2026 IIBEC INTERNATIONAL CONVENTION & TRADE SHOW

PROCEEDINGS

MARCH 12-15, 2026
Sacramento, CA
iibecconvention.org

IIBEC

434 Fayetteville St., Suite 2400
Raleigh, NC 27601

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Schedule times and presenters are accurate as of press time in January 2026.

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FRIDAY, MARCH 13, 2026

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2026 IIBEC INTERNATIONAL CONVENTION & TRADE SHOW

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Building Enclosure Performance Verification Testing: Changing the Paradigm—Supporting Sustainability, Resilience, and ESG Goals

ABSTRACT

Building enclosure performance verification testing plays a critical role in advancing sustainability, resilience, and the achievement of environmental, social, and governance (ESG) goals in the built environment. The building enclosure directly impacts energy efficiency, occupant health, and structural durability. The current paradigm of building enclosure performance verification testing largely revolves around satisfying codes and standards. However, applying testing through the lens of sustainability and resiliency may have a more impactful payoff by minimizing energy loss, reducing greenhouse gas emissions, extending asset lifespans, reducing operating costs, and supporting healthier indoor environments. This presentation will inform commissioning agents, designers, consultants, and project owners on the value of integrating testing into design, construction, and operations to align building performance with sustainability objectives and future-proof their assets against environmental and regulatory challenges. As climate change intensifies, building enclosure verification testing should be considered a foundational practice for responsible, high-performing, and resilient buildings.

LEARNING OBJECTIVES

- Identify at least three ways that building enclosure (or “envelope”) performance verification testing contributes to sustainability and resilience in buildings.
- Distinguish between code-minimum enclosure testing and testing strategies that proactively support long-term sustainability and resilience goals.
- Explain how integrating enclosure testing into the design, construction, and commissioning phases can reduce operational costs and environmental risk for building owners.
- Summarize the benefits of building enclosure testing for asset lifespan extension, citing at least two metrics (for example, energy savings, maintenance reduction) that can be improved through proactive verification.

SPEAKERS

Christopher Traynor, PEng
Senior Associate, Terracon

Chris Traynor is a building scientist in Terracon’s facilities service line in Denver, Colorado. His background includes building forensic investigation and evaluation, building enclosure commissioning services, and repair design with an emphasis on cold climates for clients in the commercial, institutional, governmental, multiunit residential, and light-industrial market segments. Traynor takes a fundamental approach to solving building enclosure problems, using a formal building science education complemented by years of experience. He also leads Terracon’s national building enclosure testing practice.

Eric Lee, EIT
Senior Staff Engineer, Terracon

Eric Lee is a senior staff engineer in Terracon’s facilities service line in the Denver, Colorado, office. Lee has extensive experience in field performance verification testing, including large whole-building air leakage and large-scale glazing water penetration testing, in addition to construction and commissioning observation services. Lee utilizes an engineering-focused approach to performing testing services. Lee has a degree in mechanical engineering from the University of Colorado Boulder.

AUTHORS:
Christopher Traynor, PEng
Eric Lee, EIT

This paper started with a rhetorical question:

Sustainability plays an important role in our company's value of caring. If this is true, how can we as a company endorse the practice of window water testing? It is absolutely crazy how much water was wasted in proving the integrity of the window seals.

But it is really the start of a bigger conversation about how spraying water at windows (or any building enclosure testing, for that matter) fits into the greater goals of sustainability and resiliency.

Fenestration water penetration tests can use anywhere from 3 gpm (0.2 L/s) to over 50 gpm (3.2 L/s) on some of the larger tests. Like many people who live in places where water is scarce, the authors share people's concerns about water as a resource and its most efficient use.

However, it is necessary to consider the total "cost" of resources, such as hidden financial costs, environmental impact such as embodied carbon and emissions, etc. It is important to consider the consequences of not performing building enclosure tests to verify performance, including the following:

- Energy waste
- Loss of use
- Decreased occupant productivity
- Increased maintenance cost
- Premature system failure requiring replacement

Most of these things hit the statement of profit and loss and are included on a balance sheet, but they are not identified as line items, and they have very real impacts, both economically and in terms of resource use.

There are many tests that building enclosure professionals perform on building enclosures that have significant impacts on their clients' sustainability objectives and efforts. Because the consequences of building enclosure performance failures are not usually catastrophic or immediate, they are not always understood and appreciated by the end user or occupants. While the benefits of these tests are not always easily measurable, they have very significant benefits to the clients' triple bottom line (environmental and social impact, in addition to financial performance).[1]

The market has been slow to consider these benefits, and the industry has not been great at selling this either, because, like most things, and especially for engineers and economists, people tend to focus on things that are most easily measurable, which are not always the most important things.

When building enclosure professionals do these tests, it is often because their clients:

- have boilerplate requirements ("We did this on the last job we did"),
- are compelled to or aspire to complete enclosure commissioning (often without adequate consideration to cost/benefit and testing rate), or
- have to follow the code ("That is all that is important to us").

But if project owners, designers, commissioning agents, and testers changed from this paradigm to consider toward a sustainability- and resiliency-oriented perspective instead, they would be more likely to help improve the performance of their clients' facilities. It is this change of paradigm that will ultimately save them energy, resources, and money over the life cycle of their projects.

SUSTAINABILITY, RESILIENCY, AND WHY THE ENCLOSURE MATTERS

Let us define some terms in the context of this paper:

- **Sustainability** means designing and operating buildings so they meet today's needs with a view to the future. It is about conserving resources, minimizing waste, and keeping the environmental impact in check over a building's whole life, not just the first cost.[2,3]
- **Resiliency** means that a building can take a hit—storms, temperature swings, power outages—and bounce back quickly without losing function, safety, or occupant comfort.[4]

There is a relationship between these two concepts: If your building leaks air like a sieve, guzzles energy, and lets water leak into the wall, it is neither sustainable nor resilient. The building enclosure—walls, windows, doors, roofs—is your first and best defense. If it fails, the things it is designed to maintain and protect and the interrelated systems ultimately cost more, work harder, and wear out faster.

This is where building enclosure performance verification testing (BE PVT) comes in. BE PVT is the practice of demonstrating—with measurable, standardized tests—that your enclosure performs as the design intended. And when building enclosure professionals do it right, they are not just "passing inspection." They are protecting the owner's asset, keeping occupants comfortable and productive, and cutting down on wasted energy and materials over decades.

REGULATORY AND STANDARDS LANDSCAPE OF BE PVT

Building Code: A Minimum

A building code provides minimum requirements.[5] Its requirements prioritize safety and human welfare. It even does a good job of describing how the building enclosure should be designed and constructed. But it really does not speak to sustainability, and there is not a reference requiring verification of the performance of enclosure construction through testing.

2024 International Energy Conservation Code: The Energy Code Backbone

The 2024 International Energy Conservation Code has raised the stakes for building enclosure performance. Large buildings now require more stringent air leakage testing.[6] Why? Because uncontrolled leakage is one of the biggest ways buildings waste energy. Every cubic foot (cubic meter) of conditioned air you lose has to be reheated or re-cooled, which takes money, fuel, and carbon.

ASHRAE 90.1: Energy Efficiency at the Core

ASHRAE 90.1, *Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings*, has always been about energy efficiency, but controlling building enclosure leakage is one of the cheapest, most durable ways to improve efficiency. Test once, seal once, and you save every day of the building's service life.

ASTM E2813 and E2947: The BECx Playbooks

ASTM E2947, *Standard Guide for Building Enclosure Commissioning*, lays out the why and how of building enclosure commissioning (BECx)—a process for making sure the whole enclosure system performs, not just its individual parts. ASTM E2813, *Standard Practice for Building Enclosure Commissioning*, takes it further, providing a convenient checklist of BECx performance testing requirements in the annex to the standard.[7] These two standards are the backbone of performance verification that extends beyond checking a box on a code inspection.

LEED v5: Points for Proof

LEED v5 Reference Guide for Building Design and Construction, a green building standard, shifts toward rewarding measured performance of building enclosures. That means airtightness tests, water penetration tests, and thermal imaging are not just nice to have—they can help earn certification by proving your building enclosure reduces operational energy and protects materials from early failure.[8]

ASHRAE 189.1 and the *International Green Construction Code*: Making Green Requirements Enforceable

ASHRAE 189.1, *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*, sets ambitious goals for high-performance green buildings—energy efficiency, water use reduction, and durability—and the *International Green Construction Code* integrates it into enforceable regulations. Together, they turn "best practice" into "you must do this," pushing enclosure testing into the mainstream of sustainable design and beyond code minimum for air leakage testing.[9]

Code-Minimum Testing Compared to Proactive Testing

Proactive strategies catch design flaws before they are baked in, avoid costly rework, and often result in tighter building enclosures and lower operating costs than the minimum requires. By performing only code-minimum testing, you only do the one required whole-building air leakage test at the end, hope you pass, and fix whatever you find under the gun. On the other hand, proactive testing starts in design review (ASTM E2813), uses mock-ups (ASTM E2947), and tests in a targeted and progressive way during construction so problems are fixed when they are small and less expensive.

Integrating BE PVT from Design to Construction

BE PVT should be integrated into all phases, from the design phase to commissioning. At the design phase, the project team should ensure BE PVT is included in the specifications or BECx plan. During the construction phase, BE PVT should be performed to verify systems and workmanship meet the standards, allowing for real-time corrections and final performance verification, demonstrates the building meets energy and durability goals before occupancy.

BE PVT Delivers Sustainability and Resilience

BE PVT delivers sustainability and resilience by doing the following:

- It reduces energy use and carbon emissions. Verified airtightness and water resistance cut heating/cooling loads, which lowers fuel use and emissions. Studies show buildings meeting advanced airtightness targets can reduce heating, ventilating, and air-conditioning (HVAC) loads, translating to significant savings.
- It contributes to better construction quality, which results in the prevention of moisture intrusion and material degradation. Early detection of leaks identified through BE PVT avoids mold, corrosion, and premature material replacement, all of which carry high costs. Moisture intrusion prevention can cut building enclosure-related maintenance calls.
- It improves long-term occupant comfort and functionality. A stable interior environment keeps people productive, healthy, and less reliant on supplemental HVAC systems.

These are not "feel-good" metrics—they directly affect life-cycle cost and carbon emissions.

CASE STUDY 1: ONLY FOLLOWING THE CODE

Project: Conservatory with tropical plants

The authors' company was engaged to investigate persistent roof leaks near internal drains in a 2019 building addition. The leaks occurred year-round, were not weather-dependent, and had persisted despite drain and piping repairs. What was originally believed to be a roof leak was actually moisture entering the roof system at the roof-to-wall connection between the main building and the conservatory. Water vapor was likely condensing within the roof assembly that flows toward the internal drains due to the structural slope of the roof. Severe deterioration of oriented strand board roof decking was found at multiple test-cut locations, comprising the roof membrane's uplift resistance.

There are many ways these issues could have been identified: during design, during construction, and most certainly prior to substantial completion using a guarded whole-building air leakage test. It is obviously not a great time to find out your building is as leaky as a sieve at the end of the construction phase, but it would have been better than waiting 5 years. But it was not required by code, and whole-building air leakage tests are not inexpensive. There are many tests building enclosure testing providers perform that they cannot provide a return on investment to the client. But the cost of uncontrolled air leakage is literally money out the window, to say nothing of the cost of uncontrolled moisture-laden air leaking into a place where it can do damage.

But beyond measuring and diagnosing air leakage in new construction, in the authors' experience, the greatest value of whole-building air leakage testing is not in performing the test but in the promise (threat?) of performing the test.

CASE STUDY 2: "THIS IS WHAT THE COMMISSIONING STANDARD TOLD ME TO DO."

Project: Medical office building

The authors' company was requested to provide third-party fenestration testing services as sub-consultants to the BECx provider on this project. The team performed water penetration testing in general conformance with ASTM E1105 and AAMA 501.2.

Of the hundred-some windows on this building, the team tested fewer than four. The exterior cladding was on, which meant that the water-resistive barrier, flashings, and sealants were mostly concealed. The building leaked water during testing, but the team was never called on for additional testing.

One day, 8 years later, scaffolding went up around the building.

Why had the team even tested in the first place? Presumably, they tested the windows because that is part of commissioning. "The ASTMs told me to do it." This is known as testing for the sake of testing. What a waste.

CASE STUDY 3: IT IS NOT THE MONA LISA (TESTING MORE THAN THE MINIMUM)

Project: International airport

Why would you test 100% of two skylights totaling over 7,000 ft^2 (650 m^2) of glazed area, each with over 1,000 ft (300 m) of rafters and purlins on a project, when the American Architectural Manufacturers Association (AAMA) says that testing as few as one specimen may provide all the information you need?

Consider the cost of a leak when you have 82 million travelers per year walking under it. Then add suspending a very large piece of custom public artwork from the rafters. Chances are that you will quickly realize the value proposition of 100% testing. Artificial intelligence is not going to put cleaners and buckets out of work on rainy days, but changing the approach to what and how much testing is performed on the building enclosure might.

CASE STUDY 4: THE COMMUTATIVE PROPERTY OF MULTIPLICATION?

Project: Medical teaching facility

When is 9 × 1 not the same as 1 × 9? The BECx standards do not really say how big a test should be. AAMA attempts to provide guidance on minimum specimens in terms of size and connections. Building enclosure consultants often let their capabilities or the size of their equipment constrain what they are going to test. If you test a specimen that is multiple bays wide or multiple stories high, there is a good chance the specimen will react differently to water testing than if you had only tested a small portion. For example, if the installer left out corner blocks in a stick-built curtainwall, water will accumulate along a vertical and discharge all of that at the bottom. How much water it handles will be different if the test area is 8 × 8 ft (2.4 m × 2.4 m), 16 × 16 ft (4.8 m × 4.8 m), or 24 × 24 ft (7.3 m × 7.3 m).

ASTM E1105 basically requires an average of 5 gal./ft^2/hr (3.4 L/m^2/min) to be applied across a test specimen for 15 minutes. So you bring out your little spray rack and this is about 80 gal. (300 L) impinging on one of the six lites in the curtainwall that the chief executive officer looks out. You do this nine times at 15 minutes each. Most of the water runs off, and a small portion of it is managed within the drainage channels and drains to the exterior, and you leave satisfied because the client, the general contractor, and the glazier were happy to see no leakage. Now consider you do the same test with your much larger test setup and spray about 720 gal. (2,700 L) of water on the same area for one time of 15 minutes. Now a defect in the system is potentially compounded, and the same test area results in water leakage.

CLOSING: FROM CODE COMPLIANCE TO INTENTIONAL PERFORMANCE

IIBEC's Sustainability and Building Enclosures policy states, "It is the policy of the International Institute of Building Enclosure Consultants (IIBEC) that the principles of sustainability be considered when consulting on building enclosures. The three principles of sustainability are environment, society, and economy." (This policy can be found online at https://iibec.org/sustainability-and-building-enclosures/.)

If sustainability is about caring for future resources and resiliency is about protecting today's investment, then BE PVT is one of the smartest moves designers, developers, project owners, and building enclosure professionals can make.

Done right, it is not about passing a test. It is about locking in decades of reduced energy use, lower maintenance, and a more comfortable, functional building—while sidestepping the environmental and financial consequences that come with premature failure.

It is caring in practice. And yes—sometimes caring looks like wasting water by blasting a brand-new window with water.

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Understanding Fire Resistance Code Standards and Ensuring Roofs Meet Those Requirements

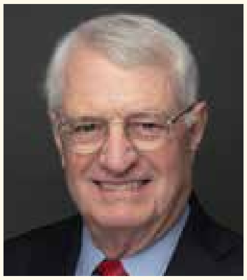
ABSTRACT

Not unlike the January 2025 Los Angeles, California, fires, burning brands blowing from roof to roof destroyed more than 17,000 buildings in the infamous 1871 Chicago, Illinois, fire. This and many more similar fires in the late 19th century have led to the development of fire resistance standards for roof coverings. Those standards are the basis for today's UL 790, *Standard Test Methods for Fire Tests of Roof Coverings*, and ASTM E108, *Standard Test Methods for Fire Tests of Roof Coverings*, requirements found in today's *International Building Code*. Most of us know Class A, B, and C fire ratings but do not understand the nuances of these ratings. As a result, every year millions of square feet of roofing are installed that do not meet the building code standards for which they are designed to prevent the types of devastating fire losses we see today. The roofing material may have a Class A or B rating, but the roofing assembly may only meet a Class C or is not rated at all. The assembly may have a Class A or B rating on a steel deck but only a Class C on a plywood deck. This presentation will provide an overview and key variables of the testing methods, code requirements, and system nuances required to meet the required fire resistance standards.

LEARNING OBJECTIVES

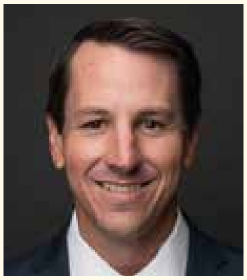
- Evaluate the different testing standards required to meet Class A, B, or C standards.
- Review the key variables in the testing that create the misunderstandings related to Class A-, B-, or C-rated materials, and Class A-, B-, or C-rated roofing assemblies.
- Discuss the development of the building codes as they relate to fire resistance of roof coverings and what the current building codes standards require.
- Identify the variables required to properly specify a roofing assembly that meets the appropriate fire resistance requirements for the roofing assembly.

SPEAKERS



Stephen Patterson, F-IIBEC, RRC, PE
ROOFTECH

Stephen Patterson has been in the roofing industry for 50 years. He founded Roof Technical Services Inc. (ROOFTECH) in 1983 and has been an active consulting engineer and roof consultant ever since. He is a Registered Roof Consultant, fellow of IIBEC, and a licensed engineer. ROOFTECH has provided laboratory testing, including testing for hail damage and hail resistance of prepared roof coverings, since the late 1980s. Prior to becoming a consultant in 1983, he was a technical director/director of engineering for two roofing manufacturers, and he managed a roof contracting company.



Jordan Beckner, RRC, PE
Director of Engineering Services, ROOFTECH

Jordan Beckner is the director of engineering services at Roof Technical Services Inc. (ROOFTECH) and a Registered Roof Consultant. He earned a bachelor of science in mechanical engineering from Baylor University and is a licensed professional engineer in 11 states. He has been working in the engineering field for more than 20 years, with more than 10 of those years specifically focused on roofs. He has investigated more than 1,000 engineering projects related to storm damage, moisture intrusion, construction defects, structural failures, and building enclosure issues.

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INTRODUCTION

Humans living together have been plagued by fire since moving from the savanna into towns and villages. Using fire for heat and lighting was a recipe for disaster when buildings were constructed out of combustible materials and built close together. As civilization progressed, fires became more and more destructive. There was the famous fire in 64 AD that destroyed Rome while Nero reportedly fiddled. A turning point in modern times was the Great Fire of London that destroyed most of the city in 1666. As a result of this disaster, London enacted building ordinances restricting the type of construction in the city to more fire-resistant construction, including requiring stone and brick walls and outlawing thatch roofs.[1] This approach of establishing fire districts would become the standard for future building codes.

The first building ordinances in the Americas were enacted in the 17th century in Boston and New Amsterdam and restricted the use of thatch roofs, because the cyclical weather patterns in America made thatch roofs even more susceptible to fire than in London.[2] Regardless of this early development, building ordinances were slow to develop as towns and cities rapidly grew across America. Trees were an abundant resource in most of America, and people took advantage. Americans framed, clad, and roofed buildings with lumber and wood shingles—and buildings burned down with increasing frequency as cities and towns grew.

Chicago was one of the largest and fastest-growing US cities in the 19th century. Like many cities of its day, its buildings were built close together and were constructed predominantly with wood. According to legend, on the evening of October 8, 1871, Daisy, Mrs. O'Leary's soon-to-become-famous cow, kicked over a lantern in her barn, essentially burning down Chicago. Whether or not Daisy did the dastardly deed or not, there was a massive fire fueled by hot, windy, and dry conditions that propelled burning brands through the air, rapidly spreading fire from roof to roof and building to building.[3] More than 17,450 buildings were destroyed, leaving tens of thousands of people homeless, and hundreds of people were killed. The roof construction of the day consisted of tar and wood that burned fast and hot.

Chicago was not an outlier. There were the Great New York Fire of 1835 and the Great Pittsburgh Fire of 1845. Fire was the major threat to our towns and cities in the 19th and early 20th centuries, and the insurance industry was paying close attention. On April 30, 1866, the New York Board of Fire Insurance Companies formed a special committee that would ultimately lead to the formation of the National Board of Fire Underwriters (National Board). There were the Great Boston Fire of 1872, the Baltimore Fire of 1904, and the San Francisco Earthquake and Fire of 1906, the last being a devastating fire that killed an estimated 3,000 people and destroyed more than 28,000 buildings. Between 1860 and 1915, fire losses exceeded more than $1.2 billion, or more than $40 billion in today's dollars.[4] In an effort to mitigate these risks, the National Board decided to print and circulate construction standards to towns and cities across the country. The construction standard known as *Building Code Recommended by the National Board of Fire Underwriters* was first published in 1905. This was the birth of our modern building codes.

A critical component in the development of fire standards was the establishment of Underwriters Laboratories (UL). UL was founded in 1894 and began testing roof coverings in 1910. In 1917, UL introduced its first fire resistance classifications.[5] These UL fire resistance standards were incorporated into the 1915 fourth edition of *Building Code Recommended by the National Board of Fire Underwriters.* Part XV, *Roofs and Roof Structures*, required that the roofs be "Class A or B under the test specifications of Underwriters Laboratories" except for "(a) dwellings, (b) frame buildings, or (c) buildings not exceeding two stories or 30 feet (9 meters) in height and 2,500 square feet (232 square meters) in area and not used for factories, warehouses, or mercantile purposes."[6] These requirements were very similar to our code standards today.

ESTABLISHMENT OF FIRE DISTRICTS AND APPROVED ROOF COVERINGS

The catastrophic fire losses were generally limited to the central business, warehousing, manufacturing, and urban districts in a city where the buildings were tightly packed. As a result, the early focus of the building codes was to reduce the risk by requiring fire-resistant construction in these susceptible districts. Small businesses and residences outside these districts were more widely spaced, so fire was much less likely to spread rapidly out of control. The first edition of the *Uniform Building Code*, published in 1927, established "fire zones" that were included in Part IV, *Requirements Based on Location in Fire Zones*:[7]

> *Sec. 1601. For the purpose of this Code, the entire City of _________ is hereby declared to be and is hereby established*

[BF] TABLE 1505.1—MINIMUM ROOF ASSEMBLY CLASSIFICATION FOR TYPES OF CONSTRUCTION[a, b]								
IA	IB	IIA	IIB	IIIA	IIIB	IV	VA	VB
B	B	B	C[c]	B	C[c]	B	B	C[c]

For SI: 1 foot = 304.8 mm, 1 square foot = 0.0929 m².

a. Unless otherwise required in accordance with the *International Wildland-Urban Interface Code* or due to the location of the building within a fire district in accordance with Appendix D.

b. Nonclassified roof coverings shall be permitted on buildings of Group U occupancies, where there is a minimum fire-separation distance of 6 feet measured from the leading edge of the roof.

c. Buildings that are not more than two stories above grade plane and having not more than 6,000 square feet of projected roof area and where there is a minimum 10-foot fire-separation distance from the leading edge of the roof to a lot line on all sides of the building, except for street fronts or public ways, shall be permitted to have roofs of No. 1 cedar or redwood shakes and No. 1 shingles constructed in accordance with Section 1505.7.

FIGURE 1. *International Building Code* Table 1505.1, "Minimum Roof Assembly Classification for Types of Construction."

a Fire District and said Fire District shall be known and designated as Fire Zones One, Two, Three and Four, and shall include such territory or portions of said city as outlined in an ordinance of said city, entitled, "An Ordinance Creating and Establishing

Fire Zones in the City of _____." Wherever in such ordinance creating and establishing fire zones, reference is made to any fire zone, it shall be construed to mean one of the four fire zones designated and referred to in this Chapter. (See Appendix.)

Four fire zones were established. Fire Zones 1, 2, and 3 comprised the fire district and required that "roofs of such buildings may be covered only with a 'Fire Retardant' roof covering as specified in Section 4305." Section 4305, *Roof Coverings*, stated the following:

Sec. 4305. Roof coverings for all buildings shall be either "Fire Retardant" or "Ordinary" roofings as specifically required either by Location in Part IV by Type of Construction in Part V or as specified in Sections 1108 and 1208.

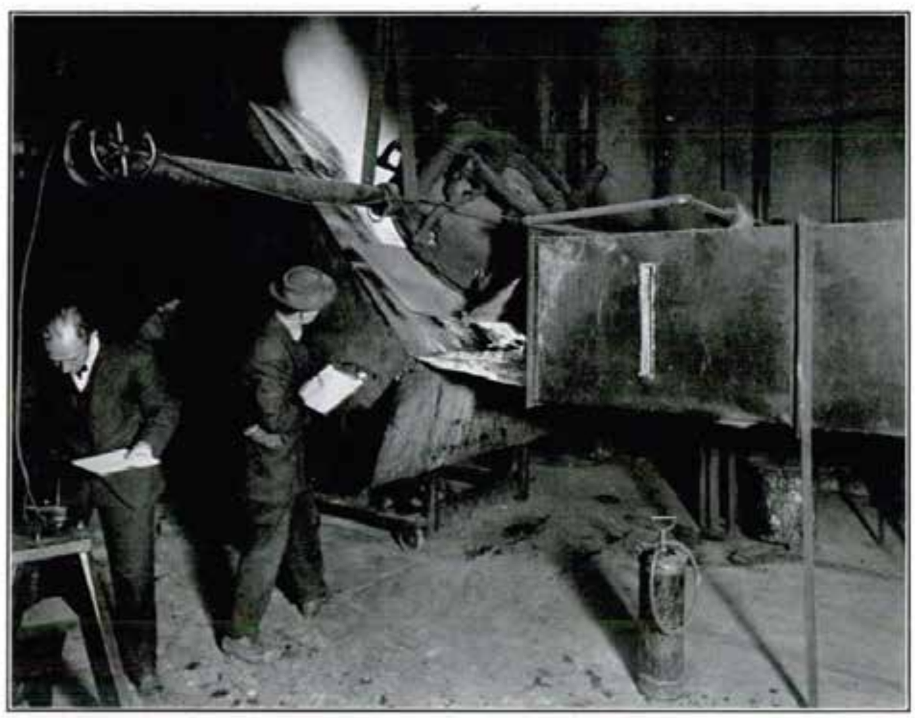
Section 4305 (a) and (b) defined *fire-retardant* and *ordinary roof covers* as shown below.

a) ***Fire Retardant Roofings.*** *"Fire Retardant" roofings shall be any roof covering which meets the requirements specified for any one of the following roofings, 1 to 13, inclusive, and shall be any roofing meeting the requirements of the Class A or B specifications of the Underwriters Laboratories, Incorporated.*

b) ***Ordinary Roofings.*** *"Ordinary" roof coverings shall be any roof covering which meets the requirements specified for the following roof coverings, 14 to 16, inclusive, and shall be any roofing meeting the Class C specifications of the Underwriters Laboratories, Incorporated, as of May 1924.*

The code defined certain specific roof coverings as fire-retardant and listed these roofs in items 1 through 13. These included aggregate-surfaced built-up roofs (BURs), tile, slate, and metal roofs. The code defined certain ordinary roofs in items 14 to 16. These included granule-surfaced BURs, asphalt-prepared shingles, and wood shingles. It should be noted that wood shingles did not meet UL Class C but were permitted as "nonrated roof coverings" until the first edition of the *International Building Code* (IBC) in 2000. Historically, fire-retardant roof coverings were defined as Class A or B, and ordinary roofs were defined as Class C or nonrated roofs. There was no distinction between Class A- or B-rated roofs in the codes.

For our purposes, it is important to understand that fire-retardant roof coverings are considered to be Class A- or



FIRE TEST OF ROOF COVERINGS

In this picture, flame propelled by an artificial gale of forty-five miles an hour is subjecting the roof covering to a *real conflagration test.* Inspectors note and record heat, air pressure, condition of roofing, etc. The drum-shaped device, suspended above the roofing, is used for making tests with radiated heat.

FIGURE 2. An early Underwriters Laboratories fire resistance test on roofing materials.

B-rated assemblies. There are very few differences between the requirements for Class A or Class B roof assemblies, whereas there are significant differences between Class B- and Class C-rated assemblies. Fire districts have given way to minimum fire classification by types of construction. Table 1505.1 "Minimum Roof Assembly Classification for Type of Construction," in the 2024 IBC, shown in **Fig. 1**, only lists Class B or C ratings.[8] The code is silent on the use of Class A as a requirement. The concepts are similar. Fire-retardant roof coverings are required for most commercial construction, while ordinary roof coverings can be used for most residential construction.

It is important to note that footnote "a" to Table 1505.1 states that the minimum classifications listed apply "unless otherwise required in accordance with the *International Wildland-Urban Interface Code* or due to the location of the building within a fire district in accordance with Appendix D," *Fire Districts*. As of 2024, "the provisions contained in this appendix are not mandatory unless specifically referenced in the adopting ordinance." Appendix D provides a framework for jurisdictions to establish fire resistance standards in areas that are susceptible to fires, which seem to be increasing exponentially.

UL 790, *STANDARD TEST METHODS FOR FIRE TESTS OF ROOF COVERING*

UL was established in 1894 by William Henry Merrill, an electrical engineer who was initially retained to assess fire risks at the 1893 World's Columbian Exposition in Chicago, home of the Great Chicago Fire of 1871. The establishment of UL and its testing was a monumental step forward in understanding fire risks. There is an entire chapter devoted to UL in *The History of the National Bureau of Standards – Fifty Years of a Civilizing Force*. The chapter begins by saying that the "two most interesting points in Chicago are the stock yards and the Underwriters' Laboratories." For a group of fire underwriters, UL's laboratories were the mecca of the scientific battle against fire they were waging. Soon after its establishment, UL began testing roofing materials and systems for fire resistance. The tested roof assemblies were rated based upon the relative fire resistance of the roofs, and today's UL 790, *Standard Test Methods for Fire Tests of Roof Coverings*, and ASTM E108, Standard Test Methods for Fire Tests of Roof Coverings, evolved from these tests. **Figure 2** shows a photograph of an early UL fire resistance test on roofing materials.

UL 790 and ASTM E108 are essentially the same test standard. This paper will refer to UL 790 as the standard, with the understanding that it also references ASTM E108. It is very important to understand the testing requirements, to understand the underlying purposes of the standard, and to recognize that there are significantly more rigorous requirements for combustible decks as opposed to noncombustible decks.

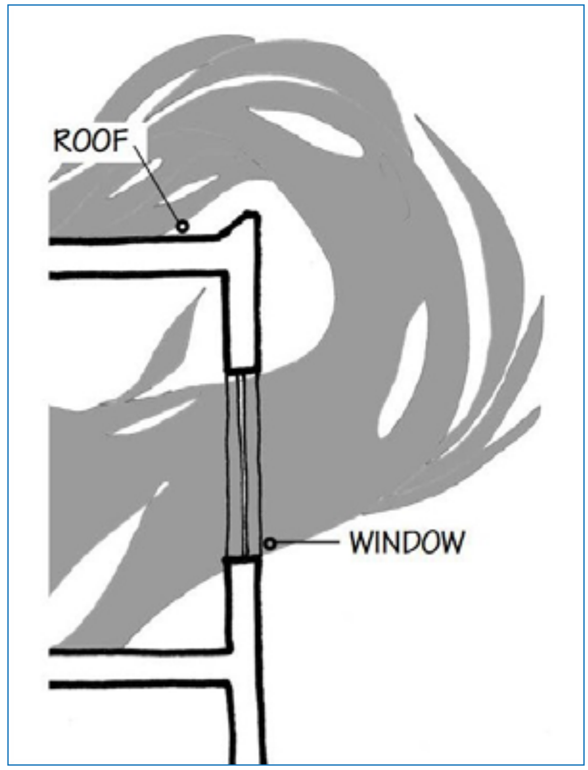


FIGURE 3. Diagram showing the danger of flames reaching the roof eaves during a fire.

UL developed three tests to evaluate the fire resistance of a roof assembly. The testing criteria were based on the ideas that roof coverings should not spread flame beyond a reasonable limit, that a roof covering should be able to protect the underlying roof deck from catching on fire as a result of burning brands landing on the roof, and that a roof should be able to protect the underlying roof decking from catching on fire as a result of the exposure to intermittent flames along the eaves of the roof, as shown in **Fig. 3**. UL defined roof decks as either combustible or noncombustible decks.

Spread-of-Flame Test

The spread-of-flame test applies to both combustible and noncombustible decks. The spread-of-flame test is the only test required on noncombustible decks. The test is straightforward. A gas burner is placed on the low end of the roof, and a fire of a specified intensity is applied to the roof over a specified time. An air blower is introduced to mimic wind blowing across the roof. The spread of flame is then measured after a designated period of time. **Figure 4** shows the spread-of-flame requirements for Class A, B, and C roofs. It is worth noting that the spread-of-flame requirement is 6 ft (1.8 m) for a Class A roof and 8 ft (2.4 m) for a Class B roof, whereas the spread-of-flame requirement for a Class C roof is 13 ft (4.0 m). The Class A and B requirements are similar, and both are rigorous, hence their designation as fire-retardant roof coverings.

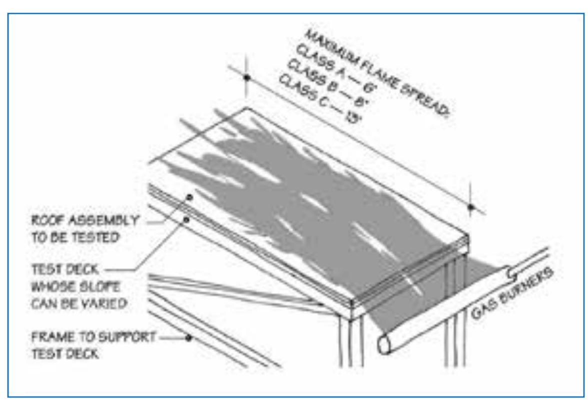


FIGURE 4. Diagram of the spread-of-flame test method and the requirements to meet the various classifications.

Table 6.1 Flame Application

Class	Flame on, minutes	Flame off, minutes	Test Cycles
A	2	2	15
B	2	2	8
C	1	2	3

FIGURE 5. Table showing the time that the specimen is to be exposed to the flame, the time on and off, and the number of test cycles required to meet the Class A, B, or C requirements.

The restricting parameter with the spread-of-flame tests is the slope. The greater the slope, the greater the spread of flame up the slope. The early solution for low-slope roofs was to cover BURs with gravel, typically referred to as tar-and-gravel BURs. Gravel does not burn, so covering a roof with 400 lb (181.44 kg) per square of gravel provides significant fire protection. Tar-and-gravel BURs met Class A fire ratings for both combustible and noncombustible decks on slopes up to 3:12. Today's typical modified bitumen, thermoplastic polyolefin (TPO), and ethylene propylene diene monomer (EPDM) are not as fire-resistant and are generally limited to slopes of about 0.5:12. So, the typical modified bitumen, TPO, and EPDM roof does not meet the code requirements on slopes greater than 0.5:12, a condition that occurs quite frequently. It should be noted that foil-faced modified bitumen and polyvinyl chloride (PVC) roofs generally perform well in the spread-of-flame tests and can be used on steeper slopes.

Combustible Decks

Burning Brand and Intermittent Flame Tests

One of the mechanisms for spreading fire is the transfer of heat through the roof, causing the underlying combustible deck to catch fire. Decks of steel and concrete are noncombustible and do not burn, so burning brand and intermittent flame tests are not an issue for noncombustible decks. Therefore, the only requirement for Class A, B, or C roofs on a noncombustible deck is the spread-of-flame test. However, on a combustible deck, the roof covering must provide a certain level of protection from fire exposure from external sources to prevent fire from spreading. As a result, UL developed the burning brand and intermittent flame tests to test the level of protection afforded by the roof covering. In both cases, the underside of the roof deck is "observed for the appearance of sustained flaming on the underside, production of flaming or glowing brands, displacement of portions of the test sample, and exposure or falling away of portions of the roof deck" to ensure that the roof covering protects the deck from combustion.

The intermittent flame test includes applying a cyclical exposure to a flame positioned at the edge of the roof to mimic the condition shown in Fig. 3. The burning brand test involves burning wood blocks on top of the roof. The intermittent flame test and burning brand test apparatus includes a gas burner that can provide a calibrated flame to the edge of the roof and to the burning brands, along with a blower to provide the required wind conditions. **Figure 5** shows the time that the specimen is to be exposed to the flame, the time on and off, and the number of test cycles required to meet the Class A, B, or C requirements. Again, it is important to note that the Class A and B requirements are significantly greater than the Class C requirements.

As previously mentioned, the burning brand test includes positioning wood blocks of specified size on the roof and burning the brands until the brands are consumed. The Class A brand is a 12 in. × 12 in. × 2.25 in. (300 mm × 300 mm × 57 mm) grid of kiln-dried Douglas fir. The Class B brand is a 6 in. × 6 in. × 2.25 in. (150 mm × 150 mm × 57 mm) grid of kiln-dried Douglas fir. The Class C brand is a 1.5 in. × 1.5 in. × 0.78 in. (38.1 × 38.1 × 19.8 mm) grid of kiln-dried non-resinous white pine. **Figure 6** shows an example of the brand sizes. Again, the Class A and B requirements are significantly greater than the Class C requirements. The brands are placed "on the surface of each test deck at the location most vulnerable (point of minimum coverage over deck joint) with respect to ignition of the deck." The brands are fully ignited and allowed to burn until "the brand is consumed and until all evidence of flame, glow, and smoke has disappeared from both the exposed surface of the material being tested and the underside of the test deck, or until unacceptable results occur, but not for more than 1½ hours."

CODE REQUIREMENTS FOR COMMON ROOF SYSTEMS

Chapters 3 and 6 in the 2024 IBC establish the classification criteria for buildings.[8] These classifications are based on the type of occupancy and the types of construction. Chapter 15 defines the fire resistance categories for buildings based on occupancies and types of construction. Below are excerpts from the 2024 IBC related to Chapter 3, *Occupancy Classification and Use*, and Chapter 6, *Types of Construction*.

> *Chapter 3 provides the criteria by which buildings and structures are classified into use groups and occupancies.*

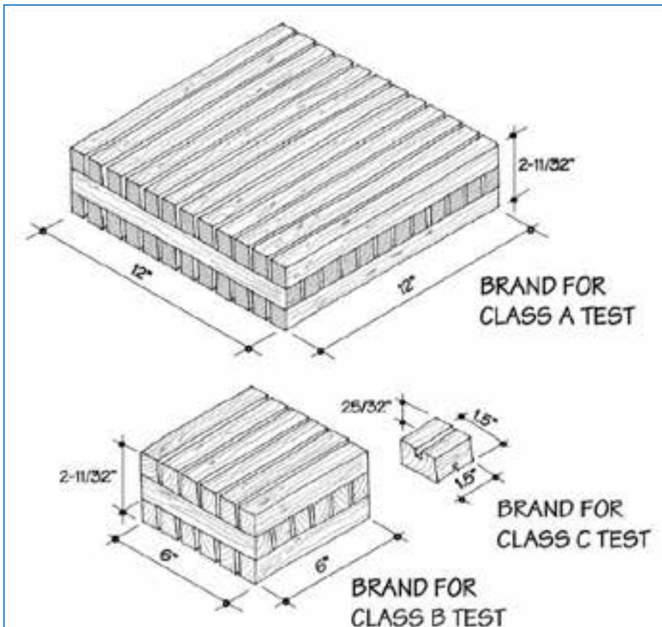


FIGURE 6. Diagram showing the brand sizes for the various fire rating classifications.

Through the balance of the code, occupancy classification is fundamental in the setting of features of construction; occupant safety requirements, especially building limitations; means of egress; fire protection systems; and interior finishes.

Chapter 6 establishes five types of construction in which each building must be categorized. This chapter looks at the materials used in the building (combustible or noncombustible) and the extent to which building elements such as the building frame, roof, wall and floor can resist fire. Depending on the type of construction and the specific building element, fire resistance of 1 to 3 hours is specified.

Table 1505.1 in Chapter 15 (Fig. 1) defines the fire resistance requirements for buildings based on the *construction classification* and *occupancy*. A minimum Class B-rated roof assembly is required on all construction classifications and occupancies except for IIB, IIIB, and VA. Most commercial, institutional, and industrial buildings require a minimum Class B rating. There is no reference to Group R, residential occupancies, in this table. Residential Group R occupancies are included in the *International Residential Code* (IRC). The 2004 IRC states, "Roofs shall be covered with materials as set forth in Sections R904 and R905. … Class A, B, and C roofing required by this section to be listed shall be tested in accordance with UL790 or ASTM E108."[9]

FIRE RATINGS FOR COMMON ROOF ASSEMBLIES

UL Product iQ is an essential online resource maintained by UL Solutions that provides fire classification listings for roof assemblies by specific manufacturers. The UL Product iQ website allows users to search under category codes—TFWZ (Prepared Roof Covering Systems) and TGFU (Roof Deck Constructions)—to locate fire-rated assemblies. Each listing includes critical information about the membrane type, deck construction, insulation components, slope limitations, and required thermal barriers to achieve Class A, B, or C ratings in accordance with UL 790.[10]

For example, a listing for a metal panel manufacturer may indicate that the system qualifies for a UL Class A fire rating over a combustible wood deck (minimum 15⁄32 in. [11.91 mm] plywood), provided a minimum ¼ in. (6.35 mm) gypsum cover board is installed between the panel and the deck. UL listings are an indispensable verification tool for architects, inspectors, and roofing professionals to ensure compliance with fire classification requirements.

Below is an overview of typical fire rating considerations for several common roofing assemblies. Always consult UL Product iQ for manufacturer-specific listings, as ratings can vary based on materials, slope, and system configuration. It should be noted that many manufacturers do not provide data for Class B-rated assemblies but instead only list Class A- and C-rated assemblies.

Metal Roofing Systems: Metal roof panels themselves are noncombustible and inherently resistant to flame spread, satisfying the spread-of-flame test for all roof slopes. However, metal is a highly conductive material and efficiently transfers heat to the underlying structure. When installed over combustible decks, metal systems typically require a thermal barrier—such as a Type X gypsum board—to prevent ignition of the deck during the intermittent flame and burning brand tests. Without a thermal barrier, most metal systems do not meet Class A or B ratings on combustible decks.

Example Assemblies:

- Class A: Standing-seam metal panels over ½ in. (12.7 mm) plywood with ¼ in. (6.35 mm) gypsum cover board
- Class B: Corrugated metal panels over 15⁄32 in. (11.91 mm) plywood with fiberboard insulation (varies by listing)

EPDM Roofing Systems: EPDM is a thermoset membrane that supports flame propagation. Most standard EPDM assemblies are limited to low-slope applications (≤ 0.5:12) and must be a fire-rated membrane. When installed over noncombustible decks like concrete or lightweight insulating concrete, slope allowances may increase up to 1:12. Class A fire ratings can be achieved when EPDM is installed over combustible decks if a thermal barrier—typically gypsum or mineral board—is used beneath the insulation.

Example Assemblies:

- Class A or B: EPDM over polyisocyanurate insulation, ½ in. (12.7 mm) gypsum board, and 15⁄32 in. (11.91 mm) plywood
- Class C: EPDM directly over combustible deck without cover board (not code-compliant in most commercial applications)

TPO Roofing Systems: TPO membranes also support flame spread and must be fire rated. Most standard assemblies are slope-limited to 0.5:12, with allowable slope increasing to 3:12 with certain assemblies. To achieve a Class A rating over wood decks, a gypsum cover board or other approved fire barrier is usually required below the insulation.

Example Assemblies:

- Class A: TPO over polyisocyanurate insulation, ¼ in. (6.35 mm) gypsum cover board, and wood deck
- Class B: TPO over polyisocyanurate directly on lightweight concrete

PVC Roofing Systems: PVC membranes have inherently better flame resistance than EPDM or TPO and may pass the spread-of-flame test without additional barriers in some configurations. Many PVC systems are approved up to 2.5:12 slopes by default, and higher slope ratings can be achieved with specific thermal barrier configurations. As with other thermoplastic membranes, Class A ratings over combustible decks usually require a gypsum or similar noncombustible barrier.

Example Assembly:

- Class A or B: PVC membrane over polyisocyanurate insulation, ½ in. (12.7 mm) gypsum board, and plywood deck

Modified Bitumen Roofing Systems: Modified bitumen roofing is a (typically) multi-ply, asphalt-based system reinforced with fiberglass or polyester mats and chemically modified with polymers such as styrene-butadiene-styrene (SBS) or atactic polypropylene (APP). These membranes are commonly installed on low-slope roofs using hot asphalt, cold adhesive, self-adhered sheets, or heat welding. While the granule-surfaced membranes themselves are generally resistant to flame spread, they conduct heat and often require a thermal barrier when installed over combustible decks to prevent ignition during UL fire testing. As with other systems, the use of gypsum cover boards or noncombustible substrates can improve fire resistance and enable UL Class A or B compliance. Most rated assemblies are limited to slopes of 0.5:12.

Example Assemblies:

- Class A: Two-ply SBS modified bitumen membrane over ½ in. (12.7 mm) gypsum cover board over polyisocyanurate (ISO) insulation over a ¾ in. (19.05 mm) plywood deck
- Class A: Torch-applied APP membrane over a mechanically attached gypsum board over ISO insulation over wood sheathing. It should also be noted that a fire-rated modified bitumen is typically required

BUR Systems: BUR systems consist of alternating layers of asphalt or coal tar and reinforcing felt, typically topped with gravel or a mineral-surfaced cap sheet. Due to their multi-ply structure, surfacing mass, and asphalt content, BUR systems are among the most fire-resistant low-slope roof systems. Many configurations can achieve a UL Class A rating directly over combustible decks without a separate thermal barrier, particularly when surfaced with gravel or mineral granules. In general, BUR systems pass UL testing by resisting flame spread and reducing heat transmission to the deck. Most rated assemblies are limited to low slopes (≤ 0.5:12), and some require surfacing to maintain their classification.

Example Assemblies:

- Class A: Four plies of Type IV asphalt felt with asphalt flood coat and gravel surfacing directly over a ¾ in. (19.05 mm) plywood deck
- Class A: Three plies of fiberglass felt with a mineral-surfaced cap sheet over ½ in. (12.7 mm) gypsum cover board over ISO insulation over a combustible deck

These are only a few representative examples, and the UL Product iQ database contains nearly limitless combinations of materials and configurations available to the designer for achieving the desired fire rating based on project-specific needs. The following limitations are significant, but they are often ignored:

- Most commercial roof applications require a minimum UL Class B fire rating. TPO, modified bitumen, and EPDM roofs are generally limited to roof slopes less than 0.5:12 to meet the minimum UL Class B ratings. How many modified bitumen, TPO, or EPDM roofs are installed on slopes greater than 0.5:12?
- Metal, TPO, modified bitumen, PVC, and EPDM roofs generally require some type of cover board on combustible decks to meet the minimum UL Class B ratings. How many metal, modified bitumen, TPO, PVC, or EPDM roofs are installed directly over plywood or OSB decks?

CONCLUDING REMARKS

Throughout the 19th century in the United States, fires plagued our cities, resulting in massive destruction, and roof construction was a major contributing factor to the spread of those fires. Building codes at the beginning of the 20th century began addressing these issues, and great strides were made in eliminating the risks of these fires by the introduction of fire-retardant construction, including the requirement of fire-retardant roof coverings. UL played an important role in establishing testing and fire ratings for roofing assemblies. The codes defined fire-retardant roof coverings as UL Class A- or B-rated assemblies or aggregate-surfaced BURs, tile, slate, and metal roof coverings. Specifiers and contractors understood these requirements. Tile, slate, and metal were required on steep-slope roofs in fire districts and for most commercial construction, and the vast majority of low-slope roofs were fire-retardant gravel-covered BURs. The various slope limitations for BURs were specifically listed in the body of the codes.

This all changed in the 1970s with the introduction of modified bitumen and single-ply roofs as well as the increased use of various types of rigid board insulations. Fire ratings suddenly became complicated. There were significant limitations related to slope and deck requirements with these new roof systems. Many of the early EPDM and modified bitumen membranes sold were not fire rated at all. The issues have become more and more complex as new products and systems have been introduced. Roofing manufacturers advertise that their roofs are Class A or B rated, but it is not always easy to find or to understand the limitations of those ratings. Further, it has been the authors' experience that there is a general lack of understanding of fire ratings and fire-rated assemblies among designers and contractors. As a result of these complexities and a general misunderstanding of the rating requirements, millions of square feet of noncompliant roofing assemblies have been installed and are at risk.

Fires like the January 2025 Los Angeles fire have been a wake-up call for designers and contractors. Fire-rated roof assemblies are essential in limiting the damage from the increasing risk of fires that we have seen. It is critical that the designer and contractor understand the requirements for Class A-, B-, and C-rated roof coverings to specify and install the appropriate fire-rated roof assemblies. Fire ratings for roofing systems are not determined by the roof covering alone but rather by the entire assembly—including substrate, insulation, cover board, and slope. UL 790 (ASTM E108) testing ensures systems can withstand realistic fire exposures, and UL Product iQ provides the necessary documentation to validate compliance. Designers and contractors must confirm that the specific assembly being installed matches a tested and listed configuration appropriate for the building's fire zone and occupancy classification.

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Cladding of the Gilder Center at the American Museum of Natural History

ABSTRACT

The Richard Gilder Center for Science, Education, and Innovation is the newest addition to the American Museum of Natural History, originally constructed in 1877 in New York City. This six-story expansion adds 230,000 ft^2 (21,367.7 m^2) of space for new exhibits, classrooms, learning labs, offices, and education spaces to the existing building, and it was completed in 2023. The new wing and accompanying renovations were designed by Studio Gang Architects, with Davis Brody Bond acting as the architect of record and Buro Happold as the exterior facade consultant. Buro Happold partnered with W&W Glass and Island Exterior Fabricators to fabricate and install the exterior facade, which wraps the building with curving steel and natural granite stone. This paper will discuss the tools and processes used to create the complicated geometric facade and the challenges and solutions related to preserving a high standard of performance and quality control. The panelization of the stone facade to fit the geometry of the design and the development of the steel frame to support individual stone pieces will be reviewed. Additionally, this paper will review the design assistance and quality assurance procedures, which included facade performance mock-up and testing, factory inspections during fabrication, on-site construction administration and reporting, and post-installation field testing.

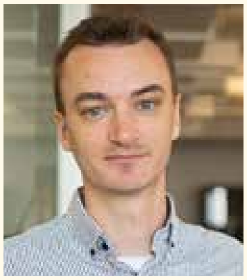
LEARNING OBJECTIVES

- Discuss the tools used to rationalize complicated geometric facades.
- Describe the key goals of the design-assist process and review recommendations for maintaining the design while collaborating with the facade contractor.
- Demonstrate the value of performance and visual mock-ups to confirm design assumptions and develop a sequence of construction for applicable trades.
- Illustrate an example of the fabrication inspection process via checklists and factory visits.
- Illustrate an example of field quality control via site visits, field reports, and on-site field testing.

SPEAKERS

Andre Parnther, ICC-Certified Masonry Inspector
Associate, Buro Happold

Andre Parnther is trained as an architect and has more than 25 years of experience engineering complex new building facades and landmark building enclosures. He provides expert facade investigation and consulting services through all phases of projects, with building typologies that include historic and new residential, commercial office, college and university, hospital and healthcare, and dormitory facilities. As a Certified Masonry Inspector by the International Code Council, he has delivered award-winning projects and continues to work with his clients to provide expert facade engineering advice in an engaging and collaborative manner.



David Lutz, PE
Senior Facade Engineer, Buro Happold

David Lutz is a senior facade engineer with 8 years of experience in the facade and waterproofing industry. Since earning his bachelor's degree in civil engineering from the University of Illinois, he has applied his strong foundation in structural engineering and passion for good design to bring success to projects across North America and the Middle East, engaging in detailing, analysis, and inspection of custom facade systems. He recently served as the primary special inspector for the facade of the new Gilder Center at the American Museum of Natural History in New York City.

AUTHORS:
Andre Parnther, ICC-Certified Masonry Inspector
David Lutz, PE

DESIGN PHASE: RATIONALIZING COMPLEX GEOMETRIC FACADES

The Richard Gilder Center for Science, Education, and Innovation is the newest addition to the American Museum of Natural History (AMNH), originally constructed in 1877 in New York City. This six-story expansion added 230,000 ft^2 (21,367.7 m^2) of space for new exhibits, classrooms, learning labs, offices, and education spaces to the existing building, and it was completed in 2023. The new wing and accompanying renovations were designed by Studio Gang Architects, with Davis Brody Bond acting as the architect of record and Buro Happold as the exterior facade consultant. Buro Happold partnered with W&W Glass and Island Exterior Fabricators to fabricate and install the exterior facade, which wraps the building with curving steel and natural granite stone (**Fig. 1**).

FIGURE 1. Gilder Center: building entrance.

In today's design and construction industry, there are many tools available to assist architects in rationalizing complex geometry. The primary purpose of rationalization of surface geometry is optimization of fabrication, material usage, and assembly. Often the goal is to limit the number of unique pieces and maximize repetition or to break down double-curved surfaces into smaller flat or single-curvature pieces to save cost.

For the AMNH Gilder Center expansion, the architect's design intent for the outer facade was to use Milford pink granite stone, sourced from the same quarry used for the existing building from the 1800s, but used in a modern and contrasting architectural style. This stone was a beautiful and dynamic material to design with but came with several challenges common to stone facades. The first challenge was the material weight: at 2 in. (50 mm) thick, a typical 4 × 4 ft (1.2 m × 1.2 m) piece could weigh upwards of 500 lb (225 kg), making it impossible to lift without the use of a mobile crane, and breaking the stone up into smaller, manageable pieces would not create the desired aesthetic impact. The second challenge was related to the installation tolerances and precision. The smooth curves and creased surfaces in the design would leave little room for error, a challenge for a natural material that is usually cut and installed with wider tolerances. The final challenge was the labor cost of construction in New York City. Individually setting these 6,000+ heavy pieces of stone on-site would take an immense amount of time and generate a significant cost.

To mitigate these known challenges, alternate construction methods were explored early in the design. In dense urban areas like New York City, a common strategy to reduce on-site labor and the construction schedule is to modularize facades into larger panels, or "megapanels," that are prefabricated in the factory and brought to the site and installed by crane to enclose the building quickly (see **Fig. 2** for design sketches of panelized construction). This method also allows a greater degree of precision

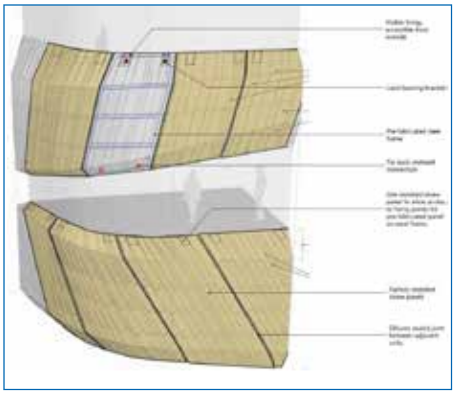


FIGURE 2. Megapanels with stone leave-outs for site installation and adjustment.

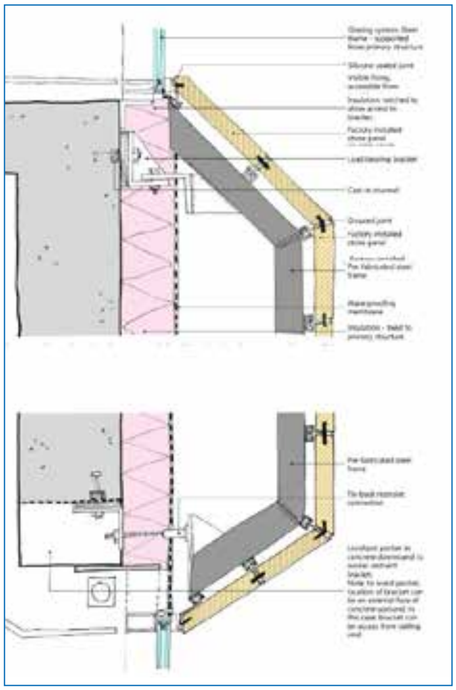


FIGURE 3. Preliminary sketch of strongback system.

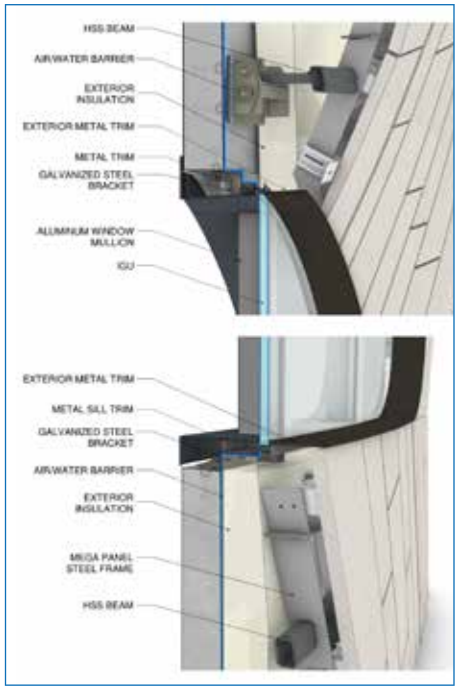


FIGURE 4. Three-dimensional construction document detail.

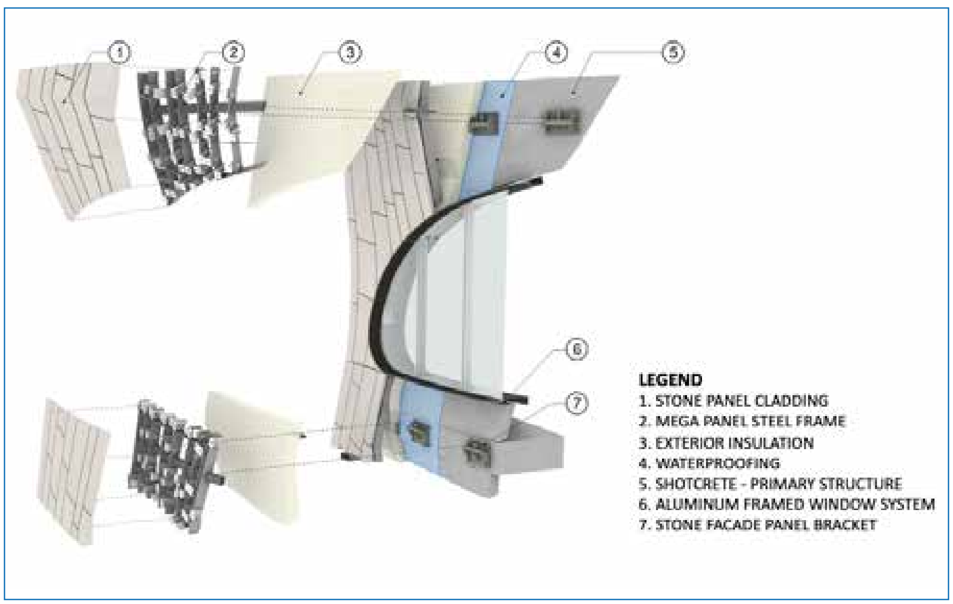


FIGURE 5. Three-dimensional construction-layered detail of strongback system.

and reduced tolerance by building under controlled conditions. For the stone, two megapanel backup structure strategies were explored: stone-faced precast concrete and a steel strongback system.

In stone-faced precast concrete construction, the individual stones are arranged in a prefabricated mold with mechanical anchors before concrete is poured on top as a backing structure. In place of normalweight steel-reinforced concrete, glass-fiber-reinforced concrete or ultra-high-performance concrete can be used to reduce weight. The efficiency in precast concrete usually comes with the repetition of panels, which allows molds to be reused. Unfortunately, the Gilder Center's double-curving and irregular geometry would have led to complex and expensive formwork for each megapanel.

The solution ultimately selected was a steel strongback system, in which the stone is supported by a large, prefabricated steel frame with adjustable brackets. This provided a more lightweight and economical solution with a high degree of flexibility in fabrication. Each module was chosen to be one story high, with the width determined by ground transportation dimensional limits. **Figures 3–5** illustrate the components that make up the steel strongback stone cladding system.

DESIGN-ASSIST: DESIGNING FOR PERFORMANCE

Design-assist is a project delivery method where the construction team collaborates with the architect and engineer during the design phase (**Fig. 6**). This method is common in the facade industry due to schedule benefits, complexity, technical challenges, and material lead time. Benefits include reduced requests for information, cost control, and shortened shop drawing review time. Facade contractors must conclude the phase with clear deliverables. The contractor will provide reviews, analyses, samples, and details to support design efforts, improving constructability and coordination and minimizing waste. They will assist in completing the design, attending review meetings, providing recommendations, and maintaining cost and schedule. Responsibilities include providing design data, shop drawings, three-dimensional (3-D) models, and engineering documents, as well as assisting in schedule development/refinement and coordination issues.

The design-assist process for the AMNH Gilder Center was a positive and collaborative effort amongst the various teams involved in delivering the project. The team included Tishman (general contractor), W&W Glass (glazier), Island Exterior Fabricators (facade contractor), Cost of Wisconsin (concrete specialist), and Hofmann Stone (stone specialist). Coordination across all these trades was essential to align sequencing, tolerance requirements, and interface conditions. Long-term movement diagrams from the structural engineer informed joint sizing strategies, ensuring that the facade could accommodate structural deflections without compromising performance or aesthetics.

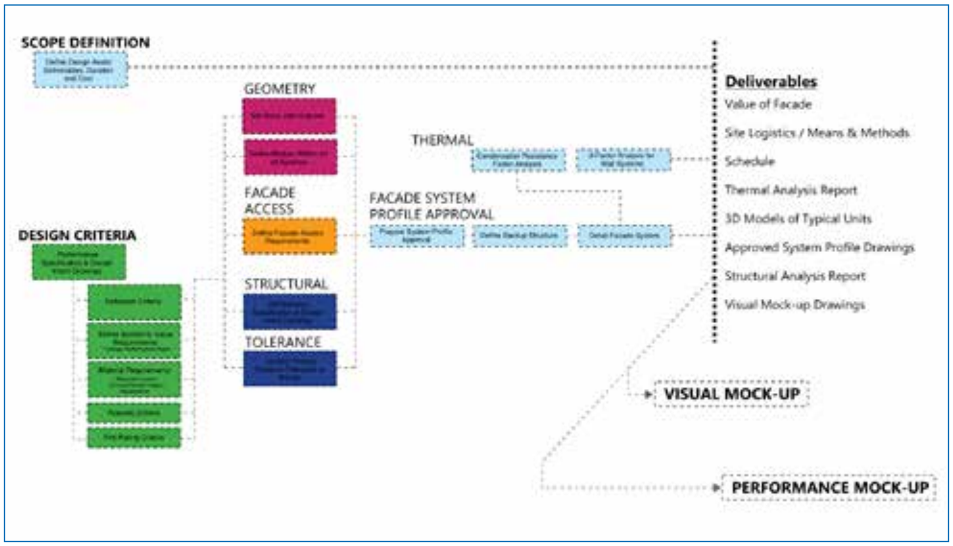


FIGURE 6. Design-assist flow chart.

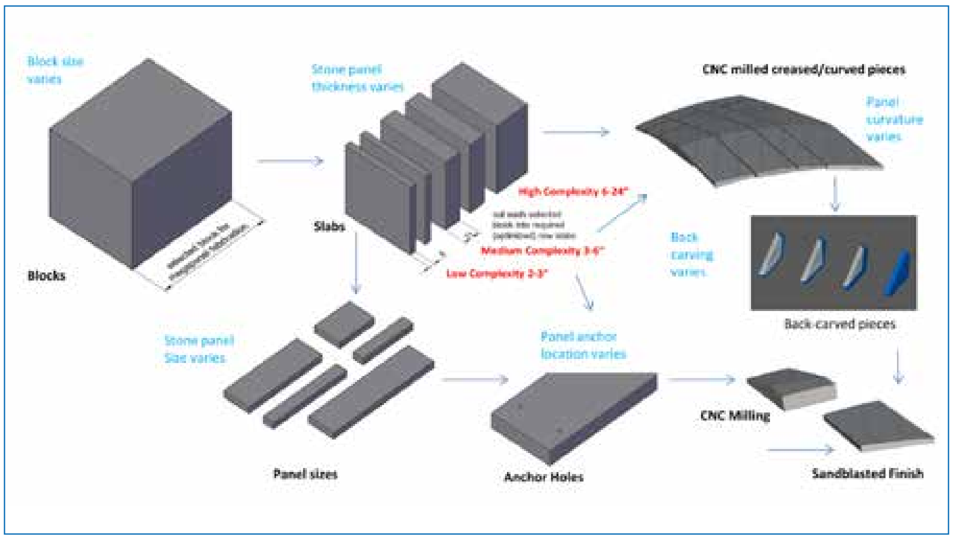


FIGURE 7. Stone fabrication process.

Panel sizes were re-evaluated to balance weight limits, site logistics, and installation efficiency. Hofmann Stone's stone fabrication capabilities were a key consideration: the team worked closely with the fabricator to optimize production time for creased, back-cut stone panels while managing the distribution of color variation across quarried blocks. **Figure 7** illustrates the stone fabrication process. The selection of stone anchors ranging from pins and clips to hybrid systems was guided by priorities of adjustability, joint sizing, and ease of replacement in the field.

Digital delivery played a pivotal role in facilitating this coordination. The design team provided bidders with detailed 3-D surface models developed in Rhino, allowing for precise visualization and early feedback. Rhino is the 3-D modelling tool of choice for complex architectural surfaces due to its powerful and precise NURBS (non-uniform rational basis spline) object generation and script-generated parametric design capabilities. These models were continuously refined through collaborative reviews, ensuring alignment between design intent and constructability. The use of coordinated Rhino models also enabled seamless integration of systems and helped establish clear milestone goals—including the development and review of a full-scale mock-up.

PERFORMANCE MOCK-UPS

The construction and testing of a mock-up have become essential for verifying methods of construction, the sequence of construction, and the anticipated performance of details and transitions prior to construction. A mock-up facilitates the discovery of possible failures in materials, transitions, or complications in the installation, which creates an opportunity for redesigning, material substitutions, and revisions in the sequence to allow for proper installation during construction. For the Gilder Center, a full-size mock-up of the proposed design included the assembly of all materials, including concrete, waterproofing, steel anchorage, insulation, glazing, and stone panels, all installed by their respective trade contractors (**Fig. 8–10**). This mock-up was then tested for structural performance, air and water infiltration, and thermal performance (**Fig. 11**).

The execution of the mock-up provided several lessons and insights about the construction of the project. These included the following:

- Hydrophobic staining of the stone from joint sealant was observed on the panels. This resulted in the testing of several types of sealant in order to select a non-staining version for the project.
- To facilitate the sequence of installation, it was required to provide stone leave-outs in the megapanels for access to adjust stone panels for alignment to meet the project tolerances.
- Additional holes in panels were required to install hybrid anchors.
- There was damage to waterproofing from megapanel anchors; some anchors were post-installed, and at locations where post installation was not possible, the waterproofing contractor had to schedule time to make localized repairs prior to installation of the adjacent panel.
- The sequence of megapanels was adjusted based on the various anchorage methods to allow for access and adjustment.
- Metal flashings were added to cover pockets in shotcrete at anchor locations.

FIGURE 8. Rebar at backup wall with insulation at window opening.

FIGURE 9. Shotcrete at backup wall and window opening.

FIGURE 10. Glazing, waterproofing, insulation, and stone panel.

FIGURE 11. Dynamic water testing of completed mock-up.

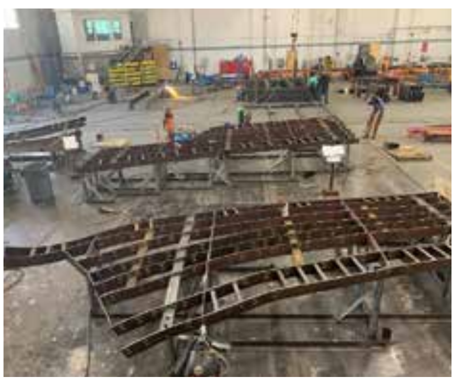


FIGURE 12. Steel strongback system.

FIGURE 13. Galvanized steel strongback system with stone units installed.

FABRICATION QUALITY CONTROL

Ensuring quality control was critical to the success of this monumental facade, given its intended long lifespan and the precision required to achieve the complex surface geometry. Achieving the desired performance and aesthetic outcomes required committed collaboration among the project's architects, facade consultants, and specialist fabricators.

The west facade comprises 156 steel-framed megapanel units, each with a unique geometry tailored to the building's sculptural form. Fabrication began with water-jet-cut steel plates and hot-rolled sections, which were welded together to form the structural skeleton supporting individual stone anchor brackets (**Fig. 12**). To ensure dimensional precision, a custom jig was created for each panel, and 360-degree total stations were used to verify measurements prior to welding. A total station is an electronic/optical instrument that uses a combination of a theodolite (to measure horizontal and vertical angles) and an electronic distance meter (EDM) to measure both angles and distances with high precision. Following welding, all joints underwent inspection, and completed frames were subsequently hot-dip galvanized to achieve full corrosion protection for the welded assemblies (**Fig. 13**).

In rainscreen assemblies featuring natural stone, material selection and interface management are critical to preserving the stone's appearance over time. Surface rust from steel components can lead to staining, so all pin anchors and support brackets in direct contact with the stone were fabricated from 316-grade stainless steel. Subframing elements behind the stone were hot-dip galvanized, and material separators were used to prevent galvanic corrosion between dissimilar metals. These measures ensured both structural durability and aesthetic preservation.

Sealant compatibility with natural stone is another key consideration. Improper sealant selection can lead to staining or "bleeding," where sealant migrates into the stone's pores. Even when discoloration is not visible, sealant migration can alter moisture behavior—causing the stone's perimeter to dry faster than its center, a phenomenon known as "hydrophobing." To mitigate this, multiple sealants from different manufacturers were tested on Milford pink granite samples. These samples were monitored over a 1-month period for signs of discoloration and hydrophobing, ensuring the selected sealant would perform both functionally and aesthetically.

Throughout fabrication, rigorous internal quality assurance/quality control procedures by the fabricators were supplemented with regular spot checks by both the architects and facade consultants. This dual-layered approach ensured each megapanel was built to match the approved shop drawings, maintained strict joint size tolerances of less than ⅛ in. (3 mm), and was thoroughly protected against corrosion.

IN-FIELD QUALITY ASSURANCE

Ensuring the long-term performance and visual integrity of the facade required a rigorous field quality control program that addressed thermal performance, weatherproofing, and aesthetics. Each phase of installation was carefully coordinated and verified to meet both design intent and technical specifications.

