glazing Materials*, filmed and laminated versions are readily available that may be tested and certified to comply with CPSC 16 CFR Part 1201.

In locations requiring a 45-minute fire protection rating, wired glass in fire doors and in fire windows is generally limited to a maximum of 1296 square inches (8361 cm^2) and a maximum dimension of 54 inches (1372 mm). When used in 20-minute fire-rated assemblies, wired glass is limited to the maximum size tested. Additionally, the International Building Code generally limits the use of fire-protection-rated glazing in one-hour partitions (corridors) to a maximum of 25 percent of the wall area.

Because the wires are mild steel, they should be protected from moisture which could induce rusting, ultimately leading to breakage of the glass. Installation techniques achieving this protection include glazing into a system that maintains a constantly dry pocket or sealing the edges of wired glass. (For information regarding the use of wired glass in fire-rated locations, please see Fire-Rated Glazing Products.)

Local building code officials should be consulted for applicable building code requirements and for the use of wired glass.

Figured/Patterned Glass
When one or more of the rollers in the rolled glass process has a pattern form on it, figured or textured glass is produced. This glass is typically available in thicknesses of ⅛ inch (3 mm) and 3⁄16 inch (5 mm), or ¼ inch thick (6 mm) for larger sizes that are required to meet loading requirements. Colors also may be available but are extremely limited. This type of glass is also called decorative glass or obscure glass because the pattern of the rollers reproduced on the glass surface diffuses the details of objects viewed through the glass. The degree of diffusion depends upon both the pattern and whether the pattern appears on both surfaces of the glass. Different patterns offer different levels of privacy. Caution should be taken when heat-treating patterned glass because of the variations in thickness and surface area. Bowing tolerances may not be able to be met on some patterns.

Art/Opalescent/Cathedral Glass
Colored translucent glass, often called art glass, opalescent glass or stained glass, is also produced by the rolled glass process, but generally only in small batch-type operations. It is available with variegated colors and each batch is unique in its hue. Thickness will also vary from sheet to sheet, with maximum thickness of ⅛ inch (3 mm). When used as a glazing material, art glass should be glazed in the same manner as tinted/heat-absorbing glass and cannot be heat-treated. Details regarding leaded glass windows and other applications of art glass are not covered in this Manual.

Recyclability of Architectural Glass Products

The float glass process recycles virtually all the glass waste (called cullet) from the in-plant production melting and cutting processes. Float glass manufacturers typically do not recycle post-consumer or pre-consumer recycled cullet from glass fabricators or other sources, primarily due to glass composition differences and possible contamination.

Over one million tons of architectural glass is recycled annually throughout North America. Due to the weight of glass, the proximity between the glass fabricator, the recycler and the end user is important in assessing recyclability. The supply chain begins with a glass fabricator shipping its glass scrap to a recycler. From there, the recycler mechanically cleans, crushes and screens the glass to create a uniform material. This material is generally sold in bulk to an end user or manufacturer, where it is melted for use in a derivative product. Occasionally, a glass recycler grinds the material to a fine powder to sell for use as a filler or an abrasive. The desire for additional recycled glass is high and scrap glass generators have an opportunity to find a better economic alternative to discarding glass in a landfill.

A wide variety of architectural soda-lime glass products can be recycled. Annealed, tempered and low-emissivity (low-e) glass can be recycled with virtually no restrictions; however, other types of glass, such as laminated, mirror, ceramic frit and insulating glass units (IGUs) require additional processing and may not be accepted by all recycling locations. Technology has evolved so that historically harder-to-recycle items, such as laminated glass, back-painted glass, mixed tints and mirror have become routinely recycled as industries have adapted to use these in their manufacturing processes. Technologies and the demand for products are changing rapidly. Finding and communicating with a local, knowledgeable glass recycler helps ensure a successful recycling program.

Many products originate from recycled architectural glass. The primary end users are fiberglass insulation and highway glass bead, which use crushed glass as part of their raw materials. Other end user industries include abrasives, terrazzo countertops and flooring, filtration and filler materials.

Flat Glass Sustainability Initiatives

Environmental Product Declarations (EPDs) allow consumers or design professionals in the building and construction industry to make better-informed decisions about the environmental impacts associated with the building material products chosen for building projects. NGA and its member companies created the industry-wide Flat Glass EPD to better understand their glass products' environmental performance from cradle-to-gate. The NGA industry-wide Flat Glass EPD conforms to the NGA Product Category Rule (PCR) for Flat Glass, published by NSF International in September 2020, which describes the format and requirements for conducting life cycle assessments (LCAs) and creating EPDs for flat glass products.

In general, EPDs may be used to inform and comply with the requirements of green building rating systems and legislative actions. The purpose of an EPD is to provide information on a number of environmental impacts of the product over the life cycle, either cradle-to-gate or cradle-to-grave. EPDs typically rely on estimations of impacts; therefore, the accuracy will differ for any particular product line and reported impact. EPDs are not meant to be comparative assertions and may not be comparable or may have only limited comparability.

The flat glass industry environmental transparency documents can be accessed via NGA Glass Technical Paper FM07-21 *Flat Glass Industry Environmental Transparency Documents*. More information about EPDs can be found in NGA Glass Technical Paper FM06-20 *General EPD Education*.

Fabricated Architectural Glass Products

In addition to primary glass products, there are a number of fabricated glass products available, including heat-treated glass (both heat-strengthened and fully tempered glass), chemically strengthened glass, coated glass, spandrel glass, laminated glass, insulating glass, bent glass, decorative glass, and mirrors. These fabricated products may be used individually, or in combinations, for various architectural applications. Each has its own specific properties and performance characteristics.

Surface Numbers

To assist in describing glass products, illustrations are shown in Figures 4 through 7 that indicate the appropriate surface number(s) to reference, as well as other components of typical fabricated glass products.

Further best practices information for specifying architectural glass constructions, and diagrams of additional glass configurations such as triple insulating glass units and vacuum insulating glass units, are provided in the NGA Glass Technical Paper FB15-07 *Describing Architectural Glass Constructions*.

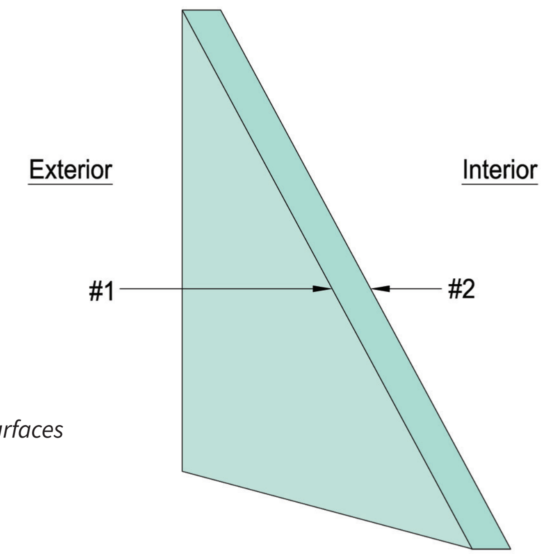


FIGURE 4 *Monolithic Glass Surfaces*

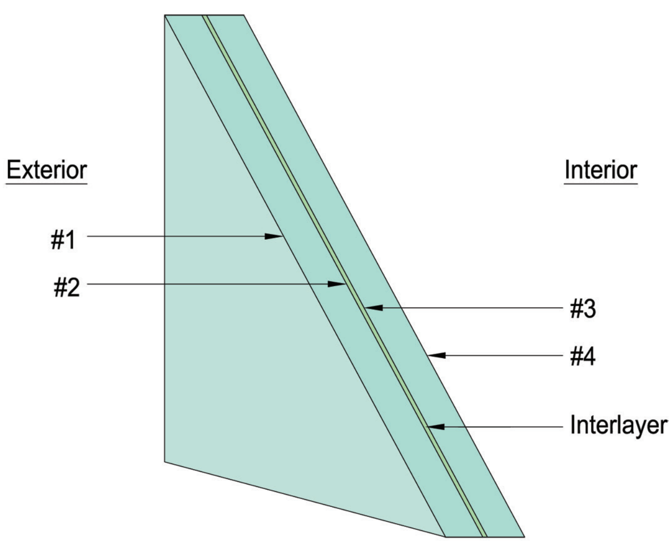


FIGURE 5 *Laminated Glass Surfaces*

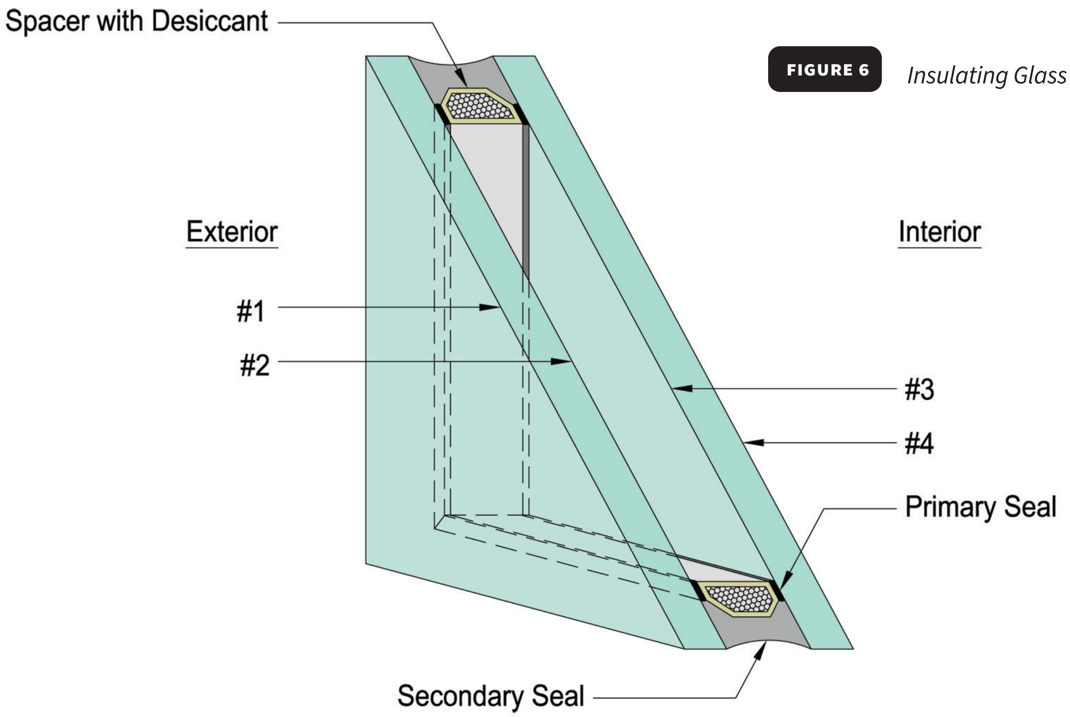


FIGURE 6 *Insulating Glass Unit Surfaces*

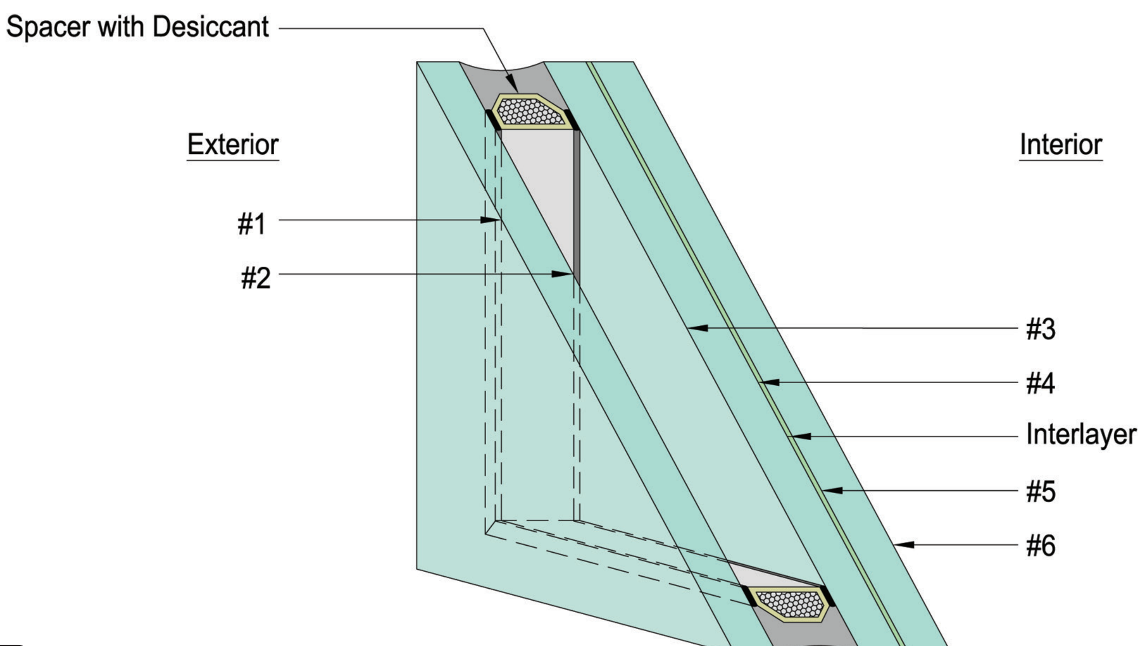


FIGURE 7 *Laminated Insulating Glass Unit Surfaces*

Edgework

Listed in Table 2 are the many types of edgework that can be performed on glass or mirror. The most common edge finishes are ground, smoothed or polished. A ground edge surface exhibits fine linear abrasion marks, a smoothed edge surface has a uniform, frosted appearance, and a polished surface is reflective in appearance, similar to the major surface of glass.

TABLE 2 *Glass Edgework*

Type of Edge Cut	Description of Edge	Common Application
Cut Edge	Raw Cut	Used when edge is not seen, has sharp edges
Swiped Edge	Swipe on top and on bottom	Used when edge is not seen, helps prevent chipping of edges, also helps reduce cutting of hands when handling
Flat Edge	Flat face and arris top and bottom edges	Very popular edge, used on all thicknesses from ¼" to ¾"
Pencil Edge	Semi-round face	Very popular edge, used on all thicknesses from ¼" to ¾". Most popular edge used on mirrors
OG Edge	Scooped top and rolled bottom	Used on glass tabletops: mostly ⅜", ½" and ¾" thicknesses only
OG Bevel	Beveled on top edge of OG	Used on glass tabletops: mostly ⅜", ½" and ¾" thicknesses only
Waterfall Edge	Three rounded edges	Used on glass tabletops: mostly ⅜", ½" and ¾" thicknesses only
Bull Nose Edge	Large rounded top edge	Used on glass tabletops: mostly ⅜", ½" and ¾" thicknesses only
Full Bull Nose Edge	Large round on top and bottom	Used on glass tabletops: mostly ⅜", ½" and ¾" thicknesses only
Miter Edge	45° angle with small edge left	Used on all thicknesses. Most popularly used for glass tabletops, heavy glass shower doors and windows
Bevel Edge	Flat polished face on top	Size of bevel can vary from ½" to 2". Very popular edge used on all thicknesses

Heat-Treated Glass

Annealed float glass products can be subjected to a heat-treating process to provide greater resistance to thermal and mechanical stresses and achieve specific break patterns for safety glazing applications. The architectural glass heat-treating process requires the glass to be cut to the desired size, transported through a furnace and uniformly heated to approximately 1150 °F (621 °C). Upon exiting the furnace, the glass is rapidly cooled (quenched) by blowing air uniformly onto both surfaces simultaneously. The cooling process leaves the surfaces of the glass in a state of high compression, and the central core in compensating tension. As shown in Figure 8, the compression zone is approximately 20 percent of the glass thickness along each face (top, bottom and edges), and the middle 60 percent of the glass thickness is the tension zone.

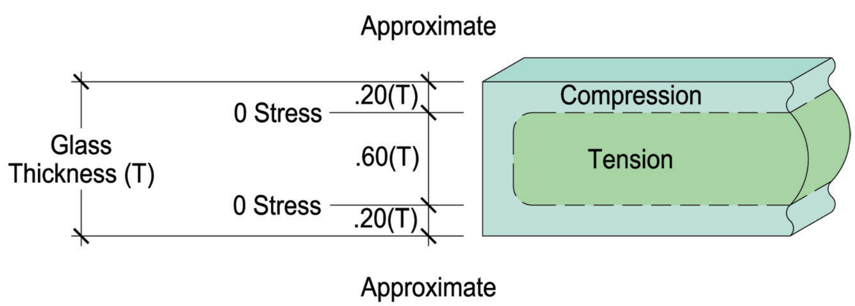


FIGURE 8 *Heat-Treated Glass Compression and Tension Zones*

The color, clarity, chemical composition and light transmission characteristics of glass remain unchanged after heat-treating. Likewise, hardness, specific gravity, expansion coefficient, softening point, thermal conductivity, solar transmittance and stiffness remain unchanged. The only physical properties that change with heat-treating are flexural and tensile strength and resistance to thermal stresses and shock. Under uniform loading, heat-treated glass is stronger than annealed glass of the same size and thickness. Heat-treating glass does not reduce the deflection of the product for any given load condition.

Heat-treated glass is separated into two categories, heat-strengthened glass and fully tempered glass, by the degree of residual surface compression or edge compression. Most furnaces can produce both. A furnace and its quench must be adjusted by the Operator for a run of one or the other. The adjustments may include changes in furnace temperature, exit temperature of the glass, residual time in the furnace, and volume and pressure of the quench air.

Production
There are two basic methods for producing air-quenched heat-treated glass. The most used heat-treating furnace, a horizontal roller hearth, transports glass on horizontal rollers through the heating and quench processes. A very small amount of heat-treated glass may be produced in vertical furnaces, where the glass is held in a vertical position by tongs as it is transported through the heating and quench processes.

Each method produces some degree of bow and warp, which is an inherent characteristic of all heat-treated glass. Tong-held glass, heat-treated through a vertical furnace, may exhibit a long arc or "S" curve plus some minor distortion at the tong points. Horizontally heat-treated glass will have characteristic waves or corrugations caused by the transport rollers. Industry fabrication requirements, product tolerances and testing procedures for heat-treated glass are defined in ASTM C1048 *Standard Specification for Heat-Treated Flat Glass - Kind HS, Kind FT Coated and Uncoated Glass.*

Heat-Strengthened Glass
Heat-strengthened glass is produced with surface and edge compression levels that are greater than annealed glass but less than fully tempered glass, as specified by ASTM C1048. Glass with the compression levels associated with heat-strengthened glass is generally considered twice as strong as annealed glass of the same thickness, size and type. The size and shape of the break pattern of heat-strengthened glass varies with the level of surface and edge compression achieved in the heat-treating process. Heat-strengthened glass with low compression levels will tend to fracture into large fragments, similar to those resulting from annealed glass breakage. As the compression levels increase, the size of the particles of broken glass tend to become smaller.

ASTM C1048 requires that heat-strengthened glass have a surface compression level between 3500 pounds per square inch (psi) and 7500 psi (24 to 52 MPa). The break pattern of heat-strengthened glass is relatively large. The glass pieces typically remain engaged in the glazing pocket, decreasing the probability of fall out. Broken glass should be removed, and the opening should be boarded up or reglazed as soon as possible.

Heat-strengthened glass does not meet the safety glazing requirements of the American National Standards Institute (ANSI) Z97.1 *American National Standard for Safety Glazing Materials Used in Buildings - Safety Performance Specifications Method of Test* or the federal safety standard Consumer Products Safety Commission 16 CFR 1201 *Safety Standard for Architectural Glazing Materials.*

Fully Tempered Glass
Fully tempered glass is required by ASTM C1048 to have either a minimum surface compression of 10,000 psi (69 MPa) or an edge compression of not less than 9,700 psi (67 MPa) or meet ANSI Z97.1 or CPSC 16 CFR 1201. Glass with the higher compression levels associated with fully tempered glass is generally considered four times stronger than annealed glass and twice as strong as heat-strengthened glass of the same thickness, size and type.

When broken by impact, fully tempered glass immediately shatters into relatively small pieces, thereby greatly reducing the likelihood of serious cutting or piercing injuries in comparison with broken annealed glass. To qualify as a safety glazing material as defined by ANSI Z97.1 and CPSC 16 CFR 1201, the ten largest particles taken from a broken fully tempered lite of glass shall weigh no more than the equivalent weight of 10 square inches (64 cm^2) of the original specimen when tested according to the standards. Fully tempered glass that meets ASTM C1048 does not automatically qualify as a safety glazing material for use in hazardous locations. Refer to the Safety Glazing in Hazardous Locations section for additional information.

The break origin of a lite of fully tempered glass may be located as the spot from which break lines radiate in all directions. If the cause of a break is to be determined, it is essential that the break origin be recovered. In many instances the break origin will be lost because the glass does not stay intact post-breakage.

North American fabricators typically offer fully tempered glass in thicknesses of ⅛ inch (3 mm) to ¾ inch (19 mm). To be considered a safety glazing material, standards and building codes typically require that fully tempered glass be permanently labeled with an etched, sandblasted, ceramic-fired or laser logo identifying the fabricator, the glass type and the standard (ANSI Z97.1 and/or CPSC 16 CFR 1201) it meets.

Refer to NGA Glass Technical Paper FB52-17 *Guidelines for the Production of Heat-Treated Architectural Flat Glass* for information on personal protective equipment, general glass processing, handling, cutting, washing, packaging and glass heating/conveying systems.

Design Considerations
Design professionals should be aware of the following considerations when selecting and specifying heat-treated glass products.

Architectural glass fabricators should be consulted to confirm the ability of the specified glass construction to meet the design parameters. Thermal and mechanical stresses in glass, as well as glass deflection, must be reviewed to ensure a successful application. While a heat-treated lite of glass may resist the design wind load, the application may yield a glass deflection that would be psychologically discomforting to persons near the glass. Typically, it is recommended that glass deflection of 1 inch (25 mm) or more be called to the attention of design professionals and building owners for consideration of occupant comfort levels.

The stiffness of annealed, heat-strengthened and fully tempered glass is the same. Deflection under a given uniform wind load will be identical for each strength level of glass of the same size and thickness. Some glazing applications require thicker glass than others due to deflection considerations or limitations.

Heat-strengthened and fully tempered glass cannot be cut, drilled or edged after being heat-treated. Sandblasting, etching or v-grooving is typically executed before the heat-treating process. Some rolled glass with deep patterns cannot be heat-treated. Fabricating glass after it has been heat-treated, such as grinding, sandblasting or etching, may compromise the compression and tension zones of the glass, resulting in a weaker or broken piece of glass. Cutting and drilling heat-treated glass will result in breakage. For further information on heat-treated glass fabrication, consult the NGA Glass Technical Paper FB13-07 *The Importance of Fabrication Prior to Heat-Treatment*.

When viewing heat-treated glass in certain conditions, a pattern of iridescent spots or darkish shadows may become visible. This is called the strain or quench pattern of the glass and is related to the stresses developed in the cooling process. Sharp angles, polarized light, thicker glass and applied coatings increase the visibility of the pattern. The intensity of the strain pattern may vary from lite to lite, and/or within a given lite. The presence of a strain pattern or the perceivable differences in the strain pattern is not a glass defect or blemish and is not normally a cause for rejection. For further information on this aspect of heat-treated glass, consult the NGA Glass Technical Paper FB20-08 *Iridescence Patterns in Heat-Treated Architectural Glass*.

The original flatness of glass is slightly modified by the heat-treating process, causing reflected images to appear distorted. Bow, roll-wave distortion and strain pattern are inherent characteristics of heat-treated glass. While fabricators take steps to minimize these conditions, they cannot be eliminated. Consult ASTM C1048 for additional information.

As a result of hot glass contact with conveyor rollers, some glass surface changes will occur. Minute glass particles (fines) from the glass cutting and edging process, typical manufacturing plant airborne debris or dust, refractory particles from the tempering oven roof, as well as external airborne dirt and grit carried into the plant by the large volumes of quench air used in the process, may adhere to one or both glass surfaces. Also, the physical contact of the soft glass surface with the conveyor rollers may result in a marking or dimpling of the glass surface. These glass surface conditions are typically not visible to the eye under normal viewing conditions. These surface conditions do not threaten the performance characteristics of the product and are not reason for rejection of glass under the current glass quality specification, ASTM C1036 *Standard Specification for Flat Glass.* This standard establishes the size and number of glass imperfections allowed based on specific visual inspection criteria. For further information on surface particles, consult the NGA Glass Technical Paper FB02-02 *Heat-Treated Glass Surfaces are Different*.

Inherent visible characteristics are accentuated by the application of coatings to the glass. The visibility of distortion in solar-control or “reflective” coated glass is greatly affected by surrounding conditions. If the reflected image is of a uniform blue sky, the glass will appear extremely flat. If the same lite of glass is reflecting the multiple gridlines of an adjacent building’s façade, the reflection may appear to be distorted. Surrounding buildings and the level of glass reflectance should be reviewed during the design process. Viewing full-size mock-ups under typical job conditions and surrounding landscape is highly recommended for user evaluation and development of expectations regarding anticipated reflective distortion. The mock-up glass should be retained for future reference.

Currently, there are no industry-wide standards that specify acceptable values for optical distortions; however, there are existing methods/instruments to measure them. Refer to NGA Glass Technical Paper FB18-08 *Methods of Measuring Optical Distortion in Heat-Treated Flat Architectural Glass* for more information on instruments such as surface contact gauges and digital photography methods.

Distortion in glass is not a color or sharpness issue, but an aberration that renders straight lines in an object or image to appear curved. The distortion prevalent in heat-treated glass is often seen as a sequence of concave and convex variations from a flat surface, creating an optical lens power which can be expressed in diopters (D or dpt) or millidiopters. A diopter is a unit of measurement describing the optical power of a lens or curved mirror (1 diopter = 1,000 mdpt). The length of the lens radius defines the lens power of the curved glass and, therefore, the optical distortion in the resultant glass. Refer to NGA Glass Technical Paper FB57-18 *One Optical Number Does Not Fit All* for more information.

Breakage

All heat-treated glass will break when the compression layer is penetrated. Surface or edge damage which does not completely penetrate the compression layer can be slowly propagated through the compression layer through thermal or wind cycling.

There are instances, after installation, of tempered glass breaking due to no apparent cause. This breakage may occur days, months or even longer after the damage has occurred. In these cases of “spontaneous breakage,” it is most often determined that the glass broke due to existing surface or edge damage that severely compromised the ability of the glass to withstand anticipated wind loads or normal building movements; or that glass-to-metal contact combined with movement under wind load initiated the break. In relatively rare instances, the breakage has been traced to the presence of nickel sulfide stones in the center tension zone of the tempered glass.

The majority of heat-treated glass breakages are from one or a combination of the following causes:

- surface or edge damage
- deep scratches or gouges
- severe weld splatter
- missile/windborne debris impact
- glass-to-metal contact
- wind/thermal loading
- inclusions

Nickel Sulfide Inclusions

In the manufacturing of float glass, although unintended, impurities may be introduced into the molten glass. Most of these cause no problem. Some may remain in a solid, opaque state and appear as dirt or other inclusions within the glass. The size and frequency of inclusions allowed are listed in ASTM C1036 and similar international quality standards. With few exceptions, inclusions are considered appearance imperfections only and do not affect the performance of the glass. Nickel sulfide (NiS) inclusions (and a few other extremely rare types of inclusions) are an exception.

Nickel sulfide inclusions may be formed whenever nickel-rich contaminants, such as stainless steel and nichrome wire, are unintentionally introduced into the glass-melting furnace. The nickel may combine with sulfur in the furnace fuel or the batch materials to form nickel sulfide inclusions. In annealed glass, these are harmless and are considered on the same basis as all other inclusions.

Glass manufacturers have implemented procedures and controls to greatly reduce the likelihood of nickel sulfide inclusions.

During the processing of fully tempered glass, nickel sulfide inclusions can be transformed into a state wherein they will expand irreversibly with time and temperature. The expansion may produce sufficient stress to cause spontaneous glass breakage at a later point in time. The expansion of the NiS inclusions is time- and temperature-dependent. Glass that has a high time-weighted average temperature will experience breakage much sooner than glass that is generally cooler, all other items being equal. For tempered glass on the exterior of a building the period of time for the inclusion to reach its ultimate size varies.

Such inclusions can occur at random. Nickel sulfide stones typically range in size between 0.003” and 0.015” (0.076 mm and 0.380 mm) in diameter. This miniscule size precludes the use of practical inspection methods common to the production of float glass. ASTM C1036 permits blemishes (including stones) between 0.020” and 0.100” (0.5 mm and 2.5 mm) in float glass, depending on glass size and quality level. Since nickel sulfide stones can occur in the production of float glass, they may be present in annealed and heat- strengthened glass, as well as in tempered glass. However, due to the much lower center tension of annealed and heat-strengthened glass, they are almost never subject to spontaneous breakage due to nickel sulfide stone inclusions.

The potential risk of spontaneous breakage associated with nickel sulfide inclusions can be minimized by using heat-strengthened glass due to the lower stresses in heat-strengthened glass. Where fully tempered glass is not required by building codes (safety glazing, fire breakouts, etc.) and/or design loads, heat-strengthened glass is normally the preferred product. Heat-strengthened glass will withstand normal thermal stresses resulting from the absorption of solar radiation and other weather-related causes.

Heat Soak Testing of Tempered Glass

The purpose of a heat soak test is to reduce the risk of a spontaneous break by influencing the inclusion to break the glass during the test. It is important to remember a heat soak test may reduce the risk, but will not eliminate the potential, of a spontaneous break due to an inclusion. Specifying heat-soaked tempered glass requires additional processing time for the fabricator since it involves an additional process step. Ensure that there is ample time built into the overall production schedule to accommodate the required processing time; this may also impact the project construction schedule.

Method

There is currently no North American standard for heat soak testing. Some companies in North America perform heat soak testing in accordance with EN 14179-1 *Heat Soaked Thermally Toughened Soda Lime Silicate Safety Glass* or ISO 20657 *Glass in building — Heat soaked tempered soda lime silicate safety glass*. When the heat soak test is performed as specified, there should be very little to no effect on the surface compression of the tempered glass.

Statistical Heat Soak vs. 100% Heat Soak

There is no consensus on using a statistical sampling approach and EN 14179-1/ISO 20657 requires all lites to be heat soaked.

Heat Soak Testing Process

The process of heat soak testing tempered glass is defined in EN14179-1 and ISO 20657. The goal of heat soak testing is to subject the fully tempered glass to high temperatures for an extended amount of time through an additional heating step to accelerate glass breakage caused by potentially harmful inclusions in the glass. The breakage occurs during the heat soak test, thus potentially reducing future glass breakage in the field. The off-line process is a batch process in which fully tempered glass is heat soak tested in a separate oven at some time after the tempering process (see Figure 9).

For additional information, refer to NGA Glass Technical Paper FB56-18 *Heat Soaking Testing of Tempered Glass for Architectural Glass Applications*.

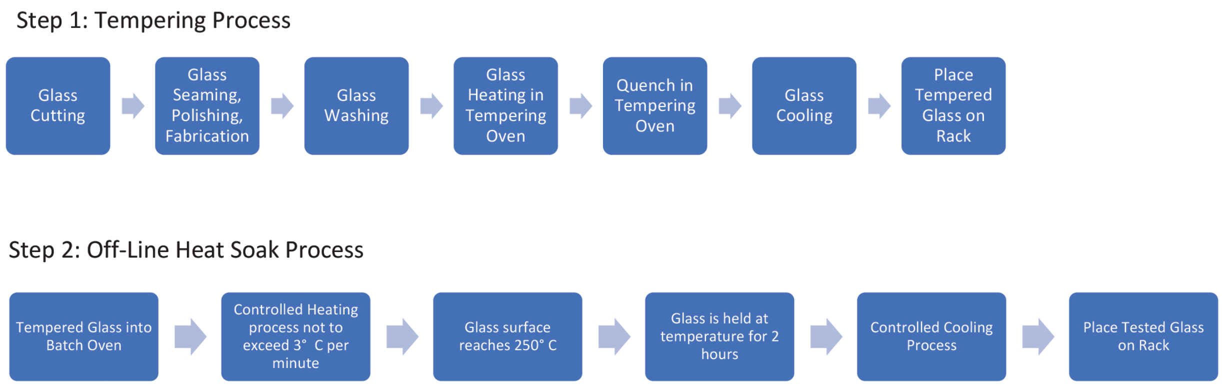


FIGURE 9 *Tempering Process with Off-Line Heat Soak Testing Process*

Pros and Cons of Heat–Treated Glass and Alternatives

The design professional must carefully consider the performance and breakage characteristics of heat-strengthened and fully tempered glass before selecting or specifying either glass type.

In some instances, increasing the thickness of annealed glass may be sufficient to meet certain uniform wind or snow load requirements without the need to heat-treat the glass. It is strongly recommended that a comprehensive wind/snow load analysis and thermal stress analysis be conducted before making a final design decision.

In addition, monolithic lites of annealed glass of any thickness will not meet safety glazing requirements of CPSC 16 CFR Part 1201 (Cat. II) and may not provide adequate thermal stress breakage protection.

As an alternative to fully tempered glass for safety glazing applications, laminated glass is a consideration. Laminated glass is a requirement for overhead glazing and should be considered for applications where glass fallout is a concern. Refer to Table 3 for pros and cons of these glass types.

TABLE 3 *Comparison of Heat-Strengthened, Fully Tempered and Alternative Glass Configurations*

	Pros	Cons
Heat-Strengthened Glass	• Increased resistance to wind and snow loads • Increased resistance to thermal stress • When broken, tends to remain in the frame until removed • Virtually eliminates risk of spontaneous breakage	• Heat-strengthened glass is NOT A SAFETY GLAZING product unless laminated • Increased level of optical distortion compared to annealed glass
Fully Tempered Glass	• May be fabricated to meet safety glazing requirements • Increased resistance to wind and snow loads • Increased resistance to thermal stress	• If broken, small particles, or clusters of particles, or even the majority of the lite, may easily fall out of the frame • Increased level of optical distortion compared to annealed glass • Possibility of spontaneous breakage
Heat-Strengthened Laminated Glass	• Increased resistance to wind and snow loads • Increased resistance to thermal stress • If broken, tends to remain in the frame until removed • Virtually eliminates risk of spontaneous breakage • Reduced sound transmission • Meets safety glazing requirements	• Increased level of optical distortion due to multiple lites of heat-treated glass • Exposed edges will show layers versus a clean monolithic edge
Fully Tempered Laminated Glass	• Increased resistance to wind and snow loads • Increased resistance to thermal stress • Meets safety glazing requirements • Improved glass retention • Reduced sound transmission	• Possibility of spontaneous breakage • Increased level of optical distortion due to multiple lites of heat-treated glass • Exposed edges will show layers versus a clean monolithic edge

Recommended Applications for Heat-Treated Glass

The guidelines offered below are general in nature and are not intended to replace specific and appropriate structural design/engineering practices.

- Vertical Glazing:
  - For vision and spandrel applications above the ground floor, heat–strengthened glass is typically recommended for the exterior lite of an insulating glass unit if annealed glass is not strong enough to resist wind load and/or thermal stresses.
  - For Fireman knockout (fire breakout) panels or other smoke evacuation applications, fully tempered glass is recommended or may be required.
  - For any safety glazing application, fully tempered or laminated glass must be used.

- Overhead or Sloped Glazing:
  - When specifying insulating glass for sloped or overhead glazing applications, heat-strengthened laminated glass is typically recommended for the interior lite facing the public space. Heat-strengthened or fully tempered glass may be used for the exterior, outward-facing lite.

- Doors, Side Lites, Entrances or other Safety Glazing Applications:
  - Fully tempered or laminated glass that meets ANSI or CPSC specifications is required.

- Balcony railings or other applications where fallout is a concern (i.e. where there are unprotected walking surfaces below):
  - Laminated glass is required. Per the International Building Code, glass used in a handrail, guardrail or a guard section shall be laminated glass constructed of fully tempered or heat-strengthened glass and shall comply with Category II of CPSC 16 CFR Part 1201 or Class A of ANSI Z97.1. Glazing in railing in-fill panels shall be of an approved safety glazing material that conforms to the provisions of Section 2406.1.1. For all glazing types, the minimum nominal thickness shall be ¼ inch (6.4 mm).
  - The exception to this is single fully tempered glass complying with Category II of CPSC 16 CFR Part 1201 or Class A of ANSI Z97.1 is permitted to be used in handrails and guardrails where there is no walking surface beneath them, or the walking surface is permanently protected from the risk of falling glass.

- Special Building Code Regions (windborne debris areas):
  - A safety glazing and impact-resistant glass is required to meet the applicable building code requirements.

For any glass application, all design aspects, structural requirements, and building and safety code concerns must be carefully and thoroughly considered before selecting the appropriate product. Refer to NGA Glass Technical Paper FB45-14 *Recommended Applications for Heat-Treated Glass* for more information.

Chemically Strengthened Glass

Chemical strengthening of glass is produced through a process known as ion-exchange. One of the methods used to chemically strengthen glass calls for the lites to be submersed in a molten salt bath at temperatures below the strain point of the glass. In the case of soda-lime float or soda-lime sheet glass, the salt bath consists of potassium nitrate. During the submersion cycle, the larger alkali potassium ions exchange with the smaller alkali sodium ions in the surface of the glass. The larger alkali potassium ions “wedge” their way into the voids in the surface created by the vacating smaller sodium ions.

Chemically strengthened glass production requirements and test procedures are defined in ASTM C1422 *Standard Specification for Chemically Strengthened Flat Glass*. The specification covers the requirements for chemically strengthened glass products, which originate from flat glass for use in building construction, transportation and other specialty applications.

Under the specification, chemically strengthened glass is classified on the basis of independent levels of surface compression and case depth. Increasing levels of surface compression permit an increasing amount of flexure. Greater case depths provide increased protection from strength reduction caused by abuse and abrasion. Consumers should consult with chemically strengthened glass fabricators regarding the recommended surface compression and case depth levels required for their individual application. Product classification levels may be confirmed through laboratory testing in accordance with the specification.

Chemically strengthened glass can be significantly stronger than annealed glass, depending upon the glass product, strengthening process, level of abrasion and the application. Chemically strengthening glass is often the alternative to thermal tempering when applications call for glass that is very thin, small in size or complex in shape.

Although chemically strengthened glass can be cut after treatment, it is not recommended, as edge strength may be reduced to that of annealed glass.

When broken by impact, chemically strengthened glass exhibits a break pattern similar to annealed glass, and, therefore, does not meet safety-glazing requirements in a monolithic form. When safety glazing performance is required, chemically strengthened glass should be laminated.

While chemically strengthened glass is often used monolithically, it can be used in laminated constructions for security, detention, hurricane/cyclic wind-resistant, blast and ballistic-resistant glazing applications.

ASTM C1422 S*tandard Specification for Chemically Strengthened Flat Glass* provides product classification, fabrication and test method for chemically strengthened glass products that originate from flat glass and are used in general building construction, transportation and specialty applications. Classification is based on the laboratory measurements of surface compression and case depth (depth of compression) and not on the modulus of rupture (MOR).

Coated Glass

Flat glass products may be coated to enhance the thermal and optical performance characteristics of products used in residential and commercial glazing and transportation applications. Coatings are typically differentiated by the amount of visible light, ultraviolet (UV), near-infrared wavelengths of energy that are transmitted and reflected, and the reflection of far-infrared (blackbody) radiation.

Low-e coatings have been developed to minimize the amount of infrared (IR) and ultraviolet light that can pass through glass without compromising the amount of visible light transmitted. There are two different types of low-e coatings: passive low-e coatings and solar control low-e coatings.

- Passive low-e coatings are designed to maximize solar heat gain into a home or building to create the effect of “passive” heating and reduce reliance on artificial heating.
- Solar control low-e coatings are designed to limit the amount of solar heat that passes into a home or building for the purpose of keeping buildings cooler and reducing energy consumption related to air conditioning.

Low-emissivity (low-e) coated glass may have various combinations of metal, metal oxide and metal nitride layers of coatings that are nearly invisible to the eye. All low-e coatings reflect long- wave IR energy. What differentiates low-e coatings is the extent to which they reflect (or absorb) the near-infrared part of the solar spectrum as well as reduce the visible light transmission. Long-wave IR can be described as comparable to the radiant heat given off by an electric coil-type heater, as well as the heat that comes from a hot air register. The re-radiated heat from room furnishings, people, walls and glass that have absorbed solar energy is also radiant heat. It is often referred to as “blackbody radiation” and the energy humans feel as heat.

The major benefits of passive low-e coated glass are:

- *Aesthetic Appeal*: the virtually invisible nature of low-e coatings provides a transparent appearance to the glazing material and building façade.

- *Energy Savings*: through its ability to reflect long-wave infrared energy (heat), low-e coated glass reduces winter heat loss and summer heat gain through the glass. Typically low-e coatings (without combining high levels of solar control) have high visible light transmission and therefore provide high levels of visible light transmittance into the building. The combination of thermal conduction control and reduction in interior lighting requirements reduces energy consumption for residential and commercial buildings.

- *Occupant Comfort*: is improved when heat gain/loss is reduced by keeping the interior temperature stable regardless of the exterior environment. Human health and well-being is also improved when there is access to natural daylight and views to the outside.

Solar-Control Coating

The solar spectrum consists of ultraviolet light with wavelengths ranging from 300-390 nanometers (nm), visible light (390-770 nm), infrared (IR) light (770-2100 nm) and far-infrared light (3000 nm to 1 mm). The distribution of energy within the solar spectrum is approximately 2 percent UV, 46 percent visible and 52 percent IR.

Solar-control glass may have a variety of metal coating layers that are highly reflective of solar energy, i.e., those energy wavelengths from 300-2100 nm that constitute the solar spectrum. Some solar-control coatings have low-e properties that support the preferential radiation of absorbed energy outside of the building, as well as contribute to a low U-factor by reducing the conductance of heat through the glass by reflecting the blackbody radiation in the room. Double silver or triple silver low-e coatings on tinted glass are also considered solar control. Electrochromic glass is one example of solar control coatings that are absorptive.

The major benefits of solar-control glass include the following:

- *Aesthetic Appeal:* colors of silver, blue, copper, golden and earth-tone coatings, applied to the wide range of clear and tinted float glass, allow the architect considerable flexibility with exterior design.

- *Energy Savings*: through its ability to reflect, absorb and radiate solar energy, solar reflective glass substantially reduces interior solar heat gain. The added cost of the coating will generally be offset by the reduced size and operating cost of the heating and cooling systems. These coatings typically come with low-emissivity properties, so they help keep heat inside in the winter by reflecting it back into the room.

- *Occupant Comfort*: is improved when heat gain is reduced and interior temperatures are easier to control. In winter, when heating is needed, solar control coatings which have low-emissivity coatings also provide thermal insulation, improving thermal comfort.

For more information on solar-control glass and its effect on heat gain and loss, see the section Thermal Performance.

Coatings within Insulating Glass Units (IGUs)

While some low-e coatings can be used in monolithic or laminated glass constructions, the coatings provide maximum performance when sealed within an insulating glass unit with the coating at an interface with air (or inert gas). The location of the low-e coating within a unit affects the product performance.

Low-e coatings are applied to various surfaces of insulating glass units. Whether a low-e coating is considered passive or solar control, they offer improvements in performance values.

- Passive low-e coatings function best when on the third or fourth surface (furthest away from the sun) and are typically used in heating-dominated climates.

- Solar control low-e coatings function best when on the lite closest to the sun, typically the second surface, and are typically used in cooling-dominated climates. “Far-infrared” radiation or blackbody radiation is the heat that is needed to be kept inside a building during winter and which is reflected back into a room by a low-e surface (preventing heat from escaping).

- For IGU systems designed primarily for thermal performance (U-factor) and not to keep solar energy out (i.e. not for low SHGC), the low-e coating is typically put on the third surface. The placement of the low-e coating on the #3 surface results in a slight increase in the solar heat gain coefficient versus placement on the #2 surface, because any solar energy absorbed by the inner pane will be preferentially re-radiated by the high-emittance surface, which is the room-side surface, thus increasing solar heat gain into the building. But since low-e coatings on surface #3 are typically used in heating-dominated climates, the extra solar heat gain is likely not detrimental to overall energy performance.

- For solar control purposes, when SHGC needs to be low, the coating is placed on the second surface. A low-e coating on the #2 surface of an insulating glass unit is most effective at reducing solar heat gain. This is because any solar energy absorbed will be preferentially re-radiated from the high-emittance surface 1, rather than the low emittance surface #2 where the low-e coating is located.

- Low-e coatings can be applied to tinted glass substrates to further reduce solar heat gain because of additional solar absorption by the tinted glass. In this instance, the tinted pane would typically be the outer pane of the IGU, and the coating would be placed on surface #2—the inside surface of that outer pane. The low-e coating reduces transmittance of the absorbed solar heat by preferentially re-radiating it back out through the exterior, high-emittance surface #1. When using low-e glass in commercial buildings and residential applications in warm climate regions, this is generally the most practical way to maintain comfort levels (see Figure 10).

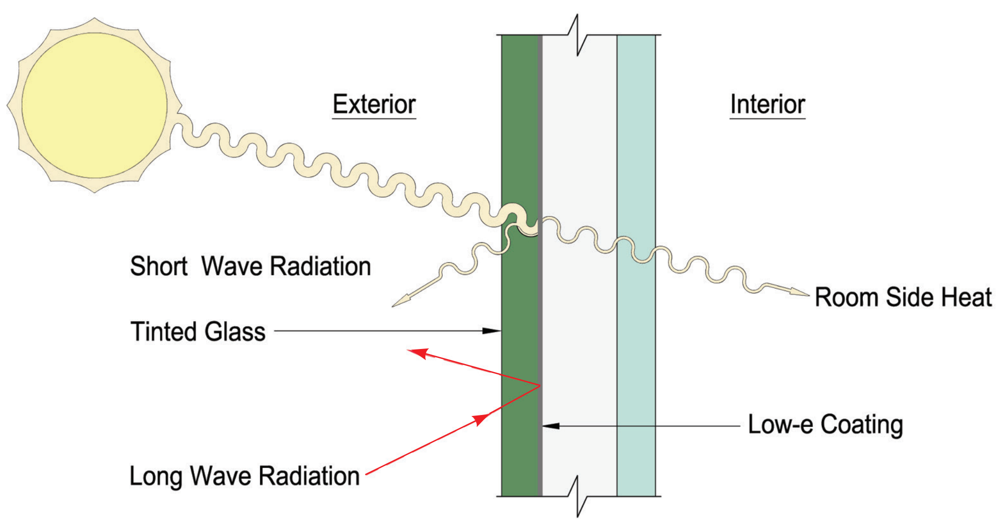


FIGURE 10 *Insulating Glass Unit, Tinted Glass Exterior Lite with Low-e Coating #2 Surface*

- In cold climate regions where building owners and occupants want to maximize solar heat gain from the sun while minimizing radiant heat loss, insulating glass units commonly incorporate clear glass with a low-e coating on the third (#3) surface. The low-e coating reduces heat loss through the glass in winter by reflecting interior long-wave IR back into the home or office (see Figure 11).

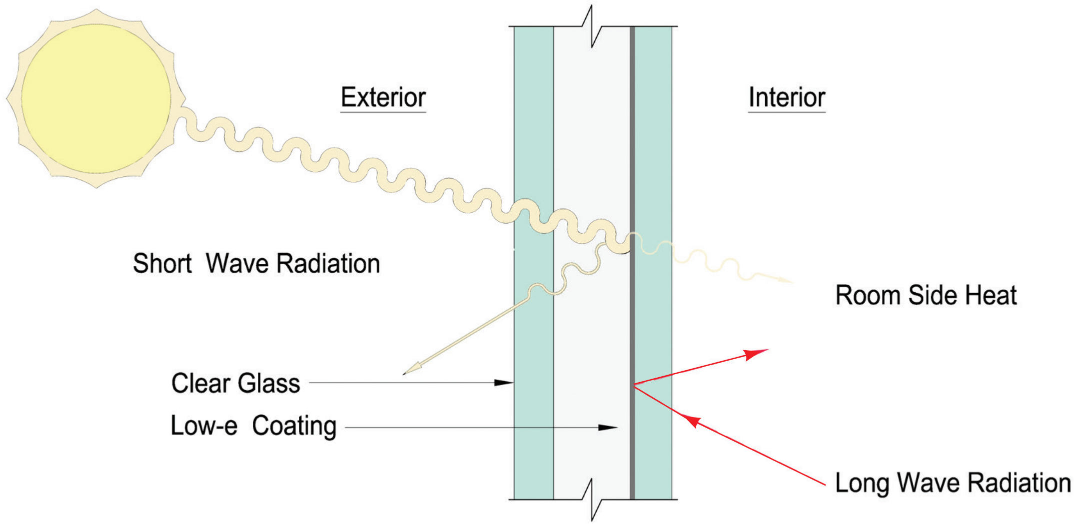


FIGURE 11 *Insulating Glass Unit, Tinted Glass Exterior Lite with Low-E Coating #3 Surface*

- In heating-dominated climates, when combined with a low-e coating on surface #2 (which provides various levels of solar control) an interior surface coating (on surface #4 of dual-pane IGUs or surface #6 of triple-pane), an interior surface coating maximizes thermal performance.

Center-of-glass U-factors in the range of 0.24 - 0.36 BTU/of.hr.ft2 can be achieved with low-e coatings on the second or third surface of insulating glass units. Since technology continues to advance and because the combinations of substrates and coatings are too numerous to list, it is best to consult the coated glass manufacturer's published current literature for comparisons. A generic listing of U-factors of various glazing products is noted in the Design Considerations section in Table 21.

Coating Methods
There are two methods used to manufacture coated glass: vacuum deposition and pyrolytic deposition. Vacuum deposition applies coatings to finished glass products in a large vacuum chamber as a separate stage of fabrication, while pyrolytic deposition applies coatings to hot glass during the flat glass manufacturing process.

Some vacuum-deposited and pyrolytic-deposited solar-control coated products can be used monolithically or fabricated into insulating units or laminated glass. Most vacuum-deposited low-e coated products cannot be used monolithically; they are intended primarily for use in an insulating glass unit with the coating facing the cavity, or in laminated glass constructions where the coating is adjacent to the interlayer.

Applications incorporating a low-e coating on a tinted glass substrate frequently require heat-treating of the lite(s) due to increased thermal absorption and thus thermal stresses associated with the substrate and coating. Glass fabricators should be consulted during the design stages for a thermal stress analysis of the product and application. Heat-treatable low-e coatings are offered, allowing fabrication and heat treatment to occur after deposition of the coating.

Specifications
Coated glasses of the same general color and visible light transmission may not be alike in visible reflectance and other solar-optical properties, solar heat gain coefficient or U-factor. The typical performance specification should state the primary type of glass (clear or tint type), specific type of coating (low-e or solar-control - including the manufacturer's product identification), visible light transmission, solar heat gain coefficient, and winter and summer U-factors for the

center of glass. Alternate bids for glass having different values than specified should have a companion alternate in the mechanical (heating, ventilation and air conditioning) specifications if those values are sufficiently different to affect the size (larger or smaller) of the heating or air-conditioning system.

Non-uniformity in coated glass may be visible within an individual lite, between lites or in replacement products in a particular building, window wall or curtain wall. The specifications should include a provision for construction of a full-size visual mock-up incorporating the glass and framing for viewing and approval by the architect and owner. The mock-up should be located at the construction site, thus giving a preview of the visual qualities, color, distortions, etc., under typical site conditions and surrounding landscape. The uniformity of coatings is addressed in ASTM C1376 *Standard Specification for Pyrolytic and Vacuum Deposition Coatings on Flat Glass*.

Coating Imperfections

The extremely thin nature of the metal layers on coated glass can lead to imperfections in the coated surface. Optical and aesthetic quality requirements for coatings applied to glass are addressed in ASTM C1376 *Standard Specification for Pyrolytic and Vacuum Deposition Coatings on Flat Glass*. Quality specifications and inspection criteria for cut-size coated vision, overhead and spandrel glass are provided in Tables 4, 5 and 6.

Since coatings can be damaged, care should be taken during handling, processing, shipping, storage, installation and maintenance of coated glass products. Glass should be inspected promptly when unpacked at the jobsite and again after installation. Monolithically coated glass can also be damaged as a result of harsh and abrasive cleaners or improper cleaning procedures. See General Guidelines for Glazing section for glass cleaning guidelines. Building owners and contractors should also consult the manufacturer’s recommendations regarding handling, installation, cleaning and maintenance of coated glass products.

Tables 4, 5 and 6 are directly from ASTM C 1376 *Standard Specification for Pyrolytic and Vacuum Deposition Coatings on Flat Glass* and are used with the permission of ASTM International.

TABLE 4 *ASTM C1376- Quality Specification for Cut Size Coated Vision Glass (Kind CV)*

Quality Specifications for Cut Size Coated Vision Glass (Kind CV)[A]

Blemish[B,C]	Central Area, in. (mm)[D]	Outer Area, in. (mm)[D]
Pinhole	1⁄16(1.6) max	3⁄32(2.4) max
Spot	1⁄16(1.6) max	3⁄32(2.4) max
Coating scratch	2 (50) max length	3 (75) max length
Mark/contaminant	2 (50) max length	3 (75) max length
Coating rub	none allowed	length plus width not to exceed ¾ (19)
Crazing	none allowed	none allowed
Corrosion	none allowed	none allowed

[A]These specifications apply to cut size glass only. For specifications of stock size glass contact the manufacturer.

[B]The glass shall be inspected, in transmission, at a distance of 10 ft (3.0 m) at a viewing angle of 90° to the specimen against a bright uniform background. If a blemish is readily apparent under these viewing conditions, the above criteria applies.

[C]No more than two readily apparent blemishes are allowed in a 3-in. (75-mm) diameter circle, and no more than five readily apparent blemishes are allowed in a 12-in. (300-mm) diameter circle.

[D]The central area is considered to form a square or rectangle defined by the center 80 % of the length and 80 % of the width dimensions centered on a lite of glass. The remaining area is considered the outer area.

TABLE 5 *ASTM C1376- Quality Specification for Cut Size Coated Overhead Glass (Kind CO)*

Quality Specifications for Cut Size Coated Overhead Glass (Kind CO)[A]

Blemish[B,C]	Central Area, in. (mm)[D]	Outer Area, in. (mm)[D]
Pinhole	3⁄32(2.4) max	1⁄8(3.2) max
Spot	3⁄32(2.4) max	1⁄8(3.2) max
Coating scratch	3 (75) max length	4 (100) max length
Mark/contaminant	3 (75) max length	4 (100) max length
Coating rub	length plus width not to exceed ¾ (19)	Length plus width not to exceed ¾ (19)
Crazing	none allowed	none allowed
Corrosion	none allowed	none allowed

[A]These specifications apply to cut size glass only. For specifications of stock size glass contact the manufacturer.
[B]The glass shall be inspected, in transmission, at a distance of 15 ft (4.6 m) at a viewing angle of 90° to the specimen against a bright uniform background. If a blemish is readily apparent under these viewing conditions, the above criteria applies.
[C]No more than two readily apparent blemishes are allowed in a 3-in. (75-mm) diameter circle, and no more than five readily apparent blemishes are allowed in a 12-in. (300-mm) diameter circle.
[D]The central area is considered to form a square or rectangle defined by the center 80 % of the length and 80 % of the width dimensions centered on a lite of glass. The remaining area is considered the outer area.

TABLE 6 *ASTM C1376- Quality Specification for Cut Size Coated Spandrel Glass (Kind CS)*

Quality Specifications for Cut Size Coated Spandrel Glass (Kind CS)[A]

Blemish[B,C]	Range Number 1, in. (mm)[D]	Range Number 2, in. (mm)[D]
Pinhole	1⁄8(3.2) max	5⁄32(4.0) max
Spot	1⁄8(3.2) max	5⁄32(4.0) max
Coating scratch	3 (75) max length	6 (150) max length
Mark/contaminant	3 (75) max length	6 (150) max length
Coating rub	none allowed	length plus width not to exceed ¾(19)
Crazing	none allowed	none allowed
Corrosion	none allowed	none allowed

[A]These specifications apply to cut size glass only. For specifications of stock size glass contact the manufacturer.
[B]The glass shall be inspected, in reflection, at a distance equal to or greater than 15 ft (4.6 m) at a viewing angle of 90° to the specimen under uniform lighting conditions. If a blemish is readily apparent under these viewing conditions, the above criteria applies.
[C]No more than two readily apparent blemishes are allowed in a 3 in. (75-mm) diameter circle and no more than five readily apparent blemishes are allowed in a 12 in. (300-mm) diameter circle.
[D]The specifications separates glass by the distance that it will be viewed when installed. Range No. 1 is for all glass within a viewing distance of 15 ft (4.6 m) or less, and Range No. 2 is all glass viewed from a distance greater than 15 ft (4.6 m).

