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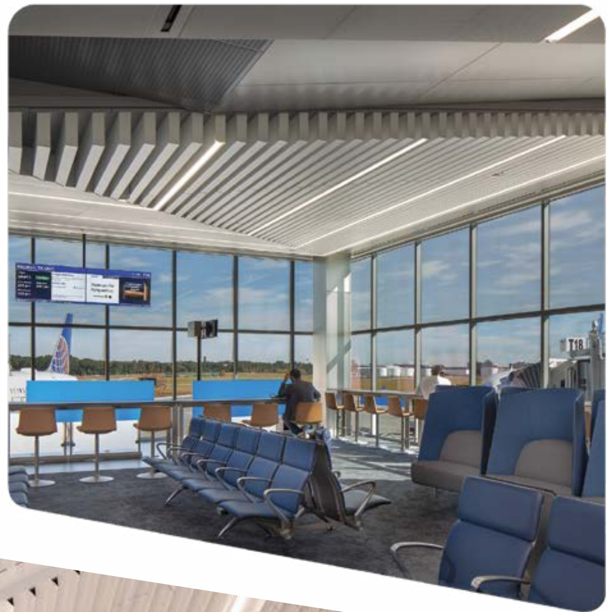

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The Seattle Aquarium Ocean Pavilion, by LMN Architects along with Thinc Design, who designed the exhibit spaces, embodies interconnectivity and sustainability, linking various iconic Seattle landmarks and the ocean. The pavilion integrates with the urban waterfront and the Aquarium's nearby harborside buildings, offering a collection of immersive marine experiences. Lighting is an important component throughout Seattle Aquarium Ocean Pavilion (SAOP), prioritizing the animals' needs while enhancing habitats and other exhibits.

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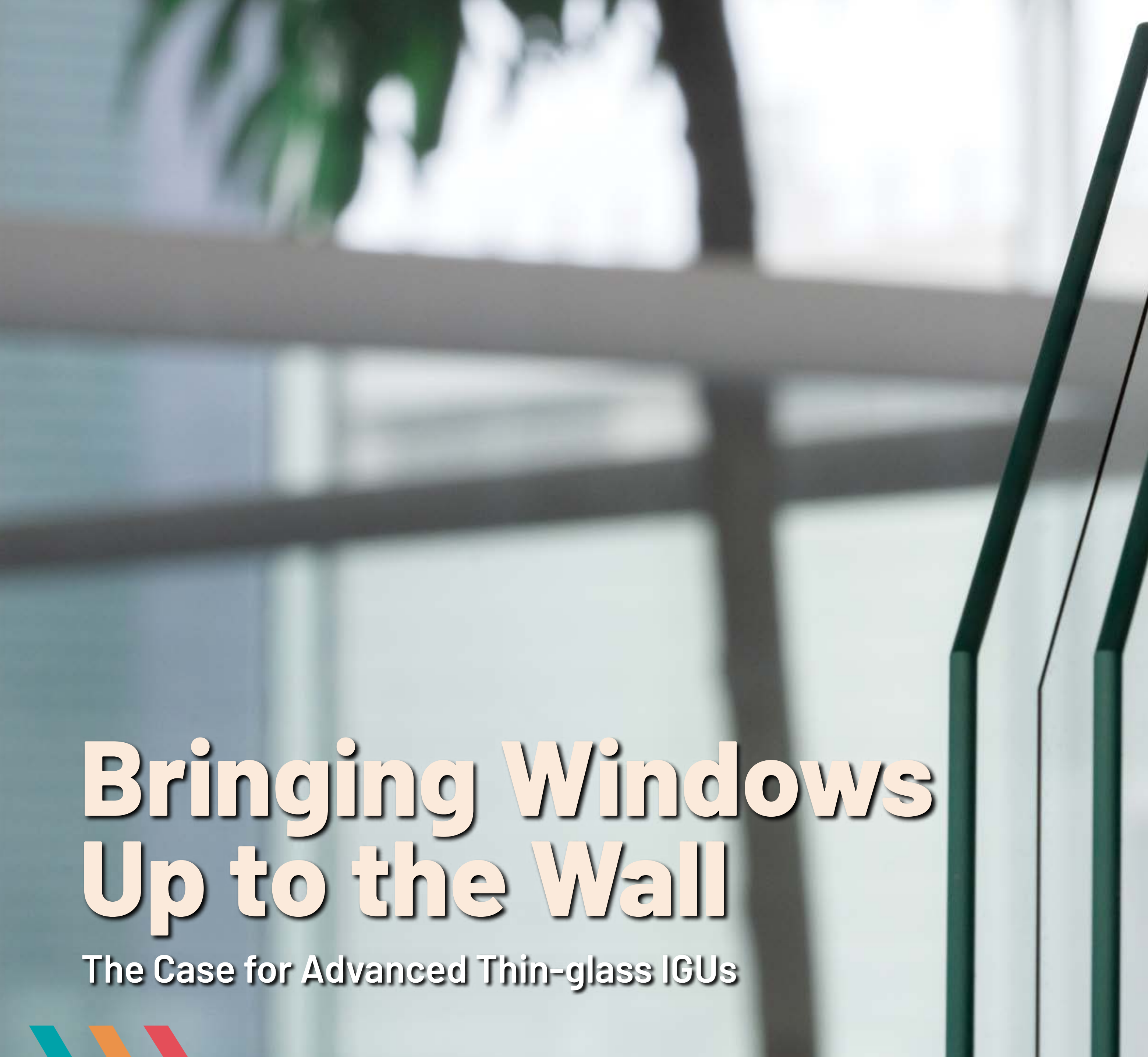

Bringing Windows Up to the Wall

The Case for Advanced Thin-glass IGUs

By Avi Bar

PHOTOS COURTESY THINKALPEN.COM

For most of the modern energy code era, Division 08 has lived with a quiet contradiction that is only complicated by an industry slow to embrace changes. Energy codes now ask buildings to perform at levels that conventional double-pane insulated glass simply cannot reach. Conventional triple-pane glass units can hit the targets, but they drag in penalties that include weight, thickness, and costs that ripple through framing, structure, and detailing. What looks like a simple "better IGU" decision on paper quickly becomes a cascade of fiscal changes in the real world.

This is not a transient building market blip. It is a structural issue in how North American fenestration has evolved. And it is exactly where advanced thin-glass insulated glass units (IGUs) enter the story today.

How we got stuck with doubles

The imbalance between walls and windows has been growing for decades. After World War II, wall assembly values crept up from roughly R–7 to R–20 and beyond. Windows stayed mostly in the R–1 to R–3 energy efficiency range. Mechanical systems filled the gap. When energy was cheap

and ductwork oversized, nobody felt an urgent need to push fenestration much further.

Two things kept that status quo in place in the U.S. long after Europe and Canada moved on. First, energy codes. Whole-building energy requirements matured later in North America than overseas, and many jurisdictions allowed relatively weak fenestration performance so long as the rest of the envelope carried most of the load.

The second was industry geometry. Manufacturers did what any rational industry does. They optimized around what the market asked for. That meant 25.4-mm (1-in.) glazing pockets, relatively light sashes, slim frames, balances, and hinges sized for the weight of a typical double. Fabrication methods were tuned to repeat that geometry at scale. Over time, that 25.4-mm (1-in.) double became the gravitational center of the North American window world.

Europe and parts of Canada followed a different path. Higher energy prices and aggressive envelope standards pushed the market toward triple glazing much earlier. Frames became deeper and stiffer. Tilt and turn hardware designed to carry heavy triple-pane windows became the norm. That infrastructure made it easier to live with 40–50 percent heavier IGUs.

In the U.S., that shift never fully happened. It now has one of the largest installed bases of framing designed specifically for 25.4-mm (1-in.) double-pane windows anywhere in the world. Many storefront, window wall, and curtain wall systems in the U.S. are engineered with the expectation of a roughly 31.7 kg/m^2 (6.5 lb/sf) double unit. A conventional triple-pane window, often in the 43.9 to 46.4 kg/m^2 (9 to 9.5 lb/sf) range, does not simply "drop in" when it comes to installation. Mullions, anchors, hardware, and sometimes floor edge details are involved.

That is why conventional triples often feel like a fringe solution in the U.S., even in a world of tightening codes. The barrier is not that people do not like better performance. The barrier is geometry, weight, and cost. Advanced thin-glass IGUs are promising, however, because they change performance without asking the rest of the geometry to change with them.

How advanced thin-glass IGUs actually work

At first glance, a thin-glass IGU looks like any other high-performance window or sliding glass door unit. As illustrated in Figures 1 and 2, there is an outer lite facing the weather and an inner lite facing the building's interior. Both of those are made of conventional soda-lime glass. They offer low-E coatings that include tints, patterns, lamination, or bird-friendly treatments. The difference is in the middle of the two pieces of soda-lime glass.

Instead of a full-thickness middle lite, advanced thin-glass IGUs incorporate a center lite of Corning's fusion-drawn boro-aluminosilicate, or

Figure 1

A corner cross-section image of an advanced thin glass triple-pane window.

soda lime float glass, typically from 0.5 to 1.1 mm (0.02 to 0.043 in.), respectively, in thickness. For context, a standard 6 mm (0.236 in.) lite is about six to 12 times thicker than that. These center lites are so thin that they add very little weight, but they still do the important job of breaking up the gas cavity into two narrow gaps.

"Splitting a single cavity into two smaller ones suppresses buoyancy-driven convection. In a single large gap, warm gas rises and cool gas falls, setting up convective loops that move heat. Two smaller gaps are much less friendly to that circulation. Paired with appropriate argon or krypton gas fills, the result is a center-of-glass U-factor comparable to or better than a conventional triple, delivered in the profile of what looks and behaves like a double." — Andrew Zech, Alpen CEO

From a physics standpoint, the composition of the thin lite matters. Boro-aluminosilicate glass has a coefficient of thermal expansion that is roughly one-third of soda-lime float glass. In practical terms, it grows and shrinks much less with temperature swings. Corning Incorporated's fusion draw manufacturing process also produces glass without contact with rollers or molten tin, which means its pristine surfaces contain far fewer micro-defects. Fewer surface flaws plus lower thermal strain translates into a higher tolerance for the kinds of stresses that an IGU will see over its life.

Just as important is where that thin lite lives in the unit. It is not exposed. It is sealed between two thicker soda-lime lites, surrounded by gas and kept away from the metal of the frame. All safety and impact requirements in hazardous locations are met by the outer lites through conventional tempering or lamination, under the same ANSI Z97.1 and CPSC 16 CFR 1201 regimes that specifiers rely on now.

The geometry does one more piece of quiet work: the thin center lite is physically smaller than the outer lites. This is known as indexing. The center lite is cut several millimeters short of the outer glass on all sides, so its edge sits fully inside the footprint of the spacer and sealant system. The thin glass never touches the frame, the setting blocks, or the glazing pocket. Structural and thermal movements are taken by the thicker soda-lime lites and the spacer edge system, not by the exposed edge of the thin center lite.

Edge construction and spacers are where a lot of thin-glass durability work is focused. Thermoplastic warm-edge spacers are natural partners. They form a continuous, fully bonded edge with low thermal conductivity and very low moisture vapor transmission. Because they are slightly elastic, they can distribute loads around the perimeter and support the indexed center lite without introducing sharp stress concentrations at corners. Modern thermoplastic spacer systems have been in service for decades in conventional triples and quads and are designed for long-term gas retention and seal durability.

Put those elements together and the picture looks less exotic than it might at first glance. From the outside, one is still looking at what appears to be a conventional double-pane unit. From the inside, it is still glazing, and the sealing appears to be a double-pane unit. However, in the cavity, there exists a very thin, very stable piece of glass doing a disproportionate amount of thermal performance work.

What changes in performance

In code terms, what matters is not only center-of-glass performance, but whole-unit U-factor. Frames and edges matter.

A typical 6 mm (0.236 in.) over 6 mm (0.236 in.) double pane IGU, with a good warm-edge spacer and argon fill, might deliver whole-unit U-factors in the 1.53–1.70 W/m^2·K (0.27–0.30 BTU/hr·ft^2·F) range in a commercial frame. That can still pass in some jurisdictions, but it is bumping against the limits of ASHRAE 90.1-2022 and *IECC* 2024 in many climate zones. For stretch codes and programs influenced by Passive House criteria, it is often not enough.

Thin-glass triples, using a 0.5 to 1.1 mm (0.02 to 0.043 in.) center lite in the same general framing geometry, commonly land whole-unit U-factors around 1.14–1.31 W/m^2·K (0.20–0.23 BTU/hr·ft^2·F) in similar systems. Thin-glass quads, with two thin center lites, can push that further into the approximate 0.97–1.02 W/m^2·K (0.17–0.18 BTU/hr·ft^2·F) range. Center-of-glass values, depending on coatings and gas fills, can approach 0.57 W/m^2·K (0.10 BTU/hr·ft^2·F) or better.

The crucial point is that these U-factors are achieved without moving to much thicker IGUs or significantly heavier glass packages. Where a conventional triple might add 40–50 percent to the weight of a double, a thin triple often adds only three to six percent. The IGU still fits within the 25.4 mm (1 in.) pocket that many systems were originally designed to accept.

