The Structural Power of Glass

PHOTO: SIMPSON GUMPERTZ & HEGER

By C.C. Sullivan and Barbara Horwitz-Bennett

Historically regarded for aesthetic qualities, the introduction of daylight indoors, and ability to link building interiors with the outside world, glass building systems have traditionally played a prominent role in commercial and institutional buildings. In recent years, glass systems have been shown to support building concepts in even more direct ways.

Thanks to technological advances and growing demand for structures with larger glazed surfaces, glass assemblies have slowly begun taking on an additional role as load-bearing systems. Part of the impetus has come from the recent trends toward modernist and high-tech architectural designs. These strikingly minimalist compositions tend toward larger areas of glass and a minimized supporting structure, compelling Building Teams to approach glass enclosures as structural elements.

These systems incorporate metals, plastics, and elastomers to work effectively. Yet on its own, glass exhibits a number of truly structural mechanical

Learning Objectives

After reading this article, you should be able to:

- ✔ Describe how glazing and glass may have structural properties of use in commercial building.
- ✔ Explain generally how glass is manufactured.
- ✔ List four types of glass applications that rely on structural performance.
- ✔ Discuss the key aspects of moisture control, thermal control, and occupant safety that are affected by glass system design and construction.

properties: high compressive strength, a good stiffness-to-weight ratio, long-term stability, and notable resistance to aggressive environments.

Theoretical abilities aside, building designers and constructors are more familiar with some of the problems associated with glass. It is an extremely brittle material, and highly vulnerable to small defects; these factors compromise its tensile properties. And unlike the metal and polymer components often used to make glazed systems work, glass is not ductile. Failure can occur suddenly and spectacularly, without warning.

Addressing these shortcomings, new products and assemblies are enabling glass to not only carry its own weight, but bear additional structural load as well. These advances include heat-treated and laminated glass materials, coupled with innovations in joint and connection design.

HOW GLASS IS MANUFACTURED

Building Teams can benefit from a good working understanding of glass manufacture and finishing. Production of float glass—which occurs in continuous batches called campaigns that may last years without interruption—begins when raw materials, ordinarily including sand, lime, and sodium carbonate, are melted at very high temperatures. Next, during the fining stage, bubbles rise to the surface and escape, followed by the process of forming, where width and thickness are shaped as the glass cools.

At this point, the glass can be annealed, heat-treated, or tempered for a stronger, better-performing product:

- **Annealing.** Annealing, which improves the durability of the final product, is essentially a process of slowly cooling the glass piece to relieve internal stresses after it is formed. This occurs by passing the material through a lehr, which controls cooling at the desired rate. While annealed glass is the least expensive treated type, it is the lowest in strength and will break in large, sharp shards.
- **Heat strengthening.** The next step up, heat-strengthened glass, involves heating the newly formed glass and then "quenching" it with a cool blast of air. This treatment hardens the outer 20% of the glass; upon cooling, the outer surface is compressed and thus strengthened, making it about twice as resistant to breakage as untreated glass.
- **Tempering.** Tempered glass goes through a comparative process; the difference is that cooling occurs more rapidly with higher volumes of air, resulting in a product that is four times more resistant to breakage than glass that is not tempered.

Steven J. Thomas, PE, senior staff I, building technology, in the Los Angeles office of Simpson Gumpertz & Heger, explains how the process works: "Quenching induces permanent compressive stresses on the glass surfaces

PHOTO: SGH

For the design of Boston's Kenmore Square MBTA Bus Canopy by DiMella Shaffer, Simpson Gumpertz & Heger's services were utilized to provide structural calculations to verify the performance of the canopy under gravity and wind loads and to identify potential problems.

that must be overcome by the applied load before the glass experiences tensile stresses." The other advantage offered by fully tempered glass is that when it does break, it shatters into relatively safe cubes, rather than large, sharp shards. As for heat-strengthened glass, "Depending on the level of pre-stress [applied], it may break into large shards similar to annealed glass or into much smaller and more rounded pieces similar to fully tempered glass," says Thomas.