Retrofit Reflective Films
Organic coatings or films can be applied to existing in-place glass to provide a reduction in solar heat gain and glare, or protective glazing characteristics. They are generally a tinted or reflective metallized polyester, adhesive-coated film. These coatings not only reflect but also absorb solar energy. This can cause higher edge stresses in the glass than existed before application of the film, possibly causing glass breakage or insulating glass seal failures which otherwise would not occur.

Before proceeding with a large-scale installation, a comprehensive thermal stress analysis should be conducted to insure against thermal stress breakage.

As a general rule, the following limitations are advisable:

- Consult the glass manufacturer/fabricator prior to applying films to annealed, heat-absorbing (tinted) glass.
- Some manufacturers will void their insulating glass, laminated glass and glass-clad polycarbonate warranties if films are applied.

Dynamic Glazing

A dynamic glazing product is a fenestration product that has the fully reversible ability to change its optical performance properties, such as visible light transmission, near-infrared transmission and solar heat gain coefficient. These properties can change based on the exposure to different stimuli; some change in response to electrical stimuli (electrochromic), others change in response to absorbed sunlight (primarily UV (photochromic)), and some respond to ambient or product temperature (thermochromic). The ability to modulate these properties provides for a building envelope that adapts to the outside environmental conditions (or user requirements) and provides higher energy performance by capturing useful daylight while controlling glare and unwanted solar heat gain.

Dynamic Glazing products are discussed further in NGA Glass Technical Paper FB32-11 *Dynamic Glazing for High Performance Buildings*, and FB63-19 *Products for Energy Applications*.

Spandrel Glass

Spandrel glass is glass that has been rendered near opaque and glazed in wall areas covering structural columns, floors, walls or other building elements that are intended to be concealed from outside view. Its major use is to mask materials or construction from view from the exterior of a building. Such areas are commonly the hung-ceiling area above a vision lite or the knee-wall area below a vision lite. It is sometimes used to hide a column in what is normally the vision-glass area.

The indoor surface of spandrel glass is not intended nor suitable for use as a finished wall, nor to be used as the sole material for light blocking. Additional suitable material, such as sheetrock, must be installed on the indoor side when used in quasi-vision areas such as transom lites, column covers, etc.

While spandrel glass is often used monolithically or in insulating glass units, product usage has increased in laminated constructions for hurricane-impact resistant/cyclic-wind resistant, security and blast-resistant glazing applications. It is recommended for laminated spandrel products to be fabricated with the opacification coating, frit or film on the #4 surface (or innermost surface) of the laminated makeup. (See Surface Designations.)

Thermal Stress in Spandrel Glass
In the case of insulating glass units (IGUs) installed as spandrel glass, the use of opaque paints and enamels, low-e coatings, thick insulation and other energy efficiency elements are creating, in essence, highly efficient solar collectors. As a result, inner lites of the IGU have been known to reach temperatures of 230 °F or more, resulting in center-to-edge temperature differences exceeding 130 °F. These gradients create a large thermal stress which, under certain circumstances, may lead to breakage. In order to reduce the probability of glass breakage due to thermal stresses, spandrel glass should be heat-strengthened according to ASTM C1048 *Standard Specification for Heat-Strengthened*

and Fully Tempered Flat Glass. For further information, refer to NGA Glass Technical Paper FB62-19 *Thermal Stress in Heat-Treated Spandrel Glass.*

Methods of Fabricating Spandrel Glass
The most commonly used methods of rendering spandrel areas opaque are ceramic frit opacification, film opacification, silicone opacification and shadow box opacification.

Ceramic Frit Opacification
Ceramic frit opacification consists of a coating of durable, colored ceramic material that is compatible with the base glass and is fire-fused into one surface of the glass during the heat-treating process. Since the basic purpose is generally to render the glass opaque, the ceramic frit is typically applied to the #2 surface of monolithic glass or the #4 surface of an insulating unit or laminated glass construction. (See Surface Designations.) Ceramic frit opacification is not intended to be used in vision applications or in areas with bright background. The opacity can be improved with thicker or multiple coats of ceramic frit.

Ceramic frit coatings are available in a wide range of colors, and can be a solid color, an applied pattern or digital imagery. The coating can be applied to otherwise uncoated glass or to the interior surface of a pyrolytically-coated solar-control/reflective glass, regardless of which surface has the pyrolytic coating. Light color ceramic frit applications may require a double coat in order to achieve a more uniform appearance.

Glass with a fired-on ceramic frit should not be used except with an opaque backup construction. If it is used where light may be seen through the glass, consultation with the glass fabricator is highly recommended. Pinholes and uneven appearance of the ceramic coating may be visible prior to the completion of the opaque backup construction. These conditions are inherent in the product and are not reason for rejection.

Film Opacification
Film opacification consists of a factory-applied polyester film adhered to the coated surface of vacuum deposition or pyrolytic coated glass by means of a solvent-based adhesive. The polyester opacifier was designed to be adhered to a metal surface and therefore should not be applied to the float glass surface of uncoated monolithic glass or the uncoated inboard lite of an insulating unit. Film-opacified glass fabricators typically recommend against adhering insulation or other materials to the opacifier surface. The fabricator should be consulted for guidelines concerning contact of other spandrel materials with the polyester surface and air space requirements behind the polyester surface.

A lite of glass with complete coverage of polyester film opacifier can be fabricated to meet the optional fallout resistance test contained in ASTM C1048.

For structural silicone glazing applications, the polyester film opacifier must be cut back to allow for structural bonding to the coated glass surface. Glass in this application will not meet the optional fallout resistance test contained in ASTM C1048.

Silicone Opacification
Silicone opacification consists of an elastomeric film of liquid silicone applied to any glass substrate via spray, roller coater or curtain coater. The chemistry utilizes strong bonding to the similarly composed glass substrate for adhesion and durability. Silicone opacifiers are applied after the heat-treating process and may employ a large variety of color and specialty pigments.

The basic purpose of the product is to render the glass opaque, thus it can be applied to both monolithic and insulating glass units. For monolithic applications, the silicone opacification is applied to the #2 surface, and for insulating glass units, to the #2, #3 or #4 surface, depending on the application. Edge deletion is required for most structural silicone glazed applications in order to avoid contact with potentially incompatible adjacent materials. Consult with the opacifier manufacturer and/or fabricator for more details and specific application needs. Edge deletion is required if a silicone coating is used on a surface sealed within an insulating glass unit. Compatibility confirmation should be obtained from the spandrel manufacturer prior to installation. Typically, silicone opacifiers should not contact neoprene or EPDM setting blocks, edge blocks or gaskets.

Consult with the manufacturer for standard application thickness for silicone opacity. Opacity may be improved with thicker or multiple coats of the silicone opacifier. Silicone spandrels may be tested per NGA Specification No. 89-1-69 Rev. #2 – *Specification for Environmental Durability of Heat-Treated Spandrel Glass with Applied Opacifiers*, ASTM C1048, and CAN/CGSB-12.9-M91 – *Spandrel Glass*.

A wide variety of silicone color coatings can be applied to all glass substrates, including especially pyrolytic and select, durable sputter-coated reflective glass substrates, without harming the reflective coating. As with all spandrel products, silicone spandrels should not be used except with an opaque backup construction. If it is used where light may be seen through the glass, consultation with the glass fabricator is highly recommended.

Water-based silicone opacification can be used and certified as “green” for the use in “green” building applications, due to polymer chemistry and pigment usage.

Silicone opacification product performance may vary between manufacturers. Consult with the manufacturer/fabricator to confirm compliance with specification performance requirements.

Shadow Box Opacification
Shadow box opacification is achieved by enclosing the space bounded by the vertical and horizontal mullions behind the glass. This is accomplished by securing a painted metal pan or dark matte-finished insulation board back from the glass. Typically, the inner face of the pan or insulation is flush with the inner plane of the vertical mullions. Shadow box detailing must also ensure that surfaces of the glazing system and surrounding materials have a dark surface to prevent read-through under some lighting conditions.

Spandrel Glass Inspection
ASTM C1376 calls for pyrolytic and vacuum-deposition-coated spandrel glass to be inspected from the exterior at an angle of 90 degrees to the plane of the glass and from a distance equal to or greater than 15 feet. (4.6 m) under uniform lighting conditions and provides specific quality specifications (See Table 6). Inspection should take place after the spandrel cavity is enclosed. While the standard practice for inspection often applies to ceramic frit and silicone opacified spandrel glass, the glass fabricators should be consulted for specific quality specifications.

Spandrel Insulation
Spandrel glazing insulation should have a foil or sheet metal vapor barrier toward the warm side, most commonly the interior of the building, and should be secured in place with foil-backed adhesive tape to create an unbroken vapor barrier. All joints and holes should be securely taped. An alternative is to use the shadow box method, adhering the insulation to a metal pan; the pan then becomes the vapor barrier. If this pan method is used, the outdoor face of insulation should be a dark color to make it less noticeable; there should be some restraining pins or wires to hold the insulation should the adhesive fail; and the perimeter of the pan should be sealed to provide a complete vapor barrier. Use of mechanical retention is also necessary in retaining fire-rated insulation during a fire.

Insulation should not be attached to or be in contact with an opacifying film or silicone coating, since there does not appear to be an applied adhesive that is compatible with the film or silicone in the long term. The insulation should be held back from the surface of the glass at least 1 inch (25 mm), according to the instructions of most glass fabricators.

Attaching insulation to ceramic spandrel glass had long been a custom in the industry, but is no longer recommended for the following reasons:

- Tapes and adhesives in contact with the glass may fail over the long term or may begin to read through the glass because of heat, ultraviolet light or condensation.

- It is very difficult to effectively keep moisture away from the glass/insulation interface, and it is not desirable to allow moisture to collect on the interior coated surface of the glass for sustained periods of time. This is of particular concern with glass having an opacified film. It is recommended that the spandrel cavity be drained/vented to minimize risk of excessive moisture and water accumulation.

The preferred practice is to space the insulation back from the interior face of the glass 1 inch (25 mm) or more, and to secure it such that it will not touch the glass even if it should sag over time or be compressed at the floor line fire-safing. The air space also will improve the thermal properties of the spandrel cavity and help assure an even distribution of heat behind the glass.

Spandrel Glass Design Considerations
Spandrel glazing applications subject the glass and opacification system to extremes in temperature and humidity. The design and specification of spandrel application must consider the following conditions:

- Condensation on the inboard surface, whether it be a glass, ceramic, film or silicone surface, may occur when outdoor temperatures are lower than indoor temperatures, resulting in a vapor pressure across the insulation. Openings in the vapor barrier may permit moisture vapor and/or water migration into the spandrel cavity.

- Construction dirt may accumulate in conjunction with condensation, between the time of glazing and the time insulation is installed, causing staining of the glass or delamination of a film opacifier.

- Volatile components of certain glazing lubricants, gaskets and sealants may condense and damage coatings by themselves or in combination with water, heat or other elements.

- Insulation may have spot contact with the glass, ceramic or filmed surface, resulting in localized discoloring, scum or other residue.

After detailing by the design professional, the appropriate contractors must consult with their material manufacturers to ensure component compatibility. The general contractor should coordinate this activity between the contractors to ensure compatibility of all building components.

Laminated Glazing Materials

The most important characteristic of laminated glass is the ability of the interlayer to support and hold the glass when broken and/or plastic sheet when cracked. This provides for increased protection against glass fragment fallout and penetration of the opening.

Types of Laminated Glazing
Laminated glass is traditionally defined as two or more lites of glass permanently bonded together with one or more interlayers. Laminated plastics (also known as plastic laminates) are two or more lites (or sheets) of rigid polymer sheeting and interlayer bonded together. Laminated glass is typically bonded together under heat and pressure. Laminated glazing can include:

- Two or more lites of glass and one or more interlayers of plasticized polyvinyl butyral (PVB).

- Two or more lites of glass bonded with one or more interlayers of a cured liquid resin. Curing types may differ between cured ultraviolet light, heat or chemicals.

- Two or more lites of glass with an ionomer interlayer.

- Two or more lites of glass and stiff polymer sheeting (such as polycarbonate, acrylic, PET-G etc.) with an interlayer between glass and polymer sheeting. Polycarbonate sheeting is bonded with aliphatic urethane or ethyl vinyl alcohol (EVA) interlayers.

- Two or more lites (or sheets) of stiff polymer sheeting with an interlayer. Polycarbonate sheeting is bonded with aliphatic urethane or EVA interlayers. Acrylic sheeting can be bonded with aliphatic urethane, EVA or specialty grades of PVB.

- Two or more lites and a composite interlayer comprised of polyester (PET) film with a polyvinyl butyral (PVB) interlayer.

Annealed, heat-treated, chemically strengthened, wired, tinted, patterned, spandrel and coated glass, as well as one- and two-way mirrors, can be incorporated into the laminated unit. Refer to NGA Glass Technical Paper FB04-03 *Design Considerations for Laminated Glazing Applications* for information on aesthetic color and visual appearance considerations and temperature performance of laminated glazing.

Quality standards for laminated glass are defined in ASTM C1172 *Standard Specification for Laminated Architectural Glass* and ASTM C1349 *Standard Specification for Architectural Flat Glass Clad Polycarbonate*. Laminated glass for use as safety glazing is covered by ANSI Z97.1, CPSC 16 CFR 1201 and CAN CGSB 12.1.

Laminated Glass Strength
Laminated glass with a PVB interlayer is generally as strong as annealed glass of the same overall nominal thickness depending on exposed temperatures, aspect ratio, plate size, stiffness and load duration. Laminated glass, however, can be made with heat-strengthened, fully tempered or chemically strengthened glass for additional benefits, such as increased wind-load resistance, impact resistance or resistance to thermal stress. The strength of laminated glass increases with glass strengthening in a similar manner as annealed. The ability of the interlayer to resist various kinds of penetration may also be dependent upon interlayer thickness, temperature and other variables. Check with the fabricator for any additional limitations, such as roll distortion, that may result from this additional processing of laminated glass.

There are several grades of PVB, each having different performance properties. Care should be taken to specify the correct grade for a given application. Consult the interlayer manufacturer/glass fabricator for full details.

Building Code Requirements for Laminated Glass
Most building codes require the use of laminated glass for overhead glazing (skylights) used either as a single unit laminate, or as the lower lite in insulating glass units. Laminated glass is also required in glass guards. Other code-driven applications include human impact safety, seismic-resistant, blast-resistant, hurricane/cyclic wind-resistant and sound reduction applications.

Laminated Glass Applications
Laminated glass can provide enhanced levels of security and safety performance properties. These properties may include resistance to ballistics, blast, hurricane/cyclic wind pressures and physical attack. Laminated glass may also have additional desirable properties such as sound reduction, fade resistance, and solar and thermal control. Laminated glazing materials are designed to provide specified levels of performance and can also be used in specialty applications such as aquariums, animal enclosures, glass stairs, floors and sports stadiums.

<u>Safety Glazing</u>
Typical applications for laminated glass include locations where safety glazing is required, such as doors, shower and bath doors and enclosures, operable windows and fixed glazed panels, balconies, railing systems, elevators, sports stadiums, atriums, greenhouses, skylights and sloped glazing.

<u>Glazing Resistant to Earthquakes (Seismic Events)</u>
In seismic events, a building will sway laterally and rack out of plane. In-and-out racking perpendicular to the plane of the wall or window is generally not harmful to most glazing systems. But any racking movement parallel to the face of the wall, to the left or right of nominal, can be more damaging. Test protocols AAMA 501.4 Recommended Static

Test Method for Evaluating Window Wall, Curtain Wall and Storefront Systems Subjected to Seismic and Wind-Induced Inter-Story Drift, and AAMA 501.6 Recommended Dynamic Test Method for Determining the Seismic Drift Causing Glass Fallout from Window Wall, Curtain Wall and Storefront Systems rate glazing for first crack tendencies and delta fallout (the time of glass fallout from the frame during crescendo racking).

The Manual section Glazing Considerations for Systems in Seismic Regions gives guidance on design considerations. Laminated annealed or heat-strengthened glass may have better retention in the frame structure than fully tempered laminated glass due to the inherent characteristics of their break patterns. Refer to NGA Glass Technical Paper FB25-09 *Performance Criteria for Glazing Subjected to Seismic Event*s for more information. The Protective Glazing Manual describes the qualification requirements for seismic events.

Glazing Resistant to Windstorms

Typically, a laminated glass product is used in conjunction with a properly designed frame to pass the hurricane requirements. The size, shape, type and frame material of the fenestration as well as anchoring of the glass and frame to the building all affect the performance of the system in this test. The Protective Glazing Manual describes typical test protocol for windborne debris impact and cyclical tests, including diagrams of impact locations and laminated glazing configurations. Systems are qualified as complete units and should be used in these applications only after verification of system qualification has been diligently completed. Hurricane/cyclic wind-resistant laminates are commonly specified using one or more of the following standards and protocols:

- ASTM E1886 *Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials*
- ASTM E1996 *Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors and Impact Protective Systems Impacted by Windborne Debris in Hurricanes*. Refer also to NGA Glass Technical Paper FB24-09 *Hurricane Product Substitution* for component substitution rules.
- AAMA 506 *Voluntary Specifications for Impact and Cycle Testing of Fenestration Products*
- Florida Building Code – Test Protocols for High Velocity Hurricane Zones
- International Building Code (IBC) and International Residential Code (IRC)
- Texas Building Code
- Texas Department of Insurance
- ICC/NSSA 500 *Standard for the Design and Construction of Storm Shelters* developed by the International Code Council and National Storm Shelter Association

Requirements for storm shelter testing in hurricane-prone areas differ significantly from the requirements for shelters in tornado-prone areas. Refer to NGA Glass Technical Paper FB61-19 *Tornado Resistant Glazing: Standards and Performance Requirements* for more information on testing requirements for the use of impact-resistant glazing in exterior glazed openings of tornado storm shelters.

Security Glazing

Laminated glass may be specified for security applications. Refer to the *Protective Glazing Manual* for the types of protective glazing available, the standards and levels of protection they provide, care and cleaning of protective glazing products, and a comprehensive glossary of terms and applications. General design considerations of laminated glass include the following:

- Thicker interlayers (≥0.060 inch) tend to provide enhanced resistance to penetration from multiple impacts.
- Rigid ionomer interlayers may provide additional performance in high design pressure and high-security applications where lower deflections and higher penetration resistance are required after the glass lites have been broken.
- Composite interlayers with PVB and PET films can provide additional performance in high-security applications where higher penetration resistance is required, reduction in the glass deflection of broken units, or reduction of interlayer tearing are desired. Multiple layers of composite interlayers have proven relatively effective against sustained attack.
- Organic coated glass-butyral consists of at least one lite of glass with its interior or protected surface laminated under heat and pressure to a composite sheet of PVB with a scratch-resistant PET film. Optionally, the organic coated glass-butyral can be applied onto multiple-lite laminated glass. The composite organic coating consists of an abrasion-resistant polyester film combined with a sheet of PVB for factory lamination to glass. The PVB is used to adhere the PET film to the glass surface. The composite must face toward the building's interior. These laminates are generally used in security applications where there is a requirement for zero spalling on the inside of a building or room following attack from the outside.
- Glass-clad polycarbonate contains glass layers to the exterior and one or more polycarbonate layers on the inside. This product combines the heat, chemical and abrasion resistance of glass with the impact resistance of polycarbonate. This laminated construction may also be unbalanced or asymmetrical, where a polycarbonate layer is exposed to the interior. Although not truly a "glass-clad" product, the industry recognizes the product under the same category. Glass-clad polycarbonates provide resistance to forced entry and ballistics and are commonly used in prisons, detention centers, jails, psychiatric facilities and other architectural settings where security is a primary concern.
- The "all polycarbonate" laminate contains no glass and is highly resistant to breaking. It has a mar-resistant surface to protect against cleaning and light abrasion but is more susceptible to abrasion than glass products. Laminated polycarbonates provide resistance to forced entry, ballistics and blast conditions with zero spalling. These applications include prisons, detention centers, jails, psychiatric facilities and other architectural settings where security is a primary concern.
- For additional information, refer to NGA Glass Technical Paper FB43-14 *Security Glazing*.

Blast-Resistant Laminates

Blast-resistant laminates are commonly specified to mitigate injuries from flying glass resulting from an air-blast explosive. All laminated glazing constructions provide some form of protection by holding the fragments together and limiting the likelihood of the glazing coming out of the window framing system. Several governmental agencies have specifications for the use of laminated glazing in buildings. When properly designed, framed and anchored, blast-resistant laminates are capable of maintaining the integrity of the building envelope following an explosion and reducing interior damage. ASTM F1642 *Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings* and GSA-TS01, US General Services Administration *Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings* are used to test window systems with laminated glazing for blast resistance. ASTM F2912 *Standard* Specification *for Glazing and Glazing Systems Subject to Airblast Loadings* can be used to specify blast loads. Designing blast-resistant glazing applications should begin with a risk assessment, and hazard mitigation must be addressed from a full-system approach. Refer to NGA Glass Technical Paper FB12-07 *Blast Resistant Glazing* for more information.

Burglar-Resistant Laminates

Burglar-resistant laminates are covered by Underwriters Laboratories (UL) Standard 972, Burglar Resisting Material, ASTM F1233 *Standard Test Method for Security Glazing Materials and Systems* and ASTM E2395 *Standard Specification for Voluntary Security Performance of Window and Door Assemblies with Glazing Impact*. Burglar-resistant glass typically consists of two lites of glass bonded by an interlayer which is resistant to penetration. UL 972 addresses "smash-and-grab" type burglaries and is considered a minimum-security product. ASTM E2395 and F1233 cover various levels of burglary resistance, from smash-and-grab to full assaults with various tools.

Bullet-Resistant Laminates

Bullet-resistant laminates are covered by UL Standard 752, *Ratings of Bullet-Resistant Materials*, National Institute of Justice (NIJ) Standard 0108.01, Ballistic Resistant Protective Materials and ASTM F1233 *Standard Test Method for Security Glazing Materials and Systems*. UL 752 consists of ten levels covering various weapons, from handguns (Levels 1-3), high-powered rifles (Levels 4-5 single-shot, Levels 6-8 multi-shot, Levels 9-10 single-shot), to supplemental tests for shotguns. This standard calls for no penetration of the projectile through the test specimen and for no spalling of material on the protected side of the test specimen to the extent that fragments embed into or damage to the cardboard indicator.

Bullet-resistant glazing is available in "all glass" configurations or in glass-clad polycarbonate makeups. The thickness and configuration of the product will determine the level of ballistic protection. Bullet-resistant glass is not always considered physical attack-resistant. Consult the manufacturers for full details of specifications and test reports. A full threat assessment should be carried out before specifying the glazing. Refer to NGA Glass Technical Paper FB16-07 *Bullet Resistant Glazing* for more information.

Physical Attack-Resistant Laminates

Physical attack-resistant laminates are specified when architects or building owners require security protection from physical attack, either to keep someone out or, in the case of a detention facility or behavioral center, to keep someone in. Physical attack-resistant laminates consist of multiple layers of glass, multiple layers of polycarbonate, or multiple layers of glass and polycarbonate. The most common configurations are multiple layers of interlayer between glass or glass-clad polycarbonate. Ballistic weakening of glazing in order to achieve forced entry is a mechanism sometimes utilized to gain entry through a secured fenestration. ASTM F3561 *Standard Test Method for Forced-Entry-Resistance of Fenestration Systems After Simulated Active Shooter Attack* provides a test method which can be used to evaluate fenestration against this type of attack. For detention facilities, refer to NGA Glass Technical Paper FB26-10 *Detention Facility Glazing*, and for educational buildings, refer to NGA Glass Technical Paper FB71-21 *School Security Glazing* for more information. The required performance must be specified. One of the following test procedures is usually specified and all contain various levels of attack-resistance for both ballistic and forced entry:

- H.P. White Laboratories HPW-TP-0500.02 – *Transparent Materials for Use in Forced Entry or Containment Barriers*
- ASTM F1233 *Standard Test Method for Security Glazing Materials and Systems*
- Walker-McGough-Foltz & Lyerla (WMFL) 30- and 60-Minute Retention – *Ballistics and Forced Entry Test Procedure*
- ASTM F1915 *Standard Test Method for Glazing of Detention Facilities*

TBALE 7 *Security Selection Quick Reference Summary*

Glazing Penetration Resistance	Basic Safety Glazing	Enhanced	Forced Entry	Forced Entry + Ballistics	Ballistic Protection
Threat to Glazing	Accidental human impact	Simulated weapon impact by 2 x 4	Repeated assaults	Ballistic assault followed by forced-entry impact to gain entry	Ballistic assault using various ammunition classes
Typical Application	Minimum requirements for lobby, entry, first-floor windows and doors	Burglary risk areas	Non-monitored areas; high risk glazing; detention facilities	Very high-risk areas	Ballistic risk areas
Typical Laminate	Two glass layers with interlayer	Two glass layers with minimum 0.060-inch interlayer	Multiple plies of glass and/or polycarbonate with polyurethane interlayer	Multiple layers of glass, interlayers, resins, and/ or plastic materials such as polycarbonate or acrylic	Multiple layers of glass, interlayers, resins, and/ or plastic materials such as polycarbonate or acrylic
Test Standards	ANSI Z97.1; CPSC 16 CFR 1201 ASTM F3006	UL 972	ASTM F3038 ASTM F1915 ASTM E2395 ASTM F1233 (forced entry class)	ASTM F1233 (forced entry plus ballistic class) ASTM F3561	UL 752 NIJ 0108.01
Test Criteria	Glass containment upon breakage	Extended deterrence to entry	Longer duration deterrence	Deterrence time extended	No penetration of witness panel from glass or plastic spall
Table excerpted from NGA Glass Technical Paper FB43-14 *Security Glazing*. For Security Selection guidance for educational occupancies, refer to NGA Glass Technical Paper FB71-21 *School Security Glazing.*					

Solar Control in Laminated Glass

Laminated glass can utilize coated and colored glasses, inserts and specialty PVB interlayers to bring enhanced solar performance to single unit laminated glass or laminated insulating glass units. Enhancement can be found through UV screening, glare reduction, solar absorption, solar rejection, or energy harvesting and conversion. Oftentimes it is a combination of a solar-performing interlayer and coating that brings noticeable performance. Consult the glass or interlayer manufacturers for options.

The section Specific Guidelines for Glazing should be consulted for information regarding glazing material compatibility.

For additional information regarding laminated glazing materials and applications, consult the NGA *Laminated Glazing Reference Manual*. The Manual provides detailed discussions of the following:

- Types of Laminating Interlayers
- Types of Laminated Architectural Glazing Materials
- Applications addressing Safety, Solar Control, Ultraviolet Radiation, Sound Control, Security, Sloped Glazing & Skylights, Windstorm and Hurricane Resistance, Seismic Resistance and Decorative
- Laminated Glass Strength
- Jobsite Receiving and Storage
- Installation, Caulking and Sealants, Maintenance
- Laminated Glazing Guide Specification

Insulating Glass Units
In order to reduce heat gain or loss through glass, two or more lites of glass may be sealed together to create an insulating glass unit (IGU).

The majority of insulating glass units consists of two lites of glass enclosing a hermetically sealed air space. The lites are held apart by a spacer around the entire perimeter. The spacer contains a moisture-absorbent material called desiccant that serves to keep the enclosed air free of visible moisture. The entire perimeter of the assembly is sealed.

The most commonly used edge constructions contain a metallic spacer of roll-formed aluminum, stainless steel, coated steel or galvanized steel. It is sealed with a single seal of polysulfide, polyurethane or hot-melt butyl, or with a dual seal consisting of a primary seal of polyisobutylene (PIB) and a secondary seal of silicone, polysulfide or polyurethane, hot-melt butyl or warm applied reactive sealant. The corners of the metallic spacer may be square-cut and joined with a metal, plastic or nylon corner key, may be miter-cut and brazed, welded or soldered, or may be bent. Recent years have seen the increased use of warm-edge technology products as spacer materials. These products include extruded butyl materials, foam rubber-based materials, formed plastics and metal strip-based products, many with desiccant included as a component. Warm-edge spacer products will improve the Edge-of-Glass U-factor and condensation resistance of a window.

Improvements in edge of insulating glass U-factors as a result of warm-edge technologies can play a vital role in meeting overall window performance requirements for state-adopted residential fenestration codes.

Thermal performance of insulating glass units is enhanced by using solar-control (tinted glass) substrates and coated glass (low-emissivity or solar-control/reflective), coated polyester suspended films, insulating gases (such as argon, krypton or xenon) and warm-edge technology products. Through the use of today's product technology, initial heating and cooling equipment costs and ongoing operating costs are reduced. For information on glazing products and components that designers can use to improve the energy performance of their building envelopes based on their need to optimize U-factor, SHGC, or both, refer to NGA Glass Technical Paper FB63-19 *Products for Energy Application*s and FB49-17 *Performance Improvements in Insulating Glass Units*.

Insulating glass units also offer benefits by reducing sound transmission. Increased glass thickness, laminated glass constructions, increased air space, and using different thicknesses of glass (also known as glazing lite decoupling) further enhance the sound reduction characteristics of the insulating glass unit. For information on glazing products and components that designers can use to reduce sound transmission in IGUs, refer to the section Sound Transmission in this Manual.

Industry product, performance requirements and testing procedures for insulating glass units are defined in the following ASTM International documents:

- ASTM E2188 Standard *Test Method for Insulating Glass Unit Performance*
- ASTM E2189 *Standard Test Method for Testing Resistance to Fogging in Insulating Glass Units*
- ASTM E2190 *Standard Specification for Insulating Glass Unit Performance and Evaluation*

Many insulating glass fabricators voluntarily participate in insulating glass certification programs. The primary purpose of the certification programs is to assure the user that the purchased product is a faithful replica of one that has passed certain prescribed tests. Therefore, participants in a certification program must complete the following requirements: 1) submit specimens of their production product to independent testing laboratories for the prescribed tests; and 2) agree to periodic, unannounced inspections of their regular production by an independent agency to ensure that actual production employs the same materials and techniques as the tested specimen.

The National Glass Association promotes the highest standards in insulating glass unit production, testing, certification and business ethics through their memberships. The industry establishes voluntary quality standards and collects statistical and other non-proprietary information related to field performance of insulating glass for dissemination to manufacturers and consumers.

Design Considerations of Insulating Glass Units

Distortion

The air (or gas) sealed within an insulating glass unit will respond to the gas laws of physics from the moment the unit is sealed. These laws govern the volume of gas as it relates to changes in temperature and pressure. As the sealed-in air is heated or cooled, the gas expands or contracts in volume. As the barometric pressure falls or rises, it likewise expands or contracts. This causes the two lites to bow away from or toward each other. Because of this, objects viewed in reflection will be distorted. The amount of distortion depends upon the amount of deviation from flatness and the pattern and movement of the objects viewed. There is no known method by which the identical internal volume, air temperature and pressure can be achieved in each and every insulating unit for a specific project and still have the advantages of a sealed unit. Distortion will also be evident in units with heat-treated glass and from unequal glazing pressures around the perimeter of the unit.

Capillary Tubes

Transportation of insulating units through or shipments to high elevations may require capillary tubes to allow the unit to adjust to extreme changes in pressure. Individual fabricators should be consulted for capillary tube requirements. Failure to properly handle capillary tubes may void the insulating glass warranty. Refer to joint NGA/FGIA Technical Bulletin TB-1601-95 *Guidelines for Use of Capillary Tubes* for more information.

Material Compatibility

Project specification documents should require that compatibility of all glazing sealants and other components be confirmed with the sealant manufacturers. Failure to use compatible sealants may result in premature failure of insulating glass units and may void the product warranty. Specific Guidelines for Glazing section of this Manual should be consulted for additional information regarding glazing material compatibility.

Glazing Guidelines

Glazing guidelines provided in this Manual and by individual insulating glass unit fabricators should be followed. Failure to properly glaze insulating glass units may result in premature seal failure and may void insulating glass warranties. Insulating glass unit sealants are degraded by prolonged exposure to water or excessive moisture vapor. Avoid improper or inoperative weep systems, which may leave water trapped in the system, causing premature failure of the IGU seals.

Solar-Control Glass
For commercial glazing applications, units with one lite of tinted low-e or reflective coated glass are normally installed with that lite to the exterior. When the tinted low-e or reflective lite is to be installed to the interior, it should be clearly called out in the plans and specifications. A thorough study of thermal stresses may show a need to heat-strengthen one or both lites to withstand thermal stresses and minimize thermal breakage.

Warranties
Since insulating glass unit manufacturers use various combinations of components and fabrication techniques, warranties are seldom exactly alike. Warranties require adherence to certain installation procedures or techniques, while typically excluding glass breakage and the replacement labor.

Vacuum Insulating Glass

Vacuum Insulating Glass (VIG) provides similar or superior thermal performance to conventional double glazing in the thickness of a single glass lite. The air in the space between two lites of glass is extracted to create a vacuum, rather than filled with air or argon, for instance. VIG can be installed in new or retrofit construction, restoration projects and refrigeration applications.

VIG is comprised of two glass lites, typically 0.12 inch to 0.23 inch (3 mm to 6 mm) thick that are hermetically sealed around the edges. The glass may be annealed, heat-strengthened or fully tempered. The air between the two lites is extracted, either through a small pump-out tube (also known as an evacuation port) or by using a vacuum chamber. The glass lites remain separated by pillars (also called microspacers) approximately 0.005 inch to 0.012 inch (0.15 mm to 0.30 mm) thick. The pillars are made of materials such as metal, ceramic or high-temperature plastic and are arranged in a pattern across the surface of the glass. Examples of patterns are a uniform grid or in a pattern spaced wider in the center of the array and closer together toward the edges. The pillars may be glued in place or held in place by the external atmospheric pressure on the glass. The edges (and the pump-out tube if applicable) are sealed to create a permanent vacuum. For units that have a visible glass pump-out tube that protrudes from the glass surface, there may be a safety cap placed over the tube to prevent breakage. VIG units normally include a getter, a reactive material in wire or button form placed within the VIG to continually absorb residual outgas molecules to maintain vacuum over time. A getter may be a separate, visible component or incorporated in another component of the VIG, such as the edge seal.

The absolute pressure of the evacuated cavity is typically in the range of 0.1 Pa (7.5 e^{-4} torr) to eliminate the conductive and convective heat exchange between the two lites of glass. To reduce radiative heat exchange, a low-e coating can be used on one of the internal surfaces of the VIG, typically surface 2. For further details about VIG, refer to NGA Glass Technical Paper FB66-20 *Introduction to Vacuum Insulating Glazing*.

VIG can be installed as a monolithic assembly or as part of an IGU. Hybrid VIG (HVIG) can be used to further reduce U-factor and SHGC. In a hybrid VIG unit, one lite of a standard double glazed IGU is replaced with a VIG. Incorporating a warm-edge spacer, the HVIG can provide excellent thermal performance center and edge of glass. This assembly is particularly suited for standard IGU replacement in typical window and door frames with minimal glazing pocket bite and depth.

Laminated VIG can be used to improve sound control, add protection against impact from wind-borne debris or forced entry and comply with the requirements of safety glazing or for overhead roof windows. In a laminated VIG unit, one of the glass lites of a standard laminate is replaced with a VIG. In these constructions, the lite added to the VIG may be heat-treated, have a low-e coating, or have other properties that improve the thermal or acoustic performance.

Double or triple insulating glazing units using VIG to replace individual glass lites are also possible. The NGA Glass Technical Paper FB72-21 *Introduction to Hybrid VIG Fabrication* highlights areas within the fabrication process that may differ from standard IGU production when incorporating fully fabricated VIGs into an existing line to create hybrid VIGs (HVIG).

The National Fenestration Ratings Council (NFRC) is developing a revised model to determine VIG center-of-glass (U_{cog}) and overall window U-values and has validated VIG modeling of the Lawrence Berkeley National Lab (LBNL) WINDOW and THERM software in accordance with NFRC 100.

Bent Glass

Bent glass is fabricated from flat glass, which has been sufficiently heated to allow for gravity or mechanically forming, then allowed to cool to the desired shape. Advances in the technology of bending glass have enabled glass benders to offer designers and architects a wide variety of options, including large lites of glass that can be bent to compound curves or to several radii with straight legs on one or both ends. Glass can also be bent to relatively sharp angles. Bent glass is available in various types, including annealed, heat-strengthened and fully tempered. Bent glass can be laminated or built into insulating glass units. Pyrolytic solar-control glass and post heat-treatable coated glass can be bent, although the radius of the bend may be limited to avoid crazing of the coating. Lites with baked-on ceramic lines, dots or images, as well as many patterned glasses, may also be bent. Designers and specifiers should check with the fabricator for any product or production limitations prior to ordering.

Mirrors

Silvered Mirrors
Most mirrors for interior use are fabricated using the conveyor, wet deposition method. To clean annealed, heat-strengthened, and fully tempered glass, fabricators apply cleaners and passing contact with oscillating scrub brush units. After the glass is cleaned and rinsed, fabricators sensitize the surface of the glass with a diluted solution of tin chloride. This surface treatment allows for the deposition of silver. Silver nitrate is sprayed onto the sensitized surface of the glass along with other chemical configurations. The final outcome is the formation of a uniform silver layer on the glass.

Once the silver layer is formed on the glass, methods to protect the silver layer from oxidation are employed. A layer of copper can be deposited directly onto the silver. Copper can be applied in two ways: chemically or galvanically. Technological advances have led to the development of a copper-free process which also resists silver oxidation.

Once the metal layers are attached to the glass, they are covered by a protective mirror backing paint. The mirror backing paint is designed to protect the metal layers from corrosion and from mechanical damage. The paint can be applied either by passing the glass through a curtain of paint or by passing glass in contact with a roller paint coater. There are many mirror backing paint products available from a number of suppliers. They offer paint systems that are applied as a single coat or double coat. Both coating systems are effective.

Silvered Tinted Mirrors
Tinted mirrors are produced using the methods described above. The silver coating is applied to one of the various tinted glass substrates available on the market. Tinted mirrors are generally used in decorative applications where color and diminished light reflection are desirable.

Silvered Mirror Quality Specification
Quality standards for silvered annealed monolithic clear and tinted flat glass mirrors are provided in the ASTM C1503 *Standard Specification for Silvered Flat Glass Mirror*. See Reference Standards section for further information.

Silvered Safety Mirrors
Tempered mirrors are manufactured using fully tempered glass as the substrate. There are optical characteristics inherent in tempered mirrors, including roll distortion and the lack of a quality surface for silvering.

Laminated mirror can serve multiple purposes. It can turn a standard mirror into safety glazing material that may 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* or the federal safety standard Consumer Product Safety Commission (CPSC) 16 CFR 1201 *Safety Standard for Architectural Glazing Materials*; it can impart color through the use of tinted glass as the second lite or by using colored interlayers; and it can even protect designs that may be applied to the mirror surface. The key to mirror lamination with traditional interlayers is that the silvered and painted back of the mirror should not be involved in the surface bonding. Any lamination should be done to the front (glass) face of the mirror and not the painted (protected) side. With most interlayer products there is minimal to no adhesion to the painted surface as tested using traditional adhesion tests for laminated glass. There may also be compatibility issues with the various protective coatings used for mirror backs. When laminating mirrors, the cleanliness of the glass, interlayer and mirror is critical because anything that is present will be seen to be at least twice as severe due to the reflective surface of the mirror.

Safety Backed Mirrors are known as Organically Coated Mirrors in the ANSI Z97.1 and CPSC 16 CFR 1201 standards. These are manufactured by applying a sheet of adhesive-backed polyethylene material to the back of annealed mirrors. The backing material does not prevent breakage of mirrors, but lessens the potential of injury on impact by retaining the fragments.

Non-Silvered Mirrors

There are two types of non-silvered mirrors: pyrolytic mirrors and transparent/two-way mirrors.

Pyrolytic mirrors are highly reflective coated glass products with performance characteristics approaching that of silvered mirrors. This product is promoted for use in shower doors and other areas where moisture can affect the substrate of silvered mirrors.

Transparent/two-way mirrors are composed of reflective glass products, and as such are not silver mirrors. Transparent mirrors are manufactured by both the pyrolytic deposition and vacuum deposition coating processes. Heavy-density coatings are offered on clear and gray tinted glass.

Transparent or two-way mirrors are designed to permit vision through one direction while giving the appearance of a standard mirror from the opposite side. Their major application is to permit undetected observation for study or surveillance in interior conditions such as learning centers in schools and universities, medical and psychiatric clinics, police departments, and security stations in casinos or high-traffic retail stores.

The transparent mirrors work by reducing the visible light transmittance through the glass. To ensure proper performance, the room lighting design and surrounding conditions must be carefully planned and executed. The glass surface in the subject room must appear to be standard mirror. In order to achieve this condition, the coated surface should be toward the subject room and the lighting ratios tightly controlled. For applications utilizing clear glass, manufacturers recommend a lighting ratio of 10:1 subject's side to observer's side. If the lighting ratio drops to approximately 5:1, the subject may detect movement or silhouettes through the mirror. If 10:1 lighting ratios cannot be maintained, a gray transparent mirror should be specified. Lighting ratios of 5:1 can be successfully used for gray transparent mirror products.

Design considerations call for bright contrasting colors in the subject room and dark, non-contrasting colors in the observer room. Light-colored surfaces or objects may be noticeable to the subject. The design of the observation room should also prevent sudden light ratio changes. Special care must be taken if transparent mirrors are used on more than one wall.

Decorative Architectural Glass

Decorative architectural glass is a fabricated glass product primarily used for its aesthetic quality due to a physical process, be it mechanical (slumping, forming, molding, etc.) or chemical (etching, imaging, pattern, etc.), that changes the visual properties of the glass appearance. Decorative architectural glass often incorporates annealed, heat-strengthened and fully tempered glass substrates. Decorative architectural glass is fabricated with a variety of processes, utilizing specialized equipment such as tempering ovens, kilns, screen print lines, spray equipment, roller coat equipment, torches, IR/convection ovens, acid etching lines, etc.

Glass that is installed in a building for decorative or artistic purposes is typically exempt from safety glazing requirements according to the model building codes and CPSC 16 CFR Part 1201. For example, IBC identifies glazing in doors as a hazardous location requiring safety glazing but includes exceptions for decorative glazing and glazing materials used as curved panels in revolving doors. Similar exceptions are included in IBC for decorative glazing in sidelites and windows. Refer to the Safety Glazing in Hazardous Locations section for additional information.

Large Glass

Architectural trends emphasize an increasing desire to bring more natural light into the interior environment and unobstructed views with increased spans of glass. As designers adapt to these demands, the size of glass products specified is getting larger. Large glass may be referred to as oversized, jumbo or similar terms. While there is no industry standard defining large glass, there are a number of factors that could be considered such as unit size, total weight (dead load) of the lites, aspect ratio and total unit thickness. Large glass products may exhibit one or more of the following attributes:

- Area over 50 ft^2 (4.6 m^2), or
- Weight over 300 pounds (140 kg), or
- Any single dimension over 144 inches (3660 mm)

When designing large glass units, standard design practices still apply. However, perimeter conditions and deflection should be reviewed more critically than for standard-sized glass units.

A single lite of a large IGU or laminate can be sufficiently heavier or larger than those typically processed by a manufacturer. The challenges of manually lifting or transporting the glass from different operations in the fabrication process should be reviewed prior to processing. The fabricator will need to evaluate existing infrastructure to ensure that crane load capacity, bridge height, and dock well clearance are sufficient to allow receiving of large stock sheet-size glass and shipping of finished fabricated product. Additionally, installation may be challenging for both factory-glazed systems and field-glazed systems for large glass due to the size and weight.

It is important to discuss and review the proper inspection and viewing criteria of large glass products with the fabricator in advance of production to understand acceptable tolerances and areas where the quality of the glass may deviate from what is acceptable with typical-sized glass products. Distortion, surface blemishes, glass size and alignment all may require extra attention to create a product that meets or exceeds the required quality standards.

Typical glass fabrication standards should be followed; if large glass exceeds the scope of the standard, project specifications should be established on a job-by-job basis with the supplier. Evaluating visual mock-ups under typical job conditions and surroundings can be helpful in defining these targets.

Fully Tempered Heavy Glass Doors and Entrances

The all-glass entrance has become increasingly popular with architects and interior designers. These entrance systems are technically not all-glass, but are better described as fully tempered heavy glass incorporating metal rails, small metal fittings and structural silicone. Heavy Glass Doors are discussed further in the Manual section Specific Guidelines for Glazing. Consult the NGA *Heavy Glass Door Design Manual* for additional information.

Reference Standards

The standards referenced in this section are under the jurisdiction of a number of organizations and agencies and are continuously being revised. The documents referenced below were in effect at the time of publication of this edition of *NGA's GANA Glazing Manual.* The design professional should reference the most recent editions of these standards. The following is a list of primary architectural glass product standards. Consult Appendix 4 for a more extensive list of glass and glazing standards.

ASTM C1036 *Standard Specification for Flat Glass* is the industry standard for thickness, dimensional tolerances and characteristics for annealed monolithic flat glass. (Note: this standard superseded Federal Specification DD-G-451D in 1985.) The standard establishes quality requirements for flat transparent, clear and tinted glass intended for use primarily for mirror coatings, glazing and general architectural or similar use; and patterned and wired glass classifications intended for use primarily for decorative and general glazing applications. Specific products may not be available in all quality levels, types, classes, forms or finishes. Design professionals and specifiers should verify availability with their supplier. The standard defines flat glass products by Types, Classes, Forms, Qualities and Finishes as follows:

Type I—Transparent Flat Glass
Class 1—Clear

Quality	Typical Use
Quality – Q 1 (cut-size or stock sheets)	Production of high-quality mirrors.
Quality – Q 2 (cut-size or stock sheets)	Production of general-use mirrors and other applications.
Quality – Q 3 (cut-size or stock sheets)	Production of architectural glass products including coated glass, heat-treated, laminated and other select glass products.
Quality – Q 4 (cut-size or stock sheets)	General glazing applications.

Class 2- Tinted

Quality	Typical Use
Quality – Q 1	Not available
Quality – Q 2 (cut-size or stock sheets)	Production of general-use mirrors and other applications.
Quality – Q 3 (cut-size or stock sheets)	Production of architectural glass products including coated, heat-treated, laminated and other select glazing applications.
Quality – Q 4 (cut-size or stock sheets)	General glazing applications.

Type II—Patterned and Wired Flat Glass
Class 1 - Clear

Class 2 - Tinted

Quality	**Typical Use**
Quality – Q 5	Applications in which design and aesthetic characteristics are major considerations.
Quality – Q 6	Applications in which functional characteristics are a consideration and where blemishes are not a major concern.

Form	**Description**
Form 1	Wired glass, polished both sides
Form 2	Wired glass, patterned surfaces
Form 3	Patterned glass

Finish	**Description**
Finish 1 (F1)	Patterned one side
Finish 2 (F2)	Patterned both sides

Mesh	**Description**
Mesh 1 (M1)	Diamond
Mesh 2 (M2)	Square
Mesh 3 (M3)	Parallel strand
Mesh 4 (M4)	Special

Pattern	**Description**
Pattern 1 (P1)	Linear
Pattern 2 (P2)	Geometric
Pattern 3 (P3)	Random

Allowable blemishes for glass types will differ and are identified as Quality – Q1 through Quality – Q6.

TABLE 8 *ASTM C1036 - Table 3 Allowable Shell Chip Size and Distribution (Type 1 Glass) for Cut Size and Stock Sheet Qualities*

Allowable Shell Chip Size and Distribution (Type I Glass) for Cut Size and Stock Sheet Qualities

Description	Q1	Q2	Q3	Q4
Chip depth	Chip depth ≤ 25 % of glass thickness	Chip depth ≤ 50 % of glass thickness	Chip depth ≤ 50 % of glass thickness	Chip depth ≤ 50 % of glass thickness
Chip width[A]	Chip width ≤ 25 % of glass thickness or 1.6 mm (1⁄16 in.) whichever is greater	Chip width ≤ 50% of glass thickness or 1.6 mm (1⁄16 in.) whichever is greater	Chip width ≤ glass thickness or 6 mm (¼ in.) whichever is greater	Not limited
Chip length[A]	Chip length ≤ 2 times the chip width	Chip length ≤ 2 times the chip width	Chip length ≤ 2 times the chip width	Not limited

[A] For stock sheets, there is no limit for chip width and length.
[B] For a chip located at the corner of a cut size, the chip length shall not exceed te a;owable chip width.

Table 8 is directly from ASTM C1036 Standard *Specification for Flat Glass* and is used with the permission of ASTM International.

TABLE 9 *ASTM C1036 Table 4 Dimensional Tolerances for Rectangular Shapes of Type 1- Transparent Flat Glass*

Dimensional Tolerance for Rectangular Shapes of Type 1 Transparent, Flat Glass[A]

Nominal Designation		Thickness Range				Length and Width Tolerance[A]				Squareness (D1–D2)			
SI Designation[B] mm	Traditional Designation	mm		in.		Cut Size		Stock Sheet		Cut Size		Stock Sheet	
		min	max	min	max	± mm	(± in.)	± mm	(± in.)	mm	(in.)	mm	(in.)
1.0	microslide	0.79	1.24	0.031	0.049	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
1.5	photo	1.27	1.78	0.05	0.07	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
2	picture	1.80	2.13	0.071	0.084	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
2.5	single	2.16	2.57	0.085	0.101	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
2.7	lami	2.59	2.90	0.102	0.114	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
3[C]	double, 1/8 in.	2.92	3.40	0.115	0.134	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
4	5/32 in.	3.78	4.19	0.149	0.165	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
5	3/16 in.	4.57	5.05	0.18	0.199	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
6	1/4 in.	5.56	6.20	0.219	0.244	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
8	5/16 in.	7.42	8.43	0.292	0.332	2.0	(5/64)	6.4	(1/4)	2.8	(7/64)	6.0	(1/4)
10	3/8 in.	9.02	10.31	0.355	0.406	2.4	(3/32)	6.4	(1/4)	3.4	(1/8)	6.0	(1/4)
12	1/2 in.	11.91	13.49	0.469	0.531	3.2	(1/8)	6.4	(1/4)	4.5	(11/64)	10.0	(3/8)
16	5/8 in.	15.09	16.66	0.595	0.656	4.0	(5/32)	6.4	(1/4)	5.7	(7/32)	12.0	(1/2)
19	3/4 in.	18.26	19.84	0.719	0.781	4.8	(3/16)	6.4	(1/4)	6.8	(1/4)	14.0	(9/16)
22	7/8 in.	21.44	23.01	0.844	0.906	5.6	(7/32)	6.4	(1/4)	7.9	(19/64)	16.0	(5/8)
25	1 in.	24.61	26.19	0.969	1.031	6.4	(1/4)	6.4	(1/4)	9.0	(11/32)	18.0	(3/4)

[A] Length and width of cut size and stock sheets of flat glass include flares and bevels.
[B] These designations apply only to ASTM International and may not reflect other international standards.
[C] Within the 3.0 designation there are some applications that may require different thickness ranges such as DST. (Typical minimum thickness for DST is 0.120 in.)

Table 9 is directly from ASTM C1036 Standard Specification for Flat Glass and is used with the permission of ASTM International.

ASTM C1036 should be consulted for additional information on product descriptions, test methods and the following additional tables:

- Allowable Shell Chip Size and Distribution (Type I Glass) for Cut-Size and Stock Sheet Quantities
- Allowable Point Blemish Size and Distribution for Cut-Size Qualities
- Point Blemishes Allowed for Stock Sheets
- Allowable Linear Blemish Size and Distribution for Cut-Size and Stock Sheet Quantities
- Allowable Distortion (Type I Glass) for Cut-Size and Stock Sheet Qualities
- Thickness and Tolerance for Wired Glass
- Thickness and Tolerance for Patterned Glass
- Allowable Blemish Size and Distribution for Cut-Size and Stock Sheet Patterned Glass
- Blemish Intensity Chart

ASTM C1048 *Standard Specification for Heat-Treated Flat Glass - Kind HS, Kind FT Coated and Uncoated Glass* is the industry standard for flat heat-strengthened, fully tempered, coated and uncoated glass used in general building construction. The standard provides fabrication information, dimensional tolerances, overall bow tolerance, and testing information for heat-treated flat glass. It replaced Federal Specification DD-G-1403C in 1985, subsequently withdrawn from use.

The following table from ASTM C1048 provides maximum allowable overall bow for heat-strengthened and fully tempered glass.

TABLE 10 *ASTM C1048 – Table 2 Overall Bow, Maximum*

TABLE 2 Overall Bow, Maximum

Nominal Thickness Desig., mm (in.)	Edge Dimension, cm (in.)											
	0–50 (0–20)	>50–90 (>20–35)	>90–120 (>35–47)	>120–150 (>47–59)	>150–180 (>59–71)	>180–210 (>71–83)	>210–240 (>83–94)	>240–270 (>94–106)	>270–300 (>106–118)	>300–330 (>118–130)	>330–370 (>130–146)	>370–400 (>146–158)
	Maximum Bow, mm (in.)											
3 (⅛)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	. . .	. . .	. . .
3 (⅛) Alternate Method[A]	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	3.0 (0.12)	5.0 (0.20)	6.0 (0.24)	7.0 (0.28)	8.0 (0.31)	10.0 (0.39)	. . .	. . .	. . .
4 (5⁄32)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	. . .	. . .	. . .
5 (3⁄16)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	. . .	. . .	. . .
6 (¼)	2.0 (0.08)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	21.0 (0.83)	24.0 (0.94)
8 (5⁄16)	2.0 (0.08)	2.0 (0.08)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	6.0 (0.24)	8.0 (0.31)	10.0 (0.39)	13.0 (0.51)	15.0 (0.59)	18.0 (0.71)	20.0 (0.79)
10 (⅜)	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	4.0 (0.16)	5.0 (0.20)	6.0 (0.24)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)
12–22 (½ –⅞)	1.0 (0.04)	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	4.0 (0.16)	5.0 (0.20)	5.0 (0.20)	7.0 (0.28)	10.0 (0.39)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)

[A] Values apply to 3 mm (⅛ in.) thickness only when the alternative checking procedure in 10.7.2 is used.

Table 10 is directly from ASTM C1048 *Standard Specification for Heat-Treated Flat Glass – Kind HS, Kind FT Coated and Uncoated Glass* and is used with the permission of ASTM International.

TABLE 11 *ASTM C1048 – Table 1 Length and Width Tolerances*

TABLE 1 Length and Width Tolerances

Nominal Thickness Designation mm (in.)	Plus or Minus mm, (in.)
3 (⅛)	1.6 (1⁄16)
4 (5⁄32)	1.6 (1⁄16)
5 (3⁄16)	1.6 (1⁄16)
6 (¼)	1.6 (1⁄16)
8 (5⁄16)	2.0 (5⁄64)
10 (⅜)	2.4 (3⁄32)
12 (½)	3.2 (⅛)
16 (⅝)	4.0 (5⁄32)
19 (¾)	4.8 (3⁄16)

Table 11 is directly from ASTM C1048 *Standard Specification for Heat-Treated Flat Glass – Kind HS, Kind FT Coated and Uncoated Glass* and is used with the permission of ASTM International.

ASTM C1048 should be consulted for additional information on product fabrication, test methods and product marking. Check the ASTM website, astm.org, for information on the latest edition of the standard.

The *NGA Engineering Standards Manual* is a valuable reference tool that clarifies the proper selection and use of heat-strengthened and fully tempered glass.

ASTM C1172 *Standard Specification for Laminated Architectural Flat Glass* is the industry standard for quality requirements for cut sizes of flat laminated glass consisting of two or more lites of glass bonded with an interlayer material for use in building glazing. Depending on the number, thickness and treatment of plies, as well as the number and thickness of interlayers, the products are intended for glazing applications including but not limited to safety, security, detention, hurricane/cyclic-wind resistance, blast-resistant, bullet-resistant and sound-reduction glazing applications. The standard provides guidelines on the maximum allowable blemishes, maximum bow and warp tolerances, dimensional tolerances, test methods and fabrication information for laminated glass products.

TABLE 12 *ASTM C1172- Table 1 Maximum Allowable Laminating Process Blemishes for Vertical Glazing, in. (mm)*

TABLE 1 Maximum Allowable Laminating Process Blemishes for Vertical Glazing, in. (mm)

NOTE 1—Refer to Specification C1036 for the quality specification for the individual glass lites.

NOTE 2—All imperfections noted should be separated by a minimum of 12 in. (300 mm).

NOTE 3—See 7.12 for method of inspection.