Prior to panel installation, total stations were employed to precisely locate each embedment on the curved concrete backup wall. This step was critical in verifying the wall's geometry and identifying any deviations from tolerance. Where discrepancies were found, panel brackets were adjusted in the shop to accommodate site conditions, ensuring a seamless fit during installation (**Fig. 14**).

The project's distinctive curving window shapes demanded a high level of precision. To achieve this, laser-cut foam molds were placed during the concrete pour to form accurate rough openings (Fig. 8). These molds ensured that each prefabricated window would nest perfectly within the concrete and stone facade. Total stations were again used to verify anchor locations for each window, reinforcing dimensional accuracy.

The silyl-terminated polyether air and water barrier applied to the concrete substrate was tested throughout the application for mil thickness and continuity, ensuring a robust enclosure. Special inspections were conducted to confirm the integrity of each embedded connection, including hardware verification and torque checks. For infill stone requiring slip-critical connections, direct tension

FIGURE 14. In-progress installation of stone megapanel.

indicator washers were used to validate proper clamping force.

To confirm the air and water performance of the windows and their perimeter interfaces, field testing was conducted in accordance with the American Architectural Manufacturers Association's (AAMA's) AAMA 501.2, *Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls and Sloped Glazing Systems*, and AAMA 503, *Voluntary Specification for Field Testing of Newly Installed Storefronts, Curtain Walls and Sloped Glazing Systems*, protocols.[1,2] Specifications required that a minimum of 2 out of every 16 windows undergo chamber testing per ASTM E783, *Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors*, and ASTM E1105, *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference*.[3,4] Custom chambers were fabricated for each window to accommodate their unique geometry. The remaining interfaces were tested using AAMA 501.2 nozzle spray procedures to ensure consistent performance across the facade.

CONCLUSIONS AND TAKEAWAYS

The success of the Gilder Center facade was the result of a collaborative effort between all parties involved, who brought their best ideas and skills to deliver a complicated project that they are all proud of. The design and construction were streamlined using 3-D parametric drawings and the sharing of models between the design team, fabricators, and contractors. The use of a performance mock-up to test the method of construction was essential. The fabrication and installation included exacting specifications, backed up by quality assurance and quality check systems at key stages in the construction process. The combination of all these processes enabled the execution of the architects' and client's vision for this project.

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Low-Slope Roofing Enhancements to Address Severe Climate Risks and ICC 500, *Standard for the Design and Construction of Storm Shelters*

ABSTRACT

As climate change drives more frequent and severe weather events, design professionals must increasingly address resilience in critical and essential facilities (Risk Categories III and IV) and community storm shelters. Low-slope roofing systems play a vital role in protecting these structures against rain, wind, and hail. The *2024 International Building Code* (IBC); ASCE/SEI 7-22, Minimum Design Loads and Associated Criteria for Buildings and Other Structures; and the ICC/NSSA 500, *Standard for the Design and Construction of Storm Shelters*, introduce new and revised provisions that influence roof system design. These updates include enhanced wind resistance design requirements and large-missile impact testing for roofing components. This presentation will examine these changes through a technical lens while incorporating an analysis of the IBC, ASCE/SEI 7-22 and the ICC/NSSA 500, and jurisdictional adoptions. It will also explore the use of the US Federal Emergency Management Agency's National Risk Index to assess project-specific hazard vulnerabilities and guide location-based mitigation strategies. With a focus on real-world applications and technical credibility, this session equips design professionals with informed strategies to specify roofing systems that go beyond minimum code—such as implementing secondary membranes for redundancy and resilience. Contractors will also benefit from understanding these enhancements to support better collaboration during installation.

LEARNING OBJECTIVES

- Identify key updates in the *2024 International Building Code* related to low-slope roofing.
- Identify key updates in ASCE/SEI 7-22, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, and apply ICC/NSSA 500, *Standard for the Design and Construction of Storm Shelters*, for low-slope roofing wind resistance and wind-borne debris protection specific to critical and essential facilities (Risk Categories III and IV) and storm shelters.
- Apply the US Federal Emergency Management Agency's National Risk Index data to better evaluate site-specific natural hazard risks and inform roofing design decisions.
- Evaluate strategies for integrating secondary membrane systems and other resilient roofing enhancements that exceed code minimums, with attention to constructability and performance.

SPEAKER

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Darren Perry, director of technical support for SOPREMA US, leads the technical support team to provide support and services for sales representatives, design professionals, and contractor customers. Additionally, he manages the codes and approvals team to engage with "outside" laboratory testing and agency approvals aimed at enhancing SOPREMA and private-label products. He also provides management and technical oversight for the warranty department and collaborates across all SOPREMA US brands, as well as the SOPREMA Group worldwide, to build stronger organizational networks. Perry has been with SOPREMA since 2010.

AUTHOR:
Darren Perry, RRC, PE

INTRODUCTION

Community leaders and building owner representatives look to the design professional to ensure building enclosure systems are designed to address severe weather challenges. Building codes offer obligatory minimum requirements, and code adoption often lags years behind the most up-to-date standards available. Design professionals may choose to seek guidance beyond code minimums to better address extreme climate exposures, specifically exposures to critical and essential facilities.

This paper examines building codes and other available guidelines to address extreme weather challenges for low-slope roofing, with a focus on critical and essential buildings to improve community resilience.

US BUILDING CODES

The *2024 International Building Code* (IBC) places additional emphasis on Risk Category III and IV buildings that represent a substantial hazard to human life in the event of failure, as well as other buildings deemed essential to a community. Buildings such as hospitals, public utilities, communications, transportation, national defense, and others are outlined in Table 1604.5, *Risk Category of Buildings and Other Structures*.[1]

Since 2000, the IBC has included a chapter focused on roofing: Chapter 15, *Roof Assemblies and Rooftop Structures*. Chapter 15 includes many referenced codes and standards that apply to roofing; those can be found in Chapter 35, *Referenced Standards*.[1]

FIGURE 1. Roof slope and roof edge conditions may not meet the requirements for secondary roof drainage. In the photo above, a secondary emergency overflow roof drain was added (foreground) to address ponding instability.[1] *Photo by Darren Perry, RRC, PE.*

WEATHER-RELATED EXPOSURES

Rainfall

Roof coverings often include tapered insulation to produce the finished roof slope. Projects commonly include roof drains, scuppers, gutters, and other roof drainage components. Requirements in Chapter 15 related to roof drainage are included with a goal of preventing unsafe loads associated with the accumulation of water on roofs.[1]

IBC Section 1502, *Roof Drainage*, references IBC Chapter 16, *Structural Design*, and the *International Plumbing Code* (IPC) Chapter 11, *Storm Drainage*. These codes include requirements related to low-slope roofing design and construction. IPC Section 1108, *Secondary (Emergency) Roof Drains*, requires independent secondary (emergency) drainage where roof perimeter conditions result in entrapped water if the primary drains allow water buildup for any reason.[1,2] Refer to **Fig. 1**, where the raised roof edge and tapered insulation result in water buildup.

IBC Section 1507, *Requirements for Roof Coverings*, includes the design slope required for each low-slope material type. The minimum design slopes listed by material type in Section 1507 are for drainage.[1]

The 2024 IBC Section 1512, *Reroofing*, clarifies the minimum slope of ¼:12 is not required for roofs that provide positive roof drainage and meet the requirements of Sections 1608.3 and 1611.2, *Ponding Instability*. Slopes less than ¼:12 cannot be ignored. If the

FIGURE 2. Insufficient slope conditions can result in ponding instability. Structural analysis requirements for low-slope roofing are independent of roofing manufacturer warranty allowances for standing or ponding water.[1] *Photo by Darren Perry, RRC, PE.*

¼:12 slope is not provided, this section emphasizes that ponding instability on roofs shall be evaluated in accordance with ASCE/SEI 7-22, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 7-22).[1] Small areas of standing water on the roof surface may indicate the roof slope is less than ¼:12, as shown in **Fig. 2**.

Wind

The US Federal Emergency Management Administration (FEMA) publishes the National Risk Index (NRI), which includes an interactive map tool intended for planners and emergency managers at the local, regional, state, and federal levels, as well as other decision makers and interested members of the public. This tool is useful to review specific risks that may be relevant to buildings and even roofing projects that may impact community resilience.[3]

Three types of wind events are identified by the NRI: hurricanes, tornadoes, and strong winds.[3]

Hurricanes can impact many communities over widespread areas along the Atlantic and Gulf coasts, with effects often reaching far from the coast. Growing populations in some hurricane-prone regions place more communities and more buildings in the path of these storms.

Tornadoes reported in the US during the past few decades average over 1,200 per year. The majority of tornadoes reported in the US from 1995 to 2016 had wind speeds of 135 mph (217 km/h) or less. The fact that most tornado wind speeds are 135 mph or less led to the consensus that it is feasible to design Risk Category III and IV buildings, for specific conditions, to resist these lower-intensity tornado wind loads.[4]

Strong winds are defined by the NRI as winds exceeding 58 mph (93 km/h).[3]

Additionally, a severe thunderstorm is defined by the National Weather Service as a thunderstorm capable of producing a tornado, strong winds, and/or hail at least 1 in. (25 mm) in diameter.[5]

The 2024 IBC requires low-slope roofing to be designed for wind loads associated with basic wind speed, *V*, and most recently tornado speed, V_T. The design wind pressures associated with these wind speeds are calculated using wind speed maps listed by risk category or as prescribed by a specific jurisdiction. The wind speeds required and shown on the maps are influenced by hurricane and tornado wind data. Generally, the higher the risk category, the higher the design wind speed as indicated on the wind maps.[1]

The 2024 IBC Chapter 16, *Structural Design*, requires ASCE 7-22 to calculate wind design pressures for low-slope roofing. ASCE 7-22 includes a helpful flowchart in Chapter 32, *Tornado Loads*, Fig. 32.1-2, to determine whether design for tornado loads is required. Tornado wind load calculations are required for only some Risk Category III and IV buildings where applicable under the conditions outlined in ASCE 7-22, Fig. 32.1-2.[1,6]

Once the roof design pressures are determined, IBC Chapter 15 requires low-slope roof coverings to be tested to resist the design wind pressures. Test standard requirements are found in Section 1504, *Performance Requirements*. The test standards and test methods prescribed for low-slope roof coverings include testing resistance of static pressure, not actual wind resistance, as shown in **Fig. 3**.[1]

ASCE 7-22 wind design procedures include calculating positive internal pressure resulting from wind entering the building interior and negative external suction pressure induced by wind flowing over the roof surface, as shown in **Fig. 4**.[6]

The greatest wind-induced loads and pressures are generally located along low-slope roof edges. Wind blowing into walls is partially directed upward to the roof edge, into roof overhangs, gutters, and roof edge systems. IBC Section 1504.6, *Edge Systems for Low-Slope Roofs*, requires metal edge system design in accordance with Chapter 16 and ASCE 7-22 and testing for resistance in accordance with ANSI/SPRI ES-1, *Test Standard for Edge Systems Used with Low Slope Roofing Systems*. IBC Section 1504.6.1, *Gutter Securement for Low-Slope Roofs*, states that gutters for low-slope roofs shall be designed and installed to resist wind loads in accordance with Section 1609 and ASCE 7-22 and tested per ANSI/SPRI GT-1, *Test Standard for External Gutter Systems*, methods G-1 and G-2.[1,6]

ASCE 7 wind design methods used for low-slope roofing do not account for wind entering the roofing assembly

FIGURE 3. A 12 × 24 ft (3.66 x 7.32 m) sample being tested for static pressure uplift resistance per FM 4474. Neither wind nor airflow is used in the prescribed testing in the IBC.[1] *Photo by Darren Perry, RRC, PE.*

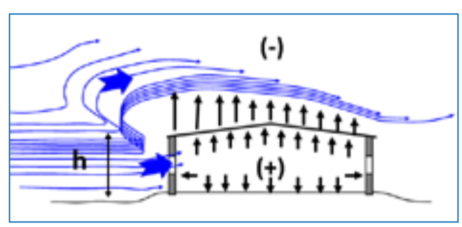

FIGURE 4. Diagram showing simplified effects of wind and wind-induced internal positive pressure and external negative pressure acting on the roof. *Figure by Darren Perry, RRC, PE.*

FIGURE 5. Unsealed/unadhered single-ply membranes along roof edges can allow wind infiltration beneath the membrane and into the roofing assembly. *Photo by Darren Perry, RRC, PE.*

FIGURE 6. Edge nailer "shims" created an opening, leaving the roofing assembly exposed to air infiltration along the roof edge. During a strong-wind event, wind infiltration combined with inadequate securement of roof edge components resulted in roof cover blow-off. *Photo by John Harold, Performance Roof Systems, a SOPREMA Group Company.*

FIGURE 7. When reroofing older buildings, transitions between the wall and roof assembly often present design and installation challenges to meet current requirements for low-slope roofing. *Photo by Darren Perry, RRC, PE.*

itself through open spaces along the roof edge. **Figure 5** shows a single-ply membrane overlapping the roof edge, not sealed along the lower edge of the membrane. When roof-to-wall transitions are not sealed to resist air leakage, wind may enter the roofing assembly itself, between roof components and/or under the roofing membrane. Extreme wind conditions leading to wind infiltration into the roofing assembly can result in significant damage, as shown in **Fig. 6**.

The *2024 International Energy Conservation Code*, Chapter 4, Section C402.6, *Air Leakage—Building Thermal Envelope*, requires the air barrier to resist positive and negative pressure differentials from wind. When low-slope roofing assemblies are relied upon to resist air leakage, the design should include materials and assemblies that can also resist anticipated wind infiltration.[7] Preventing wind infiltration along roof-to-wall transitions often presents significant design and construction challenges, as shown in **Fig. 7**.

Hail

The 2024 IBC Section 1504.7, *Impact Resistance*, references three test standards for low-slope roofing. The options include ASTM D3746, *Standard Test Method for Impact Resistance of Bituminous Roofing Systems*; ASTM D4272, *Standard Test Method for Total Energy Impact of Plastic Films by Dart Drop*; or the "Resistance to Foot Traffic Test" portion of FM 4470, *Single-Ply, Polymer-Modified Bitumen Sheet, Built-Up Roof (BUR) and Liquid Applied Roof Assemblies for Use in Class 1 and Noncombustible Roof Deck Construction*. These 2024 IBC code-referenced test standards do not correlate with low-slope roofing hail exposures. More recent test standards utilizing ice balls provide better correlation to real-world conditions, as ice balls better represent the physical properties of hail and better replicate the impact energy associated with hail. Hail hazard maps that identify hail-prone areas and the severity of hail are also absent from the IBC.[1,8]

Individuals responsible for designing low-slope roofing, specifically for Risk Category III and IV buildings, should consider guidance beyond code minimums to evaluate potential hail exposure and seek testing standards applicable to hail. Many commercial low-slope roofing manufacturers offer hail-impact-resistant roofing assemblies tested and rated by external agencies.[8]

The National Oceanic and Atmospheric Administration provides online search tools to find hailstorm data. The NRI includes an interactive map tool identifying relative hail risk for counties in the US. Factory Mutual publishes property loss prevention data sheets with helpful guidance for designing and testing low-slope roofing to resist hail and other exposures. Free online resources are available from these and other sources.[8]

STORM SHELTER REQUIREMENTS FOR LOW-SLOPE ROOFING

The 2024 IBC references ICC/NSSA 500-2023, *Standard for the Design and Construction of Storm Shelters* (ICC 500). The standard defines a community storm shelter as any storm shelter not defined as a residential storm shelter. This includes storm shelters intended for use by the general public, by building occupants, or a combination of both. Some Risk Category III and IV buildings may operate during storm emergencies and thus may need to be designed to meet storm shelter guidelines.[1,9]

TORNADO STORM SHELTERS

The requirements for buildings designated as tornado storm shelters should not be confused with the tornado wind load requirements in the 2024 IBC for Category III and IV buildings included in Chapter 32 of ASCE 7-22.[1,6,9]

For tornado storm shelters, to meet the ICC 500 windborne debris impact test requirements, the tested component must prevent perforation of the interior surface of the tested component of the storm shelter envelope by the design missile. The intent of missile impact testing is to protect the occupant area from exposure to debris and associated debris hazards.[9] **Figure 8** shows a post-impact high-speed image of 15 lb (6.8 kg) sawn lumber 2 × 4 test missile impact for tornado shelters per ICC 500 and ASTM E1886, *Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials*.[9]

FIGURE 8. Tornado storm shelter impact test. *Image by Darren Perry, RRC, PE.*

FIGURE 9. Hurricane storm shelter impact test. *Image by Darren Perry, RRC, PE.*

HURRICANE STORM SHELTERS

Hurricane storm shelters are often larger buildings, such as school gymnasiums and public buildings, that serve other primary roles in the community. Hospitals, public utilities, communications, transportation, and national defense, which are critical to community resilience, often operate during hurricanes. These and other Risk Category III and IV facilities benefit from hurricane storm shelter design. Requirements for storm shelter low-slope roofing include testing per FM 4474, *Standard for Evaluating the Simulated Wind Uplift Resistance of Roof Assemblies*; ASTM E1592, *Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference*; or UL 1897, *Standard for Safety, Uplift Tests for Roof Covering Systems*, with a factor of 1.2 or greater applied to the design tornado pressure and the design wind pressure or greater.[9]

Figure 9 shows a post-impact high-speed image of a windborne debris missile impact test for hurricane shelters per ICC 500 and ASTM E1886. The impact test requirements in ICC 500 focus on preventing perforation of the interior surface. Robust low-slope roof coverings can resist the impact test loads per ICC 500; however, real-world debris could result in exposed membrane damage.[9]

Code evaluation services, accredited by ISO/IEC 17065, *Conformity Assessment Requirements for Bodies Certifying Products, Processes and Services*, publish code evaluation reports demonstrating low-slope roofing assemblies that comply with hurricane and tornado shelter testing requirements in accordance with ICC 500.[10] Evaluation reports are published online by evaluation services and may be obtained from roofing manufacturers.

SECONDARY ROOFING

Roof coverings subjected to extreme windstorms may also be exposed to windborne debris. The source of debris may originate far from the roof, beyond practical control. Due to the chaotic nature of tornadoes and hurricanes, additional measures may be prudent to protect critical and essential buildings.

FEMA published the *Hurricane and Flood Mitigation Handbook for Public Facilities*, consisting of 30 "fact sheets" aimed at improving public facilities and other infrastructure vulnerable to damage caused by flood and wind. *Fact Sheet 3.3.2: Roof Systems—Low-Slope Roofs* offers mitigation solutions and options to improve the resilience of low-slope roofing systems to allow a building to continue to be used or to be quickly repaired following a hurricane, with an end goal of rapidly returning the building to full functionality.[11]

This FEMA document suggests installing a secondary membrane over the deck can provide extra protection against damage from debris impacts and wind-driven rain. The document points out that sealing the secondary membrane at the edges, openings, and penetrations prevents water from entering the building. Installing insulation over the secondary membrane and installing the primary membrane over the insulation system helps absorb energy from debris impact. The document also suggests considering a modified bitumen membrane, which is more resistant to puncture than other membrane systems used for roof coverings. The document recommends roofs meet current building code requirements.[11]

Secondary membranes installed at the deck level should be designed, tested, rated, and approved as part of the roofing assembly, meeting all requirements covered in IBC Chapter 15 and the design pressure requirements outlined in ICC 500 as applicable. Secondary membranes sealed airtight and watertight may meet the requirements for vapor retarders and air barriers and thus should be considered as such during design. During new construction and reroofing projects, the building roof is often "dried in" using a temporary roofing membrane for protection during construction. When appropriately designed and installed, the temporary roofing membrane often serves as a vapor retarder, air barrier, and secondary membrane.[1,9]

CONCLUSION

Since 2000, the IBC has strengthened design, testing, and construction requirements for low-slope roofing to resist extreme weather challenges such as hurricanes and tornadoes. Adoption of the latest code often lags behind for some communities, and even the latest code revisions do not include the most current guidance available. It is incumbent upon community leaders, public building representatives, design professionals, and other stakeholders to identify potential climate risks and specify low-slope roofing systems that may exceed code minimums.

Published ratings and evaluation reports for low-slope roofing are available from accredited evaluation services and approved by the local authority having jurisdiction. These reports include test results and ratings that will help demonstrate added resilience of low-slope roofing systems desirable for Risk Category III and IV buildings and community storm shelters.

Secondary roofing designed as backup protection for Risk Category III and IV buildings during and after hurricane and tornado storm emergencies should be included within the tested/rated roofing assembly. These additional design measures for low-slope roofing can help public buildings and services recover quickly after natural disasters and thus improve community resilience.

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Fene-Frustration: Headaches of Windows

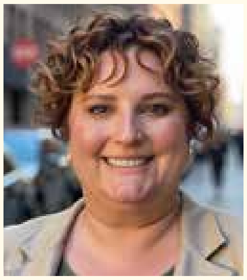
ABSTRACT

Windows are some of the prominent features on buildings and have generated some of the most innovative designs in recent years. However, fenestration can also disrupt the continuity of the exterior wall protection and tend to cause the most turmoil on projects. Windows can cause many headaches in the construction process, including poor specifications, manufacturers not fully testing their designs, and mistakes in the installation. This paper will review the basics of specifying windows, the window industry, and designs and regulations. Project examples to highlight the issues with fenestration, including window testing, mulled windows, and window flashing, will be discussed. Best practices to mitigate these issues during the design and construction phases will also be shared.

LEARNING OBJECTIVES

- Describe how designers specify windows and how manufacturers attempt to meet those specifications.
- Examine each stakeholder's role in verifying that the proposed window systems meet the project requirements.
- Analyze how small changes in window design or installation can affect window performance.
- Examine different methods the design team can use to help mitigate the issues associated with windows.

SPEAKER



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Fenestrations impact occupant comfort through natural daylighting, ventilation, and views, but poor performance can quickly lead to discomfort, energy loss, and enclosure failures. A quick study of several construction defect law firms shows numerous mentions of window leaks leading to construction defect claims on their websites.[1,2] From the author's experience, window design and continuity of the enclosure from the window to the water-resistive barrier encompass a large part of her professional time.

This paper will explore some common issues experienced with fenestrations, with a focus on the products and testing of prefabricated windows certified by the American Architectural Manufacturers Association (AAMA). While this paper will not explore all the issues associated with fenestrations, it will demonstrate that fenestrations are complex parts of the building enclosure that require careful planning, design, and understanding.

CODE REGULATIONS AND INDUSTRY STANDARDS

The majority of fenestrations installed consist of prefabricated units; they are some of the least commoditized items in the building. Each manufacturer has different preferences for fabrication and design. Because of this, it can be difficult to standardize quality and performance across the board. To provide some standards, window manufacturers formed AAMA, and they published the first AAMA 101, *Voluntary Specifications for Aluminum Prime Windows & Sliding Glass Doors*, window standard in 1985. Over the years, the organization has updated the standard to include more fenestrations and merged with other organizations to create the North American Fenestration Standard (NAFS), also known as AAMA/WDMA/CSA 101/I.S.2/A440, *North American Fenestration Standard/ Specification for Windows, Doors, and Skylights*.[3] In 2020, AAMA merged with the Insulating Glass Manufacturers Alliance to create the Fenestration and Glazing Industry Alliance (FGIA). This organization continues to publish not only NAFS but also many other design and testing standards. NAFS is the standard adopted by the *International Building Code* (IBC) for prescriptive-based prefabricated fenestrations, with the most recent iteration published in 2022.[3,4] NAFS provides minimum requirements for window grades and ratings depending on the project type and the selected materials.

FENESTRATION DESIGN PROCESS

While the building code sets the minimum standards, the design professional sets the project-specific performance requirements for the fenestrations. Project requirements are typically detailed in the project specifications. For prefabricated fenestrations, the design professional needs to specify the minimum NAFS performance grade that will meet or exceed the components and cladding minimum design pressure set forth by the structural engineer. This is one of the first stumbling blocks in the fenestration design process. Many times, this minimum design pressure or performance grade is not clearly listed in the design documents. The architect will simply reference the need to meet IBC load requirements, and the structural engineer will not list components and cladding design pressures in their drawings. The building enclosure consultant needs to raise the question. How can the contractors or manufacturers bid the project and provide window product submittals that meet minimum code requirements if they do not know the minimum design pressure and performance grade? By leaving it up to the contractor or manufacturer to set the performance level of the fenestrations, it pushes the fenestration design into "delegated-design" territory. Unless the contractor is contracted to provide delegated design for fenestrations and has a licensed professional to provide that scope, which is typically not the process when using prefabricated fenestrations, they are not qualified to do this work. It is the responsibility of the design professional to ensure this requirement is properly coordinated and documented in the contract documents.

Specifications that are often overlooked and are essential to the implementation of fenestrations are the performance mock-ups and field quality control testing requirements. While NAFS lays out the requirements for the window performance grade and minimum factory testing requirements, its regulations stop as soon as the window product leaves the factory floor. The tie-in of the window to the overall water-resistive barrier and cladding is critical to the performance and continuity of the whole enclosure. Quality assurance programs that include a performance mock-up and field testing of a portion of the fenestrations are critical to the success of the project. Field testing is intended to catch installation issues, but performance mock-ups can test the validity of the overall design intent. The design professional is responsible for specifying the testing standard, the minimum number of tests, the minimum test pressures (if applicable), and the procedure required to address failed tests.

The typical field test standards for NAFS-certified windows include ASTM E783, *Standard Test Method for Field Measurement of Air Leakage through Installed Exterior Windows and Doors*;[5] ASTM E1105, *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform of Cyclic Static Air Pressure Difference*;[6] and AAMA 502, *Voluntary Specification for Field Testing of Newly Installed Fenestration Products*.[7] While performance mock-ups and field testing are not required per code, they are highly recommended. Eventually the window will be tested by the weather and environment in service. Poor coordination of quality assurance requirements can result in confusion, lackluster testing requirements, and additional costs.

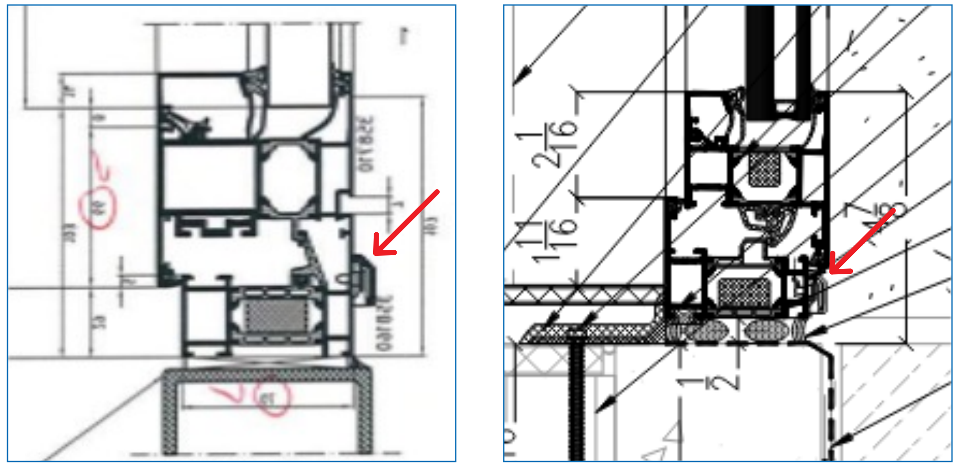

FIGURE 1. Change in sill section's weep hole location from 2009 test reports (left) to 2022 shop drawings (right).

FENESTRATION PRECONSTRUCTION PROCESS

Once the design is fully coordinated, the preconstruction process begins. The contractor typically submits fenestration product data and shop drawings for review by the design team.

One submittal that is generally not adequately scrutinized, or even included, is the laboratory test data for the fenestrations. There are many instances where laboratory tests have expired. However, in 2015, AAMA released Technical Bulletin 15-01 stating that "the test report remains valid … provided no changes are made to the design and/or construction of the product."[8] Even seemingly small changes in the window configuration can result in major differences in performance.

During a recent investigation project, several leaks were occurring at the windowsill track corners during the quality assurance field water testing. Unfortunately, the field quality assurance testing was happening towards the end of the window installation, so all the windows had already been installed on the project. The water testing subcontractor and team could not find issues with the flashing and perimeter seal. The windows on the project were installed in 2024, but the laboratory test for the windows had expired in 2014. As mentioned previously, if there have been no changes to the window construction, this may not be an issue; however, the manufacturer had altered, among other things, the location of the weep holes within the window frame since the laboratory test was performed. The weep holes through the face of the sill track were lowered on the frame down to a lower chamber within the sill section of the window frame (**Fig. 1**).[9,10] This discrepancy in the dates and the change in construction was addressed in the submittal phase of the project.

This small change in the window design moved the location of the "wet zone" within the window down to a lower region on the window frame. This became problematic at the sill-to-jamb corners. This lower chamber was significantly harder to seal than the upper chamber. With the old location of the weep, the internal seal could be installed with a bedding sealant and a top-applied sealant at the joint. With the new location, the internal seal would have to be achieved fully with a blind bedding sealant. Additionally, there is an internal connection clip at the corners that connects the sill track to the jamb. This internal clip is located within the lower chamber and appeared to be interfering with the continuity of the corner seal. This change compromised the continuity of the water-resistive layer of the enclosure and resulted in water intrusion. Even if the test report was not expired, there still would have been a change in the drainage system of the window. If the windows had been retested in the laboratory or during a performance mock-up, this issue could have been caught sooner. While laboratory testing can be very expensive, performance mock-ups are a relatively inexpensive method to test the design and field conditions prior to full production on window installation.

Another issue the author has seen is that the window test reports are for window sizes that are much smaller than what is designed for the project. NAFS allows for a registered engineer to perform structural calculations to prove that the larger designed window can meet structural loads in lieu of retesting, but there is no requirement to prove the water penetration resistance, air testing performance, or energy performance will be met with the larger window.[3] Many times, the window frame drainage chambers and weeps on the larger window are sized the same as the tested window assembly, but the volume of water that these systems need to handle has increased significantly. Larger windows mean longer glazing pockets and longer runs of gaskets that can allow water penetration into the window frame. This can result in the volume of water overwhelming the drainage capability of the window frame.

While larger windows and changes in window construction were the source of the water intrusion, the failure came from the improper coordination and vetting of the fenestrations.

Another common issue experienced is the use of mulled systems. Mulled systems are two or more individual prefabricated NAFS-certified fenestrations attached together to create a larger fenestration. This can be done in the factory or field. Mulled systems are different from performance-based designed fenestrations. Performance-based designed fenestrations are full assemblies that are designed to meet specific project performance requirements. There are many reasons why contractors and installers use mulled assemblies. For one, it is generally less expensive: instead of fully designing a custom fenestration for each project, they can use readily available products and stitch them together. Per Section 4.6.4 of NAFS, mulled systems are allowed if there is "manufacturer's involvement" in the design and use of the mulled assembly. NAFS defines *manufacturer's involvement* as "published installation procedure and manufactured parts, such as mullion stiffeners, brackets, and fasteners."[3]

FGIA has a standard for determining the performance rating of mulled window assemblies, AAMA 450, *Performance Rating Method for Mulled Combination Assemblies, Composite Units, and Other Mulled Fenestration Systems*.[11] This standard lists three methods for determining the performance rating of the mulled assembly: structural, air, and water testing of the mulled assembly; testing mullion elements as individual components with engineering calculations; or air and water testing only with structural calculations by a registered professional engineer.[10] Unless this standard is referenced in the specifications, vetting the performance rating of the mulled assemblies can be missed. However, it can be hard for designers to predict whether mulled assemblies will be used or proposed on a project. It is best to reference AAMA 450 in all standard specifications to cover all instances.

Mulling typically involves adding additional framing members such as a mulling bar or integral mullion to connect the two systems together.[12,13] This adds in an element to a prefabricated assembly that needs to be sealed and protected against air and water infiltration. It also generally requires the modification of a prefabricated assembly by cutting flanges or removing mullions, among other issues. Many times, these additional elements are back-sealed during installation and rely heavily on the installer. The top and bottom of the mulling bars are vulnerable to water penetration, particularly at the head that faces the drainage of the exterior wall above. Generally, installers will fill these areas with sealant to protect them, but this again relies on the installer. It can be easy to miss areas of sealant, which can lead to air and water infiltration. The use of additional drip caps to cover the top and bottom of the mulling bars can aid in protecting these areas.

Another consideration is the energy ratings of the mulled assemblies. The *International Energy Conservation Code* (IECC) requires specific *U*-factor ratings for window assemblies determined by the National Fenestration Rating Council's (NFRC's) ANSI/NFRC 100, *Procedure for Determining Fenestration Product* U-*Factors*.[14,15] AAMA 450 determines the mulled assembly's performance rating through air, water, and structural testing but does not require testing or recertification for *U*-factor to meet IECC requirements. Adding metal framing members or non-thermally broken mulling bars into the window assembly can create a thermal bridge and result in condensation issues. Water leakage isn't the only source that can lead to damage and mold issues. Design professionals need to consider and review all aspects of the window design and performance during the preconstruction phase.

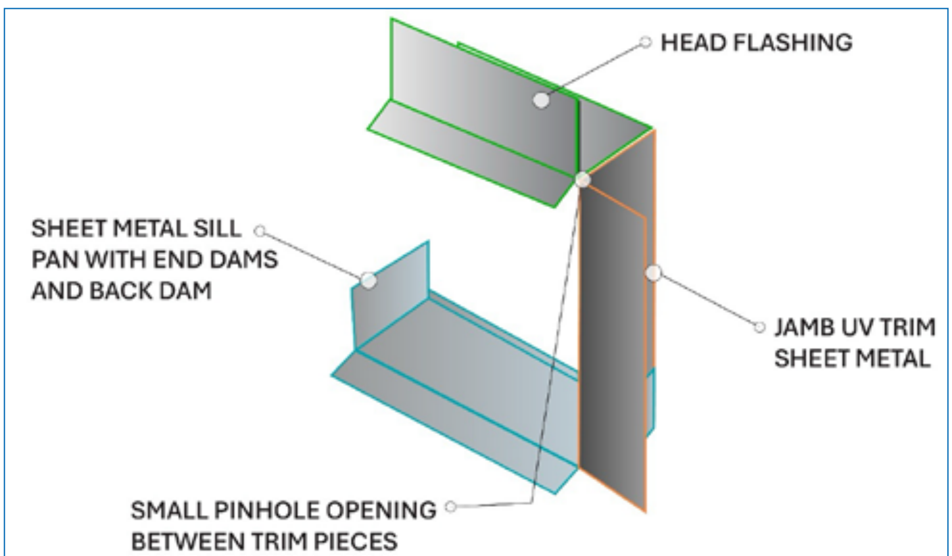

FIGURE 2. Example of interaction between various trim elements around block-frame windows. *Note: UV = ultraviolet.*

FENESTRATION INSTALLATION PROCESS

The window product itself is only one part of the window system. The tie-in of the window to the adjacent exterior walls through flashing and sealant is critical to the performance of the whole system. Installation cannot be laboratory tested or controlled. Additionally, designs that look good on paper can be difficult to implement in the field. Specifying a performance mock-up of the window and door installation and water testing prior to the full production of the installation can help avoid costly rework and delays.

This is clearly illustrated when dealing with block-frame windows. There is no AAMA-published standard for installation of block-frame windows. Many times, the weather-resistive barrier (WRB) flashing is wrapped into the rough opening, and the window is sealed with a perimeter sealant joint between the window frame and the WRB flashing. This can result in an exposed portion of the WRB flashing between the adjacent wall cladding and the window frame. One common method of covering this exposed flashing is with sheet metal or brake metal trim. This can provide ultraviolet protection and cover up the unsightly exposed WRB. This trim adds a component into the window flashing sequence that must be properly sealed to the window frame, the WRB, and the other trim pieces. Again, it can be easy to miss sealant in small areas. Many designers forget about the interaction of the trim elements at the head-to-jamb corners (**Fig. 2**, **3**). While the jamb-to-sill

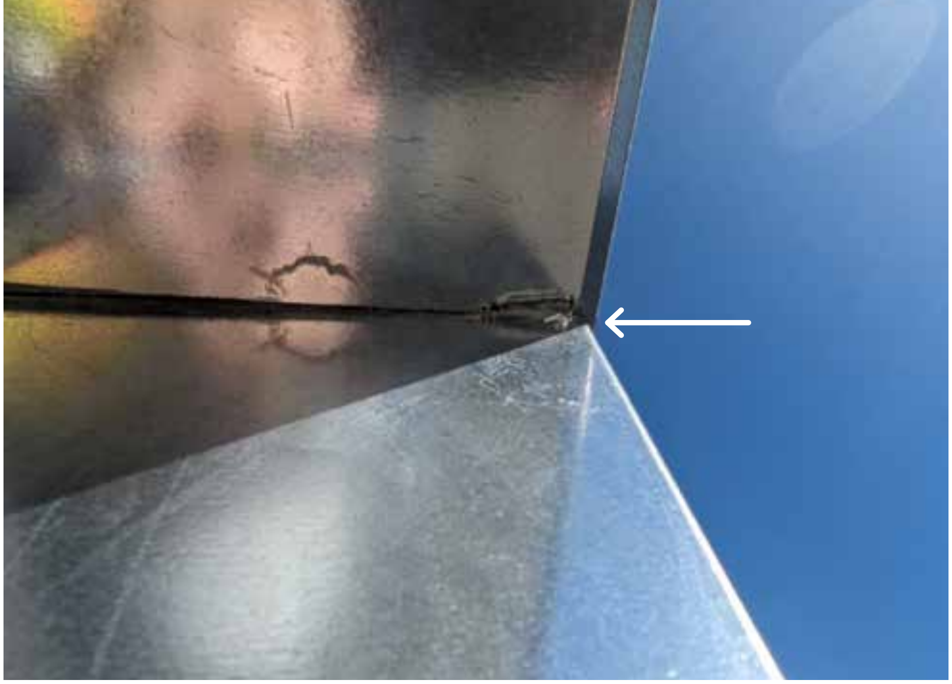

FIGURE 3. Head flashing to jamb trim; small gap between trim pieces.

corner is often overlapped with the use of end dams on the sill pan, there can be a very small gap between the head flashing and the jamb trim. Embedding these trim pieces in sealant still does not bridge this gap. The edge thickness of the sheet metal trim pieces is typically too thin to achieve proper bite of the sealant, so overlay additions of sealant also may seal the gap. This transition must be carefully detailed, installed, and tested to verify the protection of the window tie-in to the adjacent WRB.

CONCLUSION

Windows are not merely aesthetic elements; they are complex systems that interrupt the building enclosure control layers: air, water, thermal, and structural. Failures almost always come from transitions and penetrations. This is true for fenestrations as well; failures tend to come from the tie-in to the water-resistive barrier, flashing, and window framing joints. Due to this complexity, proper coordination of the project requirements and the window construction and installation details is essential to the successful performance of the entire building enclosure. This includes a detailed quality assurance program, which includes performance mock-ups and field testing.

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Innovative Stone Panels Meet Historical and LEED Requirements

ABSTRACT

A 52-story white marble-clad high-rise in downtown Dallas, Texas, built in 1965, was the center of attention for a five-star multiuse remodel aiming to meet historical requirements and attain LEED Platinum certification. Unfortunately, the marble panels had started to crack and fall, creating life-safety hazards for the public. The design team's plan was to demolish the marble and quarry the same type of marble in Greece to fabricate onto a lightweight aluminum honeycomb clip-and-rail system, lightening the structural load and meeting historical requirements. However, a better plan, which would meet LEED requirements, was proposed. In this session, the presenter will share the challenges of proving an idea through evaluation, testing, price analysis, schedule planning, and construction coordination while in a tight area next to the Dallas Area Rapid Transit system with limited space and heightened risk. This presentation will highlight challenges of working on a team with multiple viewpoints and priorities: consultant, contractor, architect, and owner. Upon completion in 2020, this building opened as one of the largest adaptive reuse projects in the state of Texas. The mixed-use development includes office, residential, retail, and a 219-room hotel.

LEARNING OBJECTIVES

- Explain why stone panels affect the structural integrity of a building.
- Recognize safety hazards in failed wall panel conditions.
- Justify why innovative ideas require investigation and validation through testing and evaluation.
- Discuss a presented case study and relate it to familiar examples for historical requirements and LEED points.

SPEAKER

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Tamara Higgins is the vice president of operations for BEAM Professionals, a building science consulting firm. She spent 10 years of her career in manufacturing, specifically operations and engineering, then the next 25 years in the construction industry, including glass and glazing, and running her own business in exterior wall panel systems as a subcontractor. Higgins has been on the forefront of design-assist for building enclosure systems across multiple market sectors in the commercial construction and existing building industry. Her expertise includes sustainability, building enclosure commissioning architectural plans and specifications reviews, new construction consultation, forensic investigations, historical building renovations, and property condition assessments.

AUTHOR:
Tamara Higgins, CBECxP, CDT

INTRODUCTION

In 1965, the $35 million First National Bank Tower was completed in downtown Dallas, Texas, becoming the tallest building west of the Mississippi River at the time. The 50-story high-rise was constructed with a steel structural frame and clad in Greek Pentelikon marble and dark gray glass. Most of the marble was concentrated at the ground and podium levels, an eight-story base featuring 48 ft (14.6 m) archway columns and a distinctive marble band wrapping the perimeter of the tower. The tower itself rose 225 ft (68.6 m) above the center of the podium. Along the upper high-rise floors, white marble panels incorporated vertical plexiglass mullions with fluorescent lighting that once illuminated the building each night.[1]

Over the decades, the property passed through a series of banking mergers, lease changes, and ownership transitions. The building was ultimately foreclosed in 2009 and placed on the market in May 2010 for $19 million.[2]

During the following 8 years, several developers proposed redevelopment plans for the 1.5 million ft^2 (approximately 139,000 m^2) tower. Meanwhile, the building remained vacant with no maintenance, and the marble facade began to deteriorate. Panels loosened from their original anchorage, and some detached and fell, breaking on the street below and creating an imminent hazard to pedestrians in the busy downtown area of Dallas.[3] As consultants began to evaluate the facade conditions, they identified hysteresis, a bowing in the marble caused by long-term temperature stresses and repeated expansion and contraction, eventually pulling the marble away from the building. This hysteresis was observed in various marble panels, leading to recommendations for mechanical stabilization anchors through the panels to temporarily secure them.

Further evaluation continued to determine proper replacement or restoration of such panels if the building was to be sold. It was determined that the estimated weight of each panel was between 6.7 and 10 lb/ft^2 (approximately 32.7 to 48.8 kg/m^2), depending on the thickness, and it took four men to safely carry the largest panel once removed from the column. The author's team also found that the panels were installed using an adhesion-based system. The large panels included an adhered stone block (**Fig. 2**), mortared to and bearing on a steel angle that had been mechanically fastened to the structure (**Fig. 1**). The small panels were adhered directly to the concrete overlaying the steel frame structure.

Timing of remediation was a critical priority, due to the danger posed by falling marble panels. The final investor/developer had established a comprehensive plan supported by a $450 million budget for the entire building. Of that amount, $100 million was anticipated from historic tax credits, and an additional $50 million was tied to City of Dallas tax increment financing. The project goal was to achieve LEED Platinum certification and obtain approval from the Dallas Landmark Commission, enabling the developer to leverage historic tax credits as part of the financing strategy. Merriman Anderson Architects (MAA) was selected as the architect of record, and Andres Construction was chosen as the general contractor.[4]

In 2016, the construction documents were issued to subcontractors for bidding. Given the known deterioration issues, as well as concerns about panel weight and long-term performance, MAA specified a clip-and-rail aluminum honeycomb panel system. This design utilized 0.25 in. (6 mm) marble bonded with a high-strength custom epoxy to an aluminum honeycomb core approximately 0.67 to 0.75 in. (17 to 19 mm) thick. The core was laminated between two 0.04 in. (1 mm) aluminum sheets, with a mechanically fastened clip on the back that

FIGURE 1. *Courtesy of UNITY Commercial Solutions.*

FIGURE 2. *Courtesy of UNITY Commercial Solutions.*

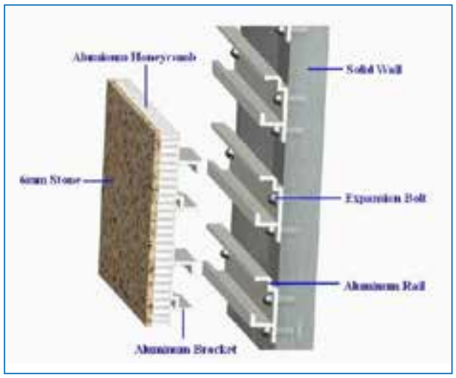

FIGURE 3.

connected to a rail system anchored to the structure (**Fig. 3**).

CLIP-AND-RAIL PANELS DETAIL

This assembly reduced panel weight to approximately 5 to 7 lb/ft^2 (24.4. to 34.2 kg/m^2), improving structural loading. The composite honeycomb panel also helped minimize expansion/contraction stresses, compared to the original installation. The one caveat was that the building's exterior facade consisted of 17,555 hand-cut marble panels originally quarried from the same Greek source that provided stone for the Parthenon, and the subcontractors would be required to procure new marble from the same Greek quarry to meet historic preservation requirements. Each individual hand-cut marble would then need to be fabricated onto this clip-and-rail system to match the aesthetics of the original building.

As the author evaluated the scope and design intent, her primary concern was whether newly quarried marble would sufficiently match the original stone after 50 years of continuous extraction, during which multiple geological layers had been removed. She was uncertain how those changes might affect the marble's color, veining, and overall characteristics. Achieving LEED Platinum certification on a repurposed downtown high-rise posed an additional challenge. Beyond these considerations, schedule and budget pressures were significant, particularly given the building's location amid busy streets, heavy pedestrian activity, bus routes, and the Dallas Area Rapid Transit (DART) rail system, which was practically wedged against one elevation. The easy part was understanding the clip-and-rail system. The author had spent many years working with similar composite panel systems as a consultant and manager of a panel installation team, so she was confident in how the system worked and knew it was the right fit for this project. She was first introduced to the system through a company called TerraCORE Panels in Dallas (**Fig. 4**). They introduced this system as an alternative approach to fully adhered large-format wall panels, including porcelain, limestone, granite, marble, and other natural stone cladding. They had a large fabrication plant overseas but had completed and passed various pertinent testing and evaluations in the United States, including ICC-ES (ESR-3675), which covers structural, durability, and surface burning characteristics; NFPA 285, *Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components*; freeze/thaw testing; and pull-out/clip capacity testing; and had panel wind load ratings (positive and negative). TerraCORE also stated they passed testing under Florida's "large missile impact" and Florida Product Approval (NOA) criteria for hurricane zones and delivered engineering calculations from a local firm on every project they were awarded.

FIGURE 4. TerraCORE Panels fabrication.

THE GAME CHANGER

The author had an idea that she believed could be a genuine game changer. When the day came to present it to the construction team, she walked into a conference room filled with people, including the developer, the owner's representative, the general contractor's executive team, the lead architect and his staff, and an engineer, all seated around a large table, ready to interview her.

The author set three pieces of marble (**Fig. 5**) on the table and asked if anyone could tell the difference between them. They examined each sample with interest, then admitted they could not and wanted to know if it was a trick question. The author then explained that one piece had fallen from the building and was something she had picked up off the ground. Another was a newly fabricated 0.25 in. (6 mm) slab straight from a quarry in Greece. The last was a 0.25 in. slice taken from the building's existing marble and adhered to an aluminum honeycomb clip-and-rail system. The team paused, processing what the author had just said. One of the executives even asked her to repeat it, so she did and added, "If the subcontractor carefully removes the existing marble from the building during demolition, it can be sent to the fabrication facility and used on the new panels. That gives you 100% repurposed material for LEED credits and 100% historic integrity." The author will never forget the faces of the people in the room. They sat back, stunned and amazed that they had not thought of it themselves, but the questions came flooding in.

The innovative concept unfolded in several parts. The first step involved carefully removing the existing marble panels, each roughly 1 in. (25.4 mm) thick, and slicing them down to 0.25 in. (6 mm) to serve as the new panel system. A sound

FIGURE 5. Tamara Higgins, author.

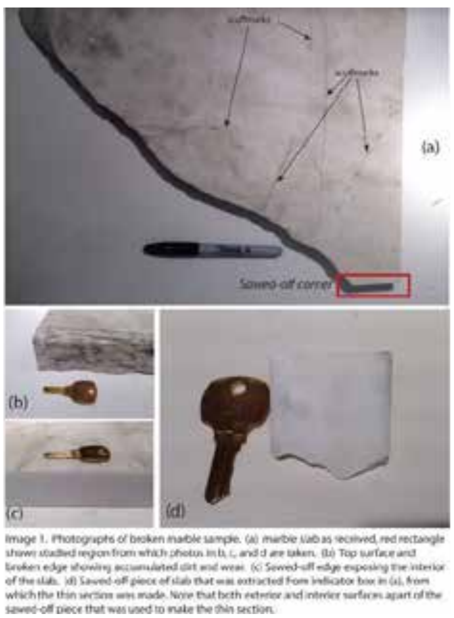

FIGURE 6. Report photo from University of Texas Dallas.

panel could yield up to three new panels, accounting for saw cuts, surface wear, and similar factors. Many of the original panels were identical in size, so if one was damaged, the subcontractor could fabricate additional pieces from another matching panel. If a smaller panel was simply unusable, a new panel could be fully fabricated from a larger panel. Of course, there should be a percentage accounted for that may need to be quarried, regardless, but this was a start.

While this approach addressed two major concerns, 1) preserving historic material and 2) reducing new marble purchases, it also raised new questions. What if the north-facing elevation had been too exposed to the environment over the past 50+ years, causing the marble to bow and become unusable? Some panels already showed signs of hysteresis. What if the panels could not be removed intact? How would the process of removing, marking, transporting, fabricating, and reinstalling the panels affect the project schedule? And how much savings would truly result from not sourcing new marble?

While the author was eager to help the design and construction teams understand the answers to these questions, she also drew on strong input from her own team to shape the next phase of the solution.

Tim Whaley, founder of EnviroGLAS and inventor of a US patent titled "Method of making a terrazzo surface from recycled glass," brought his expertise in upcycling and immediately recognized that any damaged or discarded marble did not need to go to waste. By crushing the unusable pieces and blending them with epoxy, he communicated how they could be transformed into new interior finishes such as flooring or countertops, a solution that not only reduced waste but also strengthened the project's sustainability story with the MAA design team.

At the same time, a geologist and construction superintendent, Lucas Flores, saw a different opportunity. Concerned about the bowing and long-term exposure of certain panels, he recommended sending broken slab samples to the geology lab at the University of Texas at Dallas for testing. The analysis and multiscale examinations of the marble, conducted in part by participating students, became both a learning experience and a critical source of data.

The final report (**Fig. 6**), led by Dr. Robert J. Stern and Warren Lieu, MS, confirmed that the marble showed no substantive degradation, only minor surface micro-pitting 0.008 to 0.016 in. (200 to 400 microns) consistent with age and environmental exposure. This validation strengthened the team's confidence that the historic stone could indeed be reused.

THE PLAN

To verify that the concept was viable and to address concerns and identify other potential issues, the team began by removing sections of the existing marble for testing, fabrication, and eventual installation on the new honeycomb panels. They partnered with a fabricator, HyCOMB USA in Hallandale Beach, Florida, to collaborate on the fabrication process at their small facility in the United States in conjunction with their large facility overseas (China) to support the magnitude of this project. In parallel, the team mapped out the full scope of requirements for the project: how the building would be measured and marked for replacement, how panels would be loaded and transported, the logistics of intake and delivery, the overseas lead times, equipment needs, safety procedures, and best practices. There was significantly more to consider than if the marble were simply being demolished and discarded.

For the mock-up, the team intentionally selected one of the most intricate areas of the building, the marble archway (**Fig. 8**), knowing it would likely pose the greatest challenge. The team evaluated the numerous small, individually hand-cut stones and proposed a more efficient solution: slicing the marble slightly thicker than 0.25 in (6 mm). to allow a fabricated reveal to be milled into the face, creating the appearance of multiple individual pieces in a single larger panel. A sample of this concept was fabricated and presented to the team (**Fig. 7**).

FIGURE 7. HyCOMB sample with reveal.

FIGURE 8. *Courtesy of UNITY Commercial Solutions.*

The goal was to maximize overall panel size wherever feasible, especially given the reduced weight per square foot with the honeycomb system. This approach promised meaningful savings in labor and packaging in addition to optimized transportation costs. The mock-up confirmed that the panels could be removed with minimal to no damage, validating the foundation of the idea. With that success, the team moved forward and began tackling the remainder of the logistics.

GeoNav Survey Solutions, a survey technology and systems integration company, was selected during this phase for their advanced suite of tools capable of capturing highly accurate on-site building measurements, an essential requirement for documenting the historic structure prior to renovation. Their system combined a high-precision global navigation satellite system with robotic total station integration and laser range measurements, enabling surveyors to achieve millimeter-level accuracy across the entire facade. These technologies worked together to anchor every measurement to exact site coordinates, ensuring reliable alignment even when surveying a building of this scale and complexity.

Using GeoNav's mobile field software, the survey team walked the perimeter of the building, laser-measuring each marble panel, architectural feature, opening, and elevation. The system captured precise two- and three-dimensional geometry in real time, allowing surveyors to visualize the building as it was being measured and perform immediate quality assurance/quality control in the field with distance and angle readings, measurement tolerances, and deviations outside acceptable limits. Control points established around the site ensured that all measurements, often taken over multiple days and instrument setups, tied into a single, unified coordinate system. This process produced a complete, millimeter-accurate digital model of the existing facade (**Fig. 9**).

The resulting data could be directly exported into computer-aided design and building information modeling formats, supporting the detailed planning required for panel removal, cataloging, transport logistics, fabrication at HyCOMB USA, and eventual reinstallation onto the honeycomb system. GeoNav's laser-based survey (**Fig. 10**) ultimately served as the foundation of the marble-reuse strategy, providing the precise as-built documentation needed to preserve the building's historic integrity while enabling a modernized panel system.

FABRICATION, SCHEDULE, AND BUDGET

The mock-up fabrication process naturally led to discussions about potential challenges. Many of the larger panels located around the first-level columns had exposed holes from the original mechanical stabilization anchors, while others exhibited bowing due to hysteresis. This meant the team needed a strategy not only for unforeseen conditions but also for the known conditions that required practical solutions.

For the bowed panels (**Fig. 11**), even if a perfectly straight 0.25 in. (6 mm) slice could be taken from the center, the fabrication machinery could not accommodate material with that degree of curvature. As a result, those panels were rejected.

For the larger panels that were still structurally sound **Fig.12**, the team planned to fabricate two to three new panels from each one. The mechanically compromised panels, with anchor penetrations, were designated either for smaller replacement pieces or for use in interior epoxy-based applications.

Various types of lab testing were required and further performed by Intertek-ATI,

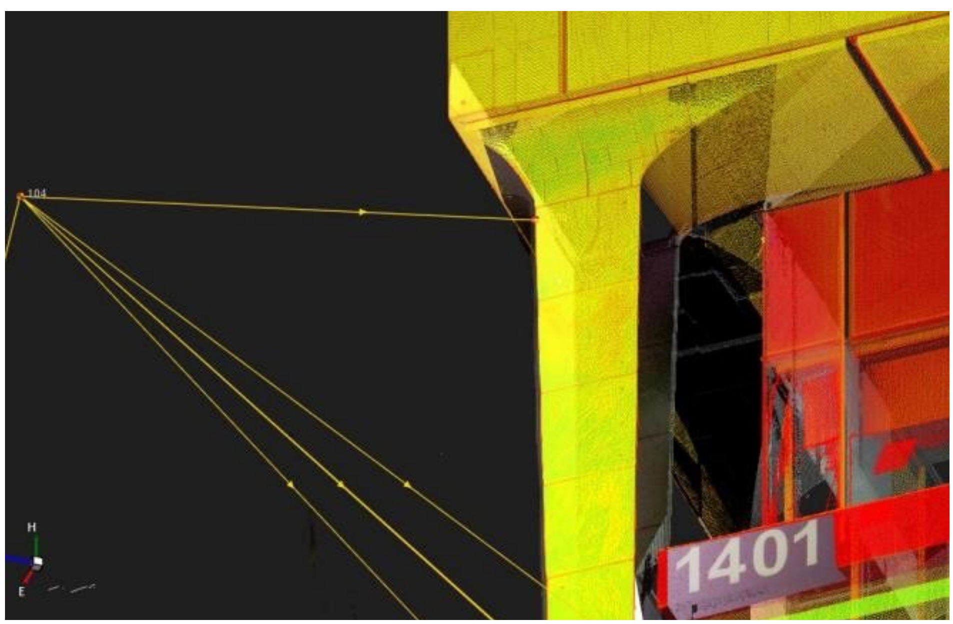

FIGURE 9. GeoNav infrared control point output.

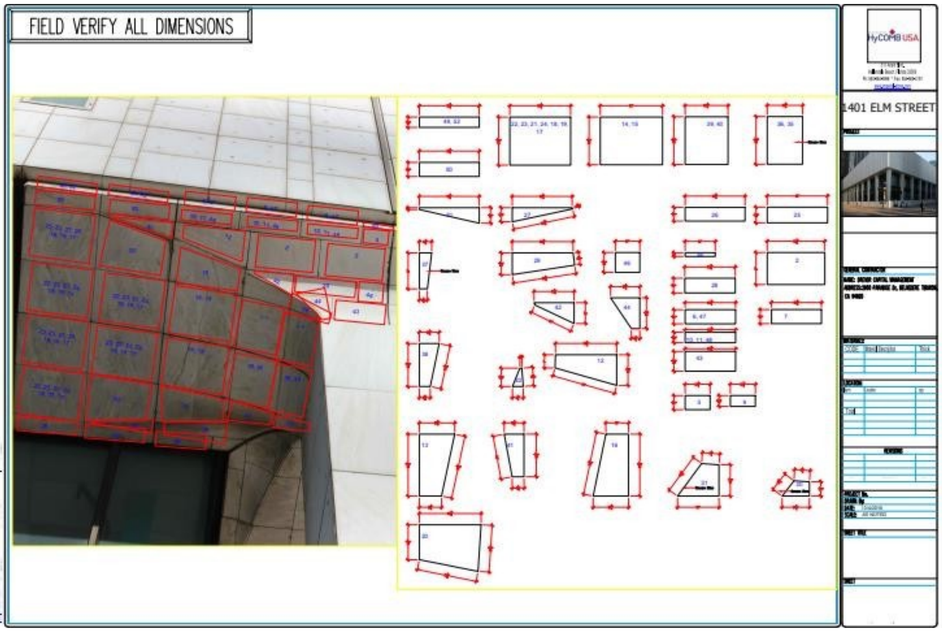

FIGURE 10. GeoNav measuring outputs.

FIGURE 11. *Courtesy of UNITY Commercial Solutions.*

FIGURE 12. *Courtesy of UNITY Commercial Solutions.*

using a variety of panels from different elevations to ensure all weather orientations were represented. The tests included 1) ASTM C97, *Standard Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone*, 2) ASTM C170, *Standard Test Method for Compressive Strength of Dimension Stone*, 3) ASTM C99, *Standard Test Method for Modulus of Rupture of Dimension Stone*, 4) ASTM C880, *Standard Test Method for Flexural Strength of Dimension Stone*, and 5) ASTM C666, *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*. These originally unplanned tests did take time and began to affect the start schedule, but passing results were necessary to proceed with the demolition/fabrication plan for using existing marble. Time was ticking, and other aspects of logistics were being planned as well in hopes of saving time or money.

As previously stated, one elevation of the building faced the DART rail system, creating logistical challenges, particularly regarding pedestrian safety while handling stone panels at significant heights. To address this, the team engaged MDM Scaffolding Services to propose a mast climber solution. A mast climber is a motorized platform that travels along a vertical mast (or multiple masts) anchored to the building, providing stable and controlled vertical access. This system offered a streamlined approach that significantly enhanced safety, supported the weight of heavy facade materials, and created a large, stable working surface for both demolition and installation crews. With proper planning and sequencing, the mast climber solution could be combined with traditional scaffolding and deployed across the entire facade replacement, supporting operations throughout both panel removal and reinstallation, yet this was not the most inexpensive way to go. Mast climbers generally cost 10% to 30% more up front than traditional scaffolding; however, they often reduce total project cost, considering faster installation and dismantlement, lower labor hours for facade trades, much higher production speed, reduced safety incidents, and the ability to carry heavy materials (stone, panels, glass) without separate hoisting equipment.

The overall budget proposed for the project fell on several subcontractors and manufacturers for the demolition, installation, equipment, and fabrication. The author's team assisted Andres Construction in performing an overall takeoff of the marble and aluminum trim up the tower (**Fig. 13**), but the rest was up to the construction team to decide who would be awarded each scope and what the best plan for logistics was.

HyCOMB Panels had originally proposed a comprehensive scope that included reprocessing the existing marble,

FIGURE 13. *Courtesy of UNITY Commercial Solutions.*

handling overseas fabrication logistics, preparing engineered drawings, and managing all export and import requirements. Given how centralized and specialized their role was, they ultimately suggested sole-sourcing the fabrication and installation directly with the owner, which likely strengthened their position. The timing also mattered, since the upcoming Chinese New Year shutdown would pause production for about 4-weeks at their overseas facility, and they wanted to have better control over managing that schedule.

This is where the author's consulting ended.

CONCLUSION

In 2017, after months of exploration, testing, and risk-weighing, the construction team made the bold decision to move forward with the unconventional idea, one that challenged industry norms and reimagined what could be done with a historic facade. What followed was 3 years of transformation, coordination, and craftsmanship unlike anything the building had seen since its original construction.

By 2020, the once-vacant tower reopened, reborn as one of the largest adaptive-reuse developments in the state of Texas.[4] The new mixed-use destination seamlessly blended office space, luxury residences, vibrant retail, and a 219-room hotel, all wrapped in a facade that honored the building's past while meeting the demands of its future.

At a staggering $460 million, the effort became the most expensive building conversion in Dallas's history but also one of its most visionary.[4] What began as a risky idea about saving marble panels ultimately became a defining chapter in the city's architectural story, proving that innovation, when matched with persistence, can literally reshape a skyline.

As an industry recognition, Andres Construction won a recognition from TEXO Association in the category of Distinguished Historic Renovation Award.

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Calling for Building Code Changes for Low-Slope Roof Drainage

ABSTRACT

This session addresses crucial updates needed in roof drainage codes to manage severe rain events effectively, featuring experience from the field that underscores the urgency of these changes. Focusing on the following five key building code modifications, this session is developed with the roofing design professional, engineer, and architect in mind. First, advocate for a unified method for the *Uniform Plumbing Code*, *National Plumbing Code of Canada*, *National Standard Plumbing Code*, and *International Plumbing Code* in calculating roof drainage requirements, including using intense short-duration rainfall data of 100-year storms. Second, the session proposes to eliminate sump pits that fail to meet the building code required roof slope. It also defines "observable" overflow language cited in codes and recommendations of positioning overflows above windows or exterior doors for enhanced visibility and safety. In addition, this session defines the installation location of collector heads to avoid water ponding on roofs. It also reviews and advocates for the idea of doubling the size of overflow drains compared to main roof drains to ensure functionality during blockages. Furthermore, it reviews the necessity of adding secondary overflow drains in reroofing projects on existing buildings, which are currently not mandated, in the context of real-world scenarios where deficiencies in current standards have compromised safety, underscoring the necessity for the proposed code enhancements. This session equips learners with the information they need to advocate for essential enhancements to improve building resilience and public safety.

LEARNING OBJECTIVES

- Explain the benefits of adopting a unified method for the *Uniform Plumbing Code*, *National Plumbing Code of Canada*, *National Standard Plumbing Code*, or *International Plumbing Code* for calculating roof drainage requirements and how it can address intense, short-duration rainfall events.
- Identify the common pitfalls associated with sump pits that fail to meet the required drainage slopes and discuss the reasons for their elimination from building codes to enhance safety and efficiency.
- Describe the concept of "observable" overflows, detail collector/conductor heads, and recommend optimal placement strategies for these features to enhance visibility and safety during severe weather conditions.
- Discuss necessary roof drainage code enhancements, using real-world case studies presented.

SPEAKER

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INTRODUCTION

Across North America, shifts in precipitation dynamics have produced increasingly frequent and intense short-duration rainfall events. These developments have revealed systemic limitations in conventional stormwater infrastructure, particularly roof drainage systems and municipal stormwater networks, many of which were designed based on historical intensity-duration-frequency (IDF) curves that no longer reflect the magnitude or temporal distribution of present-day precipitation events. Recent high-impact storms have accentuated the growing divergence between legacy design assumptions and contemporary precipitation realities.

For instance, on April 13, 2023, Fort Lauderdale, Florida, recorded over 24 in. (600 mm) of precipitation within 24 hours, with approximately 16 in. (400 mm) falling in just 6 hours. This event, currently classified with a recurrence interval exceeding 1 in 1,000 years, resulted in widespread urban inundation, the closure of key transport corridors, and structural failure of a commercial building. Similarly, in March 2023, a warehouse roof in Oakland, California, experienced a roof collapse during a localized but intense rainfall event. In both cases, the magnitude and rate of rainfall overwhelmed existing roof drainage infrastructure, underscoring the performance limitations of systems not designed for high-volume, short-duration hydrologic loading (**Fig. 1**).[1]

FIGURE 1. The March 2023 roof collapse in Oakland, California, owing to an intense rainfall event.

FIGURE 2. An example of an obstructed drain path. This shows how easily a scupper can clog, as roofs can quickly become blocked simply from objects being thrown onto them."

In Canada, a comparable event occurred in Nova Scotia from July 21 to 22, 2023, where a slow-moving convective system delivered nearly 10 in. (250 mm) of rain in under 24 hours, far exceeding the region's established 1-in-100-year thresholds. The resulting urban flooding and infrastructure damage further illustrate the emergence of extreme rainfall as a critical consideration for design, particularly in coastal regions.[2]

These cases collectively highlight a persistent industry challenge: existing drainage standards and associated design practices are increasingly incompatible with observed severe rain events.

Background

Performance failures in low-slope roof assemblies have drawn attention to technical inadequacies embedded within prevailing national and regional plumbing codes, including the *Uniform Plumbing Code* (UPC), *International Plumbing Code* (IPC), *National Standard Plumbing Code* (NSPC), and *National Plumbing Code of Canada* (NPC).[3,4,5,6] These standards typically prescribe drainage design based on 60-minute, 100-year rainfall assumptions, which fail to capture the intensity spikes and temporal variability of modern convective precipitation systems. While this provides a simple baseline, it overlooks the short-duration "spike" storms that often drive surcharges during severe weather events. NOAA Atlas 14 IDF data show that multiple high-intensity bursts within an hour can produce total rainfall far above table values. For instance, the UPC rate of 4.6 in./hr (117 mm/hr) for Houston, Texas, is significantly below the 8.6 in./hr (218 mm/hr) equivalent when 30- and 15-minute spikes are combined. Similar underestimation occurs in San Francisco, California, where the UPC's 1.5 in./hr (38 mm/hr) omits critical short-term peaks. As a result, primary drainage systems are frequently undersized, while overflow provisions are inconsistently applied or technically insufficient.

Field assessments have documented multiple recurring deficiencies: the absence of emergency drainage infrastructure in reroofing applications, the undersizing or poor placement of secondary scuppers, and the design of overflow systems that negate emergency intended redundancy. In reroofing projects, especially, the assumption of "positive drainage" often serves as the basis for exempting secondary drainage requirements despite on-site conditions such as obstructed drain paths (**Fig. 2**), inadequate slope, or collector head misalignment that compromise overall drainage efficacy.

Addressing these systemic deficiencies requires a fundamental re-evaluation of drainage design criteria currently embedded in building codes. Key recommendations include recalibrating design assumptions using updated National Oceanic and Atmospheric Administration (NOAA) or IDF datasets that reflect regional precipitation shifts; mandating the use of physically independent, conspicuously located secondary drainage systems; enlarging scupper dimensions and roof slopes to accommodate higher runoff volumes; and removing regulatory exemptions that weaken performance in retrofit conditions. An industry-wide shift toward performance-based, resilience-focused design standards is necessary to ensure safe, functional, and code-compliant drainage infrastructure under increasingly dynamic rainfall conditions.

CODE LANDSCAPE

Four model plumbing codes, which were mentioned previously, govern roof drain design on the continent: UPC, NSPC, IPC, and NPC. Each of those codes embeds a distinct rainfall calculation and overflow philosophy.

Before comparing the plumbing codes, it helps to understand how rainfall intensity data works. Roof-drain sizing in North America is based on IDF statistics, which describe how hard it rains (intensity), for how long (duration), during a storm of a given probability (frequency, such as a "100-year" event). Shorter storm durations typically produce higher intensities: a 15-minute cloudburst is more severe, in terms of flow rate, than the same storm averaged over an hour. Because each code selects a different duration from the local IDF curve (for example, 60-minute, 1-hour, or 15-minute values), the resulting design flow rates differ even for the same location.

The UPC, prevalent in the western United States, sizes primary gutters, leaders, and roof drains for the 100-year, 60-minute storm, a criterion taken directly from Section 1101.12.1 of the UPC. Before entering the capacity tables, designers must add 50% of the area of a single vertical wall, 35% of the wall areas of adjacent walls with the same height, and 0% of opposing walls with the same height. If adjacent or opposing walls are different heights, the additional height (either 50% or 35%) that sheds to the roof, capturing facade splash and wind-driven runoff, must be added to the square footage of the plan area.

The NSPC, used only in New Jersey, adopts the same 100-year, 60-minute tables for its primary system and, in commentary to Chapter 13, advises recalculating the emergency system with the shorter, more conservative IDF curve practice that aligns it pragmatically with the UPC while encouraging more robust overflows.

The IPC substitutes a 100-year, 1-hour rainfall, published in Figure 1106.1 and Appendix B, to determine flow rates. It differs from the UPC facade rule, explicitly requiring that one-half of any contributing wall be added to the roof area when sizing drains and piping. Independent secondary drains or scuppers must be provided wherever parapets or similar barriers could entrap water, and they must discharge separately above grade, protecting the primary system from blockage.

The 2020 NPC reflects Canada's steeper cloudburst profile by adopting the local 15-minute rainfall intensity. Designers multiply that intensity by the roof plan area plus one-half of the largest adjoining wall to obtain the hydraulic load. Where controlled-flow roof drains are installed, scuppers spaced along any parapet must convey 200% of the calculated 15-minute flow while limiting ponding depth to 6 in. (150 mm), and parapets higher than 6 in. trigger the same emergency-overflow requirement.

All four codes derive discharge from (roof area + facade allowance) × design rainfall, yet they differ in the rainfall duration that the codes deem critical (60 minutes versus 15 minutes) and in how assertively they increase the sizing to guard against blockage-induced flooding of the roof.