While such benefits are appealing, Thomas and his colleague, Russell H. Davies, PE, a senior project manager in SGH's New York City office, point out that both heat-strengthened and fully tempered glass are susceptible to roller-wave distortions, which can create undesirable reflectivity patterns. In addition, says Davies, "Heat-treated glass is susceptible to fracture due to edge impacts that penetrate the compressive stress zone, and fully tempered glass is susceptible to spontaneous breakage as a result of nickel-sulfide material impurities within certain production runs." One way to mitigate this is through heat-soaking—returning the glass to a high temperature after tempering—by inducing nickel-sulfide breakage before the glass leaves the fabrication plant.

Another popular glass choice is the *laminated panel* product, which employs an interlayer such as plasticized polyvinyl butyral (PVB) sandwiched between two lites, or panels, of glass. "The interlayer helps to retain broken shards if one of the lites breaks," says Thomas. "Laminated glass may also provide levels of impact resistance and acoustical control, in combination with other glazing details, and UV resistance based upon its composition."

Similarly, *insulating glass units*, or IGUs—the most frequently specified fabricated architectural glass for commercial facilities—consist of two or more layers sealed together with interstitial gas or air. While IGUs offer superior thermal and acoustical properties over single glass panels, the SGH experts point out that there may be volume changes in the sealed space due to temperature or elevation differences, which can result in glass bowing and optical distortion. Davies further cautions that "members supporting the edges of insulating glass units must be sufficiently stiff to prevent the units from experiencing seal failure."

THE DEBATE OVER GLASS STRUCTURES

The articulation of glass building components and assemblies follows for these basic properties of manufactured glass materials. A variety of glass elements beyond flat window walls and panels are used for building designs, such as columns, fins, and beams. While these products and techniques have become relatively common, there is still much debate regarding their application and structural strength.

Some conservative authorities in glass systems warn that such embellishments should only be employed as non-load-bearing elements on the interior. On the more liberal side is glass guru Jan Wurm, a materials designer in the London office of engineering firm Arup, whose book, *Glass Structures: Design and Construction of Self-Supporting Skins*, outlines a case for more use of glass in load-bearing situations. Wurm suggests that glass plates and beams actually offer a great load capacity due to the fact that they are "structure forming" and will allow system loads to be transferred in a predictable way from the loaded surface to the ground.

Graham Dodd, director of Arup's materials consulting business, and designer Felix Weber, point out that glass has approximately the same stiffness and density as aluminum alloys, and toughened glass offers almost as much strength as a low-grade alloy, despite its brittleness and lack of ductility. Glass is also nonflammable and resistant to heat, cold, and light. Thus, glass as a plate, beam, or column can offer some advantages over plastics.

In the realm of structural design, Charles D. Clift, president and senior principal of Dallas-based Curtain Wall Designing and Consulting, notes: "There are some prototypical designs that employ the use of glass tube columns and laminated glass beam as structural framing members for cladding. Such designs are visually spectacular. However, you can imagine the engineering rigor needed to avoid catastrophic collapse."

Clift also points out that while design of flat glass panels in wall systems is well codified, there are no published rules for structural design criteria of glass columns, fins, and beams.

PHOTO: MATT CALDWEL, COURTESY WAUSAU WINDOW AND WALL SYSTEMS

The University of Colorado's Research Complex Phase 2 project features highly thermally efficient glazing capable of remaining condensation-free at sub-zero temperatures.

Consequently, for those opting to use such glass framing elements, "This usually necessitates destructive testing to verify design integrity."

Offering a design tip, Peter M. Muller, a Houston-based curtain wall consultant, recommends that, in the case of horizontal glass panes, only laminated glass on non-glass structural supports be used.

GLASS BUILDING SYSTEMS

Fortunately, when it comes to glass as a building system, there is much more guidance in the form of codes and industry standards. SGH engineers Thomas and Davies recommend a focus on basic design and code-compliance issues, including:

• Coordinating glass system energy efficiency with overall building energy performance goals.

• Coordinating system movements with air- and water-related details.

• Coordinating system structural loads and displacements with supports.

