A Clear Difference

NEW DEVELOPMENTS IN LOAD-BEARING GLASS

COURTESY STUTZKI ENGINEERING INC. :

The use of light load-bearing glass to create transparent stairs, floors, and other walkable applications serves the overarching goal of transparency.

BY C.C. SULLIVAN, CONTRIBUTING EDITOR

Glass has taken on new life in recent building years. Long valued for its transparency and lightness, glass is now also being considered for its structural and protective capabilities. Beyond the technique known as *structural glazing*—an umbrella term that includes spider fittings, structural silicone, and other means for attaching glass to a support structure—today there are more uses of glass as a true load-bearing element. Underscoring this idea, two separate research teams in Europe took the idea to the extreme recently, creating composite I-beams with glass webs.

"When glass is load bearing it can serve three roles at once: structure, envelope, and transparency," says Mark DuBois, a principal with Ohlhausen DuBois Architects in New York City (www.boishaus.com). "There is no other way to achieve all this with one element, so it produces a truly unique experience." For Building Teams, the notion of supporting a structure solely with glass opens up new possibilities and challenges.

Of course, this direction is not entirely new. *Glass block*, developed in the early 20th century to bring daylight into industrial buildings, is a load-bearing element treated like masonry in detailing and application. More recently, *toughened or tempered glass* has become ubiquitous for frameless elements, including doors, stair treads, and load-bearing walls and floors. Toughened glass typically has four to six times the strength of annealed glass.

Choosing to use glass as a component of a structural assembly—or as a load-bearing or semi-load-bearing material on its own—demands the same considerations as any structural assembly. First, the integrity of the assembly must be considered, including its performance under normal dead loads and occupancy live loads, as well as other movement-inducing loads such as wind, thermal expansion and contraction, pressure equalization, and seismic events. Structural failure affects human health, safety, and welfare (HSW) in many ways, making it the primary concern for design of glazed systems.

The International Building Code (IBC) offers initial direction on glass structural systems through its reference to the American Society of Civil Engineers (ASCE) standard Minimum Design Loads for Buildings

LEARNING OBJECTIVES

After reading this article, you should be able to:

+ LIST the potential structural properties of glazing and glass systems of use in commercial building and how these properties impact sustainable design.
+ EXPLAIN how glass is incorporated into structural systems for optimal design and environmental benefit.
+ DETAIL recent advances in glazing and structural glass technology and how they contribute to a building's energy performance.
+ DISCUSS key aspects of building performance affected by glass system design and construction, notably energy savings.

and Other Structures, also known as ASCE Standard No. 7-05. Provisions for seismic design and other conditions ensure proper applications of architectural glass in typical nonstructural uses as well.

A second consideration is *weather tightness*, which is important for exterior enclosure uses of glass with metal and wood framing, concrete and other mass walls, and structural glazing with dry or wet joints using silicone. Keeping the weather out and the interior climate comfortable demands resistance to heat and cold, water penetration, and air infiltration beyond design parameters.

Third, the building design must consider the related issue of *thermal performance*, with glass panels and joints that are suitable in terms of U-value, or coefficient of heat transmission—a measure of the rate of nonsolar heat loss or gain through a material—as well as solar heat-gain coefficient (SHGC) and visible light transmittance (VLT). Less well known is *condensation resistance factor* (CRF), a designation for the glazed assembly between zero and 100: the higher the number, the better the resistance. CRF is also an important measure for overall thermal performance.

BALANCING THE TRADEOFFS OF STRUCTURAL GLASS

Clearly, material integrity is the primary challenge for load-bearing glass and structural glazing. Recent testing and field applications provide valuable guidance for glass and hybrid glass structures designed and built to exploit the inherent strength of the material. In the planning and schematic phases, an intuitive sense of how glass performs structurally will help save time and effort in design development.

Glass beams, fins, tubes, and columns generally have documented performance values that Building Teams can reference and specify and expect to hold in a range of situations. For back-of-the-envelope design ideas, glass compares with aluminum in terms of density and stiffness. Toughened glass is brittle and stiff, yet its strength is equivalent to a typical construction-grade aluminum alloy.