Comparative Analysis Example

Case Example: Enclosed Courtyard (100 ft × 100 ft [30.5 m × 30.5 m]) with 100 ft Wall Heights on All Sides

Under the IPC and the UPC, the roof plan contributes 10,000 ft² (929 m²), but these codes diverge sharply on how facade runoff is credited. The IPC mandates adding 50% of every wall area that "diverts rainwater to the roof." Four walls each measure 100 ft × 100 ft = 10,000 ft², so their combined area is 40,000 ft² (3,716 m²), and the IPC assessment adds 20,000 ft² (1,858 m²). The resulting hydraulic catchment therefore becomes 30,000 ft² (2,787 m²). The UPC applies a shielding hierarchy in which four walls of equal height are deemed to block one another; the tabulation for "four walls" assigns 0% wall allowance. Consequently, the UPC designer sizes the same courtyard on just the plan area, 10,000 ft².

Capacity Ramifications

The drainage equation common to US codes converts area to flow by

$$Q = 0.0104 \times I \times A \text{ (gal./min)}$$

where *I* is the design rainfall intensity (in in./hr and L/s) and *A* is the area (ft²/m²). Assuming a representative 4 in./hr (101.6 mm/hr),, the IPC flow becomes

$$Q_{IPC} = 0.0104 \times 4 \times 30{,}000 \approx 1{,}250 \text{ gal./min (79 L/s)}$$

The UPC counterpart is

$$Q_{UPC} = 0.0104 \times 4 \times 10{,}000 \approx 420 \text{ gal./min (26.5 L/s)}$$

Thus, the IPC requires nearly three times the discharge capacity of the UPC for an identical architectural volume. Under IPC Section 1110.4 for controlled-flow roof drainage systems, roofs 10,000 ft² (929 m²) or less require at least two drains, with additional or larger drains needed as the catchment grows. The UPC also requires at least two primary drains for roofs up to 10,000 ft² (UPC Section 1101.12.1), with capacity-based upsizing or additional drains for larger areas. In this example, the IPC's higher contribution area would necessitate both upsizing (for example, from 3 in. to 5 in. [76 mm to 127 mm] diameter) and potentially more drains than the UPC design.

Variability and Undersizing Risk

Although all four codes calculate discharge as (roof plan area + facade allowance) × design rainfall, they differ significantly in both rainfall statistics and facade accounting. Under the UPC's shielding hierarchy, certain wall configurations receive 0% credit, while the IPC and NPC require adding 50% of any wall area that sheds water to the roof. In enclosed courts, atria, or parapet-bounded roofs, this difference can triple the computed inflow, directly affecting leader sizing, collector head capacity, and overall drainage design. While the minimum ponding depth allowance is 2 in. (50 mm), structural engineers may approve higher values if the roof structure can safely support the load.

A separate hazard stems from rainfall duration assumptions. UPC, NSPC, and IPC capacity tables are based on a 60-minute design storm, yet many intense events are driven by sub-hour peaks. Reconstructing a 1-hour total from shorter bursts, such as a 30-minute pulse bracketed by two 15-minute surges, often yields depths exceeding tabulated values. Gulf Coast cities can experience composite intensities near 8 to 9 in./hr (200 to 230 mm/hr), compared to the 4 to 5 in./hr (100 to 125 mm/hr) listed in UPC tables; even mild coastal climates like San Francisco, California, can see 2.2 to 2.3 in./hr (55 to 60 mm/hr) against a 1.5 in./hr (38 mm/hr) table value. If these shorter controlling durations are not evaluated, primary systems risk being undersized and overloaded prematurely.

Harmonization with Climate-Adjusted IDF Data

Rainfall patterns are changing, and many building codes still rely on outdated "design storms" that underestimate today's short, intense bursts of rain. Rather than focusing on swapping one set of rainfall tables for another, the key is to align the assumptions that underpin roof drainage design:

- Use local, up-to-date rainfall data: Instead of relying on decades-old averages, designers should base calculations on current sources such as NOAA Atlas 14 (US) or municipal IDF curves. For example, a roof in Toronto might see its peak 15-minute rainfall rate increase by over 20% compared to data from the 1970s.[7]
- Consistent wall-to-roof runoff accounting: Some facades drain directly onto roofs. To capture this extra load, a standard approach such as adding 50% of the wall's projected area to the roof area is simple and reduces undersizing. For instance, if a 108 ft² (10 m²) upper wall drains to a lower roof, designers would add 54 ft² (5 m²) to the roof drainage calculation.
- Stronger overflow protection: Secondary drains or scuppers must operate independently from the main system and be discharged where maintenance staff can see them. These should match or exceed the primary system's capacity, with weir heights set to prevent ponding loads that exceed the roof's structural design.
- Clear design verification: Calculations should check hydraulic grade lines (water levels in pipes) at every junction, allow for surges at bends, and

FIGURE 3. A sump pit filled with water.

confirm the structure can handle any ponding loads if drains clog.

» Regular data updates: Require designers to readopt updated IDF datasets every 5 years so that designs reflect changing rainfall patterns, particularly in regions experiencing more frequent cloudbursts.

Example

If a large distribution warehouse were designed using outdated rainfall data, say, a 1-hour storm from the 1980s, it might fail to account for today's sharper, more intense 15- to 20-minute bursts. In such a scenario, a single cloudburst exceeding the design assumption by even 30% could quickly overwhelm the primary drains. Without independent secondary scuppers discharging visibly above grade, water could pond to unsafe depths, imposing loads well beyond the roof's structural capacity. Over time, repeated events like this could result in deck deflection, membrane failure, or even partial collapse.

Failure Case Study

On December 27, 2022, a Big 5 Sporting Goods store experienced a roof collapse shortly after closing. While no injuries occurred, the collapse damaged the building's fire sprinkler lines, causing additional interior flooding. Although the precise cause of the structural failure remains unconfirmed, records indicate that a severe rain event was occurring at the time.

Post-incident observations revealed that the secondary scupper was undersized relative to the primary drain. In such conditions, the overflow system lacked sufficient capacity to relieve the rapid accumulation of water on the roof. Even if the overflow scupper had been sized in accordance with the primary drain, the exceptional rainfall may still have exceeded system capacity; however, doubling the overflow provision, either by increasing the size of the scupper or by installing two independent, correctly sized overflows, could have significantly reduced the risk of collapse.

Code Deficiencies in Retrofitting

An example of code deficiencies is found in the *California Building Code* (CBC) Section 1511.1, which currently exempts reroofing projects from the requirement to install secondary (emergency overflow) drains or scuppers, provided the roof maintains "positive drainage."[8] While intended to reduce costs for straightforward recovery or replacement work, this exemption leaves many older buildings, particularly those with marginal slopes or aging primary drains, exposed to significant risk during severe rain events. Without secondary drainage, blockage or surcharge in the primary system can lead to rapid ponding, imposing loads that exceed the roof's structural capacity. In practice, many older buildings predate modern rainfall intensity criteria and were designed using now-obsolete IDF data; thus, even "positive drainage" roofs may be undersized for current or future rainfall patterns. Mandating secondary systems in reroofing would address these latent vulnerabilities and reduce the likelihood of water intrusion or structural distress.

Technical Shortcomings in Current Roof Practice

Sump Pits

Sump pits, which are commonly used to recess roof drains, present inherent vulnerabilities in low-slope drainage design. By their geometry, they encourage the accumulation of organic debris such as leaves, dirt, and vegetation (**Fig. 3**), which can block inlets and significantly reduce drainage capacity during high-intensity rainfall. When left unmaintained, this blockage can lead to ponding loads that exceed the structural design capacity of the roof.

In climates experiencing more frequent severe rain events, sump pits exacerbate the risk by concentrating inflow at a single low point rather than dispersing drainage. Industry best practice recommends eliminating sump pits in favor of tapered insulation systems or increasing roof slopes (for example, from ¼ in./ft [21 mm/m] to ½ in./ft [42 mm/m]) to promote positive drainage across the field of the roof and reduce debris stagnation (**Fig. 4**).

Secondary Drain Visibility and Observability

The *California Plumbing Code* (CPC) requires that overflow discharges be "observable" to building occupants or maintenance staff (**Fig. 5**).[9] In practice, however, field inspections reveal that overflow outlets are often poorly located, sometimes adjacent to primary drains or concealed in inaccessible locations, limiting their function as a visual alarm for primary drainage failure.

The previously mentioned March 2023 warehouse incident in Oakland, California, illustrates the hazard. On-site observations found the overflow drain located immediately beside the primary drain, rendering it ineffective as an early warning. While this proximity does not impair functionality when the overflow inlet is correctly elevated, typically 2 in. (≈50 mm) above the primary inlet,

FIGURE 4. Tapered insulation to be installed to institute positive drainage, eliminating the need for sump pits.

FIGURE 5. An observable secondary drain.

FIGURE 6. A collector head that is installed too high.

FIGURE 7. Blocked collector head with overflow that indicates water backing up onto the roof-to-wall interface due to inadequate scupper slope and detailing.

in accordance with accepted design standards, it can diminish the visibility of overflow activation if the outlet is discharged in an inconspicuous location.

In this particular case, the exact cause could not be definitively established; repositioning the overflow to discharge conspicuously above an entry door or other visible location might have prompted timely intervention. While the positioning of an overflow outlet above a doorway might expose occupants to water during rainfall or increase the chance of short-term leakage if seals are defective, the primary life-safety objective of secondary drainage is immediate, unmistakable hazard signaling, not occupant comfort.

Overflow activation inherently indicates that the roof is ponding water beyond intended limits, posing a far greater structural risk than temporary exposure to runoff or local seepage. When properly detailed, such visible discharge provides a deliberate and effective warning mechanism that prompts timely corrective action.

Collector Head Design

Collector heads, used to channel water from scuppers into downspouts, are another frequent point of failure. Improper elevation (**Fig. 6**) illustrates the installation of a tapered insulation system at a roof drain), inadequate sizing, clogging (**Fig. 7**), and poor alignment of an overflow scupper can all compromise system performance. If a collector head clogs, water can back up into the wall cavity or overflow at unintended points, leading to concealed moisture damage. Industry guidelines, such as those published by the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) and the National Roofing Contractors Association (NRCA), emphasize correct sizing, secure attachment, debris-resistant configurations, and coordinated integration with the wall and roof assemblies. Adherence to these details is essential to ensure that collector heads perform reliably under both design and extreme rainfall conditions.

PROPOSED CODE ENHANCEMENTS

Unified Rainfall Design Approach

When wall area contributions are reduced under UPC rules, this underpredicts the inflow. A unified approach should mandate NOAA-based rainfall curves across the applicable codes, evaluate multiple storm durations, and size drainage components to the controlling value. This would harmonize design practices, reduce undersizing risk, and enhance performance consistency for manufacturers, designers, and inspectors.

Standardized Sizing and Scupper Dimensions

Current scupper sizing requirements vary by jurisdiction. The CPC mandates minimum openings of 4 in. (102 mm) in height, with widths equal to the circumference of the associated drain. However, other codes lack uniform dimensional baselines or fail to clearly define overflow

FIGURE 8. Best practice in the installation of overflow (secondary) scuppers, in that they double the size of the primary scupper.

capacity requirements. Field investigations frequently reveal undersized or obstructed scuppers that cannot relieve ponding during primary system failure. Adopting standardized scupper dimensions (minimum 4 in. height and calculated width based on primary drain sizing) would ensure predictable capacity.

For secondary systems, codes should require either doubling overflow dimensions or adding an additional independent overflow. This redundancy addresses blockage risk and compensates for debris accumulation. Standardization should also extend to collector heads, whose placement, elevation, and outlet sizing are often unregulated. Following SMACNA and NRCA detailing ensures overflow entry points remain below scupper elevation, reducing backwater intrusion. A harmonized specification for sizing, configuration, and positioning would significantly reduce failure potential and simplify compliance verification.

Mandatory Secondary Drainage in Reroofing

Many codes, including the CBC, exempt reroofing projects from secondary drainage requirements if "positive roof drainage" exists. In practice, this exemption leaves older roofs without adequate overflow protection during extreme rainfall or when primaries clog. Field case studies show reroofs without secondary systems are highly vulnerable, especially where insulation retrofits or slope changes create localized ponding.

Mandating secondary drains or scuppers in all reroofing projects, whether through direct piping, exterior scuppers, or conductor heads, would close this protection gap. Requirements should specify that new secondary drainage be independent from primary systems, discharge above grade in observable locations, and meet full sizing criteria for the primary design rainfall. Pairing such upgrades with roof replacement minimizes installation costs, as access and staging are already in place. This change would not only improve resilience for existing stock but also align reroofing projects with contemporary performance expectations for new construction.

Drainage Discharge Visibility Requirements

Overflow discharges that are hidden or discharged in inaccessible locations undermine their primary function as early-warning devices. The CPC requires secondary drainage to discharge "above grade, in a location observable by the building occupants or maintenance personnel" (**Fig. 8**). Field inspections reveal overflows terminating beside primary drains or behind parapets, leaving blockages undetected until ponding becomes hazardous. Codifying explicit placement standards, such as positioning overflows above doors, windows, or other high-visibility points, would standardize observability. Additional measures could include color-contrasting terminations, signage, and minimum sight-line requirements. These features would allow occupants and maintenance staff to identify overflow activation quickly, prompting timely intervention before structural load limits are exceeded. Clear observability provisions also facilitate routine inspection, making blockage detection a regular part of maintenance cycles rather than a reactive response to failure.

COST IMPLICATIONS AND PRACTICALITY

Upgrading drainage systems to meet enhanced capacity and visibility standards carries moderate up-front costs but can significantly reduce long-term risk and maintenance expenses. For example, increasing overflow piping from 3 in. to 4 in. (76 mm to 102 mm) cast iron may add roughly $150 per drain, yet it more than doubles discharge capacity, from approximately 92 gal./min to 192 gal./min (5.8 L/s to 12.1 L/s).

Similarly, replacing sump pits with tapered insulation systems can reduce installation complexity and labor while reducing debris accumulation issues that lead to blockages.

The incremental cost of enlarging scuppers or adding secondary overflows is minor compared to the structural repair costs from roof collapse or water ingress. As previously mentioned, bundling these upgrades with reroofing projects optimizes staging and access, further improving cost efficiency. From a practical standpoint, most enhancements involve well-established materials and detailing practices, requiring only modest adjustments to design, procurement, and inspection procedures.

FEASIBILITY FOR NEW AND EXISTING BUILDINGS

Implementation strategies differ between new builds, reroofs, and heritage properties. In new construction, coordination between architectural, structural, and plumbing disciplines can integrate larger drains, independent secondary systems, and visible discharge points without impacting structural efficiency. For reroofs, secondary drainage should be installed concurrently with membrane replacement, taking advantage of existing access and minimizing additional disruption.

Heritage buildings may require discreet solutions, such as exterior scuppers or conductor heads that align with historic facades while still meeting sizing and visibility requirements. Incentives such as permitting fee reductions or inspection schedule extensions can encourage early adoption. Inspection protocols should be updated to verify sizing, independence, and discharge placement, ensuring long-term compliance. In all cases, phased implementation with clear technical guidance will facilitate industry adaptation while addressing the growing risk from climate-intensified rainfall events.

CONCLUSIONS AND RECOMMENDATIONS

Severe rainfall events are exposing significant weaknesses in current roof drainage design standards, as existing codes often underestimate short-duration peak intensities, lack consistent requirements for overflow sizing, and allow exemptions that leave many buildings vulnerable. To address these deficiencies, reforms should harmonize design rainfall data across jurisdictions, standardize detailing for scuppers and collector heads, mandate secondary drainage for all reroofing projects, and codify visibility criteria so failures can be detected before they become catastrophic.

These measures must apply consistently to both new construction and existing buildings, with industry professionals driving up adoption by presenting empirical evidence of failures and demonstrating the cost-benefit advantages of proactive upgrades. The modest upfront investment in capacity and visibility improvements is far outweighed by the prevention of roof collapses, water damage, and safety hazards, and resilience must ultimately be embedded into everyday practice through coordinated action among designers, contractors, inspectors, and code officials to ensure drainage systems are robust enough to withstand the realities of modern climate extremes.

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Cracking the Case: Lessons from a Veneer Failure Investigation and Repair

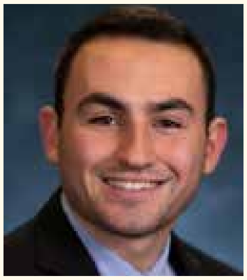
ABSTRACT

This presentation will discuss the background, failure investigation, and proposed repair strategies at a residential complex in Long Island, New York, following a brick masonry veneer wall collapse during a winter storm. The forensic assessment of the veneer condition—including examination of veneer anchorage, material and construction deficiencies, and environmental factors—to uncover the contributing causes of the failure will be highlighted. A summary of the nondestructive evaluation and testing used to evaluate the condition of the remaining brick veneer conditions, the development of the subsequent proposed repair strategies, and the methods that were undertaken to validate the feasibility and efficacy of the repairs will be presented. Participants will gain valuable insights into the practical aspects of conducting failure investigations, including the identification of inadequate construction practices and the application of effective repair solutions, as well as testing methods that can be incorporated into veneer assessments. Methods to assess and address structural vulnerabilities of veneer systems and enhance the durability of masonry veneer and wood-framed structures will be reviewed. Structural engineers, architects, and construction professionals interested in failure investigations and masonry veneer repair techniques will benefit from this presentation.

LEARNING OBJECTIVES

- Explain the purpose and methods of nondestructive evaluation (NDE) techniques, such as the use of metal detection for veneer anchorage location, as well as plumbness measurements, to understand how these assessments help in evaluating the structural integrity of masonry veneer walls.
- Identify the main factors that led to the wall collapse based on the data collected from the investigation and lab analysis.
- Recognize common construction deficiencies found in 1950s buildings, such as inadequate veneer anchorage spacing, use of undersized materials, and poor anchorage methods, and understand their impact on the building's structural performance.
- Describe effective repair strategies for masonry veneer walls, such as helical pin installations and brick replacement, informed by the findings from NDE surveys, testing, and exploratory openings.

SPEAKERS



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INTRODUCTION AND BACKGROUND

During a winter storm late in the evening on December 16, 2020, the east-facing brick masonry veneer wall of a two-story wood-framed residential building collapsed, damaging several parked cars (**Fig. 1**). This failure prompted an investigation to identify, as well as a multi-year repair campaign to address, the root causes of the collapse.

The subject of this case study is a complex of two-story multi-family residential buildings located in Long Island, New York. The majority of the 19 wood-framed structures were constructed in 1967 and are clad primarily with red brick veneer and vinyl siding. The typical wall assembly includes a single-wythe brick masonry veneer, a field-measured approximately 1½ in. (38 mm) cavity, a weather barrier, exterior gypsum sheathing, 2 × 4 (nominal) wood studs spaced at 16 in. (406 mm) on center, batt insulation, and an interior gypsum wall finish. While brick veneer is often perceived as aesthetically pleasing, durable, and low maintenance, its structural performance is highly sensitive to the quality and configuration of its anchorage system to the backup walls. Inadequate anchorage can significantly reduce the veneer's ability to resist out-of-plane loads, such as wind and seismic.[1]

Following the collapse, a broader investigation was launched to assess whether other multistory veneer walls at the property exhibited similar deficiencies and therefore lacked sufficient capacity to safely resist wind loads. The investigation involved visual observations, nondestructive evaluations (NDEs), and exploratory probe openings to identify potential

FIGURE 1. Subject building failure site.

FIGURE 2. Corrugated sheet metal veneer tie pulled from collapse debris.

FIGURE 3. Existing tie spacing measurement (32 in. [813 mm])

deficiencies and inform repair recommendations. Due to limited interior access and cost considerations, multiple repair options were proposed.

FAILURE INVESTIGATION

Weather data collected at the nearby Macarthur Airport indicated elevated wind speeds out of the east and northeast, with recorded gust speeds of up to 45 mph (72 km/h) (note, per *2020 New York State Building Code*, the service-level wind speed for this location is approximately 100 mph).[2,3] As the dominant recorded wind direction during the event was generally towards the wall face (that is, the windward wall), it is estimated that the wall experienced a positive wind pressure of up to approximately 4 lb/ft^2 (191 Pa) (based on a Components and Cladding wind pressure calculation per the American Society of Civil Engineers' ASCE 7-16, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*).[4] There were no reported signs of distress or visible warning indicators prior to the collapse.

While the weight of the brick veneer was observed to be supported on the concrete foundation, the veneer was anchored out of plane by corrugated sheet metal ties engaged in the brick masonry bed joints and fastened to the wood backup wall. Several conditions were identified that likely played a major role in the effectiveness and capacity of the anchorage assembly (**Fig. 2**).

Brick ties were observed to have been typically spaced at 32 in. (813 mm) horizontally and 18 in. to 24 in. (457 mm to 610 mm) vertically (**Fig. 3**). At one location, just above the bottom of the failure area, two rows of ties were spaced 44 in. (1,118 mm) apart vertically. The first tie was typically placed 30 in. (762 mm) from the building corner. These dimensions were in excess of the prescriptive requirements for corrugated brick veneer tie installation over wood frame backup construction per New York State Code provisions for buildings at the time of original construction (1951 *New York State Building Code* [NYSBC] and 1959 NYSBC) and exceed current code requirements (**Table 1**).[4,5,6] The observed tie spacing resulted in tributary areas ranging from approximately 2 to 4 times the maximum allowed at the time of original construction.

Existing corrugated sheet metal tie thicknesses were measured to vary between approximately 0.0174 in. (0.44 mm) and 0.0124 in. (0.31 mm), corresponding to 26 and 30 ga thicknesses, respectively. Compared to code minimum 22 ga ties, the thinner existing tie's compression capacity was significantly lower across the 1½ in. (38 mm) wall cavity. Veneer tie fasteners were observed to be located at varying excessive distances vertically above the 90-degree bend. Tie connection tensile strength is typically governed by nail pullout from the wood stud, while their stiffness is mostly a function of the magnitude of the tie bend eccentricity (with respect to the fastener) and tie thickness. Nailed tie connections not meeting minimum installation requirements exhibit reductions in strength (from using short roofing nails) and in stiffness (from using thinner-gauge ties and/or excessive bend eccentricities) of up to about 50% and 60%, respectively.[1]

TABLE 1. Prescriptive installation requirements for corrugated sheet metal ties. *(Note: NYSBC = New York State Building Code; ASCE = American Society of Civil Engineers; TMS = The Masonry Society)*[4,5,6,7]

Construction details	1951 NYSBC	2020 NYSBC (ASCE 7-16/ TMS 402)
Tie thickness (gauge) [min.]	22	22
Tie width (in.) [min.]	1¼ (32 mm)	⅞ (22 mm)
Typical wall area per tie (in.²) [max.]	300 (0.194 m²)	384 (0.248 m²)
Horizontal spacing (in.) [max.]	25 (635 mm)	32 (813 mm)
Vertical spacing (in.) [max.]	25 (635 mm)	25 (635 mm)
Fastener to wood backup [min.]	Not specified	8d common nail
Tie bend eccentricity (in.) [max.]	Not specified	½ (13 mm)
Air gap (in.) [min.]	Not specified	1 (25 mm)
Air gap (in.) [max.]	Not specified	Not specified*

*Although ASCE 7-16, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, and TMS 402/602-08, *Building Code Requirements and Specification for Masonry Structures*, do not specify a maximum air gap, Brick Industry Association Technical Notes recommend a 4½ in. (114 mm) maximum air gap before anchor design modifications are required.[8]

Corrosion was observed at the tie sections embedded in mortar joints. Laboratory total chloride analysis of the mortar, performed according to ASTM C1152, *Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete*, did not indicate the presence of any corrosion-advancing admixtures, suggesting that the section loss was likely due to exposure to moisture absorbed by the mortar.[9] This section loss reduced the capacity of the ties to support the masonry veneer out of plane, in both compression and tension. At one brick tie that was assessed via a high-powered microscope (100× magnification), section loss of approximately 46% was estimated. However, with limited eccentricity at the fastener, the withdrawal capacity of the nail from the substrate still governed the tension capacity of the tie connection. Although corrosion was observed to reduce the cross-sectional area of corrugated brick ties, section loss would have to be greater than 80% of the area to result in a lower failure load than the nail withdrawal capacity, assuming the eccentricity of the fastener was negligible.

Roofing nails measuring approximately 1¾ in. (44 mm) long—shorter and thinner than standard 8d box nails as required as a minimum by code—were observed at several corrugated sheet metal ties connected to the backup wall. With approximately ⅝ in. (16 mm) thick exterior gypsum sheathing, the 1¾ in. (44 mm) long roofing nails likely provided just about half of the necessary fastener penetration depth into the backup studs, which significantly reduces the available pullout capacity of the nails. Many nails were observed to have pulled out of the substrate after the collapse, indicating that this was likely the weak link for most veneer tie connection assemblies throughout the veneer wall as it toppled over.

As the wind direction recorded around the time of collapse was generally towards the wall (in other words, positive pressure), the load resulting from this wind pressure would have resulted in compressive forces acting on the tie connections. The cavity width between the veneer and substrate, in combination with the thin gauge of the corrugated metal ties and section loss due to corrosion, would have offered little compression resistance to resist the wall pressures resulting from wind. The inadequately supported single-wythe veneer likely became overstressed and hinged, causing excessive rotation and cracking in the brick veneer. At some locations, the corrugated metal ties that were originally engaged in the bed joint were observed to have failed by fracturing.

Based on typical material properties and installation conditions, and selecting the most severe tie spacing measured in the failure area, a veneer tie in the subject building may have supported a tributary area of nearly 8 ft² (0.74 m²). Using the 1951 NYSBC design wind load of 12 lb/ft² (575 Pa) for the first 15 ft (4.57 m) of wall height, this corresponds to an estimated tensile or compressive load of approximately 95 lb (423 N) on a single tie. Under current code demands, this load increases to approximately 198 lb (880 N) in the field of the wall and up to 244 lb (1,085 N) at building corners. These loads significantly exceed the estimated withdrawal capacity of a roofing nail embedded into a 2 × 4 wood stud through 19⁄32 in. (15 mm) oriented strand board sheathing, which is approximately 44 lb (196 N).[10] During the collapse event, wind gusts of 45 mph (72 km/h) would have imposed wind load reaction forces of approximately 36 lb (160 N) (Zone 4) and 46 lb (205 N) (Zone 5) acting on the ties (calculated per ASCE 7), representing 82% and 105% of the calculated fastener pullout capacity, respectively. It should be noted that this assessment assumes a uniform wind pressure load distribution throughout the veneer wall and the tie connections sharing the reaction forces equally based on their respective tributary areas; previous experimental testing of full-scale brick veneer wall panels over wood-framed backups, as well as analytical studies, have shown that wood-framed backup system flexibility can affect the resulting load demands acting on the brick ties (for example, stiffer backup wall areas, such as those at wall corners at the return walls and/or lines of horizontal framing at intermediate floors and at the roof level, will result in higher tie forces).

Ultimately, the collapse was likely driven by a combination of contributing factors: excessive tie spacing, undersized and corroded ties, improper fastener selection, and inadequate fastener embedment depth, resulting in insufficient out-of-plane support across the wall cavity. These deficiencies, compounded by windward loading during the storm, led to overstressing of the single-wythe brick masonry veneer—causing it to crack and hinge along the mortar bed joint—which then resulted in an unzipping effect as

FIGURE 4. Protovale Imp Wall-Tie Locator scan in progress.

ties were overloaded and failed in tension as the brick veneer toppled over. The absence of visible warning signs prior to the collapse further emphasized the vulnerability of masonry veneer systems when anchorage is compromised. These findings informed the scope of the subsequent evaluation of the remaining veneer walls across the property.

EVALUATION OF REMAINING PROPERTY

Following the collapse, a comprehensive evaluation was undertaken to determine whether similar anchorage deficiencies existed at the remaining 44 multistory brick veneer walls on the property. The investigation focused on identifying conditions known to contribute to veneer instability, including excessive tie spacing, undersized or corroded ties, improper fastener types, inadequate embedment, and signs of out-of-plane displacement. These conditions were targeted due to their direct role in the observed failure mechanism and their potential to compromise the structural integrity of other walls under wind or seismic loading. To assess these factors, nondestructive scanning and plumbness measurements were performed, supplemented by exploratory probe openings to verify tie presence and condition.

All multistory veneer walls on the property were scanned using a Protovale Imp Wall-Tie Locator (**Fig. 4**). Scans were conducted from the ground or a 6 ft (1.83 m) ladder. Plumbness measurements were recorded approximately 2 to 4 ft (0.61 to 1.22 m) from either building corner and at the center of each wall at approximately 8 ft (2.44 m) from the ground, using a 4 ft long digital level. At four representative locations, an articulating boom lift was used to scan the full wall height. These locations were selected based on accessibility and variation in brick masonry types.

Four exploratory probe openings were made to verify the findings of the wall tie locator scans and document the condition of the existing veneer anchorage (**Fig. 5**). These locations were selected based on the detected presence of ties at or near the opening location and included a wall facing each cardinal direction, two walls at original brick locations, and two walls at newer brick locations. Boroscope photography assisted in making observations within the cavity around the opening. Typical findings from both assessment methods included the following:

1. 24 ga corrugated galvanized metal veneer ties present at and around detected locations
2. Brick tie fasteners varying between 1¾ in. (44 mm) long roofing nails and 2¾ in. (70 mm) long 10d smooth-shank nails
3. Varying levels of corrosion at veneer ties and fasteners
4. Wall cavity consistently measured at approximately 1½ in. (38 mm)

Visual and NDE surveys, along with exploratory probe openings, revealed that veneer anchorage conditions at the remaining 44 walls were similar to or worse than those observed at the collapsed brick veneer wall location. Many walls exhibited signs of out-of-plane displacement, including cracked

FIGURE 5. Exploratory probe confirmation of wall tie locator scan.

FIGURE 6. Fractured tie in wall adjacent to an exploratory probe.

bricks and mortar joints, loose or displaced bricks, displacement away from the building foundation, and bulging—quantified through plumbness measurements. Plumbness measurements typically varied between 88 and 90 degrees from horizontal. Multiple readings were taken at each location to confirm accuracy and account for localized installation tolerances. Tie spacing was consistently found to exceed code requirements in either the horizontal or vertical direction, including excessive distance from building corners for the first installed tie.

The probe openings revealed that even where ties were detected, they were often undersized, fractured, not adequately fastened to the substrate, or not properly placed in the bed joint, and therefore were not effective in providing out-of-plane anchorage for the veneer (**Fig. 6**). Visibly compressed brick ties adjacent to probe opening locations were indicative of inadequate compression anchorage of the veneer wall. Wall ties were measured to be 24 ga thick at the two locations where measurement was possible, whereas both the current code and the code at the time or original construction prescribe that ties be at least 22 ga thick.

This investigation revealed that the multistory brick masonry veneer walls throughout the property lacked adequate lateral (out-of-plane) anchorage. Without proper anchorage, brick veneer does not have sufficient capacity to reliably resist out-of-plane loads. As all of the similarly constructed walls at the complex were observed to have similar or worse conditions than those documented at the failure site, they were all at risk of further damage or collapse at relatively low wind speeds and required immediate remediation.

REPAIRS

In order to remediate the multistory brick veneer walls at the subject property, the walls either needed to be removed and replaced with new brick veneer or other material that is adequately anchored to the backup framing, or the existing brick veneer anchorage needed to be supplemented. The following repair options were provided to the owner for consideration:

1. Use helical anchors installed through the brick masonry into the wood stud to pin the brick veneer anchorage to the backup wall. This option would be the most cost efficient; however, there were concerns regarding accurately locating the studs for the anchorage and penetrating the weather-resistive barrier.
2. Pin brick veneer with helical anchors similar to option 1 and clad with vinyl siding. This would have the benefit of providing additional weather resistance; however, it would be more expensive.
3. Remove and rebuild brick veneer with properly detailed and anchored assembly. This option would most closely match the original construction and would allow for improvements in the thermal enclosure and air/vapor barrier system.
4. Remove brick veneer and install vinyl siding. This would also allow for improvements to the thermal enclosure and air/vapor barrier system at a more efficient cost; however, it would alter the appearance of the buildings.

In order to validate the option to pin the brick masonry, testing was completed to verify that the studs could be reliably located to a precision required for the helical anchor installation, as well as to verify that the pinning program would not introduce risks of water infiltration to the interior. The proposed repair detail (**Fig. 7**) included helical anchors sloped upward into the cavity to allow gravity to work against any water that would infiltrate the brick veneer.

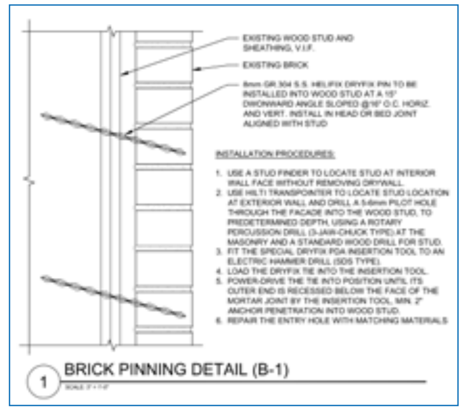

FIGURE 7. Brick masonry veneer pinning detail.

To facilitate a decision, a mock-up of helical tie pinning of the brick veneer was tested per ASTM C1601, *Standard Test Method for Field Determination of Water Penetration of Masonry Wall Surfaces* (**Fig. 8**).[11] The standard provides specific water flow rate and air pressure conditions to develop and maintain a sheet of water on the wall surface during

FIGURE 8. ASTM C1601, *Standard Test Method for Field Determination of Water Penetration of Masonry Wall Surfaces*, test setup.

FIGURE 9. Interior probe confirming helical tie engagement of wood stud.

FIGURE 10. Helical tie pull test set-up.

testing, simulating wind-driven rain. With a known quantity of water within the system, water penetration of the masonry wall surface over a duration can be quantified. Four helical ties were installed: two sealed with low-rise spray foam and two with no additional waterproofing. The test showed that neither configuration promoted water infiltration, even though the ties penetrated the weather barrier.

Once helical tie pinning was proven effective, the challenge became consistently locating studs without destructively penetrating several areas at the interior and exterior of each wall. A Hilti PX 10 Transpointer, which uses paired receivers to locate each other through wall assemblies, was used in conjunction with a wall stud locator to nondestructively identify stud locations. This method required access from the interior to lay out the stud locations, but ultimately it allowed consistent installation of helical ties from the exterior. Periodic inspections, including pull testing, verified proper installation and capacity to resist out-of-plane loads (**Fig. 9** and **10**).

CONCLUSIONS

The collapse of the brick masonry veneer wall at the subject residential complex revealed poor construction practices and systemic deficiencies in the original construction, specifically related to the anchorage of the brick masonry veneer to the wood-framed backup, resulting in diminished out-of-plane wall capacity to resist wind loads. The forensic investigation identified widespread issues, including excessive tie spacing, undersized and corroded ties, improper fastener use, and signs of out-of-plane displacement. These conditions compromised the structural integrity of the veneer and posed a risk of further failures under relatively low wind loads.

A broader evaluation of the remaining walls confirmed that similar or worse conditions existed throughout the property. Nondestructive testing, visual surveys, and exploratory probe openings provided critical data to inform the development of targeted repair strategies. Among the options considered, helical tie pinning offered a cost-effective solution, provided that installation into wood studs and sealing of weather barrier penetrations could be reliably achieved. Field testing based on ASTM standards demonstrated that properly installed helical ties did not promote water infiltration, and the use of nondestructive stud location tools enabled consistent and accurate installation.

Understanding the sensitivity of masonry veneer systems to anchorage deficiencies is critical to preventing sudden failures, particularly in buildings where original construction practices may not have met current performance standards. The tools, techniques, and repair methods applied in this case offer a practical framework for evaluating similar conditions and implementing durable, code-compliant solutions that preserve both safety and long-term performance.

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Waterproofing Shotcrete

ABSTRACT

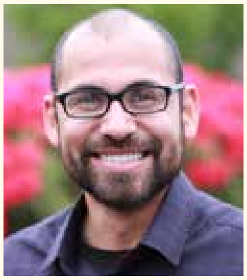
As the demands for accelerated construction schedules and cost-effective foundation systems continue to rise, the motivation to use shotcrete for foundation walls has increased as a compelling alternative to more traditional cast-in-place concrete. While the application of shotcrete offers notable advantages in terms of construction schedule and cost, it also introduces distinct challenges related to the installation and performance of below-grade waterproofing systems.

This presentation will examine the practical implications of using shotcrete for foundation walls, with a focus on below-grade waterproofing systems and details. The speakers will review case studies from recent projects to illustrate lessons learned and to discuss strategies to mitigate the potential weaknesses of shotcrete foundation walls. Learners will gain a deeper understanding of when and how shotcrete can be effectively integrated into enclosure design, and where it may introduce risks that require strategic forethought and mitigation.

LEARNING OBJECTIVES

- Identify the advantages and limitations of shotcrete as an alternative to traditional cast-in-place concrete for below-grade foundation walls.
- Evaluate the impacts of shotcrete application on the performance and installation of below-grade waterproofing systems.
- Analyze real-world case studies to understand common challenges and lessons learned from projects using shotcrete foundation walls.
- Develop strategies for effectively integrating shotcrete into building enclosure design while mitigating potential performance risks.

SPEAKERS



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INTRODUCTION

Picture a new urban building with a deep excavation and below-grade spaces; maybe it is a subterranean garage or back-of-house finished space. The waterproofing has been installed, the structure is complete, and the owner is about to occupy it. Then, during the first rainy season, water shows up in a corner of the basement. The client has paid for a waterproofing system with the expectation of a dry space, and so the project team gathers to investigate, but practical access to the exterior of the wall is impossible. Earlier in construction, the waterproofing was applied against a shoring wall substrate. A concrete foundation wall was then placed onto the installed waterproofing, concealing it. In this scenario, shotcrete was used to create the foundation wall. Regardless of the method of placing the foundation concrete, diagnosing the root cause is difficult, if not impossible. The fix (regardless of the root cause) often defaults to an interior-side corrective treatment to the offending crack or joint, such as chemical grout injections (**Fig. 1**) or routing and packing of the crack (**Fig. 2**). This scenario is all too familiar for enclosure consultants.

There are well-known common recurring risk factors for below-grade leaks. These include common sources such as shoring wall tieback blockouts, penetrations, cold joints, and terminations. One risk factor for water intrusion at below-grade foundations that the authors increasingly observe is the use of shotcrete as the foundation wall material. While shotcrete offers schedule and cost advantages over cast-in-place concrete, it also introduces distinct challenges that can impact waterproofing performance. Understanding the specific water intrusion risks that come with the use of shotcrete is crucial in avoiding pitfalls, or at a minimum, making the client aware of potential risks. In this paper, the authors will describe the distinct challenges that come with waterproofing shotcrete below-grade walls.

FIGURE 1. Left: photo of wall with leak along wall-to-floor interface. Right: view of existing foundation wall with chemical grout injection ports along wall-to-floor interface.

WHAT'S THE DIFFERENCE? SHOTCRETE VERSUS CAST-IN-PLACE CONCRETE

Although both shotcrete and conventional cast-in-place (CIP) concrete are made of cement, sand, aggregate, and water, the critical distinction between shotcrete and CIP concrete is how they are applied (**Fig 3**).

CIP concrete starts as a fluid mixture and requires formwork to contain it and hold it in the desired shape until the concrete cures into a solid. This formwork typically consists of framed and braced components constructed in advance of concrete placement. When concrete is placed, it is cast in lifts into the formwork and then consolidated—most commonly with vibration—to eliminate voids and

FIGURE 2. Left: view of leak in wall through vertical crack. Right: view of wall with routed and packed joints that are no longer leaking.

FIGURE 3. Example of shotcrete installation.

encourage uniform density. In this way, CIP concrete can be relatively homogenous once placed, vibrated, and cured. It is important to note that CIP concrete walls are most commonly placed into two-sided formwork, which is then removed after the concrete is cured, allowing a waterproofing installer to observe the concrete substrate prior to placing waterproofing.

For this paper, we are going to consider only CIP concrete that uses shoring as one side of its formwork.

When considering waterproofing applications, one of CIP concrete's advantages is its ability to conform closely to the shape of the formwork that it is placed in, filling in gaps around reinforcement and filling in voids caused by uneven substrates. The mixture proportions—water, aggregate, sand, cement, and admixtures—allow the concrete to flow and fill irregular spaces, which typically results in good continuous adhesion to any waterproofing membranes that might be pre-installed into that same formwork.

To perform as intended, CIP concrete relies on a properly engineered formwork system because uncured concrete is heavy and exerts significant lateral pressure. If the formwork is undersized, inadequately braced, or improperly installed, it can deform or fail under load—a condition known as a "blowout." As such, a lot of effort goes into designing, constructing, and inspecting formwork to safely contain the fluid concrete during placement and curing. Construction of this formwork takes time and adds cost.

Shotcrete, on the other hand, is placed by pneumatically projecting a cementitious mixture at high velocity onto a receiving surface (Fig. 3). The American Concrete Institute (ACI) provides guidance on requirements for materials, equipment, placement procedures, curing, and testing. Shotcrete is typically installed by a trained ACI-certified nozzle operator who is responsible for maintaining proper nozzle distance, angle, and application technique in accordance with ACI guidelines. These factors directly affect overall quality, including consolidation and rebound, two aspects that can impact waterproofing systems.

In application, shotcrete is intentionally formulated with a lower water-to-cement ratio than CIP concrete so that it can adhere to vertical surfaces without sloughing. This results in a relatively stiff mix that "sticks" upon impact, but the high-velocity placement also introduces important construction considerations. For example, lifts must be placed in controlled thicknesses to prevent sloughing and ensure proper curing between layers. Steel rebar reinforcing congestion, poorly prepared substrates, or improperly sequenced lifts can create voids, shadowing, or cold joints if not closely managed by the nozzle operator and inspection team—these types of voids are much less common with CIP concrete because of how CIP concrete is placed and consolidated.

It is important to note that shotcrete is almost exclusively used for below-grade foundation walls that are tight to a project property line, a condition sometimes referred to as "property line" construction. The use of shoring during this type of excavation provides a one-sided form, which can support the forces of a shotcrete foundation wall application. CIP concrete, on the other hand, would require the construction of a sturdy second formwork, which would add cost and time (**Fig. 4**).

Waterproofing membranes applied to walls in property line construction are typically installed in what is known as a "blindside" application. This term refers to the fact that the membrane is first installed and then concealed by the foundation wall (blind to the observer).

Our discussion in the following sections focuses on the relationship of common waterproofing technologies with shotcrete in a blindside property line application.

BELOW-GRADE WATERPROOFING TECHNOLOGIES

When considering below-grade waterproofing, it is helpful to remember that the wall material and the waterproofing system are inseparably linked. Designers, therefore, must understand not only the general strengths and weaknesses of each waterproofing approach but also how those approaches respond under

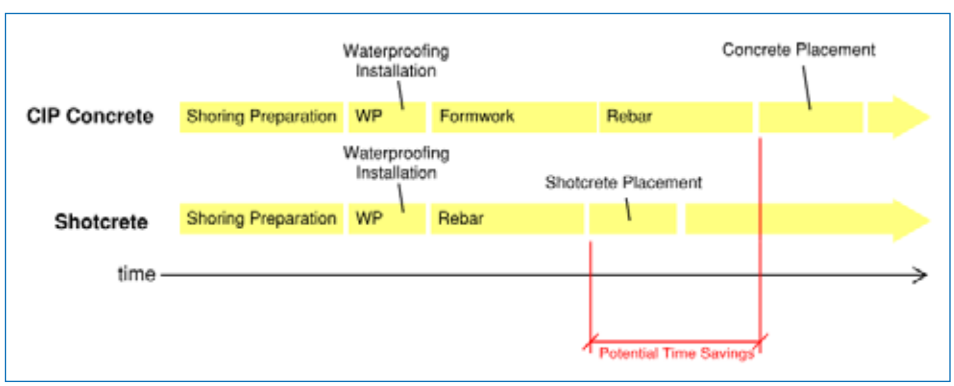

FIGURE 4. Comparative timeline of cast-in-place (CIP) concrete versus shotcrete from application to removal of formwork.

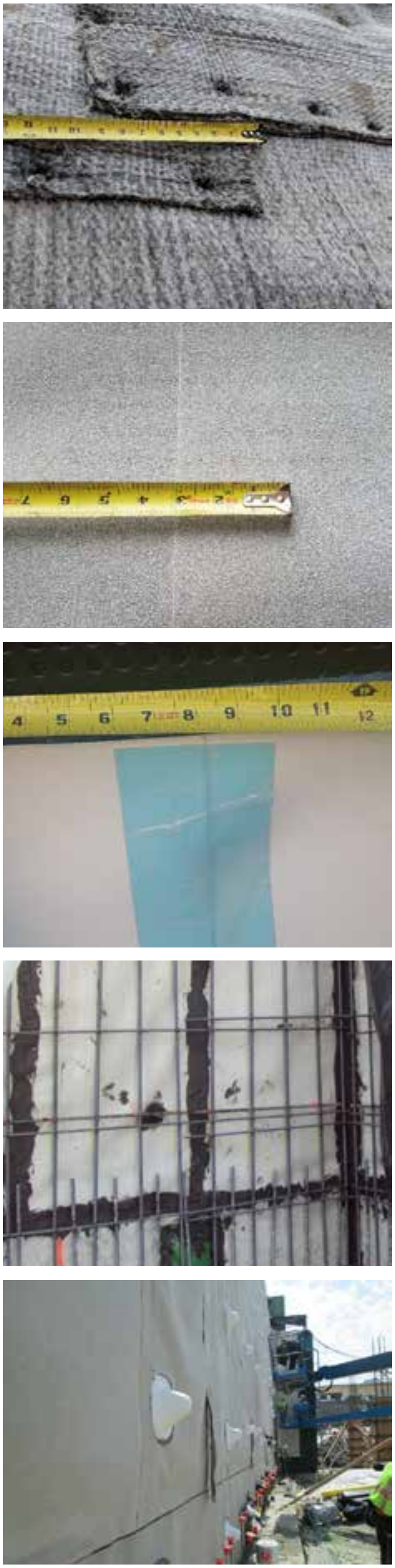

FIGURE 5. Laps in different types of sheet-applied waterproofing.

the specific conditions created by the use of shotcrete.

Roll-Applied Sheet Waterproofing

Roll-applied sheets constitute the largest class of waterproofing technology available on the market. These include manufactured sheets such as high-density polyethylene (HDPE), modified bitumen, self-adhesive-backed plastic, or composite-lined sheets. For the purpose of this paper, we will discuss only those sheet membranes that are typically intended for use with a blindside application. So, this would exclude self-adhered sheets and torch-applied sheets, which are more commonly used on backfill applications.

As a general note, roll-applied sheets are factory made, which provides a high degree of consistency and quality control within the field of membranes, but they are also highly dependent on having a smooth, flat, and regular substrate. Their seams must be carefully lapped and detailed, with different products having different lap treatments, from simple overlaps to taped laps to fully welded laps.

Lap treatment is of particular importance. Even though both ACI and membrane manufacturers provide guidance on how to apply shotcrete at laps, if not fully placed and secured beforehand, the force of application can lift laps or compromise seams (**Fig. 5**).

Bentonite-infused composite sheets are a subclass of roll-applied sheet waterproofing, but the authors feel that it is important to separate these out and discuss them separately given their relatively widespread use and given their unique susceptibility to shotcrete due to their need for confinement. Bentonite-clay-based membranes are manufactured panels that contain bentonite granules (**Fig 6**), which swell upon contact with water. These systems work effectively when they are confined under constant compression, as the bentonite clay will react with water to swell, filling small cracks and voids in the foundation wall and becoming impermeable to further water migration. In practice, this type of waterproofing can be compromised if large voids are created adjacent to the waterproofing membrane, which prevents the bentonite from being fully compressed. This reduces the system's effectiveness since bentonite cannot swell enough to fill the large voids.

FIGURE 6. Bentonite sheet examples.

Membrane-Forming Fluid-Applied Waterproofing

Fluid-applied membranes that, in the authors' experience, are most used in blindside applications for below-grade foundation walls are typically cold-fluid-applied materials that cure to form a monolithic membrane (**Fig. 7**). Hot-applied membranes can also be used at below-grade foundation walls, but they are not typically used in blindside waterproofing applications.

From a waterproofing standpoint, the main strength in using a membrane-forming fluid-applied waterproofing material is that it typically forms a monolithic material without laps.

Conversely, because fluid-applied membranes are field formed, they can be inconsistent in thickness and/or cure, making their performance characteristics more variable and potentially susceptible to impact forces from shotcrete application.

Integral Concrete Admixtures

Another option for waterproofing foundation walls is the use of an admixture that reduces the permeability of the concrete itself. This technology can work in one of two ways, either by making the concrete itself hydrophobic (and thereby resisting the passage of water through cracks up to a certain size) or by making the concrete hydrophilic and reactive (and creating crystals anywhere water passes through

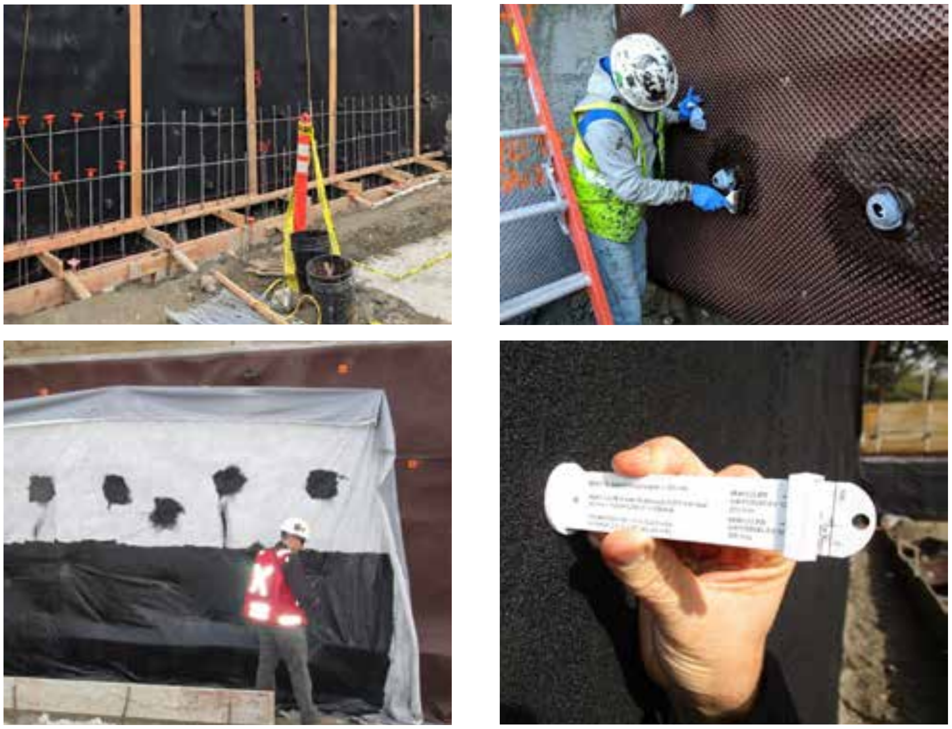

FIGURE 7. Top: fluid-applied-applied waterproofing on drain mat. Bottom: fluid-applied below-grade waterproofing applied onto a carrier sheet.

FIGURE 8. Crystal residue on a shotcrete wall (crystalline admixture).

cracks, thereby closing off the water intrusion path (**Fig 8**).

Hydrophobic admixture options are typically simply called hydrophobic, while hydrophilic options are often referred to as crystalline, alluding to the crystals that form to resist water intrusion.

These systems can be quite effective in CIP concrete walls, but in shotcrete applications the dense placement of reinforcing can create voids that can diminish the intended performance. These admixtures also require careful crack control and often additional reinforcing, which must be weighed against the potential drawbacks in shotcrete construction.

Composite Systems

Hybrid or composite systems represent another variation. These intentionally combine parts and pieces from different classes, such as sheet membranes supplemented with applications of fluid-applied waterproofing (**Fig 9**). These systems are appealing because they can take advantage of the inherent strengths of each technology: the factory consistency and puncture resistance of sheets, together with the continuity and flexibility of a fluid-applied layer at joints, laps, or irregular transitions.

As these systems illustrate, there is no single approach that resolves every below-grade condition. Each carries its own vulnerabilities, and those vulnerabilities are only magnified when the wall material is applied by shotcrete rather than conventionally placed. With that in mind, the next section explores the distinct challenges that arise when these membranes and admixtures meet the realities of shotcrete application.

WATERPROOFING CHALLENGES UNIQUE TO SHOTCRETE

When shifting from describing waterproofing materials to evaluating how they perform under the realities of shotcrete placement, the challenges come into sharper focus. What looks promising on paper or in the lab can behave very differently when subjected to the velocity, rebound, and access limitations inherent to shotcrete.

Ultimately, the two primary shotcrete-specific challenges that the authors face when waterproofing subterranean structures are issues associated with the force of shotcrete application and the tendency of shotcrete-applied concrete to contain voids and issues with consolidation.

Force of Application

The shotcrete mix easily reaches speeds of up to 90 mph (145 km/h) when leaving the shotcrete nozzle.[1] The high velocity of shotcrete placement and associated kinetic energy create forces that are very different from CIP vibration. These forces can dislodge laps in sheet membranes, disturb waterstops, or even puncture fluid-applied systems. Waterstops are typically applied at cold joints within shotcrete walls, such as end-of-day terminations within the field of the wall and at joints between floors and walls.

To mitigate this, it is important to fasten laps and mechanically secure waterstops prior to placement. Even though waterproofing manufacturers often publish

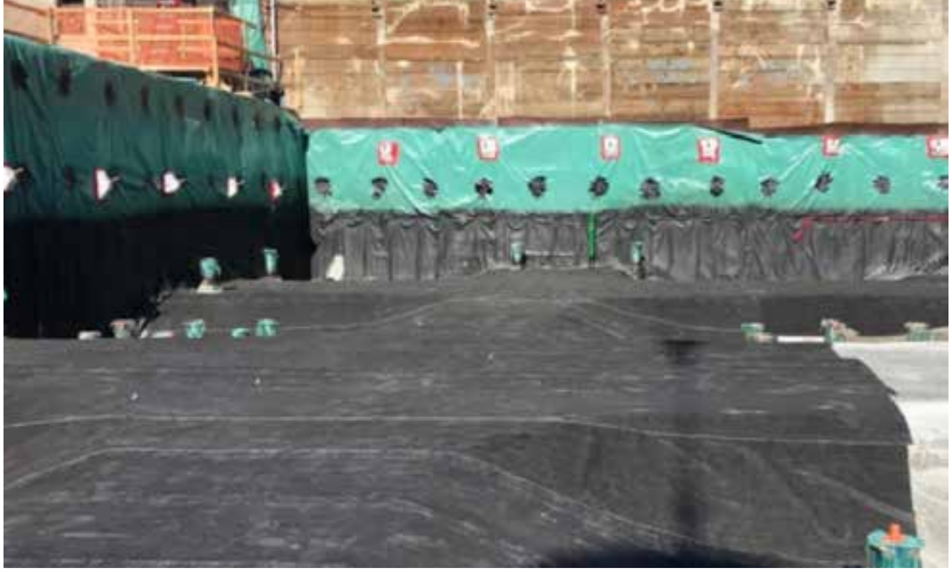

FIGURE 9. Example of hybrid approach to below-grade waterproofing, with a welded carrier sheet and an application of a cold fluid-applied spray. *Photo courtesy of EPRO Services Inc.*

FIGURE 10. Photos of shotcrete wall with one-sided form, where the usually concealed side of the shotcrete was exposed when the form was removed, uncovering typical "shadowing." *Photos courtesy of AVM Industries.*

FIGURE 11. Photo showing shotcrete used at the field of the foundation wall, with the columns that contain congested rebar left out to receive cast-in-place concrete.

shotcrete-specific installation guidelines, coordination with the shotcrete crew is just as important as following the specification.

Shadowing and Voids

Foundation walls are often highly reinforced, especially at pilasters, corners, and interfaces with adjacent structural components such as floor slabs. Dense rebar at these conditions often leads to "shadowing." The shotcrete stream cannot properly consolidate behind the bars, leaving voids between the reinforcement and waterproofing (**Fig. 10**). These voids frequently become continuous leakage pathways once hydrostatic pressure builds.

This can be particularly problematic for the bentonite class of waterproofing sheets, which rely on confinement of the bentonite clay to properly function. It is also problematic for admixtures where the gaps are too big for either hydrophobic or crystalline types to span or fill.

Where reinforcing is congested, design teams should consider either increasing spacing between reinforcements or even switching to CIP at particularly vulnerable details. In practice, this hybrid approach has been an effective approach (**Fig. 11**).

Quality Control and Sequencing

There are several standards, including the American Concrete Institute's (ACI's) ACI 506R-16, *Guide to Shotcrete*, and ASTM International's ASTM C1140, *Standard Practice for Preparing and Testing Shotcrete Panels*, which set the baseline for acceptable shotcrete practices across the industry.[2,3] In addition to these concrete industry standards, waterproofing manufacturers often publish product-specific guidance when their membranes are used with shotcrete foundation walls. These recommendations often go beyond generic concrete standards, addressing how the velocity and impact of shotcrete can affect waterproofing integrity.

Common themes across manufacturer-specific guidelines include paying particular attention to nozzle angle and distance during placement, as manufacturers acknowledge that the velocity of shotcrete can displace laps or damage seams if directed improperly (**Fig. 12**).

Manufacturers also caution against voids and shadowing in congested reinforcement zones, which they acknowledge can compromise adhesion and continuity. Several guidelines explicitly require preconstruction mock-ups to validate placement practices, including coring of the mock-up to validate shotcrete

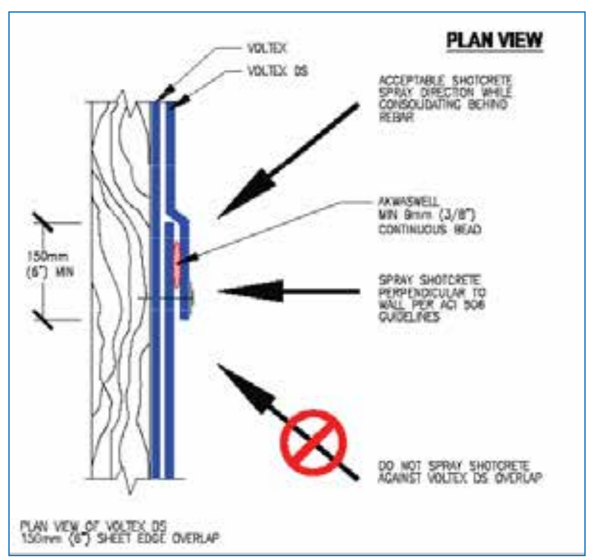

FIGURE 12. Guideline for shotcrete application from one manufacturer indicating recommendations for shotcrete placement at laps. *Source: CETCO's* VOLTEX DS Waterproofing Membrane: Product Manual for Shotcrete Foundation Walls.

consolidation. Even with cores, the authors of this paper acknowledge that once concrete is in place, there is no way to visually inspect the continuity and nature of a waterproofing membrane placement.

Another recurring requirement is that terminations, penetrations, and transitions be detailed with added protection prior to shotcrete application. Tiebacks, pipe penetrations, and cold joints are typically called out as high-risk interfaces requiring waterstops, boots, or additional sealants. In some cases, manufacturers recommend or require injection ports or supplementary grout systems to address post-placement leakage where full consolidation of shotcrete cannot be assured.

Protecting the membrane from shotcrete overspray is also important, as overspray can inhibit the ability for a membrane to adhere to the next section of a shotcrete wall.

The consistent message across these documents is that, although shotcrete is an accepted structural method, its high-velocity application introduces unique risks not encountered with CIP concrete. Industry standards provide the baseline for quality of work, but waterproofing performance depends equally on following the membrane manufacturer's shotcrete-specific requirements. Effective quality control therefore requires a hybrid approach—grounded in ACI and ASTM but attentive to the additional detailing and placement protocols outlined in the specific manufacturer product literature.

STRATEGIES TO MITIGATE RISKS

Having examined the types of challenges and risks that often arise when shotcrete is used in below-grade foundation walls, the following are examples of measures that can help mitigate these risks. These strategies reflect lessons learned from numerous projects where waterproofing integrity was either compromised or successfully preserved. They are intended to guide project teams in moving from a reactive approach—dealing with leaks after they appear—to a proactive one that anticipates challenges during design and construction and responds accordingly.

- **Early Team Discussions:** In the authors' experience, the best approach to dealing with potential risks and challenges is to highlight them early in the process to the right stakeholders and decision makers. Raise the implications of shotcrete during early design to the project owner, contractor, and structural engineer for input. This allows decision makers to consider the risks and potential challenges associated with shotcrete application and factor these into the cost savings analysis when considering a move from CIP concrete to shotcrete.
- **Waterproofing Selection:** Pay special attention to the waterproofing type, with the aim of having the waterproofing material and system respond to the project conditions. For shotcrete, the authors find that it is important to prioritize systems that are more forgiving as it pertains to the known challenges with shotcrete application, such as voids, incomplete consolidation, and ability to withstand projectiles. If possible, a system with a demonstrated track record of successful use with shotcrete is recommended.
- **Critical Details:** Pay special attention to pilasters, corners, and cold joints. Consider hybrid approaches with the team, such as the option of using a CIP approach in zones with congested rebar and using shotcrete in easier-to-access field conditions.
- **Installer Coordination:** Once a waterproofing manufacturer and installer are selected, it is valuable to bring these parties together with the design, construction, and ownership teams to discuss the project goals and known challenges associated with shotcrete. This would be the time to discuss any manufacturer-specific requirements with the shotcrete installer. More fundamental to this, it is also important to select subcontractors who are experienced in placing shotcrete onto preinstalled waterproofing and who have demonstrated successful installation. The shotcrete contractor should be required to have trained and certified nozzle operators and support crew.
- **Mock-Ups and Testing:** Conduct preconstruction mock-ups to validate detailing and identify constructability challenges before full-scale implementation. Testing of the mock-up is recommended to validate shotcrete consolidation.
- **Contingency Planning:** Despite best efforts, the authors find that sometimes it is just as important to recognize that even with best practices, some leakage may occur. To that end, the authors typically recommend planning for chemical grouting or other remedial measures as a budgeted contingency. In particularly challenging conditions, it is sometimes easiest to assume that injections will be needed and to provide for post-application injectable tube water stops.

These strategies are most effective when considered as part of a holistic approach. Early planning, careful material selection, and robust field oversight work best in combination, not isolation. Together they provide the framework for reducing the risk of water intrusion in shotcrete foundation walls.

CONCLUSION

Shotcrete is increasingly being used for below-grade foundation walls because it offers compelling benefits in schedule and cost. It also allows for zero lot line construction. However, these benefits come with a unique set of waterproofing challenges that should not be underestimated. By understanding the mechanisms of failure—voids, cold joints, displaced membranes—and by planning proactively, project teams can mitigate risk and deliver watertight foundations.

The authors have seen both failures and successes with shotcrete. The lesson is clear: shotcrete can work, but only with foresight, coordination, and respect for its limitations.

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Condensation: Refrigerated Processing and Cold Storage Operations—Complex Problems for Industrial Roofing Projects

ABSTRACT

Industrial roofing projects often come with unique challenges and unexpected obstacles that demand practical, innovative solutions. This presentation will explore case studies demonstrating the three main contributors (infiltration, conductance, and saturation) to condensation in refrigerated processing and cold storage operations, prevention and mitigation strategies, and multidisciplinary coordination for long-term performance. In these specialized environments, where temperature differentials are extreme, a well-installed air barrier system is essential to prevent moisture intrusion and potential roof system failures. Air barriers also play a critical role in maintaining temperature control, energy efficiency, and overall performance of the interior refrigerated environment. A discussion of how these systems must be designed to handle the unique challenges posed by rooftop penetrations and terminations, continuous low temperatures, high humidity differentials, and the need for airtight enclosures will take place. Practical insights will be shared on best practices for selecting materials that resist thermal bridging and moisture, as well as techniques for proper installation to ensure long-term roof system performance and durability. For roofing and building enclosure professionals, this session will provide a deeper technical perspective on how to optimize roofing and air barrier performance in refrigerated processing and cold storage facilities and how to ensure these systems exceed client expectations in terms of efficiency, reliability, and long-term performance.

LEARNING OBJECTIVES

- Identify three primary contributors to condensation in refrigerated process/cold storage facilities.
- Define specific areas of concern for condensation in industrial roofing projects.
- Discuss strategies for mitigating and preventing condensation.
- Evaluate best practices for long-term performance of roofing systems in refrigerated/cold storage facilities.

SPEAKERS

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John Sutton attended Ball State University's College of Architecture and Planning and graduated with a bachelor of science in Environmental Design. Through his education and early professional employment, he has worked at architectural, landscape, civil engineering, land planning, and surveying firms. Additionally, he worked for 7 years at Firestone Building Products as a quality assurance specialist, special projects coordinator, and technical coordinator. He then transitioned to a roofing specialist at IBP Inc., where he managed capital roofing replacement projects and provided technical support to the organization. After Tyson Foods purchased IBP, he continued in this role, expanding into the role of a thermal and moisture specialist and lead manager of enclosure asset management. He has been involved in the design and construction industry since 1984.

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Condensation, along with the typical resulting active water or ice accumulation, food safety concerns, and steel corrosion in industrial facilities with refrigerated and cold storage operations, is often linked to roof system performance. Based on a study of leaks, roof and wall repairs, and roof system replacements over the span of 30 years in the industrial food manufacturing industry, condensation was identified as the primary cause for many of the reported leaks and system failures, particularly when the roof system was a component of the refrigerated enclosure.

Refrigerated processing and cold storage areas are conditioned to maintain an internal design temperature below 50°F (10 °C) with some areas designed as low as -50°F (-45 °C). Condensation forms when moisture-laden air contacts a building material with a surface temperature at or below the dew point temperature. There are three main contributors to condensation in these cold interior environments: infiltration, conductance, and saturation. Each source of condensation is distinctly different.

CONDENSATION CAUSED BY INFILTRATION

Infiltration occurs when enclosure transitions are not fully sealed against air and vapor movement. Through vapor drive, warm, moist air traveling through roof-deck-to-wall transitions or roof penetrations from the outside or adjacent environment mixes with the refrigerated cold interior air, causing condensation on steel surfaces as the temperature equalizes (or lowers) to the dew point. While vapor drive for most climate zones and occupancy types typically occurs from the inside to the outside, it is the opposite for refrigerated buildings. Infiltration in cold storage environments is exacerbated by significant air pressurization differentials. The mechanical cooling needed to maintain the interior temperatures often creates a negative pressure environment within the cooler or freezer, which draws air through gaps in the enclosure. Additionally, because cold air is heavier than warm air, the air movement within the refrigerated space, from the ceiling toward the floor, contributes to the pull of air through any gaps in the enclosure. For most freezers, and especially those in the southern half of the United States, the outside air is warmer than the inside air of the freezer. Because the cold air within the freezer space contains significantly less moisture than the outside air, "the cold air within the building wants to wring the water out of the air entering from the outside," leading to active water and ice accumulation.[1]

Condensation from infiltration is most often observed as ice or icicles forming along the wall-to-deck transition at the interior or in the flutes of a steel roof deck within the roof system, as seen in **Fig. 1**. The condensation from infiltration presents on the cold side of the assembly as the air is drawn from warm to cold and moisture is released.

Infiltration can also be caused by the typical operation of the cold storage area. Mass infiltration occurs at openings between cooled spaces and semi-cooled or unconditioned spaces. Even when interior or exterior doors are programmed or electronically controlled to automatically open and close for forklift or pedestrian traffic, the small bursts of cold-to-warm air caused during the use of the doorway contribute to condensation on steel surfaces directly inside the doorway, as evidenced in the food manufacturing plant shown in **Fig. 2**. Mass infiltration is exacerbated when the operational controls are overridden to allow the door to be kept open for prolonged periods of time.

FIGURE 1. Ice accumulation from roof-deck-to-wall transition.

FIGURE 2. Severe deck corrosion directly adjacent to interior doorway from warm to cold area.

The infiltration of warm, moist air causes strain on the mechanical cooling equipment and can lead to microbial growth, production downtime, and even product loss. Infiltration, whether through poorly sealed transitions or mass infiltration, was identified as the most likely source of condensation in most of the system failures.

FIGURE 3. Ice accumulation on the steel decking and steel framing members caused by saturation.

CONDENSATION CAUSED BY CONDUCTANCE

Conductance is another source of condensation in industrial refrigerated spaces. Conductance will occur when a building material, such as a steel structural member, passes continuously from a cold conditioned area through a wall or roof deck into a warm or unconditioned area. Where the cooled material encounters the warmer air outside of the refrigerated area, condensation will occur whenever the temperature at the surface of the material falls below the dew point. This often occurs at structural steel beams, roof joists, and insulated metal panel (IMP) skins that travel continuously through both a cold and a warm space. Steel all-thread suspended ceiling panel support rods above freezer areas are another location where condensation and resulting corrosion often occur, where the support rod travels from the cold freezer into the warm interstitial space.

Conductance is often thought to be the cause of many enclosure system failures; however, it actually occurs far less frequently. Condensation from conductance is typically localized and relatively easy to distinguish. Condensation from conductance will always be seen on the warm side.

CONDENSATION CAUSED BY SATURATION

The third source of condensation in industrial refrigerated spaces is saturation, where the dew point in an area is close to the interior temperature. Condensation due to saturation is observed with widespread surface condensation or ice presenting on walls, ceilings, and/or the roof structure, as seen in the cold storage facility shown in **Fig. 3**. Saturation typically occurs for short periods during maintenance activities or when mechanical systems malfunction. Seasonal changes in the outdoor relative humidity may also create conditions that contribute to saturation.

Saturation provides the most obvious recognizable signs of condensation within the interior environment with widespread moisture or ice; however, it is the least frequent cause of enclosure system failure. Saturation is most often able to be controlled by mechanical or operational procedures.

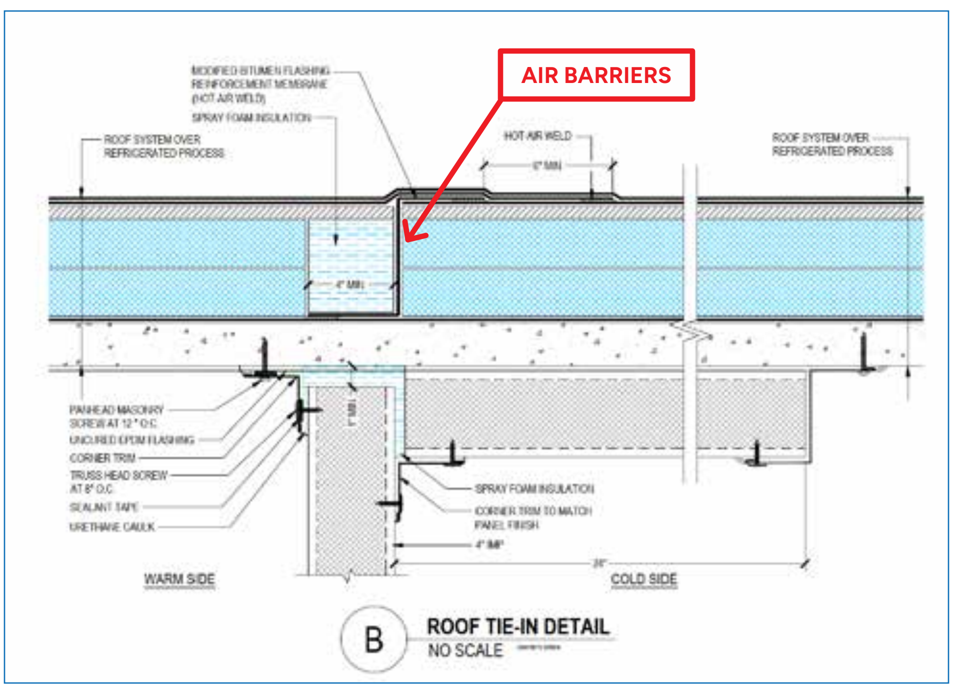

FIGURE 4. Cold-to-warm transition in occupancy with air seal in roof above.