In other words, the glass system—including non-glass components, sealants, gaskets, and other intermediating materials or products—has to work in concert with the overall building design parameters. Specifically, the following guidelines

PHOTO: MAKERAIN 3D SOLUTIONS

The blue-green glass curtain wall and storefront, designed by DSDG, at Florida's new Sarasota Yacht Club create an attractive aesthetic blending into the coastal scene. The glazing is treated to reduce solar heat gain and resist condensation.

should be considered:

Air infiltration. Based on the fact that air leakage is not uncommon and may occur as a result of poor product design, manufacturing, construction detailing, or installation, codes such as the International Energy Conservation Code (IECC) and ASHRAE Standard 90.1 from the American Society of Heating, Refrigerating and Air-Conditioning Engineers require air leakage testing by an accredited, independent laboratory. For most fenestration, the maximum permitted air leakage is 0.3 cubic feet per minute per square foot in the IECC, and 0.4 cfm/sf in ASHRAE 90.1, according to Nils Petermann, project manage with the Alliance to Save Energy's Efficient Windows Collaborative, Washington, D.C.

At the same time the IECC allows a higher maximum air-leakage rate of one cubic foot per minute per square foot for commercial glazed swinging entrance and revolving doors, according to Ken Brenden, technical services manager with the American Architectural Manufacturers Association, Schaumburg, Ill.

On the practical side, Arup's Dodd points out that because glass itself is impermeable, air infiltration protection is all about the sealing/jointing system. "The sealing system has to resist air pressure, be impermeable, and maintain performance even when distorted by the movements of the building relative to the glass," says Dodd, who specializes in the structural use of glass and has published numerous industry conference papers and technical articles on glass systems. "Frameless glass systems usually use silicone-sealant joints that are dimensioned to be wide enough that the cured silicone can flex to absorb anticipated movements in service without rupturing."

Water and moisture resistance. While the same principles apply to water-penetration resistance, experts note that moisture control is often misunderstood.

"Moisture vapor moves from areas of high vapor pressure to areas of lower vapor pressure, which for occupied buildings in many northern climates means from inside to outside," says Arup's Weber. "Consequently, insulated glazing systems have to be air- and vapor-sealed on the inside, but protected from rain and able to ventilate to the outside." On the other hand, "When detailing for other climates, such as the Gulf, the situation is reversed and the whole approach to moisture control has to be revised."

Writing about curtain walls in the Building Envelope Design Guide, part of the Whole Building Design Guide, sponsored by the National Institute of Building Science, SGH's Nik Vigener, PE, and Mark A. Brown explain that condensation occurs if the temperature of the interior frame or glazing surfaces falls below the dew point temperature for the interior air. As a result, some condensation-limiting design strategies include glazing with a low U-value and supplementing heat to the glazing in order to increase surface temperatures.

In terms of ensuring the glazing system's waterproofing performance, the following must be addressed:

- Details of the framing system that promote drainage
- Internal framing seals
- External glass-to-frame seals
- Frame perimeter seals and flashings

Furthermore, Vigener and Brown note that glazing sealants, no matter how well applied, cannot absolutely prevent water penetration over time, so providing internal drainage is a critical part of the overall design.

Recognizing the complexity of moisture passage and the issues of climate and condensation, Thomas Denslow, president of the Sarasota, Fla.-based architectural firm DSDG, says, "We highly recommend that a waterproofing consultant be involved in detailing glass systems."

Looking to the codes, AAMA's Julie Ruth, PE, an International Codes Council (ICC) consultant, points out that while the International Building Code (IBC) requires all exterior wall coverings to provide weather protection, there are no specific requirements when it comes to water and moisture resistance for the curtain wall.

Fortunately, a number of standards do offer guidance in this realm, says Paul Bostrom, an industrial associate with the Alliance to Save Energy. "ASTM E 1105 is a field-testing standard developed to ensure adequate retention of water for windows and doors, and AAMA 502 is a set of guidelines by which professionals can conduct onsite testing of the E 1105 standard," he says. "AAMA 503 is a similar set of guidelines tailored to storefronts and curtain walls."