Glass has several advantages over plastic, according to some experts. Plastic materials, which are used extensively in lightweight structural situations, are inherently highly flammable and may fail when exposed to high temperatures.

JOE VARE

Recent improvements in glass tempering technology enable manufacturers to produce large-span panes with close to zero roller wave distortion, as seen here at Alice Tully Hall, at New York's Julliard School.

There are other benefits to choosing glass. "The strongest argument for the use of structural glass in a commercial environment is its ability to enhance, diffuse, reflect, and transfer light due to its transparency," says James O'Callaghan, director of Eckersley O'Callaghan, an engineering firm with offices in London and New York. Beyond this, the ubiquity of glass façades and structures in the architecture of the last few decades often compels Building Teams in this direction. Part of the interest is the pure "aesthetic flair unattainable with more conventional materials," says Steve Thomas, PE, a principal at Optimum Designs Inc., Los Angeles (www.odiengineering.com).

On the other hand, the design of glass structures can be new and challenging. Building codes and structural design guidelines are only now emerging, says Peter Muller, principal of façade and glass structure consultant Peter M. Muller, Inc., Houston (www.petermmullerinc.com). To test new design ideas, modeling and destructive testing of assemblies help ensure the structure meets the design intent.

Armed with this information, designers can, with proper execution, address all the health, safety, and welfare criteria of glass structures, says Thomas: "Glass, like any construction material, can be safely engineered for the loads acting upon it."

Of course, the **practical benefits of transparency** are well documented. O'Callaghan points out that introducing natural daylight into a facility supports sustainability, occupant health, and even operational efficiency. Research documents the positive effects of design strategies that reduce artificial light in favor of more natural daylight on occupant productivity and absenteeism. Daylighting can also save energy costs in operations from $0.05-0.20/sf/year, according to the Whole Building Design Guide (http://www.wbdg.org/resources/daylighting.php), especially when integrated with lighting control systems, reflective interior surfaces, and elements for shading, filtering, and diffusing sunlight.

Three more arguments promote the viability of structural glass: *versatility, proven track record*, and *availability*. First, a wide range of structural glass concepts has been developed commercially in recent years. Second, says Mic Patterson, LEED AP BD+C, director of strategic development for the Advanced Technology Studio at Enclos Corp., Los Angeles (www.enclos.com), there are now "hundreds of novel structural glass applications in the built environment."

The successful track record of structural glass has increased its availability, concludes Michael J. Louis, PE, a senior principal for national engineering firm Simpson Gumpertz & Heger (www.sgh.com), with a growing list of manufacturers competing for attention. Improvements in the fabrication and manufacture of glazing and related technology have added further to its viability, in particular for

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Load-bearing glass spans, shown supporting a cantilevered steel-beam roof, could bring commercial projects closer to the ideal of complete transparency.

load-bearing glass integrated into building structures.

The challenges and limitations of these systems are just as important to bear in mind, says Muller. Long-term costs are in question, he says, because replacement cost of structural glazing and support elements can be prohibitive. There are also the limitations of the material itself: glass is by nature brittle and vulnerable to sudden and remarkable failure should circumstances exploit even minor flaws. Clearly, successful achievement of a design concept requires a great deal of knowledge and experience, says O'Callaghan, whose firm designs structural glass for Apple Stores globally. "Many glass structures dilute the original concept to the extent that the decision to use the material is questionable," he adds.

The more challenging the approach, the less likely Building Teams are to find useful precedents or design guidance, says Agnes Koltay, a façade consultant and director of Koltay Façades in Dubai, UAE (www.koltayfacades.com). "When it comes to possible application of more engineering-demanding systems, there's relatively less literature and fewer ready formulas available to help the design. The [lack of] available in-house knowledge may place limitations to designing them as well," she says.

Koltay and other experts recommend working with a façade engineer to facilitate successful application of highly technical designs, such as glass beam-supported skylights, tensioned cable-supported atrium glass walls, bent glazed enclosures, and even custom high-rise curtain walls.

In the end, spectacular designs and high-performance buildings can result, making the effort worthwhile. "Structural glass is the statement of innovation, clarity, and sense of beauty beyond pure materialistic thinking," says Christian L. Stutzki, PE, PhD, Stutzki Engineering Inc., Milwaukee. "It shows that this company cares about details, and strives for the best it can offer to its customers."