DISCUSSION

With air infiltration identified as the most common cause of reported leaks to the interior and system failure in industrial refrigerated spaces, the discussion below will focus on methods and materials for prevention and mitigation of infiltration when the roof system is a component of the refrigerated space in both new construction and reroofing situations. It should be noted that there are many situations where facility operators will report condensation as a "roof leak" that often has nothing to do with the roof.

Air barrier seals play a critical role in maintaining temperature control, energy efficiency, and overall performance in refrigerated facilities. In these specialized environments, where temperature differentials are extreme, a well-installed air barrier system between conditioned and unconditioned components (occupancies or spaces) is essential to prevent moisture intrusion and potential system failures. More moisture is transported via air movement than by diffusion or any other means; simply stopping the air movement will stop moisture migration and the resulting condensation.

Close attention must be given to roof-to-wall transitions, cold-to-warm area divider walls (changes in designed temperature/occupancy below, as shown in **Fig. 4**, for example), mechanical equipment penetrations, and parapet walls. The air barrier material must be installed to prevent air movement from vapor drive and/or operational pressures. Even though the condensation from infiltration presents at the cold side, the optimal (and arguably the only) placement for the air barrier seal is on the warm side at the location of the pressure boundary, or the point of infiltration. Typically, in a roof system over refrigerated space, this boundary is at the surface of the

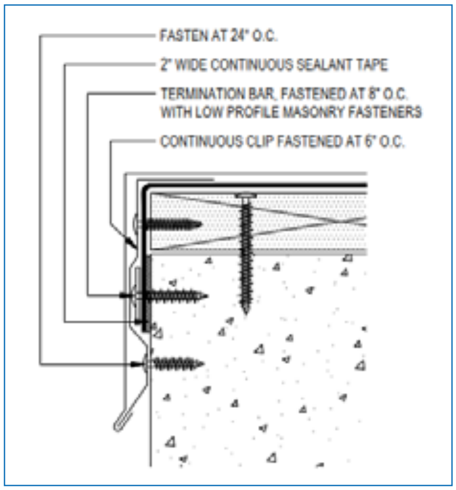

FIGURE 5. Sealed termination of roof membrane at exterior face of concrete parapet wall.

roof membrane to the adjacent walls or penetrations and/or at the termination of the roof membrane at the exterior wall, as shown in **Fig. 5**.

Improper placement will create a host of other problems. The air barrier seal must both prevent outside air from entering the refrigerated interior and keep interior cold air from being drawn through the roof or wall assembly. The goal is to prevent warm air infiltration and the moisture that it introduces. The temperature of the roof and wall components can be warm or cold, above or below the dew point; as long as no moisture is introduced, no condensation will form.[1]

The material used to create the air barrier seal must have an appropriate permeability rating for air (less than 0.02 L/(s*m^2) in accordance with ASTM E2178, *Standard Test Method for Determining Air Leakage Rate and Calculation of Air Permeance of Building Materials*) and vapor (Class II with less than 1.0 perms in accordance with ASTM E96, *Standard Test Methods for Water Vapor Transmission of Materials*), be continuous over the joint or transition, and be able to withstand normal anticipated building movement, temperature, and forces. The material must be durable, be flexible, and have the ability to conform to various shapes, components, and profiles. In truth, nearly every roof membrane can provide an effective air seal if detailed properly. Modified bitumen and single-ply membranes, such as ethylene propylene diene terpolymer, polyvinyl chloride, and ketone ethylene ester, installed in full adhesive, can provide long-lasting service. The edges of the air barrier membrane must be positively terminated to ensure it does not slip or become loose over time. Self-adhered membranes and reinforced liquid flashing systems may also provide successful performance, depending on the in-service temperature performance range provided by the manufacturer.

For many refrigerated spaces, the exterior wall systems include IMPs, masonry, or cast-in-place concrete. IMPs have tongue-and-groove side-lap vertical joints, as well as typically a fluted panel profile. The corner and vertical side-lap joints and flutes of the IMPs create chimneys for air transfer if not properly sealed. Continuity of the air seal is not only critical at the roof but also must work in conjunction with air seals at wall penetrations and vertical building corners.

Roof decking for many refrigerated spaces includes cold-formed steel roof decking, precast concrete panels, and IMPs. When the exterior wall extends beyond the roof deck or terminates flush with the top of the roof deck, the boundary between the cool interior and warm exterior is better defined and allows for the easiest air seal between the roof deck and the exterior wall (**Fig. 6**).

One of the challenges with many industrial facilities is renovating and changing the use of spaces to adapt to the ever-changing market. Making changes to the interior design temperature within an industrial refrigerated facility can have a catastrophic impact on the overall performance of the roof and wall systems. Changing the occupancy from a freezer to a blast freezer, for example, can lower the designed interior temperature by as much as 30°F. Without modification to the thermal insulation systems and a functional air seal, this occupancy change

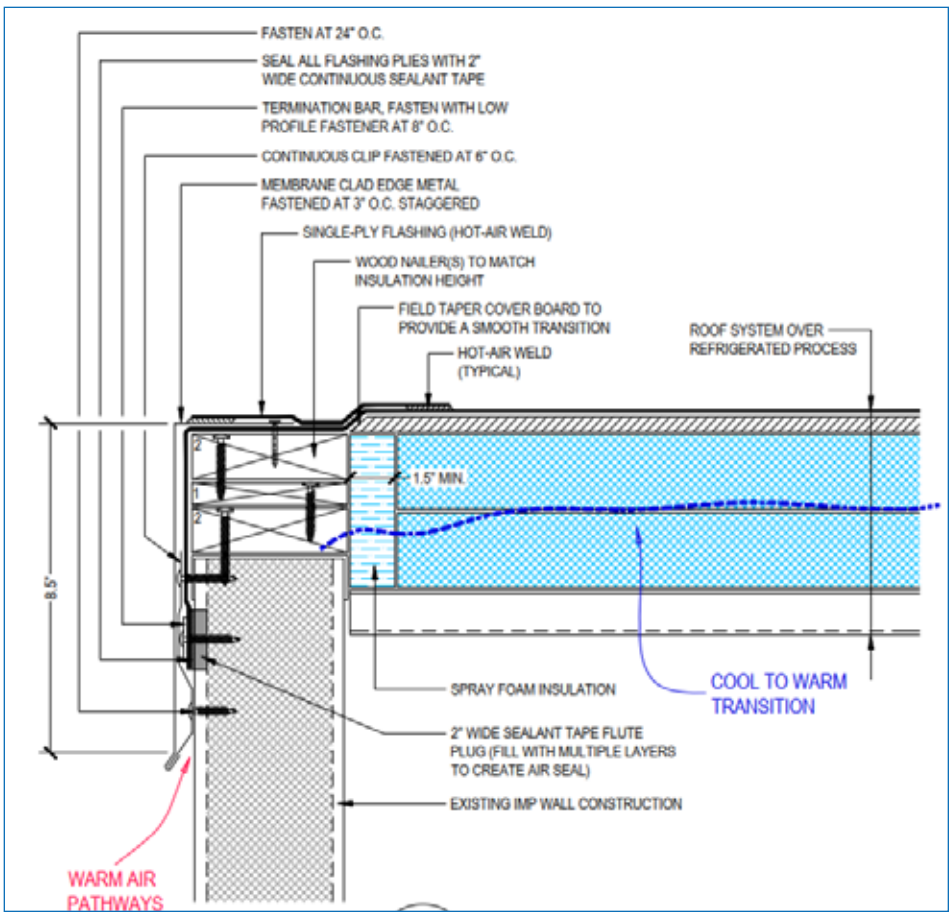

FIGURE 6. Sealed termination of roof membrane at exterior wall face and clear boundary between cool interior and warm exterior; note sealant tape within flutes of insulated metal panel to create air seal.

FIGURE 7. Warm air infiltration noted at roof to wall termination within a cold storage facility.

could easily result in condensation caused by infiltration and saturation.

Multi-wythe masonry walls with a traditional air gap present one of the toughest challenges in renovation and reroofing applications. In many older buildings, the interior wythe of the masonry wall was used to support the steel roof deck. This creates a very difficult condition to seal for a refrigerated interior space. The warm outside air, drawn through the weeps or vents of the masonry wall through vapor drive, travels up the chimneys inside the masonry wall created by the air gap between wythes and the integral holes of the masonry units and funnels into the ends of the steel decking (**Fig. 7**), where it condenses on the top surface of the steel deck and infiltrates through the flutes of the deck to the interior (**Fig. 8**). This condensation occurs cyclically whenever the temperatures outside the refrigerated space are greater than the temperatures inside, which for many refrigerated facilities is the majority of the year. If left unchecked, the repeated condensation

FIGURE 9. Roof blow-off caused by severe deterioration of the steel decking along brick parapet wall.

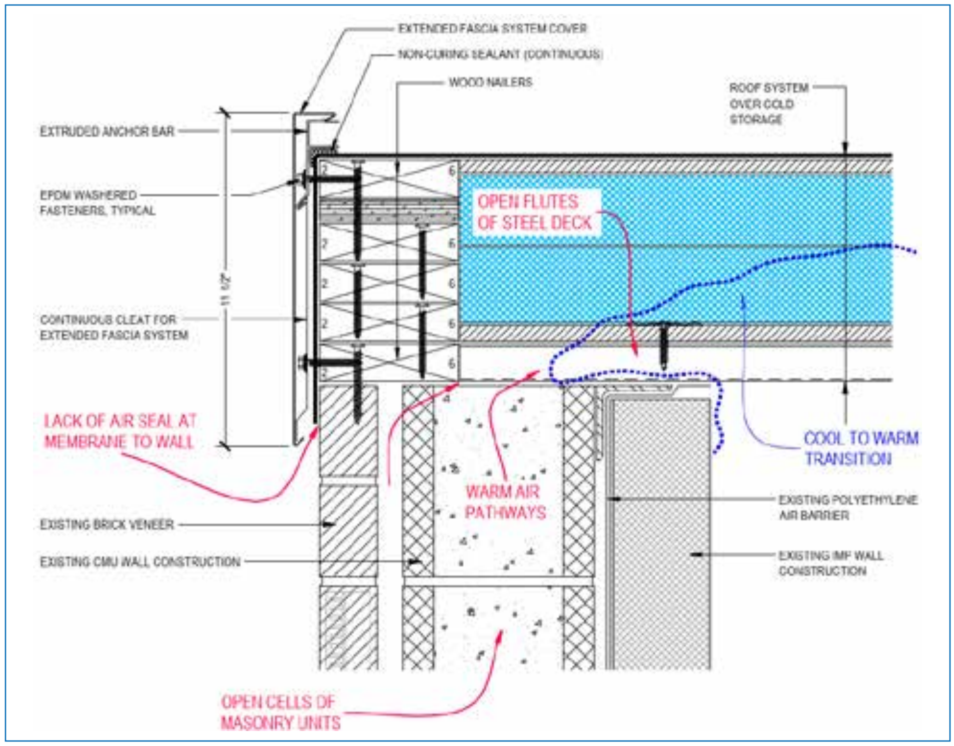

FIGURE 8. Cold storage exterior multi-wythe wall without proper air seal (condition prior to blow-off shown in Fig. 7).

will lead to the structural failure of the steel decking panels and leave the roof prone to blowing off (**Fig. 9**).

Although there are several ways to mitigate the air infiltration at this multi-wythe brick and IMP wall shown in Fig. 8, the most effective method would either require fully sealing the exterior face of the brick wall, including the elimination of any weeps or vents, or structural modifications to eliminate the brick ledge and support the ends of the steel deck at the face of the brick wall. This would allow for

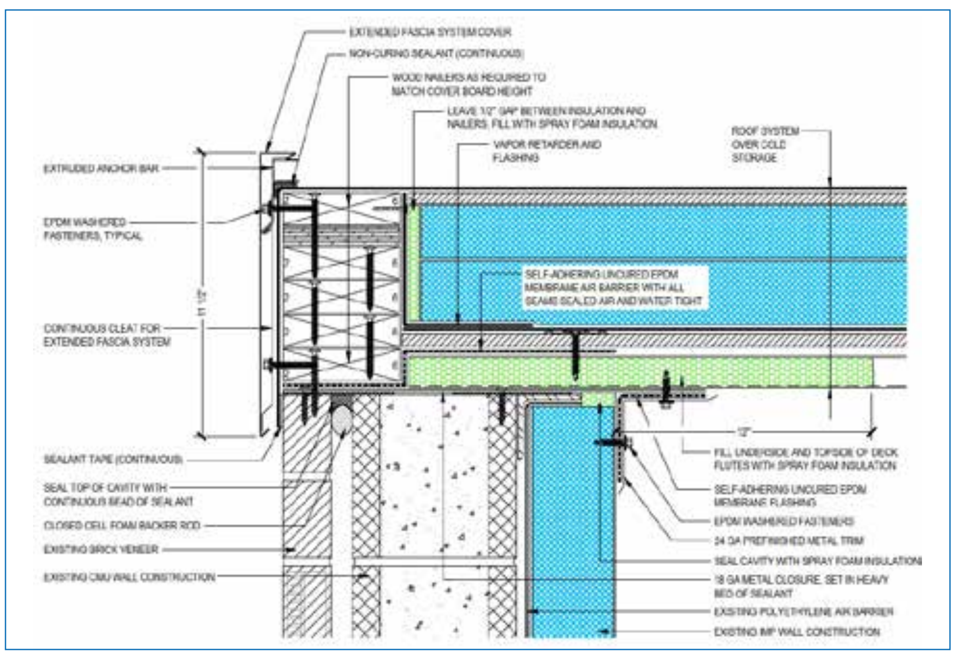

FIGURE 10. Cold storage exterior multi-wythe wall example with multiple measures to create an effective air seal.

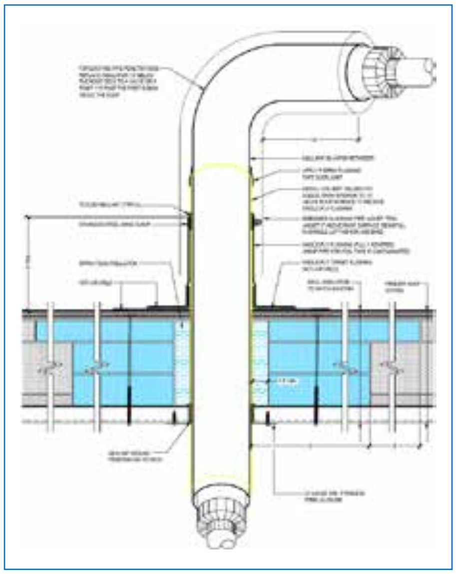

FIGURE 11. Ammonia (refrigerant) piping penetration flashing detail showing continuous air and vapor barrier protection at pipe from interior through roof assembly.

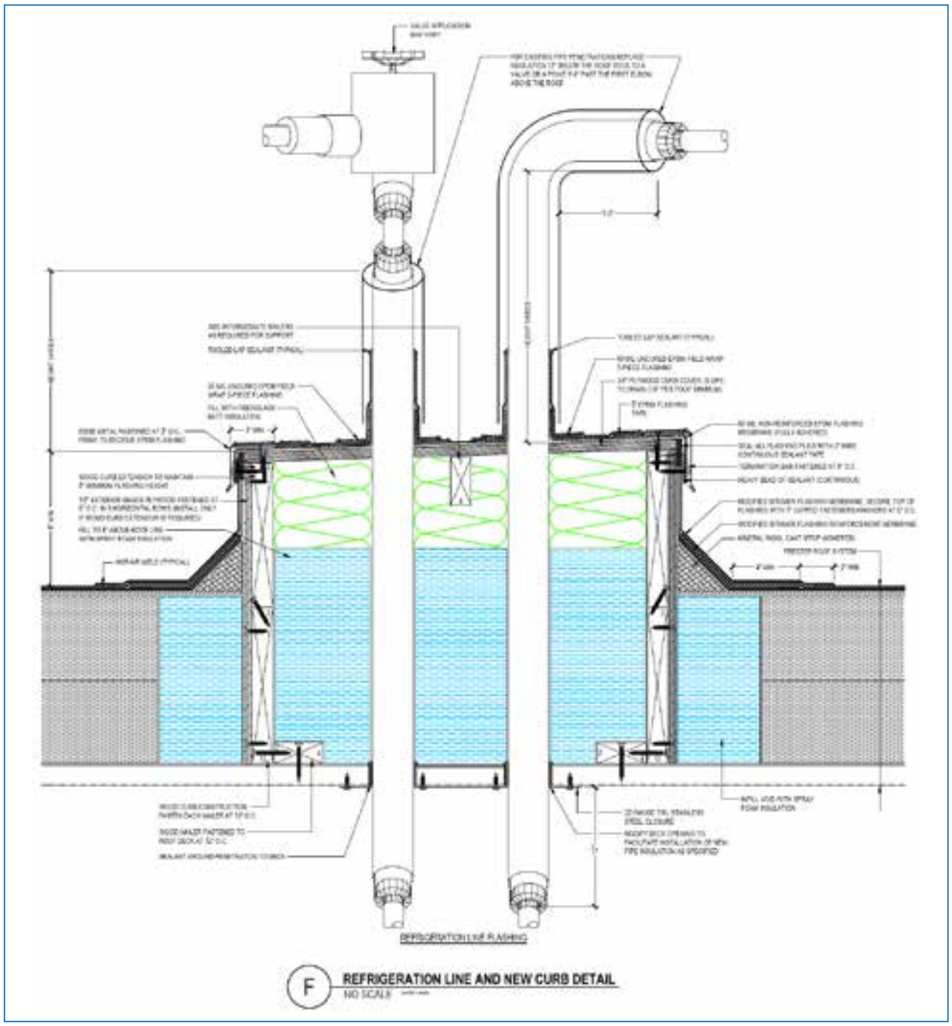

FIGURE 12. Isolation curb flashing showing spray polyurethane foam to form primary air seal at ammonia (insulated refrigerant) piping penetrations.

a clear and distinct boundary between cool and warm environments and allow for the placement of a functional air seal. Without a clear and distinct boundary for the air seal, it is possible to change the temperature and dew point to limit the occurrence of condensation, as shown in **Fig. 10**; however, full prevention will be next to impossible.

Thermal insulation plays a key role in helping to prevent condensation by changing the temperature of components to avoid the dew point. Inadequate thermal insulation will allow cyclical conditions that are prone to repeated condensation through the service life of the roof and wall components. For renovation projects, this may require supplemental insulation at either or both the cold and warm sides of the refrigerated space to control the temperatures. But as noted above, adding thermal insulation will not solve an infiltration problem.

In some cases, a vapor retarder layer may also serve as the air barrier within a roof assembly; however, for the majority of refrigerated spaces, the roof membrane itself acts as the air barrier and vapor retarder on the warm side of the roof assembly. As the first measure of protection against air infiltration, the roof membrane should be sealed to the exterior wall and at all penetrations as the primary air seal. Additional measures may be incorporated using spray polyurethane foam, but remember the more complex the detail, the less focus will be paid to the primary air seal. The secondary foam may actually delay seeing the failure, whereas if the design is simple, the success can be verified very quickly after installation, many times while the contractor is still on-site and invested.

Penetrations are often another source of infiltration, especially insulated piping penetrations. One of the most important components of refrigerated process piping is the continuous pipe wrap insulation and vapor barrier membrane. The pipe wrap is sometimes damaged or even stopped at the roof deck, which leads to air infiltration and often water intrusion into the roof assembly and space below. Ensuring that the pipe sleeve, insulation, and vapor retarder membrane wrap remain in good condition and continuous through the roof system, past the decking, and into the interior, as shown in **Fig. 11**, is critical to the performance of both the piping and the roofing systems. With a continuous sleeve through the full depth of the roofing system, the piping can be isolated from the roof system and the roof system can be flashed watertight regardless of the performance of the piping insulation or wrap. Achieving an airtight seal for the roof then becomes possible with a standard flashing detail and sealing the annular space between the pipe sleeve and the pipe wrap or can be more complex with the construction of an isolation curb **(Fig. 12)**. In either case, sealing the roof membrane to the pipe sleeve or penetration curb is critical to preventing air infiltration and condensation within the roofing system.

CONCLUSION

Once a functional air seal has been installed, a roof replacement has been accomplished, and the building is watertight, facility operators and owners carry the burden of maintaining this rather delicately balanced system. As mentioned above, although minor shifts in cooling temperatures may not immediately impact the overall balance of the system, abrupt changes, mechanical equipment deterioration, and changes in operational use can have drastic ramifications. Just as many food manufacturing plants emphasize and enforce good manufacturing practices, including procedures for maintaining the "cold chain," similar good cold storage practices should be developed to provide clear operating guidelines that allow for optimal use of the interior space and optimal performance for the enclosure components.

Preventing and mitigating condensation, as well as the resulting leaks and damages, requires interdisciplinary coordination, beginning with the design and installation phase and continuing through the service life of the systems to ensure long-term performance. Discovering the source of condensation after installation often requires destructive investigation and analysis of the interior and exterior factors contributing to the condensation. Strategic repair and replacement strategies are necessary to achieve a fully functional air seal with ideal placement to prevent infiltration in refrigerated processing and cold storage facilities.

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Trends in Roof Re-Cover Applications: United States

ABSTRACT

Over half of roof re-cover projects now omit high-density cover boards, with many new membranes—such as fleece-back and self-adhering systems—adhered directly to aged, weathered substrates. This session examines the performance trade-offs of these practices, including reduced durability, compromised adhesion, and greater sensitivity to substrate irregularities. Attendees will gain insight into how value engineering impacts system longevity and how the design community can advocate for high-performance solutions. Through technical analysis and practical examples, the presentation highlights strategies to optimize system performance while navigating economic pressures and evolving industry norms.

LEARNING OBJECTIVES

» Identify the common reasons that high-density cover boards are omitted in modern roof re-cover applications and associated industry trends.

» Evaluate the performance impacts of adhering membrane systems directly to existing weathered substrates without intermediate layers.

» Analyze the risks and limitations of value-engineered roofing designs in terms of long-term durability, adhesion, and thermal performance.

» Apply best practices and design strategies to promote high-performing roofing systems within the constraints of budget-driven project environments.

SPEAKERS

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Victor Rosenthal has over 25 years of experience in the commercial roofing industry, with a strong focus on technical consulting and system performance. He began his career with Weatherproofing Technologies before moving into technical sales and support roles with Upland Corp., representing Firestone Building Products in the New Mexico/El Paso region. For the past decade, Victor has been with Elevate (formerly Firestone BP), where he now serves as national technical manager for asphalt and ethylene propylene diene monomer systems. In this role, he provides technical guidance to architects, contractors, and building owners across the country.

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Rachael DeMeio is the insulation product manager at Holcim Building Envelope. DeMeio comes from a consulting background with a strategic focus within the protective coatings industry. Her diverse professional background includes more than 10 years of project management experience in new product development, formulation, and analytical focus. She has bachelor's degrees in biology and chemistry as well as an MBA with a concentration in product management.

AUTHOR:
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STEPS TO ENSURE A QUALITY RE-COVER ROOF SYSTEM

For a re-cover to perform as intended and achieve the specified warranty, a methodical evaluation of the existing roof system is essential. The process begins with confirming that the structural deck is both dry and structurally sound. The existing roof system must be securely attached to the deck to ensure proper adhesion and long-term performance. Before any new system is installed, it is highly recommended to conduct a noninvasive moisture survey—such as an infrared thermography scan—to identify trapped moisture within the assembly.[1] Any damaged or wet components of the existing roof must be removed and replaced; failure to do so will void the manufacturer's warranty.[2] The contractor is ultimately responsible for accepting the substrate prior to roofing.[3] The drainage system must also be assessed to ensure adequate slope, no signs of ponding water, and that all drains are clear. In addition, the leak history should be reviewed to confirm that all known leaks have been properly addressed prior to installation.

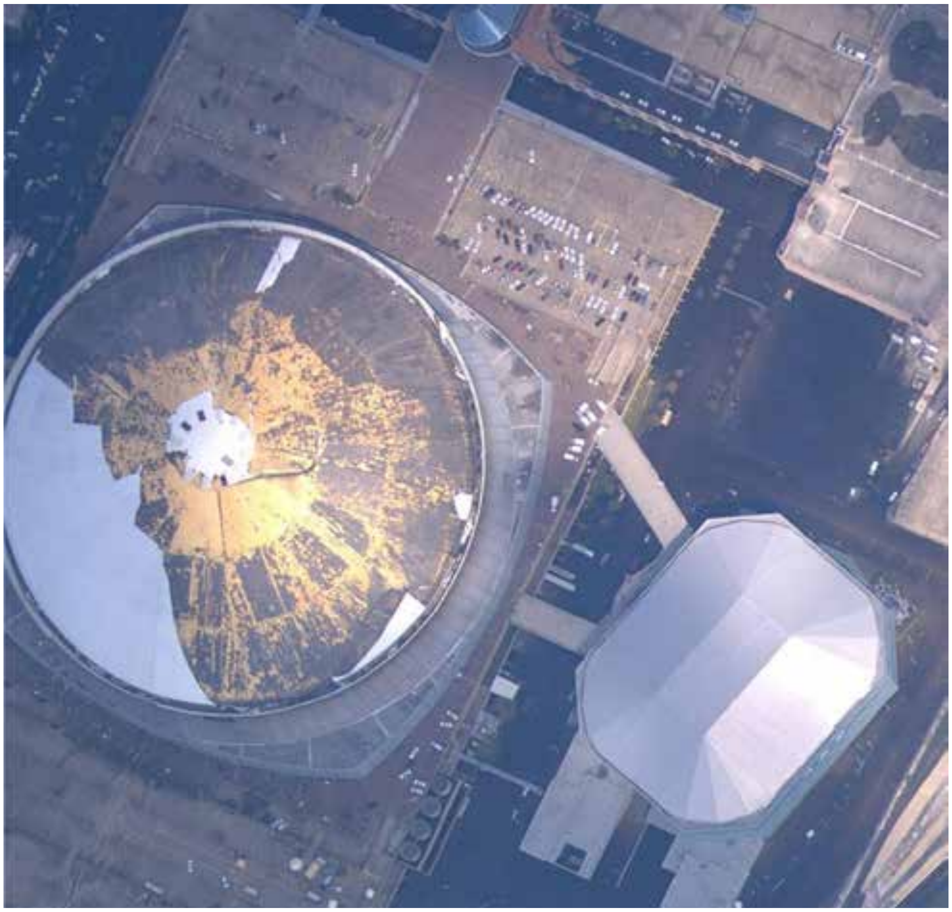

FIGURE 1. New Orleans Arena roof after Hurricane Katrina (2005). *Photo courtesy of Georgia-Pacific Gypsum.*

ADVANTAGES OF INCLUDING A COVER BOARD IN A RE-COVER

Industry data reinforce the value of cover boards. According to FM RoofNav, an online tool that lists all FM-tested and approved roof assemblies, approximately 63% of all listed roof assemblies incorporate a cover board, and about 10% of those are re-covers.[4] Cover boards provide an extra layer of defense for the roof assembly, working in tandem with insulation rather than replacing it.[5] They create a flat, rigid, and clean substrate that prevents telegraphing of imperfections from the existing roof, resists impact, and can extend roof life by reducing the need for maintenance and repairs. The two most common types of cover boards are high-density (HD) polyisocyanurate (polyiso) cover boards (HD cover boards) and gypsum cover boards. HD cover boards are valued for their high *R*-value (*R*-2.5), moisture resistance, dimensional stability, durability, and lightweight installation advantages.[6] Many are made from recycled materials and can be recycled at the end of their life cycle. Gypsum cover boards, on the other hand, are noncombustible, offering enhanced fire resistance and wind uplift performance. They protect against punctures and foot traffic damage, improve adhesive bonding, and can be specified to meet Severe Hail (SH) or Very Severe Hail (VSH) classifications.[7] They also contribute to sound attenuation, reducing noise from traffic, equipment, and aircraft.

The importance of cover boards in protecting roof systems is exemplified by events such as Hurricane Katrina in 2005. The New Orleans Arena roof, which incorporated a glass-mat gypsum cover board, remained intact during the storm (**Fig. 1**), while the nearby Superdome—lacking a cover board—suffered severe damage.[8]

RE-COVER TRENDS AND MARKET DRIVERS

The commercial roofing market is projected to grow at an annual rate of 4.5% through 2030, with reroofing, including re-covers, accounting for more than 80% of demand.[9] Single-ply roofing systems, which are commonly used in re-covers, are expected to reach $5.72 billion in market value by 2026.[10] Nondiscretionary reroofing remains the backbone of the industry, with over 90% of projects driven by essential repairs rather than elective upgrades. Severe weather events continue to influence the market, with an estimated 40 million ft² (3,716,121.6 m²) of storm-related roof replacements occurring each year. As material costs continue to climb, building owners are increasingly seeking cost-effective solutions that still deliver performance and warranty coverage. According to a published article from Roofers Coffee Shop, "5 Technology Trends Transforming the Roofing Industry," the trend toward re-covering existing roofs rather than completing full replacements is gaining momentum due to its reduced disruption to occupants and lower overall cost.[11]

COMPARATIVE CONSIDERATIONS

When comparing re-covers with and without cover boards, several trade-offs emerge and must be considered (**Table 1**). Using a cover board generally improves durability, impact resistance, fire performance, and wind uplift capacity. It can enhance thermal performance slightly and lower long-term maintenance costs. The use of a cover board, however, adds both material and labor costs and can extend installation time. While omitting the cover board can reduce up-front costs and accelerate installation, it often comes at the expense of long-term protection, warranty eligibility, and resistance to damage. In practice, cover boards are most commonly specified for projects in high-traffic areas, severe-weather regions, or where long-term performance is a priority. Projects driven primarily by budget or speed may forgo a cover board if conditions allow.

EXPANDED MARKET DRIVERS AND REGIONAL TRENDS

While national data point to steady growth, regional variations in re-cover adoption are significant. In hurricane-prone coastal states, for example, building codes often mandate enhanced wind uplift ratings, driving higher demand for mechanically attached cover boards.[12] In the Midwest and Great Plains, VSH requirements are influencing specification patterns, with school districts, government facilities, and healthcare campuses frequently prioritizing gypsum-based boards for impact resistance.

Economic factors also play a role. Inflationary pressures on insulation and membrane pricing have made re-cover solutions more attractive to budget-conscious owners, especially when existing insulation can be preserved. Conversely, supply chain disruptions—such as those experienced in 2021 and 2022—have underscored the value of adaptable re-cover designs that can accommodate alternative materials without compromising warranty coverage.

TABLE 1. Comparative performance characteristics with and without cover boards

Considerations	With cover board	Without cover board
Durability	Higher: protects membrane and insulation	Lower: insulation more vulnerable to damage
Impact resistance	High: resists hail, foot traffic, etc.	Moderate to low
Fire and wind resistance	Enhanced: noncombustible, slow fire spread, and wind uplift protection	Reduced
Thermal performance	Slightly improved: adds *R*-value and protects insulation	No added benefit
Installation speed	Slightly slower: extra layer to install	Faster: fewer layers
Cost	Higher up front: material and labor	Lower up front
Warranty	Often required for extended warranty	May not qualify for maximum warranty coverage
Maintenance costs	Lower over time	Potentially higher
Typical use cases	Long-term performance, high-traffic and severe-weather zones	Budget-driven, low-traffic, speed-critical projects

EMERGING TECHNOLOGIES IN RE-COVER SYSTEMS

Advancements in materials science and installation technology are reshaping the re-cover market. Modern single-ply membranes now incorporate reinforced scrims and ultraviolet-resistant formulations that can extend service life even in extreme climates.[13] The rise of self-adhered membranes and all-weather adhesives has reduced dependency on volatile organic compound–based systems, improving installation safety and broadening seasonal work windows. In particular, self-adhered products minimize odor concerns, making them especially attractive for schools, healthcare facilities, and retail locations. The use and advantages of self-adhered membranes and all-weather adhesives are industry-wide.

Innovations in cover board manufacturing have also contributed to higher-performing re-covers. HD polyiso and glass-mat gypsum boards are now available in lighter weights without sacrificing compressive strength, which speeds installation while lowering handling fatigue for crews. In addition, some products integrate factory-applied facers designed to enhance membrane adhesion and moisture protection. From a sustainability perspective, manufacturers are increasingly offering cover boards with recycled content and end-of-life recyclability, aligning with green building certification goals.[14,15]

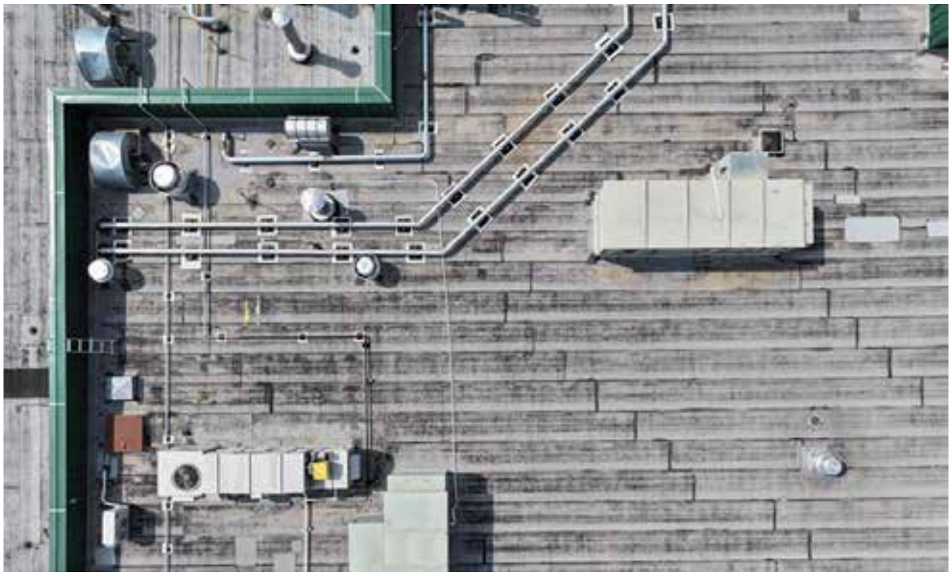

FIGURE 2. Image of roof prior to restoration.

CASE STUDIES

Re-Cover Without a Cover Board: University of Kansas Health System's Great Bend Campus

A re-cover without a cover board was chosen for the University of Kansas Health System's Great Bend Campus. The existing system consisted of a two-ply styrene-butadiene-styrene (SBS) membrane installed over wood fiberboard and polyiso insulation.[15] While the roof exhibited signs of aging and granule loss, shown in **Fig. 2**, it was still performing adequately with minimal leaks, indicating at least 5 years of remaining service life; however, a hailstorm caused significant damage that accelerated deterioration and created new leaks. A moisture survey revealed that only small sections of insulation were wet and required replacement, meaning the overall integrity of the roof remained intact. Re-covering the existing roof proved to be faster and far less costly than a full tear-off and replacement, while also minimizing disruption to the hospital's daily operations. The chosen system was a fleece-back thermoplastic olefin (TPO) membrane installed with low-rise foam, shown in **Fig. 3**, covered under a 20-year, no-dollar-limit warranty. All existing flashings were replaced, and the highly reflective TPO membrane was expected to reduce cooling costs for the facility. By using fleece-back TPO, the need for a cover board was eliminated, saving both time and material cost. The completed roof is shown in **Fig. 4**.

Re-Cover with a Cover Board: Example Scenario Within the Educational Sector

This is a created scenario from a combination of multiple projects that could be synthesized into a credible example. In contrast to the aforementioned case study, a school project in an SH zone with high acoustical performance needed to adopt a re-cover approach using a cover board. The existing roof was an older ethylene propylene diene monomer (EPDM) membrane that had sustained hail damage, and the building was located near an airport where noise reduction was an ongoing focus. The school district required a solution that would minimize disruption to classes while enhancing hail resistance and sound attenuation. The chosen approach involved removing and replacing only the most damaged sections of EPDM and insulation, then installing a combination of an HD cover board and a gypsum cover board rated for VSH. The HD board provided a rigid, stable base, while the gypsum board added both impact resistance and improved sound

FIGURE 3. Installation of fleece-back membrane over existing styrene-butadiene-styrene cap sheet.

FIGURE 4. Image of completed roof after re-cover with fleece-back thermoplastic polyolefin membrane.

FIGURE 5. Completed roof of CVS Pharmacy after installation of thermoplastic polyolefin membrane over new HD cover board.

transmission performance; a new 80-mil TPO membrane was fully adhered to the cover board. This combination significantly increased hail resistance, improved classroom noise levels, created a smooth substrate for strong membrane adhesion, and facilitated a faster, less intrusive installation process compared to a full tear-off.

Re-Cover with a Cover Board: CVS Pharmacy[16]

A commercial building owner and developer requested bids for reroofing services on a CVS Pharmacy building in Toccoa, Georgia. The building consisted of two levels of low-slope roof areas, which included an aged black EPDM membrane. Also, a recent weather event had caused wind and storm damage.

After a site inspection and careful scope considerations, a roofing contractor was chosen. To save time and reduce labor and material costs associated with a full tear-off and replacement, the owner opted to preserve the existing insulation and proceed with a re-cover that included an HD cover board and a mechanically attached 60-mil TPO. The main areas of concern where leaks were occurring were on the parapet walls. All existing wall, curb, and penetration flashings were torn out and replaced; the walls were improved by fully encapsulating them with an adhered TPO membrane that went up and over the wall and was finished off by new metal coping caps.

The installation process started with the contractor cutting up the existing EPDM membrane in a grid pattern, allowing the existing membrane to relax. This grid pattern allows moisture within the assembly to dry more easily, helping prevent further damage should a leak occur. After the preparation was completed on the existing membrane, a ½ in. (12.7 mm) HD cover board was installed over the existing system. This new cover board was required to act as a separation layer of insulation between the new TPO membrane and the existing EPDM membrane. The HD cover board also added *R*-2.5 to the system. The cover board was mechanically fastened through the existing roof, down through the metal decking, at a rate to meet the manufacturer's requirements for warranty, as well as local wind uplift requirements.

Following installation of the new HD cover board, a 60-mil TPO membrane was mechanically fastened in accordance with manufacturer specifications, incorporating perimeter half-sheets to satisfy warranty and wind uplift performance requirements.

By installing a new TPO membrane over a new HD cover board, illustrated in **Fig. 5**, and fully encapsulating the walls with TPO membrane, the contractor was able to deliver a better long-term solution and provide the owner with a 20-year, no-dollar-limit warranty.

LESSONS LEARNED FROM CASE STUDIES

Across the documented projects, several consistent lessons emerge. First, accurate moisture detection is nonnegotiable; bypassing this step can lead to premature system failure, even with a well-specified cover board. Second, the alignment of product selection with site-specific hazards—whether hail, wind, or foot traffic—yields the most cost-effective results over the system's lifespan. Third, attention to flashing details and terminations often determines whether a re-cover achieves its projected performance, as seen in the CVS Pharmacy project where wall encapsulation eliminated chronic leak points.

Finally, the case studies confirm that while up-front cost savings from omitting a cover board can be appealing, they often trade off long-term resilience and warranty flexibility. Projects that invest in a cover board tend to experience fewer post-installation service calls, maintain their aesthetic appearance longer, and preserve better resale value for the property. This performance consistency, coupled with evolving product technology, suggests that cover boards will remain a central feature in high-quality re-cover assemblies for the foreseeable future.

CONCLUSION

While incorporating a cover board into a re-cover assembly adds cost and installation time, it can significantly enhance a roof's durability, resistance to damage, code compliance, and overall lifespan. The decision should be based on the building's use, the local climate, applicable codes, and the owner's long-term maintenance and budget priorities. In many cases, the long-term protection and performance benefits outweigh the initial investment, making cover boards an integral component of a well-designed re-cover strategy.

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Thermal Performance of Spandrel Assemblies in Glazed Wall Systems: Lessons Learned from Physical Testing and Simulation

ABSTRACT

Gaps in the industry's understanding of the thermal performance of opaque (that is, spandrel) sections of glazed wall systems have led to inconsistent results and discrepancies with real-world performance, and they have stalled the innovation necessary to achieve energy-efficient systems. This presentation will provide an update on Phase 2 of a multiyear, multiphase research study aimed at closing this performance gap. Specifically, this presentation will focus on presenting results from physical testing conducted at Oak Ridge National Laboratory. The results will include measurements of several variations of thermally broken aluminum stick-built and unitized curtainwall systems along with a window-wall system. Differences in the thermal behavior of the tested spandrel assemblies will be highlighted along with the effect of several thermal upgrade options. The study is known as "Thermal Performance of Spandrel Assemblies in Glazing Systems" and is funded by the Charles Pankow Foundation with additional support from many project partners. Phase 1 of the research report is available free online. Additionally, the research aims to inform the development of techniques and tools for design professionals to accurately model, simulate, and predict building energy performance during the design stage. These techniques are crucial as energy efficiency codes advance to include absolute metrics for building energy use.

LEARNING OBJECTIVES

- Identify differences in the thermal characteristics of the measured systems (curtainwall and window wall).
- Discuss the impact of interior insulation and mullion wraps on the thermal performance of these systems.
- Identify differences between the study's testing arrangement at Oak Ridge National Laboratory and common industry test methods (for example, ASTM C1199, *Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using Hot Box Methods*, and NFRC 102, *Procedure for Measuring the Steady-State Thermal Transmittance of Fenestration Systems*).
- Interpret how physical test results may inform future design strategies for improving spandrel assembly thermal performance.

SPEAKERS

Daniel Haaland, MASc, PEng
Principal, Building Science Specialist, RDH Building Science

Daniel Haaland contributes to RDH Building Science's (RDH's) core practice areas of new construction, research, and sustainability while sharing his expertise as an author, speaker, and guest lecturer. Leading RDH's advanced analytics team, Haaland guides projects in achieving energy-efficient, high-performance building designs. Widely recognized in the field of finite element analysis for construction, Haaland has authored multiple industry guidelines and standards, including CSA Z5010, *Thermal Bridging Calculation Methodology*, and the THERM Passive House Window Simulation procedure.

Cheryl Saldanha, PE, CPHD
Senior Project Manager, Building Science Practice Leader, Simpson Gumpertz and Heger

Cheryl Saldanha specializes in designing and evaluating building enclosures for new construction projects and existing building enclosure renovations. Her experience includes curtainwalls, rainscreen facades, roofing, and waterproofing systems on a range of building types. She is adept at using multiple computer software packages to simulate building systems and details for thermal, condensation, whole-building energy, and daylighting analysis. Saldanha has co-chaired the New York City Chapter of the International Building Performance Simulation Association and has served on the NYC Commercial Energy Code Technical Advisory Committee for the last two code cycles.

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Wei Lam is principal and US East regional director at RDH Building Science. From Boston, he supports strategic growth across the eastern US. With over 25 years of experience, he specializes in designing and delivering high-performance building enclosure systems for healthcare, life science, academic, residential, and commercial projects. His expertise spans early design consulting, enclosure system detailing, construction-phase troubleshooting, forensic investigations for enclosure failures, and building science research.

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Ivan Lee is a team lead of the component modeling team at Stantec, with a focus on thermal and hygrothermal modeling. He applies his background in building science and modeling to the evaluation of thermal bridging of building enclosure details through two- and three-dimensional thermal simulations. He also helped in the creation of the *Building Envelope Thermal Bridging Guide*. Lee also uses his experience in hygrothermal simulations to evaluate risks of moisture-related deterioration of materials within building assemblies.

INTRODUCTION

For the purposes of this research program, spandrel assemblies (or spandrel panels) are defined as non-vision applications of fenestration systems consisting of fixed framing, an opaque infill, and an exterior opaque or transparent panel.

RESEARCH PROGRAM OVERVIEW

The results presented in this paper are part of a multiphase research program (**Fig. 1**) aimed at validating a thermal simulation procedure for spandrels and fostering innovation by providing an analytical method to assess improvements in spandrel thermal performance.

Phase 1 has been completed and was summarized in a 2023 report.[1] The project is approximately two-thirds of the way through Phase 2, with testing ongoing at Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee.

SYSTEM TYPOLOGIES

While stick-built curtainwall, unitized curtainwall, and window-wall systems may appear similar in elevation and glazing ratio, their underlying thermal performance can vary significantly due to differences in fabrication methods, continuity of control layers, and the treatment of spandrel or slab edge interfaces.

Stick-built curtainwall assemblies use continuous vertical members that can span multiple openings, including both vision glass and spandrel areas, and often extend over multiple floors. In contrast, unitized curtainwalls are factory assembled into pre-glazed modules, which are installed using gasketed, interlocking joints that occur floor-to-floor.

Window-wall systems differ from both curtainwall types in that they are typically installed as slab-to-slab infill systems between structural floors, rather than spanning continuously across them. These systems are anchored at the head and sill of each floor and rely heavily on slab edge covers to achieve continuity of thermal insulation.

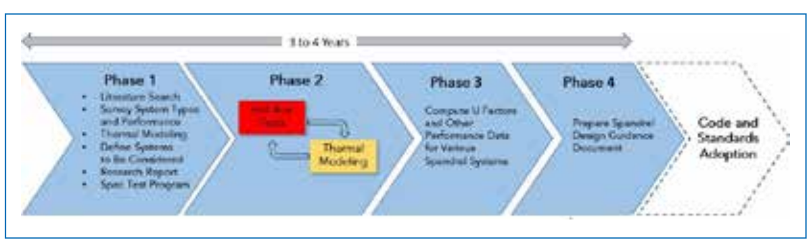


FIGURE 1. Research program phasing plan.

These system-level differences influence not only constructability and performance but also heat flow through spandrel areas. As such, it is important to characterize spandrels by system typology. In Phase 1 of the research program, six typologies were identified. Of these, three have been physically tested to date and are the focus of this paper: 1) unitized curtainwall, 2) stick-built curtainwall, and 3) non-seismic window wall.

Table 1 summarizes the characteristics of the three test articles and highlights specific system attributes relevant to the analysis presented. Framing layouts are superimposed over the elevation views to illustrate physical differences among the systems.

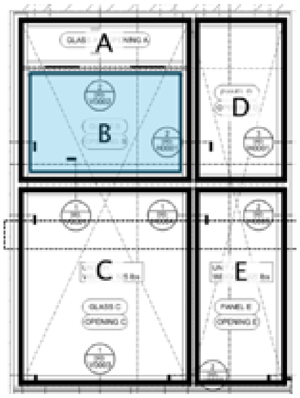
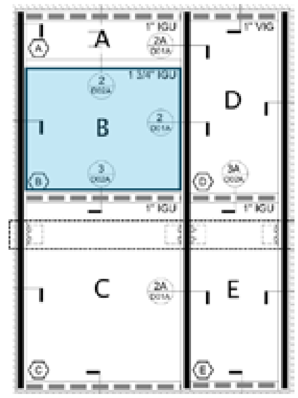
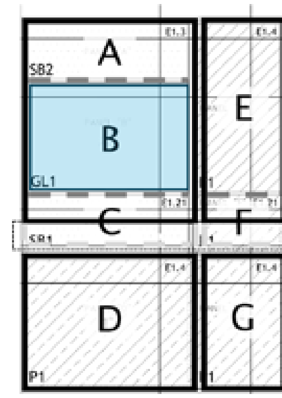
PHYSICAL TESTING METHODOLOGY

The laboratory tests are being conducted at ORNL, using guarded hot-box equipment capable of testing assemblies up to 3,000 mm (120 in.) tall by 2,500 mm (100 in.) wide under steady-state conditions.[2] **Figure 2** shows the test chamber, along with typical elevation and section views of the test articles.

To capture the unique thermal behavior of the different spandrel systems, each test article was intentionally designed to include the following:

- 203 mm (8 in.) concrete slab including anchors
- System joints, both floor-to-floor and panel-to-panel
- A vision (non-spandrel) area

TABLE 1. Summary of key test article characteristics

Test Article #1 Unitized curtainwall	Test Article #2 Stick-built curtainwall	Test Article #3 Window wall
		
Variant 1	Variant 1	Variant 1
» Thermally broken aluminum unitized structural sealant glazing curtainwall » **A, C–E:** Flat metal backpan » **A–C:** Double-glazed » **D & E:** Metal panel cladding	» Thermally broken aluminum stick-built curtainwall w/ aluminum pressure plates » **D:** Double-glazed spandrel glass » **A–D:** Metal backpans (flat) w/ 102 mm (4 in.) mineral wool insulation » **B:** Triple-glazed (vision)	» Thermally broken aluminum window wall (non-seismic header) » **A, C–G:** Metal backpan with return and 51 mm (2 in.) to 102 mm (4 in.) mineral wool insulation » **C & F:** 25 mm (1 in.) mineral wool insulation at slab

The test procedure is a modified version of ASTM C1199, *Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using Hot Box Methods*.[3] Key measured variables include surface temperatures and air velocities at multiple locations across the assembly. These temperature data are intended to be compared with results from two-dimensional (2-D) and three-dimensional (3-D) thermal simulations of the test articles to calibrate modeling assumptions and to extract performance metrics, including overall *U*-factor and condensation indices.

RESULTS

The results presented in this paper focus on vertical section cuts taken through the center of the left and right spandrel areas of each test article. These sections

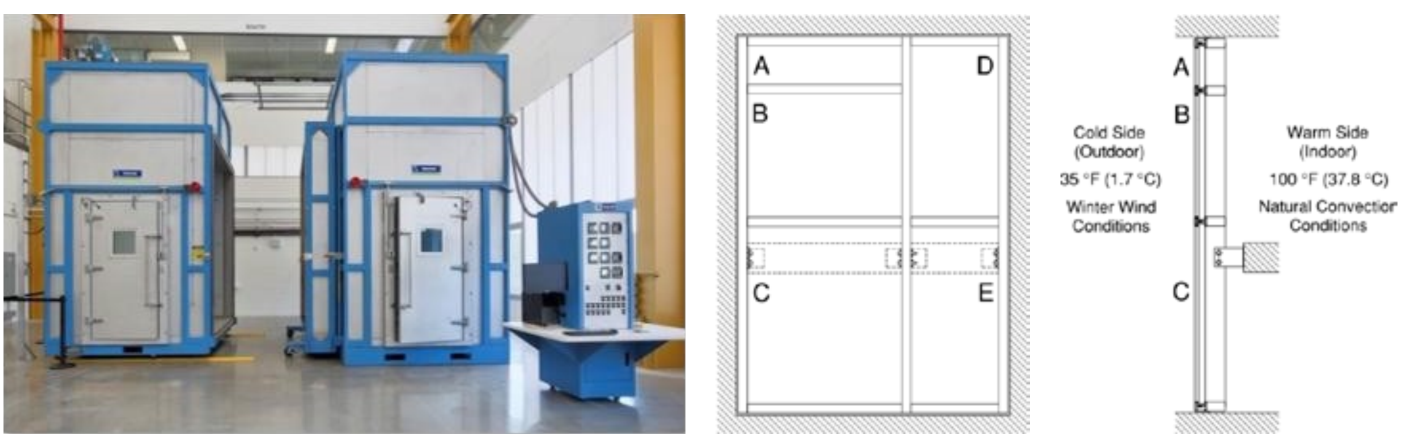


FIGURE 2. Guarded hot box at Oak Ridge National Laboratory, along with typical elevation and section views of the test articles.

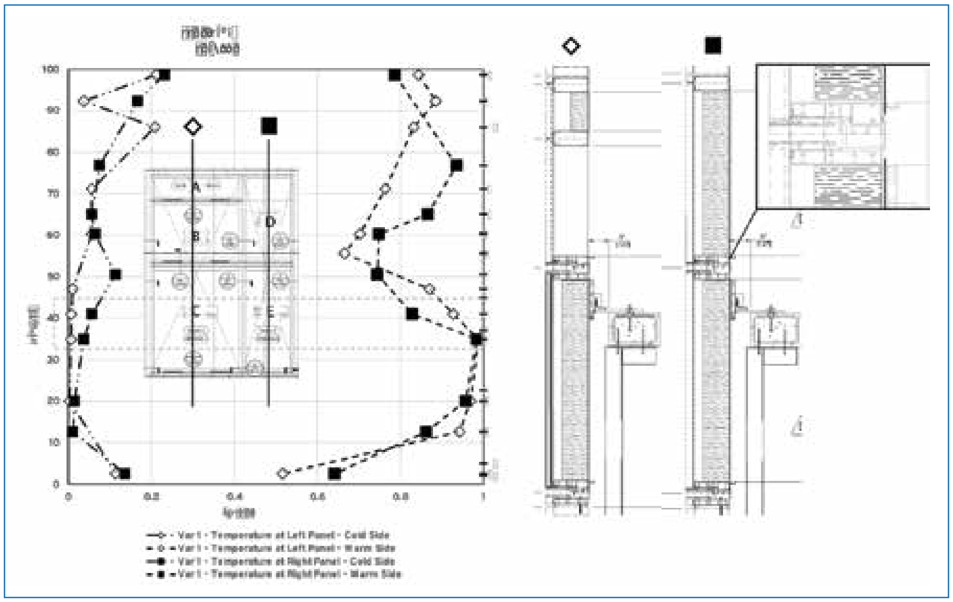


FIGURE 3. Measured surface temperatures through the left- and right-side panels of Test Article #1.

represent an idealized view of vertical heat flow profiles away from edge conditions and are expected to closely align with 2-D thermal simulation results of equivalent assemblies.

By analyzing the measured surface temperature profiles, the following questions were investigated:

» Are the test articles thermally distinct?
» Do the interior panel temperatures reach a steady state away from the framing towards the center of the panel (in other words, effective edge distance)?
» How do the measured convective heat transfer coefficients (derived from air velocity and temperature) vary across the test articles?

The following subsections present results and observations for each test article individually. The measured surface temperatures are expressed in the form of an index temperature, which normalizes the result to the interior-exterior temperature difference, Eq. (1).

$$I = \frac{T_{surface} - T_{exterior}}{T_{interior} - T_{exterior}} \quad (1)$$

Test Article #1: Unitized Curtainwall

Test Article #1 represents a thermally broken aluminum unitized curtainwall system. **Figure 3** presents the measured interior and exterior surface temperatures along vertical section cuts through the center of the left and right spandrel panels.

From the temperature profiles, the following observations were made:

» Localized temperature depression at the panel stack joint, indicating thermal bridging at the floor-to-floor interface
» Greater overall temperature range across the panel, compared to the other test articles, due to the high thermal transmittance of the system's framing members

Test Article #2: Stick-Built Curtainwall

Test Article #2 is a thermally broken aluminum stick-built curtainwall system with continuous vertical framing members spanning through the lower and upper panels. **Figure 4** shows the measured interior and exterior surface temperatures along vertical sections through the middle of the left and right spandrel panels.

The following observations are drawn from the temperature profiles:

» Exterior surface temperatures stabilize quickly in the vertical direction, with slightly warmer temperatures at mullion locations.
» Interior temperatures align with thermal modeling, showing cooler zones at mullions and warming toward the panel center.
» Steady-state edge conditions are achieved within 254 mm (10 in.) of the framing or slab edge where construction is uniform.
» Vertical mullion temperatures are generally consistent across its height, with a slight increase in temperature where it is exposed to interior conditions near the vision area.

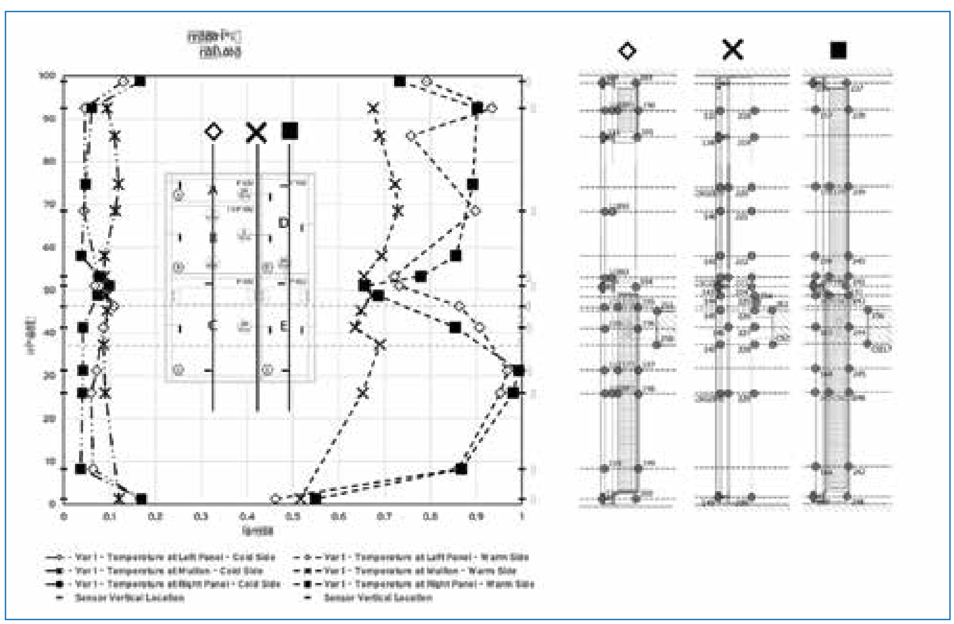


FIGURE 4. Measured surface temperatures through the left- and right-side panels of Test Article #2, Variant 1.

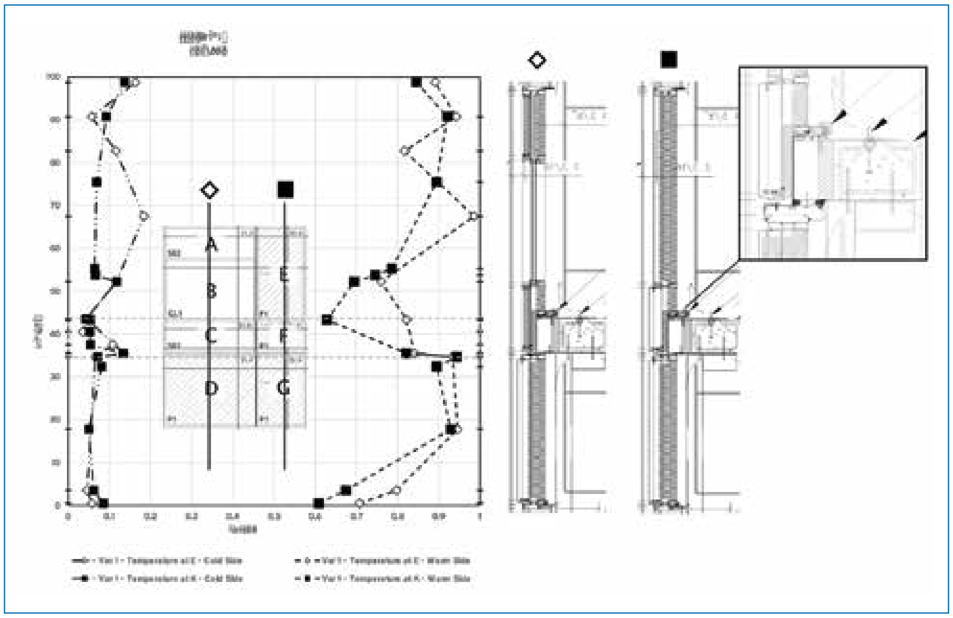


FIGURE 5. Measured surface temperatures through the left- and right-side panels of Test Article #3, Variant 1.

- Interior temperature distribution is more strongly influenced by intermediate mullions than by the slab edge.

  The slab edge increases the effective edge distance compared to the panels at intermediate mullions.
- Temperatures along the vertical mullion show a strong uniformity vertically through the test article.

Test Article #3: Window Wall (Non-Seismic Header)

Test Article #3 is a thermally broken aluminum window-wall system with a non-seismic header (that is, a clip anchor). **Figure 5** presents the measured interior and exterior surface temperatures along vertical sections through the left and right spandrels.

The following observations were made from the temperature profiles:

- Exterior temperatures stabilize quickly in the vertical direction, with slightly elevated temperatures at mullions and vision areas.
- Localized temperature anomalies at the head and slab bypass indicate thermal bridging and changes in construction detailing compared to the typical spandrel areas.
- Interior surface temperatures are significantly colder near the slab, with no evidence of a steady-state edge condition developing over the height of the smaller spandrels (C and F).
- Larger spandrels (D and G below the slab, and E above the bypass) developed an edge condition within 254 mm (10 in.) of the intermediate framing.

CONVECTIVE HEAT TRANSFER COEFFICIENTS

Exterior

Consistent with ASTM C1199, fans are used on the cold side of the test article to blow air upward between the assembly and a baffle located 152 mm (6 in.) from the exterior face. Across all tests, the measured air velocity ranged from 1.0 to 2.0 m/s (2.2 to 4.5 mph), which is significantly lower than the 5.5 m/s (12.3 mph) airflow assumed by the National Fenestration Rating Council's (NFRC's) ANSI/NFRC 100, *Procedure for Determining Fenestration Product* U*-factors*,[4] for product ratings.

Using the same convective heat transfer correlations adopted by NFRC, these lower velocities correspond to convective heat transfer coefficients in the range of 7 to 10 $W/m^2{\cdot}K$ (1.2 to 1.8 $Btu/hr{\cdot}ft^2{\cdot}°F$), compared to the NFRC default of 26 $W/m^2{\cdot}K$ (4.6 $Btu/hr{\cdot}ft^2{\cdot}°F$). A lower exterior convective coefficient results in reduced heat removal from the outer surface and therefore contributes to higher interior surface temperatures under test conditions.

Interior

Similar fans are used on the warm-side chamber to circulate air between a baffle and the test article. While operated at lower speeds, they are intended to minimize temperature non-uniformities across the test surface; however, the resulting air velocities are still higher than those typically found in real-world indoor environments.

Across the test articles, the measured air velocity above the floor slab ranged from 0.3 to 0.6 m/s (0.7 to 1.3 mph), while the air velocity below the slab ranged from 0.25 to 0.33 m/s (0.6 to 0.7 mph). These values correspond to convective heat transfer coefficients between 5.6 and 7.7 $W/m^2{\cdot}K$ (1.0 and 1.4 $Btu/hr{\cdot}ft^2{\cdot}°F$), which are higher than the NFRC values, which range from 2.44 to 4.65 $W/m^2{\cdot}K$ (0.43 to 0.82 $Btu/hr{\cdot}ft^2{\cdot}°F$).

The authors anticipate further investigation into the effect and variability of interior convective heat transfer coefficients, as these values can meaningfully impact simulated and measured surface temperatures. Higher interior coefficients promote increased heat transfer to the surface and therefore contribute to higher interior surface temperatures.

IMPACT ON SIMULATIONS

Preliminary analysis of the three tested assemblies suggests the following key findings relevant to thermal simulation:

- For large spandrels—those taller than 1,100 mm (45 in.)—a uniform center-of-panel temperature profile was observed to develop within an edge distance of 254 mm (10 in.), measured from the point where the construction became consistent.

  For smaller spandrels, no uniform center temperature was observed, indicating that 2-D thermal simulations alone may be insufficient for assemblies below a certain height.
- The thermal characteristics at slab edges, including the stack joint and window-wall bypass, differ significantly from those at intermediate mullions; these conditions require

dedicated modeling or testing to be captured.

- Conversely, in the absence of interior insulation, the slab edge in stick-built curtainwall assemblies appears to have minimal influence on the thermal performance away from corners.
- Variations in the interior convective heat transfer coefficient, both across systems and within individual test articles, indicate that a single representative value may not be adequate for accurately predicting surface temperatures.

These findings do not account for 3-D effects at corners or the presence of interior insulation. Simulations completed for Test Article #1 found that both factors produced significant differences in predicted *U*-factors and surface temperatures.[5]

IMPACT ON FUTURE DESIGNS

Despite the demonstrable influence of slab edge and floor-to-floor detailing on the thermal performance of common spandrel system typologies, current 2-D approaches to spandrel rating and modeling typically overlook these effects. The authors anticipate that as manufacturers and design teams begin to account for these areas, this will catalyze further innovation in system design—particularly in improving insulation continuity at transitions.

Although not included in this paper, additional testing has been conducted on a wide range of thermal enhancement strategies, including vacuum-insulated glazing spandrel cladding, interior insulation, and increased insulation depth. Results from these variants will be shared in future publications as the analysis progresses.

CONCLUSIONS

Initial findings from the physical testing generally align with the hypotheses developed during Phase 1 of this research, as well as with ongoing simulation studies that form part of the overall program.

Temperature profiles through the center of the spandrel panels reveal meaningful thermal differences between stick-built curtainwall, unitized curtainwall, and window-wall systems, particularly at the slab edge. The results also support the use of a 254 mm (10 in.) edge distance as a reasonable assumption for large spandrel panels under steady-state conditions, away from corners, and with no insulation inboard of the framing.

Observed variations in surface temperature and interior convective heat transfer coefficients suggest the need to evaluate unitized curtainwall and window-wall assemblies as complete systems, rather than relying solely on intermediate framing details to represent overall system performance.

The engineering team, in collaboration with the testing laboratory, is continuing both testing and simulation work across a range of system variants. The ultimate goal remains the development of a robust and standardized thermal simulation procedure for spandrel assemblies—one that can be widely applied, formalized into standards, and adopted by building energy codes.

ACKNOWLEDGMENTS

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Soffit Detailing Strategies for Performance and Durability in Modern Building Enclosures

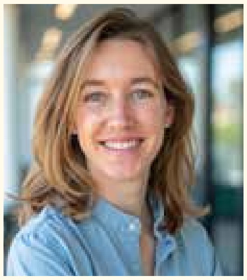
ABSTRACT

Soffits are often overlooked in the design and construction of the building enclosure, yet small missteps can significantly impact thermal performance and air and moisture management. This presentation explores common failures and best practices in soffit detailing, grounded in field investigations and building science analysis. Using WUFI hygrothermal modeling and THERM thermal bridging analysis, we will examine how soffit design affects drying potential, condensation risk, and overall enclosure performance—particularly in climate zones where venting, drainage, and thermal continuity must be carefully balanced. Through case studies and simulation results, we'll demonstrate how improper soffit detailing can lead to condensation issues, material degradation, and occupant discomfort. The session will offer best practices for detailing soffits to ensure continuity of air and water barriers, maintain thermal continuity, and avoid costly failures. Special focus will be given to vented compared to unvented soffit strategies, material transitions, and performance-driven design decisions. This session is intended for building enclosure consultants, architects, and contractors involved in the design, evaluation, or rehabilitation of building enclosure systems. Attendees will leave with actionable detailing strategies, diagnostic red flags, and a deeper understanding of the critical role soffits play in high-performing enclosures—not just for aesthetics, but for durability, comfort, and code compliance.

LEARNING OBJECTIVES

- Identify at least three common modes of failure in soffit detailing that can lead to water intrusion or premature material degradation in exterior wall systems.
- Explain the role of soffit design in maintaining moisture control, thermal continuity, and enclosure durability in ventilated and non-ventilated assemblies.
- Evaluate construction details for soffit transitions to recognize potential issues related to venting, drainage, and material compatibility.
- Apply practical strategies for improving soffit detailing on future projects by referencing real-world case studies and industry best practices.

SPEAKERS



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Xiaoran Li, PE
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Xiaoran Li is a professional engineer licensed in California and a member of Simpson Gumpertz & Heger's Building Technology group in the Los Angeles office. He provides enclosure consulting services for new design and for the investigation and repair of existing buildings across a range of markets. His expertise includes the design, specification, and testing of building enclosure systems, including roofing, plaza and terrace decks, balconies, and above- and below-grade waterproofing. Li has extensive experience in material selection, detailing, and construction-phase services to ensure the performance and durability of enclosure assemblies.

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INTRODUCTION

Soffits, canopies, and roof overhangs extend beyond the primary building enclosure yet remain integral to its performance. Their interfaces with walls and roofs are critical points where continuity of the water, air, thermal, and vapor control layers must be maintained. In this paper, the term *soffit* broadly encompasses these projecting horizontal elements.

Soffits project beyond the thermal envelope and often intersect adjacent walls and roofs at complex geometries. Even minor lapses in detailing can cause air leakage, thermal bridging, concealed wetting, and premature deterioration, particularly where multiple trades converge. Common deficiencies include discontinuous control layers, interrupted insulation, inadequate drainage geometry, and material incompatibility within the soffit cavity.

This paper distills field observations into practical guidance organized around five themes: continuity of control layers, drainage and water management, material durability, inspection and maintenance access, and vented compared to unvented strategies. A brief case study illustrates these principles in practice. The objective is to help design and construction teams deliver soffits that perform as reliably as adjacent walls and roofs.

COMMON FIELD FAILURES

Field investigations across multiple climates reveal consistent soffit failure patterns that typically stem from coordination lapses in design, material selection, and construction execution.

Discontinuous Control Layers

A common deficiency is missing or misaligned transition detailing between soffits and adjacent walls, roofs, and balconies. Continuity of the air, water, vapor, and thermal control layers is frequently compromised. Common observations include discontinuous water-resistive barriers (WRBs), interrupted insulation, incomplete flashing, and other conditions that create pathways for air leakage, thermal bridging, and moisture intrusion.

Improper Water Management

Many soffit assemblies lack defined drip edges, capillary breaks, or proper terminations. Without these features, vertical runoff can cling to the soffit, wrap exposed edges, or be wind-driven into the soffit plane (**Fig. 1**). As soffits are often not vented or minimally ventilated, trapped moisture leads to staining, microbial growth, and deterioration.

Wind-Driven Rain Vulnerability

Damage assessments following major storms show soffits are vulnerable to uplift and wind-driven rain. Soffit panels can detach when wind creates upward pressure or downward suction beneath the overhang. Detached panels expose attic or framing cavities, allowing rain to enter and damage insulation, gypsum board, and interior finishes (**Fig. 2**). Even intact panels may permit wind-driven rain to enter through vents during very high winds, a rare but high-consequence failure mode.

FIGURE 1. Metal panel corrosion at the soffit.

FIGURE 2. Hurricane Charley blew away the aluminum soffit on a fire station in Aqui Esta, east of Punta Gorda Isles.[1]

FIGURE 3. Staining and gypsum board deterioration at the soffit.

Material Degradation

Soffits often incorporate moisture-sensitive components, such as paper-faced gypsum board, untreated wood trim, or uncoated metals. Without moisture-tolerant design or protective coatings, these materials deteriorate rapidly under repeated wetting, resulting in swelling, corrosion, and loss of structural integrity (**Fig. 3**).

