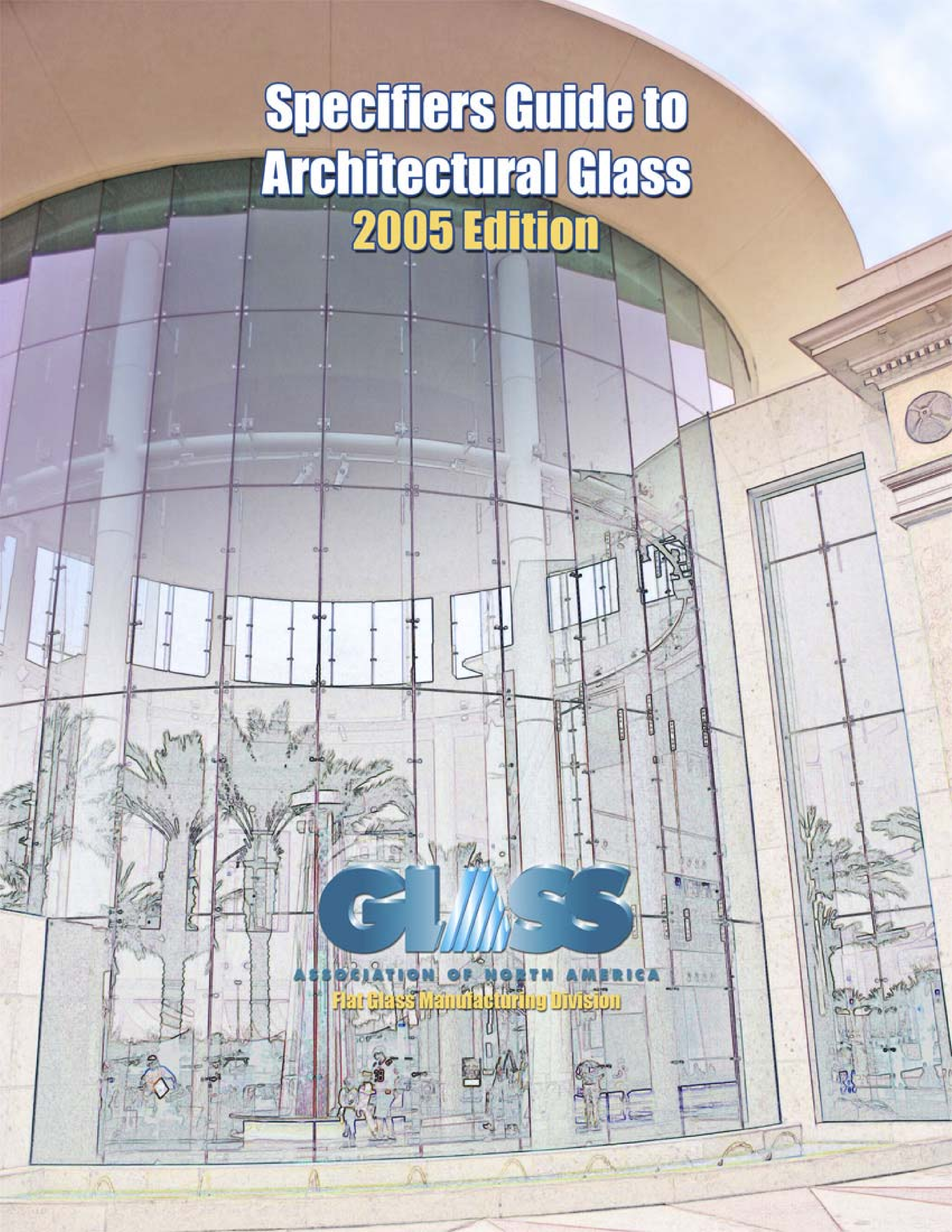
Specifiers Guide to Architectural Glass

2005 Edition



GLASS ASSOCIATION OF NORTH AMERICA
Flat Glass Manufacturing Division

SPECIFIERS GUIDE TO ARCHITECTURAL GLASS

Introduction

The Glass Association of North America (GANA) provides the organizational structure for addressing the needs of a diverse membership. Comprised of six Divisions and an Affiliate classification, GANA puts members in regular contact with their peers, customers, and suppliers in an environment that facilitates the nurturing of an understanding essential to strong, effective working relationships. GANA provides members with premiere educational programs, publications, networking opportunities, meetings, and conventions.

The Flat Glass Manufacturing Division (FGMD) is comprised of manufacturers of flat glass maintaining float glass plants in North America and associate members supplying goods and services to the flat glass industry.

GANA has developed this Guide to assist those involved in the specification, selection, and use of glass in architectural applications. Additional GANA reference manuals and informational bulletins should be a part of every fenestration product reference library. See page 16 for a list of additional resources.

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Disclaimer

The Glass Association of North America (GANA) has produced this *Specifiers Guide to Architectural Glass* solely to provide general descriptions concerning the basics of glass. It is the responsibility of the user of this Guide to ensure that glass is selected and installed by competent professionals in compliance with all relevant laws, rules, regulations, standards and other requirements.

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The standards referenced in the GANA *Specifiers Guide to Architectural Glass* are under the jurisdiction of a number of organizations and agencies and are continuously being revised. The documents referenced in this Guide are those in effect as of July 2004. The most recent standards should be referenced. Full names of reference standards and publishing entities are listed in Appendices 2 and 4.