STRUCTURAL GLASS DEVELOPMENT

"In most cases structural glass façade technology becomes more about the exposed structural systems that support the glass than about the glass itself," says Patterson. "The effort is to dematerialize the structural system." New systems and technologies continue to emerge that are largely successful in this regard, adds Patterson, who recently published a book entitled *Structural Glass Facades and Enclosures*.

For decades, curtain wall systems have dominated glass façade construction, thanks to their reliable structural and thermal performance. Window wall facades, in which the glazing is fastened between metal floor decks or concrete slabs, have largely given way to glass and metal systems hung outside the slab edge. The result has been a cleaner, airier look, but one that still plainly exhibits the underlying structure. Aluminum mullions and silicone or other sealants held the panes—or, in the case of many thermal performance designs, *insulated glass units* (IGUs) —to the frame and substructure.

The quest for what Patterson calls a "dematerialized" system led to novel technologies for commercial applications, albeit at a higher price point. *Glass fins* may represent the earliest such enhancement, dating back at least to the 1972 Willis Faber and Dumas Headquarters in Ipswich, England, by Norman Foster, says Patterson. In a fin system, panes are hung from the structure above, fastened with either pin or moment connections that transfer wind load to the structure. Glass fin units can be very large, though in practice they are limited to about 30 feet in height if the glass is floor-loaded, or "stacked," instead of hung.

Vertical applications that have followed include *cable supports, truss supports, glass-on-steel*, and *point supports*. These frameless systems have garnered significant attention for their light-as-air appearance, bringing transparency to new levels. The significant engineering revolutions involved, coupled with technological improvements in glass fabrication, have led to daring advances in sloped applications, far beyond mere skylighting.

Sloped glazing systems, because they are typically overhead of

NICOLAS FLEURY

The frameless "glass box" and light load-bearing elements (glass stairs, balustrades) put Fifth Avenue's Apple Store in New York at the forefront of structural glass aesthetic achievements in commercial applications

occupied spaces, require careful attention for safety. "It is imperative that the designer consider how the glass fails as a fundamental design parameter," warns O'Callaghan, an engineer. "Essentially the designer must assume the glass will fail rather that hope it won't." Experts such as Stutzki begin the engineering process with the imagining of worst-case "breakage scenarios." According to SGH's Louis, the following guidelines are valuable for planning the use of sloped glazing:

- Slopes must be sufficient for drainage.
- Interior panes should be laminated for safety of occupants below.
- Glazing seals are required and should be inspected regularly, because there is no drainage system as with conventional skylighting.
- Condensate gutters or a warm air supply at the underside may be used to minimize condensation (the gutters transmit water from cross-members to rafters and from there to perimeter drains.)
- Sloped glazing should overhang vertical glass walls, to reduce the flow of water down the wall.

Beyond sloped glazing, breakthroughs in glass technology have also led to the introduction of glass structures in areas other than the façade. Glass stairs, exterior overhangs, walkways with glass floors, glass columns and transparent balustrades have offered designers and their clients more ways to achieve a not-there feeling in the built space.

Patterson adds that there are applications for structural glass technology in *double-skin applications*, where the outboard skin may be supported by a cable net or mullion. Examples include Loyola University's Richard J. Klarchek Information Commons, a 70,500-sf library in Chicago designed by Solomon Cordwell Buenz with Transsolar Climate Engineering of Germany.

FROM FRAMED TO FRAMELESS

For seasoned building professionals, the term structural glass may be interchangeable with what has been called frameless systems. "Curtain wall is not what we think of as a structural glass application," says Jeff Haber, managing partner with specialty contractor W&W Glass, Nanuet, N.Y. He notes that many structural glass approaches eliminate the aluminum frame and replace it with either glass elements or stainless steel in the supporting role. Once seen as a marvel, these systems are common and well understood today.

Prominent examples include the large glass lobby wall at Time Warner Center facing Manhattan's Columbus Circle. In terms of cost, "The bigger the span, the lower the delta between point-supported glass and curtain wall," says Haber, explaining why larger spans tend to be more cost-effective for fin, cable, point-support, or similar systems. Like all such applications, says Haber, whose company engineered the Time Warner Center installation, the structural solution essentially requires two systems: the steel structure, and the glass envelope hung from it.