Based upon the Efficient Windows Collaborative's assessment that leaky fenestration is most commonly caused by poor installation and not the perimeter seals, Bostrom says "these standards provide a quality-control mechanism for installation and assembly to guarantee engineers and architects that specified products will perform as expected."

Structural performance. As has been noted, glass possesses a unique set of properties making it generally suitable as a structural support. Yet even minor scratches, abrasions, and irregularities on the surface of a glass panel can compromise its tensile strength. Moreover, glass's brittle, nonductile nature is another discouraging factor. Even so, there are ways to minimize bending forces.

According to Arup's Dodd, one approach is using either hierarchical structures with glass beams or fins, or alternatively trussed or trussed-plate structures. The hierarchical structures approach provides more structural height by adding additional members, which reduces the stresses in the glass, says Dodd. Another design strategy, according to Arup's Weber, is curved glass structures, which enables "the possibility of using the three-dimensional shape of the panel to either stiffen the glass by increasing the structural height, or creating a global shape that allows activating membrane forces in the structure."

To better understand these unique structural properties, Dodd encourages building professionals to bear in mind that glass is actually stronger against short-term loads than sustained loads. "The design stress when considering a one-second wind load is higher than that when designing a glass floor to carry a crowd of people, and not just because of the level of reliability required," he says. As a result, "When glass is subjected to a long-term tensile stress, tiny micro-cracks in the surface tend to grow longer, which makes them more intense, so they grow faster. This phenomenon of slow crack growth is what can lead to glass breaking unexpectedly, when nothing seems to have happened."

Dodd and Weber explain further that the time dependency of strength is much reduced in heat-strengthened and toughened glass, but it is still an issue that should be considered in system designs.

In general, it is essential to carefully evaluate the loads induced by environmental forces. "Wind, snow, heating, and cooling all create significant stresses on glazing," says Petermann. "Engineers must evaluate the project site, climate, altitude, proximity to large bodies of water, and other localized conditions." To assist with this, the IBC includes wind, snow, seismic, and dead load requirements, and ASTM E 1300 is generally used to determine the load resistance of glass under uniform loads.

Denslow says his firm relies "very heavily" on so-called "notice-of-approval testing" by Miami-Dade County for impact and wind-resistance testing for all such products.

PHOTO: LAWRENCE BERKELEY NATIONAL LAB

This screen capture from Lawrence Berkeley National Laboratory's next version of COMFEN, now under development, will offer enhanced features for comparing glazing options in terms of site-specific energy performance.

Still, construction professionals agree that the industry generally lacks material specification tools, relevant test methods, structural design methodologies, and standards in the realm of structural glass. "Designing for structural performance is still something of an open question, because there is no specific code for the structural use of glass, although there are many codes with different approaches for the design of window panes," says Dodd. He says there has been discussion of a European Union code for structural glass use, "but we can expect plenty of debate before that is settled, because the subject of glass strength is dependent on so many factors and there are so many approaches to simplifying the problem."

Thermal performance. Both the IECC and ASHRAE 90.1 require that the U-factor and solar heat-gain coefficient (SHGC) remain within certain limits for commercial fenestration. In addition, the National Fenestration Rating Council establishes how to determine these values through a standard procedure.

PHOTO: COURTESY YKK AP

At the Four Seasons Hotel in Miami, project architect Bermello Ajamil & Partners specified impact-resistant curtain wall and swing doors with custom stainless-steel cladding.

"The glazing contractor must also label the installation with these values, but it should be noted this is not required to be done under a third-party labeling system," says AAMA's Ruth. "Use of another method, such as a certificate of compliance provided in accordance with AAMA 507, meets the intent of the IECC," she says.

One trend in this arena is performance-based compliance through the use of software modeling tools. Advanced energy-modeling tools can help crank out the complex calculations of the numerous variables affecting energy performance, such as U-factor, SHGC, climate zone, project site, building type, total glazing area, fenestration type, shading fixtures, and building orientation. One free, user-friendly modeling tool, called COMFEN, is offered by Lawrence Berkeley National Laboratory and can be used to compare glazing options for site-specific fenestration performance.