Unsealed Penetrations

Lighting, framing, and mechanical systems are often installed without maintaining air barrier continuity or insulation protection. These unsealed penetrations introduce condensation risks and thermal bridging.

Ventilation-Related Failures

In vented assemblies, blocked ventilation channels eliminate the drying potential. In unvented assemblies, missing vapor control or misaligned insulation causes interstitial condensation and long-term material degradation.

Typical field symptoms prompting investigation include staining, delaminated finishes, corrosion at penetrations, and odors or elevated humidity (**Fig. 4–6**). These symptoms consistently indicate discontinuous control layers, inadequate moisture management, and system integration issues.

BEST PRACTICES FOR SOFFIT DESIGN

Continuity of Control Layers

Maintaining uninterrupted control layers is crucial for preventing air leakage, water intrusion, and condensation, which can significantly compromise enclosure performance and durability. Soffit transitions represent one of the most challenging locations to align these control layers due to geometry changes, the involvement of multiple trades (for example, plumbing, mechanical), and sequencing constraints. Continuity requires careful sequencing across projecting elements and early coordination among disciplines.

A high-performing enclosure relies on four primary layers: water, air, thermal, and vapor, which are applied in a coordinated and continuous manner. These layers can be integrated into multifunctional products or kept separate, with each approach presenting its own trade-offs. Combining layers can streamline installation but complicate localized repairs, while separating them increases redundancy but requires more rigorous coordination. Placement also influences performance; for example, exterior insulation improves thermal continuity but may shift the air/water barrier plane, necessitating careful transition detailing.

FIGURE 4. Staining and paint deterioration at the soffit.

FIGURE 5. Metal framing corrosion in soffit cavities.

FIGURE 6. Microbial growth within soffit spaces.

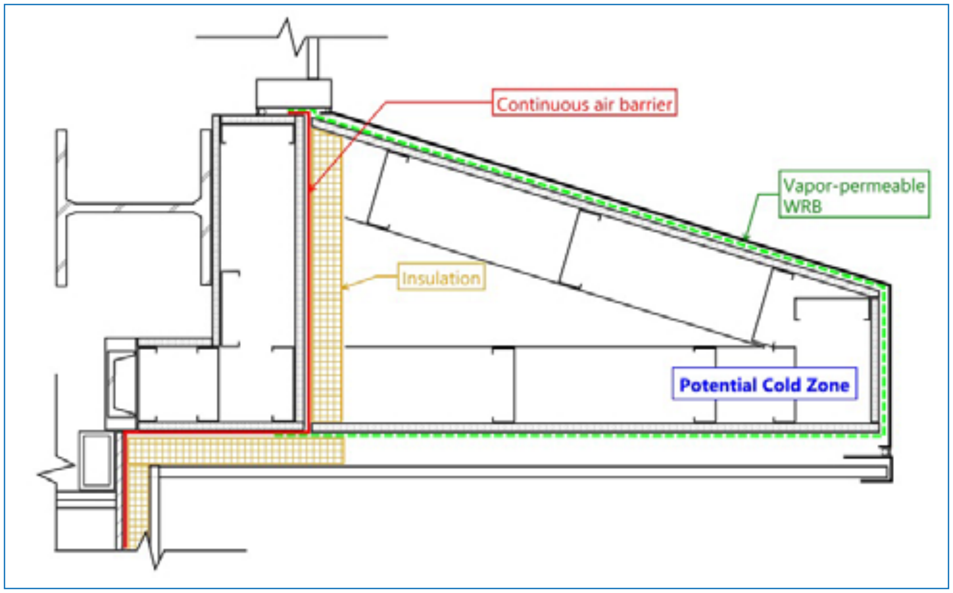

FIGURE 7. Soffit section. Placement of continuous air barrier (red), vapor-permeable water-resistive barrier (WRB, depicted in green), insulation (yellow), and cold zone (blue).

Best practices for preserving control layer continuity include the following:

- Extend air and water barriers in a shingle-lap sequence down the wall and/or around the soffit, as appropriate for the selected layout.
- Coordinate soffit-to-wall and soffit-to-parapet intersections early in design to avoid field conflicts.
- Align insulation and WRB to maintain the intended thermal and moisture management strategy.
- Coordinate around structural and all mechanical, electrical, and plumbing penetrations prior to framing closure to maintain continuity.

Figure 7 illustrates one common configuration of these layers. The continuous air barrier (shown in red) is applied to the exterior face of the primary wall, separating the conditioned interior space from the exterior environment. The insulation (shown in yellow) is placed immediately outboard of the air barrier, maintaining the thermal boundary and excluding the projecting soffit cavity from the building's conditioned enclosure. The vapor-permeable WRB (shown in green) is installed on the outboard side of the projecting element sheathing, beneath the cladding, to protect framing and sheathing from water intrusion while allowing the soffit cavity to dry outward. Proper alignment of these layers minimizes the potential for unconditioned "cold zones" (shown in blue) that can accumulate moisture through condensation.

Ventilation Considerations

Whether soffits should be vented depends on climate zone, occupancy type, construction classification, and applicable code requirements. Venting can promote drying in dry, low-humidity climates but may introduce moisture in humid or coastal environments, increasing the risk of condensation, corrosion, and material deterioration. Venting is only effective when the soffit cavity is fully isolated from the conditioned enclosure and behaves as a true exterior space. **Figure 8** illustrates a vented soffit assembly where the interior conditioned space is separated from the cold cavity space, maintaining the thermal and air boundary at the interior conditioned side while allowing air circulation within the vented soffit.

The following considerations can help determine whether ventilation is appropriate:

- Confirm whether the soffit is truly outside the conditioned enclosure or whether it is partially connected to interior spaces. Some soffits appear insulated and are assumed to be conditioned, but without dedicated heating or airflow, they often perform as unconditioned cavities. Misclassification is a common cause of condensation.
- Venting should only be used where the soffit is fully separated from attics, wall cavities, or interior spaces. Unintended airflow paths—such as unsealed steel deck flutes, gaps around beams, or openings at top plates—can convert a vented soffit into a semi-vented hybrid with unpredictable moisture behavior.
- Venting generally supports drying in hot-dry climates. In contrast, projects in humid, coastal, and cold climates may experience increased moisture loading from exterior air. Designers should consider local dewpoint conditions, marine exposure, and the potential for wind-driven rain.

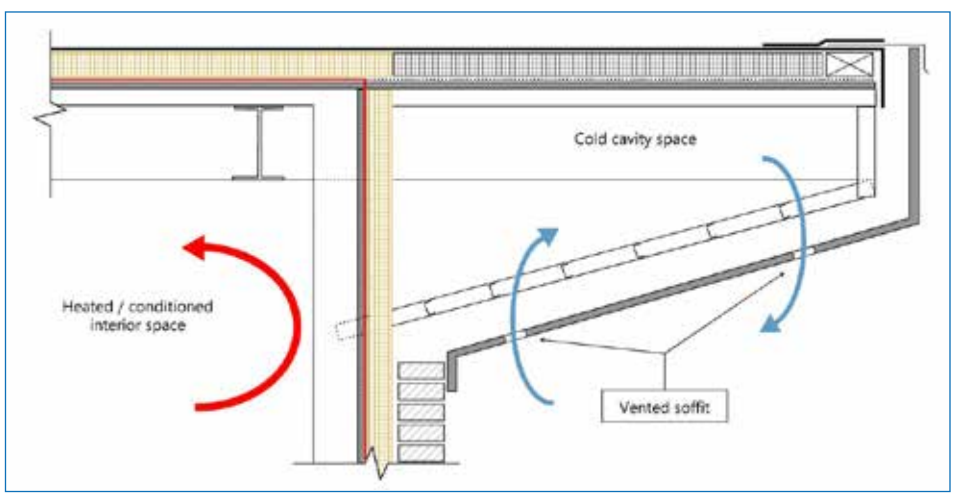

FIGURE 8. Section detail of vented soffit showing delineation of conditioned space, cold cavity space, and ventilation airflow.

- Rated exterior assemblies, soffits containing sprinklers or critical mechanical/electrical systems, and projects in Wildland-Urban Interface zones may limit or prohibit venting. In fire-prone regions, ember-resistant vents must comply with applicable codes (for example, *California Building Code* [CBC] Chapter 7A).[2]

When ventilation is used, detailing must allow effective airflow and moisture management. Provide balanced cross-ventilation where required, use vent products tested for wind-driven rain, and ensure any incidental water can drain or dry. Avoid creating moisture traps behind blocking or framing, and use perforated or vented soffit panels where appropriate to promote drying and maintain durability.

Drainage and Water Management

Soffits are not typically exposed to direct wind-driven rain. Still, they are frequently affected by moisture migrating from the assemblies above, including condensation, plumbing leaks, failed deck waterproofing, and water bypassing primary flashings. Effective water management strategies include the following:

- Provide positive slope (away from the structure) or drainage outlets where feasible.
- Incorporate flashings, drip edges, and end dams at joints and terminations to direct incidental water out of the assembly.
- Avoid geometries that trap water or impede drying.
- Utilize vented or perforated panels where appropriate to promote airflow and drying within the assembly.
- Soffits beneath waterproofed decks or cantilevered slabs should include redundant drainage paths and be coordinated with structural and enclosure detailing.

Material Durability

Exterior soffits are exposed to ultraviolet (UV) radiation, thermal cycling, and moisture. Material selection and fastening strategies should reflect these conditions:

- Avoid using interior-grade materials (for example, paper-faced gypsum board) that lack the appropriate moisture or UV resistance for exterior use. Ensure all materials meet relevant standards, such as ASTM C1186, *Standard Specification for Flat Fiber-Cement Sheets*, for fiber cement or ASTM D3679, *Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Siding*, for vinyl soffits, where applicable.[3,4]
- Utilize corrosion-resistant fasteners, hangers, and accessories (that is, stainless steel, galvanized steel, or aluminum) suitable for the local environmental conditions, adhering to codes referencing standards like ASTM A653/A653M, *Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process*, for steel coatings.[5]
- Minimize the potential for galvanic interaction (electrolysis) by ensuring that contacting dissimilar metals are isolated or appropriately selected for compatibility.
- Allow for thermal expansion and contraction in extended soffit runs by using appropriate joints and movement detailing for both cladding elements and the underlying construction to prevent buckling or cracking.
- Select UV-stable and moisture-resistant finishes and sealants that will not degrade, chalk, or peel prematurely under exposure to sunlight and damp conditions.
- In fire-prone areas (Wildland-Urban Interface), specify ignition-resistant or noncombustible materials that meet local building codes to enhance the structure's durability against fire exposure.

Inspection and Maintenance Access

Emerging legislation, such as California Senate Bills 326 and 721, requires routine inspection of exterior elevated elements, including decks and soffits.[i,ii] While planned access supports these mandates, poorly detailed openings or panels can compromise enclosure continuity, leading to water intrusion, thermal bridging, or condensation.

To balance inspection needs with long-term performance, designers, working with owners and contractors, should:

- Coordinate the soffit layout with structural framing to allow visual access to load-bearing components and associated waterproofing systems while minimizing penetrations.
- Incorporate removable panels or separable finishes at planned intervals, detailed with gaskets, flashings, sealants, and insulation to restore continuity when closed.

Cladding Attachment

Soffits often conceal mechanical or structural systems, and even limited cladding loss can lead to costly damage and repair difficulty. Attachment design must ensure a continuous load path from the cladding through its fasteners and subframing to the primary structure. Fastener type, spacing, and edge distances should be based on material properties and expected wind pressures. The required stiffness and connection detailing vary by system type, and designers should verify allowable spans and fastener performance using manufacturer data or project-specific engineering.

Field checks can reveal loose panels but do not verify wind performance. In high-wind areas, soffit cladding should be supported by testing or engineering verification (for example, ASTM E330, *Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference*; TAS 202, *Criteria for Testing Impact & Non-impact Resistant Building Envelope Components Using Uniform Static Air Pressure*).[6,7] Where testing data are unavailable, specify fastener type, size, and spacing based on calculated design pressures.

Verifying Soffit Performance

Soffit performance is difficult to evaluate using standard hygrothermal or thermal modeling tools because their complex geometry, orientation, and variable boundary conditions fall outside the assumptions these programs rely on. As a result, WUFI and THERM often produce misleading results for soffit assemblies.[8,9]

The primary limitation is that soffit behavior is primarily driven by convective heat and moisture transport. In contrast, conventional models assume diffusion-based mechanisms and are unable to represent moving or stagnant air pockets.

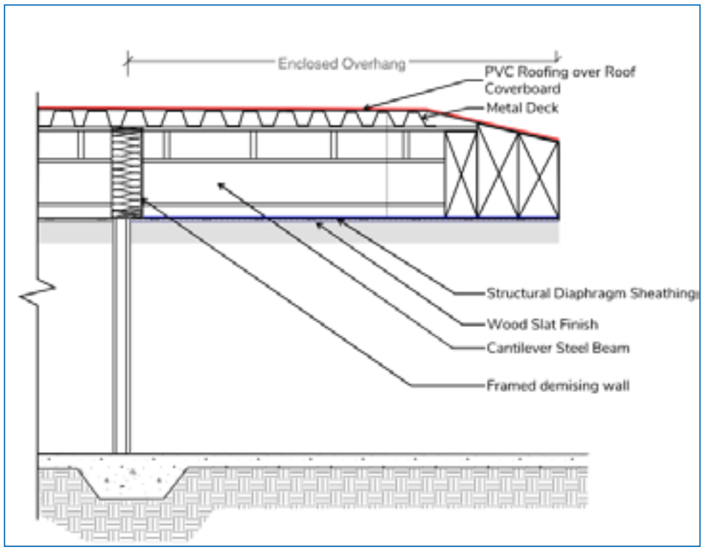

FIGURE 9. Original design of the roof overhang.

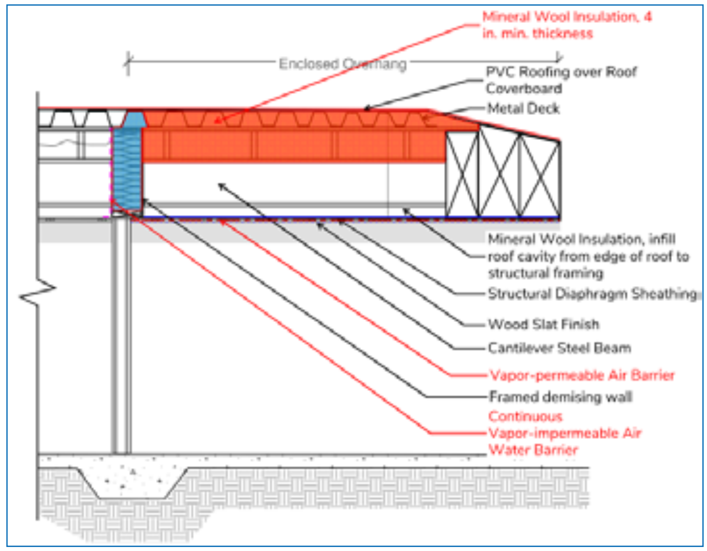

FIGURE 10. Enhanced insulation design for roof overhang.

In practice, soffit performance is best verified through a detailed review of construction documents and an understanding of the intended cavity classification (open, semi-vented, or closed). Evaluating control layer continuity and identifying potential stagnant air zones typically provides more reliable insight than modeling.

Computational fluid dynamics (CFD) can be used to study airflow and temperature in complex geometries but is generally limited to projects with unusual configurations or elevated performance requirements due to its cost and specialized expertise requirements.

CASE STUDY

A Northern California roof overhang illustrates how these principles integrate. The project team selected an unvented soffit design because the soffit sheathing functions as a diaphragm, and vents were not feasible. Venting would also have increased moisture exposure and reduced enclosure control.

The overhang is above unconditioned exterior space and connects to a conditioned attic through a framed demising wall. The team intentionally placed the soffit outside the thermal envelope to separate it from the conditioned attic while controlling moisture and air movement. The original assembly featured a low-slope polyvinyl chloride roof over metal decking supported by steel cantilever beams, with plywood diaphragm sheathing and a wood slat finish (**Fig. 9**).

The detailing approach drew on moisture-management principles from CBC Section 1202.3, *Unvented Attic and Unvented Enclosed Rafter Assemblies*, even though the section directly addresses attic spaces rather than exterior soffits.[2]

Key strategies included the following:

- Applying a hybrid insulation strategy to maintain continuity of control layers. The team used rigid noncombustible insulation where broad, accessible planes allow continuous coverage and supplemented with mineral wool batts or board-cut inserts at irregular framing or penetrations. This approach improves constructability, maintains continuity, and reduces the risk of condensation on cold surfaces exposed to nighttime cooling and sky radiation (**Fig. 10**).
- Sealing the demising wall between the conditioned attic and the soffit with a continuous, vapor-impermeable air/water barrier maintains the continuity of the air and vapor control layers and isolates the soffit from interior, moisture-laden air. The team placed the barrier on the interior side of the insulation to align with the existing interior air barrier system and simplify continuity detailing. This placement responded to constructability constraints rather than condensation risk, which is minimal in Northern California's mild, mixed-dry climate.
- Installing a vapor-permeable air barrier along the underside of the soffit sheathing prevents air infiltration through convection while still allowing moisture to dry to the exterior through diffusion.

The design team chose not to use spray foam to insulate the roof overhang cavity because, according to National Fire Protection Association (NFPA) definitions, spray foam is combustible. Spray foam in a concealed space would necessitate an A-rated thermal barrier to meet fire safety codes and could also trigger NFPA 13 sprinkler requirements, increasing construction complexity and cost.[10] Noncombustible insulation, such as mineral wool, eliminates these concerns.

This case illustrates that the decision to use a ventilated or unventilated soffit should be based on the building's functional needs, environmental conditions, and constructability considerations, with proper detailing, such as insulation placement, air barrier continuity, and moisture management, ensuring a durable, high-performance assembly.

CONCLUSION

Soffits are critical enclosure components, not merely architectural finishes. Field investigations reveal that gaps in control layers, inadequate moisture management, and insufficient attachment often result in leakage, corrosion, and premature failure.

Durable performance requires early coordination of control layer continuity, water management, vented or unvented strategies, moisture-tolerant materials, and engineered attachment systems.

When properly detailed, soffits maintain enclosure integrity, control moisture, and improve resilience during wind and rain events. Treating soffits as integral enclosure elements supports long-term durability and code compliance across building types and climates.

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ENDNOTES

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How to Investigate the Impossible

ABSTRACT

If you have ever spent months catching dripping water in a bucket or corralling unwanted moisture with sandbags, and the source of water intrusion still eludes you, what can you do to figure out the problem? After conventional flood tests and Band-Aid repairs have failed to address the issue, what are the next steps? This presentation addresses these questions by examining two case studies of water penetration in existing buildings. This presentation will delve into the investigative methods, diagnosis, and final repair strategy used in two scenarios where the source and cause of water penetration were far from obvious. For both case studies, we will explain the multistep investigative process, including red herrings, diagnostic tests, monitoring activities, and investigative repairs. Factors that limit investigations, such as the availability of as-built construction documentation, budget limitations, physical access, and disruption to building users, will be discussed. Finally, the reasons why the initial repairs were ineffective and how our investigative findings led to the appropriate repair strategies will be reviewed.

LEARNING OBJECTIVES

- Explain the factors that lead to the most difficult water intrusion investigations.
- Review techniques, methods, and tools that can be used for complex water penetration investigations.
- Discuss how water moves through materials, including capillary action, diffusion, vapor transmission, and mass transport under pressure.
- Describe the relative effectiveness of different repair techniques.

SPEAKER

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Clarissa Binkley is a principal at 4EA Building Science and is the office director for its Oakland, California, operations. She has 16 years of experience researching and consulting on the building enclosure. Her work in the industry began from the energy perspective, studying trends and correlations in building energy use. Her experience has expanded to include consulting on both new construction and existing building projects in climate zones across North America.

AUTHOR:
Clarissa Binkley, PEng

If you have ever spent months collecting dripping water in a bucket or chasing elusive leaks with sandbags, only to find the source of water intrusion remains a mystery, what comes next? When conventional flood tests and Band-Aid repairs fail, what steps can help you uncover the real problem?

This presentation addresses that question through a detailed case study of water penetration in a commercial building. It explores investigative methods, diagnostic testing, and repair strategies used in two complex scenarios where the cause of the moisture intrusion was anything but obvious. The case study outlines a multistep investigative process, including diagnostic detours, monitoring efforts, and exploratory repairs. The author also examines constraints that frequently hamper such investigations: limited documentation, tight budgets, restricted access, and the need to avoid disrupting occupants. Finally, the author analyzes why initial repairs failed and how her team's findings ultimately informed a successful, long-term repair strategy.

INTRODUCTION

Moisture intrusion remains one of the most persistent and expensive threats to building durability and performance. When water infiltrates a structure, it can damage finishes, rot structural components, promote mold growth, and pose serious health risks, all of which disrupt daily life and can trigger legal disputes among stakeholders.

What makes these problems particularly insidious is that moisture damage often develops slowly. A minor leak may go unnoticed for years while silently corroding metal, decaying wood, or supporting microbial growth within concealed cavities. What begins as a minor nuisance can escalate into a costly, hazardous issue.

This paper focuses on one of the most challenging types of water intrusion: ***the unsolvable leak***, where the source is elusive and early investigative efforts yield no clear answers. There are several factors that can contribute to an unsolvable leak, including the following:

- **Complex building designs** and assemblies often obscure the water's path. The more distance and material layers between the exterior entry point and the interior symptom, the harder the diagnosis.
- **Concealed construction**, such as rigid insulation behind waterproofing or hidden structural supports, adds to the difficulty by concealing water intrusion paths from view. Assemblies like conventional roofs, exterior insulation and finish system wall systems, or spray foam–insulated attics can conceal water movement effectively.
- **Multiple leak points** can confuse investigators. Water might follow more than one path, producing symptoms in unexpected places. Like the three-body problem in physics, overlapping variables can create misleading evidence.
- **Human factors** also complicate investigations. Inconsistent or unreliable reports from occupants can misdirect efforts. Stakeholders may hesitate to disclose past leaks or repairs due to liability concerns. Even environmental conditions may hinder testing, especially if the leak occurs only during extreme weather, making replication during dry or calm periods impossible.
- **Non-leaks** are another confusing culprit. Condensation, which can sometimes be mistaken for leakage. Warm, moist air contacting cold surfaces can cause water to condense, creating symptoms that mimic an exterior leak, particularly in poorly insulated or ventilated spaces.

Ultimately, understanding how water behaves in and around buildings is critical. While bulk water movement, driven by gravity, hydrostatic pressure, or wind, is the most obvious, it is not the only mechanism. Capillary action, osmotic pressure, and vapor diffusion can all transport water through or around building materials.

INVESTIGATIVE PROCESS OVERVIEW

Diagnosing and resolving moisture intrusion requires a disciplined, step-by-step approach. The investigator's goal is to identify the entry point, trace the water's path, and develop an effective, durable repair, while balancing cost, access, and impact on occupants.

The process typically begins with a review of existing information. Interviews with maintenance staff or tenants can offer valuable insight into when and how the leak presents. Historical construction documents, repair records, and early photographs can reveal vulnerable details or incomplete fixes. A visual inspection helps form initial hypotheses, looking for signs like staining, corrosion, efflorescence, or deformed finishes.

Next, investigators identify plausible water entry paths based on the evidence (**Fig. 1**). These are evaluated for likelihood, tested against known symptoms, and ranked. Strategic decisions must be made about which to investigate first, balancing investigative cost with the likelihood of each hypothesis.

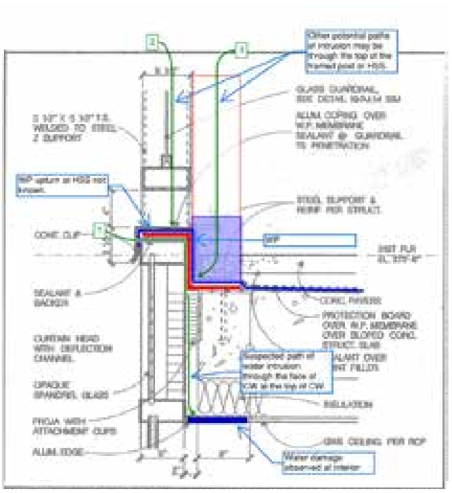

FIGURE 1. Example of document outlining potential paths of water intrusion on a record drawing detail of condition.

Testing then proceeds in phases. Controlled water testing, dye tracing, and pressurized simulations replicate real-world conditions. Infrared cameras, moisture meters, and borescopes offer noninvasive ways to detect hidden moisture. When necessary, selective demolition exposes concealed assemblies for direct observation.

Moisture investigations are rarely linear. Each test may validate or refute earlier hypotheses, requiring investigators to adapt. It is a recursive process: testing, revising, and retesting until a defensible conclusion is reached.

Only once the true source is confirmed should repairs be designed. These repairs must address root causes, not just surface symptoms. Whether the issue involves failed flashing, discontinuous membranes, drainage issues, or material incompatibilities, successful solutions typically require thoughtful design and skilled execution.

Finally, post-repair monitoring—via sensors, inspections, or occupant reports—helps confirm the problem has been fully resolved and builds confidence in the repair's success.

CASE STUDY 1: SAN FRANCISCO RETAIL STORE

This case study focuses on a commercial retail store in San Francisco, California, where ceiling leaks had persisted for over 3 years. Despite multiple investigations, including electronic leak detection, flood testing, and repeated roof repairs, the problem continued. The leak only appeared during gusty storms with heavy rains, making replication during normal weather impossible.

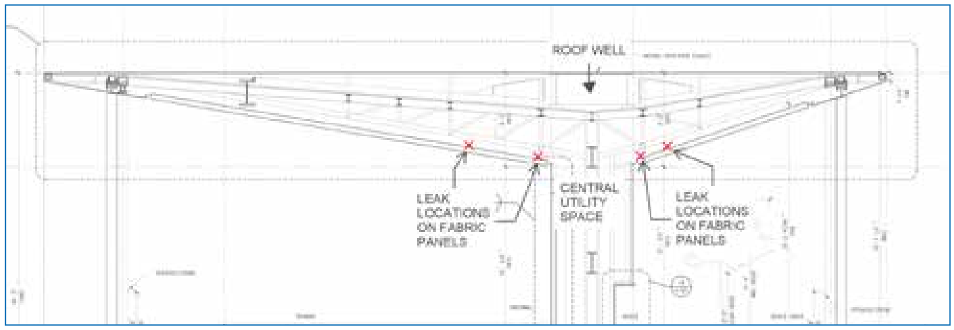

FIGURE 2. Cross section of roof with leak locations.

Water consistently pooled on the floor and dripped from ceiling panels within a central utility area (**Fig. 2**, **3**). The concealed nature of both the roof and ceiling assemblies significantly hindered direct observation. The roof was covered by a flat photovoltaic (PV) panel array, and the interior ceiling by large fabric panels that were cost-prohibitive to remove.

Prior investigations yielded no answers, so the author's team at 4EA Building Science (4EA) began with a thorough review of prior findings and added their own observations. Based on this, they identified 14 potential leakage paths, including the following:

- Field of roof (horizontal and vertical)
- PV panel and tie-off post supports
- Horizontal penetrations
- Parapet cladding attachments
- Drains, roof edge, and parapet interfaces
- Expansion joints, skylights, louvers, and access panels

The team prioritized the most plausible leakage paths based on historical data and began localized testing aimed at systematically confirming or ruling out

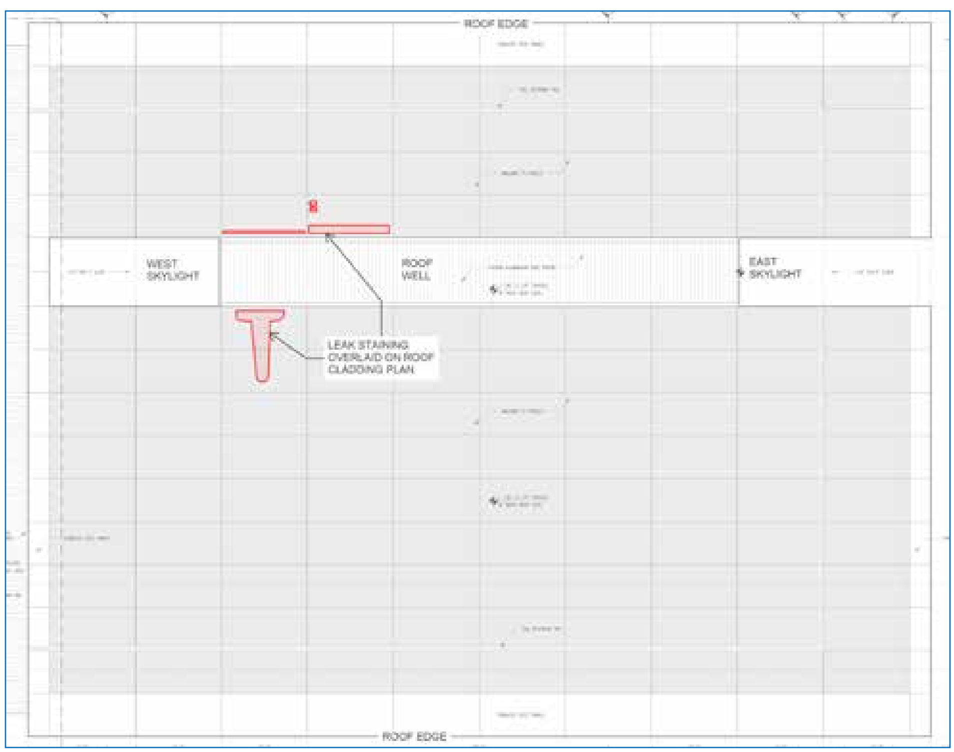

FIGURE 3. Roof cladding plan with leak stain locations overlaid.

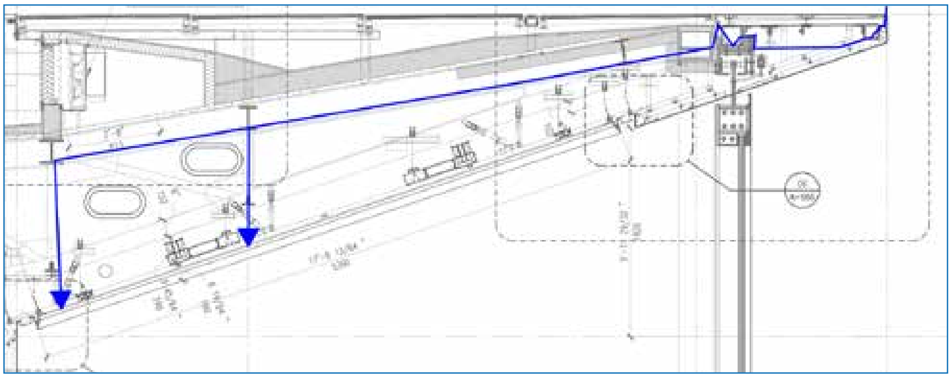

FIGURE 4. Assumed water intrusion path.

specific potential intrusion paths. They opened select roof and louver areas, conducted targeted water tests, and monitored conditions inside the ceiling plenum. Despite identifying minor roof issues (for example, membrane blisters and poor sealing at penetrations), none explained the persistent leak.

With no conclusive results from the roof well or the areas directly above the stains, the team shifted focus to the roof edges, much farther from the observed interior symptoms.

After removing several fascia panels, the team discovered potential waterproofing breaches. Water testing under normal conditions showed nothing, but during a subsequent test conducted on a stormy night with wind gusts exceeding 75 mph (120 km/h), the team finally replicated the leak: first at the exterior glazing, then, 2 hours later, at the interior ceiling panels.

This confirmed the team's suspicion: wind-driven water was entering at the fascia, then traveling inward via structural flanges, likely bypassing sealed penetrations by being drawn upward by pressure differentials (**Fig. 4**).

The team developed a comprehensive repair strategy targeting the fascia waterproofing, which was implemented shortly thereafter. Three years later, the leak has not returned.

While the exact water path may never be fully known, the team is confident that the intrusion occurred through the compromised fascia, was wind-driven along concealed structural paths, and was ultimately resolved by targeted, informed repair.

CASE STUDY 2: SEATTLE EDUCATIONAL BUILDING

The second case study focuses on a recently constructed educational building in Seattle, Washington, where there was water intrusion appearing on interior surfaces of a curtainwall below a protective roof canopy overhang.

Following the end of construction, no leaks were reported in this area. That is, until a sign was installed on the roof canopy directly above the affected area, shortly after which a leak began to appear. The sign, mounted to the roof via steel stanchions, was thought to be the obvious cause. However, the penetrations appeared to have been properly flashed into the roofing, and the leak's persistence left the true source unclear. Furthermore, water appeared on the inside of the curtainwall system during or following heavy rain, with one major leak occurring days after rainfall, a delay that suggested water movement through concealed paths.

In an effort to better understand the extent of the leak, a portion of the soffit of the canopy exterior to the curtainwall was removed, and signs of water staining were observed on the back side of the soffit sheathing. This suggested that water was somehow leaking through the roofed canopy and making its way into the building at the curtainwall head.

Given the complicated nature of the condition and the inconsistent report of water intrusion, 4EA started by identifying potential paths for water intrusion—of which four paths were identified (**Fig. 5**).

The team began to perform targeted testing and investigation to confirm or rule out the various paths for water intrusion. From initial observations, the team noted water staining and damp conditions behind the soffit, particularly around the water-resistant barrier seams and exposed fireproofing, though the insulation and sheathing behind remained dry. Attention soon turned to the curtainwall itself. At the head of the wall, the team observed inconsistent sealant detailing around the steel T-anchors that penetrated the air barrier and interrupted the primary joint seal. Some anchors were fully covered in sealant, while others were only partially sealed, creating possible gaps. Notably,

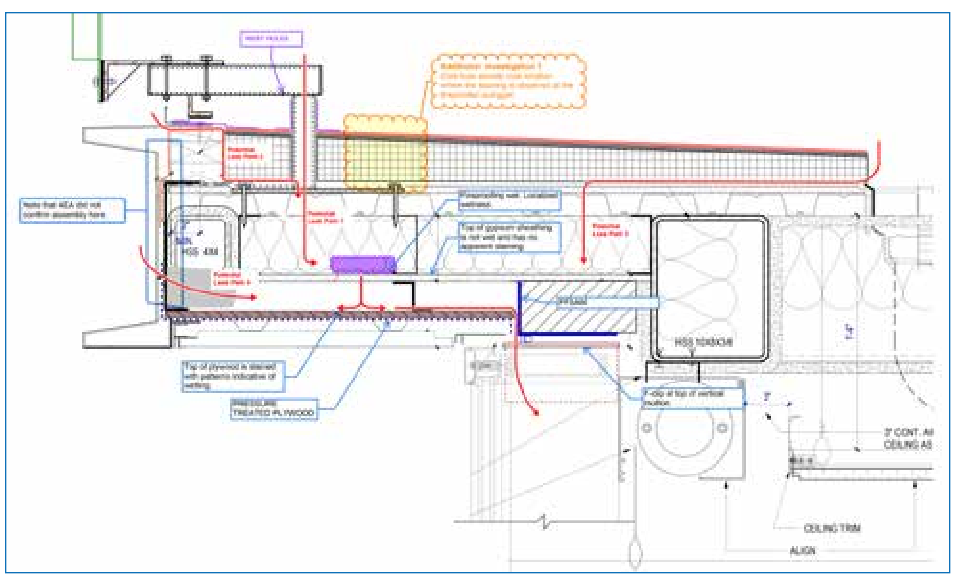

FIGURE 5. Identified potential paths for water intrusion.

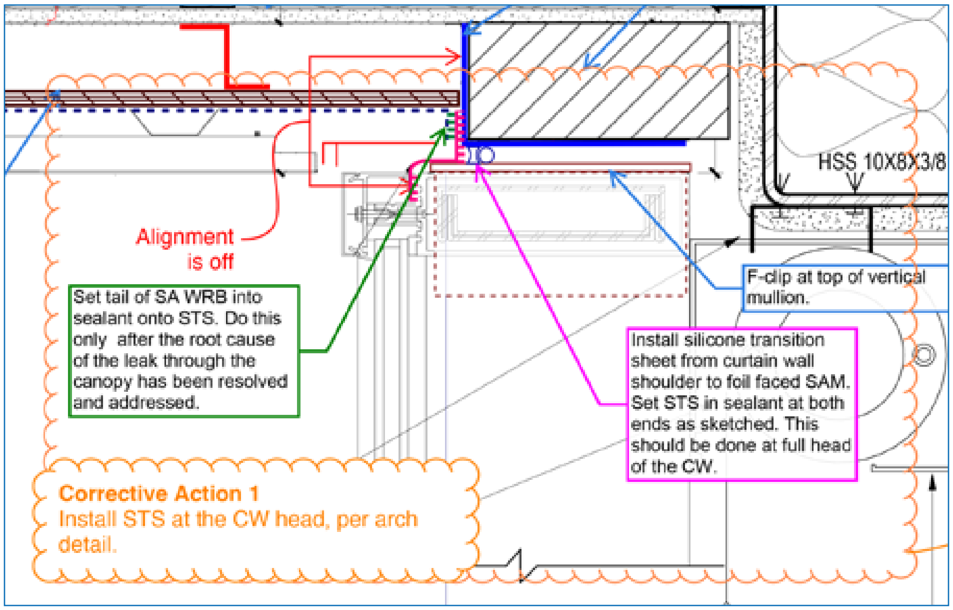

FIGURE 6. Sketch showing corrective action taken at the curtainwall head to mitigate for water intrusion into the building.

the as-built condition of the curtainwall deviated from the original design drawings, with the wall set back farther than anticipated, introducing unexpected gaps in the weather barrier interface.

Spray testing confirmed that these inconsistencies were not just cosmetic. When water was sprayed directly at the curtainwall head, leaks quickly appeared at the interior vertical mullions, tracking down through the aluminum framing. This confirmed that the curtainwall was allowing water in, and the interior symptoms were not just the result of roof leaks. Rather than bypassing the system entirely, water was entering the curtainwall extrusion through these small gaps at the T-anchors, then traveling internally within the framing and appearing on the interior of the building.

A repair strategy was developed to address this specific path of water intrusion into the building (**Fig. 6**).

While the curtainwall leaks were confirmed, the roof remained a suspect in the broader problem. 4EA returned for further investigation and performed multiple targeted exploratory openings in the roof system. Interestingly, and confusingly, the roof openings exhibited only dry roof conditions, dry sheathing, and dry insulation. However, water was found in the steel pan deck flutes below the roof.

Typically, in a leak investigation for a conventional roof assembly, the procedure would be to perform an opening at or near the suspected leak, and to search for wet materials. Once wet materials are uncovered, it is typical to "chase" the wet material back to the root cause of the leak. That could not be done here because the roof assembly, from the vapor retarder to the underside of the roofing membrane and everything in between, were completely dry at all investigative opening locations.

Water was somehow bypassing the roof assembly and leaking through the canopy where it was daylighting on the concealed side of the canopy soffit sheathing and draining toward the curtainwall.

Upon further investigation, the team soon started to dial in to a potential root cause for the observed water intrusion. It turns out that as part of the installation of the sign atop the canopy; some defects were discovered in the roof membrane above the canopy which resulted in a complete removal and reinstallation of the roof. As part of this re-roof, the roof edge flashing was left in place, and the new roof tied into the existing edge flashing.

Following additional spray testing, flood testing with dye, and targeted visual observation, the team was not able to pinpoint an exact, repeatable, cause for the water intrusion. One condition that did appear suspect was the roof edge flashing, and specifically, the tie-in of the roofing to the roof edge flashing at splices in the flashing. As part of the re-roof, additional insulation was added to the roof canopy which caused the roof surface to rise above the surface of the existing roof edge flashing, resulting in a narrow undrained trough condition. This trough appears to have been filling with water during large storm events, and exposing a discontinuity in the roof edge flashing which appears to have resulted in the leak through the soffit that also bypassed the roof assembly entirely (**Fig. 7**).

Based on these findings, 4EA recommended a two-step corrective approach to address the two leaks (**Fig. 8**):

1. Address the leak at the curtainwall interface by providing a silicone

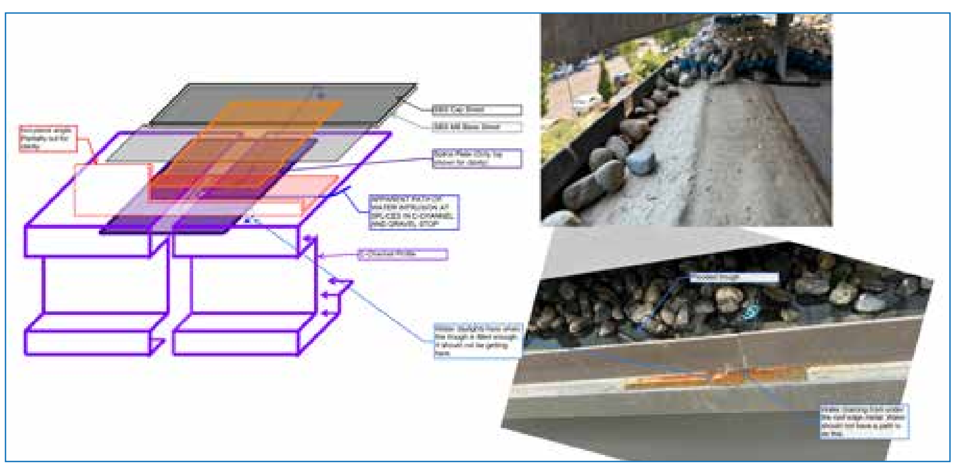

FIGURE 7. View of suspected leak path through canopy. This is also the same path as Path #2 in Figure 5.

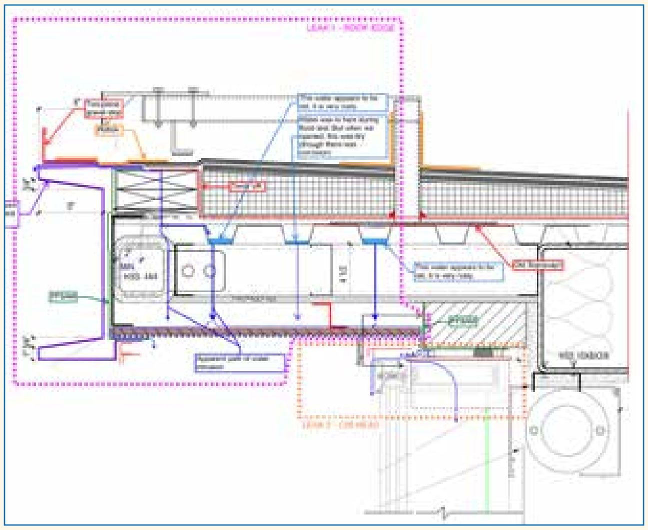

FIGURE 8. Opinion on the two likely leak paths following investigation.

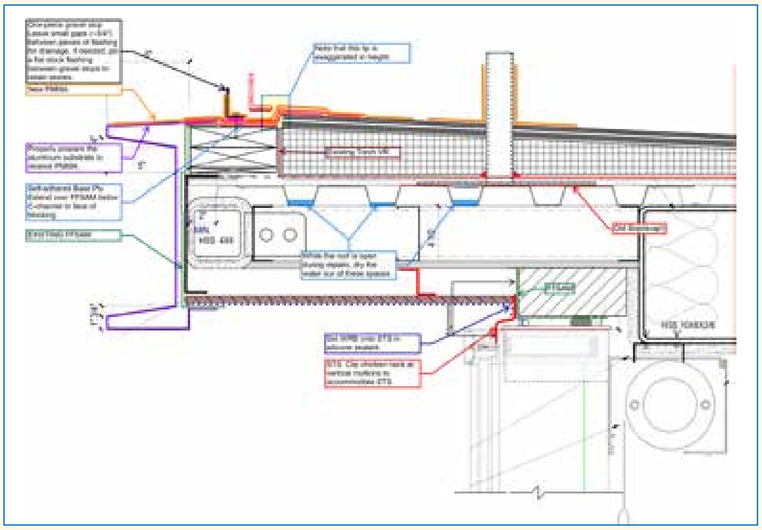

FIGURE 9. Proposed repair.

transition sheet to seal from the water-resistive barrier to the curtain-wall shoulder (**Fig. 9**).

2. Remove and reinstall the two-piece roof edge flashing with a new one-piece roof edge flashing. Relocate the roof edge flashing to remove the trough condition. Properly seal splices in the existing cladding to mitigate against future leaks (Fig. 9).

This case highlights how even relatively minor post-construction changes, such as the addition of a sign, can undermine enclosure performance if not executed with rigorous attention to detailing and sequencing. In this case, the combination of deviations from the design documents, inconsistent workmanship, and a lack of continuity in both the air and water barriers contributed to complex, multi-path moisture intrusion. Through careful observation, testing, and targeted openings, the team was able to isolate the failures and guide the project team toward comprehensive, corrective action.

CONCLUSION

When dealing with elusive water intrusion, success hinges not on having the right answer at the outset, but on knowing how to ask the right questions and persistently revisiting them as new information emerges. Both case studies in this paper demonstrate that moisture investigations are rarely straightforward. Symptoms often appear far from the source, and assumptions based on location, timing, or previous work can delay or derail progress.

In the San Francisco case, it took months of misdirection before wind-driven intrusion at a remote roof edge was identified as the cause of interior ceiling leaks. In Seattle, what began as a suspected roof penetration leak turned out to involve two distinct failures: improperly sealed curtainwall anchors and improper roof edge flashing. Neither issue alone explained the full extent of the leakage, but each was critical to the final diagnosis and resolution.

These examples underscore several key lessons:

- Unsolvable leaks are often solvable, just not with surface-level investigation.
- Diagnostic discipline, not just intuition, is essential. Water testing, controlled demolition, and documentation review must be carefully sequenced and grounded in building science.
- Construction deviations, even small ones, can have outsized impacts. As-built conditions must always be verified rather than assumed.
- Repairs should be based on root causes, not symptoms. Without understanding the mechanism of failure, even well-intentioned fixes may perpetuate the problem.

Above all, solving difficult leaks requires a methodical, skeptical mindset. It is not enough to find a plausible cause; you must find the actual cause. That often means challenging initial assumptions, confronting uncomfortable findings, and sometimes, recommending broader repairs than anyone hoped for.

In a world of hidden assemblies and imperfect documentation, leak investigation will always involve some uncertainty. But by combining curiosity with rigor, we can transform that uncertainty into clarity and design durable, effective repairs that last.

Is Wood Good? Wind Uplift Performance of Mechanically Attached Roof Assemblies

ABSTRACT

Wood decking is commonly used in residential roofing assemblies and is gaining popularity in commercial roofs due to its ease of installation and cost-effectiveness. However, numerous instances of failures and damages have been noted in oriented strand board (OSB) decking used in mechanically attached systems that were less than 5 years old, despite not being exposed to significant weather events. To address these failures and to identify acceptable wood deck types for commercial roofing, the Special Interest Group on Dynamic Evaluation of Roofing Systems (SIGDERS) completed extensive dynamic wind uplift experiments on mechanically attached membrane roof assemblies with wood decking. This comprehensive study involved both dynamic small-scale and system-level investigations following CSA A123.21, *Standard Test Method for the Dynamic Wind Uplift Resistance of Membrane-Roofing Systems*. The study assessed four different wood deck types, various mechanically attached membrane types, and two commonly used fasteners from various sources while keeping the other above deck components consistent. This presentation will discuss the data from over 200 small-scale specimens along with wind uplift resistance findings from more than 20 full-scale mock-ups. Key insights into the performance of various wood decks and recommendations tailored specifically to commercial mechanically attached membrane roof assemblies will also be presented.

LEARNING OBJECTIVES

- Describe the wind performance of mechanically attached membranes over three different types of wood decks.
- Discuss the performance small-scale dynamic testing.
- Discuss wind uplift performance based on full-scale dynamic testing.
- Discuss the key recommendations for commercial roofs in terms of wood deck types for use with mechanically attached membranes.

SPEAKERS

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Flonja Shyti is a research council officer with the Construction Research Centre of the National Research Council Canada. As part of the roofing and insulation group, her research focuses on the performance requirements for climate resilience of commercial and residential roofs and their integration into codes. She is a member of the Single Ply Roofing Industry and IIBEC and is registered with the Professional Engineers Ontario. She received her master's degree in civil engineering from the University of Ottawa.

Bas Baskaran, F-IIBEC, PhD, PEng
Principal Research Officer, National Research Council Canada

Bas A. Baskaran is a principal research officer at the National Research Council Canada where he researches the performance of roofing systems and insulation. He is an adjunct professor at the University of Ottawa and a member of the Roofing Committee on Weather Issues, IIBEC, the Single Ply Roofing Industry (SPRI), and several other technical committees. Baskaran is a research advisor to various task groups of the *National Building Code of Canada*. He was recognized by Queen Elizabeth II with a Diamond Jubilee medal for his contribution to fellow Canadians.

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INTRODUCTION

A drawback of utilizing wood as a decking material lies in its inherent susceptibility to moisture, which can result in swelling, warping, and potential structural deficiencies. Moisture-related dimensional stability problems are also reported by the National Roofing Contractors Association (NRCA), which influenced their inclination towards the use of plywood with panels complying with structural plywood, product standard 1, over oriented strand board (OSB) and wood-based structural-use panels, product standard 2.[2] On the other hand, Hogan highlights that both OSB and plywood can function effectively if kept dry.[3,4] Moreover, the intrinsic variability of wood, owing to its natural composition, can lead to inconsistencies in both performance and durability. Wood decks are more commonly found in the western regions of Canada, with wood accounting for 50% of the market share in British Columbia, based on data from approximately 10,000 roofs.[1] The majority of residential homes have wood as a decking component as part of the roof assembly, with both plywood and OSB decks being used. In commercial roofing, wood is appealing due to its ease of installation and cost-effectiveness. FM Global, a provider of commercial property insurance, only provides guidance for the securement of lumber and plywood decks through *FM Property Loss Prevention Data Sheet 1-29: Roof Deck Securement and Above-Deck Roof Components*.[5] FM Global lists FM-approved roof assemblies that confirm which roof system configurations perform as expected under demanding circumstances outlined by FM. These approved systems can be viewed on RoofNav. However, currently, there are no FM-approved systems with wood as a deck listed on RoofNav. Similarly, the Canadian Standards Association's CSA A123.21, *Standard Test Method for Dynamic Wind Uplift Resistance of Membrane-Roofing Systems*, which was developed by the Special Interest Group on Dynamic Evaluation of Roofing Systems (SIGDERS) and is mandated by the *National Building Code of Canada*, primarily addresses roofs with steel decks.[6,7] When wood decking, especially OSB, is used in mechanically attached roof systems (MARS), the fastener pull-out resistance can be negatively impacted by cyclic wind loading. A similar issue also applies to partially attached roof systems (PARS).

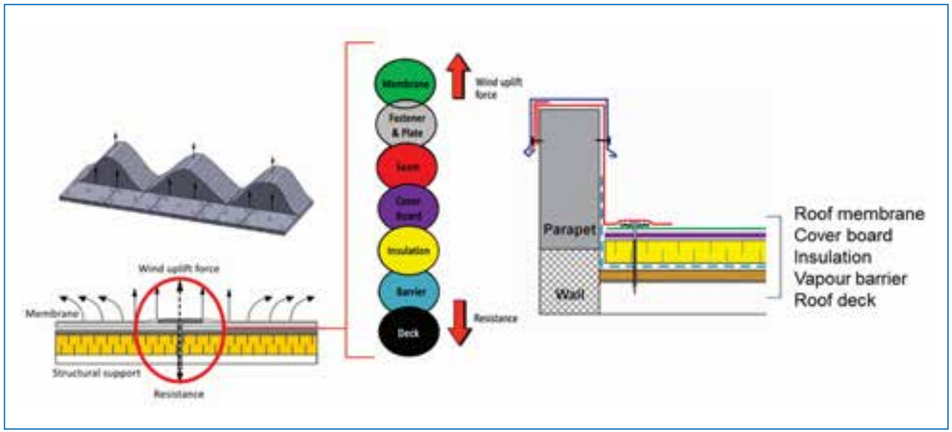


FIGURE 1. Stress distribution of a mechanically attached roofing system.[6,14]

In MARS, the deck/fastener interface experiences higher stress accumulation as the wind load travels through a structural load path from the membrane to the fasteners and then to the deck, as illustrated in **Fig. 1**.[9] Baskaran and Ko identify the deck and fastener engagement as one of the weak links in MARS, and they explore ways to optimize wind uplift resistance of MARS, highlighting that characteristics such as a thicker steel deck can enhance this resistance.[10]

The testing by Baskaran and Ko was completed only for steel decks following the dynamic standard CSA A123.21. Efforts are underway to broaden the scope of CSA A123.21 to include wood and concrete decks in commercial roofing systems. As part of this initiative, SIGDERS evaluated the performance of four wood decks and two steel decks, along with two commonly used fasteners from various sources, under both static and dynamic loading conditions. The small-scale evaluation findings under static and dynamic loading, detailed by Shyti and Baskaran, compare and quantify the reliability of different wood decks for low-slope roof systems.[11] This paper serves as part two of the *IIBEC Interface* article titled "Wood Versus Steel Versus Static Versus Dynamic: Is Oriented Strand Board Reliable for Low-Slope Roofs with Mechanically Attached Components?" The study found that plywood and steel decks deliver more reliable and consistent results when tested under laboratory conditions. Specifically, when compared to OSB, plywood consistently demonstrated higher fastener pull-out values, with less variability in both static and dynamic evaluations. This was evidenced by the coefficient of variability values for plywood decks being within a comparable range to steel decks, indicating consistent and reliable data.

Regardless of the deck/fastener combination, dynamic resistance values were lower than static values. For steel decks, dynamic values averaged 50% to 70% of the static values, while for plywood, they ranged from 60% to 75%. In contrast, OSB's dynamic pull-out resistance values were significantly lower than static values, with notable variability. This inconsistency suggests that OSB is not a reliable deck option, as it poses challenges in consistently reproducing data within the defined criteria. The dynamic results from the study for wood and steel decks are seen in **Fig. 2**. The findings of this paper apply to both MARS and PARS.

This paper builds on previous findings by assessing large-scale MARS with different membranes and decking options. The large-scale testing involved 20 specimens, each measuring 12 × 24 ft (3.7 × 7.3 m), subjected to dynamic loading according to CSA A123.21. This effort aims to validate the small-scale data gathered from over 200 specimens by Shyti and Baskaran. Additionally, it seeks to establish a protocol to extend the system rating obtained for a tested system with a steel deck to the same system with a wood deck using small-scale data.

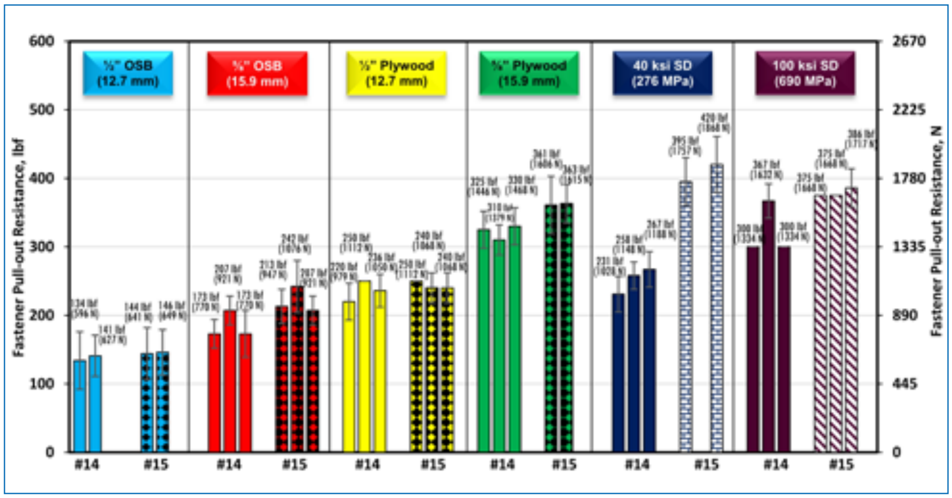


FIGURE 2. Dynamic fastener pull-out resistance for wood and steel deck (SD).[11] *Note: OSB = oriented strand board.*

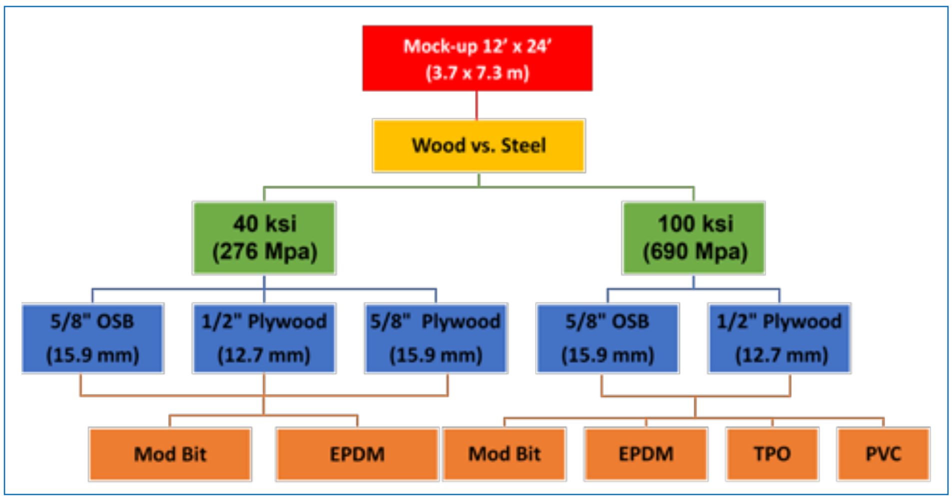


FIGURE 3. Experimental program for system evaluation. *Note: OSB = oriented strand board; mod bit = modified bitumen; EPDM = ethylene propylene diene terpolymer; TPO = thermoplastic olefin; PVC = polyvinyl chloride.*

EVALUATION OF WOOD DECK PERFORMANCE

Test Apparatus and Loading Protocol

Shyti and Baskaran's small-scale study evaluated the performance of wood decks at the interface level, under both static and dynamic conditions. This involved assessing the interaction between various wood deck types and thicknesses with commonly used fasteners. Using the same decking options as Shyti and Baskaran's small-scale study, large-scale 12 × 24 ft (3.7 × 7.3 m) specimens were constructed and cured according to the manufacturer's instructions. These specimens were then subjected to CSA A123.21 dynamic wind loading cycles. The testing in accordance with CSA A123.21 was conducted in the Dynamic Roofing Facility (DRF) at the National Research Council Canada. The DRF is composed of a bottom frame in which the roof specimen is installed and a removable top chamber placed over the roof specimen. The top chamber, where pressure suction is generated, is equipped with six viewing windows and a gust simulator. A detailed description of the DRF can be found in Baskaran et al.[13]

Test Matrix and Specimen Preparation

In line with Shyti and Baskaran's small-scale study, the large-scale evaluation investigated three types of wood: ⅝ in. (15.9 mm) OSB, ½ in. (12.7 mm) plywood, and ⅝ in. (15.9 mm) plywood. However, due to the large variability and difficulty reproducing data for ½ in. OSB in the small-scale study, it was excluded from the full system evaluation. Similar to the small-scale study, the large-scale testing included two grades of steel decks with minimum tensile strengths of 40 ksi (275.8 MPa) and 100 ksi (689.5 MPa), representing the Canadian and US markets, to compare the wind uplift resistance of roof assemblies side by side.

The systems were investigated with various membrane types—modified bitumen, ethylene propylene diene terpolymer (EPDM), polyvinyl chloride (PVC), and thermoplastic olefin (TPO)—that were mechanically fastened to the structural deck (steel or wood). All the above-deck components and application methods were kept the same. This approach ensured that each system's performance was assessed under consistent conditions, providing a reliable comparison of the different combinations of membranes and decking options to ensure a fair comparison of the systems' performance. The experimental program, as outlined in **Fig. 3**, involved evaluating one mock-up for each combination according to CSA A123.21.

For the systems tested with steel decks, both the 40 ksi (276 MPa) and 100 ksi (690 MPa) decks were fastened with #6 (1¼ in.) (31.8 mm) self-tapping screws every 6 in. (152.4 mm) on center. For the systems tested with wood decks, 2 × 10 in. (50.8 × 254.0 mm) wood joists were first installed spaced at 24 in. (609.6 mm) on center, on top of which a 4 × 8 ft (1.2 × 2.4 m) wood board was installed with #8 (2¼ in.) (57.2 mm) screws every 6 in. (152.4 mm) on center. For plywood, the boards were CSA O151:17 (*Canadian Softwood Plywood*) certified, while for OSB, they were CSA O352:21 (*Construction Sheathing*) certified.[15,16]

In the comparison of the three wood decking options to the 40 ksi (276 MPa) steel deck, the membranes selected for evaluation were modified bitumen and EPDM. For the comparison of ⅝ in. (15.9 mm) OSB wood decking to the 100 ksi (690 MPa) steel deck, TPO and PVC membranes were chosen. As previously noted, the construction above the deck was kept consistent between the systems being compared, with only the deck material being variable. The compositions of the MARS with modified bitumen, EPDM, TPO, and PVC are illustrated in **Fig. 4**.

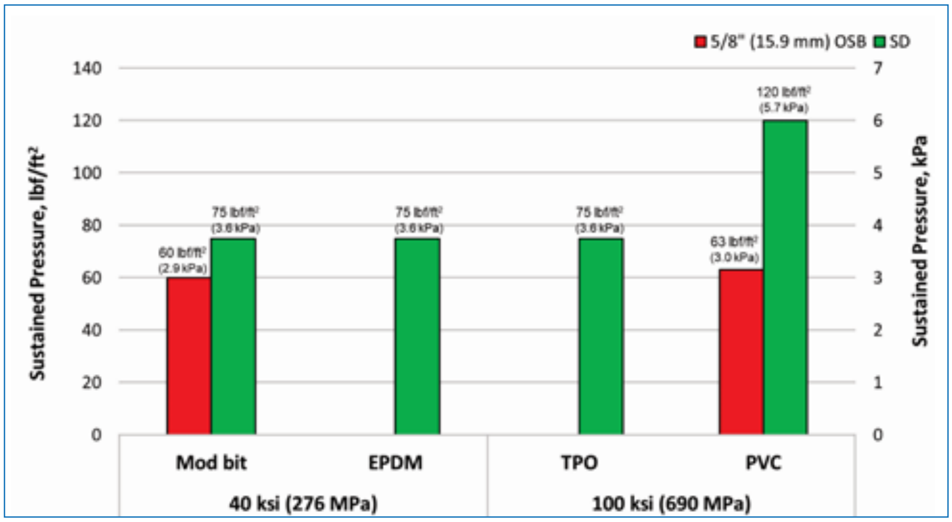


FIGURE 5. Comparison of oriented strand board (OSB) and steel deck (SD) system performance. *Note: mod bit = modified bitumen; EPDM = ethylene propylene diene terpolymer; TPO = thermoplastic olefin; PVC = polyvinyl chloride.*

RESULTS

The wind uplift performance of OSB as a decking component, compared to steel decking, is detailed in **Fig. 5**. The system with a 40 ksi (276 MPa) steel deck sustained a pressure of 75 lb/ft² (3.6 kPa) for both modified bitumen and EPDM membranes when mechanically fastened to the deck. This value remains consistent for the 100 ksi (690 MPa) steel deck with the TPO membrane. However, the 100 ksi (689.5 MPa) steel deck with the PVC membrane achieved a higher sustained pressure of 120 lb/ft² (5.7 kPa). Notably, the modified bitumen membrane featured a narrower sheet width of 36 in. (914.4 mm), whereas the PVC membrane had a wider sheet width of 120 in. (3048 mm).

In contrast, the system with OSB and a modified bitumen membrane sustained a pressure of 60 lb/ft² (6.9 kPa), while the PVC membrane allowed for a slightly higher pressure of 63 lb/ft² (3.0 kPa). When EPDM and TPO membranes were mechanically fastened to the OSB deck, the system could not meet the minimum requirement of 50 lb/ft² (2.4 kPa).

When comparing the sustained pressure of the system with a PVC membrane on an OSB deck versus a 100 ksi (690MPa) steel deck, the pressure was approximately 50% lower when the steel decking component was replaced with OSB. This highlights the significant impact of the decking material on the system's overall wind uplift resistance. The failure mode for the system utilizing a 40 ksi (276 MPa) steel deck with a modified bitumen membrane was characterized by membrane seam delamination (**Fig. 6A**). In contrast, for the same system with an OSB deck, the primary failure mode was also membrane seam delamination (**Fig. 7A**), but it was accompanied by a secondary failure mode of membrane fastener pull-out from the OSB deck. The failure mode for the system with a 40 ksi (276 MPa) steel deck with an EPDM membrane was membrane pull-through at the seam stress plates (**Fig. 6B**), while for the same system with OSB, the

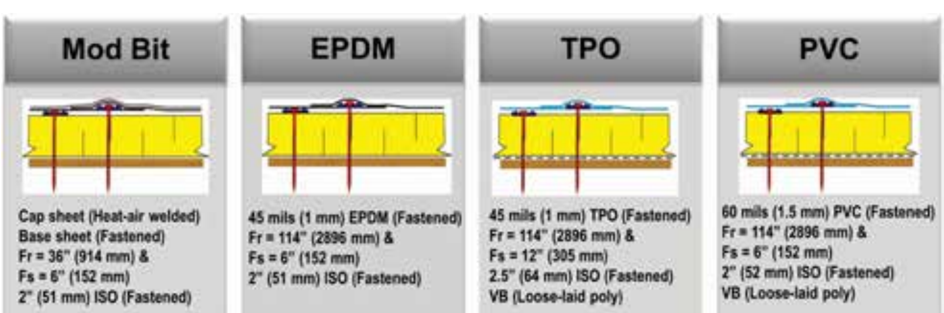
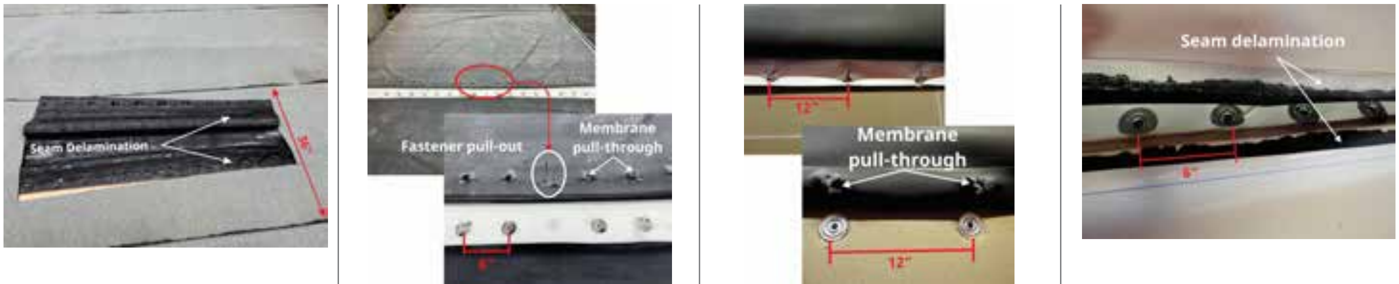


FIGURE 4. System construction for comparing system performance with wood and steel deck. *Note: mod bit = modified bitumen; EPDM = ethylene propylene diene terpolymer; TPO = thermoplastic olefin; PVC = polyvinyl chloride; ISO=polyisocyanurate Fr= fastener row spacing; Fs= fastener spacing; VB= vapor barrier.*



A 40 ksi steel deck system with modified bitumen membrane seam delamination

B 40 ksi steel deck system with EPDM membrane pulled through at seam stress plates and fastener pulled out from the deck

C 100 ksi steel deck system with TPO membrane pull-through at seam stress plate locations

D 100 ksi steel deck system with PVC membrane seam delamination

FIGURE 6. Failure mode of 40 ksi (276 MPa) and 100 ksi (690 MPa) steel deck systems. *Note: EPDM = ethylene propylene diene terpolymer; TPO = thermoplastic olefin; PVC = polyvinyl chloride.*

membrane fastener pulled out from the OSB deck (Fig. 7B).

Similarly, for the system with a 100 ksi (690 MPa) steel deck combined with either TPO (Fig. 6C) or PVC (Fig. 6D) membranes, the failure mode was characterized by membrane pull-through at the seam stress point locations. In contrast, when the same systems were used with an OSB deck, the primary failure mode observed was membrane fastener pull-out from the OSB deck, followed by the subsequent failure of the insulation boards. This failure for TPO and PVC is shown, respectively, in **Fig. 7C** and **7D**.

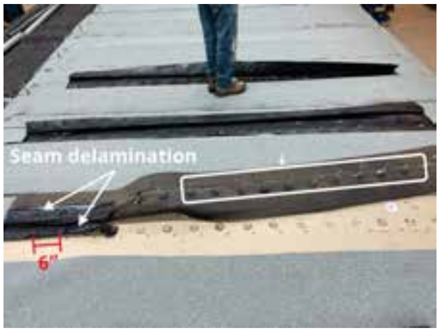
The wind uplift performance of ½ in. (12.7 mm) plywood and ⅝ in. (15.9 mm) plywood as a decking component, in comparison to steel decking, is illustrated in **Fig. 8**. Systems utilizing both 40 ksi (276 MPa) and 100 ksi (690 MPa) steel decks sustained a pressure of 75 lb/ft^2 (3.6 kPa), regardless of the membrane type mechanically attached to the deck. Similarly, the system incorporating ½ in. plywood and ⅝ in. plywood with a modified bitumen membrane also sustained a pressure of 75 lb/ft^2. However, when using ½ in. plywood, the system with an EPDM membrane sustained a pressure of 63 lb/ft^2 (3.0 kPa), while the system with ⅝ in. plywood sustained a pressure of 75 lb/ft^2. The system with a TPO membrane and a ½ in. plywood deck sustained a lower pressure of 50 lb/ft^2 (2.4 kPa). These data underscore the variability in performance based on the type of membrane used with ½ in. plywood decking.

The failure mode for the system with the 40 ksi (276 MPa) steel deck is the same as described above, while when the deck was changed to ½ in. (12.7 mm) plywood, the primary mode of failure for modified bitumen is membrane seam delamination followed by membrane fastener pull-out from the plywood deck (Fig. 7E). For EPDM, the failure is the membrane fastener pull-out from the plywood deck and cracked insulation (Fig. 7F). For both systems with ⅝ in. (15.9 mm) plywood, the failure mode was the same: membrane seam delamination. This failure for modified bitumen and EPDM is shown, respectively, in Fig. 7H and 7I.