SPECIFIERS GUIDE TO ARCHITECTURAL GLASS

Chapter One: Float Glass Manufacturing Process

The majority of glass used today in architectural applications is float glass. Float glass is manufactured in a continuous process by melting glass batch (*i.e.*, soda, lime, silica sand, and other materials) and, when melted, floating the glass on a bath of molten tin. The glass is slowly and carefully cooled in an annealing lehr to produce glass with exceptionally parallel surfaces, high optical quality, and fire-finished surface brilliance.

Float glass may be used as produced in a wide variety of applications, or it may serve as the base material for other products, such as fully tempered glass, heat-treated glass, laminated glass, insulated glass, mirrored and decorative glass. Non-architectural end-users include the automotive, aircraft, and transportation industries.

Float Glass Manufacturing Facilities

Float glass manufacturing facilities operate continuously, 24 hours per day, 365 days per year. Steady-state operations characterize the float glass industry; no hourly or seasonal variations are expected under normal conditions. The manufacturing process starts with the arrival of raw materials in bulk quantities by rail and/or truck. The raw materials are unloaded and stored in a batch house where they are weighed and mixed with broken glass called cullet. The mixed batch is then conveyed to a furnace where the raw materials are melted. Once melted, the glass flows from the furnace into a tin bath. The molten glass is drawn through the tin bath and then enters an annealing lehr where it is carefully cooled in preparation for cutting. Cut sizes of glass are placed on racks or boxes before being shipped. Unused glass is crushed and returned to the batch house to be reused as cullet.

Batch House

The most common raw materials used to make float glass are silica sand, soda ash, limestone, dolomite, salt cake, rouge, charcoal, and cullet. In the batch house, raw materials are dumped into hoppers and fed by conveyor to a bucket elevator where they are discharged into storage bins. Each raw material is weighed individually on highly accurate industrial scales and then checked on a totalizer scale prior to discharge into a mixer.

After the raw materials are thoroughly mixed, a measured amount of wetting agent is added, cullet is blended into the mix, and the batch is conveyed to a large storage hopper over the melting furnace feeder. Cullet improves the melting characteristics of the raw materials, decreases the energy consumption of the furnace, improves the quality of air emissions, and increases production yields.

Furnace

A typical float glass furnace has a melting capacity of between 300 and 600 tons per day. The batch is fed, in blanket form, into the furnace. A very accurate level detector, located near the furnace frontwall, controls the operation of the feeder. Flames, emanating from ports in the sidewalls of the melting furnace, melt the batch. Float glass furnaces typically operate at a temperature of 2900 degrees Fahrenheit. The batch is gradually refined in the melting furnace; by the time the batch reaches the furnace backwall, it is degassed, uniform in composition, and free of unmelted batch. This homogeneous blend is then delivered to the tin bath in a constant pouring action.

Tin Bath

The tin bath is an electrically heated forming oven. A continuous ribbon of molten glass flows onto and across the surface of a pool of molten tin in the bath at approximately 1900 degrees Fahrenheit and is transported along the length of the tin bath. At the tin bath exit, the glass, although still approximately 1100 degrees, is solid enough to be removed from the tin bath without marking the glass surface.

An inert nitrogen atmosphere, made slightly reducing by the addition of small amounts of hydrogen, carefully seals and maintains the tin bath chamber under positive pressure. This, in turn, maintains a clean, pristine surface on the tin that would otherwise rapidly oxidize in the air. The glass, when flowing over the tin, forms a ribbon with virtually flat, parallel surfaces. The glass is drawn through the tin bath at different speeds depending upon the thickness of the glass being manufactured.

Lehr

The annealing lehr cools the glass ribbon from approximately 1100 degrees Fahrenheit to approximately 200 degrees in a precise, uniform manner to prevent residual stresses. The lehr uses small amounts of electric heat to keep the edges of the glass ribbon from cooling at a faster rate than the center. The lehr requires special rolls and drive systems as well as a sophisticated temperature control system to accurately maintain the required cooling rate. The glass emerges from the lehr in a continuous ribbon slightly above room temperature.

Cutting and Packing

After exiting the lehr, the glass is ready to be inspected, cut, packed, and shipped. First, the glass is inspected for defects. Glass containing defects is crushed and returned to the batch house to be reused as cullet. The glass ribbon is cut to the required dimensions using computer controlled high-speed cutters. The edge trim is removed, crushed, and returned to the batch house for reuse as cullet. The glass is placed in boxes or racks for shipment to the market.

Recycling

Float glass manufacturers typically recycle all of their own cullet generated during the float glass manufacturing process. Typically, during any production period, 15 to 30% of the total batch consists of cullet. Because of the high quality requirements, the float glass manufacturing process does not lend itself to the introduction of scrap glass from offsite sources. The possibility of contaminants and varying colors and densities are a significant deterrent. Proprietary company mixtures, tinting, and glass coatings further complicate the acceptance of scrap glass from offsite sources. However, there are glass recycling programs for scrap glass that is unacceptable for use as cullet.

To see a short seven-minute film on the float glass manufacturing process, visit http://www.glasswebsite.com/video.html.

Chapter Two: Types of Glass

The Design Professional's Responsibility

In the design and use of architectural glass, the responsible design professional must carefully consider the performance characteristics of glass as they relate to construction requirements. Safety glazing laws and local municipal building codes may set minimum requirements that do not relate to the specifier's initial design criteria (i.e., wind loads, thermal stresses, solar or optical properties, and aesthetic considerations). In addition, other issues may affect the design criteria, such as break patterns, fall-out characteristics, acoustical insulation, and security demands.

The member companies of the Flat Glass Manufacturing Division of the Glass Association of North America are committed to assisting design professionals in determining glass performance characteristics, design objectives, and building code requirements.