Enclos's Patterson adds that these structural glass façades typically employ a barrier system composed of field-applied butt-glazed silicone joints between adjacent glass panels, an approach that eliminates the need for a framing system. In this way, says Haber, structural glazing eliminates other performance issues related to framed systems. "The frames can represent 10-15% of the façade surface area, so if they are not thermally broken they can compromise the performance of the weather envelope," he says. "Air infiltration can also be an issue in the framing system, as can the material finish."

Furthermore, Haber points out that frameless systems can utilize most glazing types associated with curtain walls and window walls, delivering all their attendant benefits—and drawbacks: low U-values, low shading coefficients, low SHGC, and the like. This means that frameless systems should compete well against comparable framed systems in terms of thermal performance. "Depending on climate and on how the point supports are done, you can minimize thermal transfer through the fittings with plastic and nylon isolators in the point support unit that prevent glass-to-metal contact," he says. An example of this approach is One Bryant Park, cater-corner to the New York Public Library. The LEED Platinum building features a point-supported glass lobby wall designed for overall energy performance.

The main goal of a frameless system, however, is not efficiency but aesthetics. "This is when the design and execution of the system becomes pivotal," says O'Callaghan, whose firm engineered the much-photographed glass-box entrance to an Apple Store on Fifth Avenue in New York. "When we are designing glass structures we are really designing fittings, because these are what the eye is drawn to—not the glass." In this way, the engineering and layout of connections, joints, and fittings become the priorities.

Two basic types of point-fixed frameless systems are employed today, says Patterson: the most common, the bolted type, which requires drilling holes in the glass to seat the attachment; and a clamping approach with no requirement for penetrations through the glass panels. Patterson says that the clamping system may have cost advantages in some cases.

In general, however, frameless systems are expensive to manufacture

COURTESY STUTZKI ENGINEERING INC.

The undulating canopy outside the Brooklyn Academy of Music presents a unique non-façade application of structural glass. Safety is a primary consideration in overhead applications.

and erect. There are difficulties, too, says Koltay: "Frames give visual separation of the glass lites, but for frameless glazing with only 20-25mm sealant or gasket at the joints, any misalignment, in-out stepping, or otherwise varying joint widths are very visible." The fabrication and construction crew need to consider these factors to ensure uniformity in the look of the finished frameless façade.

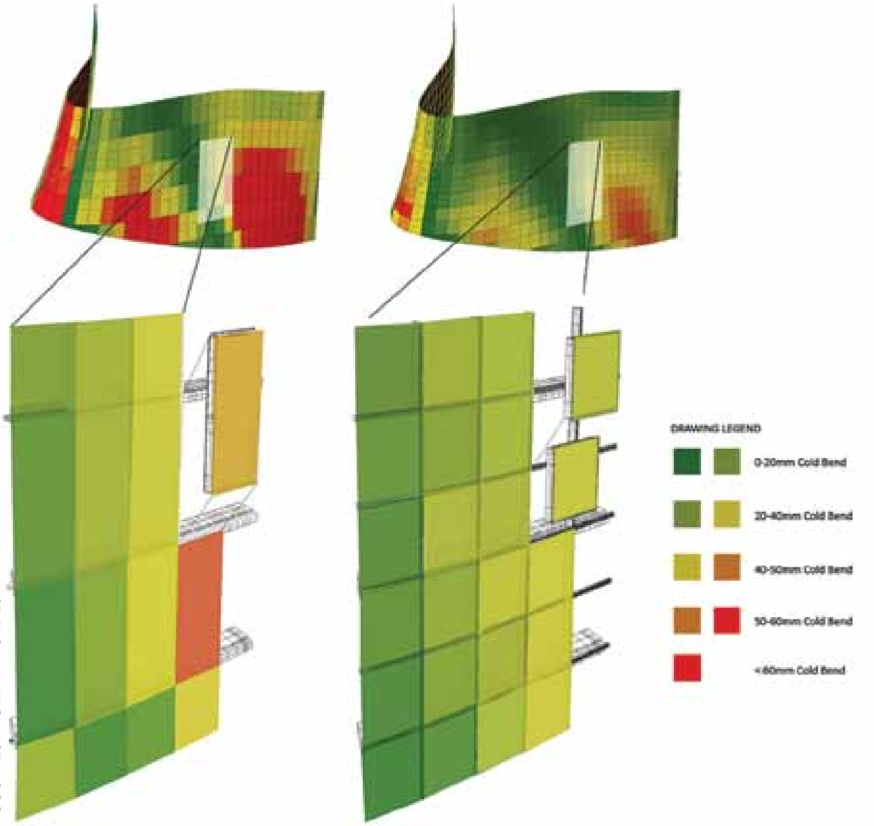
With cost and execution at issue, Building Teams should be certain that visibility is of utmost importance to the space before settling on a frameless glass solution. "The extra investment into frameless glazing systems is immediately obvious for glass walls that require 100% visibility, like protective walls in front of grandstands at race tracks, or large showcase windows for retail stores," says Stutzki. "Where aesthetics and visibility are not mission-critical, the stakeholders should consider glass curtain wall instead based on its proven reliability and return on investment."

