

# preventing and treating failure IN GLAZED CURTAIN WALL SYSTEMS



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Workers repair a failed glass curtain wall. “As glazed curtain walls age, many of their components may reach the end of their service lives,” say the authors. Then, leaks and drafts may become recurrent problems.

## LEARNING OBJECTIVES

Based on the information presented in this AIA/CES Discovery course, you should be able to:

- + **IDENTIFY** causes of distress in glazed curtain wall systems that can lead to premature failure, necessitating the consumption of additional materials, energy, and manpower resources for remediation.
- + **DESCRIBE** types of glazing and frame construction commonly used in curtain wall systems, and explain the benefits and drawbacks of each in terms of energy, safety, performance, cost, environmental impact, and construction scheduling.
- + **APPLY** ASTM International test standards to the evaluation of existing curtain wall systems, so as to assess air and water penetration resistance and structural integrity and thereby protect the health, safety, and welfare of occupants and users.
- + **ADAPT** design considerations, including energy efficiency, fire safety, seismic and wind loading capacity, and daylighting, to the rehabilitation of glazed curtain walls, in order to improve building performance (including indoor environmental quality) and extend the service life of the building (i.e., durability).

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In a general sense, the term “curtain wall” refers to an exterior wall that does not support loads other than its own weight. Curtain walls are therefore nonstructural, and serve solely to protect the building from the elements. Seismic and wind forces on a curtain wall are transferred to the supporting structure at anchorage points, where the curtain wall frame is attached to the building, generally at floors or columns.

Although curtain wall systems may incorporate a variety of materials, we will focus on the type that is so ubiquitous, it has effectively become synonymous with the words “curtain wall”: the glazed curtain wall system. Glazed curtain walls usually consist of a metal frame, often aluminum, with infills of vision and spandrel glass. Other materials may be interposed between glazing units, including brick veneer, precast concrete, metal panels, and thin stone. The hallmark of these systems is a focus on large expanses of glass, which shrouds the building in a seemingly weightless veil of light.

Glazed curtain walls were a marvel when they were first developed, in the early 1900s, and since that time American cities have seen the construction of a great number of glass buildings. With soaring heights and sweeping views, glazed curtain walls offer desirable office, retail, and residential spaces that are usually faster and less expensive to construct than are their bearing-wall counterparts. As glazed curtain

walls age, however, many of their components reach the end of their service lives. When leaks and drafts become recurrent problems, it can be difficult to determine the best course of action.

Armed with an understanding of basic curtain wall construction and familiarity with common problems, the prudent building owner or facility manager can identify and manage curtain wall distress with appropriate, proactive strategies.

## A BRIEF REVIEW OF THE DEVELOPMENT OF CURTAIN WALL TECHNOLOGY

The development of the elevator in the late 1800s launched the national impetus toward high-rise buildings. With the advent of structural steel and reinforced concrete, architects, engineers, and contractors in Building Teams no longer needed to rely on the exterior wall system to support the building structure, permitting the

practical construction of taller and lighter buildings. One of the first glass curtain walls, designed by architect Louis Curtiss, was constructed in 1909 in Kansas City, Mo. The Boley Clothing Company Building used glazed curtain walls framed by traditional cast iron and terra cotta ornaments, combining new technology with established period design elements.

Soon thereafter, in 1918, the groundbreaking Hallidie Building was completed in San Francisco. Architect Willis Polk took advantage of the properties of reinforced concrete to create cantilevered floor slabs, which permitted the glass curtain wall to appear to float at the building exterior, unencumbered by columnar supports.

With curtain wall technology thereby established, these early examples were soon followed by the first glass curtain wall high-rise in New York City, Lever House, along with the United Nations Secretariat Building, both completed in 1952. Mass production of sheet metal

## The basics of CURTAIN WALL CONSTRUCTION

Glass curtain walls consist of two basic components: *the glass* and *the frame*. How these two elements are manipulated, including the proportion, properties, and anchorage of each, constitutes the essential distinction among individual curtain wall systems.

The **frame** is the support grid that holds the glass in place. It is made from steel, aluminum, multi-laminate glass, or other resilient material.

**Stick systems** are curtain walls at their most basic, with individual mullions, or framing elements, assembled in the field.

**Unitized systems** apply the same design principles as stick systems, but sections of the curtain wall are assembled remotely in the shop and installed as a unit.

**Unit mullion systems** combine the pre-assembled panels of unitized systems with the multi-story vertical mullions of stick systems. Upright mullions are installed first, with horizontal mullions and glazing installed as a unit.