NOTE 4—Laminates with more than two lites of glass may contain proportionally more blemishes.

Blemish	Up to 25 ft² (2.5 m²)		25 to 75 ft² (2.5 to 7.0 m²)		Over 75 ft² (7.0 m²)	
	Central[A]	Outer[A]	Central[A]	Outer[A]	Central[A]	Outer[A]
Boil (Bubbles)	1/16 (1.6)	3/32 (2.4)	1/8 (3.2)	3/16 (4.8)	1/4 (6.4)	1/4 (6.4)
Blow-in; edge boil	[B]	CE 1/4 (6.4) EE 1/16 (1.6)[C]	[B]	CE 1/4 (6.4) EE 3/32 (2.3)[C]	[B]	CE 5/16 (8.0) EE 1/8 (3.2)[C]
Fuse	1/32 (0.8)	1/16 (1.6)	1/16 (1.6)	3/32 (2.4)	3/32 (2.4)	5/32 (4.0)
Hair, lint (single strand)	light intensity[D]	medium intensity[E]	light intensity[D]	medium intensity[E]	medium intensity[E]	medium intensity[E]
Inside dirt (dirt spot)	1/16 (1.6)	3/32 (2.4)	3/32 (2.4)	5/32 (4.0)	1/8 (3.2)	3/16 (4.8)
Lint-areas of concentrated lint	light intensity[D]	medium intensity[E]	light intensity[D]	medium intensity[E]	medium intensity[E]	medium intensity[E]
Separation, discoloration	none	none	none	none	none	none
Short interlayer; un-laminated area; chip	[B]	CE 1/4 (6.4) EE 1/16 (1.6)[C]	[B]	CE 1/4 (6.4) EE 3/32 (2.4)[C]	[B]	CE 1/4 (6.4) EE 1/8 (3.2)[C]
Scuff; streak	light intensity[D]	medium intensity[E]	medium intensity[E]	medium intensity[E]	medium intensity[E]	medium intensity[E]

[A] The *central area* is an area formed by an oval or circle whose axes or diameters, when centered, do not exceed 80 % of the overall dimension. The *outer area* is the area outside of the *central area*.
[B] Not applicable.
[C] CE = covered edge of glass edge bite and EE = exposed edge. (If CE or EE is unknown use CE tolerance.)
[D] *light intensity*—Barely noticeable at 39 in. (1 m).
[E] *medium intensity*—Noticeable at 39 in. (1 m) but not at 10 ft (3 m).

TABLE 13 *ASTM C1172- Table 3 Length and Width Tolerances for Rectangular Shapes of 2-ply Laminated Glass Including Mismatch up to 75 ft²*

TABLE 3 Length and Width Tolerances for Rectangular Shapes of 2-ply Laminated Glass Including Mismatch up to 75 ft²[A]

Laminate Thickness Designation, *t* in. (mm)	Tolerances, in. (mm)[B,C] Transparent Glass	Patterned and Wired Glass	Heat Strengthened and Tempered Glass
t ≤1/4 (t ≤6.4)	+ 5/32, –1/16 (+4.0, –1.6)	+ 5/16 –1/8 (+7.9, –3.2)	+7/32 –3/32 (+5.6, –2.4)
1/4 < t ≤ 1/2 (6.4 < t ≤ 12.7)	+ 1/4, –1/16 (+ 6.4, –1.6)	+ 5/16, –1/8 (+ 7.9, –3.2)	+ 1/4, –1/8 (+ 6.4, –3.2)
1/2 < t ≤ 1 (12.7 < t ≤ 25.4)	+1/4, –1/8 (+ 6.4, –3.2)	+5/16, –1/8 (+ 7.9, –3.2)	+5/16, –1/8 (+ 7.9, –3.2)

[A] For other than 2-ply laminated glass, or laminates larger than 75 ft², contact the laminator for size tolerances.
[B] Size includes cutting and fabrication tolerances as well as mismatch (see 8.5.1).
[C] For exposed edge applications, consult the supplier to determine their capabilities.

TABLE 14 *ASTM C1172- Table 4 Maximum Allowable Overall Bow for Laminated Glass*

TABLE 4 Maximum Allowable Overall Bow for Laminated Glass[A,B]

Edge Dimension, in. (mm)	Laminate Make-up Two Glass Lites of, in. (mm):				
	⅛ to 3⁄16 (3 to 5)	¼ (6)	5⁄16 (8)	⅜ (10)	½ to ⅞ (12 to 22)
0 to 18 (0 to 460)	⅛ (3.2)	1⁄16 (1.6)	1⁄16 (1.6)	1⁄16 (1.6)	1⁄16 (1.6)
Over 18 to 36 (Over 460 to 910)	3⁄16 (4.8)	⅛ (3.2)	3⁄32 (2.4)	3⁄32 (2.4)	1⁄16 (1.6)
Over 36 to 48 (Over 910 to 1220)	9⁄32 (7.1)	3⁄16 (4.8)	5⁄32 (4.0)	⅛ (3.2)	3⁄32 (2.4)
Over 48 to 60 (Over 1220 to 1520)	⅜ (9.5)	9⁄32 (7.1)	7⁄32 (5.6)	3⁄16 (4.8)	⅛ (3.2)
Over 60 to 72 (Over 1520 to 1830)	½ (12.5)	⅜ (9.5)	9⁄32 (7.1)	¼ (6.4)	3⁄16 (4.8)
Over 72 to 84 (Over 1830 to 2130)	⅝ (15.9)	½ (12.7)	11⁄32 (8.7)	5⁄16 (7.9)	¼ (6.4)
Over 84 to 96 (Over 2130 to 2440)	¾ (19.0)	⅝ (15.9)	7⁄16 (11.1)	⅜ (9.5)	9⁄32 (7.1)
Over 96 to 108 (Over 2440 to 2740)	⅞ (22.2)	¾ (19.0)	9⁄16 (14.3)	½ (12.7)	⅜ (9.5)
Over 108 to 120 (Over 2740 to 3050)	1.0 (25.4)	⅞ (22.2)	11⁄16 (17.5)	⅝ (15.9)	½ (12.7)
Over 120 to 132 (Over 3050 to 3350)	...	1.0 (25.4)	13⁄16 (20.6)	¾ (19.0)	⅝ (15.9)
Over 132 to 144 (Over 3350 to 3660)	...	1 ⅛ (28.6)	15⁄16 (23.8)	⅞ (22.2)	¾ (19.0)
Over 144 to 156 (Over 3660 to 3960)	...	1 ¼ (31.8)	11⁄16 (27.0)	1.0 (25.4)	⅞ (22.2)

[A] See 7.10 for measurement method.
[B] For other than 2-ply laminated glass, or laminates with edge dimension greater than 156 in. (3960 mm), contact the laminator.

Tables 12, 13 and 14 are directly from ASTM C1172 *Standard Specification for Laminated Architectural Flat Glass* and are used with permission of ASTM International.

The *NGA Laminated Glazing Reference Manual* is an additional valuable educational tool, as well as a guide to clarify and assist in the proper selection and specification of laminated architectural glazing materials.

ASTM C1349 *Standard Specification for Architectural Flat Glass Clad Polycarbonate* covers quality standards for cut sizes of glass-clad polycarbonate (GCP) for use in buildings as security, detention, hurricane/cyclic wind-resistant, blast-resistant and ballistic-resistant glazing applications. The specification provides product classification, test methods, fabrication information, maximum allowable overall bow and warp, thickness and size tolerances.

ASTM C1376 *Standard Specification for Pyrolytic and Vacuum Deposition Coatings on Flat Glass* provides the optical and aesthetic quality standards for coatings applied to glass using either pyrolytic or vacuum (sputtering) deposition methods to control solar heat gain, energy performance, comfort level, and condensation as well as enhance the aesthetic appearance of a building. The specification provides product classifications, quality standards for coated vision glass, coated overhead glass and coated spandrel glass. The specification addresses blemishes and uniformity related to the coating only. It does not address glass blemishes, applied ceramic frits or organic films.

ASTM C1422 *Standard Specification for Chemically Strengthened Flat Glass* provides product classification, fabrication and test method for chemically strengthened glass products that originate from flat glass and are used in general building construction, transportation and specialty applications. Classification is based on the laboratory measurements of surface compression and case depth and not on the modulus of rupture (MOR).

ASTM C1464 *Standard Specification for Bent Glass* provides the standards for bent glass used in general building construction, furniture, display and various other non-automotive applications. The specification provides product classifications, fabrication information, distortion, potential color variations, test methods, shape tolerances and maximum cross bend and twist deviations.

ASTM C1503 *Standard Specification for Silvered Flat Glass Mirror* provides standards for silvered flat glass mirrors of rectangular shape supplied as cut sizes, stock sheets or as lehr ends and to which no further processing (such as edgework or other fabrication) has been done. The specification addresses quality requirements of silvered annealed monolithic clear and tinted flat glass mirrors up to ¼ inch (6 mm) thick. The mirrors are intended to be used indoors for mirror glazing, for components of decorative accessories or for similar uses. The specification does not address safety glazing materials nor requirements for mirror applications.

ASTM E1300 *Standard Practice for Determining the Load Resistance of Glass in Buildings* describes procedures to determine the load resistance of monolithic or laminated float glass, and combinations of glass types used in a sealed insulating glass unit, exposed to a uniform load of short or long duration, for a specified probability of breakage. The practice applies to vertical and sloped glazing in buildings for which the specified design loads consist of wind load, snow load and self-weight with a total combined magnitude less than or equal to 315 psf (15 kPa). This standard may also be used in conjunction with ASTM F2284 *Standard Practice for Specifying an Equivalent 3-Second Duration Design Loading for Blast Resistant Glazing Fabricated with Laminated Glass*. The ASTM E1300 practice does not apply to other applications including, but not limited to, balustrades, glass floor panels, aquariums, structural glass members, glass shelves, or other products including wired, patterned, sandblasted, drilled, notched, grooved, or glass with surface or edge treatments that alter the glass strength.

ASTM E2190 *Standard Specification for Insulating Glass Unit Performance and Evaluation* is the North American harmonized standard specification intended to provide a basis for evaluating the durability of preassembled, permanently sealed insulating glass units with one or two air spaces and preassembled insulating glass units with capillary tubes intentionally left open or closed. The specification is not applicable to sealed insulating glass units containing a spandrel glass construction due to test method limitations.

ISO Standard 19916-1:2018: *Glass in building- Vacuum insulating glass- Part 1: Basic specification of products and evaluation methods for thermal and sound insulating performance* specifies evaluation methods for thermal and sound insulating performance and test methods for thermal insulation durability.

American National Standards Institute's (ANSI) *National Standard for Safety Glazing Materials used in Buildings - Safety Performance Specifications and Methods of Test,* ANSI Z97.1, establishes specifications and methods of test for the safety properties of safety glazing materials. It is often referenced by building codes as applicable to certain hazardous (human impact) glazed areas not specifically itemized in the Consumer Product Safety Commission's 16 CFR Part 1201.

Consumer Product Safety Commission (CPSC) 16 CFR Part 1201 - *Safety Standard for Architectural Glazing Materials* has preempted those portions of existing state, municipal or local safety glazing laws and codes pertaining to doors, patio doors, shower doors and tub enclosures that are not identical to the federal standard. The federal standard, as well as national, state and local building codes, should be reviewed by the architect and installer to identify all hazardous locations requiring safety glazing and verify compliance of the specified glass to be used in those locations with the provisions of CPSC 16 CFR 1201 and other applicable codes.

National Standard of Canada - *Safety Glazing* CAN/CGSB 12.1 is the Canadian standard, developed by the Canadian General Standards Board (CGSB) for safety glazing installed in Canada.

Labeling

Depending on the application, the type of glass and the governing state or local building code, permanent or removable labels from a manufacturer, distributor or installer may be required on a given lite of glass even if it is not a safety glazing material to be installed in a defined hazardous location. The label is a form of identification and may also serve as a means of certifying code compliance. The required content of the label may vary from jurisdiction to jurisdiction. As all codes are reviewed and modified on a periodic basis, it is essential to check the latest applicable code edition to determine current labeling requirements for glass products to be used on a project. In some jurisdictions, building code officials will waive the labeling requirements and accept affidavits or certifications of compliance from the installer or distributor.

Float Glass

Because cutting and packing processes are highly automated at float glass plants, individual lites are no longer labeled. Shipment of large quantities of cut-to-size lites of float glass to a jobsite will generally arrive in 3000 lb. (1361 kg) to 6000 lb. (2722 kg) steel racks or wooden cases with a label denoting the size, quantity and quality on one end of each case or rack. Smaller cut-to-size quantities will generally be shipped to the jobsite as loose lites or in cases. In this instance, a written statement or affidavit from the glazing contractor stating that the glass meets the specification and has been glazed in accordance with approved construction documents may be acceptable. If not, each lite may have to be labeled, identifying the manufacturer and designating the type and thickness of the glass, such as “annealed, ¼-inch.”

Other Glass Products

The model building codes and most state and local building codes have two sets of labeling requirements. One is for glass installed in defined hazardous locations and another one is for glass products installed in non-hazardous locations. Safety glazing materials installed in hazardous locations must comply with both of these sets. The fire codes require additional labeling of fire-rated glazing materials and frames installed in fire-rated openings must be labeled.

Glass Installed in Hazardous Locations:
With respect to safety glazing materials installed in hazardous locations, the International Building Code requires a label on each lite, specifying the labeler, whether the manufacturer or the installer, and the safety glazing standard (either CPSC 16 CFR 1201 or ANSI Z97.1) with which it complies, in addition to identifying its type and thickness. This safety-glazing label must be acid etched, sand blasted, ceramic fired, embossed or of a type that cannot be removed without being destroyed. There are exceptions: for tempered glass in hazardous locations, the label may be omitted if the building official approves the use of a separate certificate, affidavit or other evidence confirming compliance with the code; and for multi-lite glazed assemblies, with individual lites not exceeding one square foot, only one lite has to be marked with the required labeling identification, but the other lites in the assembly must be marked, “CPSC 16 CFR 1201.”

The CPSC also has regulations governing the labeling of safety glazing, requiring the manufacturer to certify that its safety glazing product complies with the federal standard. This certification may take the form of a separate paper transmitted with the glass or invoice. Typically, the certificate of compliance takes the form of a permanent label on the glass. This federal certification is not a substitute for, but is in addition to, the labeling requirements the building code imposes on all safety glazing materials installed in a hazardous location. The information to be listed on this certificate of compliance includes, but is not limited to, the following:

- The name and category of the standard with which the material complies,
- The business address and telephone number of the safety glazing materials fabricator,
- The identity of, and contact information for, those responsible for maintaining testing records.

The CPSC also provides for the use of electronic means, such as website posting, to certify compliance of safety glazing materials.

Table 15 summarizes current safety glazing labeling requirements of the Safety Glazing Certification Council (SGCC), ANSI Z97.1 Standard, the Federal Standard CPSC 16 CFR Part 1201, Canadian General Standards Board (CAN/CGSB) 12.1 *Safety Glazing* and the International Building Code (IBC). Note that SGCC certified products are also accessible by electronic means at www.sgcc.org/product-search.

TABLE 15 *Safety Glazing Labeling Summary*

	SGCC	ANSI Z97.1	CPSC 16 CFR 1201	CAN/CGSB 12.1	IBC
Label Required	Yes	Yes	Certificate or Label	Yes	Temporary Label; Other Certificate
Manufacturer Name or Logo or Place of Manufacturing	Yes, via a code	Yes	Yes	Yes	Yes
Standard Reference	Yes	Yes	Yes	Yes	
Thickness	Yes				Maybe
Size Class	Yes	Yes		Yes	
Date of Manufacturing			Yes		
Impact Class	Yes	Yes	Yes		
Certification ID#	Yes				
Type of Glass	Yes, via a code				Tempered Yes

Glass Installed in Non-Hazardous Locations
Glass and glazing materials not intended for installation in hazardous locations must bear a label identifying the manufacturer and designating the type and thickness of the glass or glazing material, and, if it is tempered glass, the label must be either acid etched, sandblasted, ceramic fired, embossed, or a type that cannot be removed without destroying it. Tempered spandrel glass labels may be removable paper applied by the manufacturer.

Mirrors
Factories typically imprint their logo and other identifying marks on the painted back surface of stock sheets of mirrors.

Laminated Glass
Laminators generally imprint their permanent labels on one or two corners of each stock sheet of laminated glass. The required content of this label is essentially the same as for fully tempered glass. Specific cut-to-size laminated products are normally imprinted in one corner only. Often, the location of the label can be requested to ensure the permanent label is visible after installation, particularly important for security and specialty products that may be captured in the frame by 1 inch (25.4 mm) or more.

Insulating Glass
Insulating glass certified by the Insulating Glass Certification Council (IGCC) and Insulating Glass Manufacturers Association of Canada (IGMAC) or other certifying agencies should have permanent marks on the glass or spacer indicating the manufacturer, the certified agency of the insulating glass and a date-of-manufacture code. If installed in a hazardous location, it also must comply with the labeling requirements applicable to safety glazing.

Consult the NGA Glass Technical Paper FB11-06 *Marking and Labeling of Architectural Glass* for additional information on labeling requirements.

Safety Glazing in Hazardous Locations

Federal regulation CPSC 16 CFR 1201 *Safety Standard for Architectural Glazing Materials* requires the installation of safety glazing materials in specific locations including doors and in shower and tub enclosures and requires the manufacturer to certify that its safety glazing product complies with this federal standard. In addition, it dictates the tests the glazing material must pass and how those tests are to be conducted.

Typically, the certificate of compliance with this federal safety standard and regulation takes the form of a label on the glass. Certification to CPSC 16 CFR 1201 may, with the approval of the Authority Having Jurisdiction (AHJ) and at the election of the manufacturer, take the form of a separate paper transmitted with the glass or invoice. In whatever form, the certification must include the manufacturer's name, date and place of manufacture, and reference to 16 CFR 1201 Category I or II. If in label form, this federal certification is not a substitute for, but is in addition to, the labeling requirements the state and local building codes impose on all safety glazing materials installed in hazardous location.

The model building codes and many state and local building codes may reference and require compliance with another safety glazing standard, ANSI Z97.1 *Safety Performance Specifications and Method of Test for Safety Glazing Materials Used in Buildings*. ANSI Z97.1 also details the test procedures and performance requirements by which a material may be classified as a safety glazing material. The model building codes then specify the locations in the building where compliant safety glazing must be used.

State and local building codes and the federal safety standard, Consumer Product Safety Commission (CPSC) 16 CFR Part 1201 *Safety Standard for Architectural Glazing Materials*, require safety glazing in specified hazardous applications both in new installations and in replacement glazing.

Most state and local building codes are based on the model building codes, published by the International Code Council (ICC) - International Building Code® (IBC) and the International Residential Code® (IRC). Because each state and local jurisdiction has either adopted a model building code verbatim, modified it in some sections or written completely new sections, it is imperative to consult and be guided by the particular state and local building code applicable where the glass is to be installed. In all cases, however, CPSC 16 CFR 1201 supersedes (preempts) all non-identical safety glazing requirements of state laws and local building codes to the extent they address the same risk of injury as CPSC 16 CFR 1201.

Impact Categories

Both CPSC 16 CFR Part 1201 and ANSI Z97.1 include an impact test and end-point criteria based on the material's condition after the impact. A glazing material is deemed to be safety glazing if any one of the three following conditions occurs following impact:

- The glazing material does not break.
- The glazing material breaks, but no opening (no tear or shear) develops through which a 3-inch (76-mm) solid steel sphere can pass using a horizontally applied force of 4-pound (18 N),
- The glazing material breaks, but the 10 largest particles weigh no more than the weight of 10 square inches (64 square cm) of the original specimen.

The procedure for applying the impact load is basically the same for both standards. For the ANSI test, a 100-pound impactor is swung as a pendulum from two different heights, depending upon the Class rating sought for the product — Class A (height of 48 – 48.5 inches), or Class B (height of 18 -18.5 inches).

For the CPSC test, the impact load is swung as a pendulum from two different heights based on the intended size of the glazing material as installed.

- If the area of the glazing material will not exceed 9 square feet (0.83 square meters), the glazing material is considered a Category I product and the 100-pound impactor is dropped from a height of 18 inches (457 mm).
- If the surface area will be greater than 9 square feet (0.83 square meters) or the glazing is intended to be used in shower doors and enclosures, bathtub doors and enclosures, or sliding glass door assemblies, the glazing material is required to be a Category II product and the 100-pound impact load is dropped from a height of 48 inches (1219 mm).

Table 16 compares the impact height and the resultant impact test load for the different categories of CPSC 16 CFR Part 1201 and classes of ANSI Z97.1.

TABLE 16 *Comparison of CPSC 16 CFR Part 1201 Categories and ANSI Z97.1 Classes*

Impact Height	Impact Height	CPSC 16 CFR Part 1201	ANSI Z97.1
18 inches	150 ft-lbs.	Category I	Class B
48 inches	400 ft-lbs.	Category II	Class A

Hazardous Locations

Federal standard CPSC 16 CFR 1201 mandates safety glazing in all interior and exterior doors and in tub and shower enclosures. Building codes specify additional hazardous locations, such as sidelites and large non-adjacent glazed panels, that must also be glazed with a tested, certified safety glazing material. The provisions of the building codes, noted in Table 17, are minimum requirements. Good judgment, including concerns for personal injury, may suggest other applications where safety glazing should be used even though not required by the codes.

TABLE 17 *Hazardous Locations and Exceptions in the International Building Code (IBC)*

Hazardous Location	Safety Glazing Required	Exceptions - Safety Glazing NOT Required
Glazing in doors	All glazing in doors including fixed and operable panels of swinging, sliding and bifold doors	• Glazed openings in doors through which a 3-inch-diameter sphere will not freely pass • Decorative glazing in doors • Glazing materials used as curved glazed panels in revolving doors • Commercial refrigerated cabinet glazed doors
Glazing adjacent to doors	Glazing in an individual fixed or operable panel adjacent to a door where the nearest vertical edge of the glazing is within a 24-inch (610 mm) arc of either vertical edge of the door in a closed position and where the bottom exposed edge of the glazing is less than 60 inches (1524 mm) above the walking surface	• Decorative glazing adjacent to doors • Glazing separated from the door by an intervening wall or permanent barrier between the adjacent glazing and the door • Glazing adjacent to a closet or storage area door 3 feet (914 mm) or less in depth. Glazing in this application must comply with the criteria for windows, below • Glazing in walls on the latch side of and perpendicular to the plane of the door in a closed position in one- and two-family dwellings or within dwelling units of permanent residences
Glazing in windows	Glazing in an individual fixed or operable panel that meets ALL FOUR of the following conditions: 1. The exposed area of an individual pane is greater than 9 square feet (0.84 m^2) 2. The bottom edge of the glazing is less than 18 inches (457 mm) above the floor 3. The top edge of the glazing is greater than 36 inches (914 mm) above the floor 4. One or more walking surface(s) are within 36 inches (914 mm), measured horizontally and in a straight line, of the plane of the glazing	• Decorative glazing in windows • Glazing with a horizontal rail installed on the accessible side(s) of the glazing 34 to 38 inches (864 to 965 mm) above the walking surface. The rail shall be capable of withstanding a horizontal load of 50 pounds per linear foot (730 N/m) without contacting the glass and be not less than 1½ inches (38 mm) in cross-sectional height • Outboard panes in insulating glass units or multiple glazing where the bottom exposed edge of the glass is 25 feet (7620 mm) or more above any grade, roof, walking surface or other horizontal or sloped (within 45 degrees of horizontal) (0.79 rad) surface adjacent to the glass exterior

Hazardous Location	**Safety Glazing Required**	**Exceptions - Safety Glazing NOT Required**
Glazing in guards and railings	All glazing in guards and railings, including structural baluster panels and nonstructural in-fill panels, at any area or height above a walking surface	No exceptions
Glazing near wet surfaces	Glazing in walls, enclosures and fences containing or facing hot tubs, spas, whirlpools, saunas, steam rooms, bathtubs, showers, or indoor and outdoor swimming pools where the bottom exposed edge of the glazing is less than 60 inches (1524 mm) measured vertically above any standing or walking surface Single glazing and all panes in multiple glazing must be safety glazing	Glazing that is more than 60 inches (1524 mm), measured horizontally and in a straight line, from the water's edge of a bathtub, hot tub, spa, whirlpool or swimming pool
Glazing adjacent to stairways and ramps	Glazing where the bottom exposed edge of the glazing is less than 60 inches (1524 mm) above the plane of the adjacent walking surface of stairways, landings between flights of stairs and ramps	• Guard or handrail is installed on the side of a stairway, landing or ramp and the plane of the glass is greater than 18 inches (457 mm) from the railing • Glazing 36 inches (914 mm) or more measured horizontally from the walking surface
Glazing adjacent to the bottom stairway landing	Glazing that is less than 60 inches (1524 mm) above the landing and within a 60-inch (1524 mm) horizontal arc that is less than 180 degrees (3.14 rad) from the bottom tread nosing	Glazing that is protected by a handrail or guard where the plane of the glass is greater than 18 inches (457 mm) from the guard
Fire department access panels	Tempered glass required, including all panes of insulating glass units	No exceptions

Illustrated Examples of Hazardous Locations
Except as noted, glass in defined hazardous locations must meet the test requirements of CPSC 16 CFR Part 1201. The glass must be specially labeled as complying with this standard.

<u>Required Use of Safety Glazing</u>
The following is an illustrated summary of the locations considered to be hazardous and requiring the use of safety glazing materials.

1. Glass in swinging doors and the sliding and fixed panels of sliding door assemblies (Figure 12. Examples of Doors Requiring Safety Glazing – See Examples B and D) and bi-fold doors.

   Exceptions not requiring safety glazing are:
   i. Glass in openings through which a 3-inch-diameter sphere will not freely pass
   ii. Decorative glazing in doors
   iii. Curved glazed panels in revolving doors
   iv. Doors in commercial refrigerated cabinets

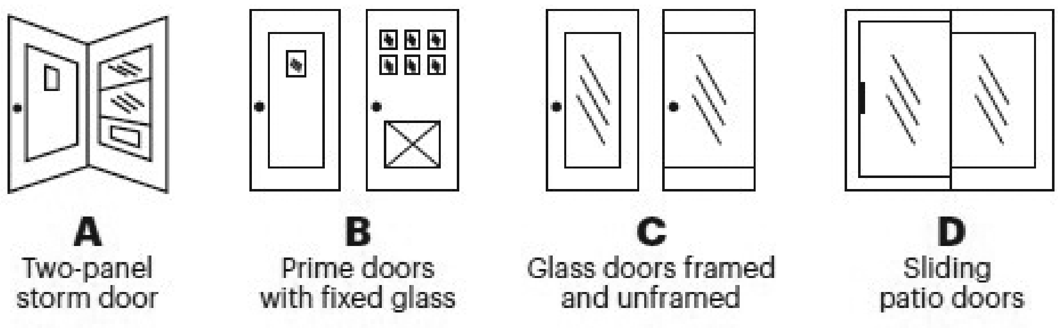


FIGURE 12 *Examples of Doors Requiring Safety Glazing*

2. Glass in storm doors. (Figure 12. Examples of Doors Requiring Safety Glazing – See Example A.)

3. Glass in unframed swinging doors ("all glass" doors). (Figure 12. Examples of Doors Requiring Safety Glazing – See Example C.)

4. Glass in doors and enclosures for hot tubs, whirlpools, saunas, steam rooms, bathtubs and showers, and glass in any portion of the building wall enclosing these compartments where the bottom exposed edge of the glass is less than 60 inches above a normal standing surface.

5. Glass in individual fixed or operable panels adjacent to a doorway where the nearest exposed edge of the glass is within a 24-inch horizontal arc of the edge of the door in a closed position, and the bottom exposed edge is 60 inches or less above the walking surface. (See Figure 13.)

   Exceptions:
   1. i. Does not apply if there is an intervening wall or other permanent barrier between the door and the glass
   2. ii. Glazing in walls perpendicular to the plane of the door in a closed position other than the wall toward which the door swings when opened, in one- and two-family dwellings or within apartments, townhouses, condominiums, dormitories and similar dwelling units)
   3. iii. Curved panels in revolving door assemblies
   4. iv. Sidelites to doors to closets that are less than 3 feet deep must comply with the criteria for windows

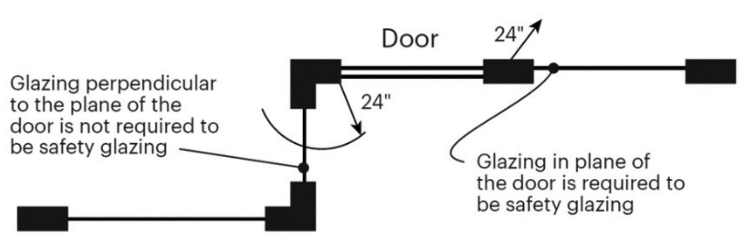


FIGURE 13 *Illustration of Sidelites Requiring Safety Glazing*

6. Glass in individual fixed or operable windows that meet ALL of the following conditions (see Figure 14):
    a. Exposed area of an individual pane is greater than 9 square feet.
    b. Exposed bottom edge of the glass is less than 18 inches above the floor.
    c. Exposed top edge of the glass is more than 36 inches above the floor.
    d. A walking surface is within 36 inches horizontally of the plane of the glass, on one or both sides.

   Exceptions:

    a. Decorative glazing
    b. Safety glass is not required when a protective bar is installed on the accessible side(s) of the glass 34 to 38 inches above the walking surface. The bar must be capable of withstanding a horizontal load of 50 pounds per linear foot without contacting the glass and be a minimum of 1½ inches in cross-sectional height.
    c. The outboard pane in an insulating glass unit or other multi-pane glass, when the bottom edge of the glass is 25 feet or more above any grade, roof, walking surface or any other horizontal or sloped (within 45 degrees of horizontal) surface adjacent to the plane of the glass.

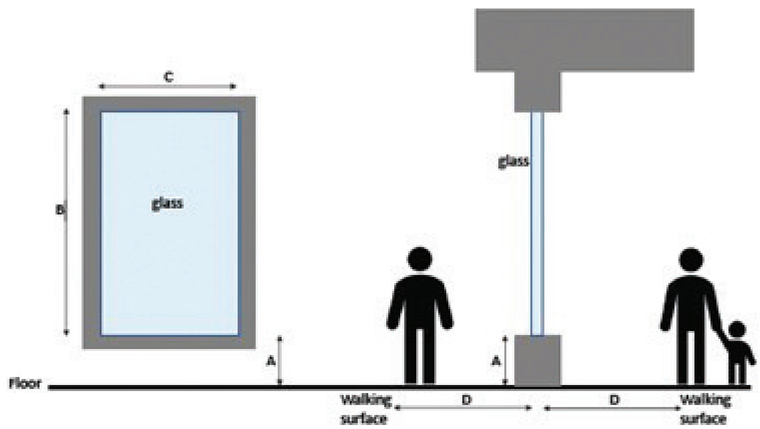


FIGURE 14 *Illustration of Individual Fixed or Operable Panels Requiring Safety Glazing*

Referring to Figure 14, glazing in an individual fixed or operable window panel is a hazardous location if all four of the following conditions are met:

1. B times C is greater than 9 sq. feet. (0.84 sq. m.);
2. A is less than 18 inches (457 mm.)
3. A plus B is greater than 36 inches (914 mm.); and
4. D is less than 36 inches (914 mm.).

All four conditions must be met to be classified as a hazardous location.

7. Glass in railing assemblies, regardless of height above a walking surface (Figure 15). Included are structural baluster panels and non-structural infill panes.

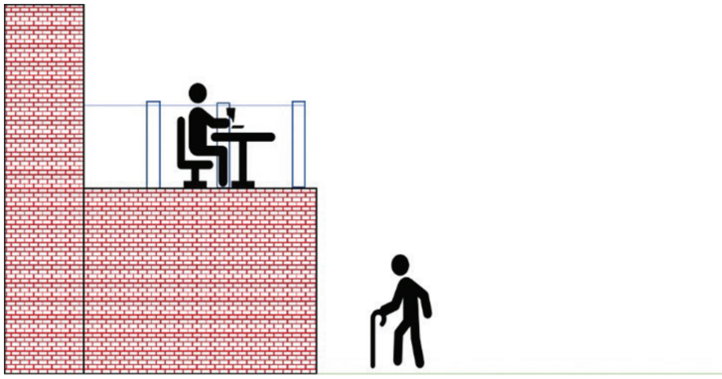


FIGURE 15 *Illustration of Glass in Guardrails Requiring Safety Glazing*

8. Glazing in walls and fences used as barriers for indoor and outdoor swimming pools and spas, bathtubs, shower enclosures and other potentially wet areas when both of the following conditions are met:
    a. Bottom edge of the glass is less than 60 inches above the walking surface on the pool/spa side of the glass.
    b. Glass is within 60 inches horizontally of the water's edge of the pool or spa.

9. Glass adjacent to stairways and ramps if both a and b are met. The net effect of this is that safety glazing is required along the wall of the stairway or ramp (see Figure 16):
    a. Glazing is within 36 inches horizontally of an adjacent walking surface.
    b. Glazing is less than 60 inches above the adjacent walking surface, or stairway

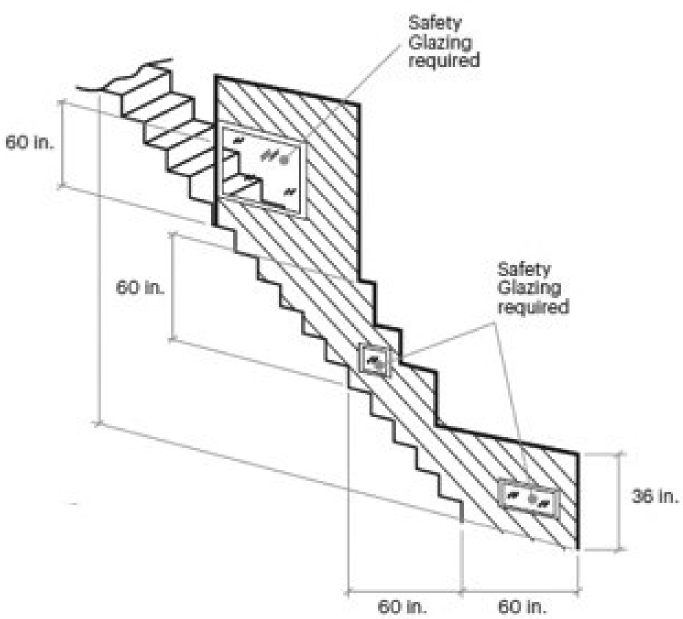


FIGURE 16 *Safety Glazing Near Stairways, Ramps and Landings*

Exception:

a. Glass along the side of a stairway where a guard or handrail, as defined by the code, is provided, when the plane of the glass is greater than 18 inches from the railing.

b. In residential code only: glazing along the side of a stairway or ramp if a solid wall or panel is provided that extends to between 34 to 36 inches in height above the walking surface and the top of that wall or panel is designed and built to withstand the same horizontal load as that required by the code for guards.

10. Glazing adjacent to stairway or ramp landings if a, b and c are all met. The net effect of this is that safety glazing is required around the landing, to a lower height (36 inches) than it is for the stairway or ramp itself (60 inches).
    a. Glazing is within 36 inches horizontally of an adjacent walking surface.

    b. Glazing is less than 36 inches above the adjacent walking surface or stairway.

    c. Glazing is within 60 inches horizontally of the bottom tread of the stairway.

Exception:

a. Glass along the side of a stairway where a guard or handrail, as defined by the code, is provided, when the plane of the glass is greater than 18 inches from the railing.

b. In residential code only: glazing along the side of a stairway or ramp landing if a solid wall or panel is provided that extends to between 34 to 36 inches in height above the walking surface and the top of that wall or panel is designed and built to withstand the same horizontal load as that required by the code for guards.

Wired Glass in Hazardous Locations
Wired glass is primarily used in fire-protection-rated applications. Wired glass was once exempt from safety glazing standards in both the United States and Canada. However, since it is annealed glass, it may break under 100 ft. lbs. of force or less, meaning it can break under accidental human impact, causing piercing and cutting injuries. The wire embedded in wired glass can exacerbate the severity of injuries resulting from human impact.

In its monolithic form, wired glass is no longer considered safety glazing in either the United States or Canada. Note that monolithic wired glass is still allowed in non-hazardous locations in both the United States and Canada, such as transom lites above doors.

Wired glass can be made relatively safe in the event of accidental human impact. Special organic coatings in the form of surface-applied safety films can be factory-applied to wired glass. The film-to-wired-glass combination must be tested by an accredited test laboratory to meet the regulations for safety and fire:

- Safety: the filmed wired glass must comply with the applicable safety glazing regulation CPSC 16 CFR 1201 at both 18-inch (Cat. I) and 48-inch (Cat. II) drop heights.

- Fire: the film must melt and delaminate from the glass without flames on the non-fire side to pass the fire endurance test for fire windows and doors (NFPA 252 and NFPA 257).

The *NGA Guide to the Glass & Glazing Requirements of the Model Building Code* contains additional information about safety glazing requirements in the building codes.

Design Considerations

General

The reference data presented here is of a general nature and is for use as a design check or guideline. It is not intended to replace the careful studies, which are normally made for each project, by the responsible design professionals.

Local building codes and federal and state regulatory agencies establish minimum design loads and other safety requirements for most structures. The design professional should investigate the adequacy of these regulatory stipulations for a given project or portion of a project. For tall buildings, buildings with an unusual shape or buildings exposed to unusual surroundings, wind tunnel tests are recommended as a means of establishing the wind load forces on the building.

The continued push for more energy conservation and the federally mandated state energy codes have brought heat transfer design into the limelight. Computer modeling and product testing of complete assemblies are becoming more common. Various standards-writing and regulatory agencies have developed criteria to provide guidance and mandatory regulations regarding heat transfer. Intimate working knowledge of local, state and national energy codes such as the International Energy Conservation Code® (IECC) published by the International Code Council (ICC) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc. (ASHRAE) Standard 90.1 *Energy Standard for Buildings Except Low-Rise Residential Buildings i*s a vital requirement in building design. Glass products which provide substantial heat transfer reduction without a corresponding reduction of glass area are available.

Structural Performance of Glass

For typical sizes and thicknesses used in windows, curtain walls and skylights, glass reacts to loads as a combination plate and membrane. Conventional engineering procedures for thin plates may not be applicable when the maximum lateral deflection exceeds half the glass thickness. Glass strength can only be accurately determined by extensive testing or complex engineering analysis.

Glass is a brittle, elastic material up to the point of fracture. Its strength is controlled by the interaction of tensile stresses with randomly occurring stress-raising discontinuities or irregularities on the surface or in the body of the glass. If a large number of samples of nominally identical lites are tested to failure, there will be a significant variation in the measured failure strength. This means glass strength normally must be addressed using statistical methods.

For weathered annealed glass, it is generally accepted that about two-thirds of the lites exposed to a uniform pressure will fail in the range of +/- 20 to 25 percent of the average breaking pressure for each size and thickness. For heat-strengthened glass the range is +/-15 percent and for fully tempered glass it is +/-10 percent. These percentages are termed coefficients of variation and are useful for the design of glass and prediction of the probability of breakage.

The guidelines for selecting glass have gone through an evolution since the early 1960s. In the early 1960s, thousands of lites of new annealed glass were tested to failure. The resulting data formed the basis for a set of empirical glass thickness selection charts, which were widely referenced by manufacturers, building codes and standards up to and including the 1990s. Additional research and testing of weathered glass that was begun in the 1970s eventually led to a new set of glass thickness selection charts for annealed glass that were first presented in ASTM E1300. The glass thickness selection charts presented in ASTM E1300 *Standard Practice for Determining Load Resistance of Glass in Buildings* have since become the accepted basis for selection of vertical and sloped glazing subjected to wind, snow and self-weight loads. The ASTM glass thickness selection charts are based on a theoretical glass failure prediction model and the results of weathered glass tests. The ASTM charts incorporate detailed information relating to the effect of aspect ratio on the strength of glass. ASTM E1300 continues to evolve as more information becomes available.

The glass failure prediction model that serves as the basis for ASTM E1300 assumes that the probability of glass breakage is a function of the distribution and severity of stress-raising surface discontinuities and the distribution of surface tensile stresses over the glass area. If the maximum stress levels in two lites with different dimensions and thicknesses are the same, the lite with the maximum stress over the greater area is more likely to fail. It is not appropriate to base the structural adequacy of glass used in buildings solely on its modulus of rupture as determined through the testing of small-scale laboratory specimens.

The ASTM E1300 standard retained some concepts from earlier work, including the use of strength factors for heat-strengthened, fully tempered and insulating glass constructions. In addition, the ASTM E1300 standard introduced load share factors for insulating glass units that incorporate glass lites of the same and different thicknesses and types. ASTM E1300 also incorporates procedures to address the variation of glass strength with load duration using glass type factors for long and short durations. The load resistance factor for laminated glass depends on the relationship of the glass dimensions and thickness, the interlayer temperature and the load duration. There are currently seven charts utilizing four-sided simple support (additional charts included for less than four sides) for laminated glass in the ASTM E1300 standard. These charts are used to directly obtain the glass strength of laminated units. The use of factors for laminated glass strength is no longer applied as was practiced in the past from the annealed monolithic charts. The only factors used for laminated glass in the current version of ASTM E1300 are for a change in glass type, i.e. heat-strengthened or fully tempered.

Unlike most metal and other architectural materials, glass is usually designed on the basis of an acceptable probability of breakage or on the basis of historical experience and engineering judgment. ASTM E1300 presents general procedures to determine the load resistance of glass for the most common design probability of breakage of 8 lites per 1000. In addition, an optional procedure is presented that allows other design probabilities to be addressed.

Table 18 gives the modulus of rupture (MOR), defined as a material’s ability to resist deformation under load.

TABLE 18 *Average Modulus of Rupture (MOR) (Flexure)[a] for Architectural Glass Produced in North America*

Glass Type	(mean)	(design: 8 in 1000)[b]
Annealed Glass	6,000 psi (41 MPa)	2,800 psi (19 MPa)
Heat-Strengthened Glass	12,000 psi (83 MPa)	5,600 psi (39 MPa)
Fully Tempered Glass	24,000 psi (166 MPa)	11,200 psi (77 MPa)

Note a - These are approximate values for short load durations (under 1 minute) for undamaged glass in four-sided support.

Note b - Probability of breakage - note that these values are for the surface of the glass (not the edge) and do not take into consideration area effects.

Frequently, it is necessary to design glass of unusual shape or construction. In such cases, calculation techniques such as finite element, finite difference or standard engineering mechanics formulas can be used to determine the maximum principal tensile stress on the surface of the glass as a result of a specific load. ASTM E1300 presents conservative glass design stresses corresponding to a probability of breakage of 8 lites per 1000 and a load duration of 60 seconds for the 2000 edition of E1300 and previous versions. Starting with the 2002 version of ASTM E1300, the load duration was changed to 3 seconds. These values were combined with statistical methods and the assumption that failure stresses are normally distributed to develop the glass design stresses presented in Table 19 for different probabilities of breakage. A calculated maximum principal stress can then be compared to the values presented in Table 19 to conservatively estimate the probability of breakage. Table 19 presents probabilities of breakage ranging from 1 lite to 8 lites per 1000. While a probability of breakage of 8 lites per 1000 is common for vertical glazing, designers and architects typically use a probability of breakage of 1 lite per 1000 for sloped glazing, skylights and other critical applications.

Probabilities of breakage greater than 8 lites per 1000 are not generally recommended for the design of flat glass.

TABLE 19 *Allowable Design Stresses for Various Probabilities of Breakage*

Allowable Design Stresses for Various Probabilities of Breakage
(60 Second Load Duration)

Probability of Breakage (breaks per 1,000 lites)	**Annealed** [(a)] psi (MPa)	**Heat-Strengthened** [(b)] psi (MPa)	**Fully Tempered** [(c)] psi (MPa)
1.0	1,900 (13.10)	4,700 (32.41)	10,200 (70.33)
2.0	2,200 (15.17)	5,000 (34.47)	10,500 (72.40)
3.0	2,350 (16.20)	5,150 (35.51)	10,700 (73.77)
4.0	2,500 (17.24)	5,300 (36.54)	10,850 (74.81)
5.0	2,600 (17.93)	5,400 (37.23)	10,950 (75.50)
6.0	2,700 (18.62)	5,450 (37.58)	11,050 (76.19)
7.0	2,750 (18.96)	5,550 (38.27)	11,150 (76.88)
8.0	2,800 (19.31)	5,600 (38.61)	11,200 (77.22)

(a) Coefficient of variation assumed to be 22%
(b) Coefficient of variation assumed to be 15%
(c) Coefficient of variation assumed to be 10%

The design stresses presented in Table 19 can be converted to 3-second duration design stresses by multiplying them by a load duration transformation factor of 1.21.

In addition to strength, the deflection characteristics of the glass should also be examined by the designer. Deflections are a consideration in maintaining proper gasket engagements that are required to maintain continuous edge support of the glass. If the glass is wet-glazed, excessive deflections can lead to improper sealant performance. Specific issues relating to overall glass movement under design load conditions may affect placement of draperies, blinds or other shading devices. In certain circumstances, excessive glass deflections can become an aesthetic concern. In the evaluation of glass deflections, the designer should be aware that annealed, heat-strengthened and fully tempered glass share a common modulus of elasticity of 10.4 x 106 psi and a Poisson's ratio of 0.22, and therefore exhibit the same deflection characteristics under the same load. For a given glass size and load, a thicker glass is required to reduce deflection. ASTM E1300 presents methods for calculating deflections in glass with 1, 2, 3 and 4 sides of continuous support.

For selection of relatively thick glass as used in viewing windows for large aquariums, glass railings, glass mullions and animal enclosures, finite element analysis, finite difference analysis or conventional engineering mechanics equations can be used to calculate stresses. Experience has shown that allowable stress ranges for such applications are as follows:

Annealed Glass	600 - 1,200 psi (4 - 8 MPa)
Heat-Strengthened Glas	1,200 - 3,000 psi (8 - 21 MPa)
Fully Tempered Glass	2,400 - 6,000 psi (17 - 41 MPa)

The suggested annealed glass design stresses are below the generally accepted static fatigue limit for long-term loads, and the suggested design stresses for the kinds of heat-treated glasses are below the minimum requirements of the residual surface compressions for these kinds of glass. The probabilities of breakage associated with these design stresses will be much smaller than 1 lite per 1000. These same allowable stress ranges can be used in the design of structural glass railings and glass mullions supporting all-glass walls.

In-Service Exposures of Glass
Various service conditions justify special considerations. These conditions may increase glass stresses and probability of breakage. If they are not considered, glass may be selected which may not be adequate for the conditions. These conditions include the following:

- Screens, eyebrows, louvers, shutters, etc., may increase or decrease wind loads and thermal stresses.

- Windborne roof gravel, hail and windborne debris may lead to surface damage, reduced strength and increased breakage under subsequent impact, wind load or thermal load.

- Severe temperature exposures, uneven temperature exposures, glazing stresses, sonic boom, seismic action, mechanical stresses from door or window operation, pressure effects of air conditioning system operation, stack effects of ventilating systems and impact load such as that caused by window-washing ladders or equipment, hose streams, etc., may impose significant stresses.

When the effect of service conditions cannot be accurately predicted for the life span of the building, it is generally prudent to specify a lower probability of breakage, e.g., 4, 2 or 1 lite per 1000.

Design Load
Various types of loads and combinations of loads must be considered for the design of glass. These types of loads include:

1. Wind loads, both positive (inward) and negative (outward)

2. Dead loads

3. Thermal loads

4. Snow/ice loads

5. Impact loads

6. Seismic loads

7. Interior pressures from HVAC equipment

8. Interior pressures due to building stack effect (these tend to be inward at the base of a building and outward near the top of the building)

9. Live loads (generally glass is not designed for people to walk on it; however, occasionally design professionals specify a live load to account for a distributed load that may be applied for maintenance)

Load duration is also of great importance.

Although all of the above types of loads must be considered by the design professional, the discussion that follows is limited to wind load, interior pressures, missile impact loads and loads associated with sloped glazing.

<u>Wind Load</u>
The principal load applied to glass in an exterior wall is the net pressure differential caused by local wind conditions. Therefore, it is important to understand this type of loading to ensure proper design. The design wind load for a lite of glass on the side of a building is dependent on the following: 1) wind speed, 2) importance of the structure, 3) type of exposure, 4) building height, 5) building shape and orientation, 6) location on the building, and 7) size of the glass. Each of these factors is discussed briefly below.

Wind Speed

Wind pressure (loading) is proportional to the square of the wind speed. At standard atmospheric pressure [29.92 inches of mercury (101.325 kPa) atmospheric pressure and 59 °F (15 °C) temperatures], the relationship between wind speed and wind pressure is found in Ensewiler's Formula: $P = 0.00256 V^2$ where P is the pressure in pounds per square foot exerted on a stagnation point on a flat surface oriented normal to the wind direction and V is the wind speed in miles per hour.

Wind speeds have been recorded by the National Weather Service and are summarized on a U.S. map in American Society of Civil Engineers (ASCE) 7 *Minimum Design Loads for Buildings and Other Structures*. Formerly, wind speeds were measured in a manner known as the "fastest mile of wind" in which the procedure was to measure the time it takes for a mile-long sample of air to pass a fixed measuring point. During the last couple of decades, wind speeds have been measured using anemometers that are able to measure gust speeds in a relatively short 2- to 3-second duration. These anemometers are located at the standard height of 33 feet (10 m) above ground level in open terrain with scattered obstructions having heights generally less than 30 ft. (9.1 m).

Now wind speeds are summarized as their "gust speeds" on a 3-second duration time basis. In the United States, the 1995 edition of ASCE 7 first introduced the 3-second gust speed wind speed maps for use in wind engineering design. With this approach, the gust factors used were significantly reduced when compared to gust factors used with fastest mile wind speed data. In most cases gust factors equal to 0.85 are used. Based upon information presented in ASCE 7 since 2002, use of a gust factor of 0.85 with a 3-second gust wind speed results in design pressures on cladding with durations somewhat greater than 3 seconds. Thus, the gust durations associated with the 3-second versions of ASCE 7 are consistent with the gust durations associated with the fastest mile wind speed versions of ASCE 7.

> "The analytical procedure provides pressures that are expected to act on components and cladding for durations in the range from 1 to 10 seconds. Peak pressures acting for a shorter duration may be higher than those obtained using the analytical procedure. The gust response factors, pressure coefficients and force coefficients of this standard are based on a mean wind speed corresponding to the fastest-mile wind speed."
>
> —ASCE 7-88, ASCE 7-93 (Last two fastest-mile versions of ASCE 7)

Cladding pressure durations of 1 to 10 seconds have been associated with wind load procedures since at least the early 1960s. Thus, it can be concluded that the durations associated with cladding pressures are not directly a function of the averaging period used to report wind speed data. Further, it is clear that introduction of the 3-second versions of ASCE 7 resulted in no significant change in the durations associated with design pressures for cladding.

The 3-second wind speed map presented in Figure 17 depicts the maximum 3-second gust wind speed that has a probability of occurrence of 0.02 in a single year or a mean recurrence interval of 50 years. However, severe wind gusts are not isolated events. Rather, they are a part of a windstorm system such as a thunderstorm, tornado, downburst, hurricane, etc. It is well understood that multiple wind gusts are associated with severe windstorm events. Because of the static fatigue properties of glass, all of the wind gusts that affect the glass have a cumulative effect at least over the duration of the windstorm event. It is not enough to simply know the magnitude and duration of a single gust event. The combined durations of all of the gusts embedded in the windstorm event should be recognized in the design of glass.

Historically, glass thickness selection charts had been based on a 30- to 60-second duration glass strength, with most code bodies referencing a 60-second duration. The reason this is the case is that a windstorm does not consist of a single maximum gust. Rather, a windstorm consists of a series of gusts, several of which are at or near the maximum value. Information presented in ASTM E 1886 *Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials* suggests that there can be as many as 100 short gusts near the maximum wind speed in a single severe windstorm event. Thus, it is very reasonable to assume that combined durations of the maximum wind speed gusts in a single windstorm event will sum to a value in the range of 60 seconds. This would involve six 10-second gusts, or twelve 5-second gusts, twenty 3-second gusts, etc.

The latest versions of ASTM E1300 standard incorporate non-factored load charts corresponding to a 3-second duration. When a wind event is of a sustained nature, the actual wind load will have more than one maximum 3-second gust. This situation will present pressures that when accumulated will have an effect on the glass that will be greater than the 3-second duration. The specifying authority should consider this phenomenon when determining the load duration to be used for the glass load resistance analysis. It may not be appropriate to use the ASTM E1300 3-second duration load charts for all wind load conditions. The standard allows for calculation of strength requirements at longer load durations.

Since the capacity of many materials to resist a load is often time-dependent, it is important to ensure that wind loads reference a duration. Glass, for example, can resist more uniform loading for a 3-second duration than it can for a 60-second duration, and it can resist more loading for a 60-second duration than it can for a one-month duration.

Figures 17, 17a, 17b, 17c are wind speed maps taken from ASCE 7. They show basic wind speed as 3-second gust speeds that are associated with an annual probability of 0.02.

Importance

An annual probability of 0.02 corresponds to a mean recurrence interval of 50 years, which is the most common design interval selected for wind design on buildings in the U.S. Through the use of an Importance Factor multiplier, adjustments are made to the annual probability of occurrence for buildings whose occupancies reflect different levels of hazard to human life. The Importance Factor is determined from ASCE 7 based on the Occupancy Category.

Type of Exposure

The type of exposure is categorized to reflect the characteristics of ground surface irregularities for the building site. Variations in ground surface roughness arise from natural topography and vegetation, as well as from constructed features. The categories of exposure classified in ASCE 7 are:

Exposure A. This exposure condition, which was originally intended to represent highly built-up downtown areas, has been removed from consideration.

Exposure B. Urban and suburban areas, wooded areas or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger. Use of this exposure category shall be limited to those areas for which terrain representative of Exposure B prevails in the upwind direction for a distance of at least 1,500 feet or 10 times the height of the building or structure, whichever is greater.

Exposure C. Open terrain with scattered obstructions having heights generally less than 30 feet. This category includes flat, open country and grasslands.

Exposure D. Flat, unobstructed coastal areas directly exposed to wind flowing over large bodies of water. This exposure shall be used for those areas representative of Exposure D extending inland from the shoreline a distance of 1,500 feet or 10 times the height of the building or structure, whichever is greater.

The ASCE standard also makes reference to increased pressures (or suctions) that can occur from channelization of wind by nearby buildings and obstructions. Also see Windborne Missiles.

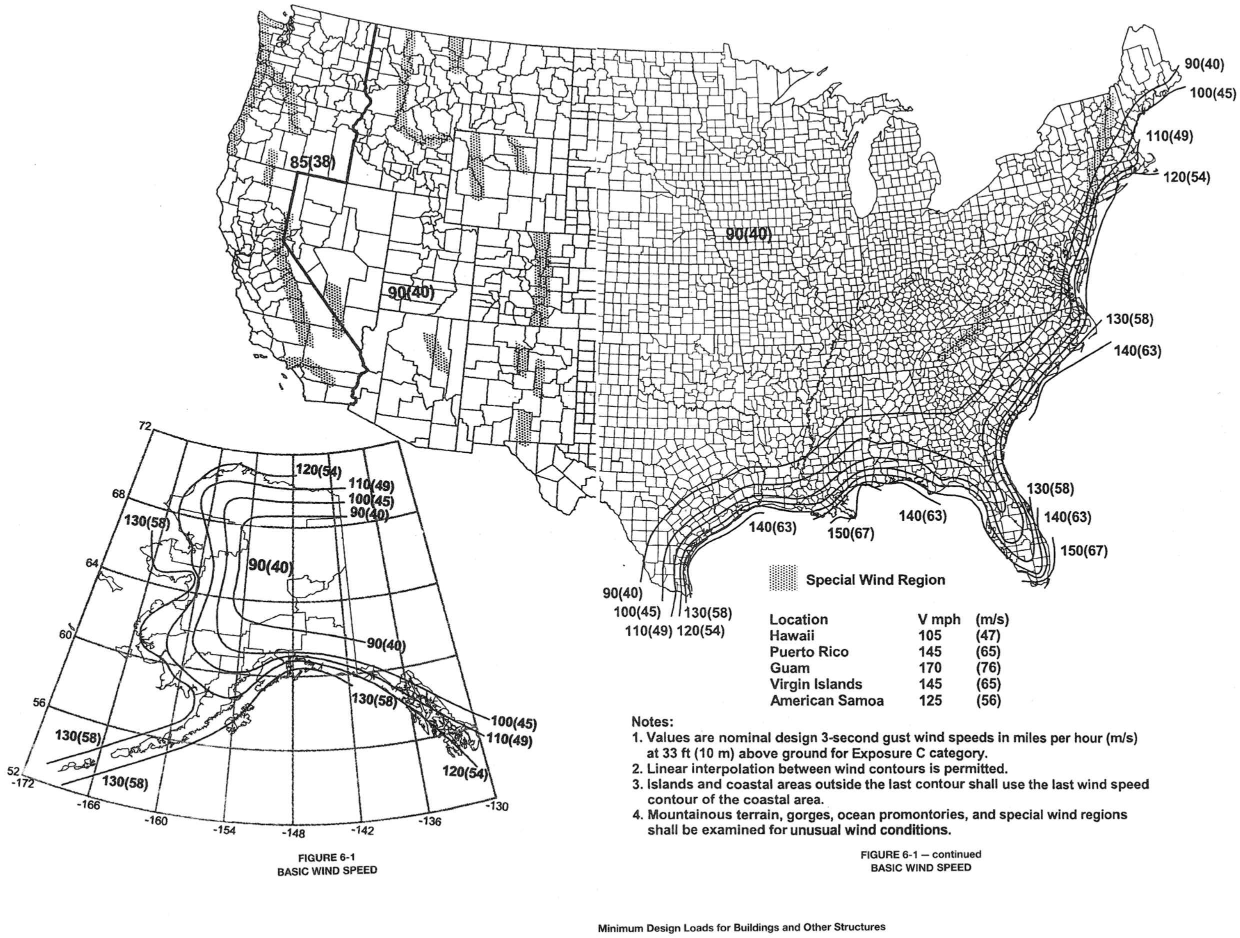


FIGURE 17 *Wind Speed Map Basic Wind Speed miles per hour (m/sec)*

NOTE: Design professional should be consulted for determination of appropriate design wind loads.