LATEST DEVELOPMENTS IN GLASS AND GLAZING FABRICATION

Whether framed or frameless, care must be taken to ensure the integrity of the glazing. "Glass is fragile, and edge chips may lead to later breakage, even years after installation," says Koltay. Stick systems and other built-up enclosures that are handled and installed on the job site are prone to edge damage. She points to *unitized systems* as an alternative, because the system is glazed in a controlled factory environment and can be fitted with edge protection, a thin protective frame around the glass.

Fortunately for design and construction professionals, glazing technology continues to advance. One important development is the ability of fabricators to produce spans of enormous size, which seasoned professionals applaud. "This approach consequently drives down the number of joints and fittings and therefore enhances the transparency," says O'Callaghan, making it arguably "the nirvana of glass structure."

To reach this enlightened state, heat-strengthening and tempering glazing have improved to make large monolithic glass plates more robust. Two or three decades ago, says Haber, the quality of glass suffered from these processes, and the materials were specified more for strength than for beauty. Pointing out the distortions and waves apparent in reflective glass façades from that era, Haber says, "That's often a function of poor quality control. If the rollers of the tempering bed are too far apart, or if the glass is too hot, the glass can become soft enough to dip slightly between the rollers, creating roller-wave distortion. The "quench"—cooling air used to stiffen the glass—can make that slight distortion a permanent feature. New, customized processes have been developed to reduce roller-wave distortion by as much as 350%, says Haber: "You can see how absolutely flat the glass is. Reflections of the surrounding environment are pristine."



COURTESY KOLTAY FACADES

Modulation studies and offset analysis were undertaken for a cold-bent curved glazing façade with draping effect, carried out for a high-rise building in Lebanon.

Other similar advances help make glass look better and smoother. Creating curved glass is sometimes desirable, for example, and heat has normally been the agent to create it. The recent advent of *cold-bent curved glazing* is now shaking up the commercial market, offering a few important advantages. "The traditional method of using heat induces distortions in the glass, which compromises the transparency of the material and the quality of its appearance," says O'Callaghan. "Using cold bending as a solution for curved glass mitigates these problems and enhances its attraction to designers and engineers."

Patterson describes two methods of creating cold-bent glass:

1) The first involves fabricating a flat glass panel and bending it during installation, fixing it to a supporting structure in the bent form. Any type of glass makeup can be cold-bent in this manner: insulated glass units, monolithic, or laminated panels.

2) The second technique involves pre-bending the glass in special forms, and laminating the glass in the pre-bent form. The shape will relax when removed from the form, but retain some level of curvature.

Stress on the panel is unavoidable, but can be minimized. For instance, bending a rectangular panel parallel to the shorter axis is easier to do than with a more squarish panel; therefore, a wide aspect ratio indicates a better piece of glass for cold bending. Patterson also notes that cold bending an IGU applies stress to the hermetic seal that must be carefully evaluated—and accepted by the glass supplier—so as not to void product warranties.

Both Koltay and Louis warn that cold-bent glass is, by definition, under constant stress. According to Louis, long duration loads cause glass to lose strength over time, including that of the bending. He cautions that the design must account for the reduced strength while maintaining adequate safety margins.