**Column cover and spandrel systems** articulate the building frame by aligning mullions to structural columns. Preassembled or field-assembled infill units of glass or opaque panels are fitted between the column covers.

**Point-loaded structural glazing systems** eliminate visible metal framework by incorporating tension cables, trusses, glass mullions, or other custom support structures behind the glass panels. Glazing is anchored by brackets or by proprietary hardware embedded in the glass.

## SEVERAL KEY FACTORS TO CONSIDER WITH GLASS

Curtain wall glazing ranges in price, durability, impact resistance, safety, and stability, depending upon the manufacturing process. The most common types:

**Float glass** was developed in the 1950s by Alastair Pilkington, whose breakthrough float process enabled production of the large glass sheets that characterize curtain wall construction. Molten glass is fed into a bath of tin, where it flows along the surface, forming smooth glass with even thickness.

**Annealed glass** undergoes a controlled heating and cooling process that improves its fracture resistance. Despite its improved durability, annealed glass can break into sharp pieces, and many building codes limit its use in construction.

**Tempered glass** is chemically or thermally treated to provide improved strength and shatter resistance. On impact, tempered glass shatters into tiny pieces that are less likely to cause injury than would larger shards.

**Heat-strengthened glass** and **chemically strengthened glass** fall between annealed and tempered glass in terms of strength. Unlike tempered glass, strengthened glass can be sharp when shattered, so it is best suited to areas with limited access. Scratches in strengthened glass have also been shown to compromise its strength.

**Laminated glass** bonds two or more sheets of glass to an interlayer of plastic, generally



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polyvinyl butyral (PVB), which holds the glass in place if broken. Laminated glass is often specified for curtain walls in hurricane-prone regions or in areas requiring blast protection.

**Insulating glazing units (IGUs)** improve thermal performance through the use of double or triple panes of glass, separated by a space that is filled with air or an inert gas.

**Spandrel glass**, which is darkened or opaque, may be used between the head of one window and the sill of the next. To create the illusion of depth at spandrel areas, transparent glass may be used in a shadow box, with a metal sheet at some distance behind the glass.

For all their variation, glass curtain walls retain the same basic components as they did when Willis Polk first envisioned them in the early 1900s. Understanding the composition of glass and frame, as well as the relationship between them, is vital to maximizing the longevity of a glazed curtain wall system.

and glass following World War II enabled larger areas of glass, and technological developments in sealants and glazing compounds permitted more reliable glazing anchorage. By the latter part of the 20th century, aluminum had widely replaced steel as the primary framing material, owing to industrial innovations that permitted its inexpensive extraction. Aluminum has the additional benefit of being easily extruded, and it is not prone to corrosion, as is structural steel.

In recent years, glass curtain wall construction has become commonplace, moving out from city centers to suburban office parks, malls, hospitals, and universities. The abundance of curtain walls means that it is especially important to understand the significance of common symptoms of aging, wear, and distress, and to respond promptly at the first signs of trouble.

## THE FOUR MAIN CAUSES OF DISTRESS AND FAILURE

Like all building elements, curtain walls have their weak points. Knowing what to look for, how to extend the service life of a curtain wall system, and when it's time to retain a consultant are critical to avoiding costly and disruptive failures. Although issues vary with frame material, construction method, and glazing type, there are some common concerns that design professionals and other Building Team members look for when evaluating the condition of a curtain wall system. These include deflection, glazing failure, gasket and seal degradation, and design or construction defects.

**1. Deflection.** Aluminum has many advantages as a curtain wall framing material, but it has the distinct disadvantage of deflecting approximately three times as much as steel does for a given load. Even when the amount of deflection

doesn't compromise the strength of the aluminum members, it still may pose a danger in that the glass may be forced out of place. To protect against excess deflection, mullions are extruded into shapes that maximize the area moment of inertia, or resistance of a particular cross-sectional shape to bending stress. Wide-flange elements, such as I-beams, have particularly high area moments of inertia, which is why this profile is used so often in construction.

To reduce deflection in a curtain wall assembly without adding excess depth to the frame profile, steel reinforcement may be added to aluminum mullions. This method protects the steel from exposure to the elements, while taking advantage of its load-bearing properties. However, water penetration into a steel-reinforced system can also lead to deflection as the steel corrodes and expands, causing the aluminum to bow outward.