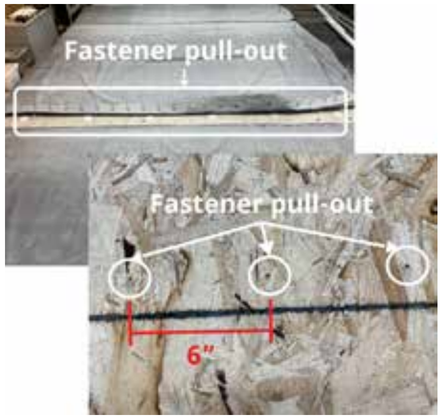
For a system with a 100 ksi (690 MPa) steel deck and either a TPO or EPDM membrane, the failure mode is as described above, while when the deck is changed to ½ in. (12.7 mm) plywood, the failure mode is membrane fastener pull-out from the plywood deck. A summary of the failure modes is illustrated in Fig. 7G for TPO.

Respective small-scale and system data obtained from a ½ in. (12.7 mm) plywood set are compared with steel deck ones by calculating the wood-versus-steel relative ratios both for small-scale ($SS_R = \frac{SS_{Wood}}{SS_{Plywood}}$) and system ($S_R = \frac{S_{Wood}}{S_{Plywood}}$) data in **Fig. 9**. Both the fastener pull-out and wind uplift resistance are higher with a steel deck compared to a wood deck, irrespective of the membrane type, and the higher the fastener pull-out resistance, the higher the wind uplift resistance. It is worth mentioning that the only difference between the two sets of data is the decking component: wood compared to steel. From this comparison, one can establish the requirements for substituting a steel deck from a tested system with a wood deck and how much the substitution affects the tested wind uplift resistance. There is a close resemblance between the small-scale ratios and the system ratios. In the case of the TPO, both the small-scale and system ratios were 0.67, whereas in the case of EPDM and modified bitumen, there was a small variation between the ratios. **Fig. 10** shows the limited data from the ⅝ in. (15.9 mm) plywood compared with a 40 ksi (276 MPa) steel deck, indicating that small-scale ratios (SS_R) were always higher than the system ratios. In the case of modified bitumen, the small-scale ratios compared to the system ratios were 1.41 compared to 1, whereas for EPDM, they were 1.24 compared to 1. In a generalized approach, the tested wind resistance data with a steel deck (CSA_{Steel}) should be modified as follows:

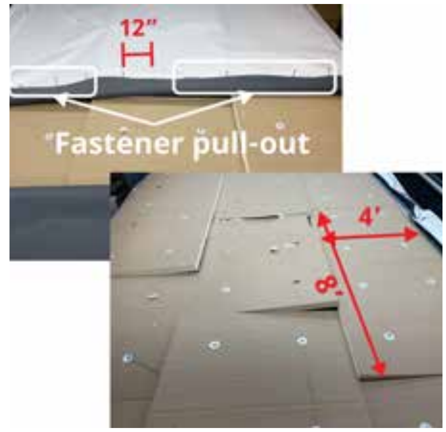
- If the small-scale ratio is greater than 1 (SS_R>1.0), then the wind resistance of a roof assembly with a wood deck (CSA_{wood}) without performing any system testing and based only on small-scale testing, can be extended from the wind resistance of the roof assembly with a steel deck (CSA_{wood}=CSA_{Steel}).
- If the small-scale ratio is greater than or equal to 0.5 and less than or equal



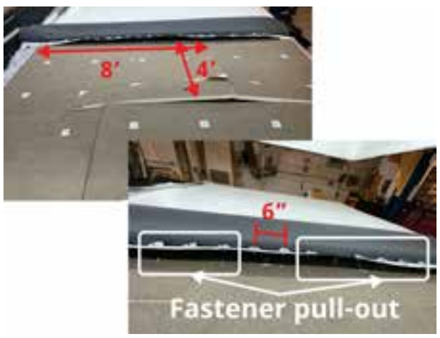
A ⅝ in. OSB deck system with modified bitumen membrane seam delamination as primary failure mode followed by membrane fastener pull-out from OSB



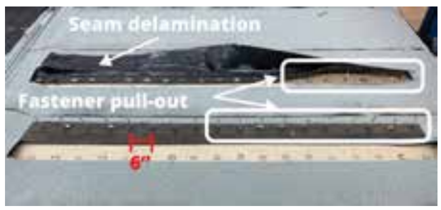
B ⅝ in. OSB deck system with EPDM membrane pulled out from OSB



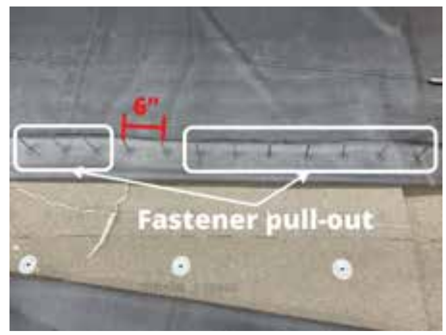
C ⅝ in. OSB deck system with TPO membrane fastener pull-out from OSB as the primary failure mode followed by insulation board failure



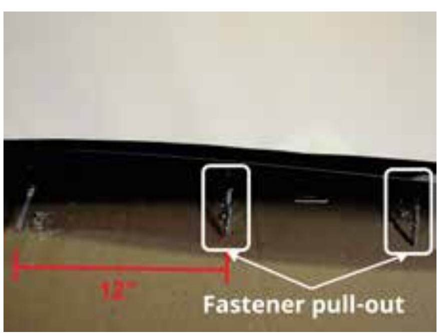
D ⅝ in. OSB deck system with PVC membrane fastener pull-out from OSB as the primary failure mode followed by insulation board failure



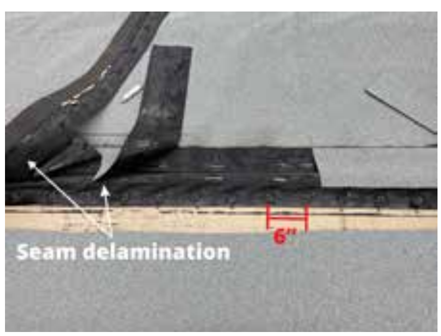
E ½ in. plywood deck system with modified bitumen membrane seam delamination as primary failure mode followed by membrane fastener pull-out from plywood



F ½ in. plywood deck system with EPDM membrane fastener pull-out from plywood and insulation cracked



G ½ in. plywood deck system with TPO membrane fastener pull-out from plywood



H ⅝ in. plywood deck system with modified bitumen membrane seam delamination

I ⅝ in. plywood deck system with EPDM membrane seam delamination

FIGURE 7. Failure mode of ⅝ in. (15.9 mm) oriented strand board (OSB), ½ in. (12.7 mm) plywood, and ⅝ in. plywood deck systems. *Note: EPDM = ethylene propylene diene terpolymer; TPO = thermoplastic olefin; PVC = polyvinyl chloride.*

to 1 ($0.5 \leq SS_R \leq 1.0$), then the wind resistance of a roof assembly with a wood deck, without performing any system testing and based only on small-scale testing, can be extended from the wind resistance of the roof assembly with a steel deck by multiplying by 0.5 ($CSA_{wood} = 0.5 \times CSA_{Steel}$).

» If the small-scale ratio is less than 0.5

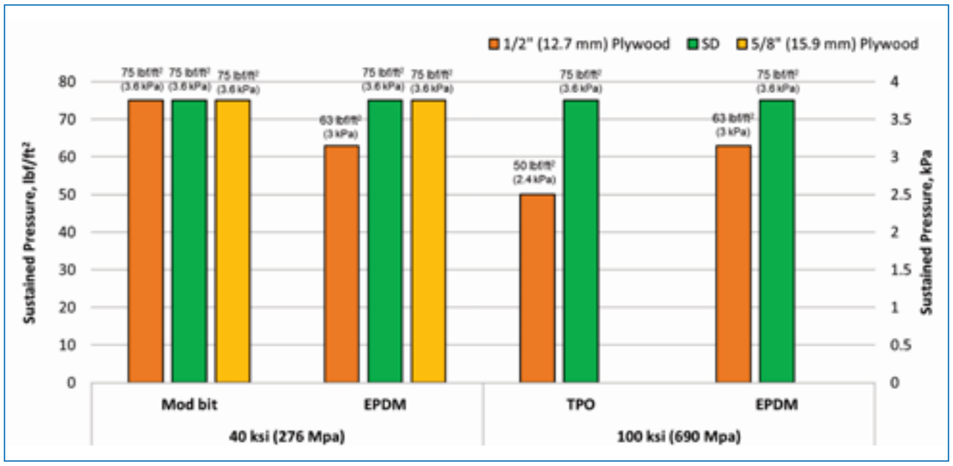


FIGURE 8. Comparison of ½ in. plywood and ⅝ in. plywood deck versus steel deck (SD) system performance. *Note: mod bit = modified bitumen; EPDM = ethylene propylene diene terpolymer; TPO = thermoplastic olefin.*

(SS_R<0.5,); Then full-scale mock-ups should be tested with a wood deck.

CONCLUDING REMARKS

This paper explored the wind uplift performance of large-scale systems with ⅝ in. (15.9 mm) OSB, ½ in. (12.7 mm) plywood, ⅝ in. plywood, and both 40 ksi (276 MPa) and 100 ksi (690 MPa) steel decks under dynamic loading as per CSA A123.21 to better understand the performance of wood decks as part of a system. Systems that had an OSB deck always failed due to fastener pull-out, irrespective of the membrane type. Thus, similarly to the small-scale data from part one the (*IIBEC Interface* article titled "Wood Versus Steel Versus Static Versus Dynamic: Is Oriented Strand Board Reliable for Low-Slope Roofs with Mechanically Attached Components?" which concluded that OSB was not a reliable wood deck option), the system data revealed not only poor performance with the OSB deck but also that the data had high variability with less probability of repeatability under laboratory conditions. For the commercial application with mechanically fastened components in commercial roofs, the use of OSB as a decking component is not suitable, and this was demonstrated with both small-scale and full-scale system testing data.

This paper also demonstrated how to obtain the wind resistance of a roof assembly with a wood deck (CSA_{wood}) without performing system testing and only doing small-scale testing.

This application of using the small-scale data to extend a system rating achieved through large-scale system testing with steel decks is another important contribution that assists in minimizing the number of large-scale system tests required.

ACKNOWLEDGMENTS

The Special Interest Group for Dynamic Evaluation of Roofing Systems (SIGDERS) contributed to the development of this standard. SIGDERS was formed from a group of partners who were interested in roofing design. These partners included Altenloh, Brinck & Co. US Inc., Atlas Roofing Corporation, Canadian Roofing Contractors' Association, Carlisle SynTec Systems, Duro-Last Inc., Element, Elevate (Holcim Solutions and Products US LLC), EXP Inc., GAF, IKO Industries Ltd., IIBEC, Johns Manville Inc., Polyglass, Roofing Contractors Association of British Columbia, Rockwool, Sika Sarnafil, Soprema Canada Inc., and Tremco Inc.

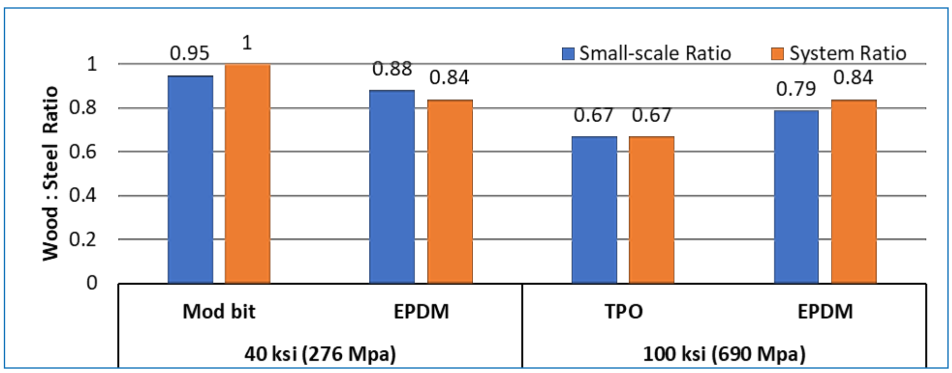


FIGURE 9. Small-scale and system data for ½ in. (12.7 mm) plywood ratios. *Note: mod bit = modified bitumen; EPDM = ethylene propylene diene terpolymer; TPO = thermoplastic olefin.*

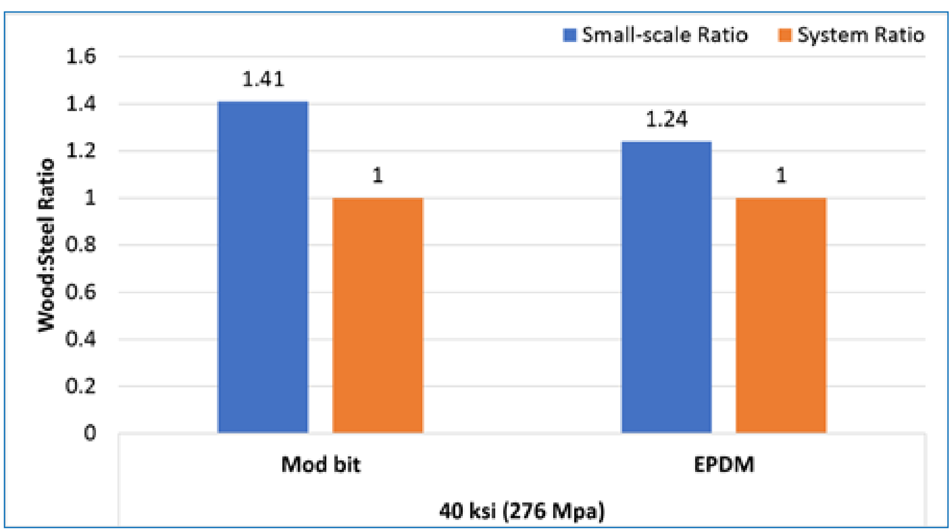


FIGURE 10. Small-scale and system data for ⅝ in. (15.9 mm) plywood ratios. *Note: mod bit = modified bitumen; EPDM = ethylene propylene diene terpolymer.*

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Effects of Interior Air Management Systems on Exterior Enclosure Performance

ABSTRACT

A mid-rise judicial building developed to replace federal and local court systems was completed in 2021. However, difficulties with closing out the project resulted in shortcuts taken by a bond company that took control over the work, culminating with an improperly phased test and balance of the building air management system that was performed floor by floor and not as a total building. By not considering the building as a whole, this phased approach to the heating, ventilating, and air-conditioning commissioning and test and balance did not identify a potential for high negative interior air pressure resulting from unbalanced supply and return to the air handler units for each floor.

Although the building enclosure was commissioned with satisfactory completion of all air/moisture barrier systems, 2 years following occupancy, the building experienced water intrusion on every floor during multiple rainstorm events. Stormwater migrated to the building's interior critical occupancy spaces during each event. Initially, it was assumed to be a cladding and glazing installation failure, even though the construction phase enclosure commissioning integrity tests were successful. After a year of diagnostic evaluations performed on the enclosure systems, a full diagnostic/forensic mode-of-failure analysis that included the building's heating and cooling design finally identified the primary cause of water intrusion.

The results of that investigation into the mode of failure, or root cause, identified significant negative interior pressure throughout the building. This interior negative pressure combined with exterior positive wind pressure during certain rainstorm events resulted in a large pressure differential exceeding the design-tested pressure of the robust curtainwall glazing system under normal use.

This presentation focuses on the physical effect of air pressure differential on a building enclosure resulting in moisture intrusion despite proper installation of exterior cladding. The interior air management of a building affects the performance of the enclosure roofing and cladding systems and must be considered as part of a leak/failure analysis protocol.

LEARNING OBJECTIVES

- Recognize that enclosure systems and heating, ventilating, and air-conditioning (HVAC) systems performance in mid-rise buildings, particularly in flat, open terrain, can be adversely affected by indoor/outdoor air pressure differential. Normal and anticipated annual storm events can have an effect on the enclosure design pressure, which should be considered in conjunction with the interior air management equipment; the two together can potentially overwhelm the cladding system design, causing unanticipated leaks of air and moisture into the building.
- Discuss that as part of building enclosure and HVAC commissioning evaluation of a facility, the design of the air management system can have direct implications for the performance of a cladding system and can affect the design wind pressure evaluation of the building.
- Evaluate the real-time performance of interior pressure induced by the HVAC system as part of the mode of failure or causation when performing failure analysis following water penetration into a new or aged building.
- Explain that diagnostic protocols for suspected failure of a building enclosure based on water infiltration should include the building system's direct digital control records and history as well as the use of temporary localized interior data loggers that can record interior barometric pressure, relative humidity, and temperature. The data from this diagnostic equipment can help point to failures and deficiencies in the air management system, which, when combined with normal weather conditions such as windstorm events, could cause water leaks that would be assumed to result from cladding or roofing installation failures.

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FIGURE 1. Overview of the subject facility's west-facing public entrance.

BACKGROUND

Designed in 2016 for the County of Lea (owner) in southeastern New Mexico (semi-arid, warm-dry, moderate climate), the subject facility is a five-story, 93,000 ft^2 (8,639.98 m^2) building with a full basement (**Fig. 1**). The facility was designed to house the Fifth Judicial Court system in one building. The primary structure is a steel frame moment-resistive construction using concrete floor plates enclosed by curtainwall cladding systems, including an open-baffle fiber cement panel rainscreen with continuous exterior insulation behind a RevealShield-brand weather barrier membrane and large areas of multi-floor aluminum stick frame bypass curtainwall glazing systems (**Fig. 2**).

Heating, ventilating, and air-conditioning (HVAC) system design includes a penthouse enclosed roof structure housing four large air handlers (**Fig. 3**) and one basement-mounted air handler, all of which provide preconditioned tempered (that is, partially cooled and regulated outdoor fresh-air intake and return) air supply to zones throughout the five floors plus basement. Reheat coils and hydronic hot and cold variable air volume coil mixers provide final conditioned air from the air handlers to each occupied space; temperature is controlled by local thermostats connected to a central computer-operated air management control system that regulates motorized air dampers and hydronic valves. Hydronic water heated by a central gas-fired boiler and cooled by an exterior evaporative cooling tower common to most multistory mid-rise buildings provides an efficient method to temper a normalized air supply. The air distribution design uses a shared common

FIGURE 2. Construction-phase enclosure sequence with gypsum sheathing over metal stud non-load-bearing curtainwall, followed by foil faced continuous foam plastic insulation and a self-adhered air/moisture barrier membrane.

return-air plenum using an enclosed vertical shaft penetrating each floor. Supply air and some return air are distributed over each floor through a network of ductwork trunk and branch lines and an interstitial ceiling plenum at each floor. Based on system operation sequencing, the air handlers provide a constant flow of air to all conditioned spaces. A computer controls the amount of pressure in the supply line based on the return-air pressure differential calculated with outside barometric pressure, wind speed, and position sensors on all of the air-mixing dampers at each room (**Fig. 4**). Demand temperature from a wall-mounted thermostat adjusts the air damper to increase or decrease airflow into the room space, which is guided past coil fins with controlled water temperature to exchange heat into or out of the airflow path. This system requires that the air handlers are always in operation and the fans must be variable speed to allow for increased air volume for each zone based on use. Air bypass into the return duct path helps regulate static pressure within the spaces based on design parameters.

Unusual for most buildings, because this facility detains persons (prisoners) not capable of self-preservation in preparation for their court appearance, the basement detention zones must be kept at a slight negative air pressure, whereas most spaces other than toilet rooms typical of most office buildings are maintained with slightly positive interior air pressure. Variable exhaust fans and passive vent systems that are open to the atmosphere in the elevator and stair towers are normally used in this type of HVAC system to expel fresh-air intake circulation that occurs in the supply line as a way to constantly replenish oxygen used by occupants. Air filters at the air handler remove particulate matter from fresh-air intake vents as well as return air from occupied spaces to ensure interior environmental air quality can be maintained for the life safety and health of occupants.

The construction phase for the building enclosure that began in 2018 was fully commissioned, including design constructability review, inspections, observations, and in-place testing for conformance verification. The basement, the first and second floors, and the fourth and fifth floors received a final certificate of occupancy in 2021. The third floor was designed as a future expansion space and was finished as a core shell only, with minimum basic conditioned air ducted into the shell, and an open through-wall duct into the common return-air plenum kept the open floor space from overheating and freezing. This unoccupied space initially was not considered to be significant to the overall building occupancy and performance.

During the final phase of construction, due to conformance-related issues, the general contractor was released from the contract by the county prior to obtaining a certificate of occupancy. The building construction was then completed by a separate general contractor retained by the bonding company covering the original construction. These entities were not familiar with the building design and history, and they did not have much time to become familiar with the project. This phase of construction for final closeout included HVAC commissioning and air balance work performed by a commissioning agent retained by the bonding company. Based on historic documentation, as an effort to reduce scheduled time for closeout and post-occupancy work, the HVAC commissioning was performed not as a total-building operation but phased for each floor separately. The result of this atypical test-and-balance approach was later found to have been adversely affected by the shared common return-air plenum, which in turn was found to have had a significant effect on the overall building performance.

With the project near completion in 2020, following final HVAC commissioning, the final field verification testing for the building enclosure commissioning (BECx) process was scheduled at several randomly selected areas of the curtainwall glazing system per the BECx plan and per project specifications. The verification testing was intended to provide a baseline performance evaluation of the curtainwall system for air bypass and

FIGURE 3. The two photographs depict the penthouse air handler units, which are large boxes the size of railroad cars. The diagram depicts the air handler configuration diagram with supply air ducts directed into a large vertical chase, which also serves as the common return air back to the units.

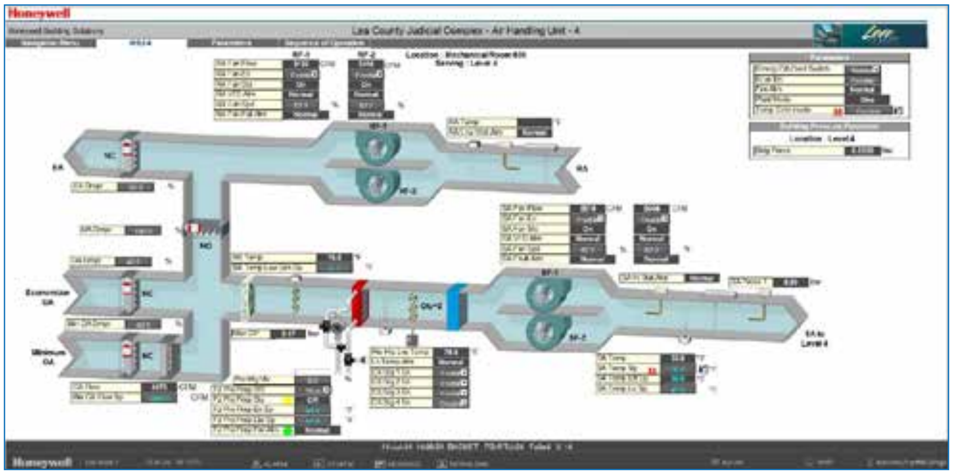
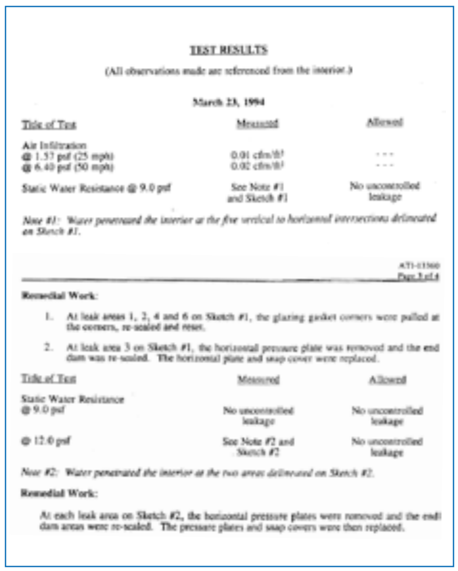


FIGURE 4. Screen capture for one of five air handler units with fan-powered supply- and return-air systems. Note that fresh-air intake is provided at the supply and return plenum intersection that is controlled by electric actuated dampers.

FIGURE 5. ASTM E1105/AAMA 501.2 field verification testing of the curtainwall system.



TEST RESULTS

(All observations made are referenced from the interior.)

March 23, 1994

Title of Test	Measured	Allowed
Air Infiltration @ 1.57 psf (25 mph)	0.01 cfm/ft²	- - -
@ 6.40 psf (50 mph)	0.02 cfm/ft²	- - -
Static Water Resistance @ 9.0 psf	See Note #1 and Sketch #1	No uncontrolled leakage

Note #1: Water penetrated the interior at the five vertical to horizontal intersections delineated on Sketch #1.

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Remedial Work:

1. At leak areas 1, 2, 4 and 6 on Sketch #1, the glazing gasket corners were pulled at the corners, re-sealed and reset.
2. At leak area 3 on Sketch #1, the horizontal pressure plate was removed and the end dam was re-sealed. The horizontal plate and snap cover were replaced.

Title of Test	Measured	Allowed
Static Water Resistance @ 9.0 psf	No uncontrolled leakage	No uncontrolled leakage
@ 12.0 psf	See Note #2 and Sketch #2	No uncontrolled leakage

Note #2: Water penetrated the interior at the two areas delineated on Sketch #2.

Remedial Work:

At each leak area on Sketch #2, the horizontal pressure plates were removed and the end dam areas were re-sealed. The pressure plates and snap covers were then replaced.

FIGURE 6. Sample portion of the curtainwall manufacturer lab test report indicating minor leaks occurred at specific test pressures.

moisture intrusion resistance to be filed as part of the project record.

Field verification testing was scheduled to be observed by the BECx team, including this author, the owner, and the bonding company's general contractor, and was performed by the curtainwall glazing system installer. The field testing was scheduled to follow ASTM E1105, *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference*, similar to the American Architectural Manufacturers Association's AAMA 501.2, *Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls, and Sloped Glazing Systems*, test protocol (**Fig. 5**).[1,2] The primary subject for field verification testing was a Tubelite 400 Series Curtain Wall glazing system that bypassed the second through fifth floors at the east- and west-facing building elevations. As part of the test protocol, test pressure consensus was required by all parties. To determine field test pressures, manufacturer reference documents were reviewed.

Based on submittal review and approval by the project team, including the architect and the BECx team, the Tubelite-designed system was confirmed to have been factory tested with code approvals performed by Architectural Testing Inc., with a test report dated April 1994 (**Fig. 6**). Similar to any cladding system available in the market, the factory testing provided performance verification to confirm that the system will perform as intended for the minimum standard of quality and safety established by building codes to protect the building and structure from weather. The third-party testing report identified that the test specimen matched this project specification using fixed insulating glazing lites of ¼ in. (6.35 mm) clear tempered glass in a 1 in. (25.4 mm) thick insulated glass unit (IGU) set into the structurally reinforced extruded aluminum curtainwall framing system.

According to the test report, laboratory air infiltration verification was performed at 6.24 lb/ft^2 (298.8 N/m^2) positive ***static*** air pressure difference, and water resistance was tested at 9.0 lb/ft^2 (430.9 N/m^2), 12.0 lb/ft^2 (574.56 N/m^2), and 15.0 lb/ft^2 (718.2 N/m^2) positive static air pressure for a 15-minute duration. Also tested was the ***dynamic*** pressure equivalent of 12.0 lb/ft^2. According to the approved submittal data, the factory test results identified that the air infiltration at 1.57 lb/ft^2 (75.17 N/m^2), which would be equal to 25 mph (40.23 km/h) wind speed, was 0.01 cfm/ft^2 (0.508 Ls/m^2). The reviewed factory test report indicated that at 6.4 lb/ft^2 (298.8 N/m^2), which is equivalent to 50 mph (80.47 km/h) wind speed, the air infiltration was 0.02 cfm/ft^2 (0.1016 Ls/m^2). These numbers confirmed that the assembly performed satisfactorily as an air barrier assembly with permeance required to have an average air leakage not to exceed 0.04 cfm/ft^2 (0.2032 Ls/m^2) at 1.57 lb/ft^2.

Also indicated by the factory test report, the static water resistance at 9.0 lb/ft^2 (430.9 N/m^2) pressure differential reportedly passed with no uncontrolled leakage. It is important to note that the key word is *uncontrolled*, which was debated at the time of the project field tests because it technically allows for water to bypass the glazing line provided that no water migrates beyond the face of the frame to interface with interior finishes or fixtures.

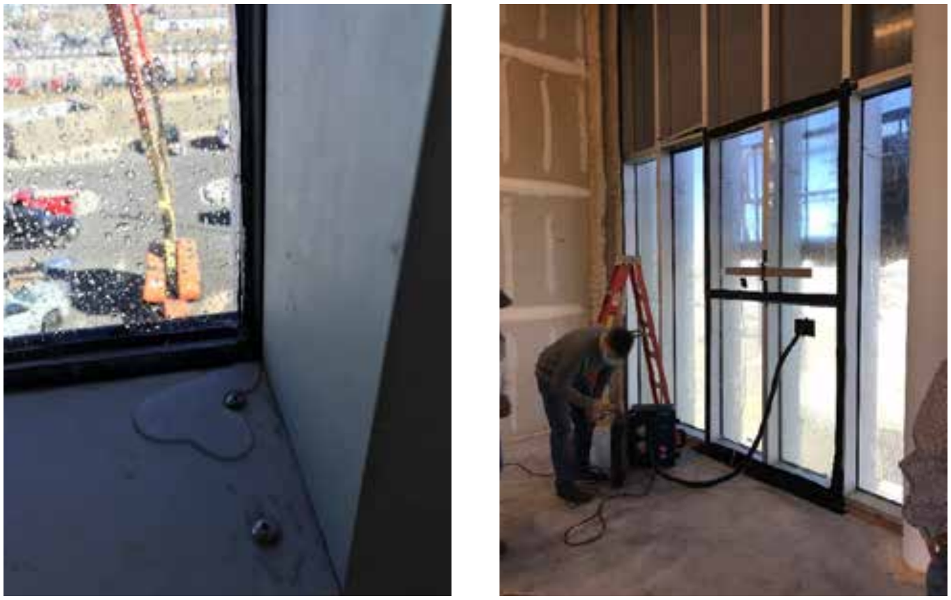

FIGURE 7. Building enclosure commissioning tests revealed a small amount of water was able to bypass the assembly similar to factory lab testing. Although water leaked past the glass units, this condition was determined by the manufacturer, architect, and owner to be acceptable.

The reviewed factory test report noted that water did penetrate five vertical-to-horizontal intersections at glazing gasket corners. According to the report test results, one leak area occurred at a horizontal pressure plate end dam that required reapplication of in-place applied sealant. Repairs were reported to have been made on the factory test specimen, and the specimen was retested with no uncontrolled leakage reported at 9.0 lb/ft^2 pressure, but at 12.0 lb/ft^2 (574.56 N/m^2), water penetrated at vertical-to-horizontal intersections of the stick frame curtainwall assembly.

Based on the factory test and manufacturer specification, the installed assembly should have been able to successfully withstand a field test pressure of 6.2 lb/ft^2 (296.86 N/m^2) with no water infiltration. This became the agreed-upon in-field test pressure differential using a calibrated vacuum apparatus on a negative pressure chamber installed on-site at several locations of the curtainwall assembly.

Field testing in 2020 revealed that water was able to bypass two out of five in-place test specimens of the curtainwall glazing system. The water bypass was found to be nearly identical to the factory test report previously reviewed. At 6.2 lb/ft^2 (298.8 N/m^2), a small amount of water entered the assembly at an intersecting vertical-to-horizontal frame interface with the IGU. The BECx agent concluded that the curtainwall frame internal water dams were likely leaking as found in the factory tests, and the removal of the exterior mullion cap with repair to the field-formed sealant dam was necessary. The installer performed the repairs on a subsequent day, and the assembly was retested; however, the same water bypass occurred. The installer presented to the owner that the test protocol did allow for some water to bypass the IGU and still be considered a satisfactory pass condition. The BECx agent did not agree, but the owner accepted the testing as satisfactory and took occupancy of the building (**Fig. 6** and **7**).

During a normal spring rainstorm event in March 2020, the owner notified the team that water intrusion was observed at multiple locations on multiple floors of the building, including the third-floor shell space (**Fig. 8**). A diagnostic test was performed on several locations of the building glazing system. Simultaneously, a storm evaluation was performed by the author to determine if the March 2020 storm was an unusual storm event. Weather records for March 4, 2020, indicated that light rain began in the early-morning hours after midnight, and a first round of heavy rain began at 2:00 a.m., with continued rain downpours totaling almost 2 in. (50.8 mm) over 6 hours with wind speeds at 30 mph (48.28 km/h) to 35 mph (56.33 km/h). Wind occurred during heavy rain from the north-northeast, providing the highest positive pressure at the northeast corner of the building, with the highest negative pressures likely occurring at the southwest corner on the lee side of the building. The near 2 in. (50.8 mm) precipitation over a 6-hour period correlates to the National Oceanic and Atmospheric Administration's (NOAA's) Atlas 2 Volume IV rainfall rate for a 2-year, 6-hour precipitation-producing storm event for this specific site location (**Fig. 10**).[3] The NOAA Atlas 2 rainfall rate for a 50-year, 6-hour precipitation-producing event is 4.2 in. (106.68 mm), and the NOAA Atlas 2 rainfall rate for a 100-year, 6-hour storm event is over 4.6 in. (116.84 mm), neither of which resulted from this storm. Going back to the manufacturer-published reports, the curtainwall glazing system was designed

FIGURE 8. Water infiltration following a normal rainstorm event.

FIGURE 9. Second-floor west-facing lobby with curtainwall glazing system that leaked rainwater through the lobby into the central judge's chambers and courtrooms visible in this photograph at the far left of the hallway.

and factory tested to resist water infiltration up to 12 lb/ft^2 (574.56 N/m^2) pressure differential. The original architectural specification for the building required the assembly structure to resist wind pressure at 90 mph, Exposure C, or 25.54 lb/ft^2 (1,222.7 N/m^2) for an enclosed building. The curtainwall assembly was rated for up to 75 lb/ft^2 (3,588 N/m^2) structural pressure, which was well above the 25.54 lb/ft^2 design pressure. AAMA recommends a field test pressure be one-third less than the design test pressure of 12 lb/ft^2, (574.56 N/m^2) which would be 8 lb/ft^2 (383.04 N/m^2).

FIGURE 10. NOAA Atlas 2 Volume IV rainfall rate for a 2-year, 6-hour precipitation producing storm event which is used by the building design team to identify basis of design conditions.

Subsequent post-storm testing used pressures from 3.5 lb/ft^2 (167.5 N/m^2) up to 6 lb/ft^2 (287.3 N/m^2) negative pressure. During the test period, positive wind pressure externally was calculated to be 2 lb/ft^2 (95.76 N/m^2) for a total test pressure differential of 8 lb/ft^2 (383.04 N/m^2). This test did not result in significant water bypass, although some water was evident on the interior frame in the same location as previously tested at a vertical-to-horizontal frame intersection.

It was concluded that the storm event that occurred in March 2020 did not appear to be unusual and was predicted by NOAA to occur at minimum every 2 years; therefore, it is likely that this type of storm could occur often, and the results could be similar to the March 2020 storm event. Based on this analysis, the curtainwall system should not have been overwhelmed by stormwater even with high wind speed, and the system should be capable of withstanding this type of storm repeatedly. Additional repair work was reportedly not performed, although the installer inspected all known leak conditions from this event and concluded that there was nothing wrong with the curtainwall system. Due to the ongoing issues related to project closeout by the bonding company, the results of the 2020 storm apparently were forgotten and remained open.

In September 2023, 2 years after occupancy of the building, the owner reported to the project team that again significant moisture intrusion occurred throughout the building during a heavy rainstorm event. During this event, additional conditions were observed, including ceiling tiles that were dislodged from their clipped ceiling frames in the basement (ceiling tile clips had been installed by facility maintenance to keep tiles in place that were abnormally vibrating during business hours). In addition, doors at the main west-facing entry lobby and at the entry-level sally port were not able to be opened from the outside, and exterior doors, once opened, would slam closed against the frames or be thrust outward, damaging the closing device.

Of particular interest during this event that occurred while the building was occupied (the storm occurred overnight, but staff were using the building for their offices) were remarks from staff that only certain rooms on the upper floors leaked water through the curtainwall. The rooms were typically smaller offices and not larger common spaces. Also notable was that water intrusion occurred in large lobby spaces of the west entrance, but only small leaks occurred in the shell third floor on the same west side of the building. This event, similar to the 2020 event, was found to be a typical regional storm event and did not approach the criteria for a 50-year or 100-year storm. Winds and wind direction were normal for isolated thunderstorms common and known to the high plains/plateau region of West Texas and eastern New Mexico. The building should be capable of withstanding this type of storm with no adverse effects.

In a period between September 2023 and spring of 2024, prior to anyone performing a field inspection or potential new round of diagnostic testing, the building site engineer in charge of operations and maintenance of the building reported that an entrance-lobby ceiling component had become detached from its frame and fallen onto a person entering the lobby, hitting her arm during a wind event. Around that same time, during a weekend storm event, a window IGU in a storefront (not curtainwall) glazing frame had become dislodged from the receiver pocket and was now sitting offset (that is,

FIGURE 11. East staff entrance lobby with storefront insulated glass unit displaced allowing uncontrolled outside air infiltration.

floating loose) in the frame, leaving a gap in the window that allowed air bypass and moisture intrusion (**Fig. 11**).

Within a few days, an interior security lobby enclosed by small-missile-impact-resistant safety glazing was observed to have cracked at the speaker port overnight. This same glazing system with a lamination of bullet-resistant polycarbonate film had reportedly been replaced soon after taking occupancy due to glass cracking in a similar manner, but that incident had gone unreported until this time, 2 years after occupancy.

It was clear that conditions were getting worse as time passed, and storm patterns coincided with many, but not all, of the deficiency and failure reports. The fact that the building was starting to cause injury to occupants became a priority issue for the owner, and immediate measures needed to be taken to determine a cause.

A visual and tactile nondestructive leak assessment and moisture survey was performed by the author and maintenance staff using standard diagnostic protocols. Infrared and moisture meters were used to attempt to identify potential sources for leaks at typical building locations such as the parapet coping caps at the top of the curtainwall system; water bypassing the coping could travel down multiple floors of the bypass framing within the hollow tubes, settling at horizontal joints and flowing into the building at glazing gasket gaps, which are known leak points for the factory-tested assembly. The single-ply thermoplastic roof was also surveyed for moisture intrusion even though the building roof area is very small relative to the building floor area and a potential roof leak would not likely present moisture at the lower floors.

Parapet saddle interfaces to rising building walls at lower intermediate roofs were inspected, although they had previously been commissioned during construction. A brise soleil at the west elevation that was clad with a rainscreen cladding system did interface with the main building structure, and these points were inspected and surveyed for potential moisture intrusion (**Fig. 12**). The penthouse waterproofing and condensate water collection systems were inspected and tested for leaks. The north and south building elevations, clad with a rainscreen system having punched window openings framed with aluminum storefront glazing systems, were inspected. These punched storefront windows are not nearly as durable as curtainwall glazing systems and would normally be the first to leak, but they were found to be air- and watertight.

The moisture survey did not result in any obvious path of moisture intrusion, particularly for mid-rise floors with robust factory-tested curtainwall glazing systems. There was no trapped moisture within the rainscreen wall systems on the north and south elevations, and there was nothing in the roof. Water was entering only through the robust curtainwall glazing systems at the east and west building elevations. The design architect was perplexed because they had used this same curtainwall glazing system (**Fig. 13**) on buildings throughout the state in different climate zones

FIGURE 12. The building's west-facing elevation with a brise soleil shade structure standing off the glazed curtainwall to provide relief from direct west sunlight.

FIGURE 13. Project-approved curtainwall system selected by the architect.

and had never experienced leaks like in this building.

Despite the owner's concern that more severe storms were occurring in the area based on maintenance staff's anecdotal history, storm history data did not indicate the recent storms were unusual, and it was recommended to the owner that any building, including this modern structure that is designed specifically for the region in which it is intended to perform, should be capable of withstanding typical weather conditions, including high wind gusts, driving rain, small hail, and frost.

This curtainwall system was designed and tested for more severe climates, including coastal marine conditions, and should not be performing as poorly as observed. Additionally, the owner should be expected to occupy the building safely during a 50-year or 100-year storm event as required by building codes, which would be more severe than either of the storms witnessed in the past 2 years. Based on BECx reports provided during the construction phase, the enclosure had been inspected and determined satisfactory for air barrier continuity, weather-resistant construction, and conformance with project requirements and building code minimums. There was no obvious reason for air and moisture infiltration. However, it was clear the building was damaged by the circumstances related to or temporally simultaneous with weather events. The owner was justifiably frustrated because the amount of water that entered the building in 2023 nearly flooded the judge's chambers and courtrooms at the inner core of the building, and based on court proceedings regulations, the courts cannot easily cancel or reschedule court appearances based on building leaks. The building that was only 4 years old and that had cost the owner $3.1 million to construct was leaking worse than the 1935-era building previously occupied by the courts. All initial observations and studies to date had concluded that the building should not be leaking during these types of storms; something unusual was taking place.

POST-OCCUPANCY DIAGNOSTIC

In August 2024, after several discussions with building operations engineers, facility maintenance, and the county facilities director regarding events over the past 3 or 4 years, a clue was provided that indicated that an event related to building systems controls could be contributing to moisture intrusion during certain weather events. An issue was reported by maintenance staff regarding cold cycling of a cooling condenser unit in the computer server room; this issue required the replacement of the condenser unit multiple times in the past few years. In addition to this cycling and subsequent freezing of the condenser coils, an indication that the thermostat's cooling demand call from the thermostat was above the unit's ability to maintain temperatures for the server computers, the maintenance team also reported that they could not maintain any space in the building at the user-set temperature. The temperatures for interior comfort were being manually monitored and adjusted at the main control computer by maintenance staff.

Finally, the maintenance team indicated that the building's smoke alarm had been triggered recently by intake of outdoor smoke and exhaust gases from the parking area and outdoor barbecue grills through the elevator shaft. This information triggered a response based on a recent evaluation of pressure-induced leaks from roof-mounted packaged terminal air conditioner ductwork performed by the author.

The author and a specialty HVAC commissioning sub-consultant were tasked with designing a forensic (that is, scientific methodology and techniques to investigate and identify systems failure) full-building diagnostic evaluation protocol, including analysis of as-built conditions relative to the design contract documents, to help the owner and architect determine probable cause for recurring moisture and air leaks and recent damage to the building interior, as well as the reported nonfunctioning and damaged HVAC system's performance.

An end-user survey report provided by occupants describing the following air-pressure-related observations:

- Whistling sounds in corridors
- Exterior barbecue grill smoke being inducted into the elevator shaft and distributed to each floor during summer sessions

FIGURE 14. One of several portable data loggers used to track interior environmental conditions over a period of time during the diagnostic test phase of 3 months.

- Door operations that prevented the general public from opening lobby doors during wind events
- Hot/cold office space conditions despite thermostat settings

Based on those observations, it was determined that the building's HVAC system should be reviewed as part of the holistic building enclosure diagnostic to determine a source or probable cause for the air and water leaks. The theory was that the building-controls computer may have information regarding weather conditions, anomalies, and user input that could shed light on the moisture-intrusion environmental issues.

The proposed diagnostic evaluation and analysis methodology included the following:

- Provide a review of the original building systems' design (that is, the construction documents and specifications used for a building permit) for baseline understanding of the intended building operations, including review of any alterations or changes to the original design that may have occurred during construction in 2021.
- Provide a review of HVAC test-and-balance reports provided by the bonding company's consultant.
- Perform in-field assessment of installed conditions at the roof, building enclosure, and basement, including placement of in-place discrete data loggers strategically located to record interior barometric pressure, relative humidity, and ambient temperature over time (**Fig. 14**).
- Perform an in-person building-controls computer audit to evaluate and monitor real-time functions of the building controls and to analyze historic environmental controls history and operations logged by the computer software.
- Perform an inspection of the enclosure systems and roof-mounted equipment related to air intake and exhaust.

Following a comprehensive review of the design documents, an on-site existing-conditions survey was conducted. At that time, seven discrete data logger units were cataloged and placed at select locations throughout the building within offices at exterior walls, interior-core lobby spaces, exterior-entrance lobbies, and basement mechanical equipment rooms related to reported issues with water bypassing the glazing system, temperature controls not functioning properly, and cracked and displaced IGUs.

Elitech Tlog 100H handheld data logger units were used to log temperature and humidity, and Track-It brand data logger units were used to record barometric pressure and temperature. These units were set to record data points every 10 seconds and were left in place for 65 days to record interior environmental conditions. To facilitate analysis of the copious data set produced by these data loggers, an internal alarm flag was set at 77°F (25°C), at which point anything greater than that temperature would flag an alarm code on that data point.

In addition, maintenance engineering provided access to the building management computer control system, and the computer was visually monitored for several hours during normal operations. As part of the monitoring, the computer was also manually tasked to perform extreme duty cycling and air ramping (ramping is the process of incrementally increasing the fan speed for each air handler unit [AHU], performed after hours in an unoccupied building) to observe the controls sequencing and compensation.

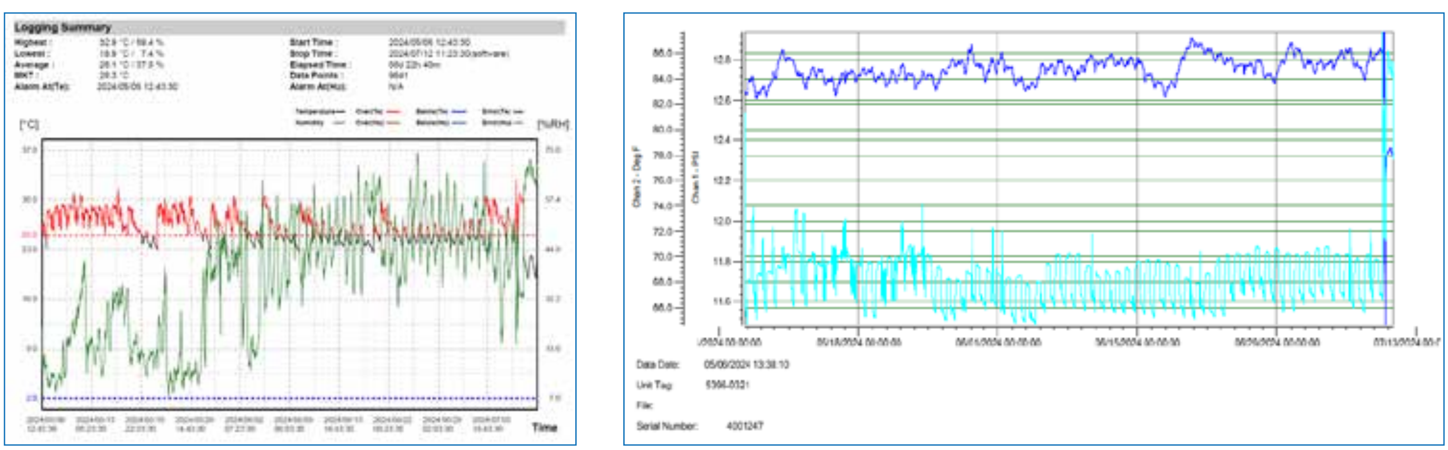

FIGURE 15. Data logger sampling graphs.

RESULTS

For the 65 days of interior environmental condition monitoring that began in early May 2024, ambient weather conditions varied in the extreme at the subject site, with temperatures ranging from 0°F (-17.78°C) to 93°F (33.89°C). Wind conditions ranged from zero wind to peak gusts at 32 mph (51.5 km/h.) Relative humidity ranged from 0% up to 100%, with precipitation occurring as sleet and rain. Documented outdoor atmospheric barometric pressure ranged from 26.0 inHg (88,046.1 Pa) to 26.3 inHg (89,062.02 Pa) (the site is located at 3,661 ft [1,115.87 m] above sea level). These conditions reflect a typical spring on the upper plains of New Mexico and Texas and were ideal to observe the building under a range of climatic environments.

Internal environmental conditions recorded by the portable data loggers and subsequently downloaded and graphed on a personal computer were revealing (**Fig. 15** and **16**).

Typical data logger events throughout the building indicate that interior atmospheric pressure was measured to range from 25.6 inHg (86,691.55 Pa) to 26.9 inHg (91,093.86 Pa), and ambient interior temperature ranged from 64°F (17.78°C) to slightly above 77°F (25°C). Thermostat set points in general were 72°F (22.22°C) for most of the building's primary occupied spaces. The data points from each logger were compared with ambient exterior weather data reported by NOAA that were contemporary with the date and time. During the logging period, a cold front was observed to move through the region during the first 2 weeks of the test monitoring phase that resulted in the HVAC system fluctuating diurnally from a temperature in the low 60s to a high point of only 72°F (the thermostat set point) while outside temperatures dropped to near freezing conditions. Normally, an HVAC system is designed to shoot the cutoff temperature beyond the thermostat set point before shutting off or ramping down, so it was unusual that the system could barely make this set point and could never get high enough to ramp down the air volume.

It was clear based on patterns in the data graphs that outdoor weather conditions improved within a few weeks, and yet internal building temperatures throughout the data acquisition period were rarely at the thermostat set points. Many occupied spaces' interior temperatures climbed above 75°F (23.89°C) for multiple days despite warm outdoor daytime temperatures, particularly the rooms adjacent to floor-to-ceiling curtainwall glass.

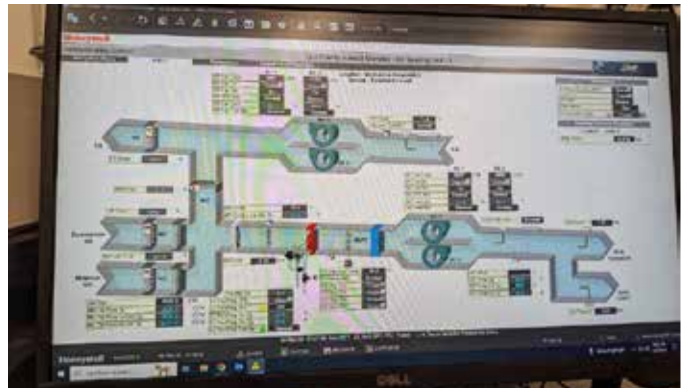

FIGURE 16. Monitoring of the heating, ventilating, and air-conditioning building management systems controls during diagnostic phase. Set points and minimum operational parameters were monitored and modified to attempt to alleviate fan pressures.

It became evident that relative to external air temperatures, internal air temperature could not be maintained by the building management system at the thermostat set point for all but 3 days within a multi-week cycle. Coincidently, for each time the interior temperature approached the thermostat set point, the interior barometric pressure dropped significantly, and for each cycle of heat demand, the interior pressure dropped below exterior atmospheric pressure (that is, negative pressure). Also, as the wind speed outdoors reached peak gusts of 32 mph (51.5 km/h) and exterior barometric pressure increased, the interior atmospheric pressure dropped ultimately to a low of 25.8 inHg (87,368.83 Pa).

In general, based on data logger information, the building operated at a fairly high negative pressure relative to the exterior atmosphere on a daily basis. An extreme example of this potential pressure differential was observed on June 18, 2024. On that day, atmospheric pressure was recorded between 26.02 inHg (88,113.83 Pa) and 26.16 inHg (88,587.93 Pa) outdoors; indoor pressures ranged from 25.65 inHg (86,860.87 Pa) to 25.85 inHg (87,538.15 Pa). Weather meteorological conditions for June 18, 2024, at 11 p.m. recorded atmospheric pressure to be 26.16 inHg outdoors. At that same time, indoor pressure was recorded to be 25.85 inHg, a difference of 0.31 inHg (1,049.78 Pa,) which can be converted to pressure in pounds per square inch (1 inHg = 0.491154 psi) and calculates to be a pressure difference of 0.15225774 psi (1,049.78 Pa). This number translates to 21.925 lb/ft^2 (1,049.88 N/m^2).

The pressure differential recorded by the data loggers immediately became the lead suspect as the contributing factor to moisture intrusion during precipitation-producing storm events. Additionally, the pressure differential was clearly contributing to poor interior air quality, with uncontrolled outdoor smoke, particulates, and allergens (in other words, unfiltered air) bypassing the enclosure (in other words, walls, windows, doors, and roof) into the occupied spaces.

Another interesting observation noted by analyzing the data logger graph points was that a two-period cycle was visibly evident in the temperature graphs over the 65-day period. One cyclic period translated to weekly peak temperature cycles that occurred simultaneously to a second cyclic period for diurnal temperature cycles. The interpretation of this pattern is that the HVAC system took 7 days or more to reach the demand set point temperature, at which time the system dropped the daily peak temperature below the set point temperature, which then took another week to ramp back up to the set point. This is not normal for an air management system and does not coincide with exterior weather conditions. It was observed that at the same time the building temperature is cycling up or down, individual room air pressure cycling also occurs, ramping up and down. This pattern was noted in particular at the security lobby, which, based on floor plan layout, has no enclosing walls to the exterior of the building and should not be influenced by the enclosure assembly, and has a history of cracked safety glazing. A pressure differential was noted to have occurred within the building interior space on each side of the security glazing system that could not have been affected by air leaks or wind and weather conditions to the building exterior.

Lastly, in addition to the temperature and humidity data points recorded over a period of weeks, staff use of specific rooms adjacent to exterior curtainwall systems was reviewed and became notable. Based on staff use patterns within the building, certain office spaces adjacent to exterior curtainwall glazing systems were occupied by personnel who set their thermostats higher than usual for personal comfort. Thermostats were often set above normal temperature and left that way for several days because the occupants felt cold. Some of the occupants also added portable electric heaters to their office space and left them running 24 hours each day. These rooms were reported to be closed and locked at corridor doors overnight due to information security purposes. These rooms were coincidently the spaces frequently reporting leaks at the curtainwall glazing system following storm events that occurred overnight.

The aforementioned patterns in temperature, pressure, building occupancy, and weather revealed by the data logger graphs indicated several patterns of building systems failure:

- Large lobby spaces facing windward to storm events produced the most leaks.
- Small office rooms that were maintained at high thermostat set points and that were closed off from the rest of the building at night were more likely to leak at the curtainwall glazing system.
- A pressure and temperature differential between each side of interior room divider walls occurred at rooms presenting stress fractures in security glazing at voice ports cut into the glass.

FIGURE 17. Depicts the third-floor shell space for future expansion. The enclosure at right of this photograph is a return-air vertical shaft that allows all floors and all air handlers to share a common return-air path.

- Ceiling spaces between floors at rooms adjacent to exterior curtainwall enclosure systems were most likely to leak large amounts of water during wind- and precipitation-producing events.

Ultimately, to determine a solution to the water intrusion issues and building damage issues, it became necessary to understand why the temperature and pressure anomalies were occurring and what could be done to stop the leaks. If the building enclosure was allowing for excess infiltration of air, it would make sense that the HVAC system could not maintain interior temperatures. The building enclosure and HVAC systems were both commissioned during construction, so it seemed unlikely that high infiltration rates were occurring, but there was no explanation for the recurring air and moisture leaks. For that effort, the sophisticated building management computer data were analyzed and compared with design documents and as-built conditions observed.

Analysis of the HVAC system design determined that the basement AHU is intended to provide air distribution to the basement and first-floor spaces, including the primary east staff entrance vestibule with displaced IGUs and the west primary public entrance with large lobby spaces that routinely leaked water. This AHU also serves the secure detention rooms in the basement and the sally port security entrance. The AHU return air is not ducted but uses a ceiling plenum for return air. This plenum also has direct connections to upper-floor air space through the elevator shaft, stairwells, and the core vertical central return-air shaft shared by all five AHUs.

The basement AHU operates differently from the others in the building because it manages a high outdoor infiltration air rate due to the numerous public- and private-entrance doors for the sally port and east- and west-entry lobbies. Per the owner's engineer's original design intent, this system provides filtered fresh-air intake through a basement duct port to the exterior of the building at the ground level, and all discharge exhaust air is managed by the opening doors, as well as by a mechanical exhaust fan that operates during unoccupied hours and infrequent usage times. Non-exhausted conditioned air recirculates back to the basement AHU to be filtered, retempered, and sent into the air supply cycle again. The design balance for the basement and first-floor air systems is intended to be slightly positive to allow the building to exhale used air through the entrance doors.

Upper floors are managed by penthouse rooftop AHUs, one for each floor, and all share the same return-air vertical shaft pathway. Individual spaces at the second, fourth, and fifth floors, including large courtrooms and small offices, are zoned with independent thermostats adjustable by user interface. As previously mentioned, the third floor is an open shell space with no thermostatic controls installed (**Fig. 17**). To enhance the air management pathway by design, a return-air fan is provided for each AHU with a computer-controlled interconnect to the supply-air fan. The two-fan system is variable to allow for static pressure management based on a differential pressure and air velocity between supply and return. Individual rooms can manage temperature by reheat or cooling coils in a mixing box tied to the thermostat. The thermostat calls for demand heating or cooling, and the building management computer adjusts the variable air-mixing box damper to increase or decrease air volume flowing through the tempering coils into the room. Managing temperature, therefore, requires both a change in air volume and a change in air temperature.

Observation of the system management computer over time identified there were two primary contributing factors to air management that were likely causing the anomalies for interior temperature and pressure:

1. The building management system is a complex user interface that allows the building engineer to adjust performance based on numerous set points in building supply- and return-air speed/volume, temperature, and outside fresh-air intake. The system relies on exterior weather data that must be taken at regular polling intervals from a rooftop-mounted mast measuring wind speed, air temperature, barometric pressure, and relative humidity.
    - The rooftop weather mast was found to be wind damaged, disconnected, and nonfunctional, so the management computer could not gauge outdoor weather conditions (**Fig. 18**).
    - The sophisticated software allows users to adjust air management controls that require knowledge and understanding to ensure proper performance. As an effort to help correct temperatures based on staff complaints regarding interior air comfort, the management engineers had improperly adjusted the fan speeds and volume out of specification. Some of the manual user override settings had inadvertently damaged or disconnected damper position sensors, duct pressure sensors, and airflow reporting stations.
2. The original mechanical design engineers understood the HVAC design was complex, but it was intended to be a high-performance, low-maintenance system, and they miscalculated both complexity and air management operations in the original design. Deviations based on installation compared to design were not caught during the HVAC commissioning phase and test and balance sequence because the testing was done on a per-floor basis and did not consider all floors simultaneously operational with a shared common return-air shaft:
    - The engineers did not anticipate the correct outdoor air volume exchange through doors and vents, such as the elevator shaft atmospheric damper vent, and they did not consider how tight the building's commissioned air barrier system could be. The engineers had apparently intended to provide a variable-drive exhaust vent system, and due to end-user complexity, they elected to specify a fixed-speed exhaust fan. They also used older building air leakage rates and did not anticipate how airtight this building had been constructed. With a shared common return-air plenum, the computers were running uncontrolled outdoor bypass air from the basement to the upper floors, resulting in a high negative pressure at the basement and first floors.
    - The engineers had also erred on the conservative side for carbon dioxide (CO_2)management, designing the system to increase outdoor airflow to adjust CO_2 proportions, with a reset demand to minimum air intake during each reset cycle that ramped up to maximum air intake before reset, despite the minimum intake setting meeting the American Society of Heating, Refrigerating and Air-Conditioning

FIGURE 18. Heating, ventilating, and air-conditioning weather mast with barometric sensors and wind meters that are required to feed the interior air handlers information about the exterior atmospheric conditions was found to have been damaged by high winds. The location of the mast is vulnerable to weather when located at the sixth-floor penthouse roof.

Engineers' (ASHRAE) requirements for air quality management.
- During the HVAC commissioning and test-and-balance phase, critical sensors for air pressure, damper position sensors, and temperature sensors were either disconnected, never connected, or not installed (visual verification could not find the sensor locations buried deep within the complex duct systems). Without the sensors functioning, the building management computer cannot identify critical values, and the computer option is to overcorrect to compensate for missing information.

CONCLUSIONS

The Lea County Judicial Complex is a mid-rise, high-performance building designed to use sophisticated and robust enclosure systems to separate the interior conditioned environment from exterior atmospheric weather. The building was designed to have an adjustable and energy-efficient interior air management system for long-term durable performance and occupant health and comfort. During the final construction phase, unforeseen issues between the contractor, consultants, and the owner resulted in a disconnect between the original design function, testing, and adjustment of building systems. The result was that the team did not have history and knowledge of the building that would be sufficient to properly complete closeout procedures and post-occupancy adjustments such as final HVAC commissioning and test-and-balance protocols.

In the immediate years following occupation, the owners witnessed persistent recurring moisture intrusion from what should be considered normal storm events for the region in which the building is intended to perform. Traditional moisture intrusion diagnostic testing and assessments were performed to attempt to identify a source of the recurring moisture intrusion, but there were no successful results. It was never anticipated that the complex air management HVAC system could have been designed and installed in such a way that it could force weather intrusion.

Using non-traditional building diagnostic protocols, including portable discrete environmental data loggers strategically placed inside areas of the building known to leak, as well as analysis of air management computer logs for the entire building over known storm-event time periods, the primary cause of moisture intrusion was found to be unrelated to the weather-protection enclosure systems, including windows, doors, rainscreen cladding, and roofing.

The cause of moisture intrusion and building damage was finally determined by analysis of the building interior environment (which occurred coincidentally during spring weather with extreme variations of exterior climate conditions) and by an evaluation of HVAC system performance that was monitored with computer software.

This analysis identified that an unanticipated air pressure differential occurred between indoor and outdoor conditions that potentially exceeded a pressure of 22 lb/ft^2 (1,053.4 N/m^2). This pressure differential that was caused by improperly designed and improperly programmed HVAC equipment ultimately created a whole-building negative-pressure air chamber that exceeded most of the enclosure system's tested performance capacity.

The original design architectural team had specified a robust, code-approved, factory-tested curtainwall glazing system that could withstand structural wind pressures up to 75 lb/ft^2 (3,591.0 N/m^2) without damage or risk to the safety of occupants. This enclosure system was intended to perform watertight at a pressure differential of 12 lb/ft^2 (574.56 N/m^2) to 15 lb/ft^2 (718.2 N/m^2). Under normal operating conditions, including high-wind events from above-average storms (500-year storm events) the tested pressure resistance would likely never be exceeded for this dry-arid climate. Due to issues with the HVAC controls, post-occupancy air pressure differential for the curtainwall exceeded nearly 200% of the design capacity.

Although factory lab testing by the curtainwall glazing system manufacturer demonstrated that a 12 lb/ft^2 (574.56 N/m^2) test pressure resulted in some moisture bypass of the IGU gaskets onto the interior frame of the curtainwall, the industry-accepted verification testing using ASTM E1105/AAMA 501.2 protocols at 6 lb/ft^2 (287.28 N/m^2) should have demonstrated the curtainwall glazing system's ability to withstand normal weather conditions with little to no water entry.[1,2]

It would not be anticipated that a 22 lb/ft^2 (1053.4 N/m^2) air pressure differential could be achieved during normal storm events while under normal occupancy use. Although the air handlers are clearly capable of inducing this type of pressure, they should never operate to that capacity except under monitored stress testing. The interior air pressures of the building should normally be balanced such that there is little to no pressure differential. Minor induced negative or positive pressure can be designed to meet occupancy use, but these pressures are typically very small and would be less than 1.6 lb/ft^2 (75 Pa), which is the air pressure for standardized air barrier testing using pressurization fans. The obvious result of this building's breach in performance was that copious amounts of stormwater could be drawn into the building like a vacuum chamber from the five-story glazed enclosure system.

This building's design would normally consider exterior wind that can create a frontal impact pressure of positive 2 lb/ft^2 (19.53 N/m^2) onto the building cladding and curtainwall, which, when combined with the addition of negative air pressure on the lee side of the building during normal wind events, could be summed with a pressure differential that would still be less than the curtainwall tested and approved 6 lb/ft^2 (287.28 N/m^2). With an unanticipated interior pressure differential of 22 lb/ft^2 (1053.4 N/m^2), the overall combined forces with normal outside air pressures would easily exceed the cladding system's design and tested performance pressure rating.

Ultimately, a mismanaged and improperly designed HVAC system was identified as the cause for a pressure differential that overwhelmed the high-performance Tubelite curtainwall glazing system. Despite the design team's best intentions, and despite the constructor's reasonable installation quality and the building management engineers' efforts to accommodate end-user discomfort during normal operations, the HVAC system was found to be the primary cause for building damage and recurring moisture intrusion.

To correct this dysfunctional system and prevent future damage to the building, a remediation and repair scope of work was developed to modify the defective HVAC system that was the primary cause of moisture intrusion and poor interior air quality. The repair scope of work included mechanical alteration to the system with new equipment and operational management procedures for the primary building management control software:

- Several new variable-speed drive exhaust fans with interconnection to sensors located at the basement (which requires design negative pressure) detention cell area and building entrance vestibules were required to help balance the slight negative pressure requirement of the basement.
- Air volume for outdoor fresh-air intake required an increase at the programming controls to accommodate all five air handlers, plus a 10% allowance for a minimum airflow set point.
- The AHU return-air fan controls required adjustment to maintain a 0.85 ratio of total supply to outside airflow.
- An industry-standard whole-building test-and-balance protocol was required to ensure computer-controlled and physically adjusted air dampers and sensors work together to maintain a proper interior air pressure that overall is slightly positive.
- A new weather-sensing station was located away from the high-pressure zone of the roof to ensure the management control computers are always aware of the exterior climate conditions.
- The facility's engineering maintenance staff required additional training to ensure controls of the computer software can be adjusted and maintained within the design parameters of the equipment.

To date, implementation of some, but not all, proposed remedial work has resulted in no additional moisture intrusion during the few storm events that have occurred. Minor repairs to the curtainwall glazing system gaskets are necessary due to the post-occupancy over-pressurization that resulted in gaps in compressed rubber extrusions.

Reconstruction of the curtainwall interior water dams at vertical-to-horizontal framing intersections that are known failure points from factory test results and field diagnostic testing could not be performed throughout the five-story building, due in part to the height and also due to the inaccessible nature of the west-elevation brise soleil that does not allow for a boom lift operator to reach the glazing.

The owner is aware that some moisture bypass is likely to occur over the years, but most water should be limited to a few ounces on the wide aluminum mullion frames at the interior that are not moisture sensitive.

Although most moisture intrusion surveys performed on buildings are likely to determine deficiencies, defects, and failures of the building enclosure system, the more difficult-to-source leaks may require a more in-depth building analysis that does not focus only on the enclosure cladding systems but also on the interior air management systems. An out-of-balance air management system can cause significant differential air pressure that will inadvertently stress the building enclosure systems.

Basic aerodynamic principles can adversely affect a building's performance. Fundamentally, the laws of fluid dynamics revolve around the understanding that an increase in the speed of a fluid (for instance, water or air) is accompanied by a decrease in pressure. In this case, the interior HVAC AHU's ramping fan speed to compensate for environmental conditions both inside and outside the building created a large decrease in building air pressure. The resulting pressure differential caused significant moisture intrusion during normal storm events. It is notable that despite the significant pressure differential on the building, the opaque wall cladding (that is, the cement-fiber-reinforced rainscreen panels over VaproShield RevealShield SA over foam plastic over gypsum sheathing) and the storefront punched windows did not present signs of leakage.

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Getting Started with Artificial Intelligence and the Evolving Technology Landscape

ABSTRACT

Artificial intelligence (AI) continues to advance, with new applications and platforms coming online on a regular basis. Many of these companies, platforms, and technologies will have the potential to impact how the building enclosure industry operates, both in the short and long term. Following the 2025 introductory AI session, this session will provide an update regarding new and upcoming technologies that will demonstrate significant potential, along with discussing what is likely to come in the next few years. Furthermore, this session will address one of the most pressing questions that most building enclosure and roofing consultants face today: "How do I get started?" Beyond knowing about new AI-enabled technology and use cases, this discussion will focus on best practices and lessons learned for those eager to try or do more with AI. The learner can expect to walk away with a clear path for testing, refining, and/or deploying AI within their processes and organizations. Tangible next steps for novices and experienced AI users alike will be a primary focus.

LEARNING OBJECTIVES

- Review recent artificial intelligence (AI) advancements that came online in 2025 or will come online in 2026.
- Discuss how to get started with identifying, testing, and implementing AI within a process or organization.
- Compare and contrast technology and AI adoption barriers that people and organizations face when wanting to advance their processes.
- Gain insight into likely upcoming AI-enabled use cases for building enclosure projects.

SPEAKER

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Michael Ramos is the president at Raymond, a minority- and veteran-owned small business that provides full architecture and engineering services. After joining Raymond in 2017, he has worked to grow Raymond's engagement and presence in the federal market and leads Raymond's internal research and development program, which is currently developing multiple artificial-intelligence-based and software solutions for the architecture, engineering, and construction industry. Prior to Raymond, Ramos was the director of analysis at DeWolff, Boberg & Associates and a senior associate with Booz Allen Hamilton. He holds a BS in chemical engineering from MIT and an MS in chemistry from Tufts University.

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The state of artificial intelligence (AI) continues to rapidly advance. And while the building enclosure industry has more nuanced and complex use cases that will challenge the rate of AI implementation, significant potential exists to start using AI in our daily workflows today.

Initially, mainstream AI adoption was characterized by broad, general-purpose chatbots, but the current landscape is evolving towards specialization, integration, and ownership. We are now witnessing the shift from "chatting with an AI" to deploying AI in highly specific and value-driven ways. Three trends are emerging, with each being an avenue for any firm, depending on priorities.

The most democratizing trend is the rise of custom generative pre-trained transformers (GPTs) for specific processes. Platforms like OpenAI's ChatGPT and Google's Gemini allow individuals, without any coding knowledge, to configure a version of the AI with specific instructions and knowledge bases. A small business owner, for example, can upload their employee handbook and expense policy to create a custom agent that instantly answers staff questions about company procedures. This trend effectively turns every employee into a "citizen AI developer," allowing them to automate mundane, repetitive tasks and create micro-tools perfectly suited to their unique workflows, boosting efficiency from the ground up.

In parallel, new software-as-a-service companies use powerful foundational models as the engine for their products. These startups build a specialized application layer on top of existing large language models and offer a subscription-based service that solves a niche business problem with AI; for instance, a company might offer a service that specifically analyzes legal contracts. These businesses are selling a prepackaged, expert use case, making sophisticated AI accessible for a specific solution. **Figure 1** provides an introductory look at the key AI uses and strengths on a relative basis for the leading 2025 AI platforms.

The third major trend involves the strategic use of powerful open-source AI models to develop internal company applications. As models like Llama and Mistral become increasingly capable, businesses with technical expertise are choosing to download and run them on their own private servers. This strategy prioritizes data security while overcoming some of the specific data limitations of a custom GPT. This allows them to build highly customized and secure internal tools while maintaining complete data privacy.