Also under development is a new commercial rating procedure for site-built product certification, spearheaded by the NFRC. According to Petermann and Bostrom, this new component modeling approach (CMA) utilizes data about individual pieces of building assemblies, analyzed together with a versatile simulation tool, to allow the Building Team to determine whole product ratings

The component modeling approach is being piloted during the fall of 2009 and is scheduled for full release in January 2010, according to Bostrom. The CMA offering will "streamline the rating procedure for individual commercial projects and can also be used for specifying and bid purposes," he says.

Regardless of the analysis used, Building Teams must evaluate glass system schematics and shop drawings to check for thermal bridging. Balancing thermal and structural requirements is not easy and relates primarily to the choice of framing materials and curtain wall anchoring systems.

Regarding curtain wall anchoring systems, Petermann explains that "each bolt used increases the likelihood of thermal bridging through the thermal break, thereby reducing energy performance. However, limiting the number of fasteners may impact structural capacity." One way to overcome this problem, according to Petermann and Bostrom, is to use fasteners that don't span the thermal barrier. However, such fasteners can be more costly to install than conventional fasteners.

Framing materials can also be affected. For example, while aluminum and steel offer good load-bearing capabilities, thermal breaks for better thermal performance can somewhat reduce the structural capacity of the frames, note Petermann and Bostrom. Consequently, some applications may call for non-metal frame materials, such as fiberglass or reinforced vinyl, which offer lower thermal conductivity levels.

GLASS CURTAIN WALLS

With proper design to guard against thermal bridging, the unique properties of glass have lent the material to the development of glass curtain walls, which offer transparency, aesthetics, and structural and thermal performance benefits. Whether stick-built on site or unitized through shop prefabrication, curtain wall systems offer specifiers the choice of numerous interior- and exterior-glazed options. In some cases, the choice is dictated by accessibility to the site. For example, according to Vigener and Brown, high-rise construction tends to work best with interior glazing because of the improved logistics and access for replacing or repairing glass.

In terms of overall thermal characteristics, the SGH engineers explain that curtain wall performance is dependent on the following factors: 1) the glazing infill panel, 2) the frame, 3) construction behind opaque areas, and 4) the perimeter details.

As for water penetration resistance, this is determined by 1) glazing details, 2) frame construction and drainage details, 3) weatherstripping and frame gaskets, 4) interior sealants, and 5) perimeter flashings and seals, they add.

A few additional moisture prevention design tips from Vigener and Brown in their WBDG primer:

- Select frames with wept glazing and pocket sills sloped to the exterior to collect water that penetrates the glazing and drain it to the exterior.
- Ensure key frame drainage features, including sloping to the exterior at surfaces that collect water, closely spacing large weep holes, and providing for drainage at every horizontal frame.
- Include flashings at curtain wall perimeters—sills, jambs, and heads—that are sealed to the air and water barrier at adjacent walls.
- Use perimeter sealants as a rainscreen for limiting air

and water penetration through the outermost plane of the wall—but take care not to rely upon them as the sole penetration barrier for air or water (or both).

• Coordinate the placement of setting blocks with the location of weep holes to avoid blocking drainage paths.

On the structural side, AAMA's Brenden and Ruth point out that ASCE 7 prescribes wind-load design pressure resistance requirements based upon climate zones. In hurricane-prone regions, the curtain wall must also be capable of resisting impact loads from wind-borne debris. "The IBC also requires special inspection of the installation of curtain wall in high-wind-speed areas," says Ruth. "In some cases, this will be on the same buildings where the impact test is required, but that will not necessarily always be the case."

One other region-specific requirement is designing to prevent glass breakage in earthquake-prone areas. "Often this does not so much entail the curtain wall being able to resist certain loads as it does the ability of the framing system to deflect in the plane of the glass, without imparting lateral loads onto the glass," says Ruth.

Summing up the recommended features for designing glass and metal framing systems, curtain wall consultant Muller cites longevity, maintainability, ease of repair and replacement, damage from public access, and ease of cleaning.

FRAMELESS GLAZING: EYE-CATCHING, INNOVATIVE

Falling right in sync with growing interest in greater transparency and structural glass design are frameless glazing systems. Whether it's structural glazing or point-supported glazing, designers have been given greater freedom to come up with some eye-catching, innovative glass façades.