Code compliance is evaluated through the same National Fenestration Rating Council (NFRC) frameworks that specifiers already use. Whole units are modeled and tested under NFRC 100 for U-factor and NFRC 200 for solar heat gain and visible transmittance. Windows and skylights receive NFRC 700 labeling. Site-built curtain wall and storefront systems route through the NFRC Component Modeling Approach. Thin-glass IGUs fabricated under Insulating Glass Certification Council (IGCC) and Insulating Glass Manufacturers Alliance (IGMA), and now the Fenestration and Glazing Industry Alliance (FGIA) certification programs—and tested to ASTM E2190 fit neatly into that existing machinery.

From the building's perspective, the impact goes beyond an abstract U-factor number. In a prototype 9,290 m^2 (100,000 sf) office with a 40 percent window-to-wall ratio, a shift from U-1.70 W/m^{2}K (U-0.30 BTU/hr·ft^2·F) to U-1.25 W/m^{2}K (U-0.22 BTU/hr·ft^2·F) glazing can reduce conductive heat loss through the window area on the order of 20-plus percent, before accounting for secondary effects. Higher window-to-wall ratios allows for more views and daylighting.

Figure 2

A similar cross-section of an advanced thin glass quadruple-pane window.

Studies from the U.S. General Services Administration (GSA) and the National Renewable Energy Lab (NREL) have shown that upgrading from high-performance doubles to lightweight low-U advanced windows can cut HVAC energy use in the range of roughly 20–30 percent in cold climate modeling and allow downsizing of heating equipment. Paybacks in roughly one to six years, depending on climate and rates. In addition, compared to a traditional triple glaze, thin glass units have a higher visual light transmittance and lower embodied carbon.

Those are the kinds of numbers that make their way into owner conversations and energy narratives. The practical question for Division 08 is how to capture that performance in specifications without prescribing one proprietary path.

This image from the Electric Pass Lodge in Snowmass, Colo., illustrates the viewing power of higher window-to-wall ratios.

PHOTO COURTESY WWW.MKMBUILD.COM

Writing advanced thin glass into Division 08

Specifiers are not being asked to become thin-glass process engineers. What they are really doing is tightening performance requirements in a way that leans on thin-glass technology to carry the load, while preserving competition among qualified manufacturers.

A useful way to think about this is in three layers.

First, define performance outcomes in terms that a code official and an energy modeler will recognize. That means:

- Whole-unit U-factor targets that align with the project's code path and performance ambitions, not just minimal prescriptive thresholds. In many stretch-code and Passive House-influenced contexts, 1.42 $W/m^2 \cdot K$ (U-0.25 $BTU/hr \cdot ft^2 \cdot F$) is a reasonable floor, with 1.14 $W/m^2 \cdot K$ (U-0.20 $BTU/hr \cdot ft^2 \cdot F$) or better as a target.
- Solar heat gain coefficients (SHGC) tailored by orientation and internal load. The same thin-glass engine can be configured for higher or lower SHGC, so this is still a design choice.
- Visible transmittance that supports the daylighting strategy, with clear expectations when dark tints or heavy frits are introduced.

Second, express the physical constraints of the framing systems in use. Many commercial systems are designed for nominal one-inch units and unit weights around 31.7 to 3 kg/m^2 (6.5 to 7 lb/sf). If the specification explicitly limits IGU thickness and unit weight to those ranges unless otherwise engineered and documented, it leaves conventional doubles and thin triples on the table and naturally screens out many full-thickness triples and quads that would demand heavier frame sections.

Third, reference the standards and certification regimes that give everyone comfort:

- NFRC 100 and 200 for thermal and solar performance
- NFRC 700 labeling for manufactured units and NFRC Component Modeling for site-built systems
- ASTM E2190 for IGU durability
- ASTM E1300 for load resistance
- NFRC 706 for gas fill, including a minimum ninety percent fill level for argon or krypton
- ASHRAE 55 for thermal comfort

Studies from the U.S. General Services Administration (GSA) and the National Renewable Energy Lab (NREL) have shown that upgrading from high-performance doubles to lightweight low-U advanced windows can cut HVAC energy use in the range of roughly 20 to

30 percent in cold climate modeling and allow downsizing of heating equipment.

High U-factor glazing does more than waste energy. It creates discomfort that mechanical systems are forced to compensate for. ASHRAE Standard 55 defines thermal comfort in part through radiant asymmetry: the difference in mean radiant temperature between a warm ceiling and a cold window surface. When interior glass temperatures drop significantly below room air temperature in winter, occupants near the perimeter feel cold regardless of what the thermostat reads. The traditional response is perimeter heating with fin-tube radiation, sill convectors, or supply air washed up the glass. These are systems that add first cost, operating cost, and spatial constraints to every floor plate they serve.

Advanced thin-glass IGUs, especially in high-performance frame systems, raise interior glass surface temperatures enough to reduce or eliminate that radiant asymmetry. When the glass is no longer the coldest surface in the room, the perimeter heating load disappears. MEP engineers can simplify or eliminate perimeter systems entirely, recapturing floor area and reducing mechanical infrastructure. That value proposition exists entirely outside the energy model. Owners and tenants feel it on day one.

Within that framework, the glass makeup is largely performance-based. On the surface, "performance-based" specifications appear ideal, but contractors find them difficult and often ask the architect or engineer what products they are based on. Outer lites can be specified as clear or tinted glass in thicknesses appropriate to structural and aesthetic needs, with low-E coating locations determined by the manufacturer's NFRC-certified files. Center lites can be called out generically as thin borosilicate-aluminosilicate glass in the approximate 0.5 or 1.1 mm (0.020 or 0.043 in.) soda lime glass; indexed smaller than the outer lites and fully enclosed within the IGU perimeter seal.

What that avoids is the need to prescribe the exact thickness of every component lite and the exact gas species in every cavity. That flexibility lets the IGU fabricator choose from their certified families to meet performance and geometry requirements, rather than locking the spec to a single proprietary make-up.

Durability, warranty, and size limits

Anytime a new technology is proposed, the same questions follow. How long will it last, what is the warranty, and where does it break?

Regarding durability, thin-glass IGUs rely on the same core classes of sealant chemistries and spacer designs as high-end conventional triples and quads. Thermoplastic warm-edge spacers used with thin center lites are not experimental. They have a service history going back to the mid-1990s and are designed for very low moisture vapor transmission and high gas retention. The addition of a thin center lite does not fundamentally change the diffusion paths for gas or moisture, which is why the same ASTM E2190 protocols apply.

Since the certification regimes and sealant systems are common, warranty terms typically match those offered for other premium IGUs in the same product family, often in the 10- to 20-year range for seal failure under normal service conditions.

Size limits are real, but they are not unusually restrictive. Many thin-glass programs currently support IGU sizes on the order of 4.65 m^2 (50 sf) as standard offerings, with some manufacturers providing larger units up to roughly 5.57 m^2 (60 sf), subject to project-specific engineering and handling plans. Those ranges are comparable to the practical limits of many conventional triple-pane configurations when structural loads, deflection limits, and glass handling are fully accounted for.

As with any glass product, very large "super jumbo" formats, extreme wind pressures, or special blast, and impact requirements may push the design into more specialized lamination and structural regimes. Thin glass can be part of those solutions, too, but should not be assumed as


Advanced thin glass triples and quads are a lot lighter than standard triples and quads, and most doubles, and thus easier and safer to work with.
PHOTO COURTESY THINKALPEN.COM

a universal substitute. A performance-based specification, backed by project-specific structural analysis, is the right place to draw those lines.

What changes for contractors

From the contractor's perspective, the questions are simpler.

Does this look different? Is it heavier? Do I have to learn a new way to install it?

Thin-glass IGUs today are engineered so that the answer to all three is essentially "no."

Once installed, they are visually indistinguishable from other high-performance IGUs with comparable coatings. The outer and inner lites are the same soda-lime products that glaziers handle every day. The slight weight increase over a conventional double is small enough that existing glass handling equipment, setting blocks, and anchorage details generally remain valid. That is a very different field experience than wrestling a significantly heavier conventional triple-pane window into a frame that was marginal for it to begin with.

Glaziers can use the same glazing pockets, stops, and sealants. Thin-glass programs that avoid capillary tubes and altitude adjustment hardware actually simplify logistics for projects that cross elevation changes. From a training standpoint, the field crew does not have to learn a new fastening system or sealing method. They are installing a sealed IGU that just happens to be more efficient inside.

This is part of what makes thin glass feel less like a speculative technology and more like an incremental evolution. It asks design teams to think differently about performance and does not ask contractors to completely relearn how to glaze. It also opens a glazing replacement option.

Other technologies in the mix

Thin-glass IGUs are not the only attempt to push fenestration performance forward.

Vacuum-insulated glazing, for example, offers very low center-of-glass U-factors by nearly eliminating gas conduction. It also introduces its own design considerations, including evacuated cavities, small internal pillars, and edge conditions that can dominate whole-unit performance if the frame is not carefully integrated.

Aerogel-filled IGUs provide very low conductance in testing, with translucent or semi-transparent infills replacing conventional gas cavities. Most of these products are still in early development or niche use, and questions remain about cost, manufacturing complexity, and long-term optical stability.

These approaches are worth watching. They may play larger roles as they mature. Thin-glass triples and quads occupy a different place in the timeline. They are already in full production at scale. They are built on familiar materials and certification frameworks. They work with the one-inch framing geometries that dominate North American practice. Millions of square feet are already installed in offices, multifamily buildings, educational facilities, and other real projects.

For specifiers working on buildings today, that combination of high performance and immediate compatibility with existing systems should be hard to ignore.

Pricing?

When it comes to modern glazing, thin glass is not an exotic luxury. It is actually a cost-effective innovation. Thanks to advancements in automated manufacturing, it now offers the best dollars-per-R-value when compared to traditional double- or triple-glazing that relies on expensive exotic room-side low-e coatings. Today's thin glass solutions present high performance without an extreme price tag. The correlation between energy-efficient windows and doors and price is historically blurred, but the bottom line is that price does not always equate to high performance.

For architects, builders, and specifiers seeking a modern, budget-friendly solution, thin glass is the sweet spot, offering a healthy return on investment (ROI). It also reduces frame support, lowers U-values, and delivers greater ROI.

These images show recently completed multi-family, affordable housing projects that employ advanced thin glass IGU solutions.

LEFT: PHOTO COURTESY THINKALPEN.COM

RIGHT: PHOTO COURTESY JIMNIX.COM

ABOVE: PHOTO COURTESY HANDEL ARCHITECTS

Conclusion: Bringing windows up to the wall

For most of the last 70 years, North American buildings have lived with asymmetry. Opaque assemblies marched steadily upward in performance. Windows followed more slowly, relying on cheap energy and generous mechanical systems to disguise their shortcomings.

Energy codes have now caught up with that imbalance. Double-pane IGUs that once represented the reasonable limit of float glass and IGU assembly are increasingly misaligned with code pathways and performance aspirations. Conventional triples can close the gap thermally, but they do it by stretching the weight and depth limits of the systems that were never designed with them in mind.

Thin-glass IGUs offer another path. By placing a very thin, very stable center lite inside the familiar outline of a double-pane window or door, triple- and quad-thermal performance is accessible without forcing a wholesale reinvention of framing, hardware, and field practice. They fit within the existing NFRC, IGCC, IGMA, and ASTM frameworks. They carry warranties and durability expectations that specifiers can easily understand. They are already in use at scale.

For Division 08 specifiers, the opportunity is clear. Master specifications can evolve from "double by default, triple by exception" to a more performance-driven posture that sets whole-unit U-factor targets, acknowledges realistic weight and thickness limits and invites thin-glass IGUs into the solution set without naming any one manufacturer.

There will always be projects that call for specialized glazing, from blast-resistant assemblies to extreme jumbo lites. In the much larger universe of buildings pursuing lower energy use, tighter envelopes and credible paths to net-zero, thin-glass IGUs are one of the most practical tools currently available at scale.

The wall has done its part. Thin glass is a way for the window to finally catch up.

additional information

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Avi Bar is chief revenue officer with nearly two decades of experience in sales leadership across the building materials and construction industries. He specializes in aligning strategy, execution, and market demand to accelerate the adoption of high-performance building solutions.

KEY TAKEAWAYS

Advanced thin-glass insulated glass units (IGUs) provide triple- and quad-performance in conventional double-pane frames, reducing weight, maintaining installation simplicity, meeting modern energy codes, and enabling cost-effective, durable, high-performance glazing solutions for Division 08 projects.