Architects, builders, and specifiers should refer to the websites of the primary glass producers for company-specific glass technical information. For a list of websites, visit Appendix 1.

Annealed Glass

Annealed glass has a surface strength that provides the wind-load performance and thermal-stress resistance needed in most architectural applications. In areas of high wind loads or in conditions where higher than normal thermal stresses occur, annealed glass may not be suitable. Annealed glass has poor resistance to hard, blunt objects or projectiles (such as storm-blown roof gravel) and, when broken, may fracture into large, sharp pieces. However, experience has shown that in-service annealed glass performs well when subjected to small, softer, low-velocity objects carried by low-level wind loads.

Annealed glass in standard thicknesses does not meet the safety glazing standards of the United States Consumer Product Safety Commission (CPSC) 16 CFR 1201 - *Safety Standard for Architectural Glazing Materials* or the American National Standards Institute (ANSI) Z97.1 - *American National Standard for Safety Glazing Materials Used in Buildings.*

ASTM International document C 1036 - *Standard Specification for Flat Glass* is the standard that specifies the required thickness, dimensional tolerances, and defect and optical characteristics of annealed glass.

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

Thickness		Thickness Range				Cut Size Length and Width[A]		Cut Size Squareness D1–D2		Stock Sheet Tolerance	
Designation mm	Traditional Designation	mm		in.						Length and Width[A]	
		min	max	min	max	± mm	(± in.)	± mm	(± in.)	± mm	(± in.)
1.0	micro-slide	0.79	1.24	0.031	0.049	1.6	(1/16)	2.0	(5/64)	6.4	1/4
1.5	photo	1.27	1.78	0.050	0.070	1.6	(1/16)	2.0	(5/64)	6.4	1/4
2.0	picture	1.80	2.13	0.071	0.084	1.6	(1/16)	2.0	(5/64)	6.4	1/4
2.5	single	2.16	2.57	0.085	0.101	1.6	(1/16)	2.0	(5/64)	6.4	1/4
2.7	lami	2.59	2.90	0.102	0.114	1.6	(1/16)	2.0	(5/64)	6.4	1/4
3.0[B]	double-1/8 in.	2.92	3.40	0.115	0.134	1.6	(1/16)	2.0	(5/64)	6.4	1/4
4.0	5/32 in.	3.78	4.19	0.149	0.165	1.6	(1/16)	2.0	(5/64)	6.4	1/4
5.0	3/16 in.	4.57	5.05	0.180	0.199	1.6	(1/16)	2.0	(5/64)	6.4	1/4
6.0	1/4 in.	5.56	6.20	0.219	0.244	1.6	(1/16)	2.0	(5/64)	6.4	1/4
8.0	5/16 in.	7.42	8.43	0.292	0.332	2.0	(5/64)	2.8	(7/64)	6.4	1/4
10.0	3/8 in.	9.02	10.31	0.355	0.406	2.4	(3/32)	3.4	(1/8)	6.4	1/4
12.0	1/2 in.	11.91	13.49	0.469	0.531	3.2	(1/8)	4.5	(11/64)	6.4	1/4
16.0	5/8 in.	15.09	16.66	0.595	0.656	4.0	(5/32)	5.7	(7/32)	6.4	1/4
19.0	3/4 in.	18.26	19.84	0.719	0.781	4.8	(3/16)	6.8	(1/4)	6.4	1/4
22.0	7/8 in.	21.44	23.01	0.844	0.906	5.6	(7/32)	7.9	(19/64)	6.4	1/4
25.0	1 in.	24.61	26.19	0.969	1.031	6.4	(1/4)	9.0	(11/32)	6.4	1/4

[A] Length and width of cut size and stock sheets of flat glass include flares and bevels.
[B] Within the 3.0 designation there are some applications that may require different thickness ranges (see manufacturer).

Extracted, with permission, from ASTM C 1036-01 – Standard Specification for Flat Glass, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428

Heat-Strengthened Glass

Heat-strengthened glass is produced by heat-treating annealed glass under regulated thermal conditions. In this process, annealed glass that has been cut to size is heated in a furnace controlled between 1100-1500 degrees Fahrenheit (593-815 degrees Celsius) and air-cooled. This sudden cooling causes a compression envelope around the glass surface and edges and a balanced tension stress within the glass itself. This equilibrium of stresses increases the strength of the glass to approximately two times that of the original annealed product (when tested under uniform pressure such as wind loads). In addition, when broken, glass with a low-to-moderate degree of heat-strengthening generally exhibits few cracks and tends to break into large pieces that initially may remain in the glazed opening. (Note: glass should be removed and replaced as soon as possible after breakage.) A significant advantage of heat-strengthened glass is its ability to withstand high thermal stresses resulting from partial shading and heat build-up from solar loading. With its edge compression levels in excess of 5500 pounds per square inch (38 MPa) and surface compression levels in the 3500 to 7500 psi range, heat-strengthened glass performs well in demanding architectural applications. Heat-strengthening should be considered in all spandrel glazing when large lites are used, when heat-absorbing and coated glass is used, and when a likelihood of external shading and reflectance exists. The increased toughness of heat-strengthened glass also reduces the likelihood of glass breakage during shipment, handling, installation, and in-service use. Heat-strengthened glass, because of its break pattern, does not meet the safety glazing standards of CPSC 16 CFR 1201 or ANSI Z97.1.

See the following section on tempered glass for notes on spontaneous breakage.