The way structural glazing works is that the glass is bonded to the building's structural framing members with a high-strength, high-performance sealant or tape, often silicone sealant. Dynamic wind loads are then transferred from the glass by the sealant to the perimeter structural support. Because such systems have less metal framing exposure, they also offer good water and air protection and improved thermal efficiency.

In terms of practical design advice, Dodd and Weber stress the importance of understanding how the glass will be supported and restrained, and how the movements of the building will be accommodated.

Further advice on this subject from Thomas and Davies:

• Many projects also require positive fastening of glass panels to supports in order to avoid reliance on adhesives during extreme loading conditions or for inverted or suspended glazing.

• Structural silicone glazing should be performed in the factory, where controlled conditions offer maximum opportunities for success.

• Whenever possible, reliable systems should include primary and secondary drainage paths to evacuate water penetration. Water-bearing surfaces should slope to drain into weep systems.

PHOTO: TOM KESSLER, COURTESY WAUSAU WINDOW AND WALL SYSTEMS

The Zorinsky Federal Building in Omaha, Neb., features blast hazard mitigation windows and curtain wall. The factory-glazed windows and unitized curtain wall are designed to comply with U.S. Department of Defense and General Services Administration requirements.

• To optimize durability, sealants should be considered hole-fillers, not waterproofing agents. Structural adhesives do not guarantee waterproofing.

• Some jurisdictions and government agencies limit their acceptance of structural silicone glazing systems.

Point-supported glazing. Systems such as bolt-fixed glass and patch-plate assemblies are generally known as point-supported glazing, meaning that the glass sections are supported at discreet locations rather than continuously along the glass panel edges. Many professionals are familiar with the highly articulated "spider" systems that use single structural mounts to support multiple glass points. In all cases, these façade types are visually compelling yet require carefully machined or cast fittings and early-phase analysis using computer finite-element analysis to ensure the systems work properly and safely.

Addressing point-supported systems from a structural perspective, the SGH engineers explain that the design team will establish load paths between the glass units and the specialized hardware, members, and connections which transmit these vertical and out-of-plane loads from the façade back to the main building system. The connections need to accommodate constructability tolerances in all directions, they add, and to allow for structural movements, including floor slab deflections and lateral motions caused by wind or seismic loads.

Of course, it goes without saying that only tested glass and hardware systems should be selected. The engineering team will require data documenting the chosen system's ability to withstand vertical and horizontal loading—numbers that are essential for calculating the final architectural design.

In terms of the fundamentals, Arup's Dodd and Weber list accurate hole shape, correct bearing materials, controlled assembly and a tested design methodology as the basics for good design. At the same time, "There are still new suppliers coming into the market, and always new things being learned about glass, such as how easy it is to get uneven residual stresses at the surface of toughened glass if it is an unusual shape," Weber says.

SLOPED GLAZING: PUTTING SAFETY FIRST

The biggest concern when it comes to sloped glazing is safety. In addition to protecting occupants below from falling glass, "Sloped glazing also has to be safe for those working over or around it, which means not allowing anyone to fall through it," says Dodd. "In our view, there is no reason nowadays to accept a glass roof that is fragile, and we should insist on glazing that will support a person even if all layers of the glass are broken."

Included in this equation is the framing system. "The way the glass has to be restrained may change dramatically between when the glass is intact and resisting its regular wind pressure, and when the glass is broken and an injured person is lying on the glass on a hot day," says Dodd.

In addition to safety, Thomas and Davies add that thermal control, condensation resistance, and, in many cases, acoustic performance be carefully considered.

One helpful resource is AAMA's Glass Design for Sloped Glazing.

According to the SGH engineers, "Sloped glazing requires condensate gutters that control modest leakage and effectively transmit all water from cross-members to rafters, and from rafters to perimeter drains. The perimeter requires through-wall flashing that is not penetrated on its horizontal surface for effective waterproofing. And systems with irregular shapes or innovative long-span framing often require detailed structural analyses to coordinate support requirements, load distribution, system displacements, component sizes, and optimized structural geometry."