Basic Wind Speed map is taken from Figure 6, ASCE 7 *Minimum Design Loads for Buildings and other Structures* and is used with permission from American Society of Civil Engineers.

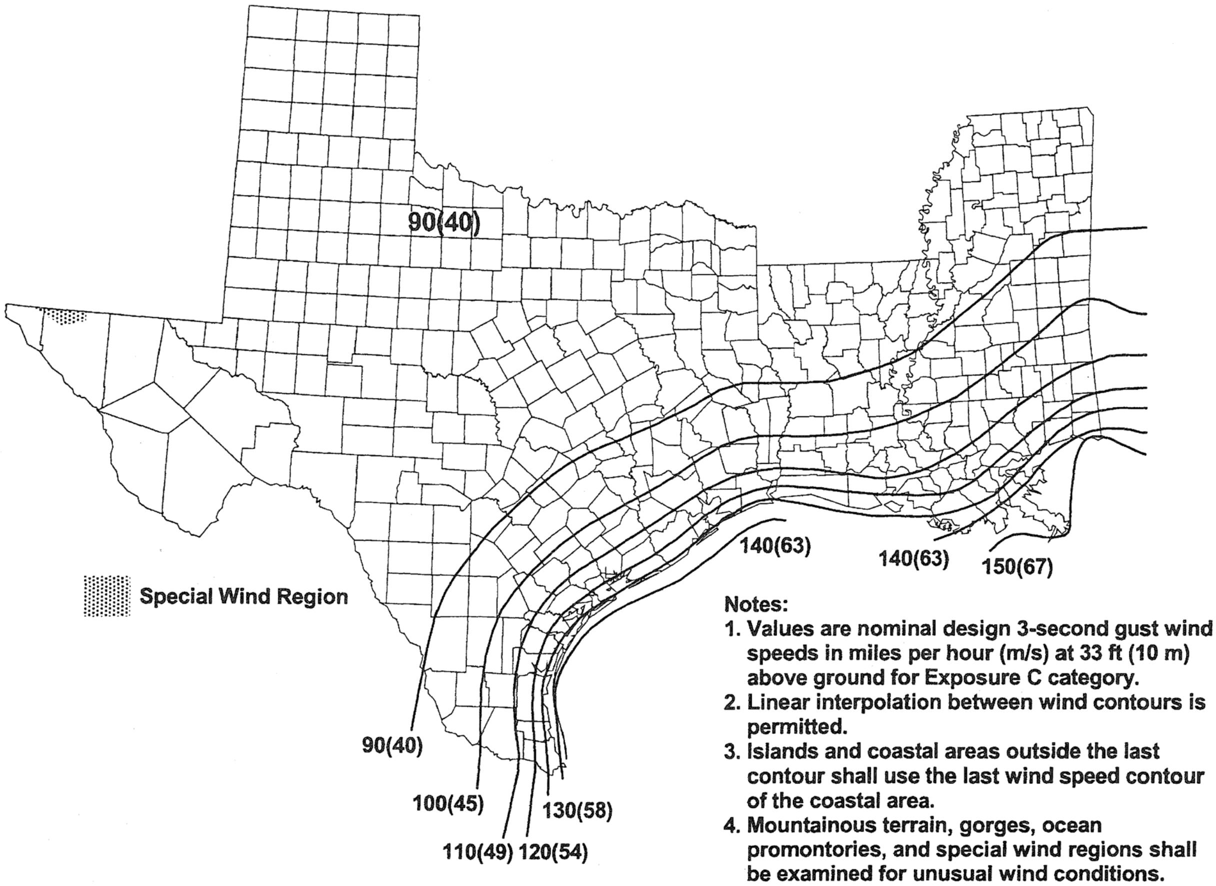


FIGURE 17a *Wind Speed Map Basic Wind Speed Western Gulf of Mexico Hurricane Coastline miles per hour (m/sec)*

NOTE: Design professional should be consulted for determination of appropriate design wind loads.

Basic Wind Speed- Western Gulf of Mexico Hurricane Coastline map is taken from Figure 6-1, ASCE 7 *Minimum Design Loads for Buildings and other Structures* and is used with permission from American Society of Civil Engineers.

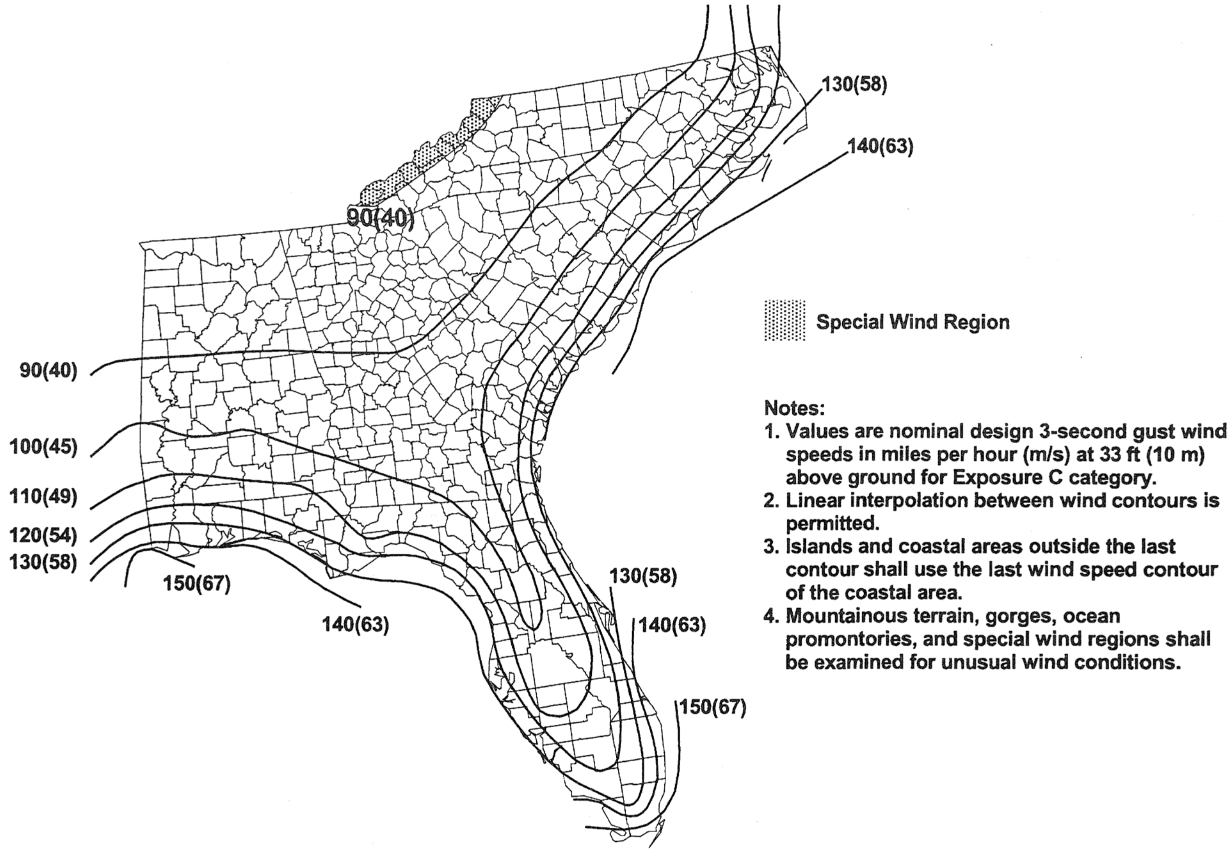


FIGURE 17b *Wind Speed Map Basic Wind Speed Eastern Gulf of Mexico and Southeastern US Hurricane Coastline miles per hour (m/sec)*

NOTE: Design professional should be consulted for determination of appropriate design wind loads.

Basic Wind Speed- Eastern Gulf of Mexico and Southeastern US Hurricane Coastline map is taken from Figure 6-2, ASCE 7 *Minimum Design Loads for Buildings and other Structures* and is used with permission from American Society of Civil Engineers

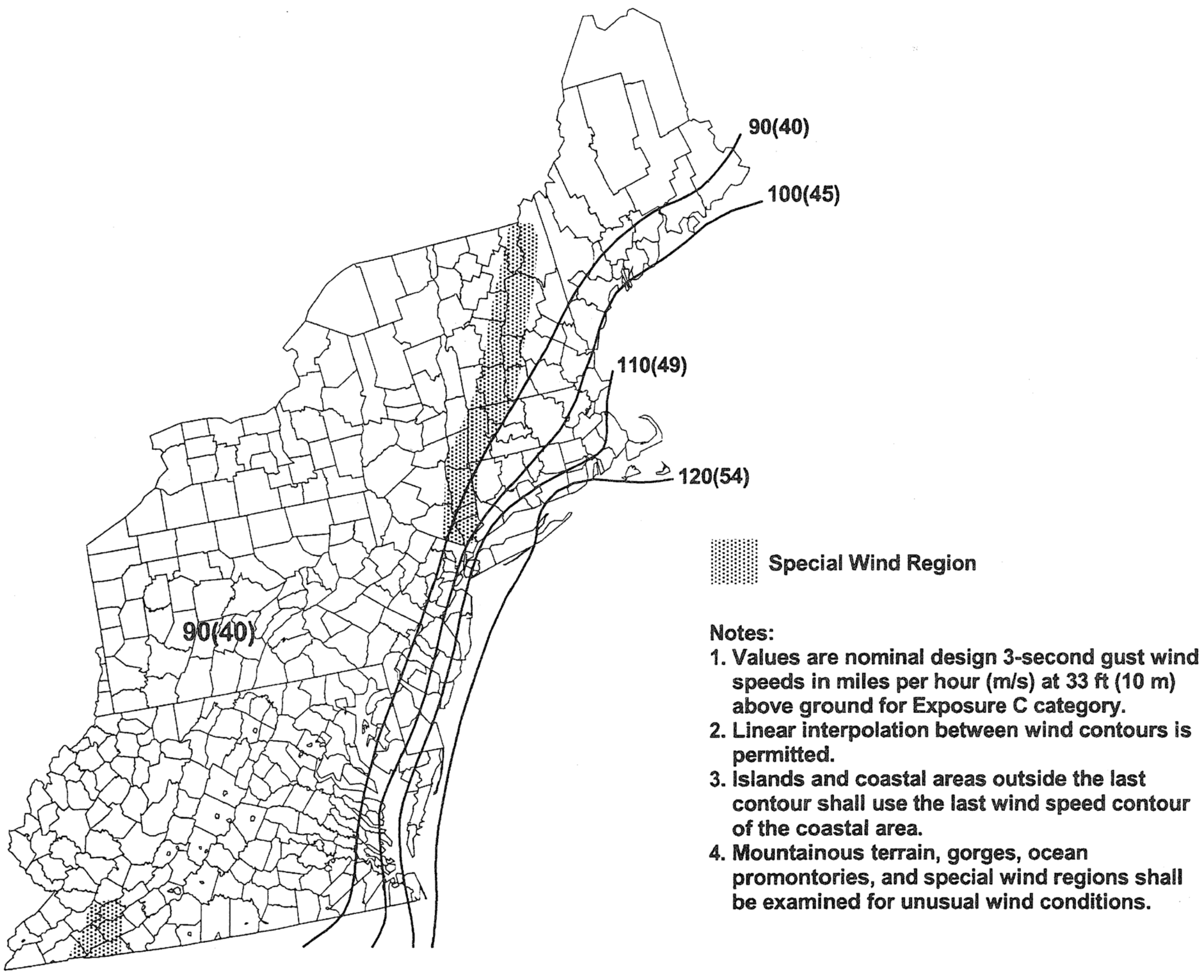


FIGURE 17C *Wind Speed Map Basic Wind Speed Mid and Northern Atlantic Hurricane Coastline miles per hour (m/sec)*

NOTE: Design professional should be consulted for determination of appropriate design wind loads.

Basic Wind Speed- Mid and Northern Atlantic Hurricane Coastline map is taken from Figure 6-3, ASCE 7 *Minimum Design Loads for Buildings and other Structures* and is used with permission from American Society of Civil Engineers.

Building Height
Wind speed, and therefore wind pressure, increases with height above ground level, and the rate of increase is related to the type of terrain over which the wind flows, i.e. the terrain applies a frictional drag to the air moving over it. The increase is not a straight-line relationship to the height nor is it a proportional relationship to the height. The rate of increase in speed decreases with height until, at the gradient level, the wind speed is assumed to be constant. See ASCE 7 for more information.

Building Shape & Orientation
When the wind blows perpendicular to a building face, it is slowed down with a consequent buildup of pressure against that face. At the same time, it is deflected and accelerated around the end walls and over the roof, creating a suction or negative pressure on these areas. A large eddy is created behind the building, which exerts suction on the leeward face as shown on Figure 18.

The magnitude of the negative pressures created on square or rectangular buildings in Exposures B and C are relatively well-known and generally can be anticipated in design. Considerably more obscure are the effects on buildings with corners that are not 90 degrees, buildings with other than four sides, and buildings not oriented to face the direction of the prevailing high winds and the channelization effects of adjacent buildings. Negative pressures are significantly greater than positive pressures at building corner zones.

Location of the Building
Corner zones and other areas of discontinuity or irregularity, such as roof ridges, have higher negative (outward) loads than flat walls away from discontinuities. Therefore, the negative loads on glass at corners are generally higher than at intermediate areas.

Size of the Glass
Glass is a component of the wall system. As such, it experiences only the load applied locally to it. Smaller areas experience greater wind loads than those averaged over large areas. Therefore, the pressure per square foot on a lite of glass is higher than the average pressure over a larger wall area. ASCE 7 has tables that contain factors for making adjustments for tributary areas.

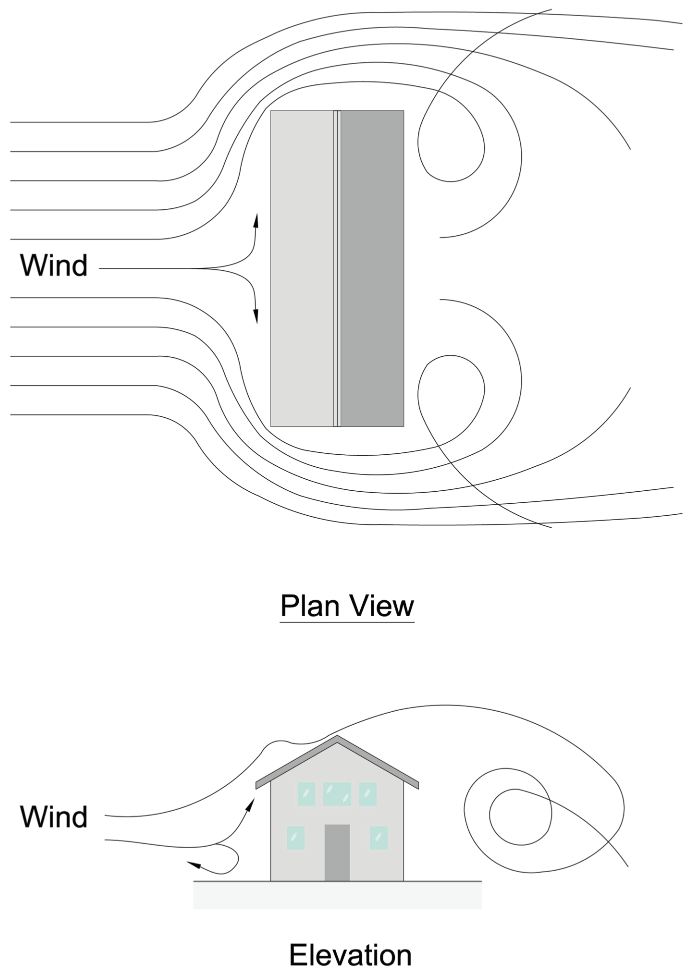


FIGURE 18 *Negative Pressure Effects*

Minimum Design Wind Loading
ASCE 7 states that the design pressure for components and cladding shall be not less than 10 psf (0.48 kN/m2) acting in either direction normal to the surface.

More complete discussions regarding wind load on buildings may be found in the American Society of Civil Engineer publication ASCE 7 and the American Architectural Manufacturers Association (AAMA) publication, *Design Wind Loads for Buildings and Boundary Layer Wind Tunnel Testing.*

Internal Building Pressures

When determining the thickness or type of glass needed to resist a specified load, internal building pressures also should be considered. These internal pressures become especially significant in partially enclosed buildings and in buildings located in hurricane-prone regions, especially when the openings are not designed to resist the impact from windborne debris. For more information reference ASCE 7.

Windborne Missiles

Current design standards and codes acknowledge the existence of small and large missile impacts upon building façades. ASTM standards E1886 *Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials* and E 1996 *Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors and Impact Protective Systems Impacted by Windborne Debris in Hurricanes* provide guidance and information relating to the testing of glass to demonstrate its resistance to the effects of both small and large missile impacts. The small missiles are intended to represent primarily roofing stones and other urban debris that can easily become windborne. The large missiles are primarily intended to represent sections of loose timber members that can be propelled by the wind.

Investigations at the Institute for Disaster Research at Texas Tech University, Lubbock, Texas, USA, indicate that a 0.2 oz. (6.0 g) roofing stone can, within a distance of 70 feet (21.3 m), attain a speed of 35 mph (56 km/h) in an 80-mph (129 km/h) wind, a speed of 42 mph (68 km/h) in a 100-mph (161 km/h) wind, and 51 mph (82 km/h) in a 120-mph (193 km/h) wind. Further, it was shown that all types, kinds and thicknesses of glass are susceptible to breakage and damage when impacted by roofing stones at relatively low speeds. For example, most common thicknesses of annealed monolithic glass will break when impacted by a roof stone missile with a speed of about 26 mph (42 km/h) and most common thicknesses of fully tempered glass will break when impacted by a roof stone missile of 45 mph (72 km/h).

Negative wind pressures can readily lift stones and other debris from roofs and inject them into the wind stream. Gravity will cause the stones to assume a curved trajectory, and they will be caught by winds channelized between buildings. The speed of wind channelized between buildings can be substantially greater than the wind speed registered at a recording station for the general area. Therefore, it can be concluded that all common types and kinds of window glass are susceptible to breakage as the result of small missile impact in relatively mild windstorms.

National and local building codes have acknowledged the existence of large and small missile impact upon building façades under high wind loads. Certain jurisdictions in the Atlantic and Gulf of Mexico coastal areas have developed building codes that require stringent impact testing and certifying of glazing systems under certain circumstances dependent on building location and wind speeds. Specialized glazing and framing products have been developed to meet these test requirements.

Sloped Glazing

Inward and outward sloping of partial or entire building façades evolved from skylights. "Sloped Glazing," the modern-day terminology for fenestration that slopes 15 degrees or more from the vertical, has attained tremendous popularity in all types of building construction. The sloped glazing system must entail a broader range of design considerations than the conventional vertical window, storefront or curtain wall system. The design and selection of glass for skylights and sloped glazing requires special attention for a number of reasons:

- Due to the great degree of solar energy exposure, both the glass and metal framing system must be carefully engineered to accommodate differential thermal stresses and opposing building reactions. For most orientations, sloped glazing may reach substantially higher temperatures than vertical glazing because the solar radiation is more nearly perpendicular to the glass surface, and because of the stratification of warm air under the glass. Consequently, the thermal stresses created usually require heat-treated glass.

- The various geometric shapes and geographic locations require that dead loads, snow loads, seismic loads, live loads and wind loads be analyzed in certain combinations in accordance with state and local building codes.

- Good, effective drainage of both condensation and water infiltration is essential. The glazing pocket should be drained into a gutter, and the gutter must freely allow water to exit to the exterior. Sealants alone should not be relied upon to prevent water infiltration. Generally, conventional vertical window or curtain wall systems do not perform adequately when installed in a sloped configuration.

- The drainage systems of sloped glazing systems generally do not function well when installed in a vertical position.

- Horizontal caps, if used, should be designed to allow proper and complete runoff of water. If not, glass staining, premature failure of insulating glass and water infiltration may result.

- Sloped glass is more susceptible to impact from falling objects, windborne debris and missiles than vertical glass.

- Sloped glazing, in most cases, is more likely to fall from the opening when it breaks than vertical glass. Good design indicates that the choice of glass should be based on eliminating or minimizing, to the degree practical, any potential hazards.

- Snow loads, unlike wind and live loads, may be imposed on the glazing for extended periods; strength of glass and contribution of the plastic interlayer in laminated glass are both time-dependent, i.e., under long-term loading, the strength of these materials is less than under short-term loading, such as wind.

- If the sloped glazing is close to walkways, consideration should be given to snow and ice sliding off, or water cascading off, striking pedestrians and potentially causing injury.

Proper glass selection is probably the single most important consideration when dealing with a sloped glazing system. Factors such as life safety resulting from glass fallout after breakage and the potential liability for the owner, architect, glass and skylight manufacturers, and glazing contractor should be carefully considered. Applicable building codes should be consulted for commercial and residential construction guidelines.

Glass Thickness and Size Selection
In order to select the appropriate glass type and thickness for a specific job, the design professional(s) should determine the design load on the glass. There are three criteria used to determine appropriate loads:

1. Model wind tunnel studies.

2. Requirements as defined in the current version of ASCE 7, Minimum Design Loads for Buildings and Other Structures.

3. Applicable local building code requirements.

Model wind tunnel studies are job-specific and are often used for large, complex building designs. Applicable local building codes are minimum requirements that must be met. Determining the design load on a building in accordance with ASCE 7 is the most-often-used method for selecting glass. Specifiers must be aware that a number of loads affect design including wind load, snow load, dead load, seismic loads and live loads. ASCE 7 provides information in determining the appropriate loads and combinations of loads to be applied.

Once the design load and duration have been determined and a suitable probability of breakage selected, the appropriate glass thickness and glass type can be chosen. The industry standard to assist in the selection of glass thickness is ASTM E1300 *Standard Practice for Determining Load Resistance of Glass in Buildings*. ASTM E1300 provides glass thickness charts relating length, width and thickness of glass to equivalent design loads of both short duration (3 seconds in versions 2002 or later of ASTM E1300 and 60 seconds for versions 2000 and earlier) and long duration (up to one month). In addition, the standard provides information on:

- Calculating maximum glass deflection,
- Estimating the probability of breakage of rectangular glass (subjected to a design load),
- Multipliers for heat-treated, laminated and insulating glass,
- Effect of aspect ratio on glass strength.

Glass is a brittle material. It will act elastically until it ruptures at ultimate load. That ultimate load will vary, depending upon the type and duration of the loads applied and the distribution, orientation and severity of the surface discontinuities. Because the ultimate strength of glass varies, its strength can best be described statistically for many applications. The commonly referenced probability of breakage of 8 lites per 1000 (Pb = 0.008) describes the statistical probability of a fracture in an annealed lite at design load or greater. It should not be confused with a statement describing the average number of lites that will fail. ASTM E1300 does provide for determining allowable load with alternative probabilities of breakage.

The design professional/specifier should be aware that the maximum center of glass lateral deflection of a lite is often a consideration in the selection of glass and should be addressed. Excessive deflection can cause poor performance of glazing gaskets or tapes and glass-to-metal contact, causing glass breakage. For the same thickness, heat-treating will not change the deflection characteristic of glass; it only changes its breaking strength.

While the glass manufacturers have the appropriate data for determining the performance of their products, it remains the responsibility of the design professional to review these performance criteria and determine if they are suitable for the intended application.

All glass products have size limitations. The manufacturer/fabricator should be consulted.

"Window Glass Design" software is available from Standards Design Group (available at standardsdesign.com/window-glass-design). This software allows the user to determine the appropriate type and thickness of glass to meet a specified wind or snow load, in accordance with ASTM E1300. The software performs calculations for editions of ASTM E1300 published in 2009, 2012 and 2016.

Thermal Performance

The high-performance capabilities of today's architectural glass products require a strong working knowledge of optical and thermal performance terminology. The following terms are commonly used to describe and analyze the performance of architectural glass products. Additional terms are defined in NGA Glass Technical Paper FB50-17 *Building Energy Performance Criteria Terms and References Related to Glass and Glazing*.

Emissivity (e): The measure of a surface's ability to emit long-wave infrared radiation. Emissivity factors range from 0.0 (or 0 percent) to 1.0 (or 100 percent).

Emittance: The ratio of the rate of radiant emission of the body, as a consequence of temperature only, to the corresponding emission of a black body at the same temperature.

Light-to-Solar Gain Ratio (Luminous Efficacy or Coolness Index): The visible transmittance of a glazing system divided by the solar heat gain coefficient (or shading coefficient). This ratio is helpful in selecting glazing products for different climates in terms of those that transmit more heat than light and those that transmit more light than heat.

Relative Heat Gain (RHG): The amount of heat gain through a glazing material taking into consideration the effects of solar heat gain (shading coefficient) and conductive heat gain (U-factor). The value is expressed in Btu/hr/ft^2 (W/m^2).

$$RHG = (Summer\ U\text{-}factor\ x\ 14\ °F) + (Shading\ Coefficent\ x\ 200)$$

The lower the relative heat gain, the more the glass product restricts heat gain.

R-Value: The thermal resistance of a glazing system is expressed in ft^2/hr/°F/Btu (m^2/W/°C). R-value is a measure of the resistance to heat flow through a material calculated as R-t/k, where t is the thickness of the material and k is the thermal conductivity. The R-value is the reciprocal of the U-factor. The higher the R-value, the less heat is transmitted throughout the glazing material.

$$R\text{-value} = \frac{1}{\text{U-factor}}$$

Shading Coefficient: An older term that has since been replaced by Solar Heat Gain Coefficient. The ratio (expressed as a number between 0 and 1) of the solar heat gain through a specific glass product to the solar heat gain through a lite of ⅛-inch (3mm) clear glass. Glass of ⅛-inch (3mm) thickness is given a value of 1.0; therefore, the shading coefficient of a glass product is calculated as follows:

$$S.C. = \frac{Solar\ Heat\ Gain\ of\ the\ Glass\ in\ Question}{Solar\ Heat\ Gain\ of\ \frac{1}{8}"\ Clear\ Glass}$$

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

Solar Energy Transmittance: The percentage of ultraviolet, visible and near-infrared energy within the solar spectrum that is transmitted through a material.

Solar Heat Gain Coefficient (SHGC): The ratio of the solar heat gain entering the space area through the fenestration product to the incident solar radiation. Solar heat gain includes directly-transmitted solar heat and absorbed solar radiation, which is then reradiated, conducted or convected into the space.

$$SHGC = \frac{Solar\ Energy\ Gain\ Through\ the\ Glazing}{Solar\ Energy\ Incident\ on\ the\ Glazing}$$

Glass manufacturers and fabricators provide center-of-glass solar heat gain coefficients. Total fenestration product values require consideration of all frame components, the edge of the glass construction and center-of-glass conditions. A generic listing of Solar Heat Gain Coefficients for various glass products is noted in Table 22.

U-Factor (U-Value): A measure of air-to-air heat transmission (loss or gain) due to the thermal conductance and the difference in indoor and outdoor temperatures of a fenestration assembly. As the U-factor decreases, so does the amount of heat that is transferred through the glazing material.

U-factors are expressed in Btu/hr/ft²/°F (W/m²/°C). Glass manufacturers and fabricators publish center-of-glass U-factors. Since the area within 2.5 inches (64 mm) of the glass edge may have a higher U-factor due to the influence of an insulating unit spacer material and framing material, window manufacturers publish total window U-factors. The U-factor is the reciprocal of the R-value. U-factors can be converted to R-values as follows:

$$R\text{-value} = \frac{1}{\text{U-factor}}$$

U-factors are calculated on the basis of the standard American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard conditions as shown in Table 20. A generic listing of center-of-glass U-factors for various glass products is provided in Table 21.

TABLE 20 *Standard ASHRAE Conditions*

Standard ASHRAE Conditions				
	Winter Nighttime		Summer Daytime	
Outside Temperature	0 °F	(-17.8 °C)	89 °F	(31.7 °C)
Inside Temperature	70 °F	(21.1 °C)	75 °F	(23.9 °C)
Wind Speed	15 mph	(6.7 m/s)	7.5 mph	(3.3 m/s)
Wind Direction	Windward		Windward	
Solar Radiation	0		248 Btu/hr/ft²	(783 W/m²)

TABLE 21 *Center of Glass U-Values*

Center of Glass U-Values				
Glazing Type	**Clear Uncoated glass**	**Low-e e = 0.05**	**Low-e e = 0.10**	**Low-e e = 0.20**
Single	1.04	n/a	n/a	0.68
Double				
1/4" (6 mm) air space	0.55	0.40	0.42	0.44
1/4" (6 mm) argon*	0.50	0.33	0.35	0.38
1/2" (12 mm) air space	0.48	0.30	0.31	0.35
1/2" argon*	0.46	0.25	0.27	0.31
Triple (low-e one surface)				
1/4" (6 mm) air space	0.37	0.30	0.31	0.32
1/4" (6 mm) argon*	0.34	0.25	0.26	0.28
1/2" (12 mm) air space	0.31	0.22	0.23	0.25
1/2" (12 mm) argon*	0.29	0.19	0.20	0.22
Triple (low-e two surfaces)				
1/4" (6 mm) air space		0.25	0.26	0.28
1/4" (6 mm) argon*		0.20	0.21	0.23
1/2" (12 mm) air space		0.16	0.18	0.20
1/2" (12 mm) argon*		0.13	0.14	0.17
NOTE: e = emissivity * 90% argon fill				

Visible Light Reflectance: The percentage of visible light (390 to 770 nanometers within the solar spectrum) that is reflected from the glass surface.

Visible Light Transmittance (VLT): The amount of visible light (390 to 770 nanometers within the solar spectrum) that passes through the glazing material of a window, expressed as a percentage of the total incident radiation in that wavelength range. A generic listing of visible light transmittance of varying glass products is noted in Table 22.

Industry-published performance values for shading coefficients, U-factors and SHGC are center-of-glass values based on laboratory measurements and calculations from WINDOW 7.8 *Program for Analyzing Window Thermal Performance,* developed by the Windows and Daylighting Group of Lawrence Berkeley National Laboratory at the University of California through contract support from the United States Department of Energy.

TABLE 22 *Solar Heat Gain Coefficients (SHGC) and Visible Transmittance*

Size (Glass Thicknesses)	Glass Type	Solar Heat Gain Coefficient (SHGC)[1,2]	Visible Transmittance (VT)[1,2]
Single Glazing			
1/8" (3 mm)	Clear	0.86	0.90
1/4" (6 mm)	Clear	0.81 - 0.83	0.88
1/4" (6 mm)	Blue-green	0.63	0.76
1/8" (3 mm)	Bronze	0.73	0.68
1/4" (6 mm)	Bronze	0.62	0.53
1/8" (3 mm)	Green	0.71	0.83
1/4" (6 mm)	Green	0.61	0.76 - 0.77
1/8" (3 mm)	Gray	0.68 - 0.71	0.60-0.62
1/4" (6 mm)	Gray	0.58-0.60	0.45-0.46
Double Glazing			
1/8" (3 mm)	Clear/Clear	0.76	0.81
1/4" (6 mm)	Clear/Clear	0.70	0.79
1/4" (6 mm)	Blue-green/Clear	0.51	0.67
1/8" (3 mm)	Bronze/Clear	0.63	0.61
1/4" (6 mm)	Bronze/Clear	0.50	0.47
1/8" (3 mm)	Green/Clear	0.60	0.75
1/4" (6 mm)	Green/Clear	0.50	0.68
1/8" (3 mm)	Gray/Clear	0.58 - 0.60	0.54-0.56
1/4" (6 mm)	Gray/Clear	0.45 - 0.48	0.40-0.41
1/8" (3 mm)	High Performance Tint	0.48-0.51	0.69-0.70
1/4" (6 mm)	High Performance Tint	0.39 - 0.40	0.59 - 0.61
Double Glazing w/low-e (0.20)			
1/8" (3 mm)	Clear/Low-e	0.71	0.75
1/8" (3 mm)	Low-e/Clear	0.65	0.75
1/4" (6 mm)	Clear/Low-e	0.67	0.73
1/4" (6 mm)	Low-e/Clear	0.62	0.73
1/4" (6 mm)	Blue-green/Low-e	0.46	0.63
1/8" (3 mm)	Bronze/Low-e	0.57	0.57
1/4" (6 mm)	Bronze/Low-e	0.46	0.44
1/8" (3 mm)	Green/Low-e	0.55	0.69-0.70
1/4" (6 mm)	Green/Low-e	0.45	0.63-0.64
1/8" (3 mm)	Gray/Low-e	0.52-0.55	0.50-0.52
1/4" (6 mm)	Gray/Low-e	0.41-0.43	0.37
1/8" (3 mm)	High Performance Tint	0.43-0.46	0.64
1/4" (6 mm)	High Performance Tint	0.34-0.36	0.55-0.56
Double Glazing w/low-e (0.10)			
1/8" (3 mm)	Clear/Low-e	0.61 - 0.64	0.75 - 0.78
1/8" (3 mm)	Low-e/Clear	0.55 - 0.58	0.75 - 0.78
1/4" (6 mm)	Clear/Low-e	0.47 - 0.59	0.44 - 0.76
1/4" (6 mm)	Low-e/Clear	0.32 - 0.55	0.44 - 0.76
1/8" (3 mm)	Bronze/Low-e	0.48 - 0.51	0.57 - 0.59
1/4" (6 mm)	Bronze/Low-e	0.32 - 0.39	0.27 - 0.46
1/8" (3 mm)	Green/Low-e	0.49 - 0.51	0.68 - 0.72
1/4" (6 mm)	Green/Low-e	0.33 - 0.38	0.37 - 0.63
1/8" (3 mm)	Gray/Low-e	0.46 - 0.48	0.54
1/4" (6 mm)	Gray/Low-e	0.30 - 0.36	0.23 - 0.39
Double Glazing w/low e (0.05)			
1/8" (3 mm)	Low-e/Clear	0.39-0.54	0.71-0.77
1/4" (6 mm)	Low-e/Clear	0.38-0.49	0.70-0.73
1/4" (6 mm)	Bronze/Low-e	0.27-0.36	0.41-0.44
1/4" (6 mm)	Green/Low-e	0.31-0.39	0.60-0.64
1/4" (6 mm)	Gray/Low-e	0.24-0.34	0.35-0.38
1/4" (6 mm)	Blue-green/Low-e	0.32-0.40	0.60-0.63
1/4" (6 mm)	High Performance Tint/Low-e	0.27-0.32	0.54-0.57

1 Manufacturing variation will yield tolerances of $\pm$ 0.06

2 See manufacturers' literature for specific optical properties

Thermal Bridging

The thermal performance of framing designs and thermal barriers/breaks is accounted for in the overall fenestration U-factor. Beyond the U-factor of the window or curtain wall itself, how the fenestration system is installed and interfaces with the surrounding wall or roof assemblies can affect the overall thermal performance of the building envelope.

Thermal bridging occurs when building components with higher thermal conductivity penetrate or bypass insulation or other surrounding materials with lower thermal conductivity, thus creating a path of least resistance for heat transfer. For example, a steel beam or balcony penetrating the wall insulation will create a path for heat transfer. This leads to heat loss and decreased energy efficiency as well as potential cold points that can lead to condensation within the building envelope.

In wall assemblies, metal penetrations can significantly reduce the effective R-value of the wall insulation. For fenestration assemblies, the potential for thermal bridges may occur where the window framing meets the surrounding wall if the surrounding insulation layer is bypassed.

Thermal bridges can be characterized as either *linear* or *point*:

- Examples of linear thermal bridges include balconies, shelf angles or fenestration framing where the installation bypasses the wall insulation. Linear thermal bridges are characterized by psi-factor, ψ, which is the thermal transmittance-per-unit length in units of Btu/(h·ft·°F) or W/m/K.

- Examples of point thermal bridges include beams, columns or anchors where the installation bypasses the wall insulation. Point thermal bridges are characterized by chi-factor, χ, which is the thermal transmittance-per-penetration-area in units of Btu/(h·°F) or W/K.

Thermal bridges associated with the interface of fenestration and surrounding conditions are generally linear thermal bridges. Thermal bridges associated with supporting exterior components in glazing systems such as sunshades, louvers, etc., are often point thermal bridges. Table 23 describes linear and point thermal bridges.

TABLE 23 *Linear and Point Thermal Bridges*

Type of Thermal Bridge	Linear Thermal Bridge	Point Thermal Bridge
Definition:	Thermal bridges associated with the interface of fenestration and surrounding conditions	Thermal bridges associated with supporting exterior components in glazing systems such as sunshades, louvers, etc.
Examples:	Balconies, shelf angles or fenestration framing where the installation bypasses the wall insulation	Beams, columns or anchors where the installation bypasses the wall insulation
Characterized by:	psi-factor, ψ, which is the thermal transmittance-per-unit length in units of Btu/(h·ft·°F) or W/m/K.	chi-factor, χ, which is the thermal transmittance-per-penetration-area in units of Btu/(h·°F) or W/K

How to Account for Thermal Bridges
The model energy codes account for thermal bridges in two ways: simple prescriptive strategies and more complex modeling using psi- and chi-factors.

The simple approach can be reduced to a basic concept of a “thermal line.” Just as designers and engineers look for a continuous line connecting the materials forming the water barrier and the air barrier, they should also look for a continuous thermal line connecting the insulating materials to create a “thermal barrier” between components. This results in different, simple prescriptive strategies as discussed below.

The more complex approach involves comprehensive heat transfer modeling of assembly details at each interface. This modeling generates psi- and chi-factor thermal transmittance numbers for each construction detail. These numbers can be used to adjust the effective U-factor of the envelope assembly and to account for the greater heat loss in whole-building performance calculations. Psi- and chi-factors can either be modeled for each custom assembly detail, or pre-calculated and provided for common constructions. These values would be necessary if using the performance path of building energy codes for compliance. The models can also provide useful information about surface temperatures to help locate cold points below the dew point at different design conditions, and therefore help identify potential condensation areas.

Strategies for Consideration
Thermal: For fenestration assemblies, whether a punched opening window or a curtain wall, the concept of a “thermal line” leads to the ideal scenario: alignment of the insulating glazing, thermal breaks within the frame, and insulation in surrounding construction without any significant bypasses. This ideal is not always possible when considering the many functional design requirements regarding structural support, water management, etc. However, better alignment will generally result in less thermal heat loss and an improved (lower) psi-factor, as shown for some example constructions in Figure 19. In each example shown in Figure 19, the thermal line is illustrated in red. Example A is Efficient: Well aligned glazing without conductive bypasses. Example B is Regular: Misaligned glazing and minor conductive bypasses. Example C is Poor: Cavity-insulated and conductive bypasses.

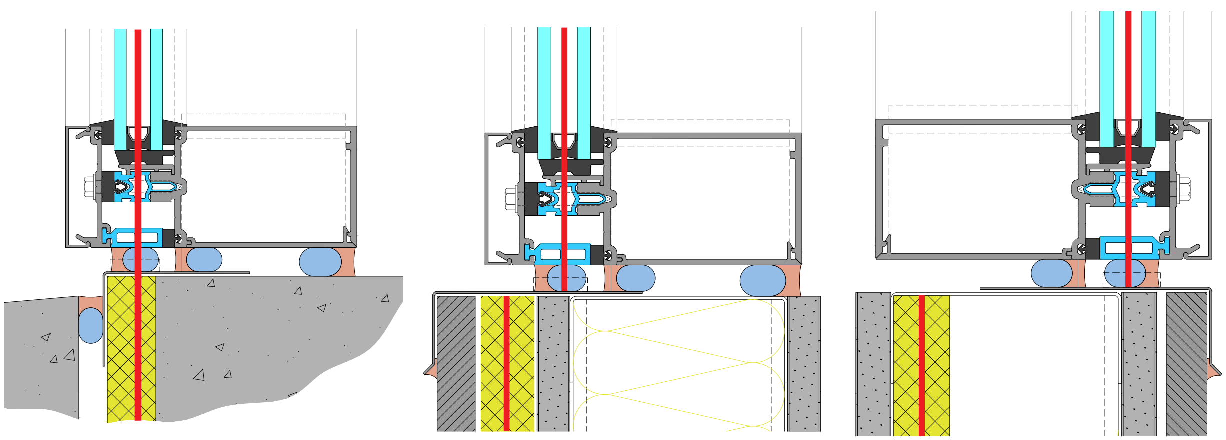


FIGURE 19 *Examples of the concept of a thermal line, Example A, Example B and Example C.*

Edges and perimeters: Edges or perimeters are often the location of many functional aspects of a glazing system interface with adjacent construction. While a drawing of a detail is “static,” the actual construction of that joint is not. It is often a dynamic joint and should be detailed and executed with that in mind. Accommodations should be made for movement and deflection, water migration strategies and insulation.

Cost-effectiveness: The cost-effectiveness of adding thermal continuity between glazing systems and surrounding construction is not easily calculated from the glazing subcontractor's perspective alone. Involvement of the HVAC and mechanical engineering professions is recommended to compare the cost of the material and labor of insulation continuity details with the expected energy savings that could be realized. This analysis should be completed, typically by the design team, prior to the bid documents being issued, and can then be used to determine whether the details should be adopted.

NGA Design Guide DG03-22 *Thermal Bridging Considerations at Interface Conditions* offers additional details and strategies.

Direct and Reflected Solar Energy

Light and solar energy incident on glazing will be partially transmitted through the glass, absorbed by the glass and reflected off the surfaces of the glass. The degree to which light and solar energy is reflected is dependent on a number of variables, including:

- The angle and orientation of the sun to the surface of the glazing,
- The flatness of the glazing,
- Coatings on the glass.

Perfectly flat glass will reflect light and solar energy. Glass may deflect due to a variety of environmental factors that may lead to the concentration of this reflection in a localized area. Such deflection can occur in monolithic glazing systems, but it is more typical of insulating glass. When an IGU becomes concave where the gap between the lites at the center of the unit becomes less than the gap at the edge of the unit reflected light may be concentrated at a distance known as the focal length (see Figure 20).

FIGURE 20 *Reflected Solar Energy*

The concentrated effects of the reflected solar energy can adversely affect the surfaces it is cast upon due to added heat from the increased intensity. The effect can be influenced by a number of design considerations:

- Glass thickness: thinner glass will deflect more easily than thicker
- Glass type: whether heat-strengthened, tempered or annealed, all glass types will deflect the same
- IGU unit size: large IGUs will deflect more easily than smaller units
- IGU aspect ratio: the ratio of the height to width or the width to height of the IGU can affect glass deflection. Aspect ratios closer to 1:1 (a square) will have greater deflection than units with higher aspect ratios.
- IGU cavity gap: units with a greater distance between glass lites that define the cavity gap (“air space”) will have greater deflection than units with narrower gaps.

Both direct and reflected solar energy can affect building cladding materials and fenestration components. All environmental conditions play a role in the heat transfer of any receiving surface that could result in material damage from exposure to excessive heat. The main five factors to consider in the design are: building location, building orientation, material selection, building design and exterior building features. NGA Glass Technical Paper FB60-18 *Understanding Reflected Solar Energy of Glazing Systems in Buildings* discusses design and glazing considerations to reduce reflectivity.

Glazing Considerations for Systems in Seismic Regions

The design professional should specify the various loads anticipated during a seismic event. The following should be considered.

<u>Glass Corner and/or Edge Cushioning</u>
Padding consisting of 50-70 Shore A durometer hardness material should be placed in the glazing channel or on the glass edges/corners to avoid any glass-to-frame contact due to the anticipated sway of the frame. This is important for both dry glazed and wet glazed, since the building structure will experience movements and vibration, e.g., during an earthquake.

<u>Gasket Performance</u>
For a dry glaze system consisting of a key-in gasket on one side and a roll-in (wedge) gasket on the other side of the glass, the wedge gasket should have a positive lock-in method so the gasket will not disengage from the metal framing system during the up-and-down and side-to-side movement that occurs during a seismic event. The gasket must remain in place when the glass moves due to the sway of the building.

<u>Setting Blocks and Supports</u>
The setting blocks should be positioned in a permanent manner by keying into the horizontal framing member, using a compatible sealant for placement or other method that will not allow movement of the block. When a setting chair is used to support the block, it should be permanently anchored or secured to the horizontal framing member and support the setting block as referenced.

<u>Wedge Blocks and Supports</u>
A wedge block should be used in four side captured glazed systems to minimize edge damage, using a compatible sealant to keep the block in place if necessary.

Snap-On or Applied Finish Strips
Members of the glazing system that act as finish strips and/or glass support members that rely on compression of gaskets or metal fit to remain in place should be attached and designed so that the member will not become loose or cease to provide glass support from vibration and sway due to seismic loads.

Sealant Design and Application
Sealant joint and application practices should be used that incorporate the anticipated movement of the glazing system and provide structural capacity (for structural glazing systems) along with weatherproofing requirements and glass retention ability.

Wall System Connection and Building Anchor Systems
Wall system connection and building anchor systems should be designed to consider the inertia loads of the cladding and the distortion and vibration sources from in-plane and out-of-plane loads. Building code requirements must be reviewed and understood for issues relating to cladding isolation and story drift limitations. Seismic movement considerations may require special analysis for the connections and building attachment methods to insure ductile behavior of the system components.

Glass Holding Frames
The glass holding frames should be designed to accommodate the inter-story drift and racking anticipated during the seismic event and allow for proper edge clearance to avoid loads on the glass edges and surfaces.

Daylighting and Biophilia

Daylighting Strategy

Glazing in a daylighting strategy can bring about obvious ecological advantages as it is one of the most environmentally responsible lighting strategies available, harnessing the power of the sun. With careful design and controls, daylighting can substantially reduce lighting energy use. Daylight has qualities that cannot be replicated by electrical light. The changing intensity, direction and color of natural light connect building occupants to the weather, season and time of day. Views through windows can stimulate the well-being and productivity of building occupants.

Glazing daylighting solutions have significantly increased, providing a number of benefits, such as:

- Enhanced light diffusion
- Glare control
- Light redirection
- Maximized light transmittance
- Increased light scattering

In addition to energy savings, countless studies cite the advantages of daylighting in terms of increased productivity, reduced absenteeism, enhanced employee retention and improved academic performance. For more information, see NGA Glass Technical Paper FB53-17 *Benefits of Decorative Glass in Daylighting Applications*. Research studies, statistics and other resources on daylighting are available at glass.org/resources/market-intelligence/daylighting.

Daylight must be balanced with glare control and thermal comfort. Generally, direct sun should be blocked from falling on occupants and task surfaces, especially if computers are involved. This is partly a matter of interior design and shading devices, but glazing design can already achieve much on its own. For instance, glazing can be separated into glazing for daylighting and glazing for views while daylight is redirected by means of light shelves. Light shelves are horizontal surfaces installed either externally or internally near the top of a window to passively reflect natural daylight into the building. Top lighting fenestration such as roof monitors can be another means of controlled daylight access. Roof monitors are installed vertically in the roof to channel natural daylighting throughout a room. Advanced glazing for daylight control is available with electrochromic coatings or between-glass blinds. Orienting glazing along an east-west axis typically reduces the potential for glare and allows for more even light conditions throughout the day.

Fundamentals of daylighting are explained in the *Whole Building Design Guide*, the Lawrence Berkeley National Laboratory (LBNL) Windows and Daylighting Group and the Daylighting Collaborative. For more project-specific advice, designers can use free and easy-to-use tools: COMFEN is an early schematic tool for quick what-if scenarios on specific façade, lighting and shading designs using the EnergyPlus simulation engine. The online Façade Design Tool allows quick comparison of glazing choices based on orientation, location and performance priorities. These easy-to-use tools can help designers understand early in the design process how orientation, shading and the choice between different glazing types affect daylight availability, the potential for glare, and thermal performance.

LBNL has also developed computer tools for much more sophisticated prediction of how specific design strategies affect daylighting performance: the building energy simulation engine EnergyPlus and LBNL's Radiance, a ray-tracing program that accurately predicts light levels and produces photorealistic images of architectural space in all sky conditions.

Despite the dramatic advances in daylighting prediction, daylighting design still remains an art as much as a science. Discomfort from glare is difficult to quantify and predict since it is highly dependent on the occupant's direction of view and task. Some of the most effective daylighting strategies include a combination of shading, surface coloring and interior design features that is rather complicated to model in its entirety. Scientific tools can be a great help, but what really allows designers to push the envelope is innovation informed by experience. For more information, see NGA Glass Technical Paper FM04-12 *Daylighting*.

Biophilia

Biophilia design is based on the concept that humans desire to be connected to and surrounded by nature. Glass is often featured in biophilic design in architecture, allowing occupants to maintain a connection to nature and light while inside a building. Glass facilitates views of nature outside and allows light to enter to support plants or trees growing inside the building.

Biophilic design can include a desire to meet sustainability goals. Advancements in energy efficiency and thermal insulation performance have made glass a sustainable choice that complements the philosophy behind biophilic design.

FIGURE 21 *Example of biophilic design*

Sound Transmission

Sound Transmission Loss (STL)

The ability of a material or group of materials (wall, floor, roof, etc.) to minimize the passage of sound is referred to as the sound transmission loss (STL). STL is related to the specific frequency (Hz) at which it is measured, and its reduction of sound energy is expressed in decibels (dB). The decibel is the unit of measure used to quantify sound pressure level, i.e., the amplitude of sound. For sound pressure level, the greater the number of decibels the louder the sound. For sound transmission loss, the greater the number of decibel loss, the better the ability of a material to resist the transmission of sound. The sound transmission loss performance of a material is dependent on its mass, stiffness, damping characteristics, size, shape and temperature (if laminated glass or other temperature-sensitive materials are used).

One way to increase glass STL is to increase the thickness, which increases its mass and stiffness. Changing glass material properties in order to increase stiffness would also help, but is not normally practical. An air space between two lites of glass can also increase sound isolation performance due to the changes in mass and damping characteristics. Air spaces for increased sound reduction must be larger than those typically found in conventional sealed insulating glass products, which are generally ½ inch (12 mm) for commercial buildings. Utilizing glazing of two different glass thicknesses, known as decoupling, also reduces total sound transmission as the differing lites attenuate different sound frequencies. See Table 24.

Another variable in sound reduction is glass damping. Damping is the mechanical property of a material or system, which quantifies the rate of dissipation of vibratory motion into heat energy. Generally, glass has very low inherent damping. The lack of damping in glass can result in reduced sound isolation performance in certain frequency ranges. This reduced sound isolation performance is greatest at the critical frequency. At the critical frequency, sound is efficiently transmitted through the material. Adding damping to glass reduces sound transmission through the glass at the critical frequency.

The most effective way to improve damping of sound by glass is through the use of laminated glass, which utilizes a viscous interlayer sandwiched between two lites of glass (See Fabricated Products, Laminated Glazing Materials section). Bending waves in the glass excited by incident sound causes shearing strains within the viscous material. Because the soft interlayer material has inherently high damping, bending wave energy in the glass is then transformed into heat energy by the viscous interlayer, i.e., sound energy is “absorbed” by the laminated layer. Using an interlayer to increase glass damping can result in improved STL, which otherwise might only be obtained through significant increases in glass thickness or significant increases in air space width for insulated glass units. When laminated glass is used in air-spaced configurations or insulating glass unit configurations, the benefits of damping are even greater. It should be noted that stiff interlayers do not contribute significantly to damping as significantly as conventional, composite or specially engineered acoustic interlayers do.

The test method used to measure sound transmission loss is ASTM E90 *Standard Test Method of Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements*. From this test, ⅓ octave transmission loss values are obtained.

Sound Transmission Class (STC) and Outdoor-Indoor Transmission Class (OITC) Ratings

Sound Transmission Class (STC) is a single-number rating as described and assigned in ASTM E413 *Classification for Rating Sound Insulation*, used to classify sound insulation of interior partitions. The STC rating is a curve fit calculation utilizing ⅓ octave transmission loss data produced by the ASTM E90 test. It is used for all glazing and materials but intended for interior walls, ceilings and floors. Prior to the creation of the Outdoor-Indoor Transmission Class (OITC) rating, the STC rating was also used for exterior façades and façade elements (including windows, doors, curtain walls, glazing, etc). Some projects are still specified using the STC rating.

Outdoor-Indoor Transmission Class (OITC), a single-number rating as described in ASTM E1332 *Standard Classification for Rating Outdoor-Indoor Sound Attenuation*, is used to classify performance of glazing in exterior applications. The OITC calculation compares the ⅓ octave TL (transmission loss) data produced by the ASTM E90 test and compares them to a standard noise spectrum. Testing can be done in accordance with ASTM E1425 *Standard Practice for Determining the Acoustical Performance of Windows, Doors, Skylight and Glazed Wall Systems.* This ASTM E1425 based practice specifies standard test sample sizes for various products. In addition to the sound transmission loss test, air infiltration and operating force tests (where applicable) are required.

Product evaluation is based on procedures with the following standards: ASTM E413; ASTM E1332; ASTM E90; American Architectural Manufacturers Association (AAMA)/Window and Door Manufacturers Association (WDMA)/Canadian Standards Association (CSA) AAMA/WDMA/CSA 101/I.S.2/A440 *North American Fenestration Standard/Specification for Windows, Doors, and Skylights;* and AAMA 1801 *Voluntary Specification for the Acoustical Rating of Residential, Light Commercial, Commercial Windows and Architectural Windows, Doors, and Glazed Wall Sections.*

Testing Considerations

Many times, window specifications require the laboratory determination of OITC or STC for specific window models and sizes proposed for use in building projects. While laboratory standards are devised to minimize the effect of sample test size, it has been observed that larger test samples tend to have different (could be higher or lower) measured sound transmission losses than smaller samples. Specimens tested for OITC or STC are often also tested for air infiltration resistance as this factor can affect STL. It is important to consider the same size glazing when comparing glass-only performance. Ultimately, the entire system, glazed and installed per manufacturer's instructions, should be tested if acoustic performance is critical.

Design Considerations

Design of a glazing configuration with acceptable air, water, structural, thermal and seismic performance does not necessarily guarantee acceptable acoustical performance. Fenestration with open joints or very lightweight frames may have a total sound isolation performance, which is less than that of the glazing when tested alone. Hence, laboratory testing of windows whose sound isolation performance is important to the success of a project should be based on laboratory-tested sound isolation performance, i.e. OITC or STC.

It is important that the entire exterior cladding (both walls and roof) be designed to accomplish the desired or required STL. The STL design of the glazing can readily be negated by the STL of adjacent materials such as masonry, pre-cast concrete, exterior insulation and finish systems (EIFS), lightweight panels, etc., including the roof coverings.

Additionally, the sound level inside the rooms of a building is affected by sound absorption of the room. To a certain extent, the greater the room sound absorption, the lower the sound level inside the room produced by an exterior sound source. Reverberant sound can be reduced by installing sound-absorptive architectural finishes such as acoustical ceilings, sound-absorptive wall panels or cushioned furniture. Doing so absorbs reverberant, or randomly reflected, sound in the space, thus reducing sound level.