Fully Tempered Glass

Fully tempered glass is produced by heat-treating annealed glass under regulated thermal conditions. In this process, annealed glass that has been cut to size is heat-treated and then cooled quickly with air, creating an edge compression greater than 9700 psi (67 MPa) and a surface compression greater than 10,000 psi (69 MPa). Fully tempered glass may show more visual distortion of reflected images than heat-strengthened glass. Its key performance characteristics are increased strength and the ability to meet the requirements of safety glazing standards, CPSC 16 CFR 1201 and ANSI Z97.1.

Under uniform static loads, fully tempered glass is about four times stronger than annealed glass of the same thickness, and twice as strong as heat-strengthened glass of the same thickness. It also has significant resistance to breakage from blunt projectiles. The increased strength of fully tempered glass (due to its compression stresses) makes fully tempered glass an option for many architectural applications.

The increase in compression stresses and equilibrium center-tension stress in fully tempered glass may, on rare occasion, result in spontaneous breakage. All heat-treated glass will break when its compression layer is penetrated. Thermal or wind loads or building creep may produce surface or edge damage that does not completely penetrate the compression layer, but may result in spontaneous breakage. In addition to surface or edge damage, spontaneous breakage may result from deep scratches or gouges in the glass surface; severe weld splatter on the glass surface; glass to metal contact; and nickel sulfide inclusions.

Nickel sulfide inclusions signify the presence of certain types of rare and very small, undissolved nickel sulfide stones that are extremely difficult to detect. Glass manufacturers take extraordinary steps to minimize the potential for nickel sulfide inclusions. Considering that a large furnace may produce up to 600 tons of glass per day, total elimination of contaminants is impossible.

ASTM C 1048 - *Standard Specification for Heat-Treated Flat Glass – Kind HS, Kind FT Coated and Uncoated Glass* is the standard that specifies the required tolerances, characteristics, and compression levels for heat-strengthened and fully tempered glass.

(NOTE: Identical sizes and thicknesses of annealed, heat-strengthened or fully tempered glass lites will have the same centerline deflection when exposed to the same uniform load. Centerline deflections may be reduced by increasing the glass thickness or reducing its size.)

Laminated Glass

There are several laminated glass manufacturing processes: 1) permanently bonding two or more pieces of glass together with one or more interlayers of plasticized polyvinyl butyral (PVB) resin under heat and pressure; 2) permanently bonding two or more pieces of glass and polycarbonate together with aliphatic urethane interlayers under heat and pressure; and 3) permanently bonding two or more pieces of glass together using cured resin as the interlayer material.

The bonding of materials to glass provides a variety of performance benefits in architectural applications. The most important characteristic is the ability of the interlayer(s) to support and hold the glass when broken. This provides increased protection against glass fall-out and penetration through the opening. Most building codes, for example, require the use of laminated glass for overhead glazing. Other applications include safety glazing, acoustical insulation, resistance to smash-and-grab burglaries, windborne debris, bullets, and blast hazard mitigation.

Laminated glass is 75% to 100% as strong as annealed glass of the same thickness depending on exposed temperatures, aspect ratio, plate size, stiffness, and load duration. The edges of laminated glass are less resistant than annealed glass to handling and installation damage. Laminated glass, however, can be made with both heat-strengthened and fully tempered glass for additional benefits, such as greater wind load, impact, and thermal resistance. Note: when heat treated glass pieces or plies are laminated together, there may be a reduction in transmitted optical quality, especially if the plies are relatively thin.

Laminated glass can meet the safety glazing standards of CPSC 16 CFR 1201 and ANSI Z97.1.

Quality standards for laminated glass are defined in ASTM C 1172 - *Standard Specification for Laminated Architectural Flat Glass* and C 1349 - *Standard Specification for Architectural Flat Glass Clad Polycarbonate*.

Other Types of Glass

- Borosilicate -- silicate glass having at least 5% boron oxide; used mainly for fire-rated applications and offering more resistance to thermal shock and harsh chemicals.
- Ceramic -- solid material, partly crystalline and partly glassy, formed by the controlled crystallization of a glass.
- Plate glass -- glass made through the process of pulling molten glass through rollers, and then exposing it to systematic grinding and polishing. Plate glass has been totally replaced by float glass and is no longer manufactured in the United States.
- Rolled glass -- glass made through the process of pulling molten glass through a series of rollers to produce such products as patterned glass (where the glass has a decorative pattern imprinted on it) and wired glass (where a welded steel mesh is introduced into the molten glass).
- Sheet glass -- glass made through the process of pulling a ribbon of glass directly out of the molten glass pool. Sheet glass is no longer manufactured in the United States.

Glass Characteristics

Performance Characteristics	Monolithic Annealed	Heat-Strengthened	Fully Tempered	Laminated Annealed	Laminated Heat-Strengthened[1]	Laminated Fully Tempered[1]
Wind-loading strength	Basic Glass Strength (1x)	Two times basic glass strength of the same thickness (2X)	Four times basic glass strength of the same thickness (4X)	75% - 100% as strong as monolithic annealed of the same thickness	Almost twice as strong as laminated annealed of the same thickness (1.5X - 1.8X)	Almost four times as strong as laminated annealed of the same thickness (3.0X - 3.6X)
Thermal stress breakage resistance (edge-strength)	Low resistance to high thermal stresses	Resists high thermal stresses	Resists high thermal stresses	Low resistance to high thermal stresses	Resists high thermal stresses	Resists high thermal stresses
Impact Resistance[2]	Moderate	Stronger than annealed	Stronger than heat-strengthened. Can qualify as "Safety Glazing"	Moderate. Can qualify as "Safety Glazing"	Stronger than annealed. Can qualify as "Safety Glazing"	Stronger than heat-strengthened. Can qualify as "Safety Glazing"
Break pattern upon impact	Many cracks forming large, long, and narrow shards	Simple, few cracks and larger pieces	Entire lite breaks into small, irregular shaped fragments.	Starburst pattern from impact point, one or both lites may break	Simple, few cracks and larger pieces, one or both lites may break	One or both lites may break into small, irregular shaped fragments.
Penetration resistance (after breakage)	Limited after breakage	Limited after breakage	None after breakage	Good penetration resistance (proportional to interlayer thickness)	Good penetration resistance (proportional to interlayer thickness)	Good penetration resistance (proportional to interlayer thickness)