GETTING STARTED

For new users, start by just trying. The leading AI platforms include OpenAI's ChatGPT, Google's Gemini, Perplexity AI, and Anthropic's Claude. Any of these options would be suitable for a new user. Each platform has a generous free usage tier that allows for substantial trial and error as you become accustomed to using an AI chatbot for tasks

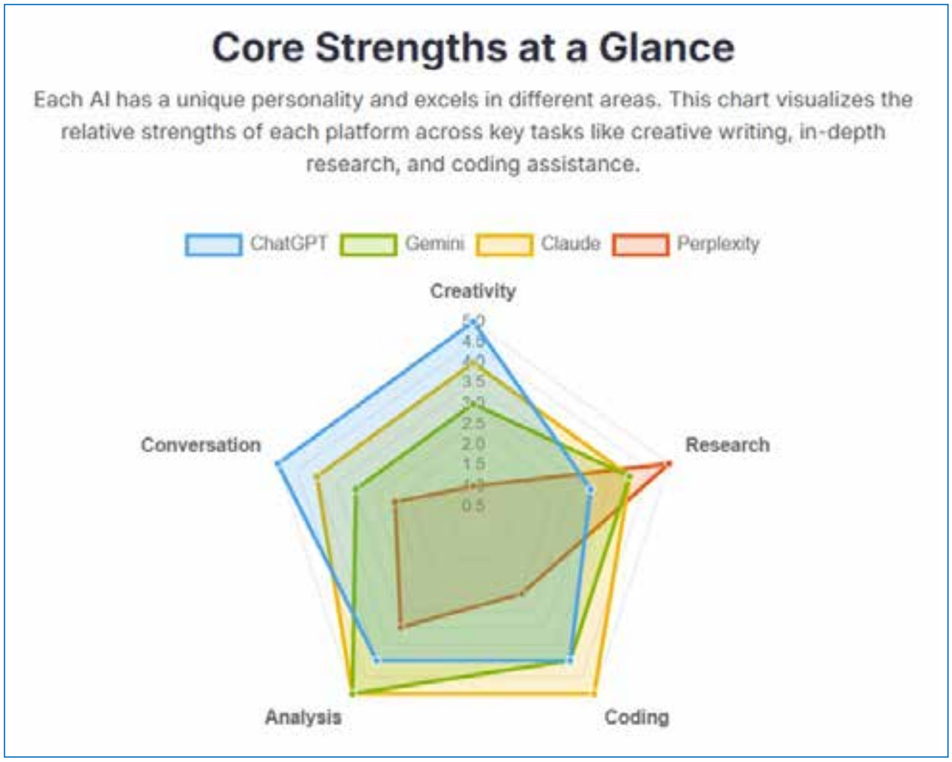

FIGURE 1. Comparison of relative strengths for leading artificial intelligence platforms in 2025.[1]

FIGURE 2. Comparison of strengths, weaknesses, and price points for leading artificial intelligence platforms in 2025.[1]

like research, questions and answers, or image creation. **Figure 2** provides a high-level introduction to strengths, weaknesses, and price points that you can expect for each of the leading 2025 AI platforms and models. You can also expect that these AI companies will continue to push AI algorithms directly into their search engines; Google now offers Gemini search results directly in their search results, and other companies are developing their own web browsers to offer the same capability. You can assume general industry technical data are available through AI search or chatbots; experiment first with asking technical questions that would require you to research answers, but always fact-check.

Prompt engineering is the next phase of learning AI; this is necessary when AI returns answers that are too generic. Interestingly, AI is exceptionally good at writing the most effective prompts; simply describe to the AI what you are aiming to accomplish, and it will help you create the best prompt. For truly sophisticated prompts, you will likely see the need for personas, where you describe the user in terms that the AI understands. For example, "Imagine you are a waterproofing consultant" is a simple persona that provides a reference point for how the AI needs to structure its thinking. Experimentation is the key to finding what works best for your use case.

IDENTIFYING, TESTING, AND IMPLEMENTING AI

Integrating AI into your operations requires a strategic, phased approach, which can be broken down into three core phases: identification and prioritization, testing and validation, and implementation and scaling. As summarized in **Fig. 3** and detailed below, this process can help new AI users get started in aligning AI to business priorities and goals.

Phase 1: Identify and Prioritize

First, you need to pinpoint tasks that are repetitive, time-consuming, or data-heavy, where automation can provide immediate value. For any process flow that you want to optimize, this begins with a comprehensive process audit on how you do business. To start, identify the most significant time sinks, such as writing detailed condition assessment reports or manually tagging thousands of project photos. The audit should emphasize the most repetitive, rule-based tasks and identify areas where human error, such as missing a subtle sign of moisture intrusion in an infrared scan or misinterpreting a building code, could lead to mistakes.

Once the process pain points are identified, they can be mapped to specific AI solutions. Common use cases may include the following:

- Image and data analysis: automated detection of building enclosure and roofing anomalies
- Automated reporting: integrating generative AI to create initial drafts of reports and summaries from structured data like field notes and measurements
- Predictive maintenance models to analyze historical data to forecast future failures

This phase concludes with selecting one use case for an initial project.

Phase 2: Test and Validate

Testing and validating an AI tool should include a controlled pilot program before committing to a firm-wide rollout. Success must be quantifiable against specific key performance indicators (KPIs). The pilot itself should be small-scale, involving a tech-savvy team of two to three employees working on a few representative projects. This team uses the AI tool while comparing their performance to the normal process—for instance, by analyzing drone imagery for one roof with the AI tool and analyzing drone imagery for a similar roof manually. Positive outcomes provide a green light to proceed to the next phase. If results are underwhelming, feedback from the pilot team is critical to analyze whether the tool or the process needs tweaking or if the firm should pivot to a different use case.

Phase 3: Implement and Scale

A gradual, phased rollout is recommended over a simultaneous firm-wide launch. The process could begin with a single department, such as the roof inspection team, before expanding to adjacent groups and culminating in full implementation. Crucial to this phase is a strong focus on training and support. This includes developing a clear playbook with documentation and video tutorials, hosting hands-on workshops using real project examples from the pilot, and designating an in-house "champion" to provide ongoing peer support.

Remember to integrate the AI with existing software stacks to avoid issues with transferring data between programs. Finally, it is essential to recognize that AI is not a "set it and forget it" solution. Continuous monitoring of

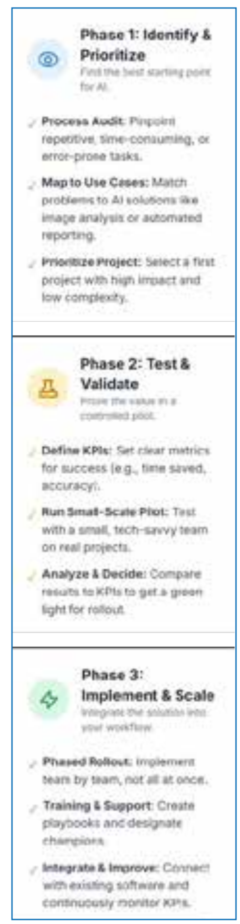

FIGURE 3. High-level process for starting artificial intelligence development initiatives.[1]

performance against KPIs and gathering ongoing team feedback are essential for refining the system, identifying areas for improvement, and discovering new opportunities for AI integration in the future.

TECHNOLOGY AND AI ADOPTION BARRIERS

Implementing AI will face any number of potential barriers. Planning for these potential hurdles is the first step toward a successful adoption strategy.

People and Cultural Barriers

The most significant obstacles are human-centered, involving the need to change established mindsets and habits. Senior consultants, who have spent decades honing their expertise, may view AI as a threat to their hard-earned experience: can AI replace their professional judgment? Also, if a firm is profitable with a steady stream of clients, management and senior staff may see investing in AI as an unnecessary and expensive complication to existing workflows. Moreover, a considerable skills gap can cause technical intimidation. The prospect of learning a complex new system can lead to resistance born from a fear of looking ineffective or perceiving AI to be overly cumbersome.

Data and Technology Barriers

A company's data tend to be variable and unstructured, which can negate some of AI's inherent benefits by creating a "garbage in, garbage out" scenario. Inconsistent terminology, such as where one consultant writes "minor alligatoring" while another uses "initial surface crazing" for the same condition, makes it difficult for a model to learn. Similarly, unstructured photos stored with random file names lack the consistent labels needed for training. Beyond data quality, a significant challenge lies in integration. If a new AI tool cannot seamlessly communicate with existing software, like report-writing applications, it simply creates another manual step and defeats the purpose of automation.

Financial and Operational Barriers

The business case for AI can be difficult to make due to financial and operational constraints. The return on investment (ROI) is often unclear; while the costs of software subscriptions and training are concrete, benefits like "better defect detection" are abstract and hard to quantify. This ambiguity can make it challenging to justify the expense. The high up-front and ongoing costs can be prohibitive for small or mid-sized firms, which also lack dedicated resources for experimentation. Taking skilled personnel off billable projects to run a pilot program represents a direct loss of revenue.

Arguably the most significant operational barrier is accountability and professional liability. A licensed designer still needs to stamp the final design and not delegate too much (if any) responsibility to an AI model to perform design tasks. Given this insurance and professional liability requirement, the industry has historically been risk-averse to adopting and accepting new technologies—AI potentially being no different. The industry can likely expect non-design AI tools to be adopted first, with more resistance coming to design tools, especially if transparency in how the AI is performing calculations is not available.

UPCOMING AI USE CASES, 2026 TO 2027

With the rapid evolution of AI, it is challenging to speculate what will be available and when. Highlighted here are some pertinent use cases that will impact the building enclosure industry, with solutions likely coming to market and/or being offered as a proprietary solution.

On-Device Computer Vision

AI model quantization will continue to improve. While a quantized model will not have the full capabilities of cloud-based AI, it will be ideal for discriminative AI functions like computer vision. For consultants, this means that on-device processing eliminates latency and data privacy concerns while allowing for instantaneous feedback during an inspection.

The practical applications of this will be transformative. During a walk-through, a consultant might use their mobile device's camera for immediate safety analysis, with the AI identifying potential hazards like missing personal protective equipment, unguarded edges, or improper ladder use. Simultaneously, the same device can perform a detailed building enclosure inspection, automatically detecting and classifying defects such as cracks, spalls, or efflorescence in real time. Furthermore, by leveraging the device's camera and light detection and ranging sensors, a quantized model can instantly collect critical design parameters, measuring dimensions, calculating areas, and even identifying material types on the spot.

Sustainability Analysis

Many companies have proprietary software for sustainability analysis and asset management; AI will make available new solutions for the larger building enclosure community over the next 2 years. Leveraging drones for thermal and high-resolution imagery, AI will offer the ability to train new models specifically for sustainability analysis. This will start with AI platforms that can process this imagery to automatically identify and quantify thermal bridging, air leakage points, moisture intrusion, and material degradation. Tools such as Ombrulla and Inspekt AI leverage advanced computer vision to not only pinpoint these defects but also measure their precise magnitude. These services will enable more consultants to enter the sustainability services part of the building enclosure market that was previously limited to a handful of specialty players. This will enable consultants to provide clients with quantifiable data on energy loss, enabling highly accurate energy modeling and precise ROI calculations for proposed retrofits, thereby making the business case for sustainability investments. Further, this will enable long-term, proactive asset management plans, complete with multi-year capital budgets, life-cycle cost analyses, and optimized maintenance schedules.

Structural and Drainage Calculations

Already, any AI user can create a custom GPT for specific functions, including calculations. For structural and drainage calculations, the key is to have the AI properly interpret the jurisdiction's building code to determine the specific requirements and the calculations to be performed. While custom GPTs do have limits on their training ability (most particularly data loading constraints), this is a realistically surmountable problem, either through scaled-down GPT design or by building an in-house solution.

In the structural engineering use case, the likely process will involve curating a specialized knowledge base consisting of authoritative documents (for instance, the American Society of Civil Engineers' ASCE 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*; the American Institute of Steel Construction's *Steel Construction Manual*; the American Concrete Institute's ACI 318, *Building Code Requirements for Structural Concrete*, for concrete; relevant local building codes). The user-defined document library will be uploaded directly to the custom GPT, which processes and indexes the information, while the user then provides a core set of instructions (for example, approaches, prioritized formulas, and desired output). The AI can then be prompted with specific project parameters—such as beam spans, material strengths, and load types—to calculate shear and moment diagrams, check beam deflections, or determine preliminary column sizes, effectively acting as an interactive, query-able version of multiple engineering handbooks at once. Similarly, this approach can be applied to create a custom GPT for drainage calculations. An AI user would upload a curated knowledge base, train the GPT, and then perform the relevant calculations. Using this type of framework, new engineering GPTs can be readily developed for numerous design use cases that can improve the speed and efficiency of building enclosure consulting and larger-scale architecture and engineering design.

New AI "Agents"

On January 23, 2025, OpenAI launched their Operator AI agent, which can perform more complex computer-based tasks within the Google Chrome web browser—an impressive AI feat. A mere 6 months later, on July 17, 2025, OpenAI announced their new "Agent" model, which had a greater ability to control native programs on a user's computer outside of Google Chrome. It is likely that within the next 2 years, AI agents are poised to evolve from specialized tools that are dependent on application programming interfaces into sophisticated digital assistants. The future AI agents will likely interact with programs like AutoCAD, Excel, or Photoshop through their graphical user interfaces, mimicking human actions like clicking menus, activating command line tools, and interpreting on-screen information. Thus, an AI agent could be given a goal, such as "Generate a wall section with detailing for the north elevation." The agent would then open AutoCAD and begin to execute a series of complex commands. While the initial AI agents will likely need training on complex programs like AutoCAD, it is likely that these agents will eventually meet the user's needs sooner rather than later. This would transform the role of the designer from a manual drafter into a strategic overseer, thereby reviewing AI-generated drawings rather than creating them.

CONCLUSIONS

The pace of new AI solutions is unlikely to dissipate, which may seem daunting to new users. However, AI should be considered a new, variable, high-impact, and high-potential tool that may enable new capabilities, services, and delivery that building enclosure consultants can benefit from. New users should remember that AI itself is the best means for learning AI and take advantage of this built-in learning tool for discovering the potential benefits, processes, and new ideas for daily process improvement. In the coming 2 years, many new AI applications will become available and provide our industry with even greater capabilities, ideas, and use cases.

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The Not-So-Perfect Wall

ABSTRACT

Nearly 2 decades ago, Joseph Lstiburek (STEE-brek) delved into “The Perfect Wall” with his *ASHRAE Journal* article. It has served as a springboard for seeking greater insight into the relationships between, and the methods used to manage, the four building enclosure phenomena of liquid water intrusion, air infiltration and exfiltration, water vapor migration, and heat transfer. The goal of this paper is to provide additional insight for managing the four phenomena by focusing on 1) the constructability of commonly used subassemblies to manage these phenomena and 2) the integration of the subassemblies within the whole of the building enclosure. This paper seeks to provide additional insight by focusing on real-world conditions. To reach this goal, common constructability-related causes for the uncontrolled intrusion of liquid water, the infiltration and exfiltration of air, the migration of water vapor, and the transfer of heat are identified and then evaluated under transient environmental conditions—as opposed to steady-state environmental conditions—to better understand the consequences of allowing the phenomena to be uncontrolled.

LEARNING OBJECTIVES

- Describe the four building enclosure phenomena of liquid water intrusion, air infiltration and exfiltration, water vapor migration, and heat transfer.
- Explain the differences between barrier wall systems and rainscreen wall systems.
- Identify the importance of maintaining continuity in subassemblies that manage the four building enclosure phenomena in barrier wall systems and rainscreen wall systems.
- Discuss the differences between transient and steady-state analyses for the four building enclosure phenomena.

SPEAKER

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Architect, MKA International Inc.

Thomas A. Gentry is a licensed architect with over 50 years of experience as a forensic and design architect, tenured university professor, general and design-build contractor, and tradesperson. He has testified before the US Congress Energy and Commerce Subcommittee on Energy and Air Quality and holds a US patent for a thermally active building system that uses a modified capillary tube hydronic system and geopolymer cement concrete to provide heating and cooling with a low-carbon footprint.

AUTHOR:
Thomas A. Gentry, AIA, NCARB

In May 2007, Joseph Lstiburek's article "The Perfect Wall" was published in the *ASHRAE Journal*. The article has served as a springboard for seeking greater insight into the relationships between, and the methods used to manage, the four building enclosure phenomena of water intrusion, air infiltration and exfiltration, vapor migration, and heat transfer.

THE BASICS

Water **intrusion** is the movement of liquid water through a building enclosure. **Transport methods** for the intrusion of liquid water are a) liquid flow by gravity, b) liquid flow by air pressure differences, and c) capillary suction. Typically, the intruding water is rainwater, snowmelt water, or irrigation water that moves into and through the building enclosure from the exterior. Water intrusion is managed with weather-resistive barriers (WRBs), flashings, gaskets, and sealants.

Air **infiltration** and **exfiltration** are the types of movement of air through a building enclosure. **Driving mechanisms** for the infiltration and exfiltration of air are d) wind effect; e) stack effect; f) heating, ventilating, and air-conditioning equipment; and g) elevator pumping effect. Infiltration is the movement of outdoor air through the building enclosure, and exfiltration is the movement of indoor air through the building enclosure. Air infiltration and exfiltration are managed with air barriers.

Vapor **migration** is the movement of water vapor through a building enclosure. **Transport methods** for the migration of water vapor are h) air movement and i) diffusion by vapor pressure differences. Outdoor sources of water vapor include atmospheric moisture and solar-driven surface moisture. Indoor sources of water vapor include respirating, bathing, cooking, dishwashing, laundering, humidifying, cleaning, and plants. Vapor migration is managed with vapor retarders and barriers.

Heat **transfer** is the movement of heat—thermal energy—through the building enclosure. Modes for the transfer of heat are j) conduction, k) radiation, and l) convection. Outdoor sources of heat are solar radiation, terrestrial radiation, and the atmospheric heat they generate. Indoor sources of heat are occupants, equipment, and lighting. Heat transfer is managed with insulation, radiation barriers and low-emissivity materials, and air barriers.

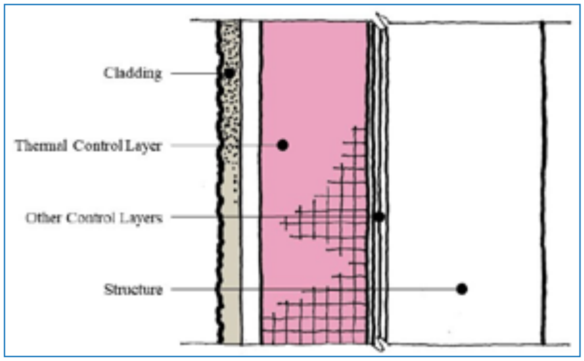

FIGURE 1. The perfect wall. *Note: gypsum board is not shown on the interior side of the wall to more accurately represent the wall depicted by Joseph Lstiburek.*

With a focus on the exterior walls of building enclosures and the management of water intrusion, three types of wall systems are discussed in this paper: barrier walls, rainscreens, and drainage walls. Barrier walls rely on a continuous seal, typically located at the exterior face, to prevent water intrusion. They include architectural precast concrete, single-component insulated metal panels (IMPs), and direct-applied thin brick veneer on concrete masonry units (CMUs). Rainscreens rely on an exterior cladding to prevent most of the water from intruding; behind the cladding, a pressure-equalizing compartmented cavity, coupled with a WRB, prevents the remaining water from intruding, and drying ventilation is promoted. They include metal panels over a ventilated dry-out air space, brick veneer cavity walls with pressure-equalizing vents, and glazed curtainwalls. Drainage walls are similar to rainscreens, except for having a narrow vertical gap in lieu of a pressure-equalizing compartmented cavity. They include stucco and exterior insulation finishing systems over grooved WRB and/or insulation board, and brick veneer and clapboard (lap siding) over a WRB on cold-formed steel and wood-framed walls.

It is not uncommon for a building to have multiple varieties of barrier walls, rainscreens, and/or drainage walls. It is at the transitions between these different wall systems where discontinuities in the WRB, flashings, gaskets, and sealants commonly occur, which often results in the uncontrolled intrusion of water. It is also common to have discontinuities in the air barriers, vapor retarders and barriers, and insulation at the transitions, which often results in the uncontrolled infiltration and exfiltration of air, the migration of vapor, and the transfer of heat.

THE PERFECT WALL

The perfect wall, as initially defined by Joseph Lstiburek, contains an exterior cladding whose "function is principally to act as an ultraviolet screen" and an interior structure, between which, "in order of importance," a "rainwater control layer," an "air control layer," a "vapor control layer," and a "thermal control layer" are located (**Fig. 1**).[1,2] (While the perfect wall contains an exterior cladding, it is not explicitly presented as a rainscreen system; in other words, the perfect wall can be a drainage wall.) The thermal control layer is located on the exterior side of the other control layers and structure to reduce their thermal expansion and contraction.

THE NOT-SO-PERFECT WALL

For the purposes of this paper, there are two reasons why a wall is "the not-so-perfect wall." The first reason is the exterior cladding, control layers, and structure are not configured per the perfect wall. The second, and more significant reason in the "real-world," is discontinuities in the exterior cladding and/or one or more of the control layers, which results in the uncontrolled intrusion of water, the infiltration and exfiltration of air, the migration of vapor, and/or the transfer of heat.

Figures 2 and **3** show the transition between a drainage wall with a stucco cladding and a barrier wall with a stucco cladding. An analysis of these walls, as well as the perfect wall, is provided below.

WATER INTRUSION

In his article, Joseph Lstiburek makes it clear that preventing water intrusion needs to be the first priority in designing and constructing exterior walls. The author of this paper concurs and also notes that, based on decades of forensic investigations, water intrusion is the most common cause of exterior wall failures.

As discussed above, there are various types of wall systems for the management of water intrusion. Where these types of wall systems routinely differ from the perfect wall is the location of the "rainwater control layer" (WRBs, flashings, gaskets, and sealants) in relation to the "thermal control layer" (insulation). With the perfect wall, the WRBs, flashings, gaskets, and sealants are located behind the insulation, whereas, with the other wall types, the insulation is located behind the WRBs, flashings, gaskets, and sealants. This difference is significant because, while the configuration in the perfect wall reduces thermal expansion and contraction in the other control layers and structure, the configuration limits insulation options to insulation types that are typically more costly and therefore less financially feasible in most markets. It is also significant because constructing the perfect wall often requires greater skill from tradespeople in a market with declining skills due to an aging workforce and retirement, a declining interest in trades, economic cycles and the Great Recession of 2007 to 2009, competition from other industries, and gaps in education and training. A better option is to locate insulation behind the "rainwater control layer" and design and construct the WRBs, flashings, gaskets, and sealants to accommodate thermal expansion and contraction. That being said, most water intrusion is due to improperly designed and/or constructed WRBs, flashings, gaskets, and sealants.

AIR INFILTRATION AND EXFILTRATION

Air infiltration and exfiltration are managed with an air barrier, which is often the WRBs, flashings, gaskets, and sealants that are used to manage water intrusion, and/or the vapor retarder that is used to manage vapor migration. As such, it can be located at or near the exterior side or the interior side of the wall.

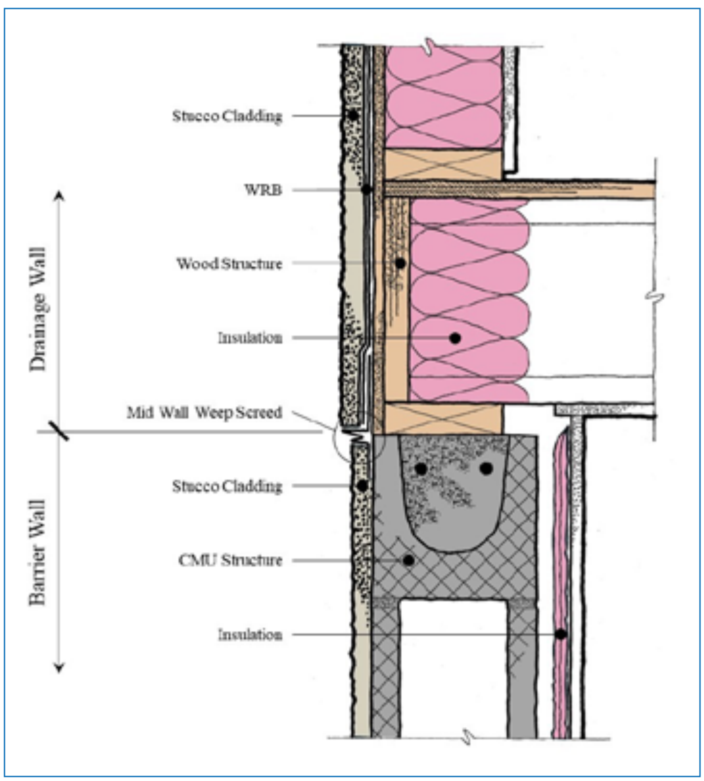

FIGURE 2. Florida framed-and-concrete-masonry-unit (CMU) wall. *Note: WRB = weather-resistive barrier.*

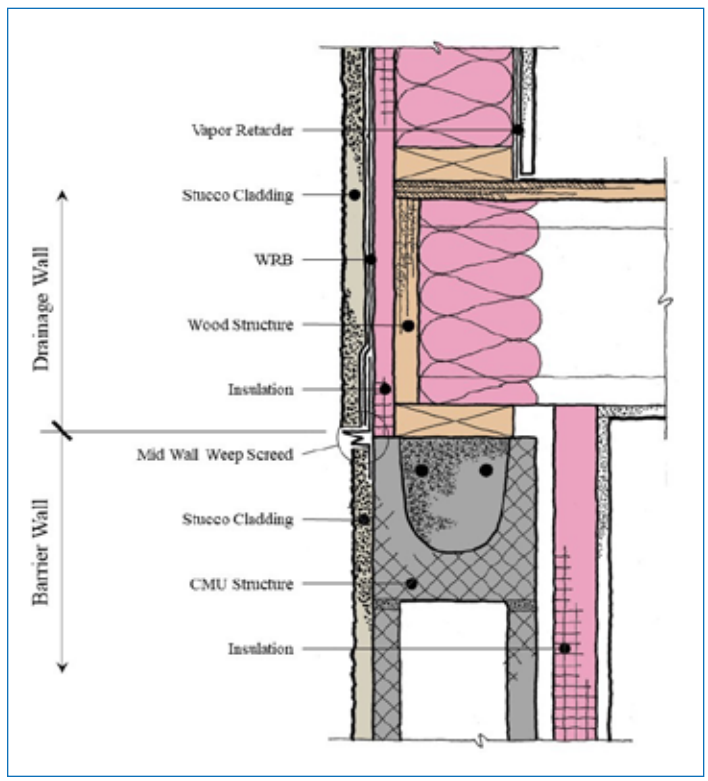

FIGURE 3. Colorado framed-and-concrete-masonry-unit (CMU) wall. *Note: WRB = weather-resistive barrier.*

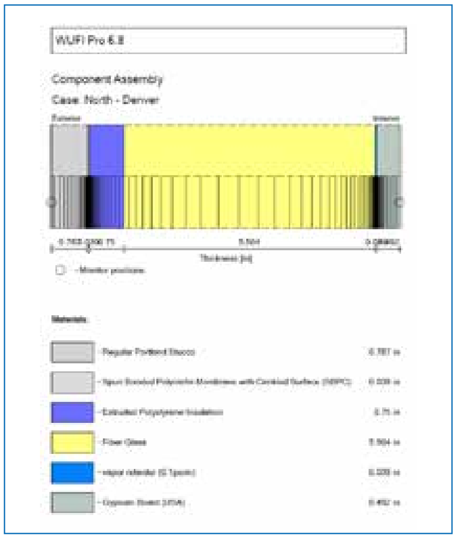

FIGURE 4. Exemplar component assembly in WUFI.

In terms of indoor air quality, the infiltration and/or exfiltration of air is typically not a problem, but in terms of vapor migration and heat transfer via convection, it is often a problem. (While operable windows are required for natural ventilation, most one- and two-family dwellings rely on air infiltration and exfiltration, rather than mechanical ventilation, to maintain indoor air quality throughout the year.) Both vapor migration and heat transfer are discussed below.

VAPOR MIGRATION

Two transport methods for vapor migration are air movement and diffusion by vapor pressure differences, with air movement typically accounting for more than 90% of vapor migration in wall cavities.[3] It is a key reason why managing air infiltration and exfiltration is important.

As for managing vapor migration via diffusion by vapor pressure differences, it is critical to prevent the vapor from condensing within the wall. This is the basis of the somewhat simplistic rule of thumb of locating a vapor retarder as close as possible to the warm-in-winter side of the wall. For hot climates, it means locating the vapor retarder near the exterior side of the wall, if one is used. (Per the *2021 International Building Code*, Class I and II vapor retarders are not permitted in Climate Zones 1 and 2. Class III vapor retarders are permitted but not required.[4]) For cool and cold climates, it means locating the vapor retarder near the interior side of the wall. The perfect wall has the vapor retarder located near the interior side of the wall, irrespective of the climate zone. Therefore, for the perfect wall to work in hot climates, the insulation cannot be affected by moisture.

WUFI is a family of software products that allows realistic calculation of the transient coupled one- and two-dimensional heat and moisture transport in walls and other multi-layer building components exposed to natural weather. WUFI analyses of the perfect wall, Florida framed-and-CMU walls, and Colorado framed-and-CMU walls show the range of water content in the stucco cladding, insulation, and gypsum board are roughly the same (**Fig. 4–6**). In other words, in practical

Water Content [lb/ft^2]

	Start	End	Min.	Max.
Total Water Content	0.51	0.3	0.25	0.51

Water Content [lb/ft^3]

Layer/Material	Start	End	Min.	Max.
Regular Portland Stucco	6.65	4.45	3.63	6.65
Spun Bonded Polyolefin Membrane w	0.00	0.00	0.00	0.00
Extruded Polystyrene Insulation	0.02	0.00	0.00	0.10
Fiber Glass	0.12	0.01	0.01	0.12
vapor retarder (0.1perm)	0.00	0.00	0.00	0.00
Gypsum Board (USA)	0.39	0.14	0.10	0.39

FIGURE 5. Water content for north-facing stucco-on-wood-framed wall in Denver, Colorado.

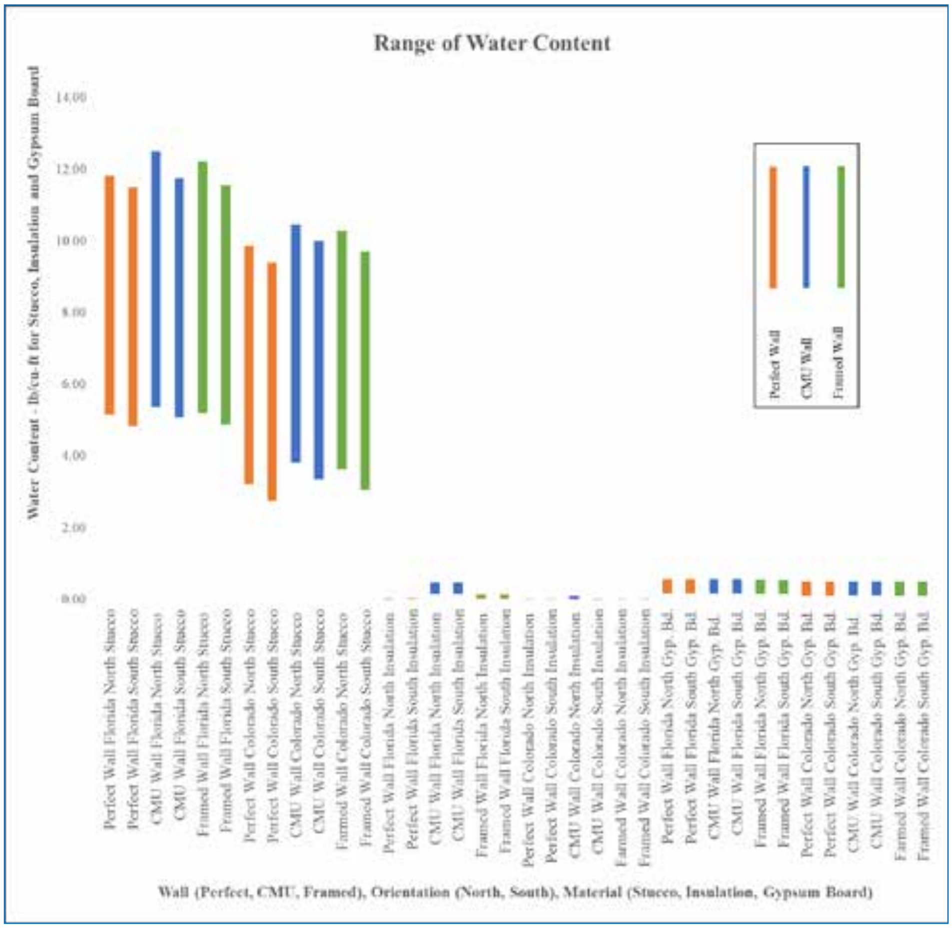

FIGURE 6. Range of water content.

TABLE 1. Monthly temperatures

	Temp °F (°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fort Myers, Florida	High	75 (23.9)	78 (25.5)	81 (27.2)	85 (29.4)	89 (31.6)	91 (32.8)	92 (33.3)	92 (33.3)	90 (32.2)	87 (30.5)	81 (27.2)	77 (25.0)
	Low	54 (12.2)	56 (13.3)	60 (15.5)	64 (17.8)	69 (20.5)	74 (23.3)	75 (23.9)	75 (23.9)	74 (23.3)	69 (20.5)	62 (16.7)	57 (13.9)
	Avg	65 (18.3)	67 (19.4)	70 (21.1)	75 (23.9)	79 (26.1)	82 (27.8)	83 (28.3)	83 (28.3)	82 (27.8)	78 (25.5)	71 (21.7)	67 (19.4)
Denver, Colorado	High	46 (7.8)	47 (8.3)	56 (13.3)	62 (16.7)	71 (21.7)	83 (28.3)	89 (31.6)	87 (30.5)	80 (26.7)	66 (18.9)	55 (12.8)	46 (7.8)
	Low	20 (-6.6)	21 (-6.1)	28 (-2.2)	34 (1.1)	43 (6.1)	53 (11.7)	59 (15.0)	57 (13.9)	49 (9.4)	37 (2.8)	27 (-2.8)	20 (-6.6)
	Avg	33 (0.5)	34 (1.1)	42 (6.2)	48 (8.9)	57 (13.9)	68 (20.0)	74 (23.3)	72 (22.2)	65 (18.3)	52 (11.1)	41 (5.0)	33 (0.5)

terms of managing vapor migration, the commonly built wall types perform as well as the perfect wall. This fact is also supported by other research (for example, Hamid Heidarali and John Javier Cheng Law's article "Taking the 'Perfect Wall' Concept to the Next Level").[5]

HEAT TRANSFER

Heating degree days (HDD) quantify the demand for energy required to heat a building, and they are based on an outdoor temperature of 65°F (18.3°C). Cooling degree days (CDD) quantify the demand for energy required to cool a building, and they are based on an outdoor temperature of 74°F (23.3°C). Annually, Fort Myers, Florida, which is located in Climate Zone 2A (hot-humid), has 252 HDD-°F (140 HDD-°C) and 4,046 CDD-°F (2,247 CDD-°C). Denver, Colorado, which is located in Climate Zone 5B (cool-dry), has 5,950 HDD-°F (3,305 HDD-°C) and 715 CDD-°F (397 CDD-°C). Similar to the vapor migration analysis, the temperatures at these two locations are used to analyze heat transfer for the perfect wall, the stucco-on-wood-framed wall, and the stucco-on-CMU wall.

When the heat transfer through an exterior wall is analyzed under steady-state environmental conditions, the relative positions of the materials in the wall are typically inconsequential. This is because the sums of the thermal resistance (R) and heat capacity (C) do not change (that is, R1 + R2 + R3 = R2 + R3 + R1, and C1 + C2 + C3 = C2 + C3 + C1). However, when the analysis is under transient environmental conditions, the relative positions of the materials can be consequential, especially when the wall is a mass wall. (The *2021 International Energy Conservation Code* defines mass walls as "above-grade walls of concrete block, concrete, insulated concrete form, masonry cavity, brick but not brick veneer, adobe, compressed earth block, rammed earth, solid timber, mass timber or solid logs. Any walls having a heat capacity greater than or equal to 6 Btu/ft^2 × °F [123 kJ/m^2 × K]".[6]) The relative positions of the materials can be consequential due to the materials' heat capacity and the time that is required for them to become thermally static with the outdoor and indoor environments. More specifically, if the daily outdoor temperature fluctuates about the desired indoor temperature and the heat capacity of one or more materials in the wall is high enough, then the wall dampens the transfer of heat.

When the interior structure of the perfect wall is CMU or some other mass wall material, the perfect wall dampens the transfer of heat if the daily outdoor temperature fluctuates about the desired indoor temperature.

As shown in **Table 1**, during the winter in Fort Myers and the summer in Denver, the average daily temperatures are between 65°F (18.3°C) and 74°F (23.3°C). During these months, the perfect wall with an interior structure of CMU or some other mass wall material will be more energy efficient than the perfect wall with an interior structure that is not a mass wall material.

By comparison, the stucco-on-wood-framed wall does not contain a mass wall material, so it will not be as energy efficient as the perfect wall with an interior structure of CMU or some other mass wall material. As for the stucco-on-CMU wall, while it contains a mass wall material, the insulation is on the wrong side of the CMU to optimize the benefits of the heat capacity of the CMU.

CONCLUSION

In terms of managing liquid water intrusion, air infiltration and exfiltration, water vapor migration, and heat transfer, Joseph Lstiburek's perfect wall is a reasonably good one-size-fits-all wall for all climate zones. However, there is little need for a single wall for all climate zones when there is one or more not-so-perfect walls for each climate zone that 1) function as well as the perfect wall, 2) are more constructable, and 3) are more affordable.

Furthermore, with the cause of most uncontrolled water intrusion, air infiltration and exfiltration, water vapor migration, and heat transfer being improperly designed and/or constructed WRBs, flashings, gaskets, sealants, air barriers, vapor retarders, insulations, and/or radiation barriers, especially at the transitions between different wall systems—which is something that neither Joseph Lstiburek's perfect wall nor the not-so-perfect wall for each climate zone is invulnerable to—it makes more sense to put the focus on matching the constructability of the walls with the skills of designers and tradespeople.

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Hail Impact Testing of Modified Bitumen Roof Membranes

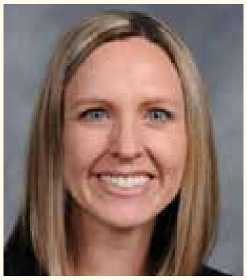
ABSTRACT

Wiss, Janney, Elstner Associates Inc. (WJE) and the Midwest Roofing Contractors Association (MRCA) have a history of collaborating to develop research and testing programs that focus on expanding industry knowledge of commonly used roofing materials. One such focus was on granule-surfaced, modified bitumen roofing membranes. WJE, in collaboration with the MRCA Technical & Research Committee, developed a testing program to evaluate the influence of hail impact on granule-surfaced modified bitumen roof membranes installed in low-slope roof assemblies. The objective was to determine the extent of damage to various aged membranes from a single manufacturer through physical testing and laboratory review and analysis. Testing was conducted in accordance with ASTM D3746, *Standard Test Method for Impact Resistance of Bituminous Roofing Systems*. Samples were impacted by a 5 lb (2.27 kg), 2 in. (50.8 mm) diameter steel missile released from a height of 53 in. (1.35 m). Sample weights, granule counts, and exposed bitumen measurements were taken both before and after the impact. Desaturation of the membrane samples was conducted to remove the bitumen and make visual observations of the reinforcement. Additionally, microscopy of the impacted cross sections was performed. This presentation will describe the testing program procedures and corresponding results. Those who are interested in hail assessment would benefit from this presentation.

LEARNING OBJECTIVES

- Discuss ASTM D3746, *Standard Test Method for Impact Resistance of Bituminous Roofing Systems*, and its procedures and parameters.
- Describe a process called “image analysis,” which uses a computer program to analyze high-resolution photographs to identify features of interest, particularly granules and exposed bitumen.
- Recognize variations in modified bitumen membranes of various ages including granule quantities and exposed bitumen area.
- Explain the differences observed between roofing samples containing gypsum and wood fiber cover boards regarding hail impact.

SPEAKERS



Heidi Mase, Licensed Architect
Senior Associate, Wiss, Janney, Elstner Associates Inc.

Heidi Mase is a licensed architect in Illinois and has broad-based experience in architectural and structural services. Since joining Wiss, Janney, Elstner Associates Inc. in 2009, she has participated in field investigations, structural analysis and design, repair document preparation, construction observation, and field testing on several different structure types ranging from historic wood-framed and masonry buildings to modern precast structures. Her primary focus is in the roofing and waterproofing practice area, where she has worked on numerous projects involving condition assessments, water infiltration investigation, repair, and replacement design.

Richard Koziol, Licensed Architect, AIA, NCARB
Principal, Wiss, Janney, Elstner Associates Inc.

Richard Koziol has 40 years’ experience as a licensed architect in five states, practicing in the areas of building enclosure assessments, investigation, construction period services, and research. He is a member of the ASTM Committee D08 on Roofing and Waterproofing. He has published articles and papers on roofing and waterproofing subject matters as well as research papers involving low-rise foam adhesive for low-slope roofing.

AUTHORS:
Heidi Mase, Licensed Architect
Richard Koziol, Licensed Architect, AIA, NCARB

INTRODUCTION

Wiss, Janney, Elstner Associates, Inc. (WJE) and the Midwest Roofing Contractors Association (MRCA) Technical & Research (T&R) Committee have a history of collaborating to develop research and testing programs that focus on expanding knowledge of commonly used roofing materials. In 2023, the focus of the research and testing was on granule-surfaced, modified bitumen roofing membranes. WJE, in collaboration with the MRCA T&R Committee, developed a testing program to evaluate the influence of hail impact on granule-surfaced modified bitumen roof membranes installed in a low-slope roof assembly. The objective of the test program was to determine the extent of damage to these membranes from a single manufacturer of various ages through physical testing and laboratory review and analysis.

TEST PROGRAM DESCRIPTION

Testing was conducted in accordance with ASTM D3746, *Standard Test Method for Impact Resistance of Bituminous Roofing Systems*. Per the standard, "this test method subjects 305 × 305 mm [12 × 12 in.] specimens of a roofing system (insulation and membrane complete with top surfacing) to a series of four impacts, one in each quadrant, from a standard missile falling freely from a predetermined height with an impact energy of 30.0 J [22 lbf-ft]. Damage to the membrane is assessed by visual examination of the felts after solvent extraction of the bitumen."

Eighteen 12 × 12 in. (304.8 × 304.8 mm) samples were divided into four 6 × 6 in. (152.4 × 152.4 mm) quadrants. A 5 lb (2.27 kg), 2 in. (50.8 mm) diameter steel missile was released from a height of 53 in. (1.35 m) and impacted the samples one time in each quadrant. The steel missile equates to a 2 in. diameter hailstone, as both have an impact energy of 30.0 J (22 lbf-ft).

Sample weights, granule counts, and exposed bitumen measurements were taken both before and after the impact to capture any changes the impact caused. Desaturation of the membrane samples was then conducted to remove the bitumen and make visual observations of the membrane reinforcement. Additionally, microscopy of the cross sections was performed on portions of each sample at the areas of impact.

SAMPLE PROCUREMENT

All samples were provided by MRCA T&R Committee members and consisted of two-ply modified bitumen membranes applied in cold adhesive, all from a single manufacturer. The samples contained two cover board types: ½ in. (12.7 mm) thick gypsum and ½ in. thick wood fiber, along with polyisocyanurate insulation. The ages of the samples varied, consisting of new, approximately 5 years old, and approximately 10 years old. All the samples came from in-service roofs from Midwest environments (in lieu of artificial weathering), with the exception of the new samples, which were fabricated for the purposes of this testing.

TESTING PROCEDURE

The testing procedure consisted of the following seven steps:

1. **Initial Documentation.** A total of 18 samples were received and consisted of the following:
   a. Three 16 × 16 in. (406.4 × 406.4 mm) modified bitumen with gypsum cover board, 10 years old

FIGURE 1. Sample trimmed and divided into four quadrants with 3 in. (76.2 mm) diameter impact zones.

   b. Three 16 × 16 in. modified bitumen with wood fiber cover board, 10 years old
   c. Three 16 × 16 in. modified bitumen with gypsum cover board, 5 years old
   d. Three 16 × 16 in. modified bitumen with wood fiber cover board, 5 years old
   e. Three 16 × 16 in. modified bitumen with gypsum cover board, new
   f. Three 16 × 16 in. modified bitumen with wood fiber cover board, new

   All samples were labeled, using a sample naming convention consisting of sample age, membrane type, cover board type, and sample number (for example, 5-MB-G-2), and then photographed.

2. **Test Sample Preparation.** All samples were neatly trimmed to a size of 12 × 12 in. (304.8 × 304.8 mm) in the laboratory and graphically divided into four 6 × 6 in. (152.4 × 152.4 mm) quadrants with 3 in. (76.2 mm) diameter circles as impact zones (**Fig. 1**). The as-received samples were larger than

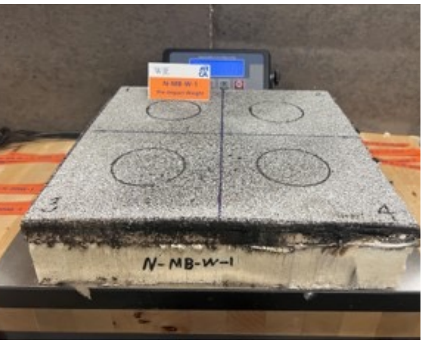


FIGURE 2. Weighing of sample.

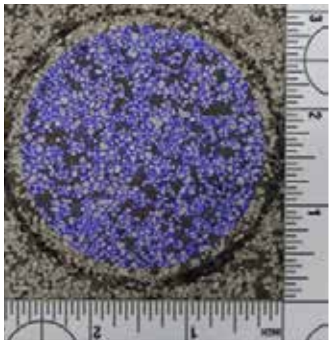


FIGURE 3. Granule identification through image analysis.

the test sample size to eliminate any negative edge effects from the removal process. Each zone was used for a different purpose throughout the testing process. Zone 1 (upper left) was used for image analysis and manual granule counts, Zone 2 (upper right) for image analysis, Zone 3 (lower left) for image analysis and desaturation, and Zone 4 (lower right) for image analysis and cross-section microscopy, all of which are described in the following steps.

3. **Pre-Impact Weights and Granule Counts.** Weights and granule counts were obtained for each sample prior to impact. Weights were obtained using a scale (**Fig. 2**). Granule counts were obtained through a process called image analysis, which uses a computer program to analyze a high-resolution photograph to identify features of interest (granules) within a 3 in. (76.2 mm) diameter circle (**Fig. 3**). A black and white image was created from the original color image, a process called color thresholding. This enabled the computer program to determine quantitative information regarding the image (granule counts and exposed bitumen area). In addition to image analysis, manual counts of the granules were also conducted.
4. **Impact Testing.** A 5 lb (2.27 kg) steel missile released from a height of 53 in. (1.35 m) impacted each quadrant of the sample per ASTM D3746. The steel missile was held at the top of the drop tube with a pin until the sample was ready to be impacted. A laser guide was used to align the missile with the center of the impact zone (**Fig. 4**).
5. **Post-Impact Weights and Granule Counts.** Weights of the samples and granule counts at each impacted zone were obtained a second time for each sample following impact. In addition to weighing the full samples using a precise scale, granules equal in number to those lost during impact were also weighed. Comparisons were made between pre- and post-impact images (**Fig. 5**, **6**).
6. **Desaturation.** Desaturation is the process of removing the bitumen from the membrane samples using a solvent to expose the reinforcement. One quadrant of each sample was desaturated to allow the membrane reinforcement to be visually inspected for damage due to the impact (**Fig. 7**, **8**).
7. **Microscopy.** One quadrant of each sample was cut through the impact site to view the membrane and cover board in cross section with the use of a microscope (**Fig. 9**, **10**).

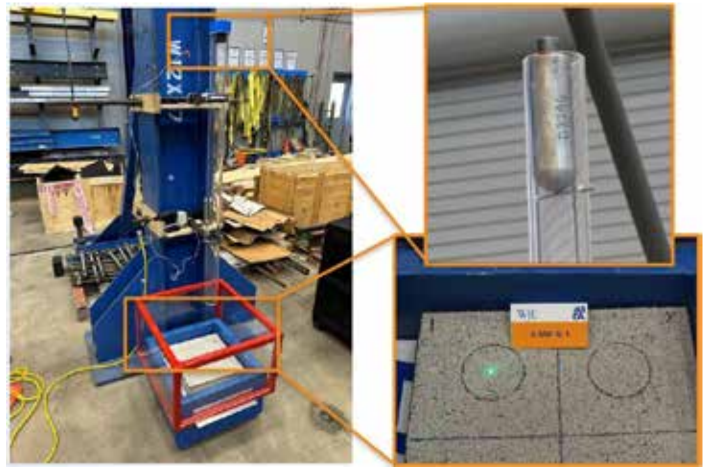


FIGURE 4. Testing apparatus at left; steel missile within drop tube at upper right; and laser spot alignment for missile drop within a typical 3 in. (76.2 mm) diameter circle at lower right.

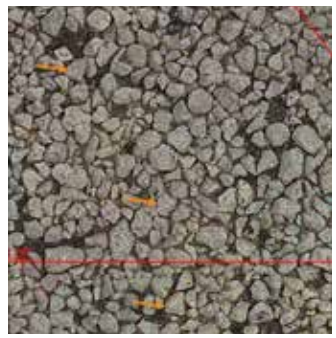


FIGURE 5. Sample 5-MB-G-1 pre-impact. Orange arrows indicate some differences between the pre-impact and post-impact images.

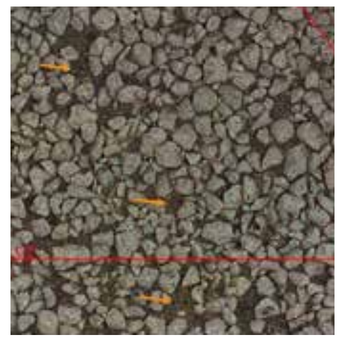


FIGURE 6. Sample 5-MB-G-1 post-impact. Orange arrows indicate some differences between the pre-impact and post-impact images.

FIGURE 7. Fiberglass reinforcement from a modified bitumen base ply.

FIGURE 8. Polyester and fiberglass dual reinforcement from a modified bitumen cap ply.

RESULTS OF IMPACT TESTING

Table 1 describes the average results of the impact testing in terms of granule counts and exposed bitumen (expressed as a percentage of area) within the 3 in. (76.2 mm) diameter impact zone for each type of sample tested.

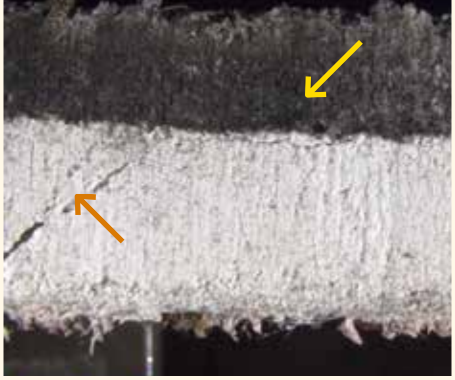


FIGURE 9. Cross section of 10-year-old gypsum cover board sample. Note separation of facer from gypsum (yellow arrow) and radial crack throughout thickness of gypsum (orange arrow).

FIGURE 10. Cross section of new wood fiber cover board sample. Note that no separations are visible.

TABLE 1. Average manual granule counts and exposed asphalt area pre- and post-impact

Cover board type	Sample age (yrs)	Granule count pre-impact	Granule count post-impact	Granule count decrease	Exposed bitumen pre-impact	Exposed bitumen post-impact	Exposed bitumen increase
Gypsum	New	2,761	2,743	18	33.9%	34.3%	0.4%
Gypsum	5	2,242	2,231	11	33.9%	35.2%	1.3%
Gypsum	10	1,845	1,794	51	40.2%	42.2%	2.0%
Wood fiber	New	2,720	2,703	17	36.9%	37.3%	0.4%
Wood fiber	5	2,246	2,,173	73	34.6%	35.1%	0.5%
Wood fiber	10	1,753	1,736	17	55.5%	55.8%	0.3%

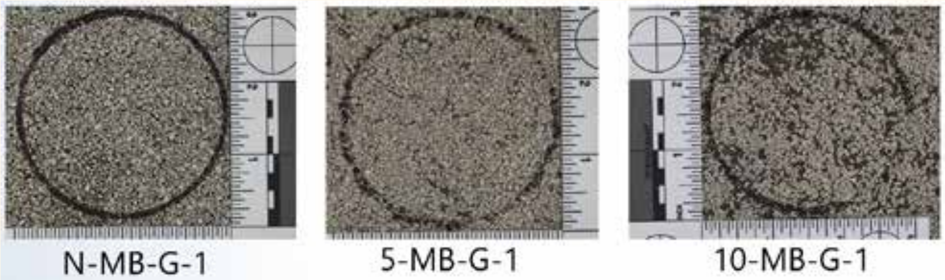


FIGURE 11. Comparison of new, 5-year-old, and 10-year-old membranes over gypsum cover board.

CONCLUSIONS

The following conclusions were drawn from the results of the impact testing and analysis:

- In general, regardless of cover board type or impact, the quantity of granules on the membranes decreased with age, while the exposed bitumen area generally increased with membrane age. There was a larger increase in exposed bitumen area between 5- and 10-year-old membranes than there was between new and 5-year-old membranes (**Fig. 11**).
- For each membrane age, the simulated hail impact resulted in minor granule loss that yielded slightly more exposed bitumen. The exposed bitumen area generally increased more upon impact with gypsum cover board than it did with wood fiber cover board.
- The impacts did not fracture the membrane reinforcement in any of the samples.
- Cracking of the gypsum cover board was observed at the impact site in all gypsum cover board samples that were tested. The impacts also caused cover board facer separation from the gypsum core at the impact sites in two-thirds of the gypsum cover board samples. The wood fiber cover board samples were visually unaffected by the impacts.
- Comparison between image analysis and manual granule counts revealed that image analysis accuracy is variable due to differences in granule shape, color, texture, and size as well as features like granule overlap or fracturing. For this reason, manual counts were found to be more accurate and ultimately what was relied upon for the study. However, image analysis was found to be more useful in identifying exposed bitumen area due to the high color contrast between the granules and the bitumen, a property that image analysis is proficient in detecting.

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Proactive Strategies for Managing Building Enclosure Penetrations: Improving Performance and Reducing Risk

ABSTRACT

Building enclosure penetrations—such as those required for mechanical, electrical, and plumbing systems—are critical junctures that can significantly impact a structure's long-term performance. When not properly addressed during design and construction, these details can lead to water intrusion, air leakage, thermal bridging, and maintenance issues. As building enclosure performance expectations increase, in conjunction with owner expectations of durability and resilience, adopting a proactive approach to managing penetrations is essential. This session examines the risks associated with poorly coordinated or improperly executed penetrations, drawing on case studies where missed opportunities in early specification decisions—or late-stage improvisation—led to enclosure failures, rework, and performance risk. Attendees will gain insight into best practices for managing penetrations from the design through installation. Participants will be provided with practical tools for addressing penetrations at every stage—whether drafting details, reviewing submittals, or observing field installation—based on real-world challenges faced by architects, engineers, and building enclosure consultants. Managing penetration effectively from the design through construction is critical to achieving resilient, high-performing enclosures. This session equips attendees with the strategies and context needed to make building enclosure penetrations a maintainable strength, not a continuing vulnerability.

LEARNING OBJECTIVES

- Describe how mechanical, electrical, and plumbing penetrations affect air, water, thermal, and structural performance in commercial building enclosures.
- Recognize the most common failure points associated with building enclosure penetrations and summarize design strategies that help mitigate those risks.
- Identify key codes and material standards that influence the design, specification, and installation of penetration protection systems.
- Explain how to align technical submittals, specifications, and field installation practices to support consistent enclosure performance.
- Consider performance-related calculations that may inform the evaluation of penetration detailing and its contribution to enclosure integrity.
- Compare the cost implications of reactive field fixes versus proactive detailing at the specification stage.
- Recommend cross-disciplinary coordination strategies that improve project outcomes for architects, engineers, consultants, and installers.

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Sheri Pettoni

SPEAKERS

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Principal, Socotec

Darbi Krumpos has over 30 years of experience with Socotec. She graduated from Seattle University with a Bachelor of Science in mathematics. She is a certified documents technologist and holds two building enclosure commissioning certificates. Project support includes code compliance and warranty support; coordination of private and public projects worldwide; litigation and remediation for condominium associations and owners; investigation and research related to construction deficiencies and litigation; specification writing and contract administration for new construction and remediation for both commercial and residential projects; building enclosure commissioning, field testing, and quality assurance; and quality control program management.

Sheri Pettoni
Marketing & Business Development Lead, RPH

With over 20 years of experience spanning architecture, engineering, and manufacturing, Sheri Pettoni is a seasoned leader in marketing and business development within the building industry. She has led growth for multiple building product manufacturers, particularly those focused on the building enclosure, through go-to-market strategy, American Institute of Architects presentations, product approvals, and technical sales support. Since 2016, she has supported IIBEC-related initiatives through strategic work with manufacturers specializing in building enclosure solutions. Her career has been defined by her ability to position complex products in competitive markets, build trust with technical audiences, and drive measurable results across the full sales and marketing life cycle.

INTRODUCTION

Roof penetrations have long been a source of water intrusion through the roof plane. Integration of the roof cover with roof penetration flashings is imperative for the performance of the roof. This applies to both steep- and low-slope roofs, and it applies to both commercial and residential projects. Rooftop penetrations plague the industry with design and performance challenges. More often than not, a reported roof leak can be directly tied to a rooftop penetration such as a drain, a conduit sleeve, a vent pipe, a chimney, or a rooftop piece of equipment.

Even during the period in which this paper was drafted, the examples that have been included within have evolved and changed as different challenges related to roof leaks and roof penetrations arose throughout the course of the authors' consulting work. There are many facets to making rooftop penetrations watertight that need attention! Rooftop penetrations should be discussed more and detailed more. This is an aspect of the building enclosure industry that is an industry in itself and has received little attention in comparison to other larger aspects of the roof or the enclosure.

In every building, the enclosure must function as a continuous system that controls air, water, heat, and, in some cases, vapor and sound. In practice, these layers are often interrupted by the need for service penetrations that allow mechanical, electrical, and plumbing (MEP) systems, information technology, telecommunications, and other infrastructure to pass through walls, roofs, and floors. These openings, while necessary, create points of weakness in the enclosure that must be addressed with care.

It is not uncommon for penetrations to be addressed reactively, resolving conflicts in the field or leaving the detailing to subcontractors at the submittal phase, without clear direction in the design documents. This approach relies on installer experience rather than coordinated design intent, producing inconsistent results. Code evolution and the push for resilience and sustainability demand increased performance requirements through stricter codes and increased attention to long-term building performance. A systematic approach, integrated into the design process from the start, is essential to avoid costly rework, performance failures, and reduced service life.

LITERATURE AND CODE REVIEW

A review of industry literature and relevant codes highlights the importance of penetration management as a building performance priority. The *International Building Code* (IBC) establishes requirements for structural performance, weather protection for exterior walls, and roof assemblies that directly influence penetration detailing; however, the code turns to manufacturers of roofing systems to provide instructions to meet the performance requirements.[1] The *International Energy Conservation Code* addresses air leakage and thermal continuity, both of which can be compromised by poorly executed penetrations and, while impacted by the roofing, are not incorporated into the roofing manufacturer's installation instructions.[2] ASHRAE Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, provides further guidance on thermal and air barrier integration, while ASTM C920, *Standard Specification for Elastomeric Joint Sealants*, outlines specifications for elastomeric sealants, a common component in penetration detailing.[3,4] AAMA 711, *Voluntary Specification for Self-Adhering Flashing*, offers performance criteria for self-adhering flashing materials used at penetration interfaces.[5]

More specialized guidance, such as ASTM E2813, *Standard Practice for Building Enclosure Commissioning*, emphasizes the role of verification in achieving long-term performance.[6] Peer-reviewed research shows that early coordination of penetrations significantly reduces post-occupancy issues related to water ingress, air leakage, and thermal loss. Field studies consistently demonstrate that penetrations left to "ad hoc" solutions in the field often lead to premature enclosure failure, as shown in the case studies herein.

HORIZONTAL VERSUS VERTICAL PENETRATIONS

Penetrations can be classified as horizontal or vertical, with each type influencing enclosure performance in specific ways. In many cases, horizontal penetrations, such as those through walls, carry fewer long-term moisture risks than vertical ones. When detailed correctly, they shed water more effectively, integrate with drainage planes, and align with multiple control layers. Design considerations should still address wind-driven rain, water shedding, and the possibility of water tracking along conduits or sleeves. These risks can be controlled through coordinated detailing during design and construction.

Vertical penetrations, including those through roofs or floor assemblies, present different challenges. Gravity, ponding water, snow accumulation, and wind-driven rain can quickly reveal weaknesses in flashing or membrane terminations. In roof assemblies, these vulnerabilities are intensified by thermal cycling and ultraviolet (UV) exposure, which can wear down sealants and flashings over time.

Whenever possible, routing services through horizontal assemblies instead of vertical ones helps reduce the number of high-risk water entry points. Combining multiple services into a single curb or wall sleeve further decreases the number of seal locations and makes maintenance more straightforward.

ROOF VERSUS WALL PENETRATIONS

Performance requirements vary significantly depending on whether the penetration occurs in a roof or a wall assembly.

Roof penetrations must account for slope, drainage, and structural loading. Water is naturally directed toward low points (gravity works!), which increases the importance of properly flashing and sealing waterproof systems and assemblies. Larger penetrations or clustered service openings are best placed on curbs where possible, positioned away from drainage paths and low areas to limit ponding. Roof systems are also subject to UV exposure, thermal cycling, and wind uplift, all of which can contribute to the breakdown of sealants more immediately and roof systems and accessories, including flashings, over time. Scheduled inspections executed under routine maintenance are necessary to identify deterioration, fatigue, or wear before failure occurs.

Wall penetrations present a different set of challenges. Assemblies may vary in thickness and cladding type or include layered systems such as water-resistive barriers and air barriers. Cavities between these layers can increase the risk of moisture accumulation, air leakage, and the movement of smoke or fire between compartments. These areas are more difficult to access and seal, which increases the need for careful coordination between trades. Proper integration of penetrations with the weather-resistive barrier in shingle fashion, along with positive drainage detailing, is necessary to maintain performance.

DESIGN COORDINATION

The design must reflect actual field conditions of the building enclosure rather than relying solely on generic details. This includes verifying wall assembly configurations, confirming roof slopes and drainage points, and accounting for structural constraints. Penetration design decisions made early in the process directly shape long-term enclosure performance and maintenance requirements.

MANAGING PENETRATIONS ACROSS CONTROL LAYERS

A high-performance enclosure relies on the continuity of four primary control layers: air, water, thermal, and vapor. Each must be considered in penetration detailing, as the failure of any one can undermine the overall system.

Air Control Layer

Air leakage through penetrations is a major driver of moisture accumulation within assemblies. Best practices include integrating the air barrier membrane with compatible penetration-sealing materials, specifying tested systems for adhesion and flexibility, and verifying continuity during construction. Case studies in northern climates have shown that poorly sealed penetrations can account for more than 20% of total building air leakage. Further, air leakage directly ties to vapor migration, which can exponentially impact building performance and moisture accumulation within roof and wall assemblies.

Water Control Layer

Penetrations are frequent initiation points for bulk water intrusion. Effective penetration coordination, material

FIGURE 1. Typical flashed pipe vent penetration—reported leaking.

FIGURE 2. Typical flashed pipe vent penetration—reported leaking.

selection, and detailing must be considered in conjunction with positive drainage to direct water away from the penetrations and building surfaces. Failures often occur at penetrations that are not properly integrated with the surrounding enclosure assemblies and systems.

Thermal Control Layer

Thermal bridging at penetrations can reduce assembly *R*-values and increase the risk of condensation. Coordination with MEP engineers during design is essential to align penetration routing with insulation strategies.

Vapor Control Layer

In certain climate zones, vapor control is a critical consideration. Penetrations through vapor retarders must be detailed to maintain continuity of the vapor retarder, avoiding unintended moisture migration and related bulk water accumulation within roof and wall assemblies where it may condense.

STRUCTURAL CONSIDERATIONS

Large or improperly located penetrations can compromise structural performance, particularly in load-bearing elements. Coordination with the structural engineer during design to avoid field modifications is essential. In some cases, reinforcement may be required, and penetrations through rated assemblies must be sealed with tested firestop systems.

LIFE-CYCLE COST IMPLICATIONS

The financial impact of poorly designed, installed, and maintained penetrations extends beyond initial repairs. Water damage remediation, increased energy consumption from air leakage, and premature component replacement can cumulatively exceed the cost of proper detailing many times over.

It is imperative we collaborate and deliberately design the holes we poke in our building enclosures!

CASE STUDY 1: STEEP-SLOPE ROOFING PIPE PENETRATIONS

In this initial case study, the penetrations relate to steep-slope roofing and primarily focus on a rather basic roof penetration, the plumbing pipe vent.

In a recent project, consultants at SOCOTEC were asked to investigate roof leaks reported by occupants in a multifamily development. The discussion evolved regarding these leaks, as the client reported multiple projects with similar reports of roof leaks at plumbing vent penetrations through asphalt-shingled steep-slope roof covers. While this case study could extend into the attics and incorporate discussions regarding air and vapor controls impacted, this particular element of the project was enlightening and is highlighted in this presentation.

The reported roof leaks were investigated, and **Fig. 1** and **2** show the points of water entry were consistently at rooftop plumbing vent penetrations, "pipe boot flashings."

The client asked if SOCOTEC would assist in helping them educate their internal teams and vendors (roof installers) regarding the code requirements and standards for detailing plumbing vent penetrations to ensure code-compliant, manufacturer warrantable, and watertight penetrations are installed.

A consultant's role often involves educating, so SOCOTEC set off to collect the data they thought they knew to assemble the package. In the process, SOCOTEC educated themselves and found some interesting nuances that need some industry attention when designing watertight roof systems.

As a starting point, typical go-to resources and standards in the roof industry were researched to present the industry standards.

The National Roofing Contractors Association's (NRCA's) *NRCA Roofing Manual: Steep-Slope Roof Systems* provides the detail shown in **Fig. 3** for a vent pipe penetration.[7]

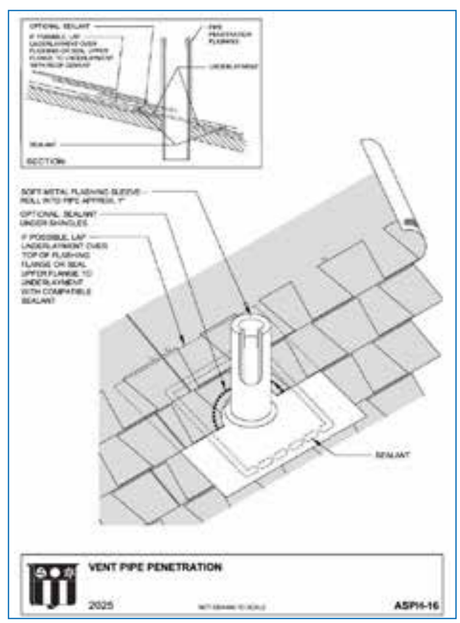
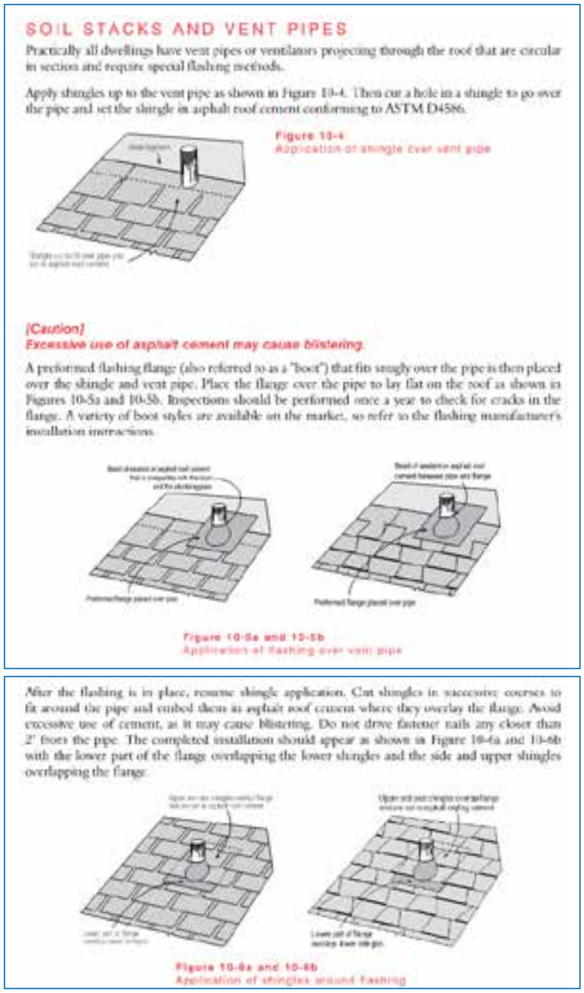


FIGURE 3. Image from the *NRCA Roofing Manual: Steep-Slope Roof Systems,* p. 124.



SOIL STACKS AND VENT PIPES

Practically all dwellings have vent pipes or ventilators projecting through the roof that are circular in section and require special flashing methods.

Apply shingles up to the vent pipe as shown in Figure 10-4. Then cut a hole in a shingle to go over the pipe and set the shingle in asphalt roof cement conforming to ASTM D4586.

Figure 10-4
Application of shingle over vent pipe

[Caution]
Excessive use of asphalt cement may cause blistering.

A preformed flashing flange (also referred to as a "boot") that fits snugly over the pipe is then placed over the shingle and vent pipe. Place the flange over the pipe to lay flat on the roof as shown in Figures 10-5a and 10-5b. Inspections should be performed once a year to check for cracks in the flange. A variety of boot styles are available on the market, so refer to the flashing manufacturer's installation instructions.

Preformed flange placed over pipe

Preformed flange placed over pipe

Figure 10-5a and 10-5b
Application of flashing over vent pipe

After the flashing is in place, resume shingle application. Cut shingles in successive courses to fit around the pipe and embed them in asphalt roof cement where they overlay the flange. Avoid excessive use of cement, as it may cause blistering. Do not drive fastener nails any closer than 2" from the pipe. The completed installation should appear as shown in Figure 10-6a and 10-6b with the lower part of the flange overlapping the lower shingles and the side and upper shingles overlapping the flange.

Figure 10-6a and 10-6b
Application of shingles around flashing

FIGURE 4. Images from the Asphalt Roofing Manufacturers Association's *Residential Asphalt Roofing Manual: Design and Application Methods*, pp. 72–73.

The Asphalt Roofing Manufacturers Association shares the detail shown in **Fig. 4** in their *2022 Residential Asphalt Roofing Manual: Design and Application Methods*.[8]

The *2018 International Residential Code* (IRC) addresses roof pipe penetrations as shown in **Fig. 5** and **6**.

Section 1507.2.8 of the 2018 IBC states almost the same language regarding commercial steep-slope roofing, as shown in **Fig. 7**.