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Rethinking Stucco Wall Design Under Changing Codes

By Anthony M. Garcia, PE, BECxP, CxA+BE, CEI, Trinidad Martinez, RRO, CEI, and Ryan Foroughi

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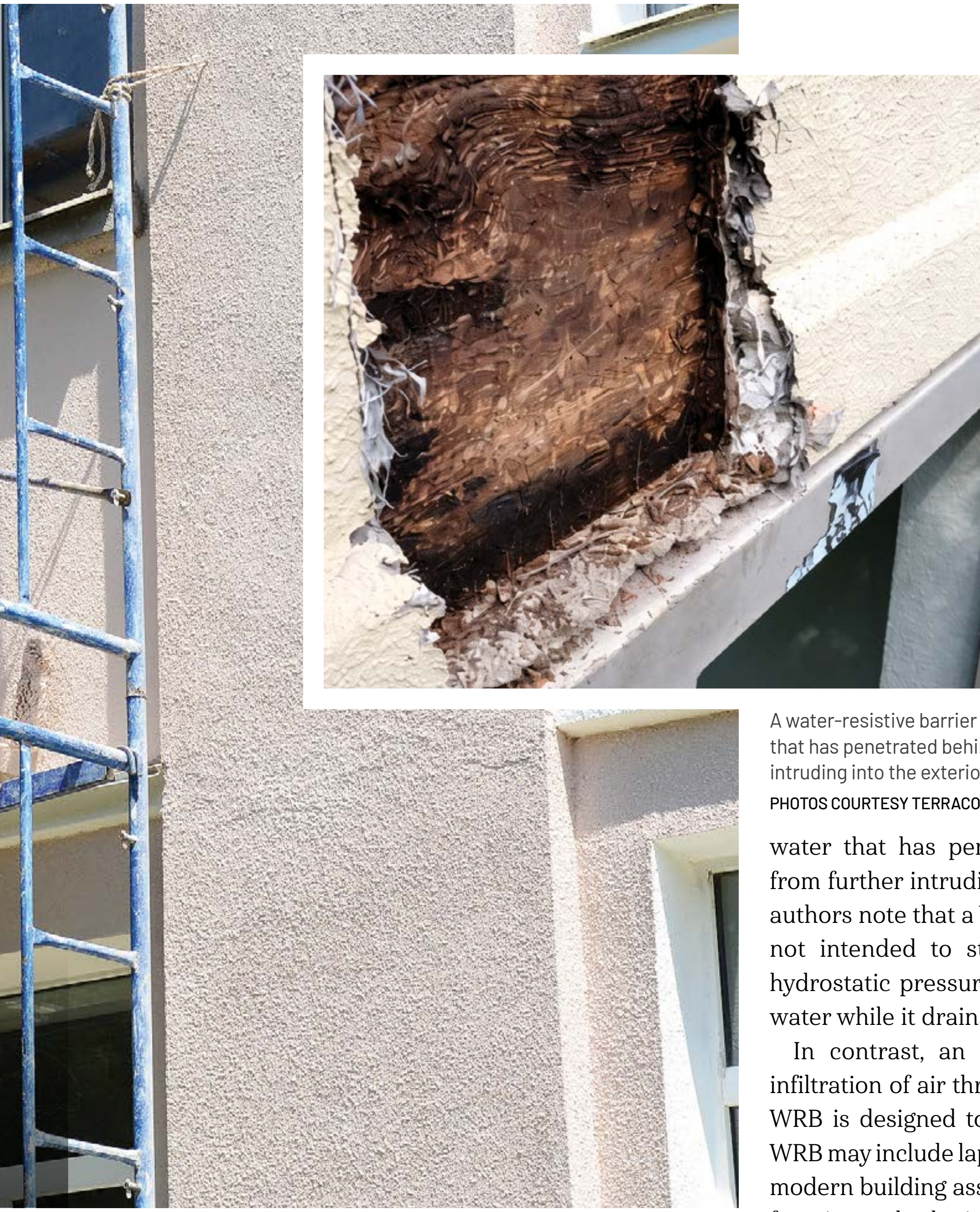
Cement plaster (stucco) has become increasingly popular as an economical and aesthetically appealing cladding on wood-framed and -sheathed construction around the country. This is accompanied by a reduction in water-diverting architectural features such as overhangs including proper flashing, and a poor understanding of installation requirements and building envelope principles, leading to low-quality installations and, for some, stucco failures that are rampant in the industry.

Historically, stucco was applied to stone, brick, or other compatible masonry walls, creating a monolithic section with high durability, vapor permeability, and drying potential. In this type of construction, the wall materials were highly absorptive; the lack of modern air sealing, insulation, and conditioning, and the high drying potential, meant these structures could get wet and dry with relatively little consequence. More recently (but not modern) stucco was often directly applied to wood lath. This system lacked an effective drainage layer and also relied heavily on the drying potential of the assembly. In addition, old growth wood was more durable than modern products when exposed to water.

Modern stucco today differs greatly from traditional methods. Instead of robust backing, wood-based backing often consists of oriented strand board (OSB) sheathing, which lacks durability when exposed to water. Instead of a compatible cementitious surface for adhesion, modern galvanized lath may corrode when repeatedly exposed to



A water-resistive barrier is intended to resist liquid water that has penetrated behind the exterior covering from further intruding into the exterior wall assembly.

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moisture. Modern water-resistive barriers (WRBs), improved air and thermal barriers, and increased reliance on mechanical heating and cooling mean drying potential in a wall assembly is greatly reduced when compared to historical wall assemblies, and condensation potential and humidity require careful management. While acrylic coatings or finish coats are sometimes used in stucco construction, the system itself is not typically referred to as "acrylic stucco," and these finish layers are not directly addressed in the code sections under discussion.

As defined by the *International Building Code* (*IBC*), WRBs are not intended to manage or prevent infiltration from excess moisture that does not readily drain from the wall assembly. Instead, a WRB is intended to resist water while it drains or dries from the cladding. The 2015 *IBC* (and all subsequent editions) defines a WRB as "[a] material behind an exterior wall covering that is intended to resist liquid water that has penetrated behind the exterior covering from further intruding into the exterior wall assembly." The authors note that a WRB is not waterproofing, meaning it is not intended to stop the ingress of bulk water under hydrostatic pressure. Instead, a WRB is intended to resist water while it drains or dries from the cladding.

In contrast, an air barrier is intended to resist the infiltration of air through the building enclosure, whereas a WRB is designed to resist the infiltration of bulk water. A WRB may include laps or joints that are not airtight. Although modern building assemblies often use products designed to function as both air and water-resistive barriers, this is not always the case. Since the code sections discussed here focus primarily on WRBs, further discussion of air barrier requirements is outside the scope of this section.

Section 1404.2 further defines a WRB as the following:

1404.2 Water-resistive barrier.
Not fewer than one layer of No.15 asphalt felt, complying with ASTM D226 for Type 1 felt or other approved materials, shall be attached to the studs or sheathing, with flashing as described in Section 1405.4, in such a manner as to provide a continuous water-resistive barrier behind the exterior wall veneer.

In addition, a lack of understanding and adherence to typical construction practices means the WRB can become littered with fastener penetrations due to improper lath installation as required in ASTM C1063, *Standard Specification for Installation of Lathing and Furring to*

Fasteners must be installed into framing members, but they are commonly blind fastened into wood sheathing, missing the framing member completely.

Receive Interior and Exterior Portland Cement-Based Plaster. For example, fasteners must be installed into framing members; commonly, these fasteners are blind fastened into wood sheathing, missing the framing member completely. This misunderstanding or ignorance of the installation requirements can lead to increased occurrences of cracks in the stucco cladding. All of these common construction defects further increase the amount of water that penetrates the wall assembly, with some of that water reaching the wood-based sheathing and framing and leading to numerous consequences, such as occupant nuisance, health and respiratory issues from biological growth (*e.g.* airborne mold spores), costly damages from rot or other water damage, and even structural failure.

Although codes have been slow to respond, the *IBC* has made regular changes to Section 2510, *Lathing And Furring for Cement Plaster* (*Stucco*), and subsection 2510.6, *Water-resistive barriers*, to reflect the increased risk associated with installing stucco cladding over wood-based sheathing when installation practices are inadequate. Wood sheathing serves important structural purposes in wood-framed construction, such as resisting lateral loads, and the type of sheathing itself is not inherently problematic when proper construction practices are followed. This article focuses on the progressive code changes regarding the WRBs and drainage requirements in this section from *IBC* 2015–2024 to help designers, contractors, and code officials understand how to comply with the code, improve the performance and durability of stucco-clad wall assemblies, and meet the project requirements for use of stucco cladding in a variety of project types, budgets, and locations.

The following is for use behind stucco, the WRB, the ability to drain water from the exterior wall assembly, and the water-resistance of other intervening layers, which have additional requirements. Changes to these requirements are captured for each code year under discussion in the following sections.

2015 *IBC*—not exactly the beginning

The 2015 *IBC* is the basis for the most common stucco assemblies and provides only basic requirements for the WRB behind stucco cladding and over wood sheathing. The authors also note that this assembly is less forgiving to defects in installation and have seen poorly installed assemblies on numerous occasions.

The 2015 *IBC* Section 2510.6 requires WRBs to be installed per Section 1403.2 where applied over wood-based sheathing, which references Section 1404.2 for minimum WRB requirements (see excerpt earlier in this article). Section 2510.6 also adds requirements for the WRB, including the requirement that the WRB "shall include a water-resistive vapor-permeable barrier with a performance of at least equivalent to two layers of water-resistive barrier complying with ASTM E2556, Type I."

A Type I WRB is defined as a "water-resistive barrier with base-level water resistance" and tested in accordance to ASTM E2556, *Standard Specification for Vapor Permeable Flexible Sheet Water-Resistive Barriers Intended for Mechanical Attachment*. In addition, "each layer [must provide] a separate continuous plane and any flashing (installed in accordance with Section 1406.4) intended to drain to the water-resistive barrier is directed between the layers."

An exception to the requirement for two Type I WRBs is included in Section 2510.6, where the WRB can comply "with ASTM E2556, Type II and is separated from the stucco by an intervening, substantially nonwater-absorbing layer or drainage space." A Type II WRB is defined as a "water-resistive barrier with enhanced water resistance" and tested in accordance to ASTM E2556, *Standard Specification for Vapor Permeable Flexible Sheet Water-Resistive Barriers Intended for Mechanical Attachment*. It is important to note that neither a "nonwater absorption layer" nor "drainage space" is defined, although the authors note that drainage spaces as little as 3.18 mm (0.125 in.) have been found effective, although 6.35 mm (0.25 in.) gap is typically recommended.[1]

For reference, a common exterior wall assembly complying with the 2015 IBC is presented as follows:

Layers (exterior to interior)

- Stucco
- Lath—Typically galvanized expanded metal lath as described in ASTM C1063, *Standard Specification for Installation of Lathing and Furring to Receive Interior and Exterior Portland Cement-Based Plaster*
- WRB—Common configurations:
  - Two layers equivalent to a Type I WRB as defined in ASTM E2556, *Standard Specification for Vapor Permeable Flexible Sheet Water-Resistive Barriers Intended for Mechanical Attachment*:
- Grade D Building Paper (Type I WRB)
- Modern Type I WRB such as building wrap, etc.
  - Two layers including one layer Type II WRB as defined in ASTM E2556, *Standard Specification for Vapor Permeable Flexible Sheet Water-Resistive Barriers Intended for Mechanical Attachment*:
- Grade D Building Paper ("intervening substantially nonwater-absorbing layer or drainage space"). Note that a drainage space used in this application is generally uncommon for this code cycle but may consist of furring strips, drainage medium, or similar assemblies attached directly through studs, with fasteners treated as recommended by the WRB manufacturer
- Modern Type II WRB such as fluid-applied air barrier
- Wood sheathing—Typically oriented strand board (OSB); less commonly, plywood

2018 *IBC*—Climate-specific changes

The 2018 *IBC* expands the requirements behind stucco by providing an exception in Section 2510.6.2 which requires "... a ventilated air space shall...between the stucco and water-resistive barrier..." in Climate Zones 1A, 2A, and 3A, which generally consist of moist southern climates, including much of the American South and Southeast as indicated within the figures on pages 20 and 21.

Modern stucco assemblies often include wood sheathing such as oriented strand board (OSB), which lacks durability when exposed to water.

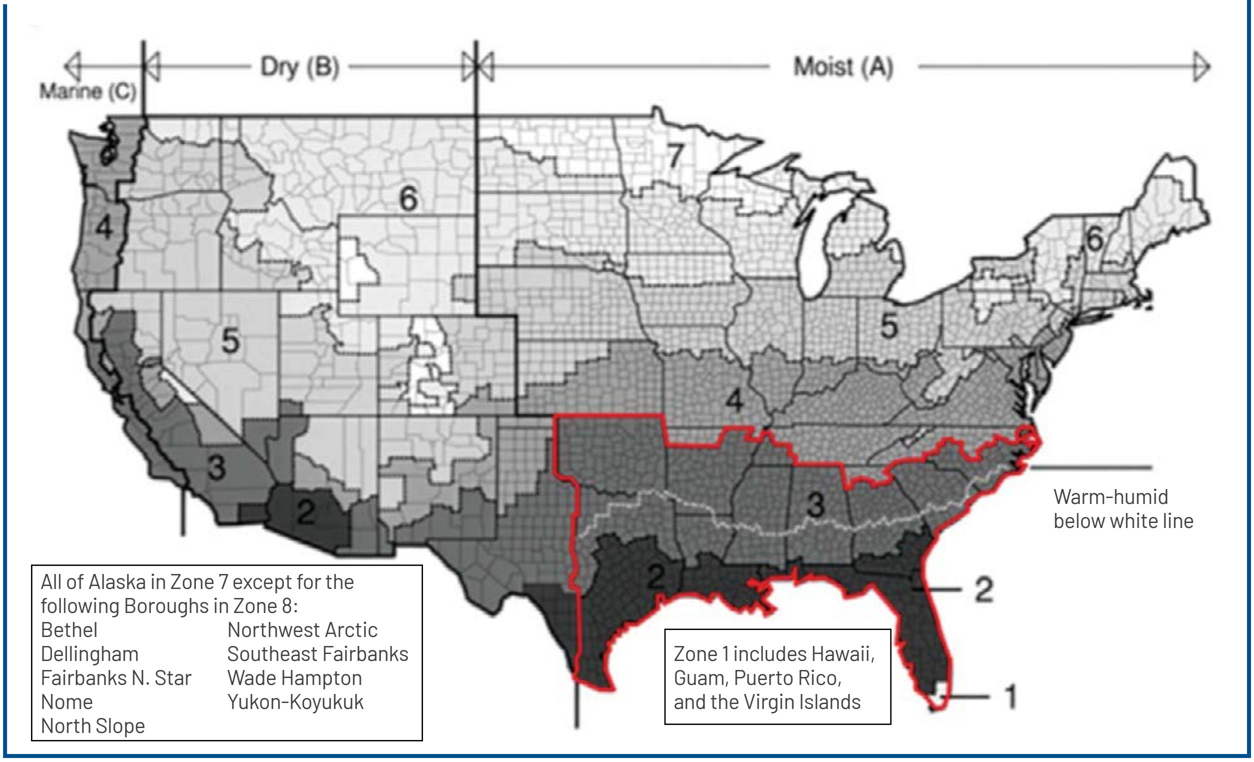
It is important to note that a ventilated air space is not defined in any of the subject publications of the *IBC*, which may cause confusion, misapplication, or ignoring of this specific requirement by designers, consultants, contractors, and building code officials. Studies show that a 9.53 mm (0.375 in.) air gap with openings at the top and bottom of the wall assembly provides venting of nearly 30 air changes per hour (ACH), which is the minimum gap the authors would recommend for best practices.[2]

For reference, a common exterior wall assembly complying with the 2018 *IBC* is presented as follows:

Layers (exterior to interior)

- Stucco
- Lath—Typically galvanized expanded metal lath as described in ASTM C1063, *Standard Specification for Installation of Lathing and Furring to Receive Interior and Exterior Portland Cement-Based Plaster*
- In Climate Zones 1A, 2A, and 3A, the code adds the following requirement:
  - Ventilated air space
- WRB—Common configurations:

Figure 1



The *International Building Code* (*IBC*), marked by the authors.