Building Teams seem highly optimistic about cold-bent glass applications. Koltay acknowledges that cold bending puts the panel and components under permanent stress that has to be "carefully calculated and tested" so that the units maintain long-term durability. Her firm, however, has been involved in several successful cold-bent facade designs for high-rise application.

Currently, there is no standard testing methodology for cold-bent glass techniques. "However, with independent research and refining the methodology project by project, we now have a good understanding of the requirements," says Koltay. "It enables architects to use a greater degree of freedom of the form, with minimal cost impact." Koltay points out that hot-bent glass is generally three to four times as expensive as flat glass, meaning that cold-bent offers a workaround for creating complex, fluid shapes without the expense of hot-bend fabrication.

Another innovative glazing type gaining traction is the *triple-glazed IGU*. Like other insulated glass units, the idea is to sandwich a layer of gas between lites as thermal insulation; the triple-glazed versions have three lites, with two layers of gas between them. The triple-glazing approach has been popular in colder northern climates; they have been specified for such projects as the Queen's Lantern, a long-span, point-supported system creating a 55-foot-tall glass box, as an addition to the Canadian Museum of Nature in Ottawa. "They've been using triple-glazed units for many years in Canada," says Haber, "so it's not as foreign an idea as it is down here in the U.S."

"But when you start using triple-glazed IGUs in a point-supported system, it does start to get pricey," Haber cautions. The main reason is that the fabrication process requires highly advanced technology; in addition, incorporating triple-glazed IGUs into a curtain wall is much more common—and less expensive.

Because glazing with excellent thermal properties is becoming more of a priority, especially in colder climates, a novel product usually referred to as "*super-insulated IGU*" has been introduced, says Thomas Schwartz, PE, president and senior principal with SGH. The assemblies use an embedded layer of silica aerogel rather than a third pane to achieve higher R-value. Similarly, as Optimum Design's Thomas points out, "Insulated glass units compartmentalized with layers of film offer a clever way of supporting energy efficiency without the weight of intermediate glass lites."

Finally, it's worth noting the increased use of glass types with embedded microtechnology. Though they are unlikely candidates for load-bearing or structural glass systems, the potential exists for the future if manufacturing costs come down significantly. *Photovoltaic glass* is one such glazing type, which in some cases combines vision glass with photovoltaic panels, says SGH's Schwartz. Indeed, advances looming on the horizon indicate the possibility of harnessing infrared and other invisible light to generate voltage, while allowing visible light to pass through unhindered.

Another technology is *electrochromic glass*, sometimes called "smart glass," a laminated glass product that includes an electrochromic layer sandwiched between conductive films. When connected to a power source, the conductive films cause the electrochromic layer to become dark, or in some cases reflective; when the power is turned off, the layer becomes transparent again. "These systems have a great potential to deliver significant energy savings to building owners," says Louis. Additionally, smart glass can be used in unique interior applications, such as having a glass-walled conference room that can become entirely private with the flip of a switch.

Beyond the structural specifications of the glass assembly or material, other performance aspects are important to consider depending on the project characteristics. "The focus varies building to building, depending on the location, geometry, and function," says Koltay. "Good performance in seismic design, U-value, shading coefficient, natural ventilation, acoustics, and even bomb-blast

WILLIAM J. SERSON

The Queen's Lantern, a 55-foot-high addition to the Canadian Museum of Nature in Ottawa, combines a frameless point-fixed system with super-insulating triple-glazed insulated glass units.

resistance can be the design driver."

Experts in glass system design tend to custom tailor their performance priorities, says Koltay. In the case of glass façade framing systems, for example, the frame itself can represent about 10-15% of the exterior surface area. The framing systems must be thermally broken so they don't act as a thermal bridge, compromising the performance of the weather envelope, says Advanced Structures' Patterson. These are factors that lend an advantage to frameless, structural glass enclosures.

Air infiltration. For exterior assemblies incorporating glass, structural loading is linked directly to air infiltration and water penetration: movement equals the potential for small openings to let air and water move to where they are not wanted. Curtain walls, for example, may be face-sealed, water-managed, or pressure-equalized types of systems; ironically, the face-sealed type may be the least reliable in terms of resistance to air leakage.