Unit skylights. According to Vigener and Brown, the most common skylight application is insulated glazing inside an aluminum frame. However, ASTM E1825 – Standard Guide for Evaluation of Exterior Building Wall Materials, Products, and Systems can be helpful in evaluating different product choices based upon track record and application.

It's also important to note that skylights experience significant summer solar heat gain and wintertime heat loss, and even the best sealed assemblies will experience some sort of water leakage. This being the case, Vigener and Brown offer a few moisture control best practice tips from their WBDG article:

- Provide a continuous system of gutters, integral with the skylight rafters and cross members, to collect leakage and condensation.
- Provide an exterior wet seal.
- Select a system with continuous rafters.
- Use a continuous metal sill flashing to collect leakage and condensation.

Quick Guide to Specifying Glass and Metal Framing Systems

Keep these basic points in mind when designing glass and metal framing systems.

- **Structural integrity.** Because structural failure may jeopardize human life, the structural integrity of the wall may be said to be the primary concern in its design.
- **Provision for movement**
  - Wind load
  - Live load
  - Allowable deflection
  - Thermal expansion and contraction
  - Seismic and inter-story drift
- **Weathertightness**
  - Water penetration resistance
  - Pressure equalization
  - Maximum allowable air infiltration
- **Thermal performance**
  - U-value
  - Solar heat-gain coefficient (SHGC) and visible light transmittance (VLT)
  - Condensation resistance factor (CRF)
- **Laboratory and field testing**
- **Building code compliance**
- **Method of fabrication and glazing**
  - Field
  - Factory

Other considerations vary in importance based upon location and building type. These include:

- Moisture control
- Sealant selection and joint design
- Thermal insulation
- Sound transmission
- Security
- Impact resistance

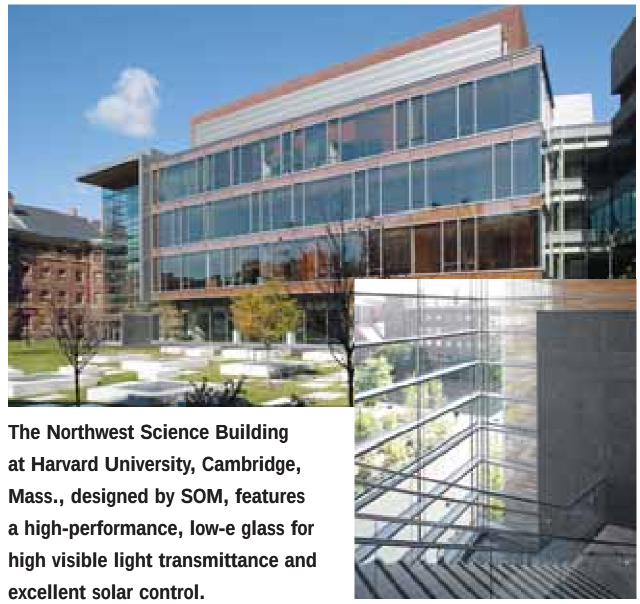
Source: This list has been adapted from a guide developed by Ken Brenden, technical services manager, and Julie Ruth, PE, ICC code consultant, with the American Architectural Manufacturers Association, Schaumburg, Ill.

• Choose a system with snap-on rafter caps rather than exposed pressure bars.

• Specify and detail flush-glazed horizontal mullions without exterior applied pressure bars to avoid bucking water run-off.

In sum, Building Teams need to be familiar with all aspects of providing safe, durable glass building systems. Glass has been and will continue to be a popular exterior building feature, and for good reason: according to Arup's Wurm, the "lucidity and good chemical resistance" of glass to most corrosive media make it an excellent building skin material.

As CDC's Clift puts it, "All glass structures have the advantage of providing maximum transparency, uniformity of material, and unique architectural style." Adding daylighting, solar control, and new structural support capabilities to the list, what could be better? BD+C



The Northwest Science Building at Harvard University, Cambridge, Mass., designed by SOM, features a high-performance, low-e glass for high visible light transmittance and excellent solar control.

PHOTO: COURTESY PPG