- ○ Two layers equivalent to a Type I WRB as defined in ASTM E2556, *Standard Specification for Vapor Permeable Flexible Sheet Water-Resistive Barriers Intended for Mechanical Attachment*:
- Grade D Building Paper (Type I WRB)
- Modern Type I WRB such as building wrap, etc.
- ○ Two layers including one layer Type II WRB as defined in ASTM E2556, *Standard Specification for Vapor Permeable Flexible Sheet Water-Resistive Barriers Intended for Mechanical Attachment*:
- Grade D Building Paper ("intervening substantially nonwater-absorbing layer or drainage space"). Note that a drainage space used in this application is generally uncommon for this code cycle but may consist of furring strips or similar spacers
- Modern Type II WRB such as fluid-applied air barrier
- Wood sheathing—Typically OSB; less commonly, plywood

2021 *IBC*—Raising the bar for climate-specific requirements

The 2021 *IBC* further expands the requirements behind stucco over the 2018 code by removing the consideration of thermal conditions and organizing requirements first by climate zone and then by WRB type. This shift replaces numeric thermal designations with moisture-based classifications (dry [B], moist [A], and marine [C]) to better address water management in stucco assemblies."

For dry climates, the requirements are nearly unchanged from previous editions, except for the expansion of the acceptable materials between a Type II WRB and stucco cladding in Section 2510.6.1.2, now allowing for "a layer of foam plastic insulating sheathing or other nonwater-absorbing layer, or a drainage space" instead of just a generic "nonwater-absorbing layer or drainage space." Once again, it is important to note that neither a "nonwater-absorbing layer" nor "drainage space" are defined.

For moist or marine climates, the ventilation requirement of the 2018 *IBC* is eliminated. Instead, "a space or drainage material not less than 3/16 inch (4.8 mm) in depth" is required in addition for the requirements of Section 2510.6.1.2 for Type I or II WRBs. Alternatively, a Type II WRB with "a minimum drainage efficiency of 90 percent as measured in accordance with ASTM E2273 or Annex A2 of ASTM E2925 [*Standard Specification for Manufactured Polymeric Drainage and Ventilation Materials Used to Provide a Rainscreen Function*]" is permissible under this version of the code.

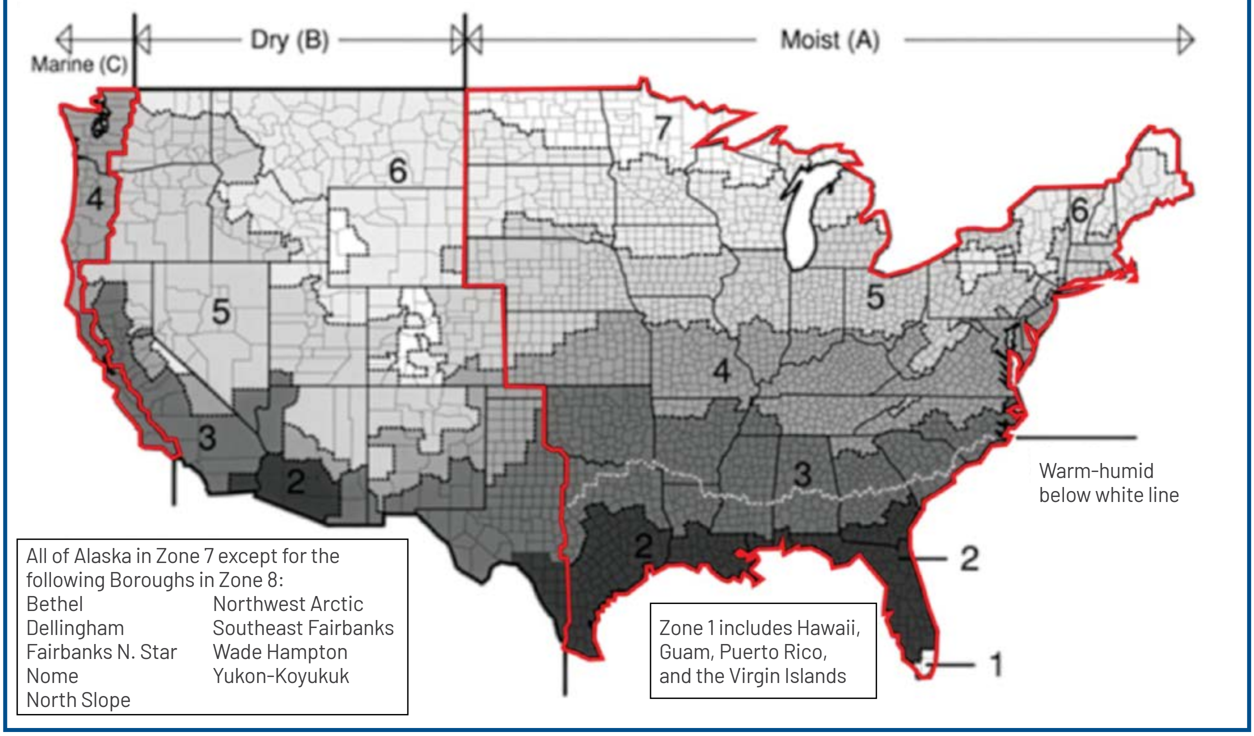
The authors support any increase in drainage capacity of the exterior wall assembly, whether a true drainage space or from a "drainable WRBs." A true drainage space is always preferred, as it requires understanding the drainage path in the exterior wall assembly and does not rely solely on the quality of WRB installation.

For reference, a common exterior wall assembly complying with the 2021 *IBC* is presented as follows:

Layers (exterior to interior)

- Stucco
- Lath—Typically galvanized expanded metal lath as

Figure 2



The *International Building Code* (*IBC*), marked by the authors.

described in ASTM C1063, *Standard Specification for Installation of Lathing and Furring to Receive Interior and Exterior Portland Cement-Based Plaster*.

- In climate zones A and C:
  - For Type I or II WRBs—"a space or drainage material not less than 3/16 inch (4.8mm) in depth"
  - For Type II WRBs—Drainable WRB
- WRB—common configurations:
  - Two layers equivalent to a Type I WRB as defined in ASTM E2556, *Standard Specification for Vapor Permeable Flexible Sheet Water-Resistive Barriers Intended for Mechanical Attachment*, are typically used so the second layer creates an additional plane for drainage:
- Grade D building paper (Type I WRB)
- Modern Type I WRB such as building wrap, etc.
  - Two layers including one layer Type II WRB as defined in ASTM E2556, *Standard Specification for Vapor Permeable Flexible Sheet Water-Resistive Barriers Intended for Mechanical Attachment*:
- Continuous insulation ("a layer of foam plastic insulating sheathing"), Grade D building paper ("other non-water absorbing layer") or a drainage space
- Modern Type II WRB, such as fluid-applied air barrier systems, which function as more robust WRBs rather than serving to mitigate moisture originating from inside the building
- Wood sheathing—Typically OSB; less commonly, plywood

2024 *IBC*—All types of backing

In addition to some clerical changes regarding the use of flashings for Type I and II WRBs, in sections 2510.6.1.1 and 2510.6.1.2, respectively, the 2024 *IBC* removes the stipulation for these requirements over wood-based sheathing, instead providing an exception to the requirements "where accumulation, condensation or freezing of moisture will not damage the materials." The most common use of this exception would be cementitious backing, such as direct-applied stucco to concrete in a warm climate not subject to freeze-thaw action.

For reference, a common exterior wall assembly complying with the 2024 *IBC* is presented as follows:

Layers (exterior to interior)

- Stucco
- Lath—Typically galvanized expanded metal lath as described in ASTM C1063, *Standard Specification for Installation of Lathing and Furring to Receive Interior and Exterior Portland Cement-Based Plaster*
- In climate zones A and C:
- For Type I or II WRBs—"a space or drainage material not less than 3/16 inch (4.8 mm) in depth."
- For Type II WRBs—Drainable WRB
- WRB—Common configurations:
- Two layers equivalent to a Type I WRB as defined in ASTM E2556, *Standard Specification for Vapor Permeable Flexible Sheet Water-Resistive Barriers Intended for Mechanical Attachment*:

- Grade D building paper (Type I WRB)
- Modern Type I WRB such as building wrap, etc.
- Two layers including one layer Type II WRB as defined in ASTM E2556, *Standard Specification for Vapor Permeable Flexible Sheet Water-Resistive Barriers Intended for Mechanical Attachment*:
- Grade D building paper ("intervening substantially nonwater-absorbing layer or drainage space"). Note that a drainage space used in this application is generally uncommon for this code cycle but may consist of furring strips or similar spacers
- Modern Type II WRB such as fluid-applied air barrier
- Wood sheathing—Typically OSB; less commonly, plywood

Conclusions

Building code updates are usually slow moving, with committees agonizing over the slightest revisions. Despite this, the requirements of section 2510.6 in the *IBC* is responding rapidly to the growth of the stucco industry and perceived risk, particularly when installed on wood structures. It is the author's hope that this article will help educate designers and installers of the requirements of *IBC* section 2510.6 and provide a background on key decisions when designing a code-compliant stucco system. Key considerations include drainage requirements and WRBs robustness, which the authors recommend designing to the most stringent requirements of the 2024 *IBC*, including a minimum 4.8 mm (0.1875 in.) drainage space and a Type II WRB in all climates. This assembly is generally more forgiving to other installation defects, such as improper fastening or cracks in the stucco, which can stress even the most robust exterior wall system.

NOTES

[1] "With a gap of 3 mm (0.125 in.), capillary rise or suction is prevented. It is common to use a 3- to 6-mm (0.125- to 0.25-in.) gap as an effective capillary break. This gap prevents capillary suction between building components, uncoupling the cladding from the WRB/AB, and allowing free drainage." Venting Cladding Assemblies Prevent Reverse Vapor Drive and Allow Vapor-Permeable Water-Resistive and Air Barrier (WRB/AB) Membranes to Enhance Wall Assembly Drying, Scott D. Wood, CBST; 33rd RCI International Convention and Trade Show.

[2] Refer to "Review on ventilation rates in the ventilated air-spaces behind common wall assemblies with external cladding" by Mohammad Rahiminejad and Dolaana Khovalyg, sciencedirect.com/science/article/pii/S0360132320309057

additional **information**

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KEY TAKEAWAYS

Modern stucco assemblies over wood-based sheathing face significant water management challenges due to changes in materials and installation practices compared to historical masonry-backed stucco. The evolution of the *International Building Code* (*IBC*) from 2015 to 2024 reflects growing recognition of these risks, with requirements progressing from simple dual-layer water-resistive barriers (WRBs) to mandates for drainage gaps and more robust, moisture-tolerant materials, particularly in humid climates. Proper installation, adequate drainage space, and use of enhanced Type II WRBs are now critical for mitigating moisture intrusion, reducing mold and structural risks, and improving durability. Designers should adopt the 2024 *IBC*'s most stringent standards for best results.

MASTERFORMAT NO.