"Generally, all-glass systems consist of glass components with organic sealants at the joints, and so depend on the continuity of the sealants for water penetration and air infiltration resistance," says Louis. Patterson adds that these structural glass facades most frequently employ a face-sealed or barrier system for weather protection. "This is a simple field-applied, butt-glazed silicone joint between adjacent glass panels," says Patterson. He calls it "an approach that eliminates any need for a framing system, and all of the accompanying issues."

Air infiltration is a key consideration with glass framing systems, says Patterson. By going frameless, the building can avoid the difficulties associated with keeping the glass-metal interface airtight, but other potential problems must be considered. For all-glass systems or silicone joints, adherence to specs and recommended details is vital to long-term performance. "The sealant manufacturer should be consulted regarding the design and application of the joint," Patterson advises.

Air infiltration is very unlikely through a glass panel, but framing systems offer leakage paths through gaskets, joinery defects in mullions, and imperfections in applied sealants. There are acceptable maximum levels of air infiltration through a curtain wall, defined by the American Architectural Manufacturers Association (AAMA) and other standard-making bodies as typically less than 0.6 cubic feet per minute per square foot (CFM/sf) of wall area at a given test pressure, as defined by the ASTM E-783 standard. System specs should call out the maximum infiltration level and also cite the testing standard if it's a manufactured system.

Water/moisture resistance. Air pressure differential is also the mechanism behind penetration of bulk water and water vapor into and through the building enclosure. In colder climates this effect tends to push air from indoors to the exterior; in warmer climates, it's reversed.

Another effect is simple gravity, says Optimum Designs' Thomas. "In sloped glazing applications, it is important to provide an appropriate waterproofing strategy so that the system does not leak."

Among the key standards used for curtain wall are ASTM E 1105, a field-testing standard developed to ensure adequate retention of water for windows and doors, and AAMA 502, a set of guidelines that show how to conduct onsite testing of the E 1105 standard. AAMA 503 is a similar set of guidelines tailored to storefronts and curtain walls. While the International Building Code requires all exterior wall coverings to provide weather protection, there are no prescriptive requirements for water and moisture resistance of curtain wall or structural glass walls.

COMING YOUR WAY:
load-bearing glass goes commercial

Few if any commercial structures have employed a cantilevered roof built from steel beams entirely supported on one side by a load-bearing glass wall. But it's coming soon.

One of the first such attempts in North America was made in 2001 for the Klein Residence in Santa Fe, N.M. The high-end project, designed by New York firm Ohlhausen DuBois Architects, sits on a pristine tract in the American West. The Kleins wanted what many commercial and institutional property owners also want: a place that protects the building interior and contents—in the Kleins' case, a collection of contemporary art—while simultaneously celebrating the landscape's power and bringing it indoors as fully as possible.

"People now are very open to the idea of space having a much more fluid definition," says Mark DuBois, AIA, LEED AP, a partner with Ohlhausen Dubois. He calls the idea of a glass-supported wall "provocative—it forces you to reassess how you think of space."

DuBois encountered the notion of using glass as an option for a structural support system in an article on the firm Dewhurst McFarlane, whom he then engaged for structural engineering on the project.

After exploring several concepts, including L-shaped and cruciform load-bearing columns in plane with nonbearing panels—concepts ultimately rejected because of connection problems revealed in the research process—DuBois and Dewhurst MacFarlane settled on a multipanel bearing wall. A rigorous phase of building and testing full-size mockups confirmed the choice.

Could integrating glass with other more conventional support systems become viable for mainstream commercial projects? "What we did, I think, could be used in many different applications, as part of more conventional kinds of buildings," says DuBois. He points out that the high-quality glass used to fabricate the support columns is readily available from a number of manufacturers.

What needs to be researched, developed, and improved is the engineering of connections and joints at the head and sill, where the glass meets steel or concrete. "I think this will start to happen," says DuBois. "The Apple Stores are generating a great deal of interest in all-glass construction."

In fact, visitors to Apple Stores see many examples of load-bearing glass, such as glass stairs, floors, balustrades, and structural glass facades that bear their own weight outright, which is no mean feat.