Note that these benefits are only obtained at room locations away from windows. At locations near windows, the sound level is typically dominated by sound transmitted directly from the window to the location. It is only away from windows that the benefit of reverberant sound control works best.

Architectural Applications

The need for sound isolation from exterior and interior sound sources in building spaces depends on individual space use. For example, broadcast studios, recording studios and special presentation spaces need good sound isolation. These spaces are among the most sensitive since the audibility of intrusive sound, no matter how slight, is often viewed as unacceptable.

TABLE 24 *Typical Sound Transmission Losses for Various Glass Configurations*

Sound Transmission Loss (dB)

	One-third octave band (Hz)	100	125	160	200	250	315	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	STC	OITC
Monolithic	**1/4"** RAL-TL85-169	23	25	25	24	28	26	29	31	33	34	34	35	34	30	27	32	37	41	31	29
	1/2" RAL-TL85-198	26	30	26	30	33	33	34	36	37	35	32	32	36	40	43	46	50	51	36	33
Laminated	**Lami - 0.030" - Lami** RAL-TL85-218	24	26	27	27	28	29	30	32	34	35	36	36	36	34	34	39	43	46	35	31
	1/8" - 0.030" - 1/8" RAL-TL04-140	27	28	27	28	28	29	29	31	33	35	35	35	34	32	34	38	41	45	34	30
	1/8" - 0.060" - 1/8" RAL-TL85-201	25	25	26	29	28	30	30	32	34	35	35	36	36	36	36	39	43	46	35	31
	1/2" - 0.060" - 1/4" RAL-TL85-230	29	30	29	32	35	35	37	38	38	38	37	41	44	48	50	53	56	56	41	36
Insulating	**1/8" - 3/8" AS** - 1/8"** (SEALED) RAL-TL85-213	26	23	23	20	23	19	23	27	29	32	35	39	44	47	48	41	36	43	31	26
	1/4" - 1/2" AS - 1/4"** (SEALED) RAL-TL85-294	29	22	26	18	25	25	31	32	34	36	39	40	39	35	36	46	52	58	35	28
	3/16" - 1" AS - 3/16"** (SEALED) RAL-TL85-215	20	25	18	17	26	28	33	36	38	39	41	44	46	43	38	40	48	51	35	27
	3/16" - 4" AS - 3/16"** (SEALED) RAL-TL85-216	24	28	30	33	30	38	38	44	46	50	50	50	51	49	41	42	50	52	44	35
Laminated Insulating	**1/4" Lam. - 3/8" AS** - 3/16"** (SEALED) RAL-TL85-189	27	27	26	24	22	28	32	35	38	38	39	40	42	43	41	45	52	57	37	31
	1/4" Lam. - 1/2" AS - 3/16"** (SEALED) RAL-TL85-238	26	23	25	23	27	31	34	36	38	39	41	43	45	46	43	49	55	55	39	31
	1/4" Lam. - 1/2" AS - 1/4"** (SEALED) RAL-TL04-136	27	27	24	28	26	33	34	35	38	40	42	43	42	40	42	47	51	54	39	32
	3/4" Lam. - 4" AS - 1/8"** (SEALED) RAL-TL85-240	29	33	31	36	38	43	44	46	47	49	50	52	52	55	59	59	58	60	49	40
Double Laminated Insulating	**1/4" Lam. - 1/2" AS** - 1/4"** (SEALED) RAL-TL04-197	28	27	27	23	32	25	34	33	36	38	41	43	43	43	42	45	51	54	40	33
	1/4" Lam. - 1" AS - 1/4"** (SEALED) RAL-TL95-299	28	28	36	32	34	37	40	44	47	50	50	49	49	48	55	62	63	62	46	37
	1/4" Lam.- 4" AS-1/2" Lam.** (SEALED) RAL-TL95-302	34	42	40	41	42	45	48	50	52	54	54	54	56	58	60	63	64	65	53	45
Triple Glazing	**1/4" - 1/2" AS - 1/4" - 1/2"AS-1/4"** (SEALED) RAL-TL95-294	25	22	29	24	25	29	34	37	40	43	46	48	47	41	41	47	52	58	39	31
	1/4" Lam. - 1" AS - 1/4" Lam.- 1/2" AS - 1/4" Lam. (SEALED) RAL-TL95-300	31	28	38	36	35	41	43	47	50	53	54	54	55	55	60	63	64	63	49	39

The data and information set forth in Table 24 are based on samples tested and are not guaranteed for all samples or applications. Riverbank Acoustical Laboratories.

1. LAG = Symmetrically Laminated Architectural Glass with 0.030 inch Saflex® Interlayer by Eastman.
2. AS = Air space
3. (S) = Insulating Glass Unit having a secondary seal
4. (UNS) = Insulating Glass Unit unsealed due to air space width

Additional glazing sound transmission loss data for PVB and cured resin interlayers are provided in the NGA *Laminated Glazing Reference Manual*.

Fire-Rated Glazing Products

Fire-rated glazing materials are intended to help compartmentalize fire and smoke in a building when used in doors, wall openings and fire-resistant products, and can be used as a wall with an approved frame as a system and ensure safe egress. A fire rating is determined by the length of time a product can meet fire endurance testing criteria. Fire-rated glazing materials are tested to specific door, window and wall performance standards and may not correlate to the building codes' requirements. Therefore, a fire rating should not be confused with approval for a particular application. The fire-protective or fire-resistive ratings mandated by the International Building Code are based on the application requirements. These requirements depend on how much time is necessary to maintain the structural integrity of the building and safe egress of its occupants. Fire-rated glazing may also be used to prevent fire from spreading from one room to another.

Fire-rated glazing materials carry a label on the glass including the manufacturer, listed fire rating and testing agency.

There are a number of glazing products that will meet the fire-rated building code requirements (see Table 25). These products are divided into fire-protective and fire-resistive categories.

Definitions

Fire-Protective Glazing – Glazing materials installed for the purpose of containing the fire, preventing the spread of flames and smoke.

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 *Standard Methods of Fire Tests of Door Assemblies* / NFPA 257 S*tandard on Fire Test for Window and Glass Block Assemblies* / UL 9 *Standard for Fire Tests of Window Assemblies* / UL 10c *Standard for Positive Pressure Fire Tests of Door Assemblies* / ASTM E2010 *Standard Test Method for Positive Pressure Fire Tests of Window Assemblies* / ASTM E2074 *Standard Test Method for Fire Tests of Door Assemblies, Including Positive Pressure Testing of Side-Hinged and Pivoted Swinging Door Assemblies*. Note the two ASTM standards referenced here were withdrawn with no replacement and currently defer to UL and NFPA standards.

Fire-Resistive Glazing – Glazing materials installed for the purpose of containing the fire, preventing the spread of flames and smoke and blocking the transmission of radiant and conductive heat.

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 *Standard Methods of Tests of Fire Endurance of Building Construction and Materials* / ASTM E119 *Standard Test Methods for Fire Tests of Building Construction and Materials* / UL 263 *Standard for Fire Tests of Building Construction and Materials (wall assemblies).*

Fire-Protective Glazing

Fire-protective glazing includes polished wired glass, ceramics, specialty tempered glass and specialty laminated or filmed glass (both non-wired and wired). These products are generally between ¼ inch (6 mm) and ⅝ inch (16 mm) thick. Fire ratings range from 20 to 180 minutes, depending on the product and application. Consult the local building codes, code official and fire marshal for appropriate use of fire-protective glazing.

Wired glass was the original fire-rated glass. It relied on embedded wires to hold the annealed glass together during a fire endurance and hose stream test. Wired glass was exempted from Consumer Product Safety Commission (CPSC) 16 CFR 1201 *Safety Standard for Architectural Glazing Materials* Category I or Category II safety standards until 2003. Prior to the removal of this exemption from IBC model codes, state and local building codes allowed traditional wired glass to only 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.). The IBC now restricts the use of traditional wired glass in hazardous locations requiring safety glazing in either specific or all building types depending on the adopted version of the model code. Safety-rated filmed or laminated wired glass complying with CPSC Category I or II standards is readily available. Consult the local building codes, code official and fire marshal for appropriate use of wired glass.

Ceramics used in fire-protective glazing 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 for ceramics range from 20 to 180 minutes depending on the application. Consult the local building codes, code official and fire marshal for appropriate use of ceramic products.

Specialty tempered glass, clear tempered glass with ratings of 20 minutes, listed for CPSC 16 CFR 1201 Category II (400 ft.-lbs.) can be used as safety glazing materials in door applications. Consult the local building codes, code official and fire marshal for appropriate use of specialty tempered glass.

Laminated non-wired glass uses two lites of annealed glass laminated with a fire-protective interlayer. This product meets CPSC 16 CFR 1201 Category I (150 ft.-lbs.) safety requirements and carries a 20-minute fire rating with 9 square feet (0.84 m2) size limitations in door locations. Consult the local building codes, code official and fire marshal for appropriate use of laminated non-wired glass.

Some of the above fire-protective products may 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

- What is the minimum fire rating required for this application?
- Is an impact safety performance certification or label also required?
- Are there size limitations placed on the usage of a product based on code requirements?

Fire-Resistive Glazing

This category includes intumescent multi-laminate and gel-filled units. These glazing products are intended to restrict the spread of flames and smoke, and limit the transfer of radiant heat for 60 to 120 minutes. Fire-resistive glazing products are listed by third-party testing agencies as transparent walls, when used in a temperature rise framing system of equal rating to the glazing, and are not limited to the 25 percent glazed area restriction that applies to fire-protective glazing.

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

Gel-filled products 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 is designed to prevent the transmission of heat, smoke and flames.

Fire-resistive products comprised of intumescent multi-laminate and gel-filled cavities must also meet CPSC Category I and II performance standards when used in hazardous locations requiring safety glazing. These products can provide improved acoustical performance and are available for exterior use with energy-saving makeups. They can also be provided in special configurations for bullet, blast, hurricane, attack-resistance and other custom protections. Contact the fire-rated glazing supplier for details on these enhanced performance characteristics.

Key Questions to Ask in Selecting a Fire-Resistive Glazing Product

- What is the minimum fire rating required for this application?
- Is an impact safety performance certification or label also required?
- Is the framing capable of meeting the fire-resistive rating of the glazing?
- What are the size limitations of the selected fire-rated glazing?
- Is the application exterior or interior?
- Will the labeled framing meet the glazing thickness requirements for the selected fire-resistive rating?

TABLE 25 *Fire-Rated Glazing Products Comparison*

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 minute [a]	ANSI Z97.1 100 ft.-lbs.	Yes	No	Yes
Filmed Wired Glass	20 – 90 minute [a]	CPSC 16 CFR 1201 Category II 400 ft.-lbs.	Yes	No	Yes
Laminated Wired Glass	20 – 90 minute [a]	CPSC 16 CFR 1201 Category I 150 ft.-lbs.	Yes	No	Yes
Laminated Annealed	20 minutes	CPSC 16 CFR 1201 Category I 150 ft.-lbs.	No	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	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.

General Guidelines for Glazing

The design of a good glazing system incorporates experience, engineering principles and good judgment. Building movements relative to the framing system, method of erection, glass type and associated tolerances should be defined along with expected loads. The glazing contractor may be involved in this process during the design and specification stage, and can assist the design team in system selection that will meet the performance requirements of the project as well as deliver the aesthetics the designers are seeking. Pricing may also affect system selection during this early development work, but will also be critical during the bidding process that likely will follow, not only for the glazing contractor assisting in the early design stages, but also if a competitive bid situation is contemplated.

A framing system should be adequately or properly designed to support and retain the glass under the design load conditions, provide effective weather-tight sealing, prevent loads or pressure points on the glass resulting from building movement, prevent glass-to-metal contact and minimize glass breakage from mechanical or thermal stresses.

It is not possible in this *NGA's GANA Glazing Manual 2022 IYOG Edition* to address specific details of every framing or glazing system. However, the following outline should be useful as a guide to the responsible design professional(s), the general contractor and the glazing contractor.

Design Review

The design professionals (architect, engineer, specifier) are responsible for selecting glass suitable for its intended application. Among other design criteria, the following items should be considered during the design review:

A. Glass Selection

1. Loading requirements, glass strength and thickness, and thermal stresses due to building orientation and/or application (i.e., north vs. south elevations, inside corners, vision vs. spandrel conditions, etc.).
2. Thermal performance requirements for glass and framing (U-factor, condensation resistant factor (CRF), etc.).
3. Design of edge seal for structurally glazed IG units.
4. Material compatibility.
5. Acoustical considerations.
6. Daylighting, glare and occupant-comfort considerations.
7. Temperature extremes to which the wall will be exposed.
8. Location and type of exterior shading and its effect on the glass.
9. Location of interior shading devices, heating and cooling outlets, blind or drapery pockets, and ventilation grilles that will affect thermal stress of the glass. See Figure 31.
10. Safety-glazing, fire-rating, energy, and other requirements of the applicable building codes.
11. Windborne debris-resistance requirements (i.e. due to hurricanes or tornadoes)

This is a non-exclusive list of design considerations. Additionally, although not specifically related to glass selection, the following items deal more specifically with the framing installation the glass will eventually be installed in:

B. Framing Selection and Installation

1. Proposed location and type of fire-safing between stories.
2. Location, type and thickness of spandrel glass insulation and vapor barriers.
3. Drip ledge at head of all glass to minimize glass staining from adjacent building materials run-off, e.g. alkaline materials such as concrete or mortar.
4. Weather-tightness, including flashings, primary and secondary seals, and weep systems.
5. The nominal position of the structure at the points where anchors will attach is dependent upon the following:
6. Deflection under construction-applied loads, i.e., material stockpiling, equipment, material handling devices, etc.
7. Deflection under dead, live, wind and thermal loads. This is especially important where cantilevered floor slabs and structural materials subject to creep deflection are involved.
8. Differential movements from floor slab to floor slab.
9. Seismic load, drift and movement requirements.
10. Building sway and twist.
11. Construction tolerances relating to the skeletal or support structure and mullion anchor points.
12. Movement of the building at isolation and expansion joints.
13. Surface of materials in spandrel areas and other locations where wash-off onto the glass may cause staining, tenacious residue or chemical attack.
14. Americans with Disabilities Act accessibility requirements.
15. Blast-hazard mitigation.

Shop Drawing and Materials Review

A. Glass and Glazing

1. The glass manufacturer or fabricator will upon request (and sometimes require) review and comment on details and evaluate glass strength and deflection due to design wind loads. It will also review the details to evaluate thermal stress-resistance of the specified glass constructions and provide guidelines for proper handling and installation. Building orientation, external shading, internal shading devices and certain glazing systems may cause excessive thermal loading on the glass, resulting in potential glass breakage. This thermal loading is a particular concern with annealed glass that is heat-absorbing (tinted) and/or coated. Heat-treating may be necessary in order to comply with the specified design factor. The glass manufacturer or fabricator should review the shop and/or architectural drawings to determine whether the glass requires heat-treating.

2. Upon written request, the sealant, glazing tape and/or gasket manufacturer(s) should review details and evaluate the effect of adjacent glazing materials and framing sealants on the glazing sealant, glazing tape and/or gasket adhesion and performance. They should also advise on the proper application of their products. This is especially critical when a structural silicone sealant or tape is used to retain the glass to the framing system. This review is typically required by these manufacturers as part of their warranty extension at the conclusion of the project.

3. See Specific Guidelines for Glazing section for compatibility considerations.

B. Glazing Operations

1. Generally, once the framing is glazed, jobsite protection and cleaning of the glass and framing are normally the responsibility of the general contractor. NGA Glass Technical Papers FB01-01 *Proper Procedures for Cleaning Architectural Glass Products* and FB03-03 *Construction Site Protection* should be consulted for additional information and recommendations.

2. Welding, sandblasting or acid washing in the vicinity of the metal framing or glass can cause unsightly damage to both, as well as reduce the strength of the glass. Heavy tarpaulins or plywood should be used to protect the framing and glass. Immediately after an acid washing, the glass should be flushed with clean water. Contact with hydrochloric or hydrofluoric acid may etch glass if not promptly removed.

3. Paint, concrete, mortar, plaster, drywall spackle or other similar materials can stain, etch or pit glass or metal surfaces if allowed to harden on them. Such materials should be immediately flushed from the glass or metal with clean water or suitable solvent. An alternate is to protect the glass or metal with a sheet of plastic or protective film. If protective films are used, the film manufacturer should be consulted for confirmation of material compatibility, assurance against adhesive staining or etching the glass and guidelines for maximum duration of adhesion to the glass surface.

C. Anchors and Expansion Joints

1. Mullion vertical expansion joints should not apply loads on the glass due to movement of the structure or the framing system.

2. Wind-load anchors should allow for free vertical expansion of the mullions without causing additional stress on the mullion, mullion connectors or anchors. Slip pads are best for this purpose; oil and grease lose their lubricating qualities over the long term. The same is true for anchors designed to anticipate any seismic activity.

3. Twin-span mullions should have the dead-load anchor located as close as possible to their midpoint, thus equalizing upward and downward expansion and contraction.

4. Generally, horizontal expansion joints should be no further apart than 30 feet (9.14M). Expansion should be from the center toward both ends to minimize joint movements and thereby reduce stresses on sealants and connectors.

D. Deflection of Framing

1. Under design wind load, for mullions that support glass, deflection of those mullions in the direction perpendicular to the plane of the wall must satisfy code requirements, but should not exceed length of span divided by 175 (L/175) or ¾ inch, whichever is less, for the glass edges to be considered firmly supported. This deflection limit criterion was developed so as not to overstress the primary and secondary seals of insulating glass units, but it's also used to frame monolithic or other glass constructions as well. AAMA TIR-A11 allows framing deflection of L/175 or ¾ inch, whichever is less,

for spans less than 13 feet-6 inches, and L/240 +¼ inch for spans over 13 feet-6 inches. It should be noted that deflection limit is for the framing. No single lite of glass, monolithic or insulating, should be supported by framing where the L/175 or ¾-inch limit is exceeded along its individual edges.

2. Under dead load, for horizontal framing members that support glass, deflection of those members in the direction parallel to the plane of the wall is generally limited to ⅛ inch (3mm) or less and should not exceed an amount which will reduce the glass bite below 75 percent of the design dimension nor an amount which would infringe upon necessary glazing clearances below. Deflection should also be limited in this direction to provide at least ⅛ inch (3 mm) minimum clearance between the member and the top of the fixed glazed panel, glass or other fixed part immediately below. The clearance between the member and an operable window or door below should be at least 1⁄16 inch (1.5 mm).

3. Twisting (rotation) of the horizontals due to the weight of the glass should not exceed one degree (1°), measured between ends and center of each span.

E. Erection Tolerances

1. Within any rectangular opening there should be no more than a ⅛-inch (3 mm) difference in the measured length of the diagonals across a single opening.

2. Maximum variation of mullions from plumb or horizontals from level should not exceed +/-⅛ inch (3 mm) in 12 feet (3.6 m) or +/-¼ inch (6 mm) in any single run.

3. Framing systems designed to have the glazing legs of the horizontal and vertical members in the same plane should have a maximum out-of-plane offset of 1⁄32 inch (0.8 mm) at the frame corners to avoid unequal stresses on the glass. Greater offsets may cause issues with gaskets properly seating and creating the necessary air/water seals.

4. To assure that the stated tolerances for items above are not exceeded in the erected framing, a simple, low-cost set of go/no-go gauges can generally be made available for use by the framing erector.

F. Adjacent Work by Others

1. Metal framing systems should be attached to walls, column covers, knee-walls and any other substrate in a manner that will not impede expansion, contraction and deflection of metal framing or add an undesigned weight to the anchors.

2. The window or curtain wall is not a load-bearing structure. Support of adjacent stud wall or other types of interior or exterior wall partitions by the window or curtain wall system(s) should not be permitted. Flexible connections can be designed to accomplish the desired effect.

3. Attachments of framing system should be performed in accordance with shop drawings. The glazing contractor should coordinate with the wall supplier to verify all planned attachment methods.

4. For additional information, see Thermal Bridging section of this Manual.

G. Drainage

1. All framing systems should have an adequate weep system to drain all infiltrated water. Edges of insulating glass units and laminated or wired glass, or glass opacified with an adhered polyester film or silicone coating, should not allow the edge of a lite of glass to set in standing water or be exposed to water or moisture vapor for an extended period of time. Extended exposure to water or moisture vapor may lead to seal failure of the insulating glass unit, delamination of the laminated glass, glass-clad

polycarbonate or laminated plastics, rusting of the wired glass, delamination of the opacifier film and/or contribute to potential attack on the coated glass surface.

2. The specific size and location of weep holes and/or weep slots vary with different glazing systems and applications. The drainage system should ensure that water does not puddle as a result of deflection of the horizontal/sill member or block water flow through the system. The size and location of weeps should be in accordance with the manufacturer's installation instructions and shop drawings and planned to allow drainage. Most framing system manufacturers recommend one or two 5⁄16-inch (8 mm) weep holes per daylight opening. Use of holes less than 5⁄16 inch (8 mm) in diameter can result in the surface tension properties of water from flowing through weep holes, thus preventing proper drainage. The glazing system supplier and glass fabricator should be consulted for specific recommendations on system requirements to provide adequate drainage, specifically the location, size and number of weep holes required.

3. Some framing systems utilize the vertical mullions as downspouts to drain all infiltrated water to the lowest point before weeping it to the exterior. When these framing systems are used on multi-story applications, the system manufacturer should approve the application. The system should provide water drainage to the exterior at a minimum of one location per length of the vertical mullion. It is important that water not be allowed to accumulate on the top of, or run down, the edges of insulating, laminated or wired glass in these systems. Proper application and utilization of water deflectors in this type of system will prevent water settling on glass units. Such conditions are likely to lead to product failure as discussed above.

4. In order to reduce the potential for leakage, whenever possible, it is best to avoid fastener penetration through the horizontal base of any water-diverting element, including glazing pockets, sill extrusions and flashings. Through-fasteners located in these elements should be sealed in accordance with the manufacturer's installation instructions.

H. Glass Clearance, Blocking and Bite

1. Glass, cushioned by resilient materials, should be free to "float in the opening" (i.e., it should have adequate clearance around all edges and laterally) so it does not directly contact the framing system during static or dynamic conditions. See Figure 22 and Table 26 for typical clearances.

   Certain materials used in the glazing system and/or engineered designs may allow a deviation from the typical clearances. Two examples are:

   a. Large lites of heat-treated glass and laminated glazing materials may require extra face clearance due to edge bow and warp (see ASTM C1048, C1172 and C1349 for tolerances), and

   b. Specialty glazing system designs such as ones with glazing tape or sealant back-bedding may be designed for reduced face clearance. Deviations from typical clearances should be fully considered within the context of the design and expected performance of the glazing system. Glass manufacturer, fabricator, glazing material manufacturer, and/or design professional should be consulted for relevant performance properties.

2. Glass should be set on two identical neoprene, EPDM, silicone or other compatible elastomeric setting blocks having a Shore (Type) A Durometer hardness of 85+/- 5. The preferred location is at the quarter points of the sill supporting frame. In some cases it may be necessary and/or acceptable to move the setting blocks equally toward the corners of the lite as far as the one-eighth points. Locating the setting blocks less than six inches from the corner of the glass may introduce additional stresses to the glass and to insulating glass seals. Glass manufacturer or fabricator should be consulted for review. See Figures 23 and 24. Also refer to paragraph D.2 *Deflection of Framing.*

3. The proper sizing and design of the setting blocks assure full bearing of the glass on them yet allows water passage to the weep holes.

    a. Width of elastomeric setting blocks should be at least ⅛ inch (3 mm) wider than the glass thickness. For settings in lock-strip gaskets, excessive width may reduce the designed lip seal pressure; gasket supplier should be consulted for proper setting block width. Lead setting blocks should not be used.

    b. The length of the blocks may vary, depending on the glazing system. Generally, each setting block, in most metal glazing systems, is 0.1 inch per square foot of glass area. Neoprene lockstrip gasketing systems use a rule of 0.4 inch per square foot of glass area.

4. Edge blocking, or anti-walk blocking as it is frequently called, should be used on all dry glazed systems to limit lateral movement of the glass caused by horizontal expansion/contraction, building sway and creep deflection. Lack of edge blocking can permit glass-to-framing contact on one edge and deglazing on the opposite edge. The first can cause glass edge damage or breakage; the latter can permit air and water infiltration as well as changing the glazing design from four-sided to three-sided support. Side blocking positioned within the top third and bottom third (measured vertically) is recommended for narrow, tall lites. See Figure 25.

    Edge blocking should be made of neoprene, EPDM, silicone or other compatible elastomeric material. Hardness should be per manufacturer’s recommendation, usually having a 50 - 70 Shore A durometer. Blocks should be a minimum 4 inches (100 mm) long, placed in the vertical channel and sized to allow a nominal ⅛ inch (3 mm) clearance between the edge of the glass and block. See Figure 25.

5. Edge blocking is also used to accommodate substantial building sway and/or seismic movement. Under these situations, it is important to attempt to identify the anticipated sway or seismic movement early in the design process. This step could assist in the proper design of the height of the glazing legs and the bite of the glass. The allowance for movement, retainment and cushioning may necessitate increased edge clearance and bite.

6. Glass should be free to “float” (move) within the glazing pocket without touching the framing, while at the same time maintaining adequate bite under the most adverse design conditions. The web of the framing is often cushioned near all four corners to prevent glass edge-to-framing contact, yet allowing the necessary clear space for the anticipated movement.

7. For wet glazed and structural silicone glazed systems edge blocking may not be required. The window/wall system manufacturer should be consulted for recommendations.

8. The designer should be aware that if glass bite is greater than typical as shown in Figure 22 and Table 26, it may lead to high thermal-edge stresses, and the glass may require heat-treatment.

9. Glass is held in the glazing system by stops sufficiently deep to retain the glass under expected loads, deflections or movements, and to cover the edge seal (sight line) of a sealed insulating glass unit.

10. Figures 26, 27 and 28 cover the special conditions required for doors, casement, and vertically pivoted and horizontally pivoted windows. Some insulating glass fabricators may modify or void their warranty when insulating glass is “cross-blocked” as in Figure 27. The insulating glass unit fabricator should be consulted.

Edge blocking for operable windows and doors is a common practice and can be acceptable as long as the glass edges are not excessively loaded. The use of blocking may prevent impact of the glass edges against the frame during movement of the frame supporting the glass and keep the glass properly positioned within the glazing system. Blocking size and position for insulating glass units should follow the guidelines shown in Figures 23 through 28.

Excessive pressure on the glass edge can lead to glass breakage or seal failure due to pressure points and mechanical bending stresses imposed upon the glass from frame movement during operation. Excessive pressure on the glass edge can also impair the sealant performance if the pressure is such that the glass movement occurs in a magnitude sufficient to shear or distort the sealants.

An allowable load on the edge of insulating glass being used for operable windows and doors would be that at each block the load applied is less than half of the total glass weight of the insulating glass unit. The design of the frames for operable windows and doors should be such that the frame is supporting the glass and the glass is not supporting the frame.

Edge blocking for operable windows and doors is a common practice and can be acceptable as long as the glass edges are not excessively loaded. The use of blocking may prevent impact of the glass edges against the frame during movement of the frame supporting the glass and keep the glass properly positioned within the glazing system. Blocking size and position for insulating glass units should follow the guidelines shown in Figures 23 through 28.

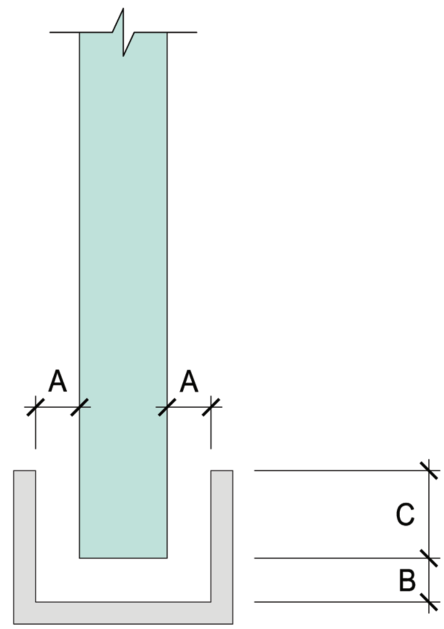


FIGURE 22 *Glazing Face & Edge Clearance & Bite Dimensions*

TABLE 26 *Recommended Minimum Face & Edge Clearance & Glazing Bite*

Thickness		Recommended Minimums					
		A=Face		B=Edge		C=Bite	
Monolithic Glass							
inches	mm	inches	mm	inches	mm	inches	mm
S.S.	2.5	1/16	1.6	1/8	3.2	1/4	6.4
1/8 - D.S.[1]	3	1/8	3.2	1/8	3.2	1/4	6.4
1/8 - D.S.[2]	3	1/8	3.2	1/4	6.4	3/8	9.5
3/16[1]	5	1/8	3.2	3/16	4.8	5/16	7.9
3/16[2]	5	1/8	3.2	1/4	6.4	3/8	9.5
1/4	6	1/8	3.2	1/4	6.4	3/8	9.5
5/16	8	3/16	4.8	5/16	7.9	7/16	11.1
3/8	10	3/16	4.8	5/16	7.9	7/16	11.1
1/2	12	1/4	6.4	3/8	9.5	7/16	11.1
5/8	15	1/4	6.4	3/8	9.5	1/2	12.7
3/4	19	1/4	6.4	1/2	12.7	5/8	15.9
7/8	22	1/4	6.4	1/2	12.7	3/4	19.0
Insulating Glass							
1/2	12	1/8	3.2	1/8	3.2	1/2	12.7
5/8	15	1/8	3.2	1/8	3.2	1/2	12.7
3/4	19	3/16	4.8	1/4	6.4	1/2	12.7
1	25	3/16	4.8	1/4	6.4	1/2	12.7
[1] Annealed Glass Only	[2] Fully Tempered Glass Only						

Note: Clearances above may vary for some glazing materials or applications. In such cases, the recommendations of the specialty glazing system manufacturer/supplier should be followed.

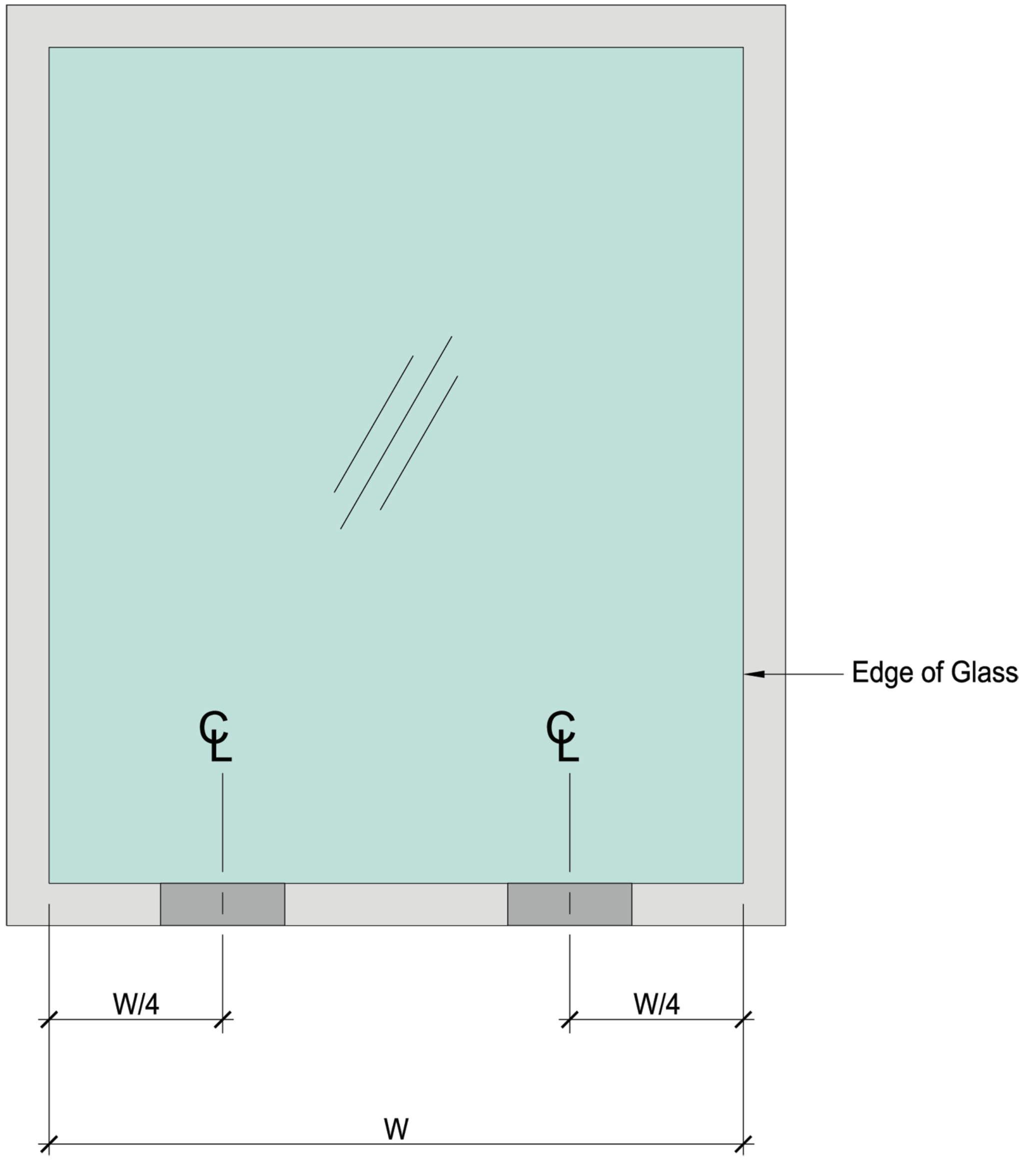
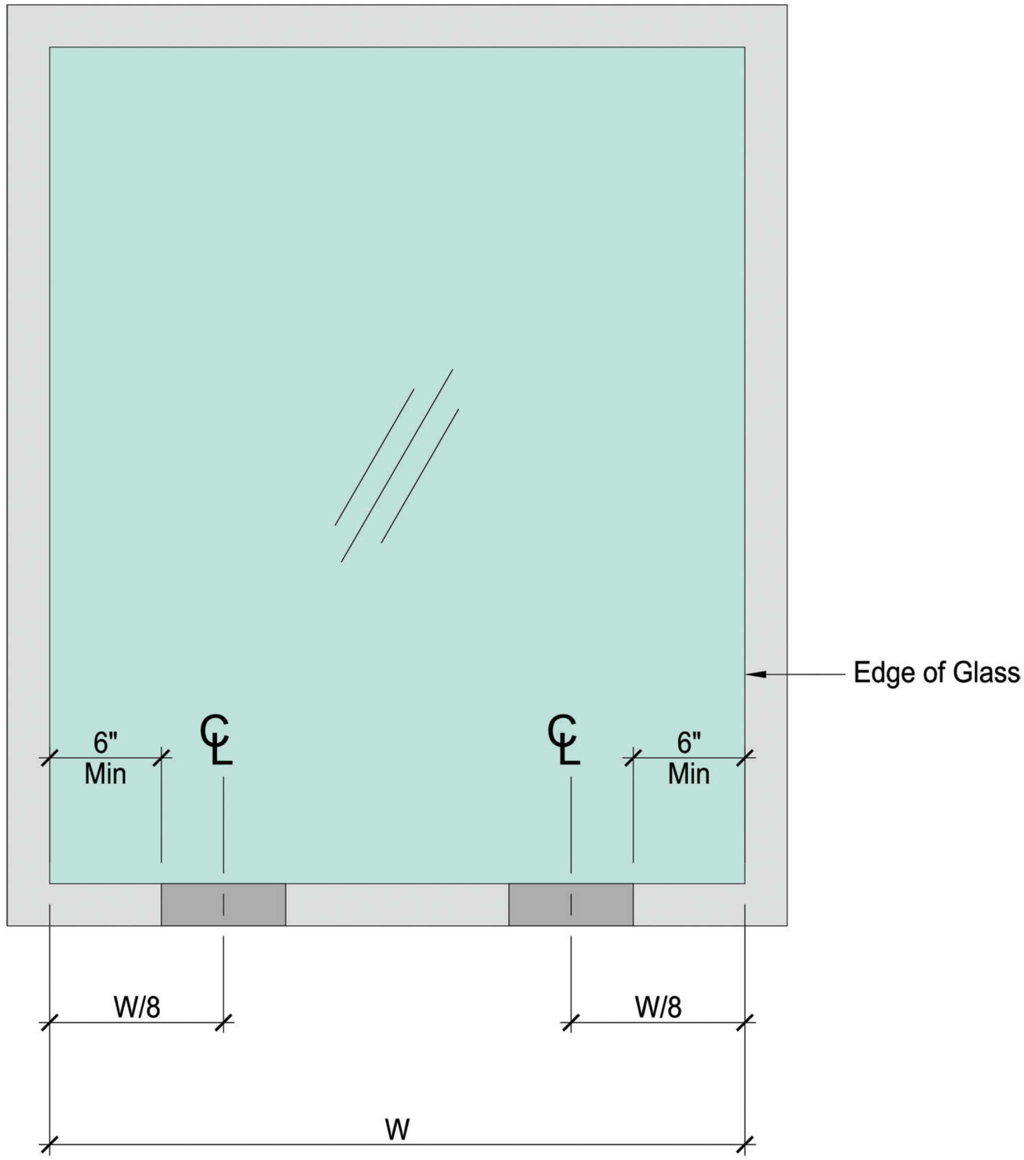


FIGURE 23 *Setting Block Location for Fixed Framing (Preferred)*

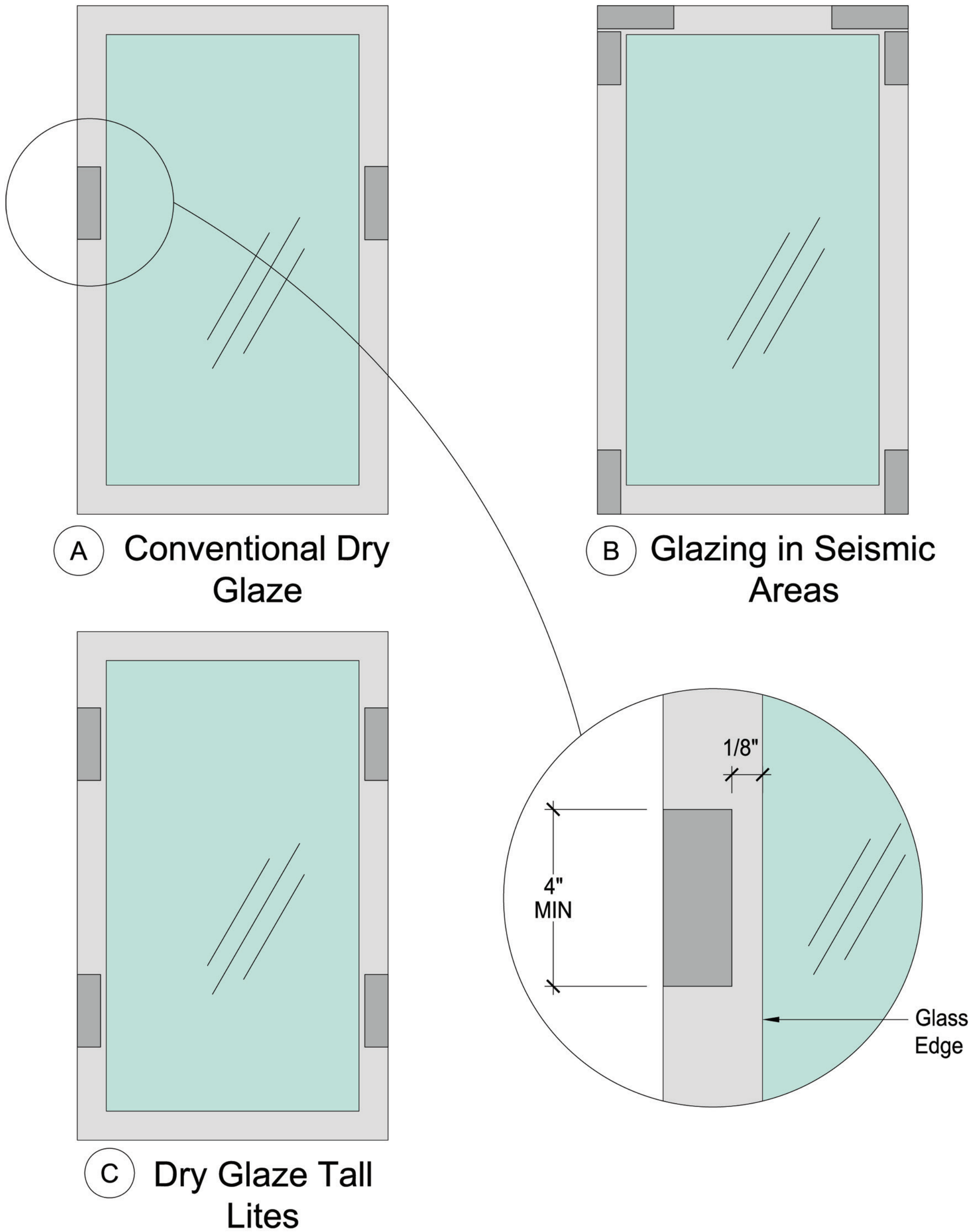


85+/-5 Shore A Durometer hardness blocks positioned within W/8 or 6 inc of glass edg, whichever is greater. Bock length is dependent on glass area.

SETTING BLOCK LENGTH PER BLOCK
1. Neoprene, EPDM, Silicone = 0.1 inch per Sq. Ft. Glass Area
2. Lock-strip Gasket = 0.5 inch per Sq. Ft. Glass Area
3. Never Less than 4 inche for #1 and #2 above for glass widths greater than 48 inch
4. Never Less than 6 inch for #3 above.

NOTE: Lead setting blocks should NEVER be used.

FIGURE 24 *Alternate Setting Block Locations for Fixed Framing*



NOTE: Consult glass fabricator for preferred location.

FIGURE 25 *Edge Blocking*

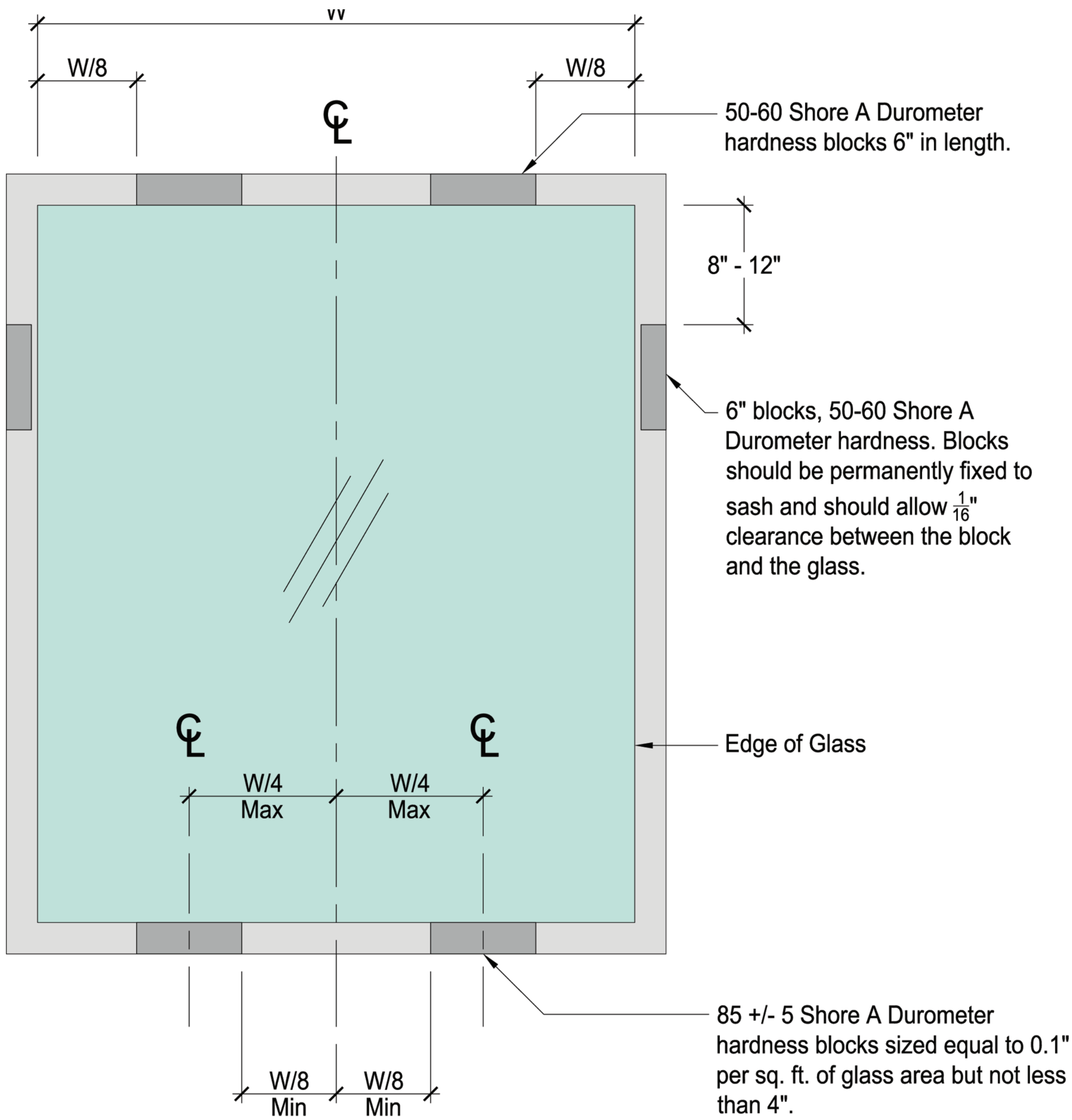


FIGURE 26 *Blocking for Vertically Pivoted Windows*

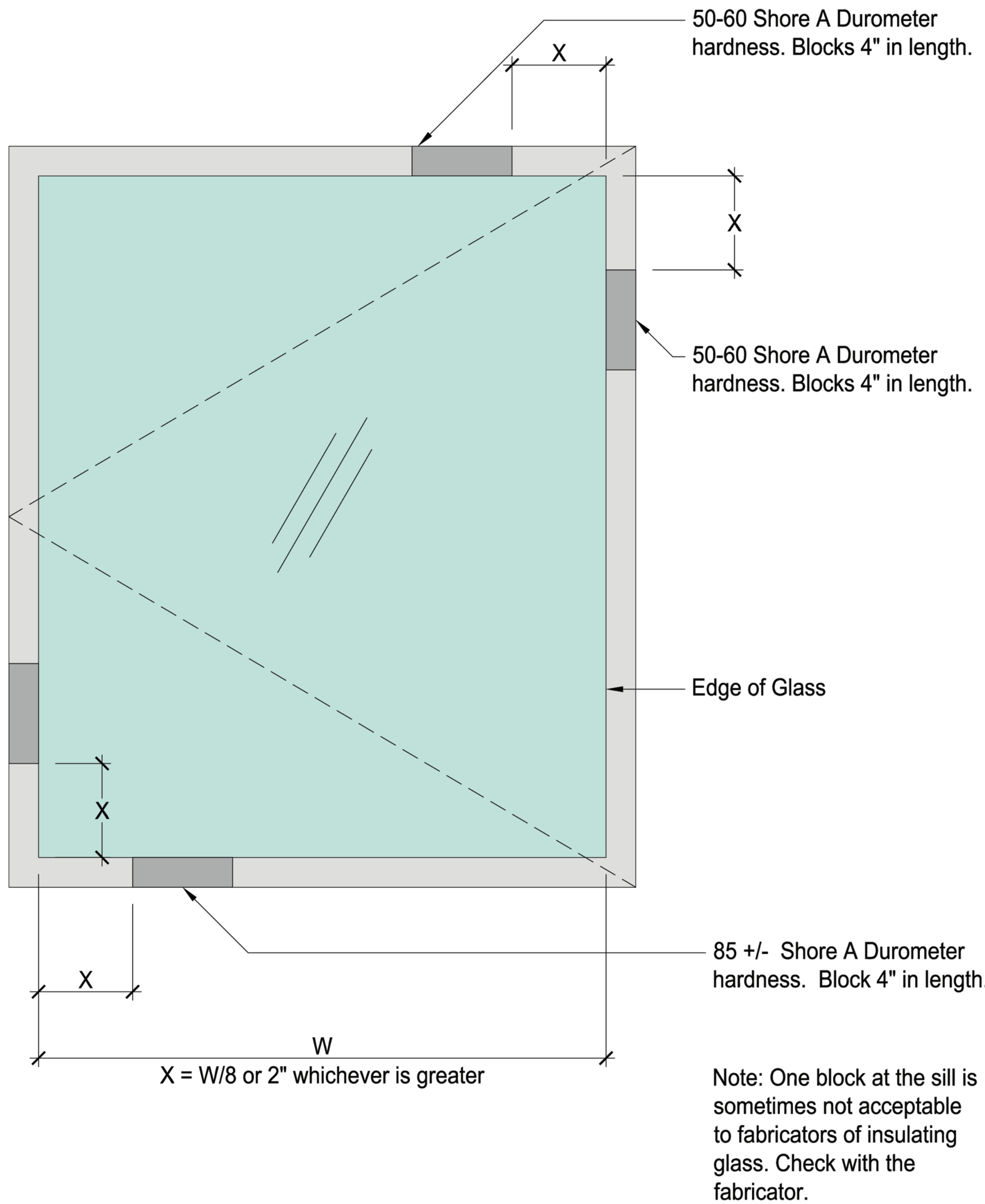
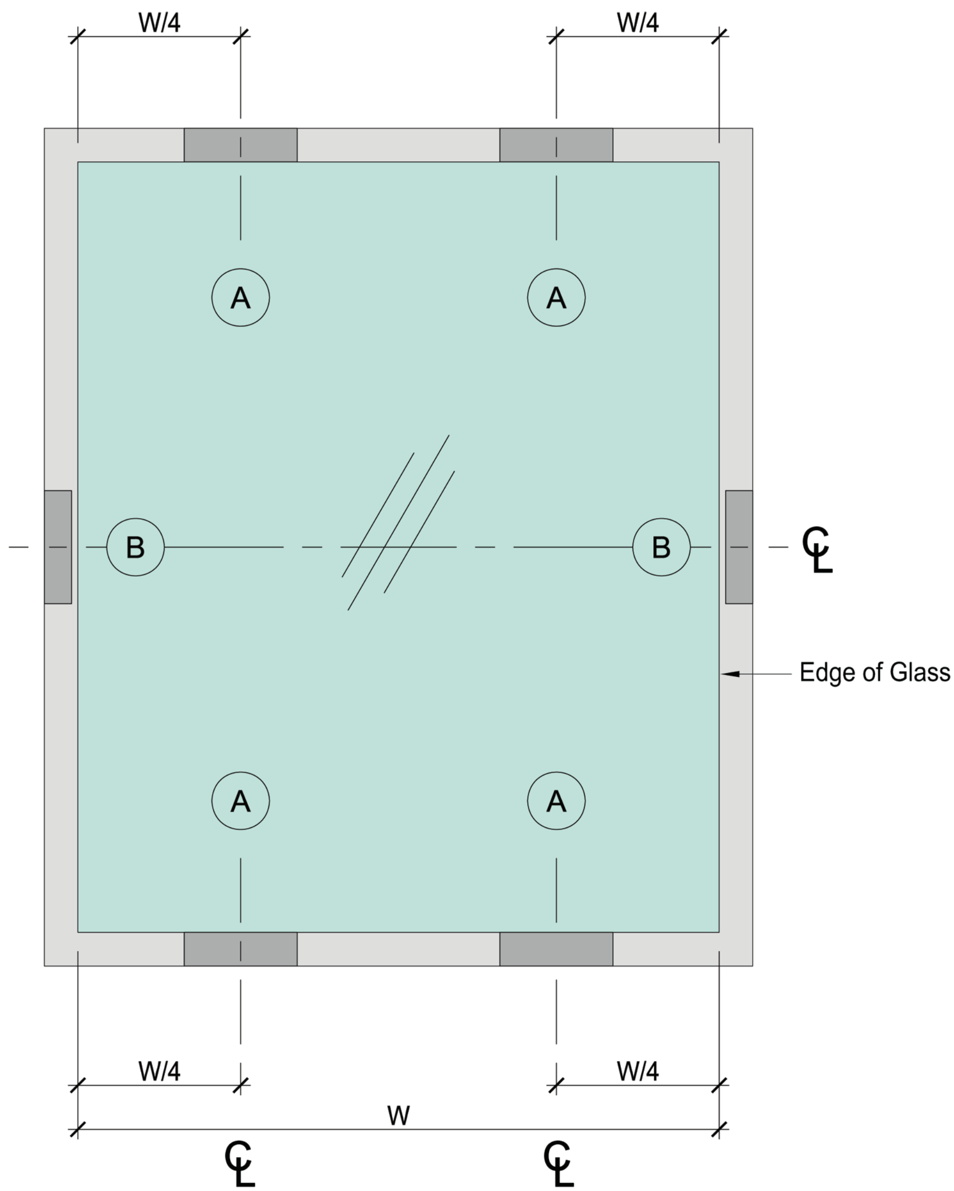


FIGURE 27 *Blocking for Casement Window and Doors*



(A) Type "A" Blocks: 85 +/- 5 Shore A Durometer hardness 0.1" in length per sq. ft. of glass area but not less than 4".

FIGURE 28 *Blocking for Horizontally Pivoted Windows*

Glazing Operations: Recommended Steps

A. Pre-construction Meeting

1. A pre-glazing meeting should be held prior to erection. This meeting should be attended by the entire construction team to review and discuss the construction schedule, unusual jobsite conditions, storage requirements and other considerations. NGA Glass Technical Papers FB03-03 *Construction Site Protection* and FB01-01 *Proper Procedures for Cleaning Architectural Glass Products* are recommended resources for presentation and discussion at the pre-glazing meeting.

B. Glass Receiving

1. Plan glass shipping schedule to minimize jobsite storage time and to avoid off-jobsite storage and re-handling.

2. Reduce handling by scheduling shipments by floors and by initially locating crated products as close to their installation areas as possible.

3. Inspect all crates, boxes and other packages at time of delivery. If damage to the packaging is visible or suspected, take photographs prior to removing the crates or boxes from the delivering vehicle or at least immediately after they are unloaded. Note on the freight bill or delivery receipt any evidence of shortage, abuse, damage or wet packaging and expressly state on the freight bill or delivery receipt that the shipment is accepted subject to inspection of contents for damage, including concealed damage. Have delivering driver sign. Set the questionable crates and boxes aside in a readily accessible space with minimum movement and request an immediate inspection by the carrier's representative. Inspect glass from a few undamaged crates on the delivery site or dock to be certain there is no concealed damage and that the product is acceptable subject to further complete inspection of the shipment. If the driver refuses to wait, conduct an inspection of the contents as soon as possible following delivery without moving the crates or boxes from the unloading area.

4. The following should be done immediately while in the unloading area:

    a. Inventory materials and notify supplier of any shortages, and

    b. Photograph and report any concealed damage to the motor or rail carrier and supplier, request prompt inspection of the packages or crates if any damage is noted, and promptly file a claim for damages with the carrier unless the supplier is planning to do so.

C. Glass Storage

1. Store crated glass in a cool, dry, shady and well-ventilated area where it will not be subject to rain or direct sun.

2. Obtain a statement from the project structural engineer as to the maximum total weight of crates that can be stored at each proposed location.

3. If not opened immediately, cover cases with waterproof plastic or canvas in such a manner as to allow air circulation around the crates. Air circulation is required to minimize the potential for condensation, which could cause staining of the glass.

4. Secure crates to building columns if possible; otherwise, stand several cases together and fasten them to each other with scrap lumber to prevent them from overturning. Crates should be placed 2 inches to 6 inches (50 mm to 152 mm) off the floor and tilted 1 inch (25 mm) per foot (305 mm) of height to expedite unpacking.

5. If prolonged storage becomes imminent, the contractor should consider appropriate measures to protect the materials such as rental of temperature-controlled storage facility.

D. Job Conditions

1. Advise the general contractor of the protective steps that must be taken by other trades in conjunction with any subsequent adjacent work.