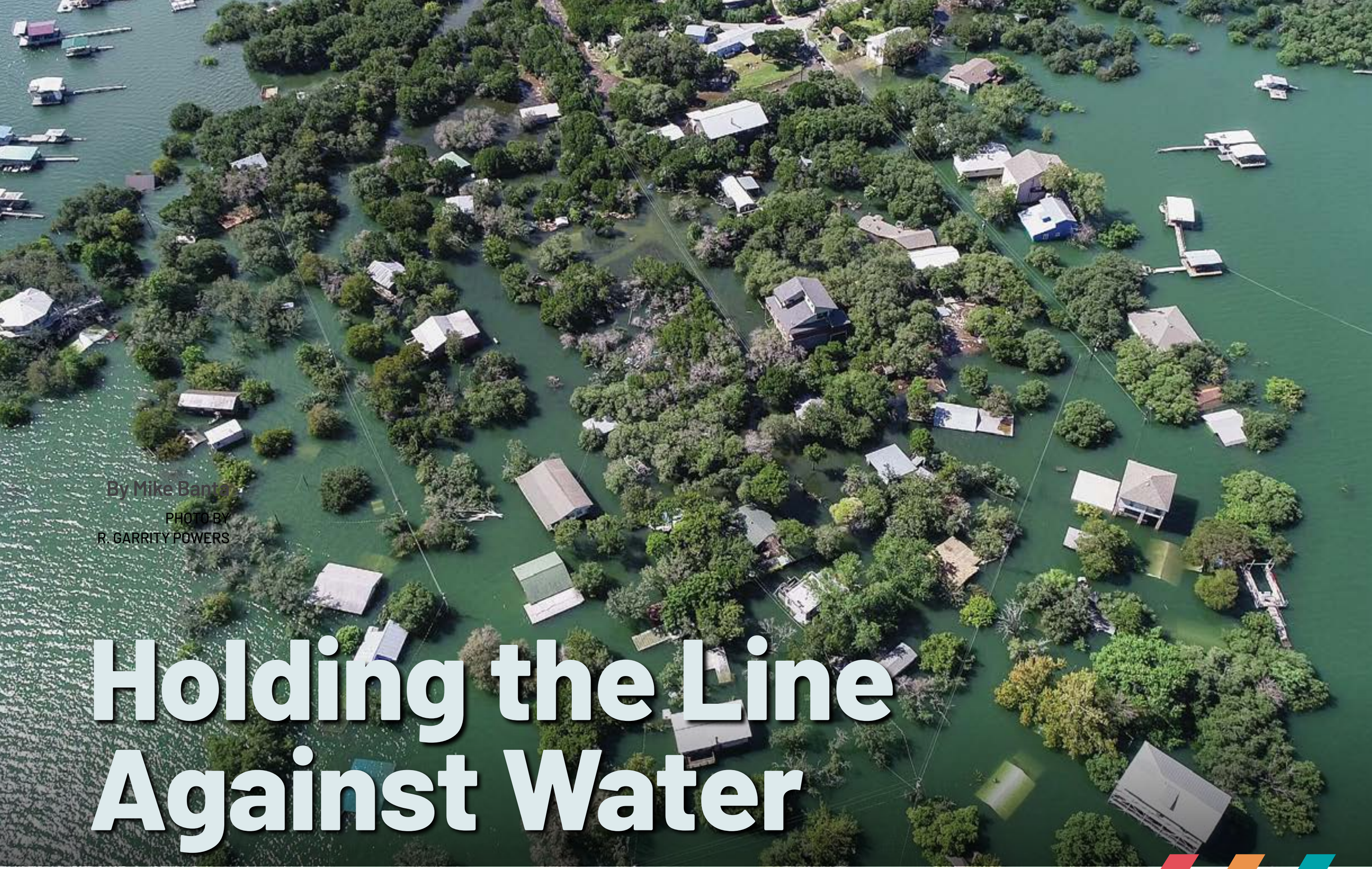
07 24 00–Exterior Insulation and Finish Systems (EIFS)
07 27 00–Air Barriers
09 24 00–Portland Cement Plastering (Stucco)

UNIFORMAT NO.

B2010–Exterior Walls
B2010.30–Exterior Wall Vapor and Air Barriers
B2030–Exterior Wall Finishes

KEYWORDS

Division 07, 09	Sheathing
Drainage	Stucco
Moisture	Water-Resistive Barrier (WRB)



Holding the Line Against Water

Performance Glazing in Flood Zones

By Ray Crawford

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Flooding is the most frequent and financially damaging natural disaster in the U.S., causing more damage each year than hurricanes, tornadoes, and other natural hazards combined. The Federal Emergency Management Agency (FEMA) reports that more than 90 percent of flood-related property losses occur in commercial buildings, with the average claim amounting to approximately $100,000. Unlike earthquakes or fires, flooding is a recurring and intensifying threat driven by climate change, urban development, and aging infrastructure. Building professionals are under increasing pressure to integrate flood resilience into their designs, including how glazing systems are specified.

Glazed openings, such as curtain walls, storefronts, and large window systems, provide transparency and daylight but are also among the most susceptible points of water entry. Traditional defenses, such as temporary barriers, are labor-intensive and increasingly insufficient against the severity of modern storms. Flood-resistant glazing systems, in contrast, are engineered to withstand hydrostatic pressure, debris impact, and wind-driven rain, delivering permanent protection as part of the building envelope.

High-risk areas: coastal and inland

Flood resilience is often associated with coastal regions. Along the Gulf Coast and Atlantic seaboard, hurricanes bring storm surge, high winds, and wave action that put extreme stress on building envelopes. Glazing assemblies in cities such as Miami, Florida; New Orleans, Louisiana; and Charleston, South Carolina must now meet some of the most stringent performance codes in the country. Systems that fail can allow water to bypass other defenses, leading to rapid and widespread interior damage.

Inland areas face different but equally critical risks. Riverfront cities along the Mississippi, Ohio, and Missouri Rivers experience seasonal flooding that exposes buildings to prolonged hydrostatic pressure. Commercial properties near levees or floodplains are particularly exposed when water levels rise. At the same time, dense urban centers in the Midwest and Southwest are increasingly affected by flash flooding caused by heavy rainfall

Floodwater from the Mississippi River covers downtown streets in Davenport, Iowa, after severe thunderstorms and heavy rain. The storms caused flash flooding that submerged roads and stranded vehicles. River flooding like this illustrates how inland communities experience prolonged hydrostatic pressure and envelope exposure comparable to coastal environments.

PHOTOS COURTESY CRAWFORD-TRACEY CORPORATION

and the strain on stormwater infrastructure. Houston, Texas, has seen extensive flooding during significant rain events, while St. Louis, Missouri, experienced record-breaking rainfall in 2022. These examples illustrate how cities far from coastal zones remain at high risk. In these environments, glazing systems located at grade or below projected flood levels can quickly become points of failure.

By considering both coastal and inland scenarios, design professionals can better understand that flood-rated glazing is not a niche solution limited to hurricane-prone states. It is a necessary specification across diverse geographies where climate and infrastructure challenges are driving more frequent and severe flood events.

The toll of flooding on commercial buildings

Floodwater causes several types of damage to commercial buildings. Structurally, hydrostatic pressure against walls and openings can cause displacement, cracking, and even collapse. Hydrodynamic forces add further stress as water moves at varying velocities. Internally, intrusion affects mechanical and electrical systems, damages finishes and furnishings, often requires complete removal of contaminated materials. Mold growth compounds losses and extends recovery timelines.

The financial consequences are significant. The National Flood Insurance Program estimates that one inch of water in a commercial property can result in more than $25,000 in damage. For multi-tenant buildings, business interruption costs may exceed physical repair costs, as downtime impacts leases, operations, and occupancy. In many cases, loss of use after a flood can determine whether a property recovers or is abandoned.

Limitations of traditional protection

Temporary measures have long been the default for flood defense. Sandbags, flood panels, and stop logs can divert or hold back water when installed correctly, but they rely on timely deployment and human labor. Their performance is inconsistent, and they are easily overtopped or displaced. Pumps and drainage systems help manage rising water, but they are ineffective when rainfall or surges exceed the municipal infrastructure's capacity.

These strategies no longer align with the intensity of storm events. A more reliable approach is to incorporate resilience directly into the building envelope. Flood-resistant glazing systems shift the burden from reactive measures to permanent, tested solutions.

Flood-resistant glazing: Design and testing principles

Flood-rated glazing systems are engineered as integrated assemblies that combine laminated impact glass, reinforced aluminum framing, and specialized seals. Unlike standard curtain wall or storefront systems, they are designed to withstand hydrostatic loads for prolonged periods, resist wind-driven water, and endure debris impact without catastrophic failure.

Performance is validated through laboratory testing. ASTM E331 evaluates resistance to water penetration under static air pressure, while ASTM E547 measures performance under cyclic pressure to simulate fluctuating conditions. ASTM E1886 and ASTM E1996 establish debris-impact and pressure-cycling protocols that are particularly

important in hurricane-prone regions, where flooding often coincides with high winds. In addition, hydrostatic head testing subjects glazing systems to sustained water depths to measure leakage resistance, simulating the conditions buildings face in a real flood. Together, these tests confirm that assemblies can withstand the combined forces of water, wind, and impact, ensuring that systems remain watertight and durable even during prolonged events.

Codes and compliance

Flood-resistant design has been increasingly integrated into model codes and standards. ASCE 24, *Flood Resistant Design and Construction,* establishes minimum requirements for buildings located in FEMA-designated flood hazard areas. The standard addresses elevation requirements, use of flood-resistant materials, and floodproofing strategies such as dry floodproofing. Dry floodproofing refers to design methods that prevent floodwater from entering a structure by using watertight walls, sealed penetrations, structural reinforcement, and flood barriers capable of resisting hydrostatic and hydrodynamic forces.

The *International Building Code* (*IBC*) references ASCE 24, and local jurisdictions in coastal states have adopted stricter provisions.

In coastal and hurricane-prone regions, state and local codes often adopt requirements that exceed the *IBC*'s minimum provisions. For example, the *Florida Building Code* incorporates more stringent wind-pressure, wind-borne debris impact, and water-penetration resistance requirements for exterior assemblies, particularly in designated High Velocity Hurricane Zones (HVHZ) such as Miami-Dade and Broward counties. These provisions are intended to address the combined risks of hurricane winds, storm surge, and wind-driven rain common in these regions.

For glazing systems, these requirements typically include impact-resistant testing protocols, higher design wind loads, and stricter water-penetration performance criteria than those applied in lower wind-risk regions under the *IBC*.

For specifiers, compliance is only part of the equation. Insurers and financiers are demanding performance beyond code minimums as a condition of coverage or investment. This shift is accelerating the adoption of flood-rated glazing even in regions where codes have not yet mandated it.

Long-term benefits for owners and developers

Integrating flood-resistant glazing offers clear advantages. Permanent systems reduce reliance on temporary defenses and minimize the risk of water intrusion through vulnerable openings. Owners benefit from reduced remediation costs, faster recovery, and improved business continuity. Buildings with resilient envelopes are more insurable and often more attractive to tenants, as they demonstrate a commitment to long-term reliability.

Architecturally, flood-rated glazing enables the continued use of transparent facades in high-risk areas. Designers do not have to sacrifice daylighting or aesthetics to achieve performance. Instead, resilience is built into the envelope, aligning with both functional and design goals.

Events like this test how glazing systems maintain performance under wind-driven rain and rapid pressure shifts across the building envelope.

The combined force of storm surge, wind, and debris impact shows how glazing systems are exposed to simultaneous water pressure and impact loads during severe storms.

Water flows through the glass doors of a flooded office after Tropical Depression Imelda in Houston, Texas, in September 2019. Interior flooding like this demonstrates how water intrusion through glazed openings can damage mechanical systems, finishes, and structural materials within hours.

Durability and installation considerations

The durability of flood-rated glazing depends not only on product engineering but also on proper installation and integration with adjacent assemblies. Shop drawings, pre-construction mock-ups, and field testing confirm that seals, anchors, and transitions perform as designed. Maintenance is also important. Gaskets, sealants, and framing need to be inspected periodically to support long-term reliability.

Regional conditions influence durability requirements. In coastal environments, corrosion resistance for frames and fasteners is necessary. In colder climates, systems need to resist freeze-thaw cycling without degradation. In high-wind regions, glazing needs to be designed to withstand simultaneous wind and water loads. Each of these conditions highlights the importance of specifying assemblies that are tested and certified for the risks associated with the intended environment.

Consequences of failure

Failures in glazing under flood conditions result in immediate water intrusion that bypasses other envelope protections. Once water enters, it damages finishes, systems, and structures, often requiring extended remediation and disrupting occupancy. Mold growth can render spaces uninhabitable for months, while mechanical and electrical system failures may need replacement.

From a professional liability perspective, failures also expose design teams and contractors to claims. As owners and insurers increasingly expect resilient envelope performance, untested or improperly specified systems pose a significant risk to all project stakeholders.

Specifier's considerations

When evaluating flood-rated glazing systems, specifiers should verify that assemblies have been tested to recognized standards, including ASTM protocols for water penetration, impact, and cycling, as well as FEMA and Miami-Dade County guidelines where applicable. It is equally important to confirm hydrostatic head testing, which demonstrates performance under sustained water pressure. Integration with adjacent envelope systems should be addressed in shop drawings and mock-ups to ensure continuity of seals and anchorage. Field testing during construction provides additional assurance that performance achieved in the laboratory translates to the installed condition. Because regional factors such as humidity, salt exposure, freeze-thaw cycles, and wind pressure can affect long-term durability, products should be evaluated not only for code compliance but for their ability to perform reliably over the service life of the building.