1 - Laminated heat-treated glass may have more distortion in transmission than laminated annealed glass.
2 - Impact resistance and break pattern after breakage are dependent upon the size, weight and type of impactor and the speed at which it impacts the glass.

Availability of Various Glass Options

Glass Type	Float	Sheet	Patterned	Wired	Ceramic	Borosilicate
Clear Annealed	Yes	Imported	Yes	Yes[1]	Yes	Yes
Tinted Annealed	Yes	Imported	Imported	Imported	No	No
Heat Strengthened	Yes	Yes	Imported	No	No	Yes
Fully Tempered	Yes	Yes	Yes[2]	No	No	No
Laminated Annealed	Yes	Imported	Yes	Yes	No	No
Laminated Heat Strengthened	Yes	Limited	Difficult	No	No	No
Laminated Fully Tempered	Yes	Limited	Difficult	No	No	No
Reflective Coatings	Yes	Rare	Rare	No	Unlikely	Unlikely
Low-E Coatings	Yes	Rare	Rare	No	Unlikely	Unlikely
Sealed Insulating Glass	Yes	Yes	Yes	Yes	Unlikely	Limited

1 Polished wired glass is imported
2 The availability of tempered patterned glass is dependent upon the type and depth of the pattern.

Chapter Three: Physical Properties and Glass Strength

The Nature of Soda-Lime Float Glass

Glass is a brittle material. It acts elastically until it fractures at ultimate load. That ultimate load varies, depending upon the type and duration of the loads applied and the distribution, orientation, and severity of the inhomogeneties and micro-flaws existing in the surface of the glass. Because of its nature, glass cannot be engineered in the same way as other building envelope materials with a predictable specific strength. In those cases, factors can be (and are) assigned to minimize the likelihood that breakage will occur at the selected design load. Because the ultimate strength of glass varies, its strength is described statistically. Architects and engineers, when specifying 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).

Glass manufacturers can provide the appropriate data for determining the performance of their products. However, the responsible design professional must review these performance criteria and determine if they are suitable for the intended application.

The Average Physical and Mechanical Properties of Soda Lime Float Glass

1. Modulus of Elasticity (E) -- 10.4×10^6 psi (71.7×10^6 kPa)
2. Modulus of Rigidity (Shear) (G) -- 4.3×10^6 psi (29.6×10^6 kPa)
3. Poisson's Ratio -- 0.23
4. Coefficient of Thermal Expansion -- 4.6×10^{-6} strain per ^oF (8.3×10^{-6} strain per ^oC)
5. Density -- 156 lbs. per cubic foot (2500 kg/m^3)
6. Modulus of Rupture (Flexure)[a] -- 6000 lbs/sq. in. (41.4 mpa):

	(mean)	(design: 8 breaks 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.

7. Hardness (Moh's Scale) -- 5 to 6

8. Specific Heat Capacity -- 0.84-0.88 J/Kg x K)

9. Thermal Conductivity -- 0.9-1.0W/mk (.52-.57 Btu/hrftF)

10. Mean Refractive Index @ Sodium "D" Line 1.5

11. Chemical Composition:

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%

12. Softening Point -- 715-729^oC (1319-1345^oF)
Annealing Point -- 544-548^oC (1011-1018^oF)
Strain Point -- 504-511^oC (939-952^oF)

13. Emissivity -- 0.84

14. Reflection -- 4% from each surface (for 3mm glass)

15. Visible Light Absorption – 1 to 2% (for 3mm glass)

16. Far Infrared Transmission -- 0

17. Chemical Resistance -- Excellent

18. Electrical Resistivity -- High

Design Loads and Glass Strength

Determining the design load of glass frequently is done on the basis of model wind tunnel studies, the current version of American Society of Civil Engineers (ASCE) document ASCE 7 - *Minimum Design Loads for Buildings and Other Structures*, and applicable state and local building code requirements.

Model wind tunnel studies are project specific and generally are only conducted for large, complex building designs. Applicable building codes normally represent only the minimum requirements that must be met. Determining the design load in accordance with the most recent version of ASCE 7 is the most frequently used method for selecting architectural glass. The wind load on a specific building depends upon its height, shape, and relationship to surrounding buildings and terrain, as well as local wind speeds and wind gust duration.

ASTM E 1300

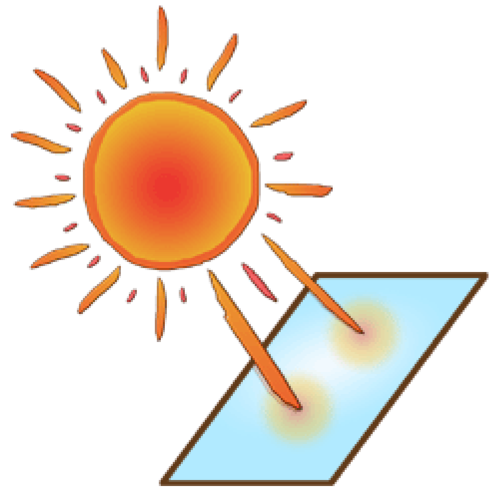
Once the design load and its duration have been determined and a suitable probability of breakage has been selected, the appropriate glass thickness or glass type can be chosen. The industry standard for selecting glass thickness is the most current edition of ASTM E 1300 - *Standard Practice for Determining the Load Resistance of Glass in Buildings*. This standard provides glass thickness selection charts relating length, width, and thickness of glass to equivalent design loads. A copy of ASTM E 1300 can be obtained at http://www.astm.org.