2. Inspect the substrate/framing for compliance with the following:

    a. Framing is within tolerance for plumb and level and is in plane;

    b. Each opening is within tolerance for size and squareness;

    c. The preceding waterproofing/flashing is installed continuously and per approved plans/specs;

    d. Offsets at framing corners are within project-specified tolerance;

    e. Assess project-specific alignment with any adjacent systems (ex. Plaster control joints, metal panel joints, etc.);

    f. The glazing channel is free of debris and obstructions;

    g. The weep system is open, free of debris and allows uninhibited water flow;

    h. The glazing surfaces are free of moisture, dirt, grease, oil or any deleterious material;

    i. Screws, bolts, rivets or weld fillets do not reduce the minimum required face or edge clearance;

    j. All joinery, connectors, screw or bolt heads, rivets and water dams are effectively sealed;

    k. Confirm fenestration system perimeter sealant compatibility with rough opening substrates (ex. Waterproofing/flashing); and

    l. All steel or wood glazing pockets and contacts of dissimilar metal are painted.

3. A clear area should be established and maintained to allow the proper and safe installation of material, including a controlled access zone directly below any elevated work.

E. Installation of Glass

1. Temperature conditions during glazing should be within the limits required by the sealant and gasket manufacturers.

2. Measure glass for proper dimensions.

3. Use a rolling block to rotate glass. See Figure 29.

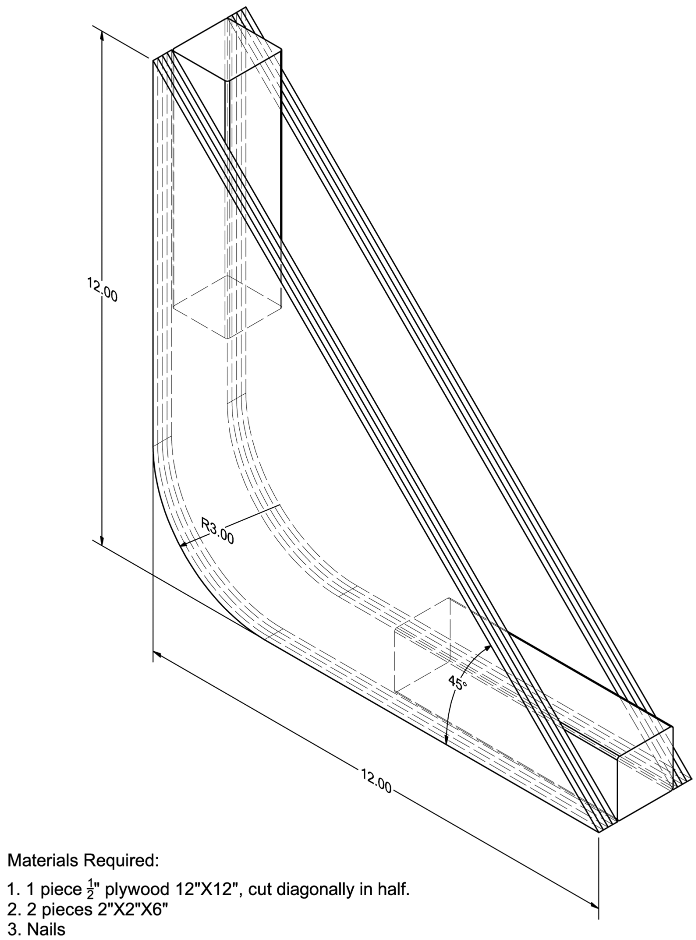


FIGURE 29 *Rolling Block*

4. Do not impact the glass against the framing during installation to avoid causing edge damage. Pocket, or “Flush Glazing,” is particularly susceptible to glass edge damage from impacting the frame and requires precise sizing of the glass and extra care during installation.

5. Use suction cups to shift a lite of glass within the opening. Raising or drifting the glass with a pry bar can cause edge damage.

6. Glass with questionable edge conditions should be set aside for inspection by glass manufacturer or fabricator. See Figure 30.

7. Glass with flares or bevels at the bottom in the vicinity of the setting blocks should be rotated 180 degrees to place these at the top, if acceptable to glass manufacturer or fabricator.

8. Some insulating and laminated glass fabricators place temporary glazing instruction labels on their product such as “Glaze This Side In” and/or “Glaze This Edge Up.” Field supervision should confirm these instructions, validate the correct surface orientation and then instruct installers to adhere to these instructions. Some products are provided with specific performance characteristics (energy, security) that will not perform appropriately if not properly installed. Note that if there is a question as to the proper orientation or makeup of glass surfaces, tools such as a low-e detector and/or spectrophotometer may be helpful.

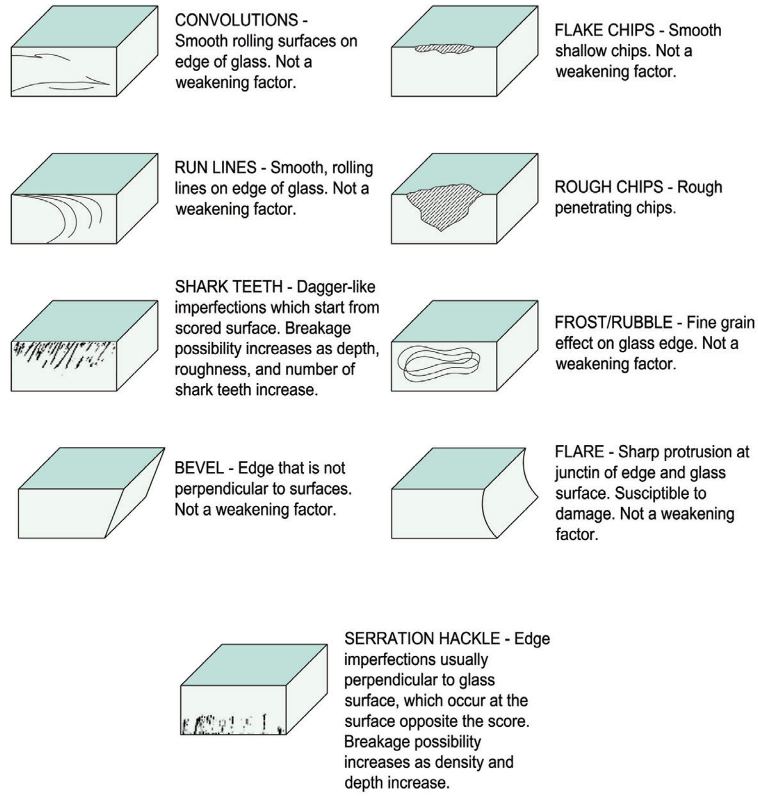


FIGURE 30 *Glass Edge Characteristics*

9. Prior to or immediately following glazing, remove all temporary labels from the face of the glass. Note: some code officials may require that the labels remain on the face of the glass for a short time until the code compliance inspection has been completed. Be considerate of all labels that may not be accessible by the building occupant after installation and consider removing temporary labels after final inspection is completed by the code official.

10. After installation, skylights and sloped glazing systems should not be used as a walking surface unless the system has been designed and engineered to support the load for use as a walking or maintenance surface. For additional information, consult the NGA Glass Technical Paper FB10-06 *Skylights and Sloped Glazing Are Not Walking Surfaces*.

F. Post Glazing

1. In order to avoid damage to the finished surfaces, do not mark or attach anything directly to the exposed glass or framing surfaces. Advise general contractors to avoid adhering tape to installed glass as it may damage certain specialty types of glazing (e.g. lead-lined glazing). Check with manufacturer/fabricator specifications and instructions before adhering any tape or signage to the installed glazing.

2. Construction dust, leachate from concrete and rusting from steel can combine with dew or condensation to form chemicals which may etch or stain glass and metal. During construction, glass and metal should be cleaned frequently and appropriately by trained professionals. Glass should be cleaned in accordance with NGA/IWCA Glass Technical Paper FB01-00 *Proper Procedures for Cleaning Architectural Glass Products* and the manufacturer/fabricator guidelines.

3. If any welding is to take place above or near glass, the glass surfaces should be protected with plywood or other suitable material to reduce the likelihood of weld splatter damaging the glass surface(s). Refer to NGA Glass Technical Paper FM02-09 *Protecting Glass Against Weld Splatter*.

4. Advise general contractor not to permit materials to be stored adjacent to the glass in such a manner that a heat trap is created which could cause glass breakage.

5. Advise general contractor not to store or place other materials in contact with the glass.

6. Advise general contractor to protect the glass from other trades.

7. Glass, especially monolithic coated glass, can be permanently damaged if not protected from workers, tools and other materials. Also, see Shop Drawing and Material Review, Glazing Operations, B1 through B3.

8. Refer to NGA/IWCA Glass Technical Paper FB03-03 *Construction Site Protection and Maintenance of Architectural Glass*.

Shading Devices

1. Draperies, Venetian blinds or other interior shading devices should be hung so as to provide space at the top and bottom or one side and bottom to permit natural air movement over the room side of the glass (see Figure 31). The following criteria should be met to avoid formation of a heat trap:

    a. Minimum 1-½ inch (38 mm) clearance required top and bottom or one side and bottom between shading device and surrounding construction.

    b. Minimum 2-inch (50 mm) clearance between glass and shading device.

    c. Heating/cooling outlets located to room side of shading device.

2. If Venetian blinds are being used and these clearances cannot be provided, a two-direction positive stop or lockout that limits the movement of the blinds should be incorporated. For horizontal blinds, the lockout should limit the rotation of the blinds in both directions so that they are in a position 60 degrees off the horizontal when in the most-closed position. For vertical blinds, the lockout should limit movement in both directions so that ½-inch (12 mm) spacing exists between the blinds when in the most-closed position. If these guidelines cannot be maintained, heat-strengthened glass should be specified in lieu of annealed glass.

3. Exterior sunscreens and solar shades produce shade patterns across the glass. Heat-strengthened or fully tempered glass may be necessary for some installations to offset the effects of glass size, solar absorption, exterior shading, interior shading, climatic conditions, lack of proper clearances noted above or improper placement or directing of air flow.

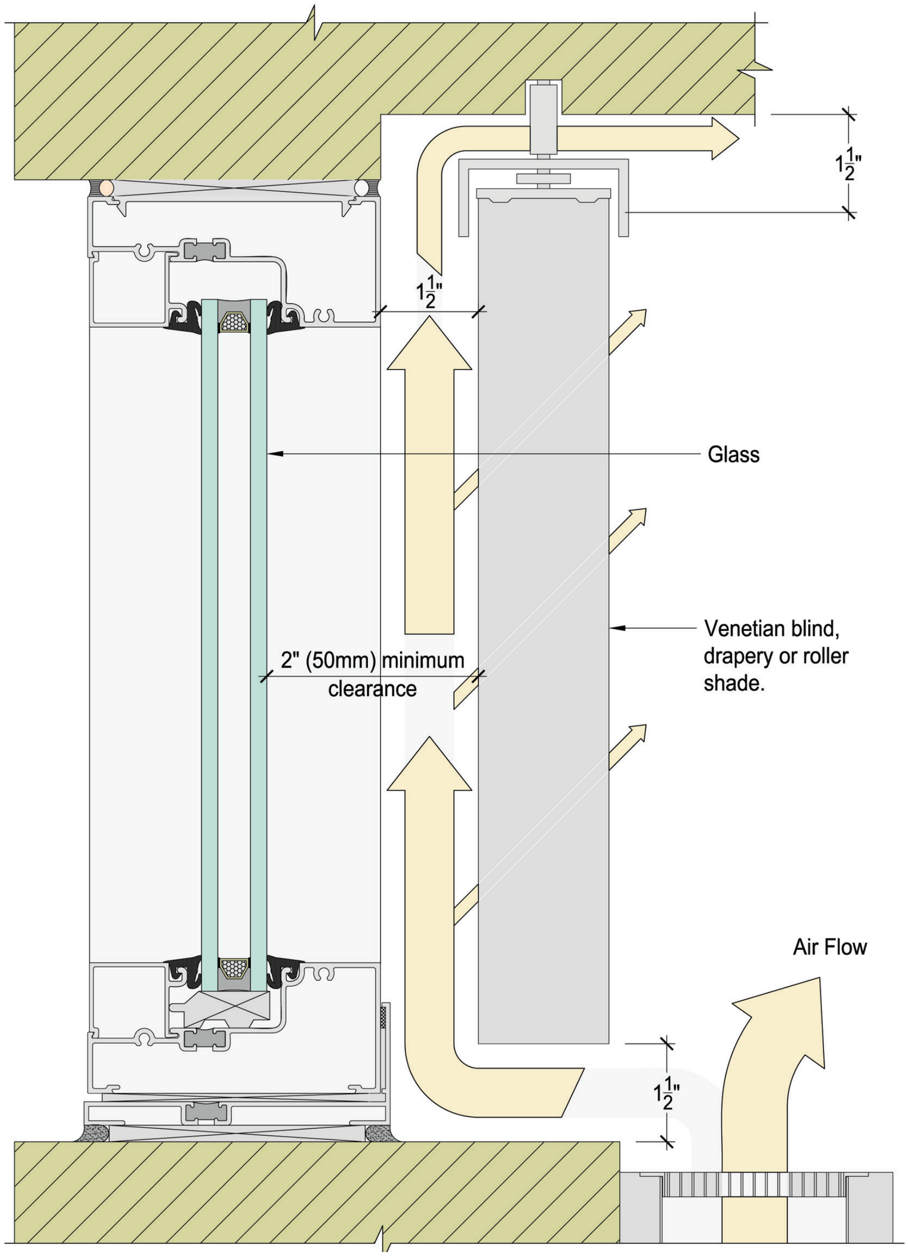


FIGURE 31 *Indoor Shading & Heat Duct Locations (Glass and Shading Device Clearances)*

Specific Guidelines for Glazing

The compatibility of materials is essential to the long-term performance of any glazing installation. Chemical reaction from physical contact or close proximity exposure to incompatible materials may occur over time. Less frequently, volatile elements given off by one material can adversely affect other materials within the closed confines of the glazing pocket. Fillers, plasticizers, oils or other components may migrate out of sealants, gaskets, spacer shims, jamb blocks or setting blocks and cause possible adverse effects on the sealants, adhesives or coatings of fabricated glazing products. Some of these components act alone, while others are influenced by moisture, heat and/or other elements or compounds.

Most sealant manufacturers are capable of performing compatibility testing in their laboratories and providing a test report upon completion to verify adhesion and compatibility with adjacent components and materials. Most sealant manufacturers require compatibility testing as part of their structural glazing warranty process. Insulating glass, laminated glass and opacified spandrel glass require special attention. Insulating glass units are fabricated with a variety of sealants, which vary by manufacturer. Laminated glass is fabricated with polyvinyl butyral (PVB), urethane, ionomer, cured resin or other interlayer materials. Opacified spandrel glass is typically coated with a ceramic frit, film or silicone coatings, which may vary by manufacturer. Fabricated products as well as the other materials used in the glazing operation must be compatible with the sealants and gaskets installed in glazing areas. For additional information, refer to NGA Glass Technical Paper FB28-11 *Assessing the Compatibility of Glazing Materials and Components*.

Testing should be conducted by the material providers to understand how their materials may interact with other materials in the glazing process. These materials include the following:

- Applied films
- Cleaning materials (neutral, acid, basic, solvated)
- Dissimilar metals (oxidation/rust, may need a dielectric isolation)
- Anti-Walk blocks or edge blocks (EPDM, PVC, SCR, silicone)
- Fluids
- Gaskets (EPDM, PVC, SCR, silicone)
- Glazing sealant, adhesive or mastic
- Glazing tapes
- Inorganic coatings
- Insulating glass sealants
- Insulation
- Interlayers (laminated glass, composite panels)
- Marking materials
- Metallic coatings (mirror, reflective, etc.)
- Organic coatings
- Sash joinery sealant
- Setting blocks
- Silicone coatings
- Spacer shims
- Structural silicone sealant
- Weather sealants

When wood sash and framing materials are used, all wood preservatives should be dried out to reduce the opportunity for the wood preservatives to create an incompatibility with the insulating glass unit sealants, which could result in premature seal failure.

Compatibility should always be considered and not assumed. The following tests are good starting points for guidance:

- ASTM C510 *Standard Test Method for Staining and Color Change of Single- or Multicomponent Joint Sealants*
- ASTM C794 *Standard Test Method for Adhesion-in-Peel of Elastomeric Joint Sealants*
- ASTM C864 *Standard Specification for Dense Elastomeric Compression Seal Gaskets, Setting Blocks, and Spacers*
- ASTM C1087 *Standard Test Method for Determining Compatibility of Liquid-Applied Sealants with Accessories Used in Structural Glazing Systems*
- ASTM D543 *Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents*

Glass Setting

When the glass is set, sufficient pressure should be placed against the glass, as it is lowered onto the setting blocks, to properly place the gasket or tape under pressure or compression. This should properly position the glass on the setting blocks. Uneven or point pressures on glass can result from improper positioning of the glass on the setting blocks. The pressure-producing glazing material should immediately be inserted to maintain the pressure.

Proper glass setting is typified by the example of a wet/dry glazing method having pre-shimmed tape for the weather seal and a hard rubber wedge as the pressure-producing member, see Figure 32. The glass should be pushed firmly against the tape across the sill while held with cups, up off the setting blocks about 1⁄32 inch (0.8 mm); the wedge should then be inserted the full width of the sill before the glass is allowed to settle onto the setting blocks. If this procedure is not practical, ease the glass onto the setting blocks while firmly pushing outward against the tape, insert the wedge the full width of the sill, then lift the glass off the setting block about 1⁄16 inch (1.6 mm) and ease it down again. Short, temporary pieces of wedge material should be used with caution when the fit of all components is extremely tight; excessive point pressure can readily cause glass breakage. If the proper pressure is not achieved initially, or is not maintained, the result can be an insufficient weather seal and/or point pressure on the glass at the setting blocks.

Wet Glazing

Wet glazing materials can be classified into three general types: pre-formed tape, gunable elastomeric sealants (non-curing or curing), and putty and glazing compounds.

Edge blocks or anti-walk blocks are normally required with wet glazing materials to center the glass in the glazing pocket and to hold the glass in position when subjected to wind load, vibration or building movement. A typical wet glazing installation is shown in Figure 32.

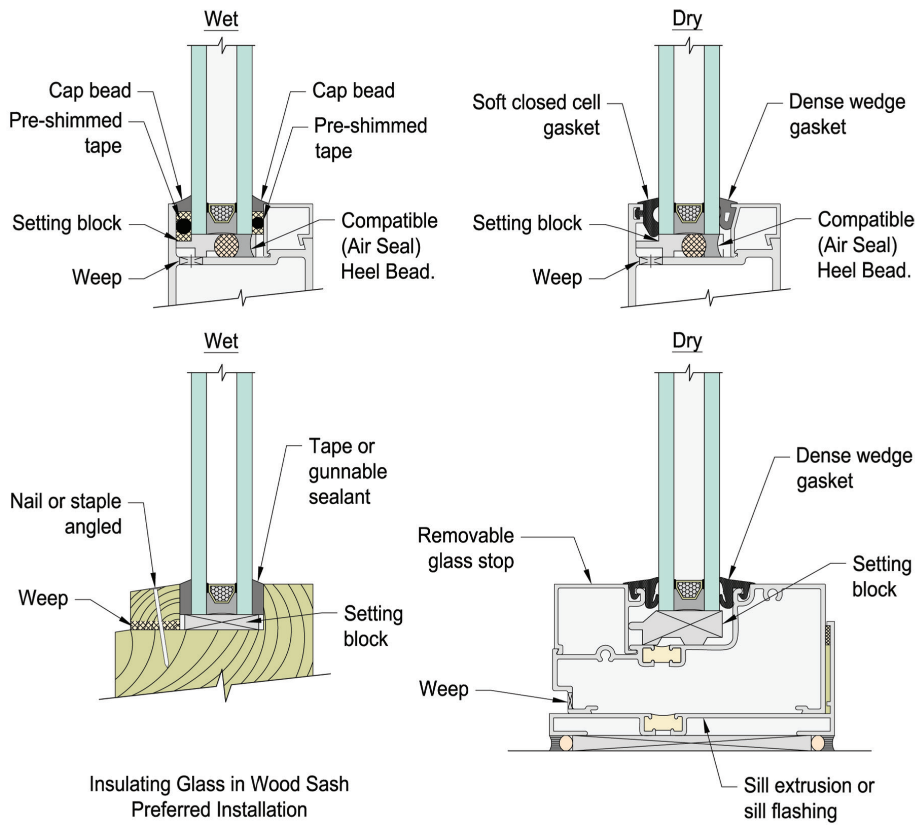


FIGURE 32 *Typical Wet & Dry Glazing Systems*

Preformed Tape

Preformed tape is generally an elastomeric material extruded into a ribbon of a width and thickness suitable for a specific application. The tape should remain resilient over a long period and have excellent adhesion to glass, metal or wood when continuous pressure is applied. Tape incorporating an integral, continuous shim is available and desirable. Elastic hybrid tapes, without an integral shim, are now available for many applications of compression glazing. These tapes should not be confused with the typical, non-elastic tapes that have long been available without an integral shim.

The tape comes as a roll with a release paper on one side. It should be applied to a properly prepared, clean, dry surface not more than 24 hours prior to glazing. Glazing surfaces should be prepared in accordance with the manufacturer's instructions to assure good adhesion. The release paper should not be removed until the glass is ready to be installed. All joints and corners should be squared and tightly, neatly butted; they must NOT be overlapped. The tape should not be stretched to make it fit. Joints should be lightly daubed with a compatible gunable sealant to assure a positive seal. The only joints in the tape should be at the corners with the horizontal tape typically running through.

Gunable Elastomeric Sealants

There are two types of gunable sealants for use in glazing applications: non-curing and curing. Non-curing sealants remain soft and tacky, whereas curing sealants become a semi-firm piece of synthetic rubber and are no longer tacky after fully cured.

Non-curing gunable sealants are usually used as a metal-to-metal joint sealant in non-exposed locations. When using the non-skinning type, the always-tacky surface can quickly collect dirt and become unsightly if used in an exposed location.

Curing-type gunable sealants are materials such as the polysulfides, silicones, urethanes, acrylics and other synthetic polymers/copolymers. They cure to an elastomer by chemical reaction with external conditions such as temperature and humidity, or by solvent release or by use of a catalyst. They are often used as a gunned-in-place glazing sealant or as a cap bead. Surfaces should be clean, dry and, if necessary, primed in accordance with the manufacturer's instructions. Ambient temperatures should be within the manufacturer's specified range during time of application and cure.

Putty and Glazing Compounds
Putty or glazing compounds have largely fallen into disuse because of a lack of service effectiveness in medium-to-large lite glazing. The oil and solvent content normally make putty and glazing compounds incompatible with neoprene, butyls, polysulfides, silicones, EPDM and acrylics. Putty or glazing compound should not be used to glaze laminated or insulating glass.

For additional sealant applications and guidelines, consult the *GANA Sealant Manual*.

Spacer Shims
Spacer shims center the glass within the glazing pocket, between the stops. They are either intermittent or continuous and should provide for a consistent gap between the glass and the sash. They control face clearance, dimension A of Figure 22 and Table 26.

Intermittent shims should be spaced uniformly at 18-inch (457 mm) to 24-inch (610 mm) centers. The length of the shims may vary. The minimum shim length should be 6 inches (152 mm). Improper placement or sizing of shims can create pressure points on the glass, which may lead to breakage. Positioning should start at the setting blocks and proceed equally, both left and right, so shims on opposite jambs are opposite each other. If the glazing system is wet glazed both inside and outside, the inside and outside shims should be exactly the same dimensions and exactly opposite each other.

Continuous shims are preferable in that they provide a uniform cushion around the perimeter of the glass and save the labor of separately and properly positioning individual shims. Pre-formed tape with an integral continuous shim has proven to be highly acceptable in tape-glazed systems. Elastic hybrid tapes, which do not require an integral shim, are also normally acceptable for compression glazing; they are not to be confused with non-elastic, unshimmed tapes.

The hardness range of shims varies according to the requirements of various glass manufacturers. Typically, 40 to 60 Shore A hardness durometer is recommended, but the glass manufacturer should be consulted for its recommendations for specific projects.

Dry Glazing

Dry glazing is the common designation for systems utilizing extruded rubber gaskets as one or both of the glazing seals. The performance of dry glazed systems is not as affected by installation, weather, workmanship and compatibility issues as with wet glazing systems. Dry glazing is also known as compression gasket glazing systems.

Two basic rubber gasket types are employed in compression gasket glazing systems: 1) Soft, closed cell gasket, and 2) Firm, dense gasket. A particular glazing system may use only one type of gasket on both sides of the glass (dense/dense) or may use a combination of the two (soft/dense). Gaskets need some way of preventing disengagement. They may use an integral dart, a locking nub or an adhesive material to prevent disengagement. When using gaskets with an integral dart or locking nub, the gasket and metal manufacturers should be consulted to verify fit and tolerances.

Gaskets are generally comprised of EPDM, silicone, neoprene and silicone-compatible rubber compounds. Compatibility of gaskets that may be in contact with sealants should be confirmed. By careful sizing of the gaskets, with proper consideration given to the plus and minus tolerances of glass, metal and rubber, the softer member will compress 25 to 40 percent and form a weather-resistant seal when the dense gasket is in place.

The corners of the soft gasket are frequently molded or vulcanized (if not, they should be sealed at the corners), thus forming a continuous, joint-free glazing material around all sides of the glazing pocket. A weep system is essential with any compression gasket glazing system.

Gaskets should be fabricated or cut slightly longer than the opening they are to fit (known as crowding). This is to account for the natural relaxing of the gasket material that may occur after installation. Some gaskets, depending on the type of material, may shrink. The gasket manufacturer should be consulted for shrink rates, if applicable, and guidelines on gasket sizing (crowd factor).

Installation of the soft gasket should begin from two adjacent corners of the opening and 2 or 3 inches (51 to 76 mm) of gasket should be pressed into place at each corner. Next, 2 or 3 inches (51 to 76 mm) of the gasket at its center should be pressed into place at the midpoint between corners. If the opening dimension is large, the process should be repeated at the quarter points. Then insert the balance of the gasket, working from two already-inserted points toward each other. This procedure should distribute the excess of the gasket equally and forestall any tendency to stretch the gasket. If the glass is not positioned properly on the setting blocks, starting installation of the wedge at the corners, as most gasket manufacturers recommend, can cause severe bending stress on the glass causing glass breakage. See the suggested procedure under Glass Setting.

Wet/Dry Glazing

Wet/dry glazing is simply a combination of wet glazing and dry glazing design. A typical wet/dry glazing system is shown in Figure 33.

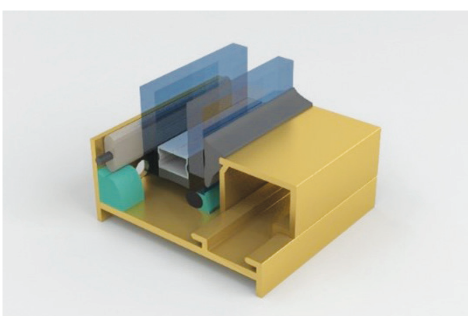


FIGURE 33 *Typical Wet/Dry Glazing System*

Cap Beads

Cap beads are generally applied around the exterior perimeter of the glazing. Their purpose is to make the glazing watertight/weather-tight. They may be a part of the original installation or may be a post-installation corrective remedy. Attributes of a good cap bead are as follows:

- They are of sufficient resiliency to absorb the expected differential movement between glass and framing without failure.
- They achieve good adhesion to both substrates.
- They are compatible with, but do not adhere to, the backer material (sometimes a bond breaker may be necessary).

- They have a width-to-depth ratio of 2 or greater, depending on the elongation/compression characteristic of the sealant.
- They form a watershed.
- They have sufficient contact area with each substrate to ensure proper performance.

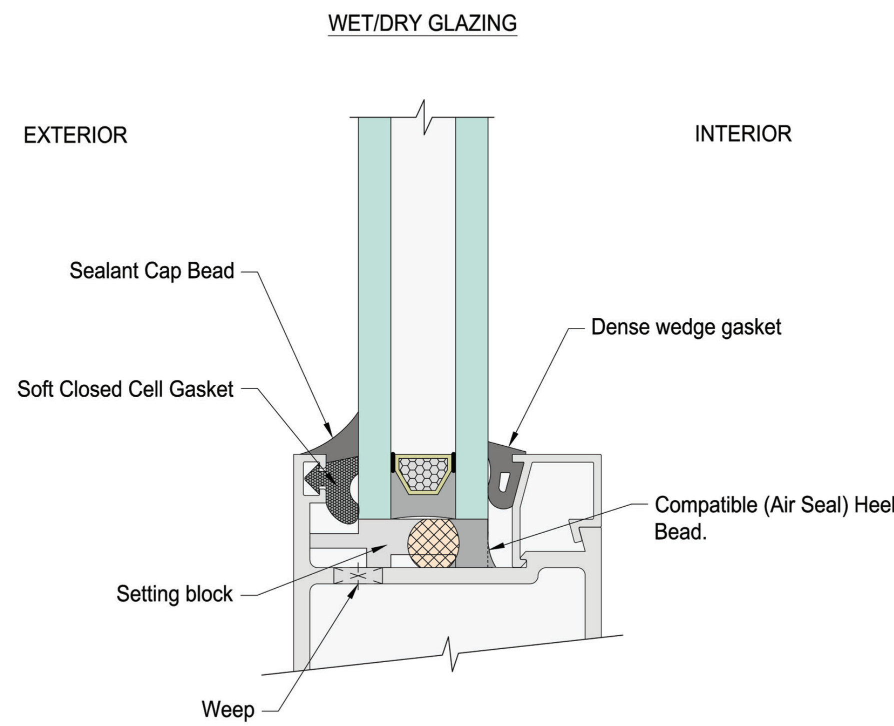


FIGURE 34 *Example of Good Cap Bead*

Refer to Figure 34 for an example of a good cap bead. Note typically weeps drain to the exterior, not below the sill.

Pressure Glazed Systems

Pressure glazed systems derive their name from the fact that the pressure or compression required to achieve weather-tightness is mechanically applied by a wrench or screwdriver.

Figure 35 shows a pressure equalized system (curtain wall) with a screwed-on exterior pressure plate. EPDM, silicone, neoprene, and silicone-compatible rubber compounds are typically used as the exterior weather seal. Excessive torque of the pressure plate bolts may cause harmful stress on the glass edge. A continuous isolator is typically used to control compression on the glass and to provide control of water at the horizontal rail. Inadequate torque on the pressure plate bolts may result in possible air and water leakage. The manufacturer’s installation instructions should be referred to for the proper pressure plate torque requirements and pressure bar screw spacing, if applicable. In pressure equalized systems such as a typical stick-erected curtain wall, the weeping of the water happens at each individual lite. Therefore, the installation and sealing of the system joint plugs are important to provide proper system performance.

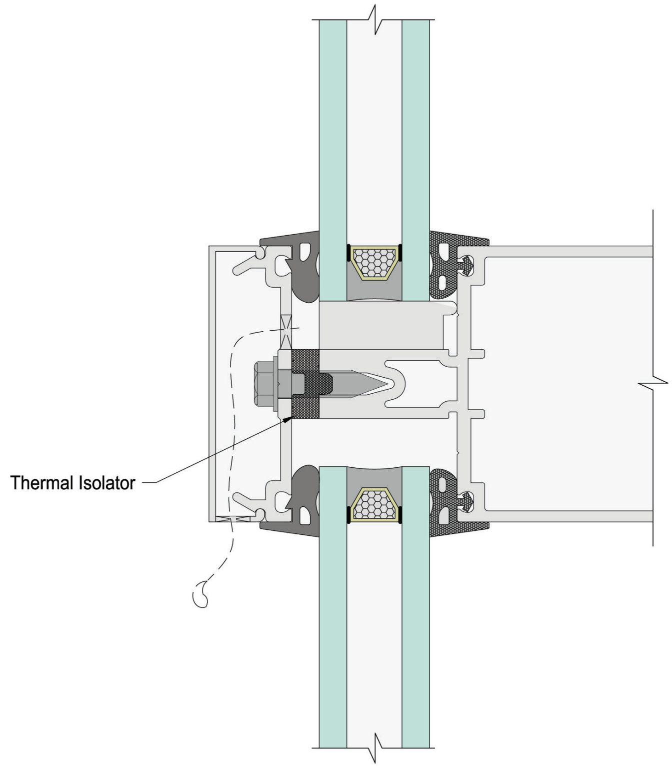


FIGURE 35 *Pressure Glazed System*

With a pressure plate system, the screws at the setting blocks should be fastened first, then at the quarter points of the jambs so pressure is applied evenly to opposing edges of the glass. Gaskets should contact the glass ⅛ inch (3 mm) or more from the glass edge; contact at or near the glass edge can induce chipping. Review the Glass Setting section.

Butt-Joint Glazing

Butt-joint glazing is a method of installing glass to provide wide horizontal areas of vision without the interruption of vertical framing members. It utilizes a conventional (captured) approach to the head and sill glazing, using metal or wood retaining members with wet, dry or wet/dry sealants. However, the vertical glass edges are spaced slightly apart and sealed with a silicone sealant. The sealant is generally intended for use as a weatherseal for the vertical joints and not the sole means of structural attachment even though it can help stiffen the connection between the plates of glass. In some interior applications in which sealants are not used between adjoining lites, clips, fittings or buttons may be used to maintain the adjacent lites in the same plane to avoid the potential for pinching of fingers and for acoustic reasons.

The design and execution of a satisfactory butt-joint glazing installation require more attention to detail at every stage than does a conventional system with vertical framing members. Since the glass is supported on only two edges (usually head and sill), design load charts for four-edge support are not valid. Glass deflection and stress under design load will be substantially greater for two-edge supported glass than glass of the same thickness and size supported on four edges. Deflection and glass stressing under design load is substantially greater than with four edges supported. The design professional should consider glass strength, deflection and potential glass edge pullout. Typically, a minimum of ⅜-inch (10 mm)-thick glass is recommended for butt-joint glazing applications. Thicker glass will reduce deflection.

Heat-treating will not reduce glass deflection (see Heat-Treated Glass). The inherent warp of heat-treated glass can complicate the achievement of a neat vertical silicone joint.

Refer to the *NGA with GANA Engineering Standards Manual* for additional information regarding height and thickness recommendations for fully tempered interior butt-glazed fixed glass panels.

Precise leveling of the sill member should be achieved, and provision should be made at the head for deflection of the structure. The vertical glass edges should be ground with a slight arris and should be polished for most acceptable aesthetics.

Insulating glass is typically not suitable for butt-joint glazing. When the glass deflects, the sealants can be placed in extreme shear along the unsupported edge between the glass and spacer. Typically, insulating glass manufacturers do not warrant their products in this application. Glass-clad polycarbonates and all-plastic laminates are not considered suitable for butt-joint glazing due to the expansion and contraction rate of the materials.

Cured clear silicone sealants may have (or develop) a cloudy, translucent appearance over time. Even with proper application and tooling, clear silicone sealant in a butt-joint may have visible bubbles. This is more likely in butt-joints between glass thicker than ⅜ inch (10 mm). To minimize the appearance of bubbles, use opaque colored (black, bronze, gray, etc.) silicones.

Building codes generally do not provide specifically for the use of two-edge glass support systems; therefore, these should be engineered. It is normally the responsibility of the design professional to call to the attention of code officials the use of two-edge supported glass and to secure the necessary approvals. A typical butt-joint is shown in Figure 36.

Glass and sealant manufacturers' recommendations for edge treatment and edge quality of the glass, specific sealant, use of primers and construction (sealing) of the butt-joint should be followed exactly. Recommended joint widths are listed in Table 27.

Butt-joint glazing should not be confused with structural silicone glazing. Both have the same exterior appearance, but structural silicone glazing has an interior vertical mullion to which the glass is adhered.

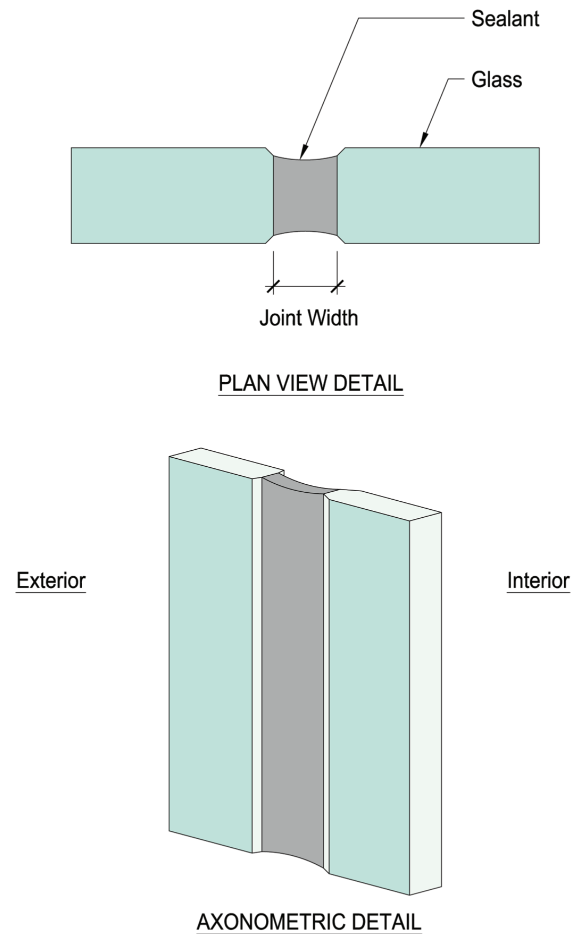


FIGURE 36 *Butt-Joint Glazing*

TABLE 27 *Recommended Joint Widths for Butt-Joint Glazing*

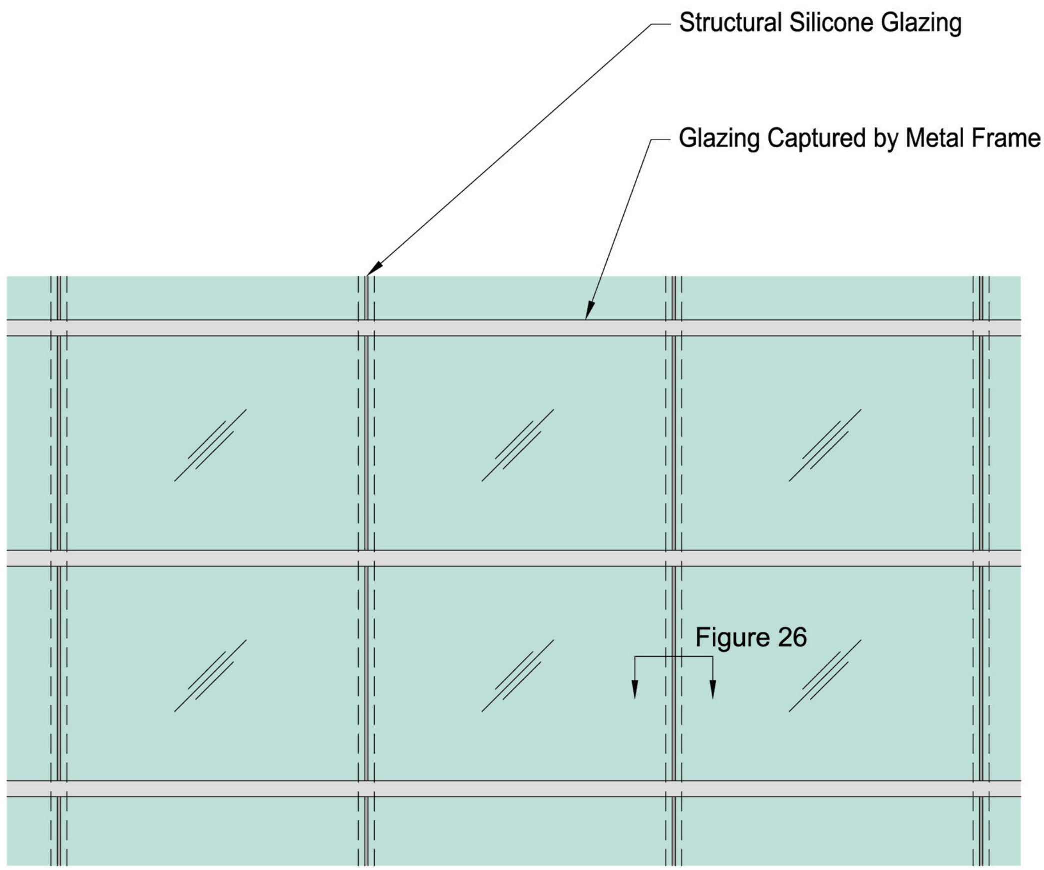
Recommended Joint Widths For Butt-Joint Glazing		
Glass Thickness	Joint Width	
	Min.	Max.
3/8" (10 mm)	3/8" (10 mm)	7/16" (11 mm)
1/2" (12 mm)	3/8" (10 mm)	7/16" (11 mm)
5/8" (16 mm)	3/8" (10 mm)	1/2" (12 mm)
3/4" (19 mm)	1/2" (12 mm)	5/8" (16 mm)
7/8" (22 mm)	1/2" (12 mm)	5/8" (16 mm)

Structural Silicone Glazing

Structural silicone glazing incorporates support for the edges of the glass. In that respect, the design parameters are normal. The difference is in the exterior appearance and the method of fixing the glass to the framing system.

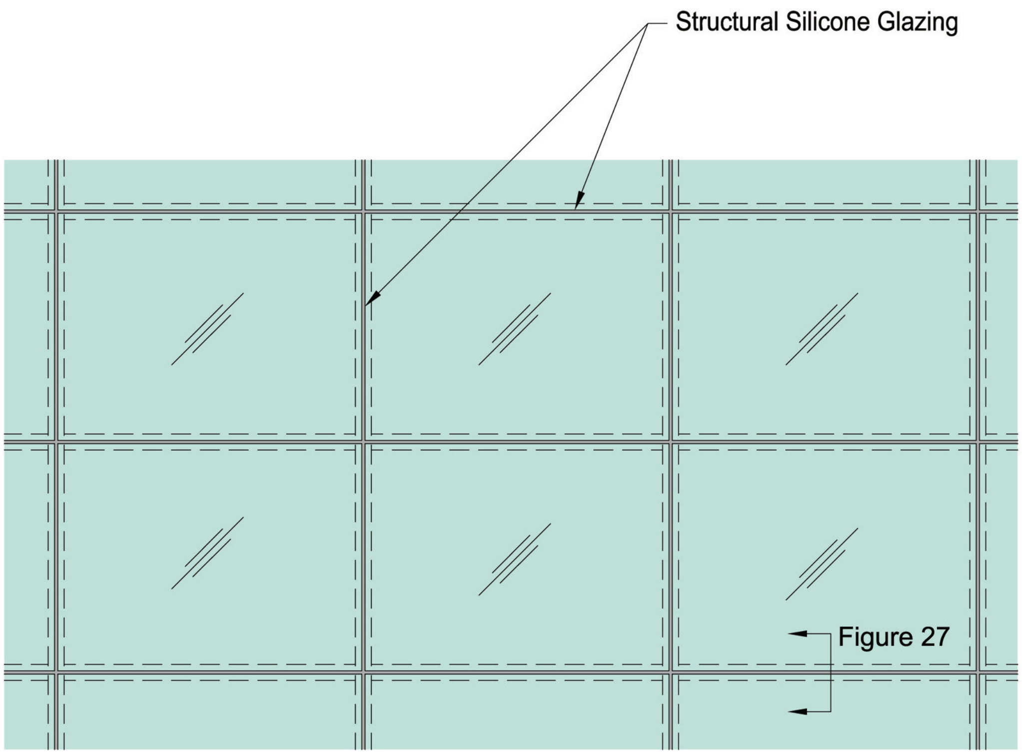
Structural silicone glazing systems utilize structural silicone sealant as the means of attachment for support of one or more edges of the glass. These are typically described in a manner that summarizes the number of sides of the glass that are supported in this manner (Refer to Figures 37 a-d,), e.g., four-sided structural silicone glazing of rectangular lites indicates that all four edges are supported by structural silicone sealant (Refer to Figure 37b).

A two-sided structural silicone glazing system will generally have the opposite two edges of the glass structurally sealed (adhered) to the mullions, as shown in Figure 37a. The other two edges of the glass will be retained in a conventional manner. From the exterior, a two-sided system does indeed look like butt-joint glazing, hence the confusion if proper terminology is not used.



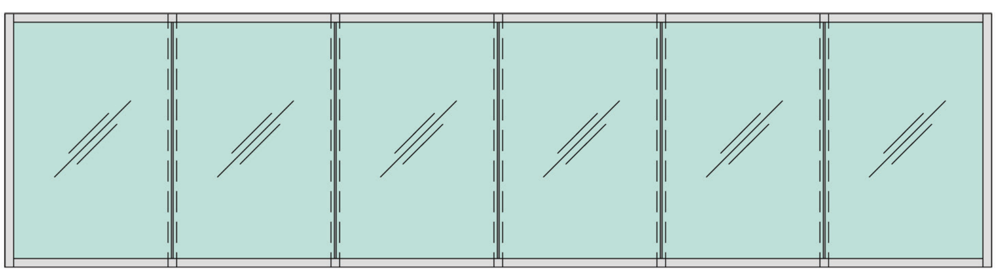
Two-Sided Structural: Glass structurally adhered to vertical mullions with horizontal sides captured in glazing pockets.

FIGURE 37a *Structural Silicone Glazing Typical Configurations Two-Sided Structural*



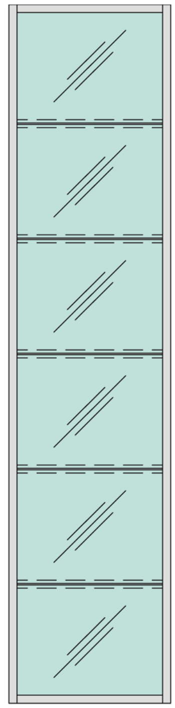
Four-Sided Structural: Glass structurally adhered to vertical and horizontal mullions.

FIGURE 37b *Structural Silicone Glazing Typical Configurations Four-Sided Structural*



Two-Sided Structural Strip Window: Glass structurally adhered to vertical mullions with horizontal sides captured in glazing pockets.

FIGURE 37c *Structural Silicone Glazing Typical Configurations Two-Sided Structural Strip Window*



Vertical Strip Window: Glass structurally adhered to horizontal mullions with vertical sides captured in glazing pockets.

FIGURE 37d *Structural Silicone Glazing Typical Configurations Vertical Strip Window*

Four-sided systems generally have verticals similar to Figure 38, and horizontals similar to Figure 39 to provide support for the setting blocks and the glass.

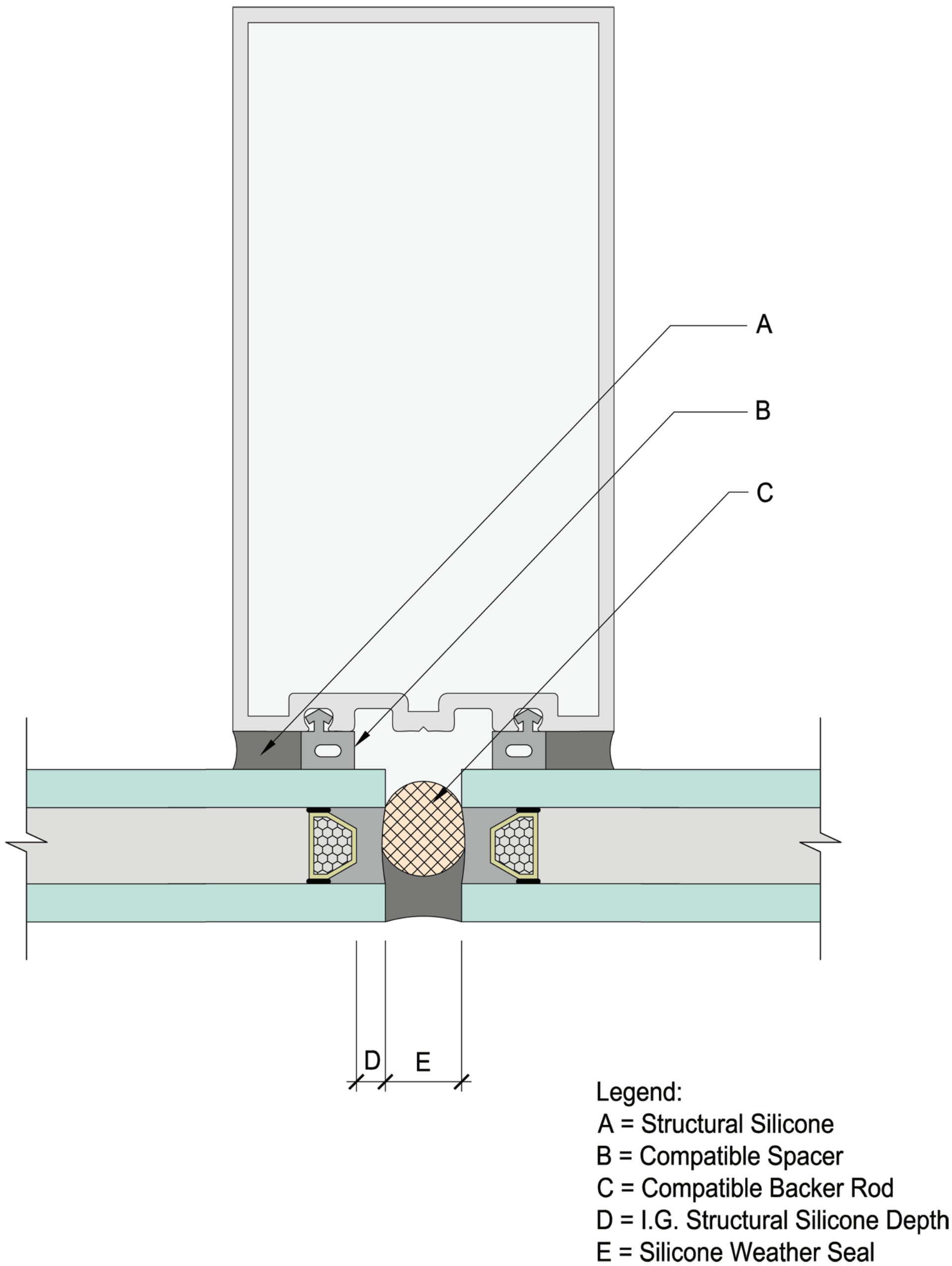


FIGURE 38 *Structural Silicone Glazing Typical Vertical Mullion for Two-Sided System*

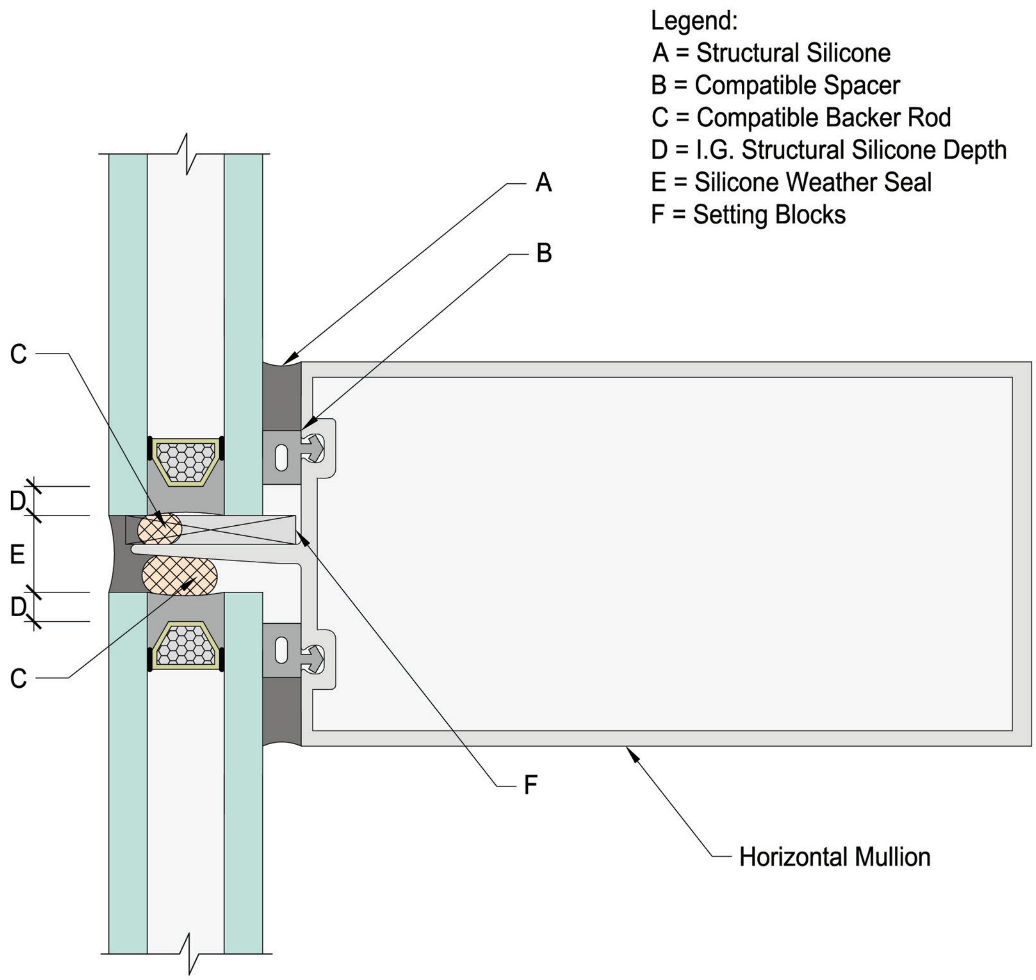


FIGURE 39 *Structural Silicone Glazing Typical Horizontal Mullion for Four-Sided Systems*

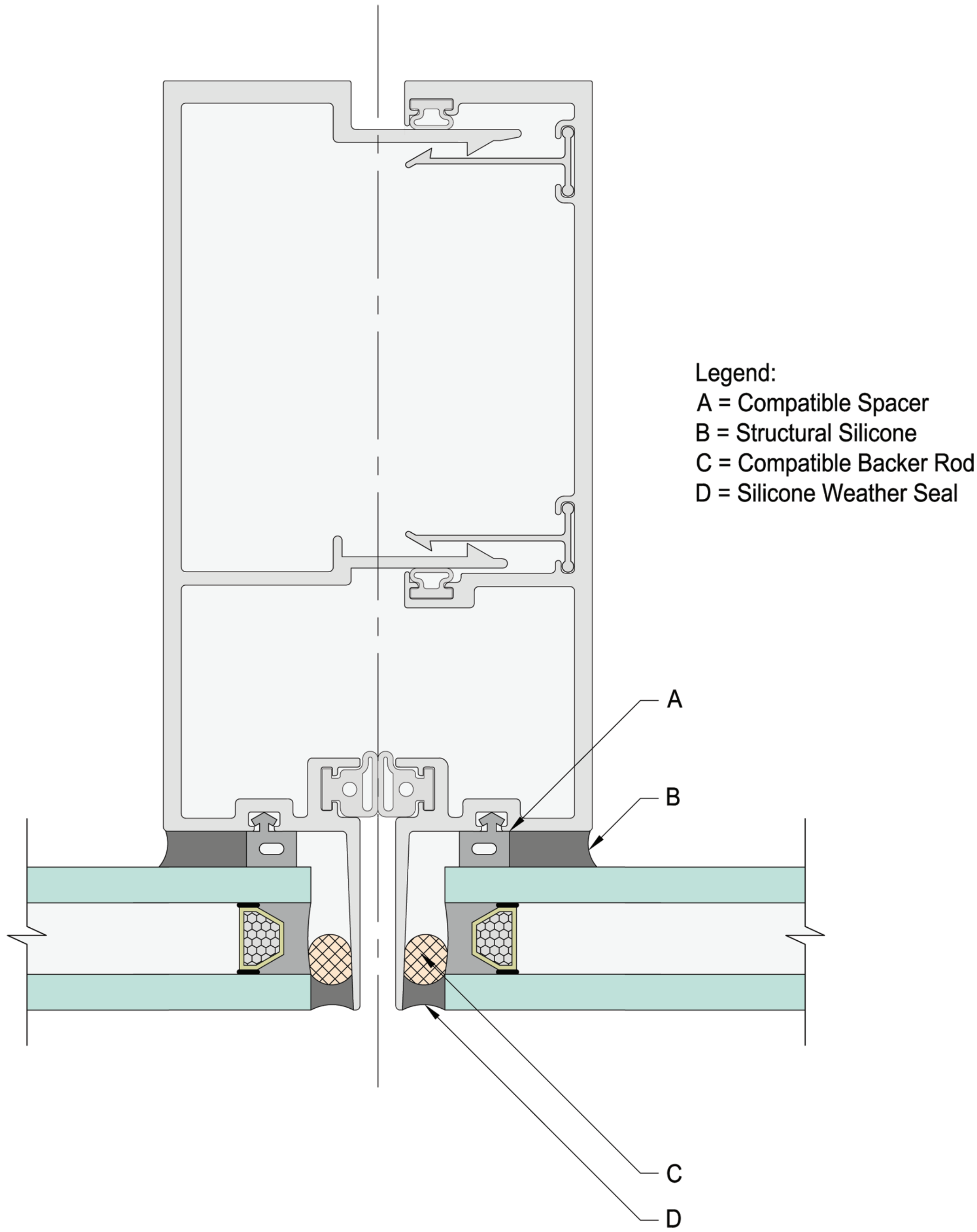


FIGURE 40 *Unitized Split Mullion*

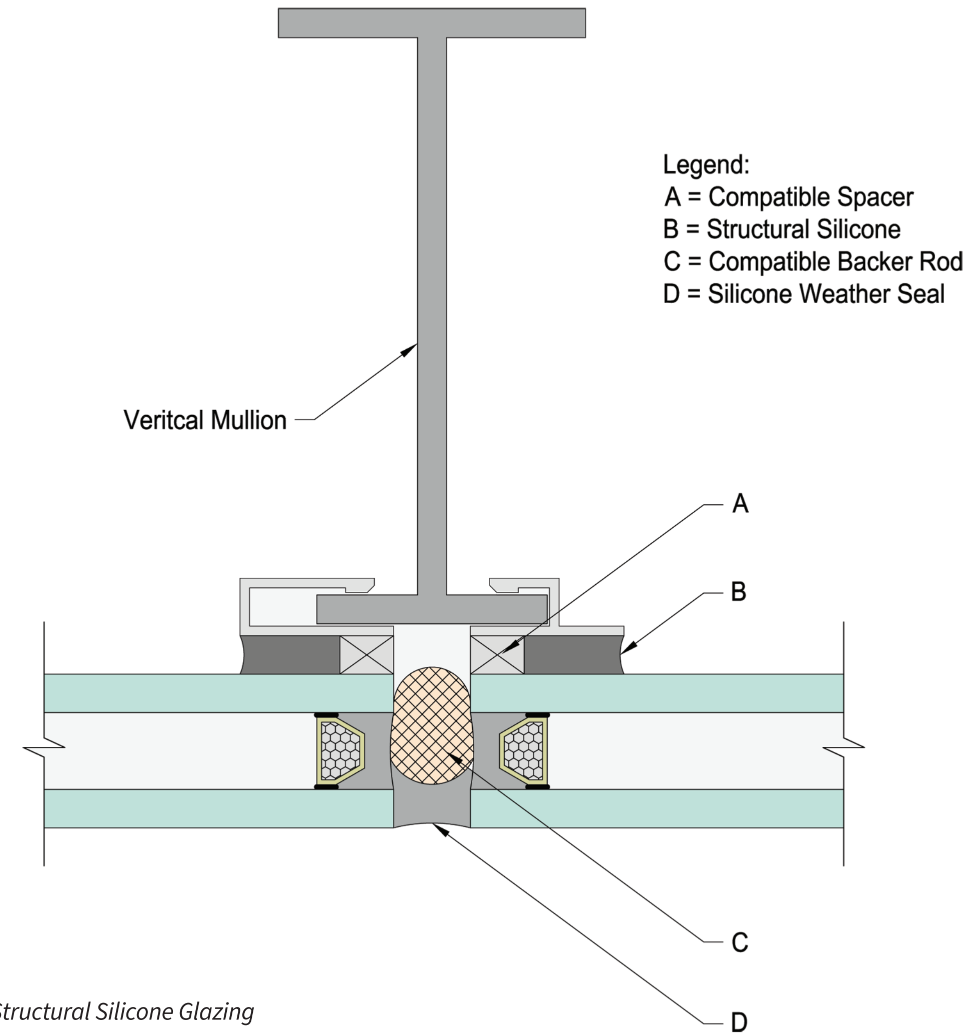


FIGURE 41 *Structural Silicone Glazing*

Four-sided systems should be designed to be shop-glazed. The glass is adhered to the extruded aluminum frame in the shop with structural silicone sealant. The assembly is normally transported to the project site after the sealant is fully cured, erected as a unit and then weather seal is applied to complete the project, although some systems are designed for the weather seal to be shop-applied. Two-sided systems can be designed to be either shop- or field-glazed, although shop glazing is generally recommended.