GLASS AND ENERGY: BECOMING MORE OPAQUE

Regardless of the glass system design approach, any glass materials selected for use as part of the building envelope must be chosen with energy-efficient performance in mind. Recent design trends suggest that the pendulum may be swinging back in the direction of more opaque surfaces, which insulate better and more easily meet today's demanding energy codes.

For example, when designing a structural glass façade, which is driven by the pursuit of maximum transparency, a design rationale must address energy strategy.

"Energy efficiency is arguably the most critical issue with regard to the implementation of glass building systems, and it can only be expected to intensify in the future," says Optimum Designs' Thomas. He recommends integrating thermal modeling and energy strategies within the design process to avoid making glass façades amount to a long-term liability.

Often, Building Teams run thermal simulations in parallel with structural calculations, says Stutzki. The results will also provide details on light-in transmission into the building as well as reflections onto neighboring buildings, and can compare the relative benefits of introducing adaptive shading systems.

In addition to shading, the selected glass materials may be available with low-e coatings or other means of controlling how much heat and light enter the building, according to Eckersley O'Callaghan's James O'Callaghan.

In all applications of glass, says SGH's Louis, "The design approach must balance the amount of light transmission with the solar gain through the glass system." Techniques available for any glass application may be useful in structural glazing and load-bearing glass applications: low-e and other coatings, films, tinting, fritting, and smart or insulating glass sandwiches.

To reach a degree of energy efficiency that is truly sustainable, Building Teams can look to many of these new technologies and approaches and be thankful that the main material choice is more efficient and more protective than ever before. +

> EDITOR'S NOTE

This completes the reading for this course!
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1. The structural integrity of load-bearing glass assemblies includes which effects on occupant health, safety, and welfare (HSW)?
   A. Performance under dead loads and live loads.
   B. Thermal expansion and contraction.
   C. Seismic resistance.
   D. All of the above.

2. For building designs, the structural properties of glass compare with what other materials?
   A. Aerated concrete
   B. Construction-grade plastics
   C. Aluminum alloys
   D. None of the above

3. The primary benefit or benefits of specifying structural glass in a commercial project, whether as part of the facade or elsewhere in the building, are:
   A. Thermal performance
   B. Aesthetics and transparency
   C. Blast resistance and security
   D. Air and vapor permeance

4. The use of glass as a structural element benefits from a variety of recent developments, including:
   A. Modeling and destructive testing of assemblies.
   B. Commercial availability of structural glass systems.
   C. Improved manufacture of load-bearing glass.
   D. All of the above.

5. True or False: Glazing fabricators and structural system manufacturers have introduced hundreds of novel structural glass applications for commercial facades and other building assemblies.
   A. True.
   B. False.

6. The architect Norman Foster's 1972 Willis Faber and Dumas Headquarters in Ipswich, England, is one of the earliest examples of what structural glass technique?
   A. Window walls
   B. Sloped structural glazing
   C. Structural glass fins
   D. Curtain walls

7. Experienced glass structure and façade designers strongly recommend which of the following strategies for commercial projects involving structural glass?
   A. Having practiced and knowledgeable designers and engineers on the team, who have first-hand experience with the system being specified.
   B. Hiring a façade consultant.
   C. Approaching overhead and sloped applications with safety as a priority, essentially assuming that the glass will eventually fail and planning for that eventuality.
   D. All of the above.

8. The distortions and waves apparent in reflective glass façades, particularly apparent 20 to 30 years ago, were generally caused by:
   A. Structural stresses from live loads.
   B. Tempering roller dips that occurred in manufacturing.
   C. Thermal shock caused by solar gain or HVAC systems.
   D. All of the above.

9. There are two techniques for cold-bent glass. Which of the following is NOT a technique for bending or curving glass panels?
   A. Creating a metal form to cast molten glass into a curved shape.
   B. Bending a fabricated laminated flat glass panel during installation.
   C. Pre-bending glass in special forms before lamination.
   D. Bending an insulated glass unit (IGU) after it is manufactured.

10. Structural glass assemblies are typically face sealed. Curtain walls, on the other hand, may be:
    A. Face-sealed systems
    B. Water-managed systems
    C. Pressure-equalized systems
    D. All of the above.