Comprehensive Window Glass Design Software

The E 1300 software may be purchased from the Standards Design Group. The program allows the user to determine the appropriate type and thickness of glass to meet a specified wind or snow load in accordance with ASTM E 1300. For more information, see http://www.standardsdesign.com

Chapter Four: Thermal and Solar Optical Properties of Float Glass

Specifiers choose glass as a building envelope material for a number of reasons. Some of the more important reasons include architectural expression, interior lighting, and a view to the outside world. All of the benefits of glass relate to its thermal and optical properties, absorptance, and reflectance. Glass exposed to the sun will transmit, absorb, or reflect all of the sun's energy.



The Solar Spectrum

The sun transmits energy in the form of waves. Each wave is defined by its length and is measured in nanometers (nm). There are three specific ranges within the solar spectrum: ultraviolet light in the 300 to 380 nm range, visible light in the 380 to 780 nm range, and infrared light in the 780 to 2100 nm range. The transmission and reflection at each wavelength are affected differently by the glass and glazing products present in the building envelope. Measurements to determine the optical properties of glass are made with spectrophotometers and may be calculated in accordance with National Fenestration Rating Council (NFRC) 300 - *Standard Test Method for Determining the Solar Optical Properties of Glazing Materials and Systems.*

Visible Transmittance

Daylighting or visible transmittance (Tvis) depends upon the portion of the visible light spectrum transmitted through the glass. The appropriate amount of visible light transmittance reduces the need for artificial light and greatly improves worker productivity, occupant comfort, and interior appearance. Too much daylighting can cause overlit workspaces and glare. Determining the right amount of visible transmittance depends upon the building orientation, the size of the glazed product in the building envelope, and the color, reflectance, or tint of the glass itself.

Solar Heat Gain

The rate of heat exchange from solar energy is called solar heat gain. The amount of solar heat gain through a window or door depends upon the incident solar ratio and the optical properties of the glass. Two terms related to solar heat gain are solar heat gain coefficient (SHGC) and shading coefficient (SC).

Solar Heat Gain Coefficient

Solar heat gain coefficient is the fraction of solar heat admitted through a glazed product. Three tools are available for determining SHGC: the latest versions of *WINDOW – Program for Analyzing Window Thermal and Optical Performance* and *OPTICS – Program for Analyzing Optical Performance of Glazing Systems*, computer software programs developed by the Lawrence Berkeley National Laboratory (LBNL) Windows and Daylighting Group (http://windows.lbl.gov); the procedures outlined in the Chapter on Fenestration in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) *Handbook of Fundamentals;* or the protocol of NFRC 200 - *Procedure for Determining Fenestration Product Solar Heat Gain Coefficient and Visible Transmittance at Normal Incident*. Glass manufacturers and fabricators normally provide solar energy performance data, including SHGC, in their published literature.

Solar Heat Gain Coefficients (SHGC) and Visible Transmittance (Tvis)

SIZE	TYPE	SHGC[1,2]	Tvis[1,2]
Single Glazing			
3 mm	clear	0.86	0.90
6 mm	clear	0.81 – 0.83	0.89
6 mm	blue green	0.50	0.67
3 mm	bronze	0.73	0.68
6 mm	bronze	0.53	0.55
3 mm	green	0.70	0.82 – 0.84
6 mm	green	0.58 – 0.60	0.74 – 0.76
3 mm	grey	0.68 – 0.70	0.62
6 mm	grey	0.56 – 0.62	0.44
6 mm	blue	0.53 – 0.61	0.56 – 0.57
Double Glazing			
3 mm	clear/clear	0.76	0.82
6 mm	clear/clear	0.71	0.78 – 0.80
6 mm	blue-green/clear	0.50	0.67
3 mm	bronze/clear	0.62	0.62
6 mm	bronze/clear	0.50	0.48
3 mm	green/clear	0.60	0.75
6 mm	green/clear	0.45	0.66
3 mm	grey/clear	0.59 – 0.62	0.56
6 mm	grey/clear	0.44 – 0.50	0.40
6 mm	blue	0.41 – 0.49	0.50
3 mm	high performance tint[2,3]	0.32 – 0.39	0.61 – 0.69
6 mm	high performance tint[2,3]	0.31 – 0.39	0.57 – 0.59
Double Glazing w/low-e (0.20) on Surface #2[2]			
3 mm	clear/low-e	0.70	0.76
3 mm	low-e/clear	0.65	0.76
6 mm	clear/low-e	0.65	0.73
6 mm	low-e/clear	0.60	0.73
6 mm	blue-green/low-e	0.45	0.62
3 mm	bronze/low-e	0.57	0.58
6 mm	bronze/low-e	0.45	0.45
3 mm	green/low-e	0.55	0.70
6 mm	green/low-e	0.42 – 0.44	0.63
3 mm	grey/low-e	0.53	0.51
6 mm	grey/low-e	0.41	0.37
6 mm	blue/low-e	0.36 – 0.45	0.46 – 0.47
3 mm	high performance tint[3]	0.45	0.64
6 mm	high performance tint[3]	0.34	0.55
Double Glazing w/low-e (.10)on Surface #2[2]			
3 mm	clear/low-e	0.60 – 0.64	0.75 – 0.78
3 mm	low-e/clear	0.54 – 0.58	0.75 – 0.78
6 mm	clear/low-e	0.47 – 0.59	0.44 – 0.76
6 mm	low-e/clear	0.32 – 0.55	0.44 – 0.76
3 mm	bronze/low-e	0.48 – 0.51	0.57 – 0.59
6 mm	bronze/low-e	0.32 – 0.39	0.27 – 0.46
3 mm	green/low-e	0.49 – 0.51	0.68 – 0.72
6 mm	green/low-e	0.33 – 0.38	0.37 – 0.63
3 mm	grey/low-e	0.46 – 0.48	0.54
6 mm	grey/low-e	0.30 – 0.36	0.23 – 0.39
6 mm	blue/low-e	0.33 – 0.39	0.46 – 0.47