Shop glazing generally results in a better structural seal because of uniform, controlled working conditions, better quality assurance and the ability to use a fast-curing, two-part silicone sealant. Certain building codes require shop glazing on four-sided structural silicone glazing applications and some municipalities restrict its use altogether. Refer to the NGA Commercial Fenestration Systems Manual for more information on shop glazing and field glazing.

Structural silicone glazing requires special considerations. Continual close attention should be given to all details of the installation. Some of these considerations are as follows:

- A proper structural sealant, approved by the sealant manufacturer, should be used in 2-sided or 4-sided structural sealant applications. Only certain silicone sealants can be used or are generally approved by the sealant industry for structural applications.

- Joint size must be designed for structural loads. Consultation and cooperation with the sealant manufacturer are highly advised. A minimum glueline thickness of the joint is also important to ensure the silicone can flow into the full depth of the joint. Consult with the structural silicone manufacturer for this dimension.

- The structural sealant should be tested for compatibility with all other sealants or accessory materials (gaskets, spacers, backer rods, weather seal, setting blocks, metal finishes, glass coatings, etc.) that the structural sealant will contact. Sealant manufacturers currently use ASTM C1087 *Standard Test Method for Determining Compatibility of Liquid-Applied Sealants with Accessories Used in Structural Glazing Systems.*

- The structural silicone sealant should be tested for adhesion with the substrates that it must adhere to on a project specific basis. Sealant manufacturers currently use ASTM C793 *Standard Test Method for Effects of Accelerated Weathering on Elastomeric Joint Sealants (C 794) Peel in Adhesion.* This testing is typically conducted by the structural silicone manufacturer.

- The surface preparation and sealant application procedures (solvent cleaning, priming, masking, cure time, etc.) supplied by the structural silicone manufacturer should be followed. Failure to properly prepare the bonding surfaces or to properly apply the structural sealant can result in failure of the structural sealant.

- Good, close supervision and a quality control program are the primary means to assure a viable installation. In addition to complying with the proper sealant application procedures, glazing contractors should develop appropriate quality control programs to ensure appropriate workmanship during fabrication. Structural silicone sealant manufacturers have developed a list of recommended quality control steps, including tests and deglazing, to assist with the development of quality programs.

- When field glazing or re-glazing, follow the structural sealant manufacturer's recommendations for the use of temporary retainers to hold the glass in place during sealant curing. This is undertaken to avoid premature stressing of the sealant.

- Insulating glass units used in structural silicone glazing applications should be fabricated with a structural silicone secondary sealant. Polysulfide, polyurethane or hot melt butyl should not be used in this application. Indicate lites to be structural silicone glazed to the glass manufacturer in the request for quotation and order.

- Insulating glass units used in structural sealant applications may require a deeper secondary seal, generally 5⁄16 inch or more. The insulating glass fabricator should be advised that the units are to be used in a structural silicone application. Reference ASTM C1249 *Standard Guide for Secondary Seal for Sealed Insulating Glass Units for Structural Sealant Glazing Applications.* Insulating glass units with a deeper secondary seal may result in spacer and sealant visibility on dimensions where framing systems provide ½ inch (12 mm) glass bite or coverage.

For more information on structural glazing, see the *GANA Sealant Manual*.

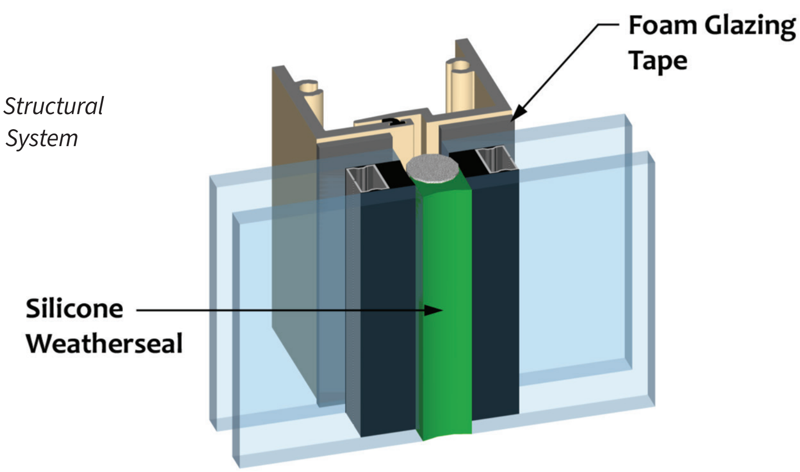
Acrylic Foam Tape Structural Glazing

Acrylic foam tapes are also used in structural glazing applications. These foam tapes consist of an acrylic adhesive throughout the entire tape construction including the foam core. In a curtain wall or commercial window system the main role of the acrylic foam structural glazing tape is to act as the primary bonding agent of the glass to the metal frame, as shown in Figure 42.

The same basic guidelines for structural silicone glazing should be followed when considering acrylic foam structural glazing tape for a glazing application. This includes a technical review of the glazing system and project details, adhesion testing, proper surface preparation, training and a quality assurance program. Only acrylic foam tapes designed, tested and manufactured for structural glazing should be considered for curtain wall, commercial window, door and skylight system applications. Acrylic foam structural glazing tapes should only be used on factory (shop) glazed projects. System design should also take into account the rigidity of the bond by the tape and the stress this can place in the glass.

Refer to the *GANA Sealant Manua*l for best practices regarding proper sealant use and application.

FIGURE 42 *Acrylic Foam Structural Glazing Tape System*



Sloped Glazing

Sloped glazing systems include both conventional capped glazing and two- and four-side structural silicone techniques. With a cap glazing system, each edge of the glass lite is retained with a metal glazing cap. This type of system usually experiences a greater amount of water infiltration due to the damming caused by the purlin cap and the corner intersections with the sloping rafter caps. The concept of two-sided structural silicone glazing eliminates the horizontal glazing caps on the purlins. Four-sided structural silicone glazing systems eliminate virtually all exterior aluminum on the sloped wall. Structural silicone glazed purlins (see Figure 43) with a minimum recommended slope of 15 degrees off horizontal will help minimize water infiltration, sediment accumulation and staining of the glass.

It is important to note that for two- and four-sided silicone glazing systems, an insulating glass unit should be structurally retained on all sides. The adjacent edges are secured to the purlin using a structural silicone joint. Although silicone glazing systems reduce the amount of water infiltration, good design practice should incorporate mechanical gutter systems to drain water infiltration and condensation. Refer to Specific Guidelines for Glazing section, “Compatibility” and “Structural Silicone Glazing,” for compatibility testing and adhesion testing procedures that must be followed to assure a proper installation.

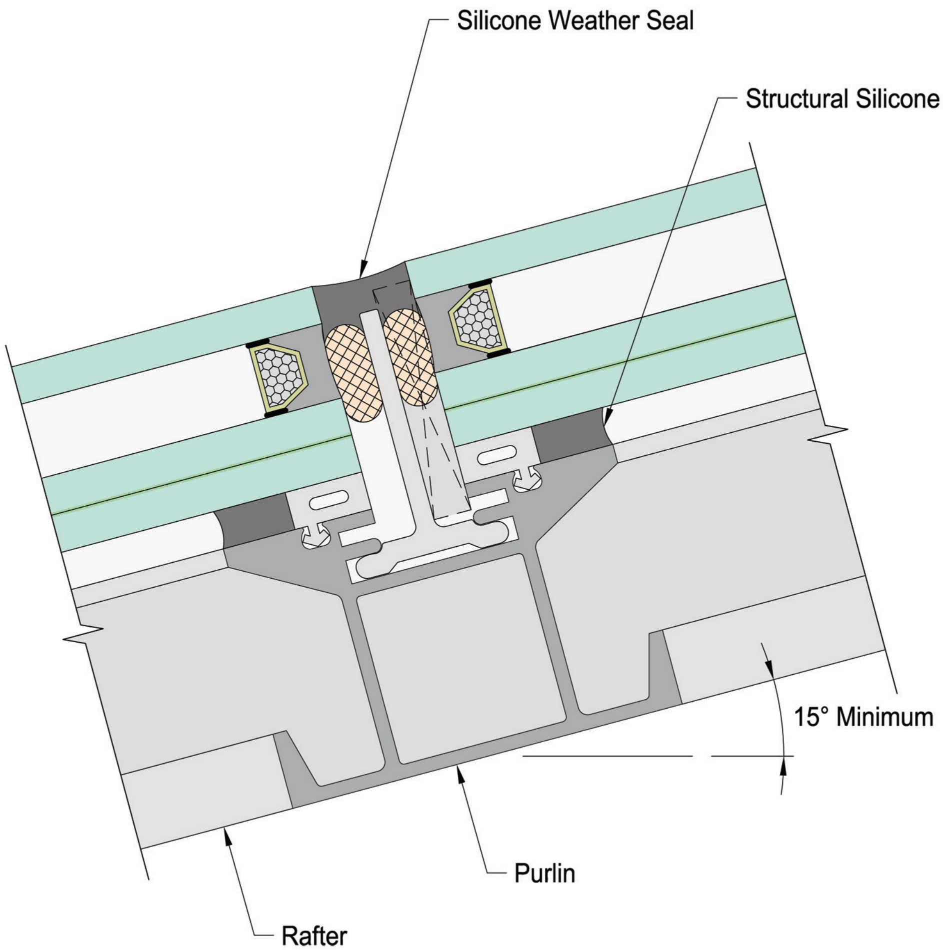


FIGURE 43 *Structural Silicone Glazed Purlin*

For safety reasons, workers should not be permitted to walk on or put their weight on sloping glass to set added lites into place or to apply glazing caps or sealants. The work should always be done from a secured temporary platform. The platform should not touch the glass. The above also applies to maintenance personnel.

See also, Design Considerations section, "Sloped Glazing." For additional information on cap beads, see Specific Guidelines for Glazing, "Cap Beads." For further information, refer to AAMA GDSG-1 *Glass Design for Sloped Glazing.*

Bent Glass

Bent glass is frequently used as the transition lite from sloped to vertical glazing, corner zones, to create S walls, complex compound shapes or decorative features. Standard dry, wet, structural and point-support glazing are typically employed with bent glass. Glazing face clearance is greater than flat glass and should be a minimum of ⅜ inch (10 mm) interior and exterior to allow for larger tolerances. Refer to *General Guidelines for Glazing*, Figure 22, and Table 26 footnote. Compatibility of components specific to the bent glass should always be considered, especially if used in a mixed project of flat and bent structurally glazed IGU. The standard empirical definitions regarding production tolerance, or standard architectural samples may not adequately describe the final perception of the product. Mock-ups are highly recommended. Bent glass may have differing perceptions from flat glass when viewing for distortion and perceived coating colors that may not be adequately defined by industry standards. Viewing full scale mock-ups is highly recommended. Specific design expectation or quality requirements exceeding published industry standards should be communicated early with the fabricator and incorporated as a provision of the specification in writing when ordering. The user specifying the glass should consult with the fabricator and the primary glass producer regarding any limitations in size, radii or warranty for the product considered.

Specific Glazing Operations for Bent Glass

When bent glass is installed with the bend axis running vertically, i.e., such as the rounded corner of a building, a minimum of three setting blocks should be used instead of the usual two. There should be the usual ones at the quarter points plus the added one at the mid-point of the curve. The blocks should be of a length comparable to those used in the setting of a flat lite of glass and should be notched in several places to allow them to be bent to the same curvature as the glass. When the bent glass is installed with the bend axis running horizontally, as the eaves at the transition of a slope to the vertical, the two setting and edge blocks as specified for flat glass are recommended. In either case blocking is the same as flat glass. Refer to *General Guidelines for Glazing* for block type, durometer, thickness and area. Compatibility of glazing components with IGU coatings, sealants and laminated glass interlayers should be verified. Refer to *Specific Guidelines for Glazing – Compatibility*.

Bent annealed or bent annealed laminated glass, because of tolerances and other considerations, is more vulnerable to pressure breakage; designers should consider a wet glazing system. The use of wet glazing systems and an applied stop as retainment offer an added measure of adjustment. Installed glazing should be protected from damage.

Receiving and Storage of Bent Glass

Like flat glass, receiving, storage and inspections of bent glass should be planned and reviewed with the general contractor and other trades to avoid damage in storage, glazing or post-installation. Bent glass packaging is specialized, contains fewer lites and requires greater care. The fabricator’s instructions for storing and opening crates should be requested and followed. Look for obvious damages to crates when receiving the glass and immediately inspect crates that appear to be altered or have other indicators of possible hidden damage. Any detected damage should be promptly reported to delivering motor carrier and supplier and claims for damage filed with the carrier. Outdoor and prolonged storage should be avoided. Storage longer than 30 days should be in a controlled environment. Inspection and early detection of damage is important to avoid possible delays since replacement products generally have longer lead times and may require setups or materials not readily available should damage or breakage occur.

Handling of Bent Glass

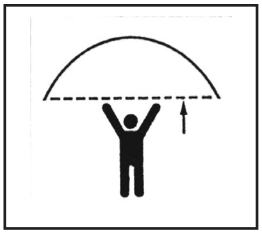
Bent glass warrants installers exercising a higher level of care when handling the glass than when handling flat glass. Fabricator’s instructions should be followed when opening crates to avoid damage. Glaziers should note the center of gravity changes when glass is bent. This may necessitate the use of more manpower, power cups or slings to carry or set bent glass than when handling a lite of flat glass of similar size and thickness. Adequate padding should be used to avoid edge damage when pitching or rolling bent glass. Chipping, or crushing edge damage may weaken the glass and lead to post-installation breakage.

Cleaning Bent Glass

General cleaning instructions in NGA Glass Technical Paper FB01-00 *Proper Procedures for Cleaning Architectural Glass Products* (joint technical paper with the International Window Cleaning Association, IWCA) should be followed as well as the fabricator’s written instructions. Cleaning instructions should be provided early in the process to the general contractor and to any others who may perform interim cleaning during construction, final product cleaning and building maintenance. Providing for documented inspections of glazing condition from storage to final acceptance is recommended.

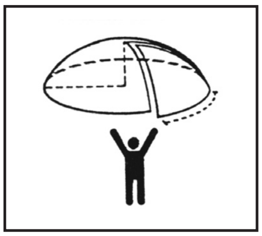
Terminology for Bent Glass

The bending of architectural glass and aluminum is an important service to the glass and glazing industry. As happens in all specialized fields, terminology unique to the bending industry has developed over the years. Additionally, many common terms take on different meanings when used in reference to glass and metal bending. To assist in understanding bent glass, its framing and to accurately describe a project, Figure 44 is a glossary of bending terms.

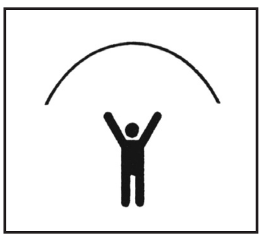


Chord: The dimension of an imaginary straight line connecting the end points of a curve or arc. Sometimes referred to as the "point to point" dimension or measurement.

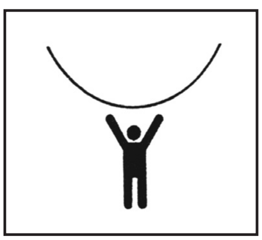
Circumference: The length of a curve of arc of a circle. It should be specified whether the measurement is along the exterior or interior face of the glass.



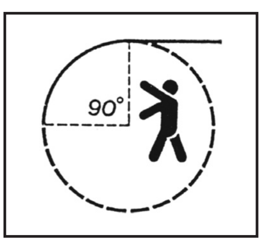
Compound Curve: A condition having a curve in a horizontal and vertical plane.



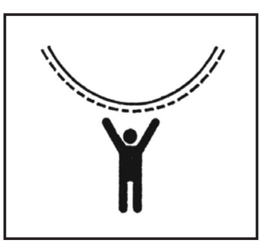
Concave: When viewed from the exterior, the curve bends away from the observer.



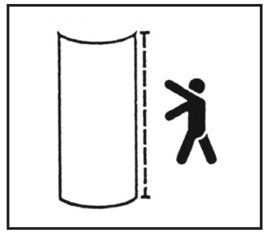
Convex: When viewed from the exterior, the curve bends towards the observer.



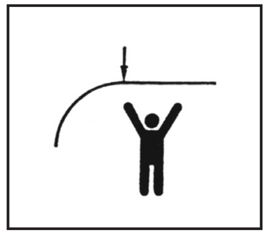
Degree: Every circle regardless of radius contains 360 degrees of arc or curvature. The girth or arc length of curved glass or aluminum can be determined when the "degree of arc" is given.



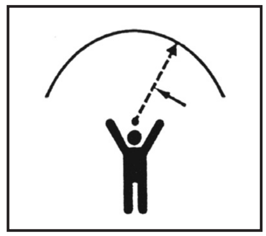
Girth: The length of the curve or arc required. The dimension or measurement of the material required if viewed in a "stretched-out" or "flattened" state. The longer girth should be specified.



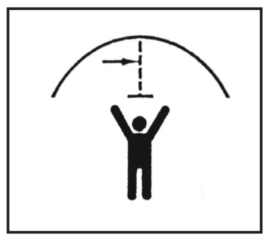
Height: The straight edge dimension or measurement of a lite of glass as opposed to the girth dimension or measurement. Could also be referred to as the WIDTH if the lite is installed in an overhead application



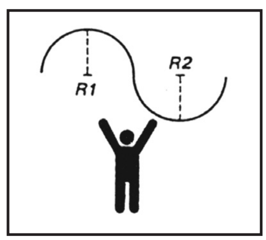
Point of Tangency: The point at which a straight line meets a curve or arc. Determination of this point is crucial for the interfacing of curved glass and metal.



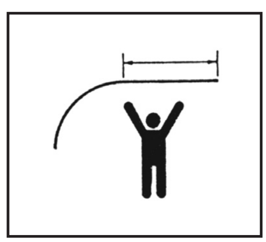
Radius: The dimension or measurement of an imaginary line taken from the center point of a circle to the arc or circumference of the circle.



Rise: In geometric terms, the rise is known as the height of the arc. While not critical when adequate information is submitted, the rise or height of the arc, when used in conjunction with the chord dimension, can be used to calculate an unknown radius and girth.



Serpentine Curve: A condition having concave (R1) and convex (R2) curves in the same plane.



Tangent: A straight line coming out of an arc or curve. Sometimes referred to as a straight leg.

FIGURE 44 *Glossary of Bending Terms*

Laminated Glazing Materials

Laminated glazing materials should be installed in a glazing system that incorporates a weep system. The edges of the glass should remain dry and not be exposed to water vapor for extended periods of time. Prolonged exposure to solvents, solvent vapors (including that of acetoxy silicones), water or water vapor may cause delamination or haziness around the periphery. See Compatibility for additional information concerning material compatibility.

Laminated glass should be used with caution in butt-joint or structural silicone glazing systems. In all laminated glass installations, sealant compatibility with the interlayer material should be checked prior to glazing. Direct contact with organic solvents or prolonged exposure to water can lead to delamination or haziness along the edge. Recommended sealants include polysulfides, silicones, butyl, polybutylene tapes and polyurethane. Review General Guidelines for Glazing section, Glazing Operations, “Installation of Glass,” and consult your glass and sealant suppliers.

Laminated glazing materials are assembled with corresponding layers of materials where each layer of glass or plastic has two sides. The interlayer material surfaces are ignored for this numbering system. The numbering system is important to distinguish the exterior surface, always #1 (or attack), to the interior surface (or safe). See Figures 5 and 7 for surface numbering. When ordering laminated products incorporating a coated glass, it is important that the correct surface number for the location of the coating is known in order to facilitate proper thermal and optical performance. Production orders should provide specific construction and surface details.

Laminated glazing products have specific length, width, thickness and squareness tolerances. This may become a critical consideration with laminates consisting of several layers of glass and/or polycarbonate and plastic interlayer material. Also to be considered is the effect of overall bow or warp caused by the heat-treating process. Heat-treated glass may require a thicker interlayer. There may be instances where a watertight installation cannot be achieved with the usual dry glazed systems. It may be necessary to recess appropriate spacers on both sides and wet glaze both sides. Certain products may require special installation clearances and methods. The fabricator should be contacted prior to ordering window framing materials to ensure all details are correct.

Emergency Egress and Ingress of Laminated Glazing
A consideration regarding the installation of laminated glazing systems is how the glazing will affect the ability of an occupant to use the window as an emergency egress. In residential applications, doors are utilized for emergency egress, and in those instances where windows are used for egress, the windows can be opened using the standard locking/latching mechanism prior to egress. If a resident must leave a burning building through a window, typically they open the window to escape. In office buildings, the installation of laminated glazing in non-operable windows would not affect their use for points of egress since these windows are usually installed in multi-level (high-rise) buildings, where such windows are not the designated point of egress and are only a secondary means of escape.

Often of greater concern than the issue of emergency egress is the perceived deterrence that laminated glazing poses to fire and rescue personnel attempting to enter a building. In some severe cases it may be necessary for a firefighter to enter through a window. Fire and rescue personnel participate in response training programs which instruct them to quickly identify the presence of penetration-deterrent glazing. Fire and rescue personnel are normally equipped to penetrate laminated glass using tools they bring with them in an emergency. These tools vary from a common fire axe or fire hook to saws and other cutting devices. For further information, refer to NGA Glass Technical Paper FB05-04 *Emergency Egress through Laminated Glazing Materials*.

Heat-Treated Glass

The surfaces of heat-strengthened and fully tempered glass are in states of high compression; therefore, edge or surface damage is likely to be the cause of any spontaneous breakage. In the case of fully tempered glass, seldom does enough glass remain in the opening following breakage to define the break origin.

Every reasonable precaution should be taken to ensure that no damage occurs to the lite during transportation, handling or installation.

Permissible bow can be substantial on large lites. Consideration of this condition may require extra face clearance. See dimension A of Figure 22 and Table 26. Review General Guidelines for Glazing, Glazing Operations, subsection E. Installation of Glass. (Also see Table 10 Overall Bow, Maximum.)

Insulating Glass Units

The weep system should be open and the glazing pocket free of all debris. Prolonged exposure to water or water vapor can cause failure of the edge seal and may void the insulating glass manufacturer's warranty.

Glazing materials should be resilient compounds whose compatibility with the edge seal has been previously established. Use of material of unknown compatibility poses a material risk of seal failure. Refer to the section Compatibility in this Manual for more information.

Many glazing systems apply pressure to the edge of the glass to achieve a weather-tight seal. Generally, edge pressure should be a minimum of 4 pounds (8.8 kg) and a maximum of 10 pounds (22 kg) per linear inch of perimeter and not bear on the marginal ⅛ inch (3 mm) of the unit glass surface at the edge of the unit. Excessive pressure can increase mechanical stresses and distortion, and possibly cause glass breakage.

Insulating glazing units which will undergo a change of altitude greater than 2500 feet (762 m) between point of fabrication and point of installation should be evaluated for the need of capillary tubes to permit pressure equalization. The difference in barometric pressure for a 2500-foot (762 m) change is 1.335 psi (0.092 kg/cm^2), or 192 psf (9.2 kPa), the approximate equivalent of a 275-mph (443-kph) wind load. Insulating glass fabricators utilizing capillary tubes may instruct that the tubes be closed and/or sealed within a specified number of days; otherwise, the desiccant will absorb excessive moisture, shortening the life of the unit and voiding the IGU warranty. Under certain circumstances capillary tubes may not require sealing at the final destination, but this should be specified by the IGU fabricator. Capillary tubes may not require sealing at the final destination. When designed to remain open, capillary tubes require a specific length of material and therefore should not be cut. Cutting or removing capillary tubes may shorten the life of the insulating glass unit. Capillary tubes are not recommended for insulating glass units containing any inert gas as there may be significant gas loss through the tubes. Refer to joint NGA/FGIA Technical Bulletin TB-1601-95 *Guidelines for Use of Capillary Tubes* for more information.

A concave unit should not be repaired in cold temperature as the condition of concern may be just temperature related. Repairs, if needed, should be conducted in concert with the IGU fabricator.

Wrap-Around Glazing

Wrap-around (marine) glazing is a method of glazing that was originally used on powerboat windows, hence, the name, "marine." From boats, it was adapted to patio doors, then to horizontal sliding windows and today is often used in security applications utilizing vulcanized gaskets. Originally it was used with monolithic glass because insulating glass was not used in these types of residential applications.

An extruded U-channel of vinyl or synthetic rubber is wrapped around the edges of the lite of glass or insulating unit. A single butt-joint is typically made at the top center of the glass. The corners are partly slit to make the 90-degree turn. The extruded aluminum frame members are then forced onto the channel and screwed together at the corners; the framed lite is then ready to be installed into the main frame, which has already been attached to the structure.

Slit corners of the wrap-around will generally provide drainage of any water that penetrates between glass and the U-channel (see Figure 45). This may not be adequate for insulating glass. Under certain conditions, the drainage is so slow that the infiltrated water has time to attack the seals of the insulating glass, resulting in premature failure of the unit. Holes of ½-inch to ⅝-inch (12 mm to 16 mm) diameter, punched 6 inches (152.4 mm) on center in the base of the U-channel may alleviate this problem.

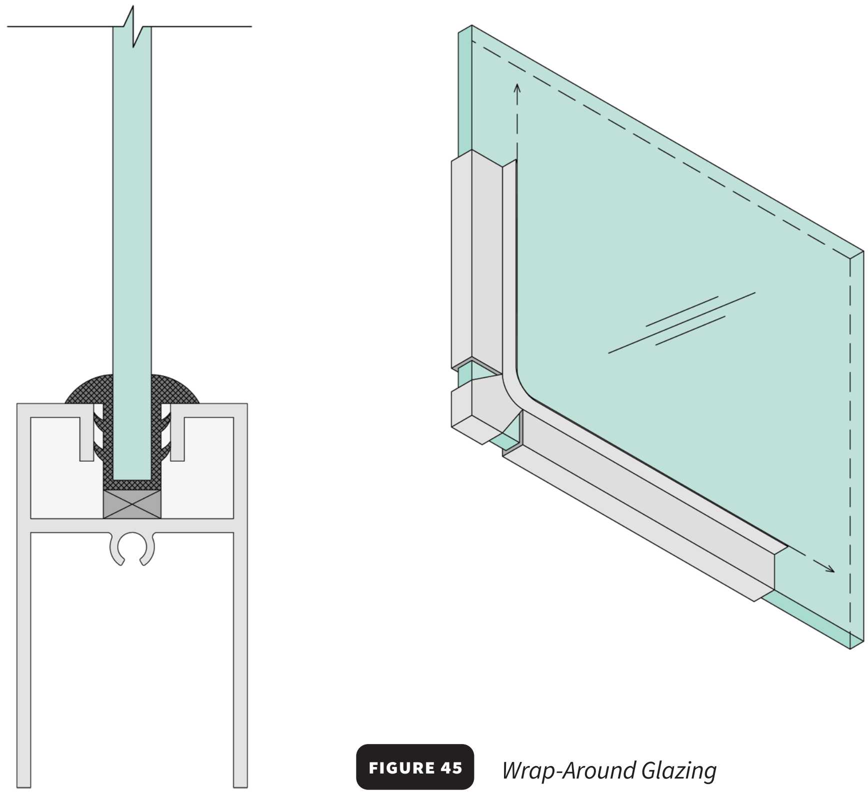


FIGURE 45 *Wrap-Around Glazing*

Interior Glazing

General Guidelines

- Most interior glazed openings, which are not exposed to the weather, do not require a watertight or airtight glazing system.

- Good glazing practices in these openings entails proper edge clearances, setting blocks and a design to minimize glass rattle.

- Setting block location and length per block should follow the parameters shown in Figure 26 with the exception that for glass ¼ inch (6 mm) or less in thickness in which both the glass width and height are 48 inches or less, the setting block length per block may be 2 inches (50 mm) in length rather than the 4-inch (100 mm) minimum length required elsewhere.

- State and local building codes and federal safety glazing laws apply to interior glazing as well as to exterior glazing.

- Building code requirements of minimum loads on interior walls should be considered along with loads supplied by the design professional for the specific glazing application. IBC section 1607 specifies a minimum of 5 psf (0.24 kPa) horizontal loading for interior walls.

Guidelines for Interior Butt-Joint Glazing

- Where silicone sealants are used vertically between adjacent lites, follow the guidelines for butt-joint glazing in this Manual.
- Where the vertical joints between adjacent lites are left open (as is frequently the case in malls), additional steps should be taken to minimize the risk of pinching or trapping fingers or small hands between adjacent lites that may not deflect under pressure in the same plane. The addition of buttons, clips or other fittings should cause adjacent lites to deflect in the same plane, thus substantially reducing this potential injury risk.
- Glass deflection characteristics and glazing system support conditions should be designed to provide firm glass edge support under the design loads for the application.
- The design professional should consider the psychological impact of glass deflection on persons near the glass. At a given height and for the same applied load, the thicker the glass, the less the deflection.
- Reference *NGA Engineering Standards Manual,* Recommendations for Fully Tempered Interior Butt Glazed Fixed Glass Panels.

Guidelines for Glazing in Wood Frames
Listed below are some commonly used methods for setting glass in interior wood frames with removable glazing beads on four sides:

Wood Method A

1. Apply an adhesive-backed foam tape or glazing tape to the fixed stops.
2. Install glass on setting blocks and firmly press glass against the tape.
3. Install the removable glazing beads firmly against the glass.

Wood Method B

1. Apply a toe bead of silicone around the perimeter of the fixed stops.
2. Install glass on setting blocks and against the silicone and the fixed stops. (Note: it is important to apply silicone in Step 1 so that the silicone does not squeeze out when the glass is installed.)
3. Install the removable glazing beads firmly against the glass.

Guidelines for Glazing in Non-Fire-Rated Metal Frames
Listed below are some commonly used methods for setting glass in non-fire-rated hollow metal frames with removable glazing beads on all sides:

Hollow Wood Method A
Same as Wood Method A above.

Hollow Wood Method B

1. Apply an adhesive-backed foam tape or glazing tape to the fixed stops.
2. Install glass on setting blocks and firmly press glass against the tape on the fixed stops.

3. Apply foam tape or glazing tape to the removable glazing beads.

4. Install the taped removable glazing beads against the glass.

5. Trim off any excess tape beyond the top of the glazing beads.

Hollow Wood Method C

1. Apply adhesive-backed foam tape or glazing tape to the fixed stops.

2. Install glass on setting blocks and firmly press glass against the tape on the fixed stops.

3. Install the removable glazing beads.

4. Insert neoprene, foam or silicone spacers between the removable glazing beads and the glass.

5. Apply glazing compound, silicone sealant or other specified sealant material to the space between the removable glazing beads and the glass.

6. Trim off excess sealant to line up with the top of the glazing beads.

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 (NFPA) 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 (Underwriters Laboratories (UL), Intertek, 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 during testing 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 should 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 ⅛ inch (3 mm). The ⅛-inch (3 mm) clearance should not be exceeded unless otherwise noted in the individual listing or the manufacturer's installation instructions.

Mirror Installation

A number of options are available to mount an unframed mirror securely and attractively on a wall. The choice of the most acceptable technique will depend on the type of wall construction, location and other factors. It is strongly recommended that a professional be consulted before the installation of any mirror.

Installation Options

Mastics

Mastics should be applied per the manufacturer's recommendations. Failure to do so may affect the manufacturer's warranty. The mastic should be compatible with the mirror backing and the wall. The wall should be clean and free of any loose wallpaper. New walls should be prime-painted and sealed. The mirror should be installed so air is allowed to circulate vertically. The bottom of the mirror should be supported with clips or a "J" channel. The top of the mirror should be treated with some means of mechanical fastening to the building structure.

Double-Faced Tape
Tape should be applied per the manufacturer's instructions. The tape must be compatible with the mirror backing and capable of bonding permanently to the wall. The wall should be clean and free from any loose wallpaper. The tape should be at least ⅛ inch (3 mm) thick. It should be applied vertically to the wall. The top of the tape should be clipped to a point to prevent water condensation collection on the upper edge of the tape. A tape with an adhesive capability of 2 psi (13.79 kPa) is recommended. Sufficient tape surface area should be used to meet necessary support requirements. The bottom of the mirror should be supported with a "J" channel or clips. The top of the mirror should also be supported by clips. Under no circumstances should double-faced tape be used as the only source of attachment in mounting a mirror to a vertical wall or substrate. Variations in temperature, climatic condition or age could cause a release of the tape from either the mirror or the substrate.

Skeleton Wood Back
Since wood strips fastened to a wall can be shimmed to bridge irregularities in the wall, this method offers the best possibility of getting a near-perfect plumb and in-plane installation in adverse situations. Nominal 1-inch by 2-inch (25-mm by 50-mm) lumber is usually adequate. The wood should be prime-painted before mounting on the wall to eliminate interactions between resins in the wood and the mirror backing. After the skeleton is installed, any of the following mirror mounting methods may be used successfully.

Channel and Clips
A continuous "J" channel anchored securely and in plane with the skeleton back should be used to support the bottom of the mirror. Clips should be used to support the top and/or sides of the mirror. Two ⅛-inch (3-mm) by 4-inch (100-mm) setting blocks should be in the channel at the quarter points and two ¼-inch (6-mm) weep holes drilled in between the blocks.

Metal Frames
Metal-framed mirrors seldom offer mounting problems because the frame normally provides adequate support and edge protection.

General Precautions
General precautions to take while installing mirrors include the following:

- Mirrors should be installed plumb and in line to prevent distorting reflected images.
- Mirrors should not be installed on new plaster, new masonry, unsealed wood or plywood, or on a freshly painted wall. Nor should mirrors be installed where airborne solvents, heavy-duty cleaners, etc. are in the air.
- In humid climates, mirrors should not be installed until air conditioning is operating.
- Allow for air space behind a mirror installation to provide for ventilation for the mirror backing. Trapped moisture can deteriorate backing with time.
- Mirrors should not be installed in conditions that would allow for puddling of liquids on the bottom edge. Raise the mirror slightly off of backsplashes, cabinet or vanity tops, etc.

For more information on handling, cleaning and installing mirrors, see the following NGA Glass Technical Papers:

- FB06-05 *Proper Procedures for Cleaning Flat Glass Mirrors*
- FB21-09 *Installation Techniques Designed to Prolong the Life of Flat Glass Mirrors*
- FB22-09 *Proper Procedures for Fabrication of Flat Glass Mirrors*
- FB30-11 *Proper Procedures for Receiving, Storage and Transportation of Flat Glass Mirrors*

Fully Tempered Heavy Glass Doors and Entrances

When designing storefront or entrance systems, the requirements for accommodation of traffic, plus the effects of wind, rain, and cold or hot weather should be considered. Severely cold climate areas usually require vestibules with both exterior and interior doors. Heavy glass doors are not typically weather-tight, so they are most frequently used as the interior vestibule doors, shop-front entrances in interior shopping malls, and interior office applications.

The following section gives the designer and glazier an overview of the types of entrances and doors available from heavy glass fabricators. Consult the NGA *Heavy Glass Door Design Manual* for information about hardware, entrance components such as locks and handles, metal finishes, structural design of interior and exterior glass entrance systems, application guidelines, protection and cleaning.

Types of Entrances
Figure 46 shows typical fully tempered heavy glass entrances:

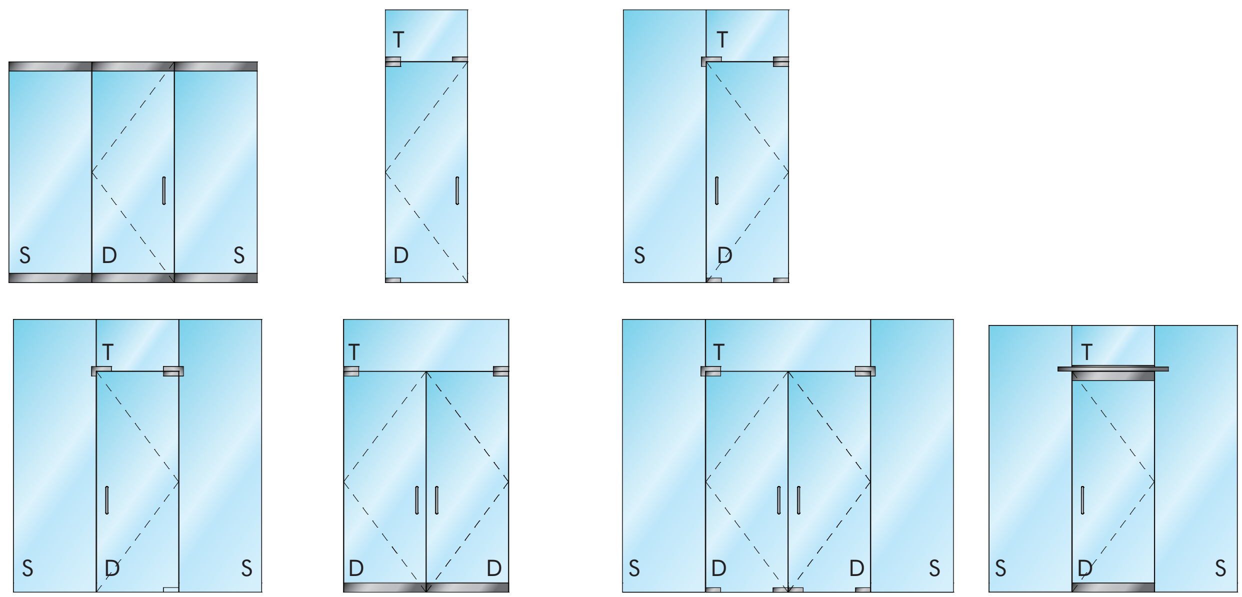


FIGURE 46 *Typical Entrance Configurations*

Note: S = sidelite, D = door, T = transom

Types of Doors
Common styles of fully tempered heavy glass doors are shown in Figure 47.

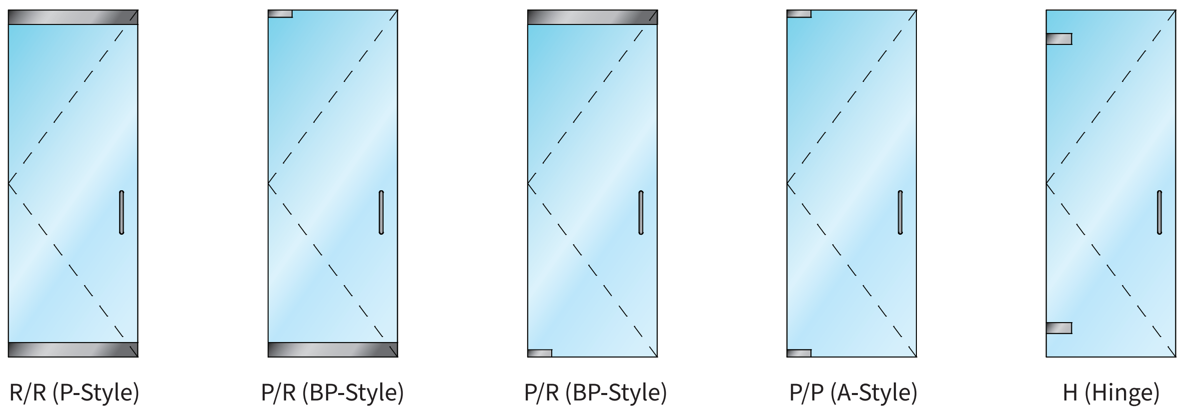


FIGURE 47 *Types of Doors*

- R/R (P-Style): Full width top and bottom rails.
- P/R (BP-Style): Full-width bottom rail with a partial top rail or top patch fitting at the pivot corner.
- P/P (A-Style): Partial rails or patch fittings for top and bottom pivot corners. Mid-panel locks or integral locking pulls are required to lock this style of door.
- H (Hinge): Self-closing hinge eliminates the need for a separate closer. A patch lock, mid-panel lock or integral locking pulls are typically required to secure this style of door.

Types of Glass
Fully tempered glass or fully tempered laminated heavy glass doors and entrances consist of clear and tinted substrates; monolithic fully tempered float glass normally complies with the standards defined in ASTM C1036 and C1048. Typically, a clear substrate is used and ranges in thickness from ⅜ inch (10 mm); ½ inch (12 mm); ⅝ inch (16 mm); and ¾ inch (19 mm). Low-iron, tinted and obscure heavy float glass products are also available for these same applications.

Fully tempered laminated glass doors should be a minimum of ½ inch (12 mm) thick. See ASTM C1036 and ASTM C1072 for laminated glass fabrication guidelines.

Rail Types

Figure 48 shows typical rail profiles. Typical profiles shown may vary by manufacturer. Glass attachment methods include wet (cement) glazing, mechanical and dry gasket glazing. Rails can be full-width or partial-width (patch) for corner application.

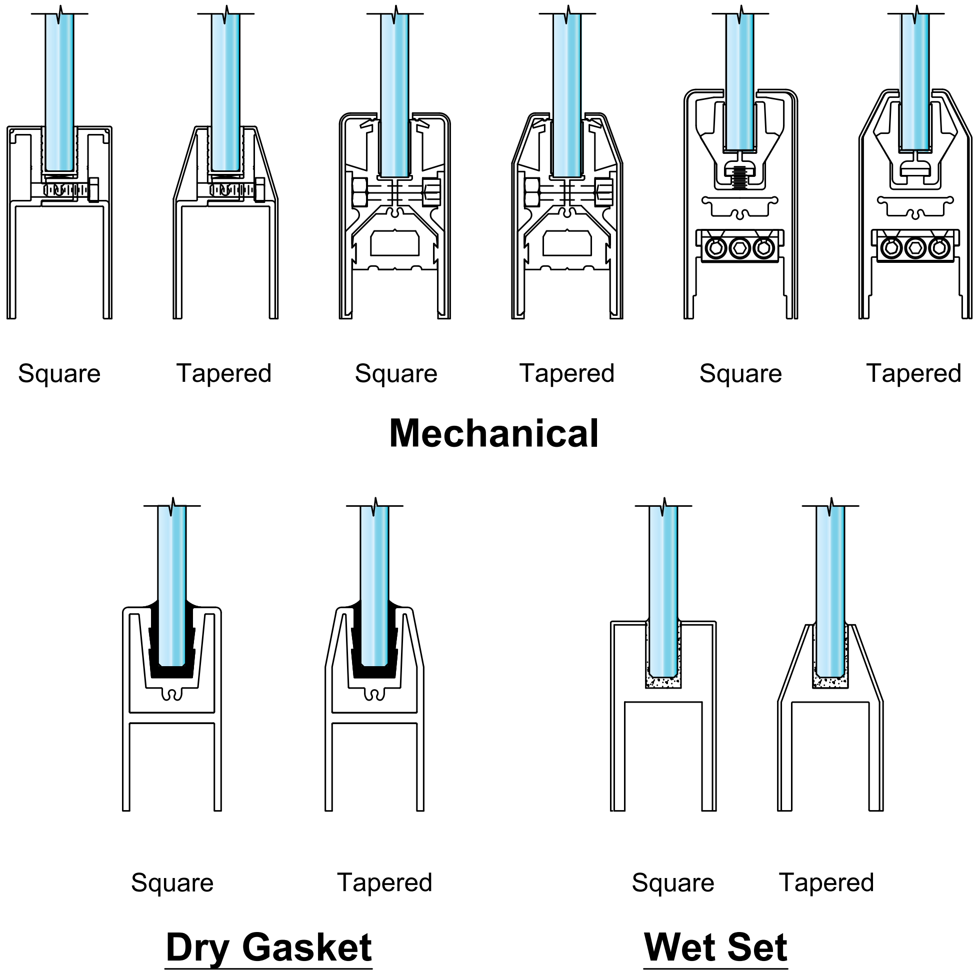


FIGURE 48 *Typical Rail Profiles*

Patches

Figure 49 shows common small profile patch types. Many different entrance configurations can be obtained by using other patch types (not shown).

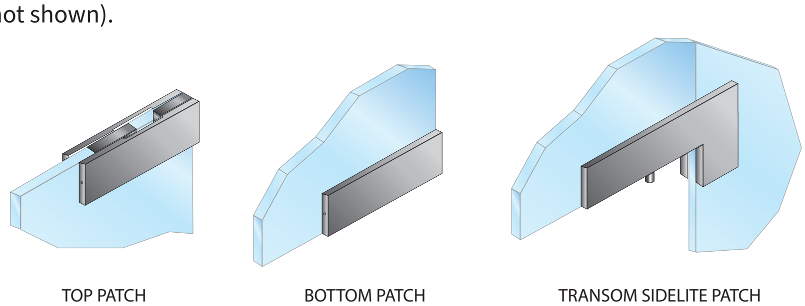


FIGURE 49 *Common Patch Types*

Swinging Door Systems

Top and Bottom Pivots
The function of pivots is to support the door and provide swinging action. Pivots fall into two general categories: Center-hung (Figure 50) and Offset (Figure 51).

Note: pivot location dimensions shown are standard. Other options may be available for specialized applications.

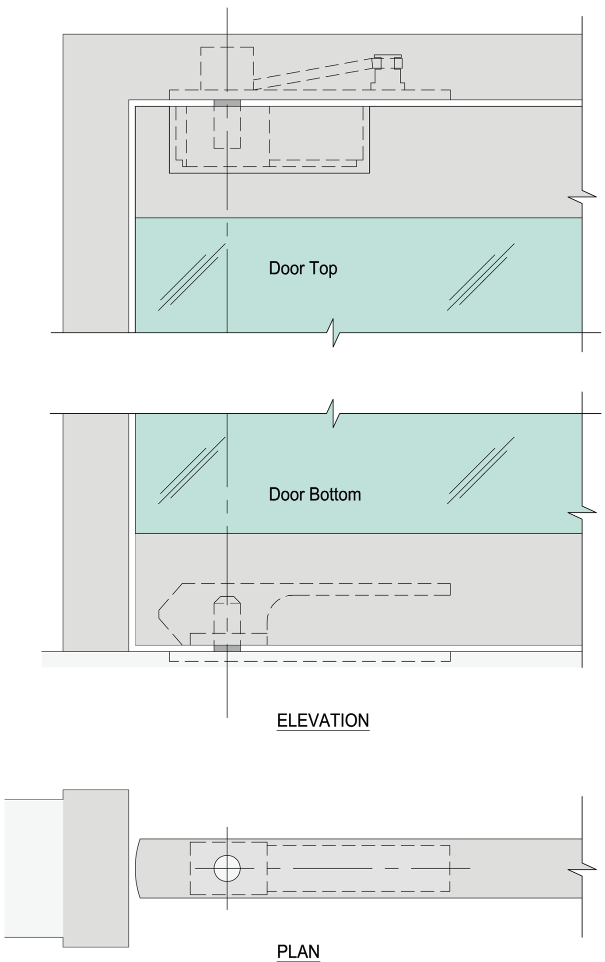


FIGURE 50 *Center Pivot*

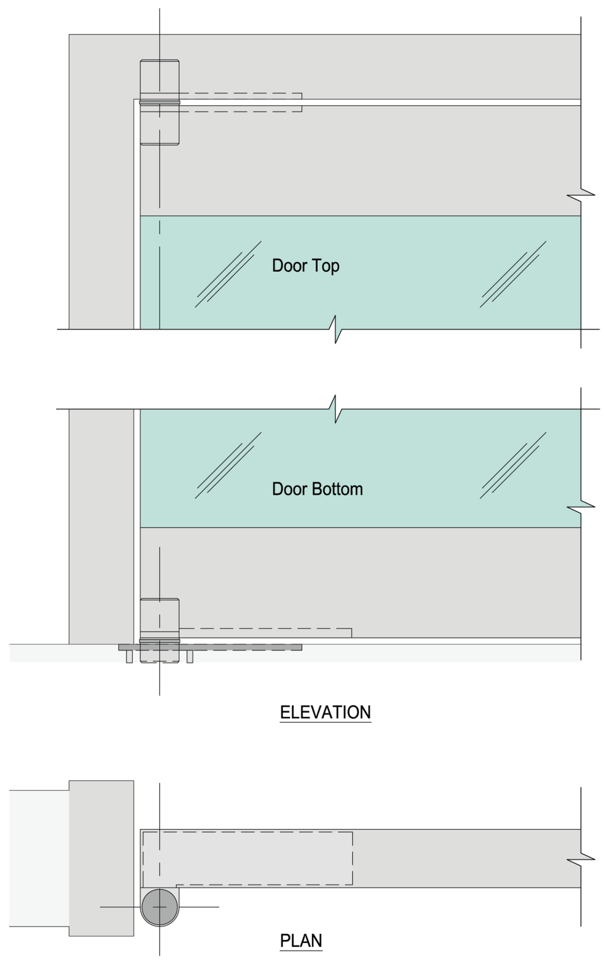


FIGURE 51 *Offset Pivot*

Sliding Door Systems
Heavy glass doors can be utilized in sliding door systems using either top rollers or floor-loaded rollers. When a sliding door is opened it is moved parallel to and in the same plane as the opening. The weight of the sliding doors can be suspended from rollers in an overhead track or supported by rollers on a floor track. Generally, door panels in sliding door systems may be wider than swing doors. The manufacturer should be consulted for size limits. Sliding doors can be operated manually or by automated mechanisms. Refer to the *NGA Heavy Glass Door Design Manual* for details on top-hung and floor-mounted sliding systems.

Sidelites with Rails
Sidelites and other fixed glass may have rails, at top and bottom or bottom only, to match the rails or doors. To maintain an even sightline with the door, track/saddles of various heights are provided. The track/saddles should be anchored to a load-carrying building structure at ceiling and floor. Additional anchoring of the rail to the track may be required.

Sidelites with rails are available in two types: pre-applied rails (individual panel only) and field-glazed rails (individual or multiple panels). Manufacturer's recommendations for anchoring sidelite rails should be examined. Minimum bite and clearance requirements for field-glazed rails are shown in the *NGA Heavy Glass Door Design Manual*.

Note: see the NGA with GANA *Engineering Standards Manual* (reprinted in the NGA H*eavy Glass Door Design Manual)* for additional information regarding height and thickness recommendations for fully tempered interior butt-glazed fixed glass panels.

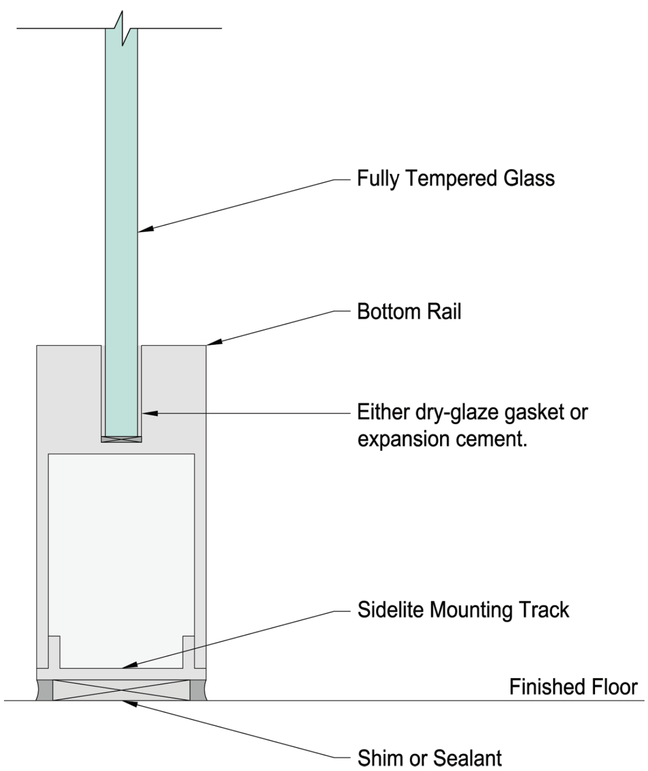


FIGURE 52 *Pre-Applied Rails*

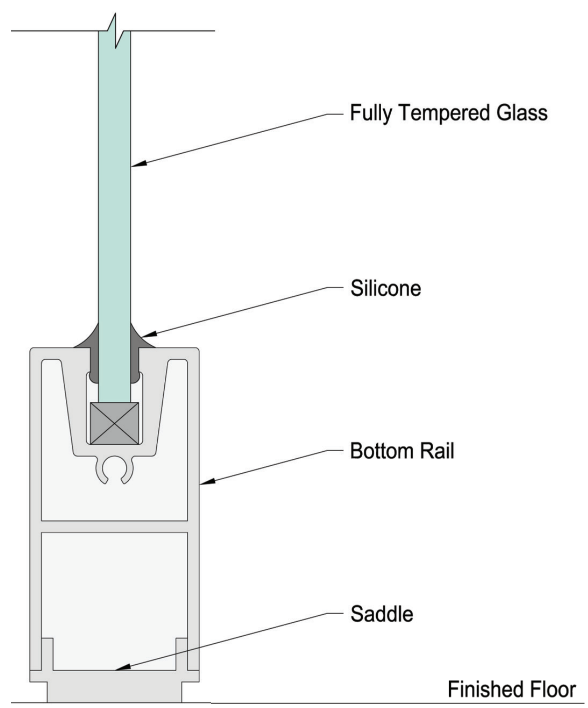


FIGURE 53 *Field-Glazed Rails*

Glass Transoms

Fully tempered or tempered laminated glass transoms are those fixed glass panels immediately above the door opening and often span between the top of the doors and the finished ceiling. These transom lites can be incorporated into the glass entrance using patch fittings or other transom support methods. Glass transoms using patch fittings may require mechanical fastening to ceiling structure based on weight, size and other design considerations.