**2. Glazing failure.** A number of problems can lead to glazing failure. Condensation on glass curtain walls may be an indication that the relative humidity of the interior is too high, and the heating and cooling equipment may need to be adjusted. However, condensation may also point to failure of the curtain wall system. If moisture is observed between panes of glass in an insulated glass unit (IGU), the hermetic seal may have failed, permitting air intrusion into the interstitial space and compromising thermal performance, as well as visibility.

Hairline cracks in glass may indicate excessive thermal loading, particularly if the glass has a coating, such as a low-e film or tint. When the sun strikes the glass, it heats the exposed portion of the pane, causing it to expand. The unexposed edges remain cool, creating tensile stress that can lead to cracking, particularly in glass that has not been heat-strengthened or tempered.



Loose gaskets or seals.



Streaked glazing.



Gaskets disengaged from glazing.



Leaks and drafts in curtain wall assembly.



Displaced mullion covers.



Broken glass in glazed curtain wall.

Nickel sulfide (NiS) inclusions can cause glass to shatter suddenly, sometimes years after installation. All glass has microscopic imperfections, or inclusions, that result from the manufacturing process. Generally speaking, these are of little concern. The exception is NiS inclusions in tempered glass, which have led to a number of dramatic glass failures. As glass is heated during the tempering process, NiS converts to a compressed (alpha) phase. When the glass is cooled rapidly to temper it, the NiS lacks sufficient time to return to a stable low-temperature (beta) phase. Over months or years, the trapped NiS transitions to the beta phase, expanding as it does so. The resultant pressure leads to microcracks in the glass, which can propagate until the glass structure is thoroughly compromised, and the glass shatters in what seems to be a spontaneous breakage.

In an existing structure, ultrasound, laser imaging, or heat soak testing may be used to identify NiS inclusions; however, such test methods can be labor-intensive and expensive. For buildings with multiple glass failures, the pros and cons of full glazing replacement should be weighed against the costs of testing and isolated replacements.

**3. Gasket and seal degradation.** A common cause of curtain wall problems is failure of the gaskets and seals that secure the glazing. Gaskets are strips of synthetic rubber or plastic compressed between the glazing and the frame, forming a watertight seal. Gaskets also serve to cushion the glass and to accommodate movement due to wind, thermal, or seismic loads.

As they age, gaskets begin to dry out, shrink, and crack. Subjected to ultraviolet radiation and freeze-thaw cycles, the elastic material degrades, much like an old rubber band. At first, air spaces created by the shrinking, dried gaskets admit air and moisture into the system, leading to condensation, drafts, and leaks. As the gaskets further disintegrate, they may loosen and pull away from the frame. Without the support of flexible gaskets, the glass loses stability and may shatter or blow out. For this reason, it is important to maintain and routinely replace gaskets to keep the curtain wall system operational and safe.

In lieu of compression gaskets, some curtain wall systems use structural sealant, usually a high-strength silicone product, to secure the glass to the frame. Like gaskets, sealants have a finite service life. Signs that it's time to replace perimeter sealants

include shrinking or pulling away from the surface, gaps or holes, discoloration, and brittleness.

**4. Design or construction defects.** As with any type of construction, curtain walls are subject to the shortcomings of human capability. Material failure and age-related deterioration may be common causes of curtain wall distress, but many catastrophic and costly failures are attributable to avoidable errors.

Missing, incorrectly applied, or otherwise *deficient sealants* at frame corners and other intersections can lead to serious water infiltration problems. Failure on the part of the contractor to follow manufacturers' guidelines, or on the part of the design professional to provide sufficient oversight, can result in water damage that is both difficult to access and expensive to repair.

*Flashing detailing*, too, requires fastidious attention to prevent leaks at intersections between the curtain wall and other building elements. Without detailed contract documents that fully describe and illustrate perimeter flashing conditions, along with coordination between the curtain wall installer and construction manager during installation, flashings may not be adequately tied or terminated, permitting water to enter the wall system.

*Poorly installed trim covers and accessories* can pose a danger to people and property below, particularly when adhered using structural glazing tape alone, without mechanical attachments. Construction sequencing is of particular importance, as swing staging and scaffolding can damage or displace mullion covers. Maintenance activities may also be responsible for loose trim elements.

*Unforeseen structural interactions* among building elements may lead to failure if the curtain wall has not been properly engineered. Inadequate provision for differential movement, as well as incorrect deflection calculations, may be responsible for cracked or broken glass, seal failure, or water intrusion. Glass and framing must be evaluated not only independently, but also as a system, with consideration given to the impact of proximal building elements.