SIZE	TYPE	SHGC[1,2]	Tvis[1,2]
Double Glazing w/low-e (0.05) on Surface #2[2]			
3 mm	low-e/clear	0.41	0.72
6 mm	low-e/clear	0.37	0.70
6 mm	bronze/low-e	0.26 – 0.33	0.42
6 mm	green/low-e	0.30 – 0.37	0.60
6 mm	grey/low-e	0.24 – 0.30	0.35
6 mm	blue-green/low-e	0.27	0.45
6 mm	high performance tint[3]/low-e	0.27 – 0.30	0.53
6 mm	blue/low-e	0.30 – 0.33	0.44

Note 1 Manufacturing variation will yield tolerances of +/-0.06.
Note 2 See manufacturers' literature for specific optical properties. Listed values are approximations.
Note 3 Refers to a number of proprietary tinted glasses.

Shading Coefficient

Shading Coefficient (SC) is a term that has been widely used in the past; however, Solar Heat Gain Coefficient (SHGC) is more frequently used today. The shading coefficient of a product is the ratio of the solar heat gain of a specified product to the solar heat gain of a referenced standard (i.e., single-pane (1/8") clear glass. SHGC is a more accurate method of stating the performance of a glazed product in a building envelope because it represents the amount of solar heat gain relative to that through an unglazed opening. For conversion purposes, the SHGC of a specific glazing is approximately 86% of its SC (under a specified solar incidence).

Solar Energy Absorptance

An understanding of the absorptance of solar energy is important in order to determine the appropriate glass type to specify to reduce the risk of solar-induced thermal stress breakage. Various glass tints absorb differing amounts of solar energy that in turn build up thermal stresses in the glass. Heat-strengthened and fully tempered glass provide increased performance and reduced risk of breakage due to thermal stress when compared to annealed glass.

Glazing Emissivity

The net amount of solar energy transferred into a building through vision glass areas depends upon the solar reflectance and solar absorptance and emittance of the glazing. Some solar energy will be reflected, some will be directly transmitted through the glass, and some will be absorbed and either conducted through the glass and re-radiated to the interior or re-radiated back out to the exterior. The solar reflectance of low emissivity coatings further reduces solar heat transfer to the interior. Solar reflectances range from minimal to significant, depending upon the type and nature of the low emissivity coating. Low emissivity (or low-e) glass products are formulated to reflect long-wave length infrared energy (i.e., furnace heat, heat generated by people, artificial lights, absorbed shortwave length infrared energy emitted as long wave length energy, etc.) back to the interior. Low emissivity coatings on glass have a greater effect on unwanted winter heat loss from a building than uncoated glass. Uncoated glass has an emissivity or emittance of 0.84. Low-e glass products are currently available in emittance values as low as 0.03. Low emissivity coatings reduce the infrared heat transfer across the air space of double sealed insulating units. A low-e coating on either surface #2 or #3 will make the double glazing insulate as well as or better than uncoated triple glazing.

U-Factor

U-factor is the thermal transmittance of a material or assembled wall. It is often used to communicate the thermal effectiveness of glass windows, curtain walls, and doors. As such, the framing and support systems themselves affect the overall U-factor published for these products. The *WINDOW* computer software program produced by Lawrence Berkeley National Laboratory offers a simple method for determining the U-factor of fenestration units. U-factor calculations are based on NFRC 100 – *Procedure for Determining Fenestration Product U-factors.*

Center of Glass U-Factors

Glazing Type	Clear Uncoated Glass	Low-e e = 0.05	Low-e e = 0.10	Low-e e = 0.20	Low-e e = 0.40
Single	1.11	n/a	n/a	0.76	n/a
Double					
1/4" air space	0.57	0.42	0.43	0.46	0.50
1/4" argon	0.52	0.33	0.35	0.38	0.43
1/2" air space	0.49	0.30	0.32	0.35	0.40
1/2" argon	0.46	0.25	0.27	0.30	0.36
Triple (low-e one surface)					
1/4" air space	0.39	0.31	0.32	0.33	0.35
1/4" argon	0.34	0.25	0.26	0.27	0.30
1/2" air space	0.31	0.21	0.22	0.24	0.27
1/2" argon	0.29	0.18	0.19	0.21	0.24
Triple (low-e two surfaces)					
1/4" air space		0.26	0.27	0.29	0.33
1/4" argon		0.20	0.21	0.23	0.27
1/2" air space		0.16	0.17	0.20	0.24
1/2" argon		0.12	0.14	0.16	0.21

Coated Glass

The four basic properties of coated glass are solar reflectance, solar absorbance, visible light reflectance, and long-wave length heat reflectance (low-emissivity coatings). These properties may be present singularly or in combination. The differences between any two coatings are the amount and type of solar transmission (ultraviolet, visible or infrared) allowed through the glass. Solar reflective glass may have some type of metallic coating that reflects a greater portion of the entire solar spectrum. A reflective coating on vision glass areas reduces the solar heat gain within the building envelope and thereby offers economies in the sizing of HVAC equipment and reduces energy consumption.