Pro-tech glazing systems

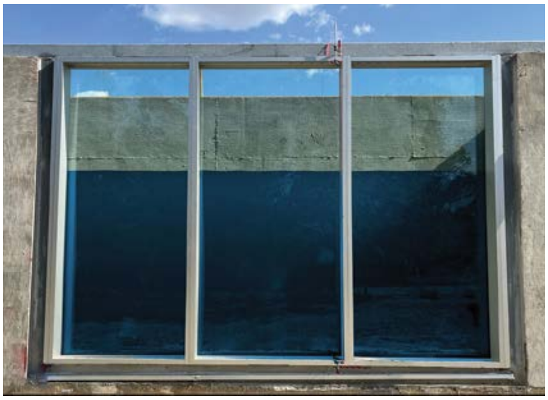
Flood-resistant glazing systems have been developed to address performance challenges associated with hurricane and flood events. Drawing on established expertise in hurricane-resistant glazing, these systems are engineered to withstand both extreme wind pressures and hydrostatic flood loads.

Some unitized, structurally glazed curtain wall and storefront assemblies are rated to as much as 4,788 Pa (100 psf) static pressure water resistance, demonstrating the capacity to resist water at significant flood depths.

Following extensive testing under HVHZ requirements in accordance with ASTM and Miami-Dade County protocols, certain systems have also been evaluated for resistance to floodwaters and floating debris impact under ANSI/FM 2510. Impact-rated flood barrier glazing technologies have also been subject to patent protection.

Unlike deployable flood barriers, permanently integrated glazing assemblies are built directly into the building envelope, eliminating the need for additional labor, storage, or installation. This integrated approach enables architects and building owners to maintain facade transparency and design continuity while incorporating consistent, passive flood protection.

Heavy rain in downtown Miami reflects the exposure of coastal cities where glazed facades face combined wind and water pressures during tropical storms and hurricanes. In South Florida, glazing systems must meet ASTM and Miami-Dade protocols for impact, cyclic pressure, and water penetration to maintain envelope integrity under storm conditions.



Testing of this glazing system demonstrates performance under hurricane wind pressures and hydrostatic flood loads. Rated for 1.22 m (4 ft) of water and a 4,788 Pa (100 psf) water-resistance rating, this system achieved no water intrusion during 24 hours of ANSI/FM 2510 testing. The companion system, rated for 2.13 m (7 ft) of water, extends flood and impact resistance to taller spans and higher design pressures, advancing resilient glazing performance for flood-prone and hurricane-exposed buildings.

Building for the future

Flooding will remain one of the defining challenges for commercial buildings in the coming decades. For architects, engineers, and specifiers, glazing systems need to be reimagined not only as aesthetic elements but as defenses against water intrusion. Permanent, tested flood-rated assemblies represent the next step in resilience, ensuring that buildings remain functional and valuable despite increasing environmental risks.

Conclusion

Commercial properties face some of the greatest financial losses from flooding, and glazed openings remain one of the most vulnerable points of entry. Whether in coastal hurricane zones or inland regions exposed to river flooding and flash rainfall, these openings can quickly fail under storm pressure. Sandbags, temporary barriers, and other stopgap defenses cannot consistently withstand the combined forces of hydrostatic pressure, debris impact, and wind-driven rain. Flood-rated glazing systems are engineered and tested to meet these demands as part of a complete building envelope solution. By specifying these systems, owners can lower repair costs, reduce downtime, and strengthen resilience in the face of increasingly severe weather events.

additional information

AUTHOR

Ray Crawford is president of Crawford-Tracey Corporation, a leading glazing contractor and innovator in commercial glazing systems. With over five decades of experience, including more than 30 years as president, he has advanced the development of unitized, pre-glazed, and impact-resistant systems that have set new performance standards. Under his leadership, Crawford-Tracey Corporation has delivered glazing assemblies tested to rigorous high-pressure, impact, and water resistance standards. Headquartered in Deerfield Beach, Fla., with an additional office in Jacksonville, Fla., Crawford-Tracey Corporation designs, manufactures, and installs custom and conventional glazing systems across the Southeastern United States and the Caribbean.

KEY TAKEAWAYS

Building codes, insurers, and investors are placing greater focus on resilience, which is changing how glazing is specified. Flood-rated systems are moving from optional upgrades to expected components in flood-prone regions. Their use reflects a more deliberate approach to design, one that accounts for stronger storms, limits damage, and helps properties return to operation sooner. For owners and design teams, flood performance is best treated as a core requirement of the building envelope, not an afterthought, because it directly supports risk reduction, business continuity, and long-term asset protection.

MASTERFORMAT NO.

08 44 13—Glazed Aluminum Curtain Walls

UNIFORMAT NO.

B2020—Exterior Windows
B2030—Exterior Doors

KEYWORDS

Division 08
Flood-rated systems
Glazing

Infrastructure That Lasts

Type IL Cement in Action

By Rick Bohan

PHOTO ©ANOO77/COURTESY BIGTOCKPHOTO.COM

People are expecting the built environment to last longer and perform better while also demanding the same strength, durability, and resilience, not to mention cost-effectiveness. One of the unsung heroes among the construction stakeholders are specifiers. They play a vital role in selecting the materials and methods that balance an endless litany of competing requirements.

Specifiers have rediscovered that blended cements such as Type IL are a ready-made off-the-shelf high-performance solution that meets the dual challenges of both structural requirements and environmental aspirations. These cements are readily available throughout the U.S.

The cement industry has always been a cornerstone of the U.S. economy and a partner to the various stakeholders along the construction value chain, innovating to meet market needs. As demands for more environmentally responsible materials have grown, the industry has had a part in meeting that need. In 2021, the American Cement Association (ACA) developed its Roadmap

Indiana University Ferguson International Center from ground-level, angled up.

PHOTO COURTESY WEDDLE BROS., BUILDING GROUP LLC, IRVING MATERIALS INC., AND HEIDELBERG MATERIALS/ ENHANCED WITH AI

to Carbon Neutrality, outlining various levers to reduce emissions in the built environment. Blended cements are among the imperatives.

Blended cements represent just one part of the cement industry's ongoing commitment to add value throughout the construction value chain. They represent an innovative set of product solutions that were highlighted in ACA's Roadmap to Carbon Neutrality. The association's engagement with each link of the value chain identified other solutions that specifiers can implement.

Blended cements and their benefits

Blended cements use precise additions of limestone and other materials to lessen the energy impacts from more traditional cements. Those additions include limestone and calcined clay, as well as industrial by-products such as steel slag or harvested fly ash. All additions must be carefully controlled, meeting strict physical and chemical requirements and demonstrating their performance in concrete mixtures.

In addition to sustainability benefits, blended cements offer:

- Greater flexibility—Blended cements provide the flexibility to tailor concrete mixes to specific performance criteria, enabling specifiers to optimize designs based on a project's unique needs. This customization also extends to aesthetics. For instance, trial batches can be used to refine the color and finish of the concrete, ensuring they align with the project's visual and functional requirements.
- Meeting emerging regulations—There is growing demand for lower-carbon building materials. States and cities are passing 'green

The University of Iowa Health Care North Liberty Campus, with the hospital in the background, with signage displaying the name in the foreground.

PHOTOS COURTESY QUIKRETE/ENHANCED WITH AI

procurement' regulations, and many companies have decarbonization goals. Blended cements will help fulfill these needs.

- Proven capabilities—Blended cements have undergone extensive testing and research in the U.S. and other countries to ensure durability and resiliency. Researchers have studied fresh properties related to placing and finishing, as well as hardened properties that relate to durability. Blended cements can provide the same proven performance as traditional cements.

Planning and working with blended cements

A transition from traditional cements to blended cements requires planning and attention to detail. It is far more than just swapping out one material from another or changing over a concrete mixture in the space of one day. And that is true for any new product considered for a concrete mixture. That means everyone involved in the construction project communicates early and often and on an ongoing basis. The entire project team should know not just the required strength, durability, and sustainability performance requirements, but just as importantly, the reasons behind each of those requirements. The team must also be prepared to meet each of those targets. This only works when everyone embraces a team approach, and that is true for any switch in material.

A baker would not switch from whole wheat flour to oat flour without first getting a comfort level with how oat flour impacts the baking time and oven temperatures required, or how the oat flour works or does not work with the other ingredients. And it is the same when a project team switches from traditional cement to blended cement in a concrete mixture. Everyone on the project team needs a comfort level, and that means everyone from the cement producer to the general contractor to the concrete provider to the concrete contractor, all the way down the value chain to the workers pumping, placing, and finishing the concrete. That early engagement is an assurance of guaranteed success.

When specifying blended cements, it is important to consider the following and the implications to the full team:

- Work with the cement supplier to use performance-based specifications instead of falling back on prescriptive cement types that may not give them the flexibility they need.

- Use trial batches and mock-ups to match performance with expectations, including project schedule and project budget expectations.
- Communicate with suppliers from the very start to understand regional material differences and be aware of local material availability, challenges in transportation, and how local climate or materials may impact mix performance.
- Ensure certified field-testing technicians are monitoring slump and air content since higher fineness can affect these properties and may impact admixture dosages.
- Consider the effects of temperature on set time and strength development. Remind contractors to watch out for lower bleed rates and avoid finishing too early, which can trap water and cause surface issues.
- Using test sections or mock-ups to better understand timing is always encouraged.

Type IL cement has a proven track record of reliability, durability, and flexibility in a range of projects from buildings and pavements to bridges and other infrastructure. Thanks to extensive research and thorough testing, all 50 State Departments of Transportation (DOT) accept the use of blended cements in new infrastructure, and many are using Type IL cement.

Versatility throughout a structure

Faced with the need for more bed space to serve the community of North Liberty, Iowa, the University of Iowa Hospitals opted for a concrete building for occupant safety and the overall long-term benefits of concrete durability. As an inert substance, concrete does not off-gas harmful chemicals, and its extremely high stiffness can reduce vibrations in buildings, which can be beneficial where sensitive medical equipment operates.

For this project, the team used 22,937 m^3 (30,000 yd^3) of concrete products made with Type IL. Concrete was used in cast-in-place, precast and post-tensioned products ranging from foundations to floor slabs, columns and walls, and even the parking lot. The team collaborated closely and, as a result, built the six-story, 43,555 m^2 (469,000-sf) hospital on a 24-month schedule. The result was a facility that not only met the highest standards for strength and durability but also delivered a meaningful reduction in carbon emissions. This project stands as a testament to what is possible when sustainability is embedded in the design process from day one.

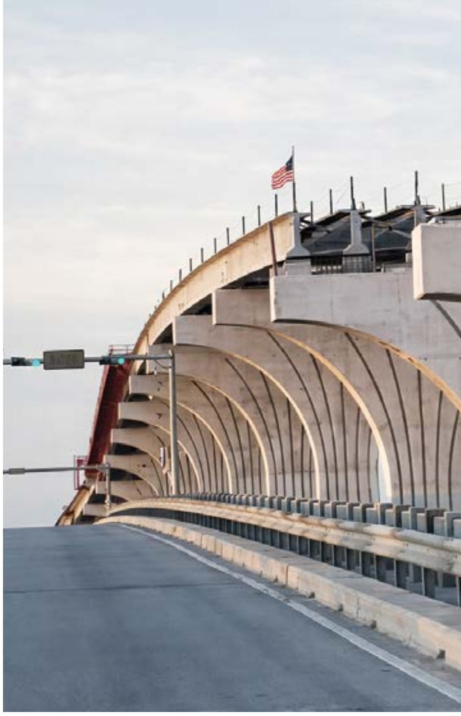
Meeting strength and aesthetic requirements

The Indiana University Ferguson International Center project required white concrete to coordinate with the campus's historic tan and gray limestone buildings, many of which date back to the original 1820s campus construction. Initially, the plan was to use white cement with imported materials for the four-level post-tension deck, which required architectural concrete on the outer perimeters and vertical elements.

However, the project team decided to switch to Type IL because it could achieve the needed color, durability, and strength while being more budget-friendly. The university was also looking for locally produced, more sustainable materials.

To match the color of the surrounding buildings, the team completed 29 trial batches, making subtle adjustments each time. The extensive trials paid off, achieving a color match that met the university's stringent requirements.

Another unique aspect of this project was the post-tension deck, which used two different mixes simultaneously. The project required different PSI levels for various components, including a 41,369 kPa (6,000 psi) post-tension deck concrete and 27,579 kPa (4,000 psi) for



Landscape photo of SR 679, Bayway Bridge in Pinellas County, Fla., while under construction.

architectural walls. To achieve the 41,369 kPa (6,000 psi), the team chose a 34,474 kPa (5,000 psi) design using slag and strength-enhancing admixtures. Two different pumps were used to pour two different mix designs in the post-tensioned concrete deck. The greater mass of the center section was the 41,369 kPa (6,000 psi) non-air-entrained ash mix, using an F ash. With the cantilever section, there was a 1.83–2.44 m (6–8 ft) section around the outside rim, which used a 34,474 kPa (5,000 psi) slag mix, air-entrained.

The limestone percentage across this project was approximately 11 percent. The careful blend ensured that the project met structural and aesthetic requirements, while providing substantial sustainability benefits. The team used several smaller mockups and stayed attentive to detail throughout the process, enabling them to move forward with confidence it would meet required standards and aesthetic requirements.

Paving the way to more resilient infrastructure

Thanks to extensive research and thorough testing, all 50 State DOT accept the use of blended cements in new infrastructure, and many are using Type IL cement. In Tennessee, where the local DOT looks to reduce the environmental impact of new projects, Type IL was selected for bridge deck repairs along a critical automotive corridor in the Southeastern U.S.