Glass Stabilizer Fins

With all glass transoms and sidelites, perpendicular fully tempered glass mullions, sometimes called fins, may be mounted from the ceiling to the bottom of the transom to reduce the amount of deflection of the glass entrance. The fin should be mechanically secured and anchored to the overhead load-carrying structure. Suspended ceilings generally do not provide an adequate structure for attachment of stabilizer fins. Typically, these glass fins are made using ½-inch (12-mm), ⅝-inch (15-mm), or ¾-inch (19-mm)-thick fully tempered glass. For design criteria and use of glass stabilizer fins, see the NGA *Heavy Glass Door Design Guide*.

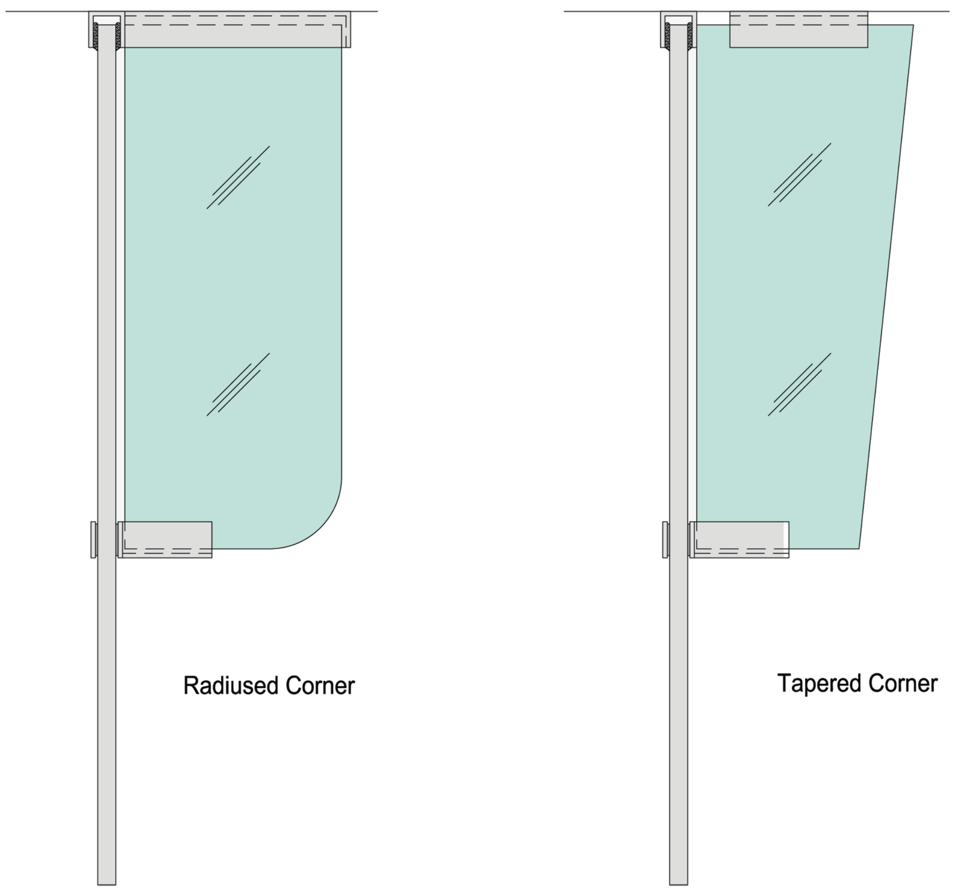


FIGURE 54 *Examples of glass stabilizer fins*

Design/Installation Considerations
All fully tempered heavy glass entrance systems generally require proper installation to assure optimum performance and long life. Performance is dependent upon proper and adequate attachment to the adjoining perimeter framing or structure. Headers, jamb tubes, channels, etc. should be sufficiently anchored to a building load-carrying structural member in a manner appropriate to the specific site conditions.

Structural review and formal calculations should be prepared by a structural engineer licensed in the state at which the project will be constructed.

A successful installation requires attention to many details, both in the design and installation stages.

Considerations during the design stage include:

- Traffic volume
- Compliance with the ADA and all applicable building codes (Local code interpretation varies widely. Check requirements with local building officials.)
- Wind load conditions
- Security requirements
- Perimeter conditions (ceiling, floor and jambs)

Considerations during installation include:

- Inspect and verify opening size and squareness
- Align and firmly secure pivots
- Secure anchoring to load-carrying perimeter structure
- Securely fasten all attached hardware
- Adjust door closing speeds

Special Applications of Glass

Guidelines for most applications of glass used in construction are included in this Manual. These are based on standards developed by the glass and glazing industry and provisions of the local, state and model building codes. The following applications are unique and typically require design by an engineer familiar with the structural properties of glass. As this glass is custom-fabricated, it is desirable to purchase attic (extra) stock in advance in order to reduce the time required to replace a broken lite.

Viewing Windows for Large Aquariums
Aquarium view windows typically require a substantially different design approach than the approach used for windows in buildings subjected to wind loads. Most current glass thickness charts are predicted on 3-second uniform loading, whereas aquarium glass is subjected to continuous, long-term loading. Also, the magnitude of loading is considerably greater for water than for wind. Many industry publications, such as ASTM E1300, do not provide guidance for these “special applications.”

Pressure on the glass is directly related to the depth of the water. Water pressure increases from the water line down to the bottom of the glass. The pressures are, therefore, triangular or trapezoidal. In addition to the water pressure, additional considerations should be given to the weight of the marine animals and frequent impact where animals, such as polar bears, can potentially scratch or abrade the glass. Design procedures based on uniform loads do not apply.

Windows for aquariums, swimming pools and similar enclosures should be designed to assure that potential risks to people are minimized. In their design, it should be assumed that glass may fail for a multitude of reasons including impact, mechanical stresses, thermal stresses and some inclusions. Safety dictates that laminated glass should be used and designed to prevent complete failure should one ply fail. Consideration should also be given to the extra time needed for replacement of broken glass. First, the aquatic life must be removed and relocated and then the tank drained before re-glazing may occur. Therefore, the load on the glass may remain sustained for some time.

The edges of the laminated glass should not be under continuous exposure to water. The edge conditions should be designed and constructed to drain moisture from the glazing channel and avoid such exposure.

Cast acrylic panels have been used for sizes greater than the available sizes of fully tempered or laminated glass.

Viewing Windows for Animal Enclosure

The force applied by an animal impacting glass depends on the animal's weight, the velocity of impact, the rigidity of the glass and any cushioning provided by its supports. The latter three items are required to estimate the deceleration of the animal upon impact, a factor necessary to determine the applied force. For a particularly active animal, the force applied to the glass may be four or five times the animal's weight. Determination of the glass requirements to sustain this loading is a complex iterative calculation.

The selection of glass should assume that breakage may occur for a number of reasons, including impact, mechanical stresses, thermal stresses and some inclusions. Experience, limited testing and engineering calculations show that, in most cases, a proper design is a lamination of at least two plies of tempered glass. The selected safety factor is influenced by the threat to people from the animal.

For butt-glazed applications, a thicker laminate may be required to decrease deflection, particularly when direct animal contact is likely. Silicone butt-joint seals may not be the optimum choice for mammal enclosures, such as gorillas, orangutans and monkeys as they have shown the ability to remove (and eat) these materials.

Framing systems for animal enclosures should incorporate a weep system. Laminated glazing materials in these applications are frequently cleaned with high-pressure water hoses, which can result in moisture accumulation in the glazing channel. The weep system should ensure that any water that enters the glazing system will be drained. Prolonged exposure to moisture vapor in the glazing channel may result in premature delamination of the laminated glazing material.

Walkways (Floors, Stairs, Landings and Ramps)

Building codes define the uniform and concentrated loads for walking surfaces. Load requirements are generally defined by occupancy (residential, commercial, etc.) and use. Industry standard ASTM E2751 *Standard Practice for Design and Performance of Supported Laminated Glass Walkways* contains calculation and testing methods applicable to the design of glass walkways constructed with laminated glass. This standard assists the designer in better understanding the elements related to performance, design and safe behavior of glass walkways that include interior and exterior walking surfaces constructed and intended for pedestrian use, including floors, ramps, sidewalks and stair treads.

The glass selection should minimize the risk of total glass failure. For safety reasons, laminated glass should be used, and designed to prevent complete failure should one ply fail. Single glass, including fully tempered glass, is not considered a safe product for this application regardless of its thickness or design factor.

Glass walking surfaces may experience breakage from impact, severe surface damage and concentrated loads. In high-traffic areas, abrasion and other marring of the top surface often results in an unsightly appearance after a period of time. In some installations, an expendable cover plate is added to the laminated glass. This is generally a relatively thin fully tempered glass. It is laid on the laminated glass with an intervening plastic sheet. This glass is removed and replaced as it becomes marred.

The walking surface is often treated to minimize the risk of a person slipping on that surface. The Occupational Safety and Health Administration (OSHA) requires a minimum slip resistance, expressed as a static coefficient of friction, of 0.50. ASTM E2751 also notes a minimum static coefficient of friction of 0.5 for walking surfaces under dry conditions. However, special situations such as dance floors, sloped walkways and wet conditions may require a different, greater level of slip resistance. Using a dynamic coefficient of friction that reflects an object in motion is typically more appropriate for these situations. For additional information on slip resistance, installation, fire-resistance and maintenance, consult the NGA Glass Technical Paper FB14-07 *Glass Floors and Stairs*.

All-Glass Wall Systems

Systems using glass fins (or stabilizers and stiffeners) and mainplates may be one lite or more in height. In all cases, the glass stiffeners are designed as support members in much the same way as metal mullions and rafters. Designs are not limited to vertical walls. All-glass entrance enclosures and similar designs incorporating sloped and horizontal glass have also been successful.

The stiffeners are generally ¾-inch (19-mm) fully tempered glass or laminated glass. The mainplate glass may be laminated or fully tempered glass, or may be insulating glass using those or a combination of those glass types.

The attachment of the mainplate glass to the fins may be with a structural silicone bond or by point-supported mechanical attachment with bolts. The latter method is typically used for assemblies more than one row of lites in height. For point-supported mechanical attachment, holes in the glass are typically required for multi-row assemblies.

In many designs, the glass is not firmly supported continuously on all edges. Conventional strength-of-glass charts and graphs should not be used. The design of glass wall systems can be complex, normally requiring design by an engineer familiar with the structural properties of glass. The design is often controlled by guidelines furnished by the suppliers of these systems.

Point-Supported Glazing Systems
Monolithic, laminated or insulating architectural glass has traditionally been supported by capturing the edges of the glass. As architects have expressed their desire to make the walls of the buildings even more transparent, engineers have developed methods to reduce the amount of framing required to support the glass.

It has become increasingly common to attach the glass to the structure using fittings directly connected through holes in the glass or with fittings through the joints between the glass. These fittings allow improved transparency and offer additional architectural opportunities in the detailing of the bolted connections.

Main components of such systems commonly include fully tempered and/or laminated lites of glass, metal structural components (spider clips, patch fittings, bolts, etc.), and a glass or metal support behind the main exterior glazing panel.

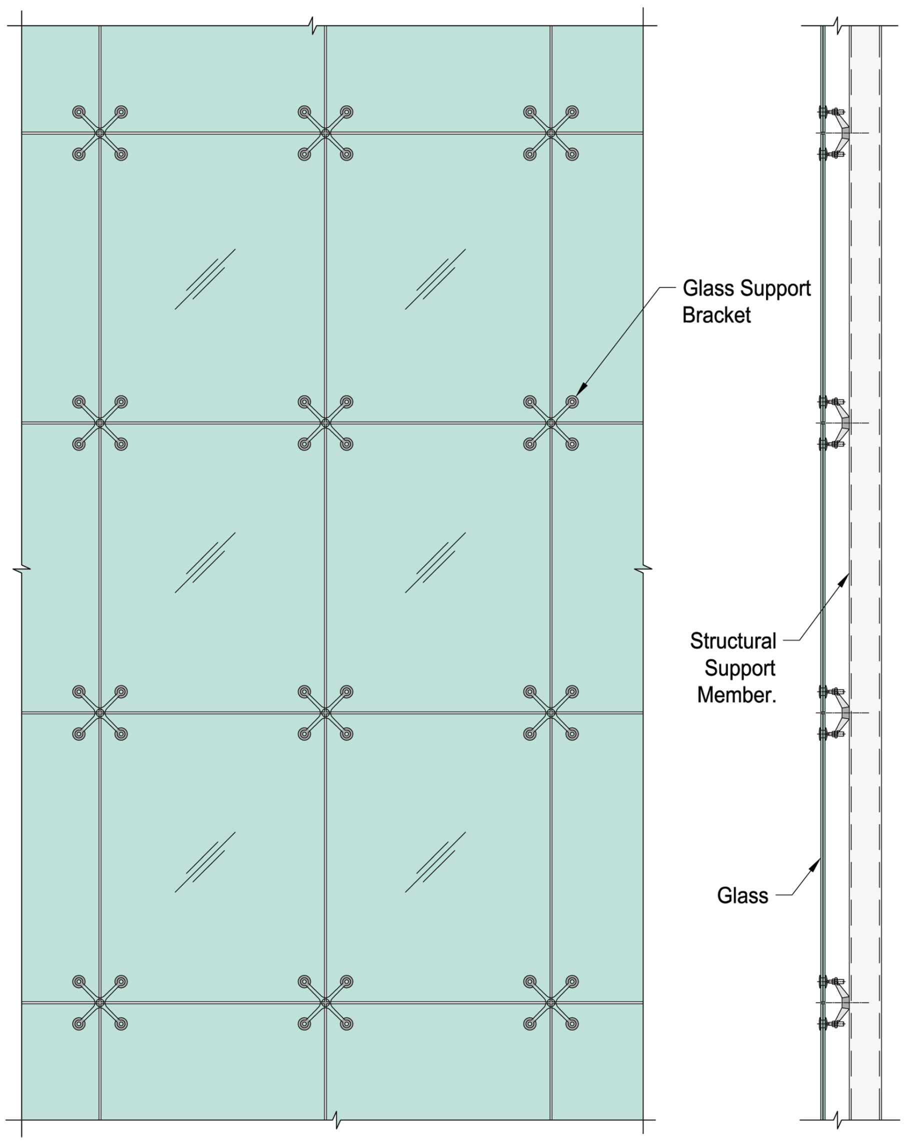
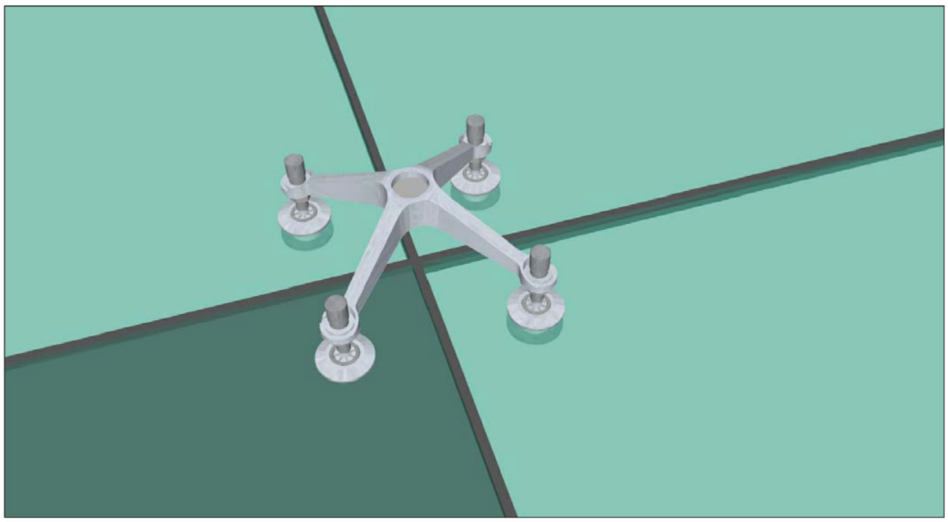


FIGURE 55 *Point-Supported Glass*

Hardware

Point-supported hardware comes in various configurations, including a simple bolt-and-patch-plate system, simple countersunk bolts and several others. Some hardware systems utilize flexible washers and gaskets, while some utilize articulated bolts. All of these hardware systems have been successfully used for façades and canopy structures, but the structural glass should be designed and fabricated properly to be compatible with the particular hardware system specified. The amount of stress in and around the hole in the glass will vary depending upon the location and size of the clamping hardware. Hardware manufacturers often do not make recommendations regarding glass thickness, distance from hole to glass edge, and maximum distance between point connections. Glass holes and notches should be designed and fabricated in accordance with the guidelines established in ASTM C1048 *Standard Specification for Heat-Treated Flat Glass.* Loading requirements may dictate a more conservative approach to hole and notch locations than found in ASTM C1048. Design and fabrication processes should be coordinated.



Point Support Bracket Detail

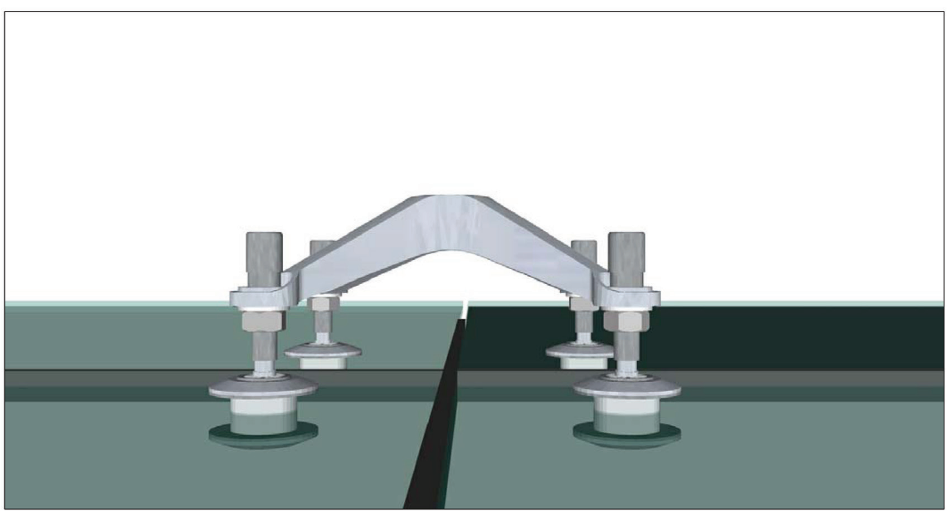


FIGURE 56 *Point-Supported Glass Hardware*

Applications
Point-supported glass is used in two distinct applications: vertical glazing and sloped/overhead glazing. Vertical glazing can use monolithic or insulating glass units of tempered glass or heat-treated laminated glass. Sloped glazing and overhead canopies normally require heat-treated laminated glass. The fundamental difference between sloped/overhead glazing and vertical glazing is that sloped/overhead glazing is subject to permanent gravity load from its self-weight and may be subject to a long-term snow load or maintenance activity load.

For further information on point-supported glazing systems, consult NGA Glass Technical Paper FB07-05 *Point-Supported Glazing*.

Glass Protection for Sports Viewing
Glass has become widely used in impact-prone areas such as barriers surrounding hockey rinks, private suites in baseball stadiums, golf-club walls in the potential path of wayward drives, racquetball courts, and other sports-related uses. Each application should be designed based on the unique impact forces that may be applied and the potential for injury. Fully tempered laminated or heat-strengthened laminated glass is most commonly used.

Glass Railing Systems
Glass railing systems are used in a variety of residential and commercial settings for safety, unobstructed views and the beauty glass adds to a structure. The 2021 International Building Code (IBC) makes specific reference to glass railings in Section 2407 of the code. The code requires the use of laminated glass with very few exceptions. Refer to NGA Glass Technical Paper FB33-11 *Use of Glass in Guardrails* for further details.

Laminated glass is usually recognized as the ideal glazing material for this application and offers a variety of design options. The interlayer can be clear, tinted or custom-printed. The glass can be clear, tinted or decorative; flat or curved; fully supported on 1, 2, 3 or 4 edges; or minimally supported with bolts and/or clamps. Laminated glass offers a benefit over monolithic tempered glass when used in railings; if breakage occurs, glass particles tend to adhere to the laminate interlayer, increasing the likelihood of glass retention in the system.

Two ASTM standards and one Canadian Standards Association (CSA) standard address testing, specification and design of glass railings:

- ASTM E2353 *Standard Test Methods for Performance of Glass in Permanent Glass Railing Systems, Guards and Balustrades*

- ASTM E2358 *Standard Specification for the Performance of Glass in Permanent Glass Railing Systems, Guards and Balustrades*

- CSA A500 *Guard Standard*

Glass in Photovoltaic Applications
Glass is uniquely suited for the design and fabrication of solar cells, modules and arrays. While many different technologies are used in the engineering and science behind these solar-power devices, they all have one thing in common: they convert light energy into electrical energy through the photovoltaic effect (PV effect). Soda-lime float glass is commonly specified with a low iron content to increase the solar and visible-light transmittance for PV applications. Borosilicate glass is another option because of its excellent optical quality and resistance to thermal shock. Generally, PV applications use glass as cover glass (superstrate) or as back glass (substrate).

Cover glass tends to protect the active substrate from chemical and mechanical and/or environmental damage, and may serve as a base for thin-film circuitry. Because the electrical output of any PV device is directly proportional to its ability to collect the maximum light energy, an optically clear material such as glass normally represents the ideal choice for cover glass applications. Anti-reflective coating on cover glass is commonly used to increase transmission. The glass should be as flat and smooth as possible and free of any deformations in the surfaces or mid-plane of the glass. In addition, uniform thickness is a factor, since thickness variations can decrease transmittance efficiency.

Sometimes a pattern of small prisms is imprinted onto the surface of the glass in order to gather and focus more light energy. Heat-treated glass is often specified to add strength and thermal shock resistance.

Back glass tends to provide structural support, protection and cosmetic appeal, and may serve as a base for thin-film circuitry. The back glass of a PV cell module is on the side of the module not facing the sun. Its purpose is to provide structural support for the assembled unit and, in some cases, a decorative appeal. The type of glass used may be annealed, heat-strengthened or fully tempered, based on strength specifications, process and cost considerations. Because transmittance is not important, it can be fabricated from standard soda-lime float glass and produced with a tint, pattern or texture to fit into BIPV or spandrel applications.

For more information on types of PV cells and industry standards for PV applications, refer to NGA Glass Technical Paper FB39-14 *Glass Properties Pertaining to Photovoltaic Applications*.

Glass Personal Protective Barriers
Retail, medical, educational and manufacturing facilities are implementing changes due to the worldwide outbreak of COVID-19, a respiratory illness believed to spread primarily by droplets from coughs or sneezes of infected persons to those nearby. Many businesses are installing clear personal protective barriers to physically shield employees from each other and from consumers to reduce potential exposure to the virus (as shown in examples in Figure 57). In many applications, the barriers will become a permanent fixture; therefore, aesthetics and cleanability are important design considerations. Barriers can be constructed of plastic sheet or glass. Glass has several advantages in physical barrier applications and may be preferred over plastic, especially for permanent and public-facing barrier installations. Compared to plastic, glass is easy to clean, transparent and aesthetically pleasing.

Types of Glass
The types of glass recommended for physical barriers are laminated or fully tempered glass which meet ANSI Z97.1 *Safety Glazing Materials Used in Buildings – Safety Performance Specifications and Methods of Test* and/or CPSC 16 CFR 1201 *Safety Standard for Architectural Glazing Materials.* Safety film that passes ANSI Z97.1 and/or CPSC 16 CFR 1201 standards may be applied to some glass products. The fabricator may be contacted for additional details. Bump-guard type gasketing or similar edge protection around the perimeter of exposed-edge glass barriers is recommended unless edges are ground and polished.

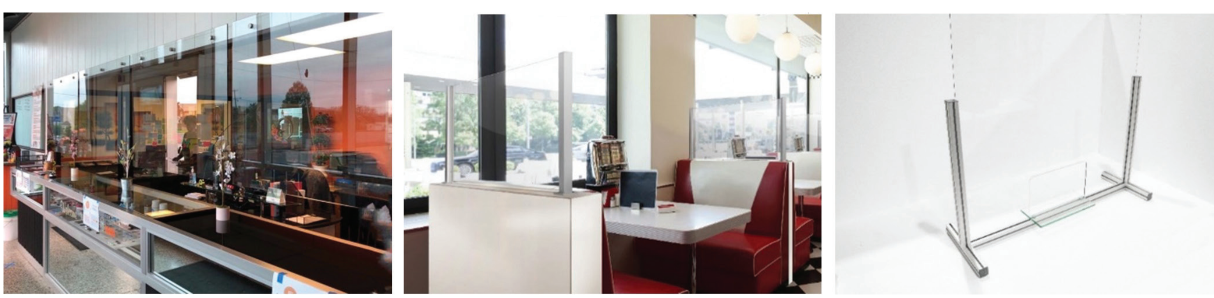


FIGURE 57 *Examples of glass personal protective barriers*

Installation Techniques
Edge clamps and adhesives are examples of simple and efficient ways to mount glass panels without designing and drilling holes into the glass. Using this technique, the mounting components should support the glass along a minimum of two edges and bite depth of the edge clamping over the glass edge should be appropriate for the glass thickness, as specified in Figure 22 and Table 26 and in the NGA *Laminated Glazing Reference Manual.* Hardware is readily available for glass guards to support the weight of the glass panel without crushing or locally stressing the glass surface. An alternative mounting technique involves point-supported glazing, where glass panels are supported by through-hole or patch/clamp fittings. Typical hardware includes a bolt-and-patch-plate system, a countersunk

bolt, hardware with flexible washers and gaskets within the supporting structure, and hardware with articulated bolts. Refer to ASTM C1048 *Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass* for requirements for fittings and hardware and placement of holes, notches and cutout fillets. For additional information, refer to NGA Glass Technical Paper FB65-20 *Glass for Personal Protective Barriers*.

Bird-Friendly Glazing

Bird collisions with buildings are within the top three principal causes of avian mortality in North America. Clear and reflective surfaces of commercial and residential buildings are theorized to be invisible to potentially all birds due to what have been defined as fly-through conditions, reflected habitat conditions, or black-hole effect. Studies have shown that creating visual markers, muting reflections in glass façades and minimizing light pollution are ways to create a more bird-friendly environment. There are a variety of glass and glazing solutions offered by glass fabricators and other stakeholders that can reduce bird collisions. Some jurisdictions have bird-friendly code or law requirements applicable to glazing.

Elevation Treatment

Bird collision mitigation practices should be considered for all glazed structures up to either a height of 50 feet from grade or the height of mature vegetation, whichever is greater. At levels above 50 feet, bird collision mitigation practices should be applied to all glazed structures to a height of 12 feet above the surface of green roofs, rooftop gardens and terraces (or other similar areas) where mature vegetation is present or to the height of such vegetation, whichever is greater.

Visual Appearance and Markers on Vision Glazing

- Marker spacing (2-inch by 4-inch rule): research on songbirds, the most numerous victims of collisions, has shown that horizontal lines on markers should be two or fewer inches apart to significantly deter bird collisions. Vertical lines should be four or fewer inches apart. This difference correlates with the average shape of a flying bird (see Figure 58). The 2-inch by 4-inch "rule" may not be adequate to protect smaller birds. A 2-inch by 2-inch spacing may be better at protecting these smaller birds, like hummingbirds, which are common victims of collisions. Pattern density should be balanced with building occupants' well-being.

- Marker appearance: bird deterrent solutions employ a variety of visual markers, including but not limited to dots, lines, decorative elements and random patterns. Markers should have enough visual contrast between the pattern elements and the reflected/transmitted glass image that birds can recognize it as signaling there is something physical in the way of their flight path.

- Marker size: the scientific knowledge supports the use of markers of ⅛ inch (3 mm) or greater (length, width, diameter or irregular dimensions). However, be aware that this use of markers may not meet all applicable codes, regulations and other requirements.

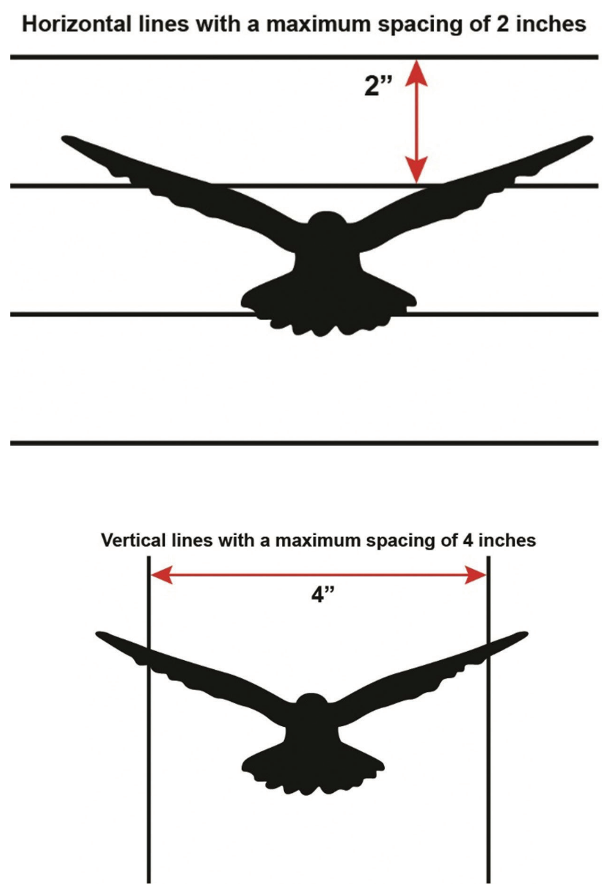


FIGURE 57 *The 2-inch by 4-inch rule for bird-friendly marker spacing*

- Glass surface on which to apply markers visible to birds:
  - o Outboard lite: visual markers applied on the outside surface of the glass (surface 1) can be most effective in a variety of conditions. Markers on surface 2 and laminated markers can be effective in conditions where the markers can overcome specular and visual reflections as viewed from the outside looking in.
  - o Inboard lite: markers on surface 3 or 4 are not recommended unless testing is supplied and reviewed for effectiveness with the specific glass and end-use conditions.

For more information, including risk factors, existing legislation, glass product solutions and references, refer to NGA Design Guide DG01-21 *Best Practices for Bird-Friendly Glazing Design Guide*.

Acrylic & Polycarbonate Sheet
Plastic sheets are subject to greater dimensional change due to thermal expansion and contraction than most other materials with which they are commonly used in construction. Table 28 compares this characteristic.

TABLE 28 *Comparison of Coefficients of Thermal Expansion with Other Building Materials*

Comparison of Coefficients of Thermal Expansion with other Building Materials		
	Inches/inch/°F	Inches per 10' length 100°F temperature change
Acrylics	.0000420	.504"
Polycarbonates	.0000375	.430"
Aluminum	.0000129	.155"
Steel	.0000063	.076"
Glass	.0000050	.060"

Plastic sheet has a relatively high rate of water vapor transmission, and accordingly is not usually recommended for use as one or both lites of an insulating glass unit. However, for security applications, plastic sheet can be used, provided appropriate weep systems are incorporated so that neither the IG sealant nor plastic is sitting in water.

While most acrylic and polycarbonate sheets are classed as safety glazing materials, the manufacturer should be consulted to confirm compliance with ANSI Z97.1 and the state and local building codes. They are exempt from compliance with CPSC 16 CFR 1201 because the federal standard applies only to glass.

The glazing characteristics of these plastics are substantially different from those of glass. Particular attention must be paid to expansion and contraction, adhesion and compatibility with glazing materials, preparation of the glazing pocket and deflection. The modulus of elasticity of polycarbonate is 345,000 psi (2,378,691 kPa) and glass is 10,400,000 psi (71,705,475 kPa). If polycarbonate and glass of the same size and thickness are subjected to identical uniform loads, the deflection of the polycarbonate will be approximately 30 times that of the glass.

The following general information and recommendations should be compared and supplemented with the latest information available from manufacturers:

- Plastic sheets or panels should be installed in a metal frame engaging the edges of the material, so the material is free to expand and contract without restraint.

- The pocket depth should be sufficient to allow for the thermal contraction or deflection of the plastic without withdrawal of the edges from the frame.

- Through-bolting or other inflexible fastenings, which do not provide for expansion and contraction, can cause failure of the installation.

- Before installation in the metal frame, plastics should be cut sufficiently shorter than the channel frame dimensions to allow for thermal expansion.

- Sealant compounds and tapes should be types that are sufficiently extensible to accommodate thermal expansion and contraction, and which adhere to both the plastic and frame. The cure by-products of certain sealant chemistries may adversely react with polycarbonate and allow for increased probability in stress cracking. Carefully consider the choice of sealant chemistry when selecting materials.

- Depth and width requirements of the pocket are determined by type, thickness and the wind load requirements. See plastic manufacturer's recommendations for minimum pocket size limitations.

- Screw-applied stops to the interior side of the sash may be applied tight against the plastic. It is not generally practical to apply snap-on glazing beads tight against the sheet. A bond breaker tape applied to the stop is recommended to avoid scratching of the plastic during normal thermal movements.

- With pressure equalization and weep systems, it may be necessary to use setting blocks to prevent blockage of weep holes. With non-pressure equalization systems, it may be permissible to set the sheets directly on the bottom of the sill member. Check with the plastic glazing supplier for their particular products' glazing guidelines.

- Wash with mild soap or detergent and water. Use as much water as possible in washing. Apply to large areas with a bristle mop used in window washing and to smaller areas with a clean, soft cloth, sponge or chamois. Follow supplier's washing and cleaning recommendations.

- Use a clean, damp chamois if it is necessary to dry the washed surface.

- Abrasives will scratch the surface of acrylic and polycarbonate sheets. The exercise of reasonable care in cleaning acrylic plastic will minimize scratching.

- Polycarbonates and acrylics have about the same coefficient of thermal expansion (change in length = coefficient of expansion x length x °F temperature change). This coefficient is approximately eight times more than glass and three times more than aluminum. This high degree of thermal expansion and contraction results in much greater movements than those of glass. Therefore, careful consideration should be given when selecting the glazing system.

- Sash designs suited for glass are not necessarily suited for glazing plastics. At dimensions (height or width) greater than 72 inches (1828 mm), more bite is required than on glass. The sealant dimension (face clearance) must also be increased to allow for the greater movement of the plastic.

- Glazing systems should be installed in accordance with good glazing practices and manufacturer instructions.

- There are coated plastics on the market which improve the scratch resistance by use of a transparent coating applied to the acrylic or polycarbonate sheet. The resistance of such coatings to ultraviolet or atmospheric chemical degradation should be fully investigated prior to use.

- A difference between temperature and/or humidity conditions, prevailing on opposite sides of a sheet, may cause the sheet to bow slightly toward the surface exposed to the higher temperature and/or humidity. However, the sheet should return toward its original condition as soon as the temperature or humidity differential has been reduced. This bowing puts a great amount of stress on the glazing system.

- In wet glazed systems, plastic sheets with major dimension greater than 24 inches (609.6 mm) should be installed with a continuous bead. Glazing compound should not be used; only elastomeric sealants with adequate elongation characteristics and proven adhesion to the specified plastic substrate should be used.

- All surfaces of wood and steel should be prime painted as required by the manufacturer before application of sealants. Aluminum sash should be cleaned with an appropriate solvent to remove protective finishes and grease. Plastics should not be exposed to solvents such as Xylol, Toluol, MEK, etc. VM&P Naphtha may be used as an effective cleaner for some plastics. Confirm with the plastic glazing supplier before using any cleaning product. When using solvents, follow the recommendations on the Materials Safety Data Sheets (MSDS) supplied by the solvent manufacturer.

- If unusual loading, temperature, humidity or sash conditions exist, consult with plastic manufacturer for recommendations.

- Unmask plastic sheet edges before installing. This will protect glazing during installation. Unmask entire sheet immediately after installation.

- The edges of a plastic lite should be thoroughly cleaned with VM&P Naphtha before setting in a sash if approved by plastic manufacturer.

- Protect plastic from excess sealant smears with a paper-backed adhesive tape around the edges adjacent to the pockets.

- Plastic glazing should be regarded as a finishing operation and should be scheduled as one of the last steps in the completion of the building. If this is not practical, acrylic plastic should be protected from paint, plaster and tar splashes with drop cloths or other suitable covering.

Appendix 1

Organizations Publishing Referenced Standards and Information

The following organizations publish standards and reference materials commonly used in the glass and glazing industry. These organizations are commonly referred to by their acronyms. Consult these organizations for additional information.

TABLE 29 *Organizations Publishing Referenced Standards and Information*

Organization Name	Acronym	Website
Adhesive and Sealant Council Inc.	ASC	ascouncil.org
Aluminum Extruders Council	AEC	aec.org
American Architectural Manufacturers Association	AAMA	*See Fenestration & Glazing Industry Alliance*
American National Standards Institute	ANSI	ansi.org
American Society of Civil Engineers	ASC	asce.org
American Society of Mechanical Engineers	ASME	asme.org
ASTM International	ASTM	astm.org
Building Officials and Code Administrators	BOCA	*See International Code Council*
Canadian General Standards Board	CGSB	tpsgc-pwgsc.gc.ca/ongc-cgsb/index-eng.html
Council of American Building Officials	CABO	*See International Code Council*
Federal Emergency Management Agency	FEMA	fema.gov
Fenestration & Glazing Industry Alliance	FGIA	fgiaonline.org
General Services Administration	GSA	gsa.gov
Glass Association of North America	GANA	*See National Glass Association*
Glazing Industry Code Committee	GICC	*See National Glass Association*
H.P. White Laboratory Inc.		*See Intertek*
International Code Council	ICC	iccsafe.org
International Conference of Building Officials	ICBO	*See International Code Council*
International Window Cleaners Association	IWCA	iwca.org
Intertek		intertek.com
Lawrence Berkeley National Laboratory	LBNL	lbl.gov
LBNL Windows and Daylighting Group		windows.lbl.gov
National Institute of Justice	NIJ	nij.ojp.gov
National Fenestration Rating Council	NFRC	nfrc.org
National Fire Protection Association	NFPA	NFPA.org
National Glass Association	NGA	glass.org

Organization Name	**Acronym**	**Website**
Sealant, Waterproofing and Restoration Institute	SWRI	swrionline.org
Southern Building Code Congress International	SBCCI	*See International Code Council*
Underwriters Laboratories Inc.	UL	ul.com
U.S. Consumer Product Safety Commission	CPSC	cpsc.gov

Appendix 2

This appendix provides a list of National Glass Association (NGA) Glass Technical Papers (GTPs) developed by NGA task group volunteers and reviewed via consensus process. The publication dates have been omitted as the materials are subject to review and updates. References to these materials made in this manual are based on the most current version as of August 1, 2022. Revisions may be published prior to the update of this manual. Visit the NGA website at glass.org/store to access the GTPs and other resources.

FB01-00 . . . . Proper Procedures for Cleaning Architectural Glass Products (with IWCA)

FB02-02 . . . . Heat-Treated Glass Surfaces Are Different

FB03-03 . . . . Construction Site Protection and Maintenance of Architectural Glass

FB04-03 . . . . Design Considerations for Laminated Glazing Applications

FB05-04 . . . . Emergency Egress Through Laminated Glazing Materials

FB06-05 . . . . Proper Procedures for Cleaning Flat Glass Mirrors

FB07-05 . . . . Point-Supported Glazing

FB09-06 . . . . Suggested Procedures for Dealing with Broken Glass

FB10-06 . . . . Skylights and Sloped Glazing are Not Walking Surfaces

FB11-06 . . . . Marking and Labeling of Architectural Laminated Glass

FB12-07 . . . . Blast-Resistant Glazing

FB13-07 . . . . The Importance of Fabrication Prior to Heat-Treatment

FB14-07 . . . . Glass Floors and Stairs

FB15-07 . . . . Describing Architectural Glass Constructions

FB16-07 . . . . Bullet-Resistant Glazing

FB17-08 . . . . Glossary of Terms for Color and Appearance

FB18-08 . . . . Methods for Measuring Distortion

FB19-08 . . . . Guidelines for Handling and Cleaning Decorative Glass

FB20-08 . . . . Iridescence Patterns in Heat-Treated Architectural Glass

FB21-09 . . . . Installation Techniques Designed to Prolong the Life of Flat Glass Mirrors

FB22-09 . . . . Proper Procedures for Fabrication of Flat Glass Mirrors

FB23-09 . . . . Approximate Weight of Interlayer used in Laminated Architectural Flat Glass

Appendix 3

NGA Reference Manuals, Design Guides, Courses and Test Methods

This appendix provides a list of National Glass Association (NGA) reference manuals, educational courses and other industry documents. The publication dates have been omitted as the materials are subject to review and updates. References to these materials made in this manual are based on the final print form as of August 1, 2022. Additional NGA resources may be published prior to the update of this manual. Visit the NGA website at glass.org/store for additional reference documents.

Manuals & Guides

NGA Engineering Standards Manual

NGA Commercial Fenestration Systems Manual

NGA Glossary of Architectural Glass & Glazing

NGA Heavy Glass Door Design Manual

NGA Laminated Glazing Reference Manual

NGA Project Managers Reference Manual

GANA Sealant Manual

NGA Guide to the Glass and Glazing Requirements of the Model Building Codes

GANA/PGC Protective Glazing Manual

NGA Glass and Glazing Estimating Essentials

Bob Maltby's Glass Book

NGA Employee Safety Guide

NGA Glass and Metals: A Guide for Architects and Specifiers (from Glass Magazine)

GANA Guide to Architectural Glass

World of Glass Map: Global Float Plant Database (from Glass Magazine)

World of Glass Map: Architectural Glass Fabricator Database (from Glass Magazine)

Design Guides

Best Practices for Bird-Friendly Glazing

Frameless Shower Enclosures

Thermal Bridging Considerations at Interface Conditions

Test Methods & Specifications

Standard Specification for Ball Drop Impact Resistance of Laminated Architectural Flat Glazing

Standard Test Method for Ball Drop Impact of Laminated Architectural Flat Glass

Standard Test Method for Center-Punch Fragmentation of Fully Tempered Flat Glass

Standard Test Method for Laminated Glass Edges

Fenestration Industry Reference Materials

Appendix 4

The publication dates on all of the following references have been omitted as many of them are in a state of frequent revision or review. All references to any of the following materials in NGA's GANA Glazing Manual IYOG Edition are based on revisions published as of 2022. This list is not all-inclusive.

AAMA/NWWDA 101/I.S.2. . . . . . . Voluntary Specifications for Aluminum, Vinyl (PVC) and Wood Windows and Glass Doors

AAMA 501. Methods of Test for Exterior Walls

AAMA 502. Voluntary Specification for Field Testing of Windows and Sliding Glass Doors

AAMA 503. Voluntary Specification for Field Testing of Metal Storefronts, Curtain Walls and Sloped Glazing Systems

AAMA 800 Series . . . . Series of publications on sealant specifications

AAMA 850. Fenestration Sealants Guide Manual

AAMA 1503.1 . . . . Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors and Glazed Wall Sections

AAMA 1504 . . . . Voluntary Standard for Thermal Performance of Windows, Doors and Glazed Walls

AAMA 1600 . . . . Voluntary Specification for Skylights

AAMA AFPA . . . . Anodic Finishes/Painted Aluminum

AAMA CW-DG-1. . . . . Aluminum Curtain Wall Design Guide Manual

AAMA CW-RS-1 . . . . Rain Screen Principle and Pressure Equalization

AAMA FSCOM-1. . . . . Fire Safety in High-Rise Curtain Walls

AAMA JS-1 . . . . Joint Sealants

AAMA GDSG-1. . . . . Glass Design for Sloped Glazing

AAMA CW-11 . . . . Design Wind Loads and Boundary Layer Wind Tunnel Testing

AAMA CW-12 . . . . Structural Properties of Glass

AAMA CW-13 . . . . Structural Sealant Glazing Systems

AAMA CWG-1. . . . . Installation of Aluminum Curtain Walls

AAMA GAG-1 . . . . Glass and Glazing

AAMA MCWM-1. . . . . Metal Curtain Wall Manual

AAMA SDGS-1 . . . . Structural Design Guidelines for Aluminum Framed Skylights

AAMA SFM-1 . . . . Aluminum Storefront and Entrance Manual

AAMA SHDG-2. . . . . The Skylight Handbook Design Guidelines

AAMA TSGG . . . . Two-Sided Structural Glazing Guidelines for Aluminum Framed Skylights

AAMA TIR-A7 . . . . Sloped Glazing Guidelines

AAMA TIR-A9 . . . . Metal Curtain Wall Fasteners

AAMA TIR-A11. . . . . Maximum Allowable Deflection of Framing Systems for Building Cladding Components at Design Wind Loads

AAMA WSG.1 . . . . Window Selection Guide

AIA. . . . . MASTERSPEC®

ANSI Z97.1. . . . . Performance Specifications and Methods of Test for Safety Glazing Materials Used in Buildings

ASCE 7 . . . . Minimum Design Loads for Buildings and Other Structures

ASTM C509 . . . . Standard Specification for Cellular Elastomeric Preformed Gasket and Sealing Material

ASTM C510 . . . . Standard Test Method for Staining and Color Change of Single- or Multi-component Joint Sealants

ASTM C542 . . . . Standard Specification for Lock-Strip Gaskets

ASTM STP 552. . . . . C. J. Parise, “Window and Wall Testing,” pp. 44-46, American Society for Testing and Materials, 1974.

ASTM STP 606. . . . . J. A. Dallen & P. Paulus, “Lock-Strip Glazing Gaskets,” pp. 223-266, ASTM, 1976.

ASTM C162 . . . . Standard Terminology of Glass and Glass Products

ASTM C716 . . . . Standard Specification for Installing Lock-Strip Gaskets and Infill Glazing Materials

ASTM C717 . . . . Standard Terminology of Building Seals and Sealants

ASTM C793 . . . . Standard Test Method for the Effects of Accelerated Weathering on Elastomeric Joint Sealants

ASTM C794 . . . . Standard Test Method for Adhesion-in-Peel of Elastomeric Joint Sealants

ASTM C864 . . . . Standard Specification for Dense Elastomeric Compression Seal Gaskets, Setting Blocks and Spacers

ASTM C920 . . . . Standard Specification for Elastomeric Joint Sealants

ASTM C962 . . . . Standard Guide for Use of Elastomeric Joint Sealants

ASTM C964 .... Standard Guide for Lock-Strip Gasket Glazing

ASTM C1036 .... Standard Specification for Flat Glass (Replaced DD-G-451(d))

ASTM C1048 .... Standard Specification for Heat-Treated Flat Glass— Kind HS, Kind FT Coated and Uncoated (Replaced Federal Specification DD-G-1403 (b) and (c))

ASTM C1087 .... Standard Test Method for Determining Compatibility of Liquid-Applied Sealants with Accessories Used in Structural Glazing Systems

ASTM C1115 .... Standard Specification for Dense Elastomeric Silicone Rubber Gaskets and Accessories

ASTM C1135 .... Standard Test Method for Determining Tensile Adhesion Properties of Structural Sealants

ASTM C1172 .... Standard Specification for Laminated Architectural Flat Glass

ASTM C1184 .... Standard Specification for Structural Silicone Sealants

ASTM C1193 .... Standard Guide for Use of Joint Sealants

ASTM C1249 .... Standard Guide for Secondary Seal for Sealed Insulating Glass Units for Structural Sealant Glazing Applications

ASTM C1265 .... Standard Test Method for Determining the Tensile Properties of an Insulating Glass Edge Seal for Structural Glazing Applications

ASTM C1279 .... Standard Test Method for Non-Destructive Photoelastic Measurement of Edge and Surface Stresses in Annealed, Heat-Strengthened and Fully Tempered Flat Glass

ASTM C1281 .... Standard Specification for Preformed Tape Sealants for Glazing Applications

ASTM C1294 .... Standard Test Method for Compatibility of Insulating Glass Edge Sealants with Liquid-Applied Glazing Materials

ASTM C1349 .... Standard Specification for Architectural Flat Glass Clad Polycarbonate

ASTM C1369 .... Standard Specification for Secondary Edge Sealants for Structurally Glazed Insulating Glass Units

ASTM C1375 .... Standard Guide for Substrates Used in Testing Building Seals and Sealants

ASTM C1376 .... Standard Specification for Pyrolytic and Vacuum Deposition Coatings on Flat Glass

ASTM C1377 .... Standard Test Method for Calibration of Surface/Stress Measuring Devices

ASTM C1392 .... Standard Guide for Evaluating Failure of Structural Sealant Glazing

ASTM C1394 .... Standard Guide for In-Situ Structural Silicone Glazing Evaluation

ASTM C1401 .... Standard Guide for Structural Sealant Glazing

ASTM C1422 .... Standard Specification for Chemically Strengthened Flat Glass

ASTM C1464 . . . . Standard Specification for Bent Glass

ASTM C1472 . . . . Standard Guide for Calculating Movement and Other Effects When Establishing Sealant Joint Width

ASTM C1487 . . . . Standard Guide for Remedying Structural Silicone Glazing

ASTM C1503 . . . . Standard Specification for Silvered Flat Glass Mirror

ASTM C1564 . . . . Standard Guide for Use of Silicone Sealants for Protective Glazing Systems

ASTM E90. Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions

ASTM E119 . . . . Standard Test Methods for Fire Tests of Building Construction and Materials

ASTM E283 . . . . Standard Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors

ASTM E330 . . . . Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls and Doors by Uniform Static Air Pressure Difference

ASTM E331 . . . . Standard Test Method for Water Penetration of Exterior Windows, Curtain Walls and Doors by Uniform Static Air Pressure Difference

ASTM E336 . . . . Standard Test Method for Measurement of Airborne Sound Insulation in Buildings

ASTM E413 . . . . Standard Classification for Determination of Sound Transmission Class

ASTM E488 . . . . Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements

ASTM E514 . . . . Standard Test Method for Water Penetration and Leakage Through Masonry

ASTM E546 . . . . Standard Test Method for Frost Point of Sealed Insulating Glass Units

ASTM E547 . . . . Standard Test Method for Water Penetration of Exterior Windows, Curtain Walls and Doors by Cyclic Static Air Pressure Differential

ASTM E576 . . . . Standard Test Method for Frost Point of Sealed Insulating Glass Units in the Vertical Position

ASTM E631 . . . . Standard Terminology of Building Constructions

ASTM E754 . . . . Standard Test Method for Pullout Resistance of Ties and Anchors Embedded in Masonry Mortar Joints

ASTM E773 . . . . Standard Test Methods for Seal Durability of Sealed Insulating Glass Units

ASTM E774 . . . . Standard Specification for Sealed Insulating Glass Units

ASTM E783 . . . . Standard Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors

ASTM E894 .... Standard Test Method for Anchorage of Permanent Metal Railing Systems and Rails for Buildings

ASTM E966 .... Standard Guide for Field Measurement of Airborne Sound Insulation of Building Façades and Façade Elements

ASTM E987 .... Standard Test Methods for Deglazing Force of Fenestration Products

ASTM E997 .... Standard Test Method for Structural Performance of Glass in Exterior Windows, Curtain Walls and Doors Under the Influence of Uniform Static Loads by Destructive Methods

ASTM E998 .... Standard Test Method for Structural Performance of Glass in Windows, Curtain Walls and Doors Under the Influence of Uniform Static Loads by Nondestructive Method

ASTM E1017 .... Standard Specification for Generic Performance Requirements for Exterior Residential Window Assemblies

ASTM E1105 .... Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls and Doors by Uniform or Cyclic Static Air Pressure Difference

ASTM E1233 .... Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls and Doors by Cyclic Static Air Pressure Differential

ASTM E1300 .... Standard Practice for Determining the Minimum Thickness of Annealed Glass Required to Resist a Specified Load

ASTM E1332 .... Standard Classification for Determination of Outdoor-Indoor Transmission Class

ASTM E1425 .... Standard Practice for Determining the Acoustical Performance of Exterior Windows and Doors

ASTM E1423 .... Standard Practice for Determining the Steady State Thermal Transmittance of Fenestration Systems

ASTM E1424 .... Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors Under Specified Pressure and Temperature Differences Across the Specimen

ASTM E1825 .... Standard Guide for Evaluation of Exterior Building Wall Materials, Products and Systems

ASTM E1886 .... Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors and Impact Protective Systems Impacted by Missile(s) an Exposed to Cyclic Pressure Differentials

ASTM E1996 .... Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors and Impact Protective Systems Impacted by Windborne Debris in Hurricanes

ASTM E2010 .... Standard Test Method for Positive Pressure Fire Tests of Window Assemblies (Withdrawn; refer to UL and NFPA tests)

ASTM E2074 .... Standard Test Method for Fire Tests of Door Assemblies, Including Positive Pressure Testing of Side-Hinged and Pivoted Swinging Door Assemblies (Withdrawn; refer to UL and NFPA tests)

ASTM E2094 .... Standard Practice for Evaluating the Service Life of Chromogenic Glazings

ASTM E2099 .... Standard Practice for the Specification and Evaluation of Pre-Construction Laboratory Mock-ups of Exterior Wall Systems

ASTM E2112 .... Standard Practice for Installation of Exterior Windows, Doors and Skylights

ASTM E2128 .... Standard Guide for Evaluating Water Leakage of Building Walls

ASTM E2188 .... Standard Test Method for Insulating Glass Unit Performance

ASTM E2189 .... Standard Test Method for Testing Resistance to Fogging in Insulating Glass Units

ASTM E2190 .... Standard Specification for Insulating Glass Unit Performance and Evaluation

ASTM E2269 .... Standard Test Method for Determining Argon Concentration in Sealed Insulating Glass Units using Gas Chromatography

ASTM E2270 .... Standard Practice for Periodic Inspection of Building Façades for Unsafe Conditions

ASTM F1233 .... Impact Tests for Security Glazing

ASTM F1641 .... Standard Test Method for Measuring Penetration Resistance of Security Glazing Using a Pendulum Impactor

ASTM F1642 .... Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loading

ASTM F1915 .... Standard Test Methods for Glazing for Detention Facilities

ASTM F2248 .... Standard Practice for Specifying an Equivalent 3-Second Duration Design Loading for Blast-Resistant Glazing Fabricated with Laminated Glass

ASTM STP 1054 .... Technology of Glazing Systems

CGSB .... CAN/CGSB 12.1 Safety Glazing

CPSC 16 CFR 1201 .... Safety Standard for Architectural Glazing Materials

NFPA 80 .... Standard for Fire Doors and Other Opening Protectives

NFPA 251 .... Standard Methods of Tests of Fire Endurance of Building Construction and Materials

NFPA 252 .... Standard Methods of Fire Test of Door Assemblies

NFPA 257 .... Standard on Fire Test for Window and Glass Block Assemblies

NFRC 100 .... Procedure for Determining Fenestration Product Thermal Properties

NFRC 200 .... Procedure for Determining Solar Heat Gain Coefficients at Normal Incidence

NFRC 300 . . . . Procedure for Determining Solar Optical Properties for Simple Fenestration Products

NFRC 301 . . . . Standard Test Method for Emittance of Specular Surfaces Using Spectrometric Measurements

NFRC 400 . . . . Procedure for Determining Product Air Leakage

UL 9 . . . . Standard for Fire Tests of Window Assemblies

UL 10C . . . . Standard for Positive Pressure Fire Tests of Door Assemblies

UL 263 . . . . Standard for Fire Tests of Building Construction and Materials

What is the International Year of Glass?

The United Nations International Year of Glass 2022 celebrated the essential role glass has and will continue to have in society. The vision is to celebrate the past, present, and future of this transformative material following the United Nations' goals in Agenda 2030. NGA's GANA Glazing Manual IYOG Edition is updated from the GANA Glazing Manual 50th Anniversary edition.

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