Finally, *haphazard erection techniques* may be responsible for premature curtain wall failure. Any of the above construction defects may result from unskilled and poorly supervised installation. Sloppy sealant application, for example, can block drainage outlets at the glass perimeter or weep holes, trapping water inside the wall system.



Gaps at frame corners.



Loose or missing weather stripping.



Scratches and hairline cracks.

Scratches to glass during installation may diminish its strength and durability, and improperly applied window films also may decrease the lifespan of the glass.

## EVALUATION AND TESTING

If leaks, deflection, etched glass, or other issues have become a concern, the Building Team should conduct a systematic evaluation of the curtain wall system, beginning with close visual inspection. ASTM International provides test standards for the evaluation of air and water penetration, as well as structural performance of glass in curtain wall applications. Tests for water penetration, such as ASTM E1105, use a calibrated spray rack system with a positive air pressure differential to simulate wind-driven rain. ASTM E783 specifies test procedures for determining field air leakage at specific pressures.

Glazing that displays systematic scratches or other defects after installation may need to be evaluated for structural integrity. In such cases, a representative sample of glass units may be removed and tested under laboratory conditions. ASTM E997 is one test method for determining the probability of breakage for a given design load.

## SIX FACTORS TO CONSIDER IN REHABILITATION PROJECTS

Shrinking of neoprene exterior gaskets is a common concern, and it is not always easy to fix. Although some curtain wall systems, such as those that incorporate pressure bars, may permit gasket replacement without glazing removal, by and large it is difficult or impossible to replace gaskets without removing the glass. Wet sealing, which involves cutting out worn gaskets and adding perimeter sealant, may be an option; however, wet sealing does not generally result in a reliable water barrier, and it creates an ongoing maintenance demand. Where possible, it is best to maintain the original glazing system.

Anodized aluminum frames should be cleaned as part of a routine maintenance program to restore an even finish. For powder coats, fading and wear can be addressed with field-applied fluoropolymer products, although these tend to be less durable than the original factory-applied thermoset coating. Other coatings on the market aim to improve durability, but their track records and maintenance requirements should be considered prior to application.

Should major rehabilitation or replacement of a curtain wall be indicated, at least six factors should influence the design process: 1) thermal performance, 2) structural capacity, 3) fire safety, 4) acoustics, 5) light, and 6) aesthetics.

**1. Thermal performance.** Even as recently as 50 years ago, curtain wall systems weren't as energy-efficient as solid wall construction. With energy costs and environmental considerations now topping the list of building management concerns, retrofits that increase the efficiency of glazed curtain walls have become an attractive option for improving overall building performance.

However, before investing in facade upgrades for the sole purpose of reducing energy expenses, it's a good idea to evaluate the projected time period for cost recovery. While minor retrofits may pay for themselves relatively quickly, some major upgrades may have a protracted

payback period, depending upon the existing energy profile.

Incorporating insulating glass is one of the primary methods for enhancing the thermal properties of glazed curtain walls. Some frame systems may be retrofitted to receive IGUs. Note, however, that double-pane glass is generally thicker and heavier than its monolithic counterparts, requiring, in most cases, structural modifications.

Low-emissivity (low-e) glass can improve building energy performance by keeping heat indoors during winter and outdoors during summer. Low-e coatings reflect infrared radiation without diminishing visible light, reducing solar heat gain (SHG), a rise in indoor temperature due to heat from the sun. Some coatings may be added as a retrofit to existing glazing, but use caution, as incompatible films may lead to differential heating and stress cracks in the glass. Low-e glass is also available as a glazing replacement option.

Because it is a highly conductive material, aluminum readily transfers heat between the exterior and interior of the building. Thermal breaks, made from a nonconductive material such as plastic or rubber, prevent heat transfer across the metal. Properly designed thermal breaks of adequate thickness can substantially improve the thermal performance of an aluminum curtain wall frame, as well as provide resistance to condensation.

Because spandrel areas are not generally exposed to the building interior, as vision glass is, they are more subject to condensation and differential movement due to temperature extremes. Back pans—metal sheets designed to prevent water infiltration in spandrel areas—may require superimposed insulation to mitigate temperature fluctuation.

Recent changes to state and local energy codes, including adoption of the 2012 International Green Construction Code (IgCC) and International Energy Conservation Code (IECC), may place more stringent requirements on curtain wall performance than did the codes in effect when the building was constructed. Depending upon the jurisdiction, even minor rehabilitation projects may need to comply with the tougher codes.