Working closely with their cement suppliers, ready mix concrete producers began testing mixes for compressive strength, setting time, air content, slump, and bleed potential. They used a mixture containing 9,932 kg/m^3 (620 lb/ft^3) of Type IL with a 25 percent fly ash replacement. The fly ash provided better consistency for the mix. After running some 450 trial batches, producers were confident in the compressive strength results of 27,579 kPa (4,000 psi) at 28 days, noting little to no difference between the Type IL mixes and their typical Type I/II mixes. Ready mix employees commented that it was easy to make the change.

With this information in hand, the ready-mix producer approached TDOT about using Type IL concrete for its bridge decks. TDOT agreed to use the Type IL/fly ash mixes. As a result of the 1:1 replacement level for traditional Portland cement and the additional 25 percent fly ash content, TDOT was able to use Type IL to reduce

bridge; and replace a seawall south of the bridge along SR 679 in Pinellas County.

These structures are all exposed to a marine environment. Although such exposures are aggressive to reinforced concrete because chlorides corrode steel, encasing metal reinforcement in concrete protects it from salt and corrosion. Sensing an opportunity to promote sustainable and performance aspects of concrete, the ready-mix concrete supplier provided submittals for Type IL mixes to the contractor, American Bridge Company. FDOT already encourages the use of Type IL in all their projects. As a result, Type IL was used for much of the 13,520 m^3 (17,704 yd^3) of concrete, excluding precast elements.

the carbon footprint for several bridge decks while producing concrete with the required properties.

Maintaining bridges is critical everywhere, but in Florida, a state heavily dependent on tourism, bridges are especially important for access to the 1,066 km (663 miles) of beaches and small islands along Florida's 2,173 km (1,350 miles) coastline. In Pinellas County Florida, south of St. Petersburg, the island of Tierra Verde and its renowned beaches are accessed via SR 679, Bayway Bridge-Structure E. In 2018, the Florida Department of Transportation (FDOT) began a $56.8-million design-build project to replace the 60-year-old bascule bridge with a high-level, fixed bridge to reduce congestion and minimize delays related to boat traffic; repave the existing SR 679 roadway between SR 682 and the new

Building a better future

Traditional Portland cement has been in use for nearly two centuries. Blended cements present an exciting and critical shift in the construction industry, driven by the urgent need to reduce carbon emissions while still meeting durability and resiliency requirements. While blended cements accounted for only three percent of U.S. cement consumption in 2020, they surpassed 50 percent by 2024, reflecting growing confidence among producers, contractors, and architects in their performance.

Through the ACA, construction stakeholders have access to technical resources, workshops, and direct support to help project teams navigate the transition to blended cements, validate performance, and optimize every product for both sustainability and strength.

additional information

AUTHOR

Rick Bohan, senior vice president of cement for the American Cement Association (ACA), has been at the forefront of research and technology throughout his career as a licensed professional engineer. As ACA's lead on the development and now the implementation of its Roadmap to Carbon Neutrality, Bohan is passionate about engaging the industry as the solution to society's grand challenge of global warming.

KEY TAKEAWAYS

Blended cements such as Type IL offer durable, resilient, and sustainable concrete solutions. They meet strength and aesthetic requirements, reduce carbon footprint, and are proven across buildings, bridges, and infrastructure nationwide.

MASTERFORMAT NO.

03 30 00—Cast-in-Place Concrete
03 41 00—Precast Concrete

UNIFORMAT NO.

B2010—Exterior Walls (Concrete)
C1010—Foundations

KEYWORDS

Division 03
Type IL
Cement

Designing for the End

Why Roof Recycling Should Start in the Specification

By Bill Bellico

PHOTO ©DORALIN TUNAS/COURTESY BIGTOCKPHOTO.COM

Sustainability is not a niche concern in building construction and related disciplines. It is becoming an expectation. Increasingly, architects and construction specifiers are asked to demonstrate that material choices align with climate goals, corporate responsibility commitments, and green building standards.

Much of the conversation has focused on a finished building's energy use, embodied carbon, and material transparency, but one critical topic still receives less attention than it deserves: what happens to building materials at the end of their service life.

This is not a question that can be put off until tomorrow. Planning now for the future recyclability of building materials saves money, helps offset carbon emissions, and brings industries closer to the circularity everyone craves.

Starting at the top

As much as 75 percent of the commercial low-slope roofing market involves reroofing, making the opportunity to recycle end-of-life roofing materials significant. For commercial roofing systems, particularly single-ply membranes, polyvinyl chloride (PVC) roofing has emerged as a leader in establishing a credible, scalable pathway to circularity.

Among commercial roofing materials, PVC has the most established and mature recycling infrastructure.

Recycling PVC roof membrane dates back to the late 1990s. The Coated Fabrics and Film Association-Vinyl Roofing Division (CFFA-VRD) started collecting recycling data for both pre- and post-consumer PVC roof membrane in 2014. Within 10 years, CFFA-VRD members had recycled more than 91 million kg (200 million lb) of pre- and post-consumer membrane. This translates to millions of square feet recycled per year.

This is not theoretical or experimental—it is happening at scale, with defined logistics, quality controls, and end markets.

Other single-ply systems, such as ethylene propylene diene monomer (EPDM) and thermoplastic polyolefin (TPO), are exploring recycling pathways, but PVC currently stands apart in terms of proven methods and consistent

For commercial roofing systems, particularly single-ply membranes, polyvinyl chloride (PVC) roofing has emerged as a leader in establishing a credible, scalable pathway to circularity.

PHOTOS COURTESY COATED FABRICS AND FILM ASSOCIATION-VINYL ROOFING DIVISION (CFFA-VRD)

outcomes. For architects and specifiers evaluating materials through a lifecycle lens, this matters.

From values to viability

Most architects today bring a sustainability mindset to their work. Climate impact, material health, durability, and lifecycle performance are now core components of architectural education and professional culture. Specifiers routinely seek Environmental Product Declarations (EPDs) that assess all aspects of raw material generation, product manufacture, and installation on a building. Comparison of embodied carbon information provided in EPDs should not be the sole focus of product selection, since performance over the life of the product and end-of-life solutions for future carbon avoidance should also be weighed when prioritizing materials intended for decades-long use.

External drivers such as client requirements, regulations, green building rating systems, and corporate environmental commitments can be used as leverage to move sustainability from intent to action.

Roofing systems often fall into a unique gap. Architects are typically focused on new construction, while reroofing decisions tend to involve roof consultants and contractors later in a building's life. As a result, many architects who care deeply about sustainability may not realize that roof recycling is already possible today. Building design and specification decisions made now can determine whether recycling is feasible 20 or 30 years from now.

Awareness is critical. Landfilling roofing materials will likely become more difficult and expensive over time. Designing roofs today with end-of-life considerations can help project owners improve tomorrow's environmental outcomes.

The proven pathway of PVC

Mechanically fastened or induction-welded PVC single-ply roof membranes are designed for recycling because they can be removed (skinned) without much contamination from other roof components and transported to recyclers. This provides a relatively clean material for recyclers skilled in handling it, eliminates the need to landfill the membrane, and reduces dumpster and roof disposal costs.

In a tear-off situation, the existing PVC roof membrane is already being removed, so all that is needed is for the contractor to bundle and package the membrane for shipment to a recycler. On a reroofing project where it is intended to leave the existing roof system in place and simply install a new membrane over it, it may make sense to remove or skin the original PVC roof membrane to provide additional reroofing options for the next renovation cycle.

The PVC roofing industry has created information to make recycling easier to specify

Mechanically fastened or induction-welded polyvinyl chloride (PVC) single-ply roof membranes are designed for recycling because they can be removed (skinned) without much contamination from other roof components and transported to recyclers.

and execute. Contractors now have access to clear guidance on membrane removal, packaging, and transport. Educational tools, FAQs, specification language, bid line-item templates, and documented success stories help reduce the uncertainty, one of the biggest barriers to adoption.

Watch and learn

Some building project stakeholders have spoken of reticence to recycle PVC roofing because they either do not know the proper procedure or fear it is prohibitively expensive. CFFA-VRD developed a video to demystify the process. It explains, in detail and using plain language, how to prepare used PVC roofing for recycling.[1]

With a few extra steps and minimal extra labor, mechanically fastened or ballasted PVC roof membranes can be removed and packaged for recycling. The video walks through the steps for a successful recycling project, from the first meeting to the flatbed driving to the recycling facility.

Building stakeholders will also be pleased to learn that there is no one right way to package and bundle the old roof. The video explains several popular options and notes that recycling takes only up to three more steps than a standard roof removal process.

Why recycling belongs in the specification

CFFA-VRD recommends that roofing contractors include PVC recycling as a separate alternate bid line item, where appropriate, to enable building owners to evaluate costs alongside environmental benefits. The comparison can help project managers understand that, while recycling adds some cost to the overall reroofing project, that cost can be offset by eliminating landfill fees. For building owners seeking or renewing green certifications, recycling roof membranes at the end of their service life can help maintain or even increase building value and occupancy rates.

By incorporating language that requires or allows for membrane recycling, and by calling for a separate bid line item, architects give project managers the ability to make an informed decision at the time of construction or reroofing. Even if recycling is not selected on every project, its inclusion signals intent, creates transparency, and promotes future action.

To encourage PVC roof recycling and make it easier for specifiers to include it in their re-roofing specifications, CFFA-VRD has created a downloadable PVC Roof Recycling Guide Specifications and Suggested Bid Line Item form.[2]

Roofing contractors are encouraged to coordinate any recycling opportunities directly with the PVC roofing manufacturer. Final project documentation should include confirmation of the amount of material diverted from landfills.

This approach aligns well with how sustainability decisions are actually made. Owners may weigh the incremental cost of recycling against corporate sustainability goals, waste diversion targets, or public commitments. Without that option in the specification, the conversation never happens.

New white paper tells the story

Brian Whelan and Richard Krock are two consultants who have been helping CFFA-VRD hone its sustainability efforts and messaging. Whelan is the owner of Roof Resources and past executive of Sika Sarnafil, Krock is the owner of VyChlor Advisors, LLC, and former senior vice president of the Vinyl Institute. The two have co-authored a paper recently published by the National Institute for Standards and Testing (NIST) titled, "Opportunities for Recycling in Building Cycle Renovations: A Case Study of PVC Roofing Membranes."[3]

"With this paper, we want to give property owners something more tangible they can look to and say, 'this is why we're choosing to recycle,'" says Krock, who notes the U.S. Environmental Protection Agency (EPA) has set a goal to hit a 50 percent recycling rate for the entire country's waste materials by 2030.

The paper examines the carbon-reduction potential of recycling PVC roofing membranes during building renovations and compares traditional disposal (landfilling) with three recycling scenarios: closed-loop recycling into new roofing products, open-loop recycling into other products, and a combination of both.

Using EPDs and lifecycle data, the analysis shows that all recycling pathways can deliver significant carbon avoidance compared to business-as-usual practices. Overall, the findings support transitioning from landfilling to recycling PVC roofing membranes as a practical strategy to reduce emissions and advance circularity in the building sector.

"There's wide diversity in awareness levels about the efficacy of PVC roofing membrane recycling," says Whelan. "There is value in recycling a roof for all stakeholders, including specifiers and consultants."

In the push toward more sustainable buildings, industry can no longer afford to think only about how materials perform on day one. True lifecycle thinking begins with the end in mind. By recognizing that PVC roof membranes already have a proven, scalable recycling pathway, and by reflecting that reality in today's specifications, architects and project teams can turn reroofing from a waste stream into an opportunity.

The choice to plan for recyclability is not a distant ideal; it is a practical, available strategy that reduces landfill use, manages long-term costs, and supports measurable progress toward circularity. When end-of-life is part of the original design conversation, sustainability can move from aspiration to action.

In the push toward more sustainable buildings, the industry can no longer afford to think only about how materials perform on day one. True lifecycle thinking begins with the end in mind.

NOTES

[1] Watch the video at youtu.be/3SotriN-5Jg?si=ZrMSWNDhhlHkMibl

[2] Refer to vinylroofs.org/wp-content/uploads/2025/06/CFFA_Recycling_Specification_Bid_Form.docx

[3] Review remadeinstitute.org/mp-files/2025-77-opportunities-for-recycling-in-building-cycle-renovations-a-case-study-of-pvc-roofing-membranes.pdf/

additional information

AUTHOR

Bill Bellico is the vice president of marketing and inside sales at Sika Corporation. He has worked in the commercial construction industry for 22 years as part of Sika's roofing and flooring divisions. Bellico began his career in sales and eventually evolved into roles in sales and marketing management, as well as leading key digital transformation projects for the company. He is a LEED-accredited professional with a strong background in sustainability. Bellico is the current acting marketing chair for the Chemical Fabrics & Film Association (CFFA)—Vinyl Roofing Division, as well as the Vinyl Sustainability Council, and is also a participating member of the Roofing Technology Think Tank (RT3). Bellico has bachelor's degrees in English and psychology from Bridgewater State University and completed the business strategy certificate program from Cornell University.

KEY TAKEAWAYS

Planning for end-of-life material recovery is becoming essential in sustainable building design. Polyvinyl chloride (PVC) roofing membranes offer a proven recycling pathway, enabling reroofing projects to reduce landfill waste and support circular construction practices.

MASTERFORMAT NO.

07 54 19—Polyvinyl Chloride (PVC) Roofing

UNIFORMAT NO.