Low-emissivity coated glass has various layers of nearly invisible coatings that reflect a significant part of long-wave infrared energy. These glass coatings may be applied either during the float process (pyrolytic coatings) or to the finished glass surface (vacuum deposition coatings).

ASTM C 1376 – *Standard Specification for Pyrolytic and Vacuum Deposition Coatings on Flat Glass* publishes quality standards for coated glass.

APPENDIX 1
Member Companies

Glass Association of North America
Flat Glass Manufacturing Division
www.glasswebsite.com

AFG Industries, Inc.
www.afg.com

Guardian Industries Corp.
www.guardian.com

Pilkington North America, Inc.
www.pilkington.com

PPG Industries, Inc.
www.ppg.com

Visteon – Float Glass Operations
www.visteon.com

APPENDIX 2
Referenced Standards

ANSI Z97.1	*American National Standard for Safety Glazing Materials Used in Buildings*
ASCE 7	*Minimum Design Loads for Buildings and Other Structures*
ASHRAE	*Handbook of Fundamentals*
ASTM C 1036	*Standard Specification for Flat Glass*
ASTM C 1048	*Standard Specifications for Heat-Treated Flat Glass – Kind HS, Kind FT Coated and Uncoated Glass*
ASTM C 1172	*Standard Specification for Laminated Architectural Flat Glass*
ASTM C 1349	*Standard Specification for Architectural Flat Glass Clad Polycarbonates*
ASTM C 1376	*Standard Specification for Pyrolytic and Vacuum Deposition Coatings on Flat Glass*
ASTM E 1300	*Standard Practice for Determining the Load Resistance of Glass in Buildings*
CPSC 16 CFR 1201	*Safety Standard for Architectural Glazing Materials*
NFRC 100	*Procedure for Determining Fenestration Product U-factors*
NFRC 200	*Procedure for Determining Fenestration Product Solar Heat Gain Coefficients and Visible Transmittance at Normal Incident*
NFRC 300	*Standard Test Method for Determining the Solar Optical Properties of Glazing Materials and Systems*

APPENDIX 3
Technical Resources

Reference Manuals

FGMA *Fabrication, Erection & Glazing Hours Manual*

FGMA *Sealant Manual*

GANA *Engineering Standards Manual*

GANA *Fully Tempered Heavy Glass Door and Entrance Systems Design Guide*

GANA *Glazing Manual*

GANA *Laminated Glazing Reference Manual*

Correspondence Course

GANA *Blueprint Reading and Labor Estimating Course*

Glass Informational Bulletins

GANA	01-0300	*Proper Procedures for Cleaning Architectural Glass Products*
GANA	02-1004	*Flat Glass Industry Specifications*
GANA LD	01-1003	*Design Considerations for Laminated Glazing Applications*
GANA LD	02-0704	*Emergency Egress Through Laminated Glazing Materials*
GANA TD	02-0402	*Heat-Treated Glass Surfaces Are Different*
GANA TD	03-1003	*Construction Site Protection of Architectural Glass*

APPENDIX 4
Referenced Organizations

American National Standards Institute ANSI
11 W. 42nd Street, New York, New York 10036
T: 212-642-4900 F: 212-398-0023 E-Mail: info@ansi.org Web Site: http://www.ansi.org

American Society of Civil Engineers ASCE
1801 Alexander Bell Drive, Reston, VA 20191
T: 800-548-2723 F: 703-295-6277 E-Mail: (See web site.) Web Site: http://www.asce.org

American Society of Heating, Refrigerating, and Air-Conditioning Engineers ASHRAE
1791 Tullie Circle, NE, Atlanta, Georgia 30329-2305
T: 404-636-8400 F: 404-321-5478 E-Mail: (See web site.) Web Site: http://www.ashrae.org

ASTM International (formerly the American Society for Testing and Materials) ASTM
100 Barr Harbor Dr., West Conshohocken, Pennsylvania 19428-2959
T: 610-832-9585 F: 610-832-9555 E-Mail: service@astm.org Web Site: http://www.astm.org

Glass Association of North America GANA
2945 SW Wanamaker Drive, Suite A, Topeka, Kansas 66614-5321
T: 785-271-0208 F: 785-271-0166 E-Mail: gana@glasswebsite.com Web Site: http://www.glasswebsite.com

Lawrence Berkeley National Laboratory LBNL
Windows and Daylighting Group, 1 Cyclotron Road, Mailstop 90-3111, Berkeley, CA 94720
T: 510-486-5064 F: 510-486-4089 E-Mail: (See web site) Web Site: http://www.windows.lbl.gov

National Fenestration Ratings Council NFRC
1300 Spring Street, Suite 500, Silver Spring, Maryland 20910
T: 301-589-6372 F: 301-588-0854 E-Mail: NFRCUSA@aol.com Web Site: http://www.nfrc.org

Standards Design Group, Inc. SDG
3417 73rd, Suite K3, Lubbock, TX 79423
T: 806-366-5585 F: 806-792-5086 E-Mail: info@standardsdesign.com Web Site: http://www.standardsdesign.com