**2. Structural capacity.** In addition to the dead load of the curtain wall components themselves, the façade must be able to withstand



Evaluation may include measurement of gasket hardness (top) and glazing alignment (above). Glazing that exhibits systematic scratches or defects may need to be evaluated for structural integrity under laboratory conditions, the authors warn.

live loads impinging upon it during operation. Particularly for tall buildings or those in hurricane zones, wind loads are a prime design consideration. Curtain wall anchorage should be able to withstand lateral forces, while remaining flexible enough to permit movement of the curtain wall and underlying building structure. Seismic loads present a similar design challenge, as glazing pockets must retain sufficient flexibility to accommodate building sway without shattering the glass.

**3. Fire and life safety.** The open design of a suspended curtain wall makes it susceptible to the spread of fire. For this reason, firestops are required at the perimeter of each floor to prevent the migration of flames up the side of the building. Firestop material is incorporated into the hollow area between the floor slab and curtain wall to create contained space at each story. Knockout glazing panels made from tempered glass allow relatively safe emergency access in the event of a fire.

**4. Acoustics.** Laminated and insulating glass provide some measure of noise reduction, as does airtight construction. Sound-attenuating infill at spandrel areas may also help to dampen outside noise.



To achieve optimal performance for a well-designed glazed curtain wall., Building Teams should identify emerging problems and take swift corrective action, say the expert authors.

**5. Light.** Glazing replacement is expensive, but so is the cost of running heating and cooling equipment overtime to combat solar heat gain. Poorly designed windows can make looking at a computer monitor difficult, and daylighting can hardly realize energy savings when glare results in drawn blinds and daytime lights. Generally speaking, visible light transmittance (VLT) ratings of about 40 out of 100 help cut glare and restrict visibility from the exterior, without compromising occupants' views. Once VLT reaches about 70, however, the tinted glass becomes the primary focal point, diminishing visual access to the outside. The right glazing provides ample views, sufficient—but not excessive—natural light, and comfortable indoor temperatures.

**6. Aesthetics.** The most subjective metric, appearance, may also be the most persuasive when curtain wall replacement is under consideration. Changes in glazing, such as replacing nonreflective glazing with reflective glass, can have a dramatic impact on the building aesthetic. For owners wishing to maintain the current façade appearance while improving performance, replacement glass selection should consider existing sightlines, frame profiles, and glass properties.

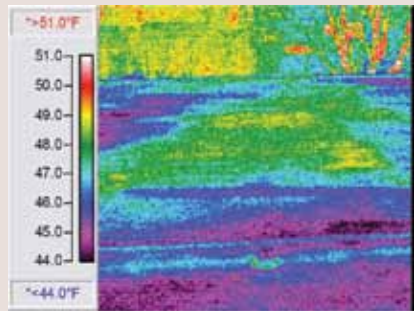
## Quantifying heat loss: INFRARED TESTING

BY RICHARD P. KADLUBOWSKI, AIA, SENIOR VICE PRESIDENT AND DIRECTOR OF ARCHITECTURE, HOFFMANN ARCHITECTS, INC.

Visual observation provides a general picture of curtain wall conditions, but there are many things you can't see. Deficiencies beneath the surface can be detected through infrared thermographic testing.

Infrared analysis can locate thermal anomalies caused by such factors as missing thermal breaks, air or moisture infiltration, or "hot spots" where mechanical or electrical equipment is malfunctioning. Thermography is noninvasive and can be performed during normal building hours. Using temperature scanners, the test generates pictorial representations of a building component's thermal profile. Correct analysis of this data can reveal problems not otherwise identifiable on an existing, occupied structure.

However, accurate interpretation of thermal images demands understanding of building envelope composition. Certain types of construction tend to dissipate heat, leading to false negative readings, whereas others reflect heat and generate false positives. In the right hands, thermographic testing can be a useful diagnostic tool. When incorporated into a comprehensive condition assessment, infrared analysis can save resources by prioritizing renovation efforts and avoiding unnecessary repairs.



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## EXTENDING THE LIFE OF GLASS CURTAIN WALLS

Glazed curtain walls offer unparalleled design options, panoramic views, and the flexibility to integrate with other types of façade systems. They also have their shortcomings. To achieve optimal curtain wall performance, Building Teams should identify emerging problems and take swift corrective action. Respond promptly to leaks, clouded glass, deflection, and other signs of wear, as these can be difficult and expensive to remedy if allowed to proliferate. Gasket and sealant replacement, generally every 10 to 15 years, should be part of a planned maintenance program. Through good design practices and routine upkeep, building owners and managers can realize improved curtain wall durability, for a system that is serviceable and attractive for many years to come. †

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