B3010—Roof Coverings

KEYWORDS

Division 07
Polyvinyl chloride
Roofing

From Pike Place to the Pacific Ocean

The Art of Aquarium Design

By Matthew Szymansk

PHOTO BY LARA SWIMMER/COURTESY ETSO

The Seattle Aquarium Ocean Pavilion (SAOP) embodies interconnectivity and sustainability, linking various iconic Seattle landmarks to the ocean. The Ocean Pavilion integrates with the urban waterfront and the Aquarium's nearby harborside buildings, offering a collection of immersive marine experiences. The new Ocean Pavilion highlights the connection between people and marine life at home and around the world. The facility also serves as a link to downtown Seattle, Pike Place Market, the newly revitalized central waterfront, Elliot Bay, and the ocean beyond.

The 4,645-m^2 (50,000-sf) building features living habitats and ecological experiences, moving beyond traditional aquarium models to highlight the connection between human and marine life. As a complement to the habitat experience, the Ocean Pavilion tells an unforgettable story about Earth's one ocean through state-of-the-art digital

PHOTOS COURTESY SEATTLE AQUARIUM

storytelling.[1] The project honors its location on the traditional lands of the Coast Salish peoples, incorporating their input into the design and cultural framework for the building, landscape, exhibits, and public art.

The Pavilion, designed by LMN Architects along with Thinc Design, who designed the exhibit spaces, includes two large, public-facing habitats where visitors can observe the aquatic life.

The first habitat is The Reef, a nearly 1.89-million L (500,000-gal), multi-story area designed to mirror an Indo-Pacific coral reef. The second habitat consists of two smaller habitats—the Archipelago, an Indonesian mangrove forest that's surrounded by a pool of sea stars, fish and rays, as well as live plants, and another habitat that includes a variety of fish species and live coral.

Unique construction

The large habitats have essentially no straight edges and The Reef consists of 520 m^3 (680 yd^3) of concrete and 322 tonnes (355 tons) of rebar—four times the rebar used on a typical core—comprise the 0.61-m (2-ft) thick walls with six layers of reinforcement. The aquarium is in the heart of downtown Seattle's waterfront, which has been undergoing a multi-year redevelopment. Site constraints, coupled with a small footprint on a fill site in a seismic zone, required careful logistics planning to depict the multiple milestone phases of construction. The small footprint left little space for staging, and the geometry of the primary habitats meant that formwork coordination and prefabrication efforts would need to account for numerous life-support systems and embedments prior to site delivery.

Among the software products used to overcome these challenges were Trimble Access with TSC7 data collector, Trimble FieldLink, Trimble Connect, Trimble RTS771, Trimble X7, SketchUp and Tekla Structures. The imported geometry, facilitated by the Tekla Live Link, served as the foundation for subsequent detailing and constructability analysis. Tekla Structures provided a comprehensive suite of analysis for creating accurate concrete elements, formwork, embed, rebar and more. These tools enabled the creation of detailed installation sequence drawings specifically developed for the tank's formwork and concrete lift drawings.

While the project presented several challenges, one of the issues the Turner Construction team managed was working from a contractual 3D model provided by LMN Architects that represented the geometry of the primary habitats. This was the basis for Turner's self-performed concrete detailing efforts, combining all formwork, rebar, embedments, acrylic viewing windows, and mechanical systems into one model used to generate the necessary shop drawings and digitally fabricated formwork elements.

To ensure the lights—critical for the living habitats—would not be obtrusive to the guest experience, the lighting design included custom fixtures for over the coral habitat, which took extensive work to set in place and focus where needed to best recreate the look of a marine ecosystem in the wild.

Environmental stewardship

The Aquarium's vision is to produce more environmental benefits than harm, helping ensure a climate-resilient, sustainable future for all—in other words, to become a regenerative aquarium. This commitment is reflected throughout the Ocean Pavilion, which is certified LEED Gold and is targeting Zero Carbon Certification. The facility operates fossil-fuel-free, recirculating nearly all of the saltwater in its habitats—saving water and energy. Water-to-water heat exchangers recapture heat from tank water being discharged, and use it to heat the incoming makeup seawater from Puget Sound. Using water from Puget Sound reduces the amount of potable water used for exhibits.

The heating and cooling systems use 91 percent less energy than traditional systems, and the architectural and design teams carefully chose materials, such as the Alaskan yellow cedar exterior panels on the building's west face, which are Forest Stewardship Council-certified and come from an Indigenous-led company.

The Zero Carbon Certification requires the Aquarium to offset 100 percent of the building's operational energy use with new renewable energy. Some buildings meet this requirement by installing rooftop solar panels, but SAOP's rooftop is a public space to enjoy. To that end, the organization is working with the local utility to enter into a power purchase agreement that will add solar renewable energy capacity to Seattle's electric grid.

Green materials, from carpet made of recycled fishing nets to recycled-paper panelling, reflect the commitment to environmental stewardship, while every detail, from the dichroic acrylic accents and exposed mechanicals to working with Indigenous consultants, speaks to transparency, inclusion, and interconnectedness.

To honor and acknowledge the Aquarium's location on the traditional lands of the Coast Salish people, the project team worked closely with Indigenous consultants and members of the urban Native community to inform the programming, design, and cultural framework for the building, landscape, exhibits, and public art. Engagement included hearing traditional stories from tribal elders, workshops with tribal youth, and regular design sessions with Indigenous consultants.

Additionally, the pavilion uses concrete mixes designed to reduce its carbon footprint, including Portland-limestone cement.

SAOP is the first aquarium building in the world to pursue Living Future Institute (ILF) certification.

Corrosive environments and lighting

Lighting is an important component throughout SAOP, prioritizing the animals' needs while enhancing habitats and other exhibits. For example, the team had to ensure there were sufficient lighting requirements for all the plants, including grow lights.

"The animals are very sensitive to light, so the entire facility includes a lighting control system based on the animals' circadian rhythm. This means the front-of-house light output slowly increases over an approximately 90-minute timeframe. The duration that they stay at this level, and when the light output gradually decreases, is all specifically planned with the Seattle Aquarium Ocean Pavilion aquarists," says Hanna Kato, project architect, LMN.

Equally critical to the facility is the back-of-house (BOH) infrastructure, which requires extensive planning, including specifying luminaires that can withstand the unique challenges of this environment.

Unlike the BOH facilities in museums, entertainment centers, and art galleries, aquarium life support systems operate 24/7/365 to maintain water quality and keep the animals healthy. These corrosive settings need chemical-resistant luminaires, certified for wet locations, to ensure the fixtures do not fail, while performing at optimum light output. High ingress protection (IP) ratings prevent the ingress of dust and water into the fixtures, reducing maintenance costs and time. These factors are crucial for ensuring worker safety, optimizing productivity, and maintaining efficient operations.

Corridor lighting

When specifying lighting for SAOP, project designers considered the duties of aquarium employees who work with the animals, as well as those responsible for the building systems and areas accessible to guests.

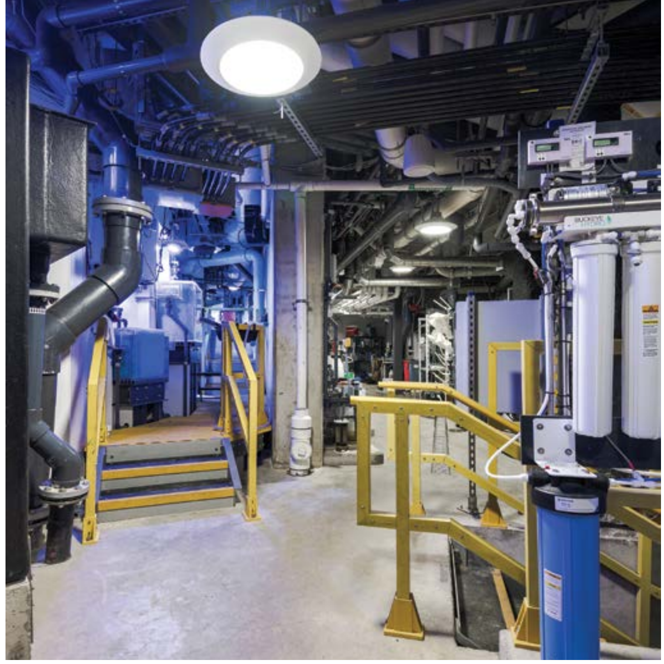
"The aquarium and the exhibit designer collaboratively decided to incorporate behind-the-scenes (areas) as a component for the guest experience," says Susan Bullerdick, the aquarium's senior director of capital projects. "As such, the lighting ensures guests can safely navigate hallways and also allows them to clearly observe intricate details of the animal habitats and equipment."

LED luminaires have been installed in the back-of-house (BOH) corridors as part of the sustainable infrastructure features. The lighting system is designed to be energy-efficient and withstand a corrosive environment.

Jesse Phillips-Kress, vice president of facilities and operations, worked with PAE-Engineers to ensure the lighting system selected met these challenges. This project uses 457-mm (18-in.) diameter ceiling-mounted luminaires.

The luminaires are constructed from marine-grade die-cast aluminum, ensuring corrosion resistance and high-abuse properties, making them ideal for the aquarium's back-of-house (BOH) corridors. Additionally, the IP65 rating is appropriate for this wet location.

SAOP's aquarists, marine technicians, and facilities team need the BOH corridors uniformly illuminated. The light output ranges from 3,086 to 12,943 lumens, ensuring corridors are evenly lit and illuminated with bright, white light.



The facility's efforts to reduce energy and water consumption, and carbon footprint include innovative use of a central air heat pump system and a semi-closed water system. Complementing these are LED luminaires installed in the back-of-house (BOH) corridors. These luminaires are energy efficient and, more importantly, able to withstand the highly corrosive environment.

PHOTO COURTESY KENALL MANUFACTURING

"Knowing the fixtures withstand a 1,000-hour salt spray test gives me confidence that these luminaires installed in the corridors can meet SAOP's challenging environment," says Phillips-Kress.

Results

The entire team and trades partners maintained a singular focus on delivering the best possible facility through intense collaboration and innovation. The award-winning facility engages, inspires, and educates visitors from around the world and greatly benefits the Seattle community.

additional information

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Matt Szymanski is Western regional sales manager for Kenall and may be reached at matthew.szymanski@kenall.com. Kenall, a brand of Legrand, was founded in Chicago, Illinois in 1963 and has built a reputation for durable lighting solutions of superior quality and exceptional value. Kenall luminaires are designed and manufactured in Kenosha, Wisc., and can comply with the *Buy American Act*. For additional information, visit kenall.com.

KEY TAKEAWAYS

Seattle Aquarium's Ocean Pavilion (SAOP) links urban waterfront to ocean, showcasing immersive marine habitats, sustainable design, Indigenous collaboration, advanced lighting, and regenerative practices, setting a new global standard for aquariums and environmental stewardship.

MASTERFORMAT NO.

03 35 00—Concrete Finishing
13 34 00—Water Treatment Equipment
26 51 00—Interior Lighting

UNIFORMAT NO.

D3020—Lighting
G2010—Exhibition/Display
G2020—Special Construction / Aquarium Systems

KEYWORDS

Division 03, 13, 26
Aquarium design
Sustainability

The Imperfect Storm (Window)

Condensation can form on and within a building enclosure system when its surface temperature falls below the dew point of the surrounding ambient environment. When interior environments operate at elevated relative humidity (RH) levels, the potential for condensation increases. Even with high-performance building enclosures, fenestration systems (particularly their glazing infill) are typically more vulnerable to surface condensation because they provide less thermal resistance (*i.e.* greater heat transfer) than properly designed and constructed opaque wall assemblies.

Providing warm air flow across the interior plane of a glazing system has long been well understood and employed, mainly to increase human comfort by eliminating down drafts. During heating seasons, providing forced warm air across the interior surface via mechanical provisions can also increase the surface temperatures of the glass and framing components, thereby reducing condensation potential on these exposed interior surfaces.

Conversely, installing window treatments and furnishings that isolate (or buffer) a window system from the influence of the interior ambient temperature can increase the potential for condensation on the now-cooler, exposed interior surfaces of the system. In certain circumstances, particularly in existing buildings, interior glazing systems (commonly referred to as storm windows) are installed directly inboard of the primary system to improve the overall fenestration's energy efficiency. As this interior glazing also buffers the primary system from the interior temperature, the "storm" system must incorporate air seals to prevent interior moisture from migrating into the interstitial buffer zone. If airflow is not managed, that moisture can contact the now-cooler surfaces of the primary system, thereby increasing the potential for condensation.

This was recently observed at a humidified, mission-critical facility in the northeast that intentionally installed an interior "storm" window with an integral mini-blind inboard of the primary punched-opening glazing assembly; not to improve the fenestration's overall energy

Widespread condensation of the interior glazing surface of the primary system, resulting in water pooling on the sill framing.

Open joints at mitered corners of the interior "storm" window, allowing humidified interior air to reach the primary glazing system.

performance, but rather to provide privacy while limiting blind access and maintaining a more sterile environment. During the first heating season after installation, widespread condensation formed on the interior glass surface of the primary glazing assembly.

Upon further review of existing conditions, it was determined that the interior storm windows were not airtight, exhibiting open joints at mitered frame corners and along perimeter interfaces. Additionally, the building was operated at a slightly positive air pressure relative to the exterior, which encouraged moist interior air to flow into the interstitial space between the primary and storm windows through the open frame joinery. Since the interior "storm" window isolated the primary glazing assembly from the influence of the interior temperature, the primary assembly's interior surface temperatures were more influenced by exterior temperatures and thus reduced, making these surfaces more vulnerable to condensation caused by contact with moist interior air within the interstitial air space—an unexpected consequence of the design and installation.

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