This indicates, by reference, the code requires the designer and installer to comply with the asphalt shingle manufacturer's installation instructions. Not all manufacturers publish the same installation instructions and sequences, so then code compliance will vary depending on the manufacturer of the product being installed.

One steep-slope roofing manufacturer's published guide is shown in **Fig. 8** below with instructions for "plastic cement" for installation.

A second roof manufacturer includes in their installation instructions the application of asphalt roofing cement, as shown in **Fig. 9**.

A roof penetration pipe boot manufacturer that is common in residential roofing applications, shown in **Fig. 10**, cautions the installer not to use petroleum-based mastics, sealant compounds, or paint on flexible collars. This is counter to roof shingle manufacturer instructions.

A second roof penetration pipe boot manufacturer that is common in steep-slope roofing applications, shown in **Fig. 11**, warns not to use paint or petroleum-based products during installation.

A quick review of the steep-slope code and manufacturer requirements indicates conflicting and/or confusing information that must be incorporated into discussions during materials selection and design development.

- » The code references the manufacturer's installation instructions for installation requirements.
- » Manufacturers vary in their installation instructions and, further, do not necessarily produce pipe penetration flashing themselves.
- » The pipe penetrations vary in materials with lead-, rubber-, and plastic-based products.
- » A manufacturer specifies sealants that are not always compatible with all penetration boot flashing material types.
- » Penetration flashing manufacturers indicate petroleum-based products should not be used.

If the material selection and design development stages do not consider material selection and compatibility, in

R905.2.8 Flashing. Flashing for asphalt shingles shall comply with this section and the asphalt shingle manufacturer's *approved* installation instructions.

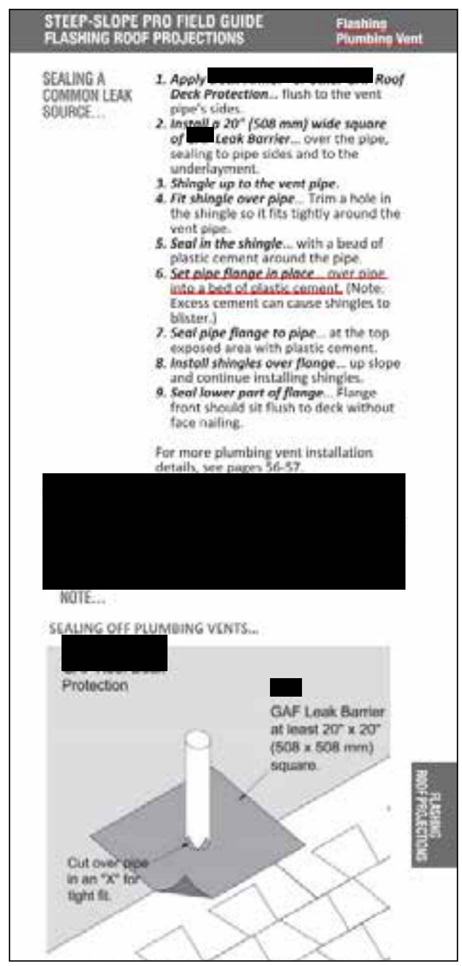
FIGURE 5. Excerpt from the *2018 International Residential Code*, Chapter 9, *Roof Assemblies*, Section R905.2.8, *Flashing*.

R905.2.8.4 Other flashing. Flashing against a vertical front wall, as well as soil stack, vent pipe and chimney flashing, shall be applied in accordance with the asphalt shingle manufacturer's printed instructions.

FIGURE 6. Excerpt from the *2018 International Residential Code*, Chapter 9, *Roof Assemblies*, Section R905.2.8.4, *Other Flashing*.

1507.2.8 Flashings. Flashing for asphalt shingles shall comply with this section. Flashing shall be applied in accordance with this section and the asphalt shingle manufacturer's printed instructions.

FIGURE 7. Excerpt from the *2018 International Building Code*, Chapter 15, *Roof Assemblies and Rooftop Structures*, Section 1507, *Requirements for Roof Coverings*.



STEEP-SLOPE PRO FIELD GUIDE
FLASHING ROOF PROJECTIONS
Flashing
Plumbing Vent

SEALING A COMMON LEAK SOURCE...

1. *Apply* [redacted] *Roof Deck Protection*... flush to the vent pipe's sides.
2. *Install a 20" (508 mm) wide square of* [redacted] *Leak Barrier*... over the pipe, sealing to pipe sides and to the underlayment.
3. *Shingle up to the vent pipe*.
4. *Fit shingle over pipe*... Trim a hole in the shingle so it fits tightly around the vent pipe.
5. *Seal in the shingle*... with a bead of plastic cement around the pipe.
6. *Set pipe flange in place... over pipe into a bed of plastic cement.* (Note: Excess cement can cause shingles to blister.)
7. *Seal pipe flange to pipe*... at the top exposed area with plastic cement.
8. *Install shingles over flange*... up slope and continue installing shingles.
9. *Seal lower part of flange*... Flange front should sit flush to deck without face nailing.

For more plumbing vent installation details, see pages 56-57.

[redacted]

NOTE...

SEALING OFF PLUMBING VENTS...

FIGURE 8. Field installation guide for roofing shingles, dated October 2021.

conjunction with installation instructions and warrantability by the manufacturer, there could be issues after construction is completed.

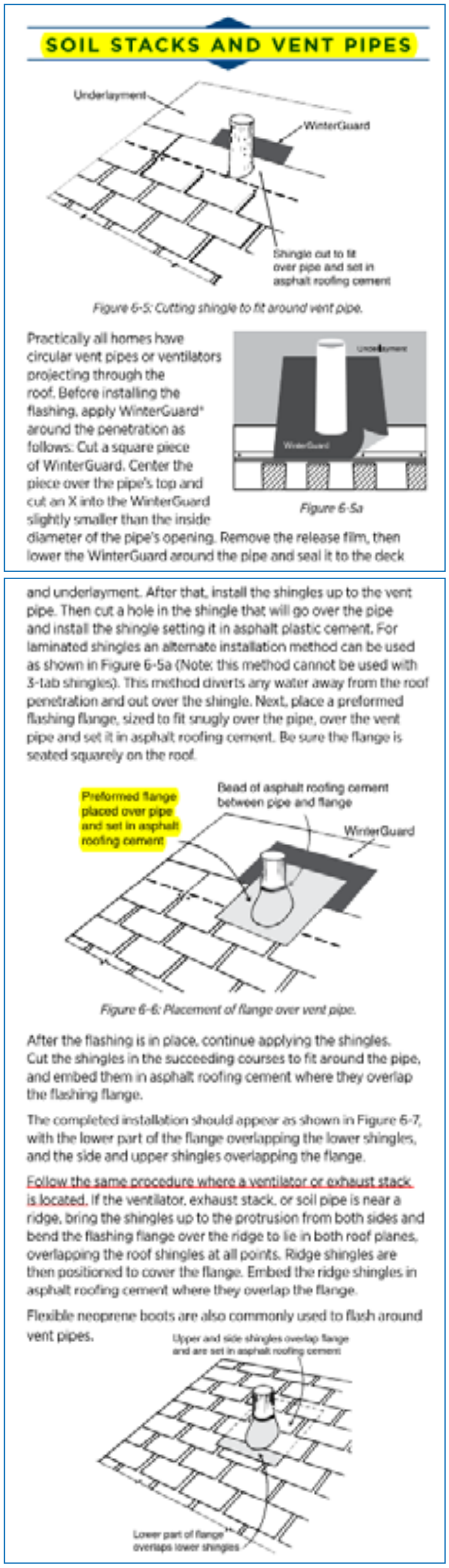

SOIL STACKS AND VENT PIPES

Figure 6-5: Cutting shingle to fit around vent pipe.

Practically all homes have circular vent pipes or ventilators projecting through the roof. Before installing the flashing, apply WinterGuard® around the penetration as follows: Cut a square piece of WinterGuard. Center the piece over the pipe's top and cut an X into the WinterGuard slightly smaller than the inside diameter of the pipe's opening. Remove the release film, then lower the WinterGuard around the pipe and seal it to the deck and underlayment. After that, install the shingles up to the vent pipe. Then cut a hole in the shingle that will go over the pipe and install the shingle setting it in asphalt plastic cement. For laminated shingles an alternate installation method can be used as shown in Figure 6-5a (Note: this method cannot be used with 3-tab shingles). This method diverts any water away from the roof penetration and out over the shingle. Next, place a preformed flashing flange, sized to fit snugly over the pipe, over the vent pipe and set it in asphalt roofing cement. Be sure the flange is seated squarely on the roof.

Figure 6-5a

Figure 6-6: Placement of flange over vent pipe.

After the flashing is in place, continue applying the shingles. Cut the shingles in the succeeding courses to fit around the pipe, and embed them in asphalt roofing cement where they overlap the flashing flange.

The completed installation should appear as shown in Figure 6-7, with the lower part of the flange overlapping the lower shingles, and the side and upper shingles overlapping the flange.

Follow the same procedure where a ventilator or exhaust stack is located. If the ventilator, exhaust stack, or soil pipe is near a ridge, bring the shingles up to the protrusion from both sides and bend the flashing flange over the ridge to lie in both roof planes, overlapping the roof shingles at all points. Ridge shingles are then positioned to cover the flange. Embed the ridge shingles in asphalt roofing cement where they overlap the flange.

Flexible neoprene boots are also commonly used to flash around vent pipes.

FIGURE 9. Excerpt from shingle applicator's manual.

If not addressed, could the instruction from the pipe boot manufacturer be interpreted as a deviation from code, which is the manufacturer's installation instructions?

There are similar deviating instructions related to the fastening of the pipe boot flashing flange. Is it fastened through the flange on the face of the downslope shingle, or should the fasteners be on three sides (upslope, right, and left), concealed behind the fasteners?

Then the owner, developer, general contractor, quality assurance/quality control observer, and manufacturer must collectively collaborate to ensure code compliance, material compatibility, and warrantability with long-term performance for a leak-free installation.

CASE STUDY TWO: LOW-SLOPE ROOFING PENETRATIONS

On a grander scale, this paper will now take a look at low-slope roofing penetrations. Commercial low-slope roofs often have a greater number of holes through the roof plane that all have nuanced components that create greater challenges in comparison to the pipe boot flashing.

While there are still soil pipe penetrations, there are also ganged and sleeved penetrations for electrical and mechanical systems that penetrate the roof deck and roof assembly. Electrical supply for rooftop equipment can lead from the breaker box to the roof. Larger mechanical ducting can penetrate the roof for air or water supply lines. All of these need careful detailing to avoid water intrusion and ensure long-term performance of the installed final assemblies. A sealant-dependent pipe penetration may be initially effective; however, sealant often provides temporary weather protection that requires reapplication after movement, whether from wind, seismic, or thermal forces. The following penetrations, often found in low-slope designs, created some challenges for a penthouse unit at a luxury mixed residential/hospitality high-rise in a well-known vacation destination, Hawaii!

Shortly after construction was completed, the owner experienced water intrusion during rain events at multiple locations. After investigation of the water entry points, two of the points of water entry (there were more related to improperly flashed screen walls and missing door flashings—but that is another case study for the future!).

FIGURE 10. Pipe boot manufacturer installation instructions with caution regarding the use of petroleum-based mastics.


[redacted] FLEX-FLASH™ ROOF FLASHINGS TECHNICAL SPECIFICATION

SPECIFICATIONS

APPROVALS AND LISTINGS

DESCRIPTION

FIGURE 11. Pipe penetration flashing manufacturer specification with warning regarding use of paint or petroleum-based products.

FIGURE 12. Exposed electrical supply conduit identified as water source after rain event.

FIGURE 13. Electrical panel after weather event resulted in water entry through unsealed conduit for rooftop power supply.

FIGURE 14. Air and water penetrations for mechanical systems.

The 2018 IBC states the following regarding roof flashings for most roof cover material types.

> *At the juncture of the roof and vertical surfaces, flashing and counterflashing shall be provided in accordance with the manufacturer's installations instructions and where of metal shall be not less than 0.019-inch corrosion resistant metal.*

SECTION 1503
WEATHER PROTECTION

1503.1 General. Roof decks shall be covered with *approved* roof coverings secured to the building or structure in accordance with the provisions of this chapter. Roof coverings shall be designed in accordance with this code, and installed in accordance with this code and the manufacturer's *approved* instructions.

1503.2 Flashing. Flashing shall be installed in such a manner so as to prevent water from entering the wall and roof through joints in copings, through moisture-permeable materials and at intersections with parapet walls and other penetrations through the roof plane.

FIGURE 15. Excerpt from the *2018 International Building Code*, Section 1503, *Weather Protection*.

Section 1503 of the IBC is shown in **Fig. 15**.

Similar to the IRC, the IBC incorporates by reference the manufacturer's approved installation instructions into the code requirements.

Manufacturer detailing for penetrations through low-slope single-ply assemblies are shown in **Fig. 16–19**. Note the consistency in the focus on solely the watertight aspects of the detailing.

Both of the manufacturer examples only provide a pipe penetration; they do not provide a conduit or ganged penetration flashing. Similarly, they both provide a methodology for flashing a hot stack exhaust pipe; however, there is no guidance regarding thermal performance. An insulated pipe would require a different approach to exterior flashings and sealing.

In many cases, the more complex grouped penetrations are addressed in the field using manufacturer details, but the details only provide guidance as it relates to the waterproofing performance of the roof cover assembly. The manufacturer's installation instructions do not provide guidance related to thermal bridging, nor do they warn against sealant-dependent joints that will require ongoing maintenance.

There are manufacturers of flashings for penetrations that focus solely on protection at and around the holes we put through our exterior enclosure. These manufacturers have developed designs to support the integration of a rooftop structure that houses the penetrations with the surrounding thermal, air, vapor, and water control layers.

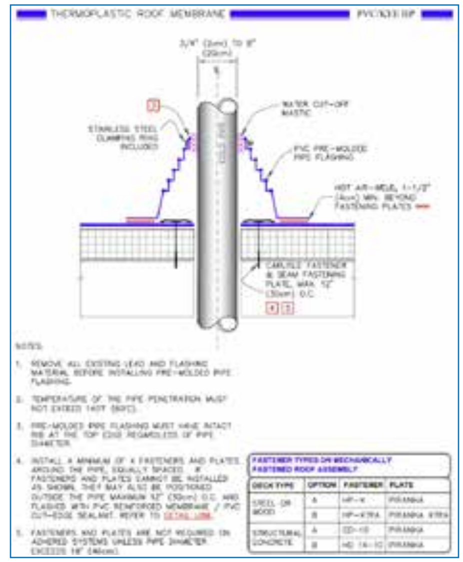


FIGURE 16. Single-ply roof manufacturer pipe penetration detail through low-slope roof assembly. Note detail focuses only on watertight aspects of performance.

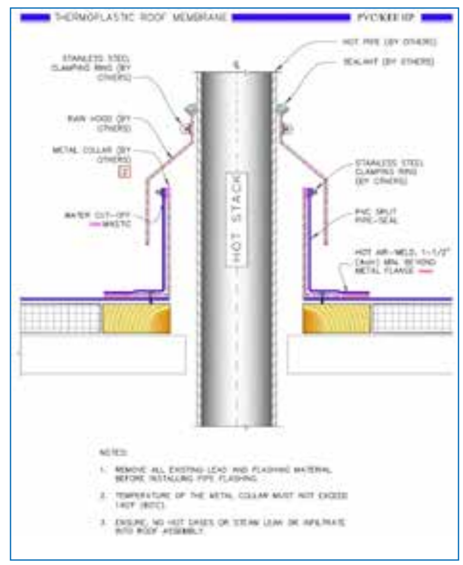


FIGURE 17. Single-ply roof manufacturer hot stack installation detailing. Also focused on watertight aspects of assembly; no thermal, air, or vapor aspects show.

One rooftop penetration housing manufacturer product data sheet showing styles and types of products for ganged penetrations is shown in **Fig. 20**.

A second rooftop penetration housing manufacturer product data sheet showing styles and types of products for ganged penetrations is shown in **Fig. 21**.

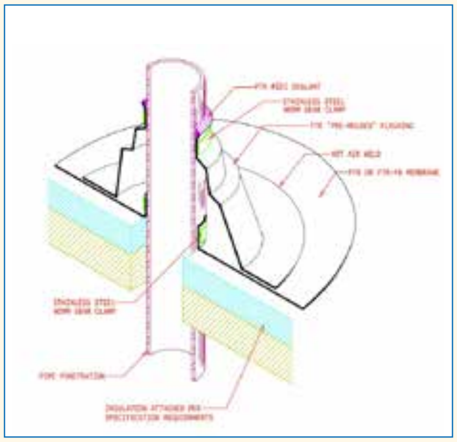


FIGURE 18. Pipe boot manufacturer pipe penetration detail through low-slope roof assembly. Note that detail focuses only on watertight aspects of performance.

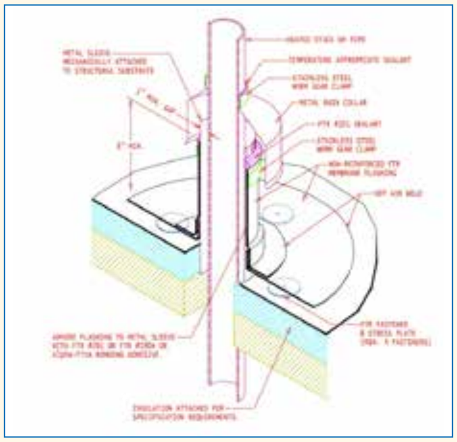


FIGURE 19. Pipe boot penetration manufacturer details for low-slope roofing application. Note that air, vapor, and thermal continuity are not referenced.

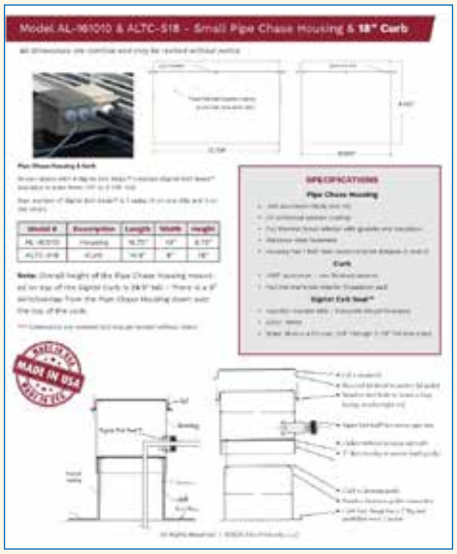


FIGURE 20. Product data sheet for rooftop penetrations housing.

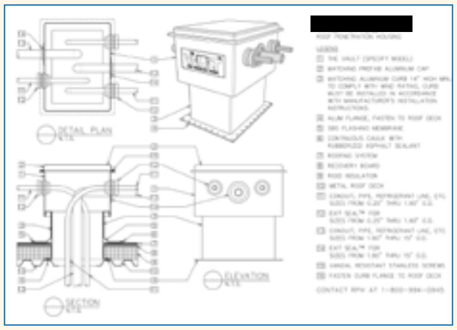


FIGURE 21. Product data sheet for rooftop housing for ganged penetrations.

The low-slope roofing industry has penetration housing options, which will provide improved detailing and sealing of ganged penetrations to allow for increased protection from rooftop penetrations; however, the continuity of the thermal, air, vapor, and water barriers must still be verified through design and construction. The ganged penetration manufacturers, however, do offer warranties associated with their products, though separate from the roof cover manufacturer. Coordination between the manufacturers of the different products must still include some compatibility confirmations and warranty assurances direct from the manufacturers.

CONCLUSION

Penetrations are unavoidable, yet their risks can be mitigated through deliberate design, specification, and verification.

Treating penetrations as integral components of the enclosure rather than incidental openings leads to measurable improvements in performance, durability, and cost control.

Product selection, specification, and installation must all consider code compliance, manufacturer installation instructions, and compatibility for maximizing performance, resilience, and longevity. This is critical as products evolve with innovative designs for new products fabricated out of engineered materials. While a lead pipe has no compatibility issues with roofing asphalt mastics, newer products on the market do, and code requirements in conjunction with manufacturer installation instructions must consider this.

Penetration flashings that consider the thermal performance of the assembly provide a tie-in to the assembly at both the vapor barrier and the roof cover, and moving the weather-facing penetration to a horizontal surface should be considered, where possible and practical, in designing through-roof penetrations.

REFERENCES

1 International Code Council (ICC). 2024. *2024 International Building Code*. Country Club Hills, IL: ICC.

2 ICC. 2024. *2024 International Energy Conservation Code*. Country Club Hills, IL: ICC.

3 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 2022. *Energy Standard for Buildings Except Low-Rise Residential Buildings*. ASHRAE 90.1. Peachtree Corners, GA: ASHRAE.

4 ASTM International. 2023. *Standard Specification for Elastomeric Joint Sealants*. ASTM C920. West Conshohocken, PA: ASTM International.

5 American Architectural Manufacturers Association. 2022. *Voluntary Specification for Self-Adhering Flashing*. AAMA 711. Schaumburg, IL: AAMA.

6 ASTM International. 2023. *Standard Practice for Building Enclosure Commissioning*. ASTM E2813. West Conshohocken, PA: ASTM International.

7 National Roofing Contractors Association (NRCA). 2025. *NRCA Roofing Manual: Steep-Slope Roof Systems*. Rosemont, IL: NRCA.

8 Asphalt Roofing Manufacturers Association (ARMA). 2022. *Residential Asphalt Roofing Manual: Design and Application Methods*. Forest Hill, MD: ARMA.

Addressing the General Design Requirements: Methods for Managing Water and Accommodating Differential Movement in Masonry Veneer

ABSTRACT

Masonry veneer is a common building facade material used internationally due to its attractive aesthetics and durability. Although there are explicit code requirements for the attachment of masonry veneer, the *2024 International Building Code* (IBC) and its referenced masonry code, TMS 402/602-22, *Building Code Requirements and Specification for Masonry Structures* (TMS 402-22), include only general design requirements for accommodating differential movement and managing water penetration within veneer. This lack of specificity provides the designer with freedom to use a myriad of modern materials and for manufacturers to continue to push the envelope, no pun intended, for improving and advancing masonry construction.

However, with new building materials, construction methods, and inexperienced design professionals come the risk of new problems and the repetition of old problems in new ways. As building enclosures become more complicated, it is more important than ever to remember and understand the intended performance of the building enclosure system to avoid the omission of critical details and premature failure of the masonry veneer.

This presentation will discuss masonry veneer code requirements in the IBC and TMS 402-22 and will review the intended system performance related to water management and differential movement. Additionally, we will explore common ways for meeting code intent with modern enclosure materials to achieve long-term durability of masonry veneer construction.

LEARNING OBJECTIVES

- Review the strengths and weaknesses of nonexplicit code requirements for accommodating differential movement and managing water infiltration.
- Discuss the intent of differential movement requirements and the repercussions of noncompliance.
- Explain the significance of water management requirements and the repercussions of noncompliance.
- Explore methods of designing and constructing to meet differential movement and water management requirements via case studies.

SPEAKERS

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Robert "Bobby" Chamra is a professional engineer with 12 years of experience focused on structural restoration and building enclosure consulting in existing buildings. Chamra is currently serving as a voting member for The Masonry Society's TMS 402/602, *Building Code Requirements and Specification for Masonry Structures*, for the 2028 code cycle, and he is the secretary for the Veneer Subcommittee. He has also served as a member of ASTM International Committee C15 on Manufactured Masonry Units, Mortars, and Grouts. When not working on the existing built environment, he enjoys spending time with his family, playing golf, gardening, cooking, and eating.

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Masonry veneer is a frequently used exterior cladding system known for its durability and unique appearance that can define the identity of a region. While the attachment of anchored or adhered masonry veneer has explicit prescriptive and engineered requirements, building enclosure requirements such as water management and material behavior requirements like differential movement accommodation are handled in a more general, often performance-based manner for masonry veneer assemblies.[1]

The good news: building enclosure consultants have the freedom to specify new products and systems to meet the performance requirements without needing to wait for building code updates. The bad news: new materials and methods can ultimately lead to new mistakes or, more frustratingly, repetition of old mistakes. In the hierarchy of needs, function comes before aesthetics. Let us get back to basics regarding water management and material behavior to add some specific recommendations for these general design requirements.

THE GENERAL DESIGN REQUIREMENTS

To complete the code requirement picture, two separate documents must be consulted: the model building code and the referenced technical masonry veneer code, which will be the *2024 International Building Code* (IBC) and TMS 402-22/602-22, *Building Code Requirements and Specification for Masonry Structures* (TMS 402/602-22), or simply TMS 402-22, for code discussion purposes within this paper.[2,3] There is a circular nature within these documents, where each references compliance with the other. Here is a fun fact: both the adhered masonry veneer and anchored masonry veneer references in the 2024 IBC require compliance with Section 13.2 in TMS 402-22, which deals exclusively with anchored veneer. Within this paper, the adhered veneer requirements within **Section 13.3** will be stated instead.

The combined code requirements between the 2024 IBC and TMS 402-22 for both anchored and adhered veneer, unless noted otherwise, reduce to the following bullet list:

- Design and construct to prevent the accumulation of water with the masonry veneer assembly.
- Design and construct to accommodate deformations and differential movement.
- For anchored veneer, provide a 1 in. (25 mm) minimum drainage space with flashing.
- For anchored veneer, provide weep holes of at least $\frac{3}{16}$ in. (4.7 mm) in diameter at less than 33 in. (8.4 m) on-center horizontal spacing at the flashing.

Beyond the minimum code requirements above, there are many technical masonry organizations, such as the Brick Industry Association, the International Masonry Institute, and the Concrete Masonry & Hardscapes Association (formerly known as the National Concrete Masonry Association), that provide industry standards, guidelines, and typical details to meet the code intent described above that are available in addition to the discussion within this paper.

WATER MANAGEMENT PERFORMANCE

Water management in masonry veneer walls, similar to other building enclosure assemblies, can be summarized by the Four *D*'s: **deflect**, **drain**, and **dry** to result in a **durable** assembly. The masonry veneer itself **deflects** bulk water from rain events and other sources of moisture. However, masonry units and mortar are porous, so a small amount of moisture becomes absorbed and can cause a variety of detrimental effects, such as unit expansion, efflorescence, biological growth, and, in colder climates, freeze-thaw damage. Water repellents and other types of exterior coatings can be applied to the masonry surface to reduce water absorption, but these methods tend to reduce the vapor permeability of the masonry and may detrimentally reduce the drying potential of the wall assembly.

Additional moisture can penetrate the masonry veneer through cracks, other unsealed openings, or diffusion into the air cavity behind the veneer. On the other side of the air cavity, there is typically a water-resistive barrier, which may also function as an air and vapor barrier, per code requirements, that prevents infiltration of liquid water to the building interior. The liquid water in the air cavity then **drains** through a series of flashings and weeps to the exterior to exit the wall assembly. However, breaches in the water-resistive barrier, such as abandoned fastener holes, unadhered seams, or fishmouths, will allow this water to infiltrate further into the building interior and lead to detrimental effects such as corrosion, biological growth, or damage to interior finishes. Obstructions within the air cavity, such as mortar droppings at the base of the wall or veneer ties and other construction debris, can prevent water from draining out and increase the likelihood of water infiltration.

Furthermore, most waterproofing products bond to the substrate and will move along with it. At joints or other locations where movement is expected, the waterproofing product itself must have sufficient elongation properties. Such accessory materials include expansion joints and silicone sheets. Another option is to allow for slack provided through extra material, such as a bellow of membrane flashing, to maintain the integrity of the water-resistive barrier.

Chemical compatibility when selecting products is critical to the performance and durability of the assembly. This is generally not an issue when sole-sourcing a single system from one manufacturer, but it is a key consideration at interfaces between different systems, such as roofing or below-grade waterproofing. A common chemical incompatibility is between polyvinyl chloride and asphaltic products. A common adhesion incompatibility is with non-silicone onto silicone. It is best practice to obtain sign-off from all manufacturers that their products are compatible based on either field testing or history of successful use.

Moisture within the cavity can also exist in the form of water vapor and exit the wall assembly through convective flow via similar pathways as liquid water, **drying** the wall assembly. Increasing the number of weeps and also locating them at the top of air cavities can increase the drying potential of the wall.

These basic principles and design rules of thumb in your geographic area are the starting point of designing a **durable** masonry veneer wall. However, when encountering new materials, unusual climatic conditions, or altering properties of an existing masonry veneer assembly, hygrothermal modeling of the wall is the best tool to predict its durability. A detailed discussion of hygrothermal modeling is beyond the scope of this paper, but common techniques to adjust where condensation occurs in the wall assembly include modifying the ratio of insulation *R*-value within the stud cavity compared to continuous insulation and exchanging products with different vapor permeability.

MOVEMENT ACCOMMODATION PERFORMANCE

Masonry veneer experiences differential movement from a variety of mechanisms, such as structural deflection, thermal cycling, moisture variations, and differential foundation movement. Different masonry veneer materials, such as clay brick, concrete masonry units, and natural stone veneer, will behave differently based on their thermal expansion coefficient and moisture content. In order to accommodate the expansion and contraction in masonry veneer walls, movement joints are designed to be installed at critical locations to prevent distress in the exterior wall.

There is no definitive rule for sizing expansion joints; their width ultimately varies according to the exterior wall cladding, backup wall framing, and climate conditions. The total expansion joint width is typically designed to account for two times the total expected differential movement from all contributing factors. In addition to adequately sizing expansion joints, the selection of the expansion joint material is crucial to ensure it can accommodate the expected movement, have necessary ultraviolet resistance, and be compatible with the applicable substrates.

In a typical masonry veneer wall with shelf angles, horizontal expansion joints are installed between the shelf angle and masonry unit directly below to allow for differential movement. The full horizontal expansion joint gap should be free and clear of any rigid material that will restrict its ability to accommodate movement. Compressible filler materials can be utilized to occupy this gap beyond the expansion joint product to prevent mortar and other rigid materials from restricting movement.

Masonry veneer wall construction with no, or inadequately sized, horizontal expansion joints or expansion joint gaps filled with rigid material results in hard joints that restrict the masonry's ability to accommodate differential movement. In this circumstance, the gravity load is unintentionally transferred from the shelf angle to the masonry veneer directly below. This effect continues from floor to floor down to the lowest masonry support condition, resulting in overloading of the masonry units and masonry support. The lack of adequate expansion joints in a masonry veneer wall can result in cracking, bowing, crushing, spalling, and displacement of masonry units, which can be a pathway for water infiltration into the exterior masonry wall and create a life-safety hazard.

In addition to horizontal expansion joints, the vertical expansion joints should be installed at the masonry veneer to accommodate the expected differential movement and prevent cracking. The spacing of the vertical expansion joints will vary based on the exterior wall length, change in plane geometry, openings within the veneer, and changes in veneer substrate. Spacing and location of the vertical expansion joints should be designed for the unique conditions of every building to ensure long-term performance and durability of the exterior wall.

RECOMMENDATIONS AND CASE STUDIES

This section will review critical details to highlight their importance in the design and construction of masonry veneer assemblies in contrast with the consequences from real-life case studies resulting from noncompliance with the code intent. The presence of flashings and weeps are the primary components explicitly required in the code. In addition to always following the manufacturers' installation instructions, this section will discuss waterproofing detailing best practices to ensure your wall assembly is performing its best.

Horizontal Transitions

Water management considerations include the following:

- Include weeps at 16 in. (406.4 mm) on center to drain water to the outside (preferably the "cell-vent" type that are the full height of the masonry head joint rather than a weep tube at the bottom of the head joint) for anchored masonry veneer, and include weep screeds for adhered masonry veneer.
- Include a mortar net (or drainage medium) at the base of the veneer cavity.
- Tie in flashing with the water-resistive barrier at shelf angles. If using membrane flashing, secure the top edges with a termination bar and a sealant lip. Alternatively, use a reinforced liquid-applied flashing shingle-lapped by the water-resistive barrier.
- Design through-wall sheet metal flashing to
  - overlap seams that are fully embedded in sealant,
  - slope towards the outside of the building to facilitate drainage,
  - include end dams to contain and encourage water to exit the wall assembly, and
  - extend the drip edge beyond the outside face of the masonry below to direct water away from the face of the masonry underneath.
- Consider these additional recommendations at the base of the wall:
  - Locate the weeps above the minimum requirement per code to avoid being obstructed by soil or other at-grade conditions.
  - If there is an interface with below-grade waterproofing, tie in with the air- and water-resistive barrier in the wall assembly to create a continuous air- and water-control layer.

Differential movement considerations include the following:

- Include a horizontal expansion joint between the bottom of the shelf angle and the masonry directly below.
- Keep a free and clear gap between the shelf angle and the masonry directly below or install compressible filler material within the gap.

For the first case, a five-story commercial building clad with cast stone veneer was experiencing water infiltration along with dislodged and loose masonry units. The water infiltration was discovered to be caused by deficiencies in the installed waterproofing. The membrane flashing was not adhered, and the release film was still in place. A drip edge was absent at the sheet metal flashing, and fishmouths were observed along the edge of the membrane flashing (**Fig. 1**, **2**). The improper waterproofing installation provided a pathway for water to get behind the water-resistive barrier. In addition, there was no appropriately sized horizontal expansion joint at the shelf angle, which resulted in widespread cracks in the brick masonry mortar joint above and below the shelf angle (**Fig. 3**).

The second case study is a commercial building clad with brick masonry veneer that reported water infiltration at windows and cracks in the exterior masonry wall. Based on a review of the as-built condition, the through-wall flashing was discontinuous, sealant blocked

FIGURE 1. Self-adhered membrane flashing installed with release film (red arrow) left in place.

FIGURE 2. Loose self-adhered membrane flashing at shelf angle (red arrow) with fishmouths along perimeter (white arrows).

FIGURE 3. Inadequate size horizontal expansion joint at shelf angle measured to be less than $^{1}/_{8}$ in. (3.18 mm).

FIGURE 4. Discontinuous through-wall flashing and sealant blocking drainage path (red arrow) at shelf angle.

FIGURE 5. Mortar and debris within drainage cavity.

FIGURE 6. No horizontal expansion joint between shelf angle and masonry immediately below.

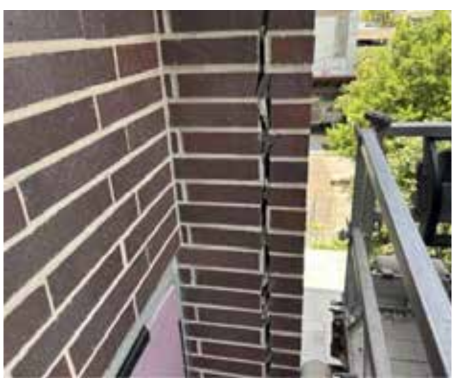

FIGURE 7. Cracked brick masonry units and mortar joints at column.

the brick masonry drainage cavity, weep holes were sealed, and mortar droppings were present within the drainage cavity (**Fig.** 4, 5). All these items obstructed the drainage path. Furthermore, there was no horizontal expansion joint between the shelf angle and masonry continued immediately below (**Fig.** 6). The mortar joint was also installed at the toe of the shelf angle. The lack of the appropriate horizontal expansion joint resulted in extensive cracking of the masonry veneer (**Fig.** 7).

Vertical Transitions

Water management considerations include the following:

- Select or detail a waterproofing product with sufficient movement capacity.
- Locate the primary seal at the air/water barrier and a secondary seal at the veneer location.

Differential movement considerations include the following:

- Install vertical expansion joints at dissimilar materials, geometric changes, or within long runs of uninterrupted masonry.
- Keep a free and clear gap across the expansion joint or install compressible filler material within the gap.
- Extend the vertical expansion joint to the top of the exterior wall and integrate it at the roof and below grade as necessary for continuity.
- Show vertical expansion joints schematically on elevation details, in lieu of providing generic spacing requirements in the specifications.

In the next case, a commercial building reported distresses in the exterior brick masonry wall. Cracked masonry mortar joints were observed at the masonry wall in a stair-step pattern below the punch window (**Fig.** 8). The masonry distresses were due to a lack of appropriately spaced vertical expansion joints at the masonry wall, corners, and re-entrance corner of punch openings.

Veneer Ties

Water management considerations include the following:

- Require fastener penetrations, such as masonry veneer ties, to be treated per the air/water barrier manufacturer's instructions. The specific treatment method can be determined via air leakage testing, such as per ASTM E1186, *Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems* of the masonry veneer mock-up (**Fig.** 9). There are many typical treatment methods, or you may find that no treatment is required as the air/water barrier is self-gasketing.
  - Install membrane flashing underneath veneer ties.
  - Install an air- and water-resistive barrier over veneer ties.
  - Predrill fastener holes, fill them with sealant, then set the fasteners.
- Require abandoned fastener holes to be repaired.

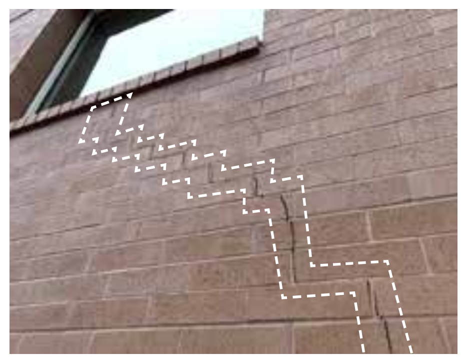

FIGURE 8. Cracked masonry units and mortar joints (white outline) below punch window.

FIGURE 9. ASTM E1186 testing performed at masonry veneer tie.

- Specify veneer ties made from corrosion-resistant material, such as stainless steel.

Differential movement considerations include the following:

- Install masonry veneer ties within 12 in. (304.8 mm) of each side of the movement joints.
- Install masonry veneer ties within 12 in. of the veneer panel edge.

In the following case, the installed masonry veneer tie fasteners and abandoned fastener holes were unsealed (**Fig. 10**). The unsealed penetrations provide a pathway for water infiltration into the building interior.

In addition to these design considerations, a design professional's oversight during construction is also critical in achieving the intended performance. The designer's diligence in key construction steps such as preinstallation meetings, submittal reviews, and site visits all contribute to a durable masonry veneer wall.

FIGURE 10. Masonry veneer tie with unsealed fasteners and abandoned fastener holes (red arrows) at exterior sheathing.

CONCLUSIONS

Like other modern-day cladding systems, there are many exciting possibilities with masonry veneer in more complex geometries and in combination with other cladding types. Masonry veneer has been a durable cladding system for decades and can continue to endure with proper detailing for water management and differential movement accommodation. With increasing enclosure complexity, new cladding products, and new building enclosure consultants in our industry, it is more imperative now than ever to return to the basics and mentor the next generation to push the envelope, pun definitely intended this time.

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Practical Tools for Managing Building Enclosure Projects with Consistency and Quality

ABSTRACT

Building enclosure projects are complex undertakings that require strong collaboration among owners, contractors, architects, and consultants. Enclosure consultants play a pivotal role in supporting the design and construction of the enclosure by establishing performance goals, managing risks, and addressing technical challenges. However, without structured workflows and established quality assurance/quality control (QA/QC) processes, these projects can face delays, miscommunication, and potential liability. This presentation will outline practical approaches for managing building enclosure projects more effectively across all phases: design, pre-construction, and execution. It introduces a project management approach tailored to enclosure consulting that includes streamlined workflows, QA/QC checklists, and performance tracking methods. Real-world examples, including facade retrofits, roof replacements, and energy code compliance upgrades, will demonstrate how these frameworks can be adapted to different project types. Each example will be tied to specific challenges, with discussion on how the tools were applied to improve coordination, reduce errors, and guide decision-making. These case studies ground the strategies in actual project experience, highlighting lessons learned and what would be adjusted next time. This presentation will also explore how to scale these tools for large or small projects, support teams with varying levels of experience, and encourage adoption without adding complexity. Attendees will be provided with practical strategies they can begin using right away to improve communication, simplify coordination, and support consistent quality across their own work.

LEARNING OBJECTIVES

- Describe the components of a project management framework specific to building enclosure consulting, including workflows, quality assurance/quality control checklists, and performance tracking methods.
- Identify common challenges within complex enclosure projects, such as miscommunication, team expertise gaps, and process scalability, and explain approaches to address them.
- Analyze how structured project management tools improve collaboration and consistency across a range of project types, including facade retrofits and roof replacements.
- Apply at least one project management strategy to support improved coordination, quality assurance, or efficiency within attendees' own building enclosure projects.

SPEAKER

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Building Envelope Consultant,
Walker Consultants

Alexis Garcia is a building envelope consultant and associate architect with over a decade of experience in architecture, project management, contract administration, and permitting. At Walker Consultants, she focuses on roofing, glazing, waterproofing, and moisture barriers for new and existing buildings, helping clients improve performance, reduce risk, and extend service life. Her work spans adaptive reuse, tenant interiors, parking garages, and existing commercial properties. Garcia brings a practical, technical approach to every project, combining design knowledge with construction insight. She is passionate about mentoring, collaboration, and helping teams deliver resilient, efficient, and durable building enclosure solutions.

AUTHOR:
Alexis Garcia, AAIA

BACKGROUND

Walker Consultants was engaged by an interior architecture firm, on behalf of the building owner from Canada who recently acquired the property, to provide building enclosure consulting for a remodel project in Houston. The work was primarily an interior build-out of a three-story commercial office building constructed circa 2005. While most of the scope centered on interior improvements, several exterior modifications created the need for dedicated enclosure support. These included creating an opening in the exterior insulation and finish system (EIFS) panel facade for a new operable sliding glass partition, converting the second-floor roof into an outdoor patio with a pedestal-supported paver and landscape tray system, and evaluating options for upgrading or replacing the existing roof insulation.

The project also required coordination with other disciplines. Structural modifications included designing a new canopy at the employee entrance and accommodating a rooftop generator. Mechanical upgrades and energy compliance reviews further tied the interior scope to exterior performance. The roof conversion relied entirely on internal drains, making drainage coordination a critical part of the enclosure scope. At the start of design, the building documentation available to the team was limited, with no complete set of shell plans for the structural or envelope systems. This lack of information increased the importance of site verification and direct engagement with manufacturers to assess assembly compatibility and that proposed details could be executed reliably.

FIGURE 1. Example of existing roof conditions with inconsistent tapered insulation observed during demolition.

CHALLENGES

Converting the second-floor roof into an occupiable patio introduced enclosure issues that extended well beyond the interior build-out. The existing roof was a modified bitumen system over tapered polyisocyanurate insulation, but the taper was poorly installed and inconsistent (**Fig. 1**). Roof cores and site observations showed insulation thicknesses ranging from 5.5 in. (139.7 mm) near the drain to as much as 13 in. (330.2 mm) along the south wall. Because the concrete roof deck sat flush with the adjacent interior floor, the added taper layers rose above the finished floor elevation, complicating drainage, flashing, and transitions.

Maintaining adequate base flashing heights was another concern. At curbs that remained at 6 in. (152.4 mm), even with the use of thinner vacuum insulated panels (VIPs), the resulting base flashing height would be below manufacturer recommendations. This raised questions about warranty compliance and long-term durability, which had to be answered before design decisions could be finalized.

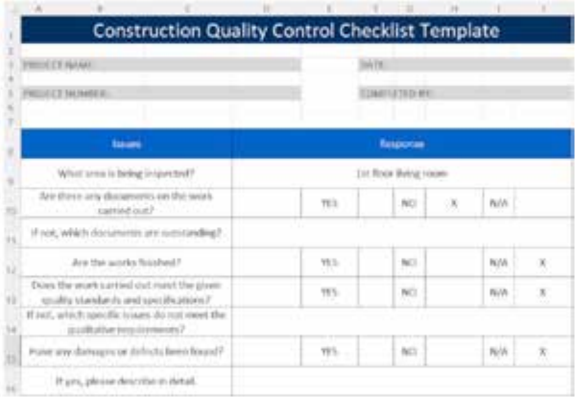


FIGURE 2. Example quality assurance/quality control checklist used to standardize enclosure reviews.

FIGURE 3. Typical building enclosure consulting workflow across project phases.

Drainage strategy also required careful review. The roof relied entirely on internal drains, with no secondary scuppers or overflow protection. Coordinating pedestal supports, pavers, and vegetated tray assemblies that did not restrict water flow or add risk around the drains was critical.

Finally, limited documentation from the original construction made it difficult to confirm structural and waterproofing conditions in advance. Without reliable shell drawings, the team had to rely heavily on field verification during demolition and proactive coordination with manufacturers to validate assumptions. This uncertainty amplified the importance of a structured approach to documenting issues and tracking their resolution.

APPROACH

To address these challenges, the team applied a structured management process that combined manufacturer engagement, field verification, and disciplined documentation. Outreach to product manufacturers provided clarity on both technical feasibility and procurement. Direct discussions with Kingspan confirmed that VIPs were a viable option and available with reliable lead times and pricing, countering widespread industry concerns about scarcity and cost premiums. Kingspan recommended their encapsulated VIP system paired with a rigid extruded polystyrene (XPS) cover board to spread pedestal loads. They also offered to prepare a full insulation layout, taper study, and condensation analysis, giving the team confidence that the insulation strategy could meet both performance and constructability goals.

Parallel coordination with Siplast addressed compatibility questions between the modified bitumen roof system and the proposed assemblies. Manufacturer input was essential in confirming whether base flashing heights, transitions, and warranty conditions would be acceptable. Rather than relying on assumptions, the consultant team recorded manufacturer responses directly into the project record to support design decisions with reliable guidance.

Pedestal suppliers were also engaged to confirm installation requirements and uplift resistance. Feedback clarified that the pedestals could remain unanchored, with self-leveling and locking components available where additional stability was needed. This confirmed that the system could accommodate drainage slopes without interfering with roof performance.

Field verification was equally important. During demolition of storefront rough openings, existing taper insulation was exposed and documented, confirming field conditions that had previously been uncertain. This information was communicated promptly to the design team and coordinated with structural and mechanical consultants.

Checklists (**Fig. 2**) and comment logs reinforced consistency throughout. Each issue, whether related to flashing, drainage, insulation, or pedestal performance, was logged, assigned, and tracked to resolution. This reduced the risk of oversights and created a transparent record of decision-making for the client and design team.

OUTCOMES AND LESSONS LEARNED

The structured approach produced several clear outcomes (**Fig. 3**). Direct engagement with manufacturers early in design allowed the team to refine the roof assembly and confirm that the solutions were both technically sound and buildable. Kingspan's confirmation of their encapsulated VIP system, paired with a rigid XPS cover board, provided an insulation strategy with an effective *R*-value of nearly 40 in just over 2 in. (50.8 mm) of build-up. This resolved concerns about clearance at curbs while maintaining thermal performance and the ability to support the pedestal system.

Coordination with pedestal suppliers clarified installation requirements and addressed wind resistance. The manufacturer confirmed that pedestals could remain unanchored, with the weight of the trays and pavers providing stability and locking discs available where uplift protection was needed. The structural

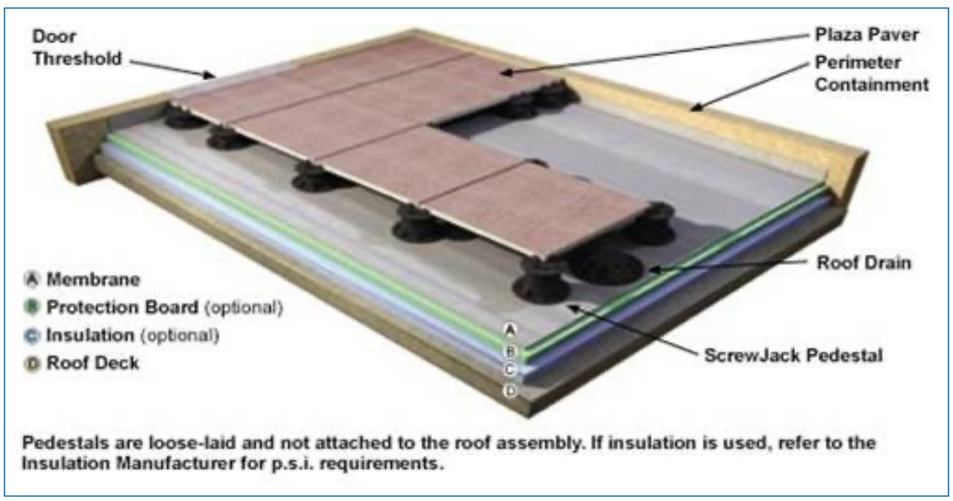


FIGURE 4. Conceptual roof-to-patio assembly illustrating roof assembly, pedestal, and pavers.

ISSUE PROJECT MANAGEMENT LOG TEMPLATE

Project Name:	<optional>
National Center:	<required>
Project Manager Name:	<required>
Project Description:	<required>

ID	Current Status	Priority	Issue Description	Assigned To Owner	Expected Resolution Date	Escalation Required (Y/N)?	Impact Summary
	Open	Critical	**EXAMPLE:** Issues raised by board members about the financial viability of the project are preventing the project from moving forward as planned.			Yes	**EXAMPLE:** Potential project stoppage
	Work In Progress	High	**EXAMPLE:** The project is short on a specific skill set.			No	**EXAMPLE:** Possibility of project work not completed on time
	Closed	Medium	**EXAMPLE:** Negotations with functional managers in an organization competing for scarce human resources are forecasted to delay project completion.			Yes	**EXAMPLE:** Possability of project work not completed on time
		Low					

FIGURE 5. Example issue-tracking log used to document concerns and resolution status.

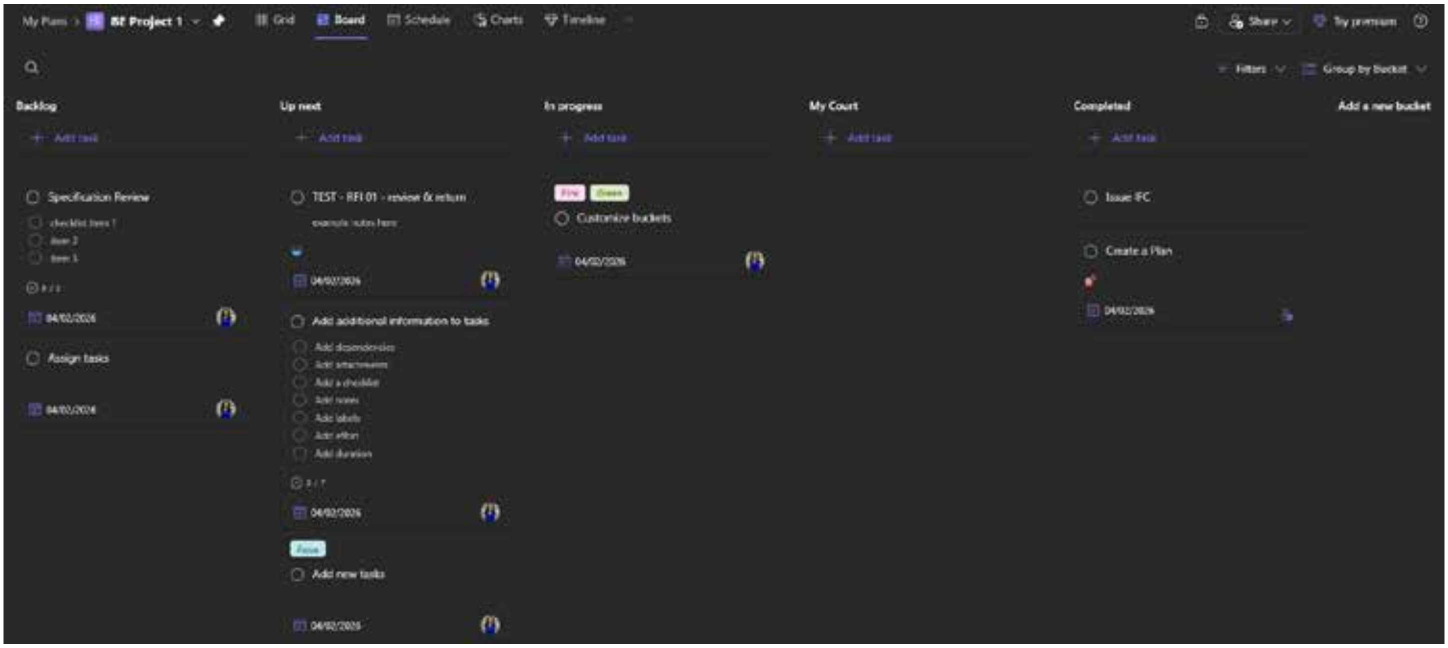


FIGURE 6. View of Microsoft Planner and Buckets.

engineer reviewed the combined loads of the trays, soil, and finishes and confirmed they were within capacity. The architect and contractor aligned on a tray-based system that could support planting, mulch, or turf, depending on client preference, provided that adequate wind performance data were documented (**Fig. 4**).

Documenting each of these decisions through structured logs (**Fig. 5**) and checklists ensured that questions about insulation thickness, pedestal adjustment, and wind data were resolved transparently and preserved in the project record. This gave the client confidence that risks were being actively managed.

The lessons learned highlighted the importance of structured workflows on projects where enclosure issues are not the primary design focus. Because the remodel was led by an interior architecture team, enclosure performance could easily have been underemphasized. Instead, systematic manufacturer engagement, disciplined documentation, and consistent coordination allowed the team to identify risks early, align disciplines, and protect long-term performance. The patio conversion showed how even a relatively modest project benefits from applying a tailored management framework when multiple enclosure elements are in play.

SCALING TOOLS FOR DIFFERENT PROJECT TYPES AND TEAMS

One of the most consistent challenges in building enclosure consulting is adapting processes to fit projects of different scales and levels of complexity. A full commissioning plan with detailed logs and layered checklists may be appropriate for a high-rise facade retrofit, but the same approach can overwhelm a small roof replacement. The value of a structured framework lies in its ability to scale to the needs of the project without losing consistency.

Technology plays a central role in making this possible. While there are many project management platforms available, such as Asana, Trello, and Deltek, experience has shown that the most practical options for enclosure consultants are often the tools that firms already use. Microsoft Planner (**Fig. 6**) and Microsoft Project, for example, are widely available and relatively easy to implement. Planner,

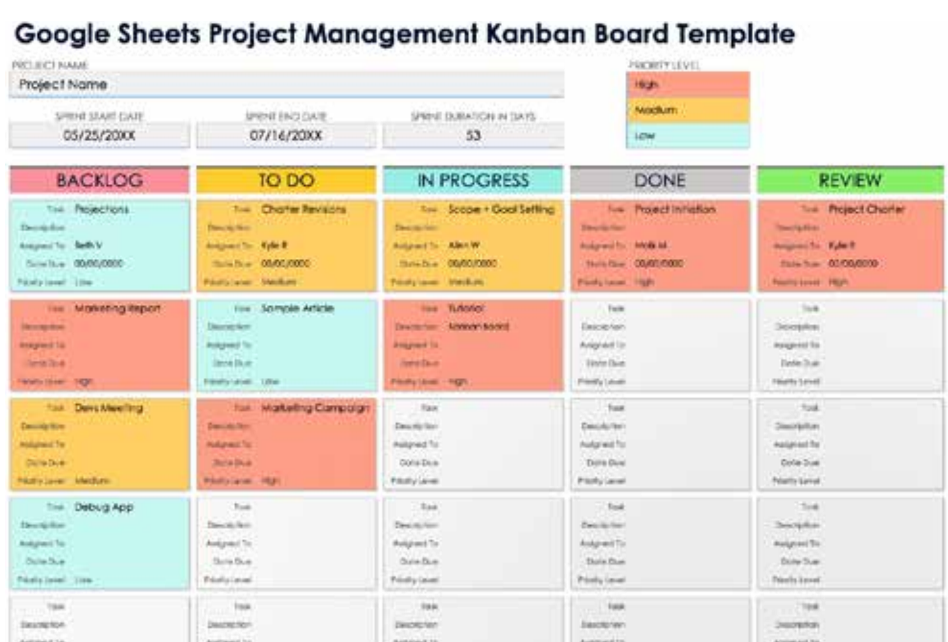


FIGURE 7. Example Kanban task board used to track tasks and milestones.

included in most Office 365 subscriptions, provides a straightforward way to assign tasks, track deadlines, and view project progress using a board or list format. Microsoft Project offers more advanced scheduling and reporting functions for teams that need greater detail. Setting up these tools may require coordination with an information technology group, since permissions and account structures vary by firm, but once in place they allow consultants to assign responsibilities, track milestones, and keep all stakeholders aware of critical deadlines.

For day-to-day management, lightweight methods can be equally effective. A Kanban approach, where tasks are organized into columns such as “To Do,” “In Progress,” and “Complete,” works well for tracking submittals, field issues, or open comments (**Fig. 7**). This method emphasizes visibility and flow, which is especially important for enclosure consultants who often need to be plugged into the project without always being included in milestone updates. Gantt charts, while more traditional, can also be useful for identifying dependencies between enclosure work and other trades, such as when waterproofing must precede cladding installation.

Scaling also applies to the experience level of the project team. For newer staff, checklists and structured workflows can serve as training tools, reducing the chance that details are overlooked. For more experienced teams, the same framework operates as a safeguard, confirming that review processes remain consistent even when projects move quickly.

By selecting the right level of structure, whether through simple task boards or more detailed scheduling platforms, consultants can adapt project management tools to match both the complexity of the project and the needs of the team. The goal is to keep enclosure risks visible and manageable without adding unnecessary complexity.

PRACTICAL STRATEGIES FOR IMMEDIATE USE

The most useful tools are the ones that can be applied immediately, without requiring new software platforms or extensive training. For building enclosure consultants, a handful of strategies can introduce structure and improve project delivery while staying manageable within everyday workloads.

Start with a checklist. A concise but targeted checklist can significantly raise the quality of reviews and field observations. For example, a drawing review list might include flashing terminations, waterproofing continuity, drainage slopes, and transitions between systems. A field checklist might prompt the reviewer to confirm base flashing height, sealant continuity, and the presence of end dams. By writing down these items once and applying them consistently, consultants reduce reliance on memory and eliminate variability between staff members. The checklist also creates a paper trail—if a condition is later questioned, the consultant can point to what was reviewed and when.

Use a simple tracker for issues. A structured log is one of the easiest ways to prevent concerns from falling through the cracks. A spreadsheet or Microsoft Planner board can record each open item, assign it to a responsible party, and show its current status. For example, a log might track when a submittal was received, what comments were issued, and whether the revised package has been resubmitted. This transparency reduces confusion when multiple stakeholders are involved and provides the client with visible proof that enclosure issues are being managed.

Engage manufacturers early. Many enclosure failures stem not from design intent but from incorrect assumptions about product limitations, compatibility, or warranty requirements. Early conversations with manufacturers can resolve these uncertainties before details are finalized. A brief call to confirm whether a roof system allows for reduced flashing heights, or whether a proposed insulation type is compatible with the chosen membrane, can prevent major revisions later in construction. Documenting these responses also builds credibility with the design team and reassures the client that decisions are supported by reliable sources.

Adopt a lightweight project management method. Enclosure consultants are not always notified when schedules shift, yet their work is directly tied to critical path items such as roofing and cladding. A Kanban board or simple Gantt chart allows consultants to see task flow and anticipate when their input is needed. For example, a Kanban board might show open enclosure issues under “In Progress” until they are fully resolved, keeping visibility high for the team. Gantt charts, even at a basic level, highlight dependencies—such as waterproofing needing to be complete before exterior finishes can proceed—which helps consultants plan site visits and submittal reviews around milestone dates.

Each of these strategies requires minimal overhead, but together they create consistency, improve communication, and strengthen accountability. By starting small and maintaining these practices throughout the life of a project, consultants can deliver more reliable outcomes while reducing the risk of enclosure-related setbacks.

CONCLUSION

Building enclosure projects demand more than technical knowledge of materials and assemblies—they require a structured approach to coordination, documentation, and decision-making. The case study of the patio remodel project demonstrated how early manufacturer engagement, field verification, and consistent use of checklists and logs can resolve complex challenges such as inadequate flashing heights, inconsistent insulation, and drainage constraints. By applying a management framework, the project team was able to make informed decisions, preserve warranty compliance, and maintain client confidence.

Scaling these tools to match the scope of work is essential. A small roof replacement may need only a streamlined checklist and issue log, while larger projects benefit from more advanced tracking systems and scheduling tools. In every case, the framework can be adapted without losing consistency.

Practical strategies such as starting with checklists, maintaining issue trackers, engaging manufacturers early, and adopting lightweight project management methods provide consultants with tools they can use immediately. These practices improve communication, reduce risk, and ensure that enclosure concerns remain visible throughout design and construction.

The overarching lesson is that consistency matters. By embedding structured tools into their work, enclosure consultants can support project teams more effectively, deliver higher-quality results, and reduce the chance of costly enclosure issues.

Condensation Control: Designing Resilient Low-Slope Roof Assemblies

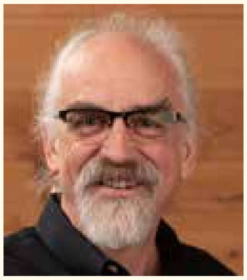
ABSTRACT

Effective moisture control is essential for extending the service life and maintaining the performance of low-slope commercial roofing systems. While traditional vapor retarders and air barriers help reduce air leakage, this paper will discuss newer technologies that offer more adaptive solutions that align with today's roof performance demands. This paper explores the next generation of moisture management, permeable vapor retarders, and air barriers, and their role in mitigating moisture intrusion, improving energy efficiency, and enhancing wind uplift resistance. Readers will examine the science behind condensation and its often-overlooked consequences, including material degradation, reduced thermal performance, and premature roof failures driven by uncontrolled moisture-laden air movement. Through current research and real-world case studies, this paper highlights how strategic design and installation of these advanced materials can significantly increase roof resilience, extend system longevity, and reduce long-term operational costs—ultimately offering better protection for the entire building enclosure.

LEARNING OBJECTIVES

- Discuss the modes of moisture transport in roofing assemblies, with an emphasis on the dominant role of moisture-laden air.
- Describe design strategies and advanced moisture management solutions that protect against condensation buildup and extend roof system longevity.
- Evaluate the risks associated with air leakage and condensation buildup, including material degradation, compromised thermal performance, and increased wind uplift effects.
- Review how permeable vapor retarders block moisture-laden air while allowing balanced vapor diffusion, providing effective moisture control without full vapor restriction.

SPEAKER



Scott Wood
Senior Building Scientist, VaproShield

Scott Wood, senior building scientist at VaproShield, provides product technical support for staff and clients, runs the VaproShield laboratory, and evaluates products. A Level III thermographer and principal of SWA Consulting, Wood provides Level I & II certification courses in building science thermography, infrared inspections, and hygrothermal modeling. Wood has authored numerous papers and American Institute of Architects presentations covering thermography and building science, and he also serves in many other organizations, including as director of building science of the International Association of Certified Thermographers, as an active voting member for ASTM E06 and C16 committees, and as a member of the Seattle Building Enclosure Council.

NONPRESENTING AUTHOR

Matt Walters
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Matt Walters is the marketing manager at VaproShield, where he leads the planning and execution of marketing campaigns across digital platforms and live events. He manages project timelines, develops social media content, updates product literature, and creates technical articles and presentations. He plays a key role in cross-departmental coordination and customer engagement. With over 3 years at VaproShield, he conducts training sessions and contributes to educational content. His efforts support both domestic and international outreach, ensuring consistent messaging and a strong brand presence across the building materials industry.

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Low-slope commercial roofs are typically built with common components: roof membrane, insulation, and structural deck. While this system meets basic code requirements for waterproofing and energy performance, it often falls short of protecting the roof assembly from air-transported moisture from the internal environment.

Driven by changes in climate, occupancy, and material choices, modern roofs are seeing higher rates of internal condensation, insulation, material degradation, and premature failure.[1] There is a common misunderstanding that vapor diffusion is the primary vehicle of moisture, when in fact air-transported moisture is the main method of transport.[2]

This paper explores the limits of traditional roofing designs and introduces permeable vapor retarders as a next-generation solution. With proper placement and design considerations, these materials offer a balanced approach to moisture control, extending roof service life and improving overall system performance.

TYPICAL LOW-SLOPE ROOF ASSEMBLY

Before we can address the threat of moisture in a roof system, we need to understand the basic functions of a roof assembly. A typical low-slope commercial roof consists of a roof membrane, insulation, and structural deck. The roof membrane serves as the primary defense against weather, foot traffic, and ultraviolet exposure from the external environment. Common membrane types include single-ply systems such as thermoplastic olefin, polyvinyl chloride, and ethylene propylene diene terpolymer, as well as multi-ply systems like modified bitumen and built-up roofing. Insulation provides thermal resistance but is extremely vulnerable to moisture. According to research by Tobiasson et al., insulation types, such as polyisocyanurate (polyiso), perlite board, and mineral fiber, can lose 50% or more of their *R*-value when saturated with water, highlighting the critical need for effective moisture control in roof assemblies.[3] The structural deck provides structural integrity, an attachment surface, and internal fire resistance (**Fig. 1**). Common substrates include steel, concrete, and wood, all of which influence material selection and load management within the roof system.

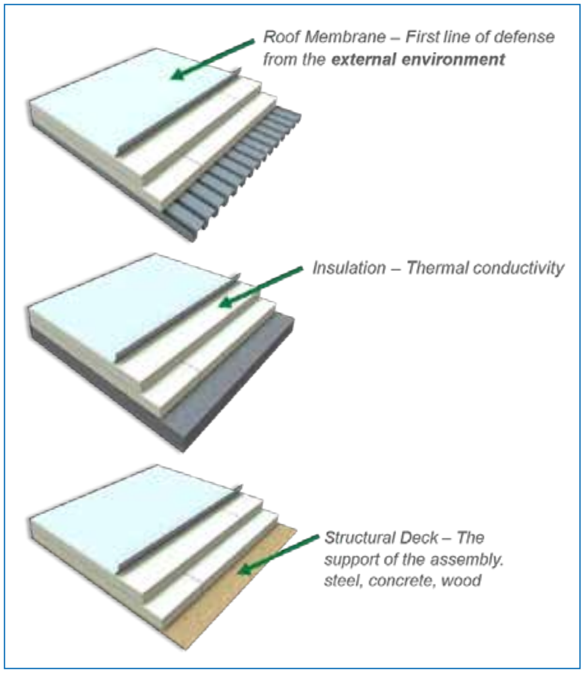

FIGURE 1. Typical components of low-slope roof assemblies.

ENHANCING LAYERS

Enhancing layers, such as cover boards, thermal barriers, and air barriers/vapor retarders, are often integrated to enhance performance (**Fig. 2**). A cover board improves impact resistance and contributes to system longevity. A thermal or fire barrier is typically included below the insulation to meet fire-resistance code requirements. An air barrier/vapor retarder may also be installed to control moisture entry into the assembly, though it is often overlooked unless required by climate zone or interior occupancy conditions.

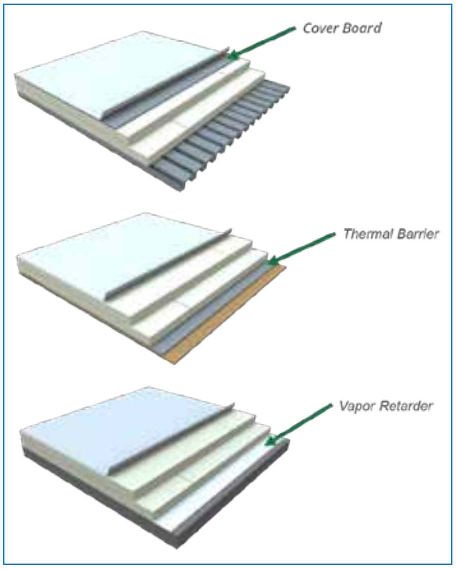

FIGURE 2. Enhancing low-slope roof layers: cover board for membrane support, thermal barrier for fire resistance, and vapor barrier.

ROOFING INDUSTRY EVOLUTION

For years, low-slope roof design has remained relatively unchanged. The industry has relied on familiar assemblies and legacy practices, often guided by habit and cost rather than performance. One of the most notable shifts has been the move from dark roofs to white, high-albedo, or highly reflective roofs, driven by energy codes aimed at reducing the urban heat island effect.[4] This shift has provided measurable benefits, reducing solar heat gain, lowering urban heat island temperatures, and improving cooling efficiency. It has also introduced new challenges. Highly reflective roofs can increase the risk of condensation within the roofing assembly, making the need for proper moisture controls more critical than ever.[5] Night sky radiant cooling and cold exterior winters cool the roof membrane, reducing the temperature to below the dew point, causing internal buildup of moisture. High-albedo roofs reduce daytime roof temperatures. Daytime high roof temperatures drive the condensed moisture out of the roof enclosure and into the interior conditioned space. This is typically referred to as a self-drying roof.[6]

Economic pressure has led to aggressive value engineering. This often means eliminating the enhancing layers such as air barriers, vapor retarders, cover boards, or thermal barriers. The result is easier, faster, cheaper assemblies that frequently perform at the bare minimum required by code. As building use becomes more complex, climates become more extreme, and the demand for stability increases this “good enough” approach is increasingly falling short.

Modern roofs must do more than keep water out. They must manage heat transfer, air movement, and moisture. Component functions are commonly misunderstood. For example, sometimes it is assumed that the roof membrane can serve as the air barrier for interior air transport into the roof assembly or that staggered rigid insulation fully prevents air movement into the roof assembly from the interior conditioned space, which will be discussed later in the paper.

Today’s demands, whether from extreme weather, solar integration, or tighter energy codes, require better roofing assemblies. Meeting modern performance standards means moving beyond legacy habits and embracing systems built for durability, resilience, and control.

MOISTURE INTRUSION AND CONDENSATION

When moisture accumulates in a roof assembly, the source is often assumed to be external. Punctures, tears, poorly sealed penetrations, and seam or edge failures are well-known culprits. These issues are typically visible and easy to identify during inspections. However, one of the most overlooked causes is internal moisture intrusion.

Moisture from the interior space, driven by air leakage caused by air pressure differentials or large vapor pressure differences, can infiltrate the roof system and condense within the roof assembly. Air intrusion is rarely addressed in traditional roofing designs, yet it is a hidden cause of long-term poor roof performance.

Internal moisture buildup can lead to the following:

- **Compromised Roof System Performance:** Moisture in insulation lowers *R*-values by increasing conduction, reducing thermal performance.
- **Premature System Failure:** Wet components degrade faster, leading to earlier replacement cycles.
- **Structural Damage:** Trapped moisture corrodes fasteners and diminishes the structural integrity of the supportive deck.
- **False Leaks and Asset Damage:** Water seen inside the building is often blamed on membrane failure, but a cause may be internal condensation from air-transported moisture.

Addressing moisture from the inside requires controlling the conditioned space from entering the roof assembly. It demands a performance-based roofing design that incorporates proper air control and, when needed, vapor control strategies.

MECHANISMS OF MOISTURE MOVEMENT

When moisture accumulates in roofing assemblies, it enters into roof assemblies by three primary mechanisms: bulk water intrusion, moisture-laden air transport, and vapor diffusion through materials. Bulk water intrusion is typically addressed with proper design, drainage, installation, and maintenance.

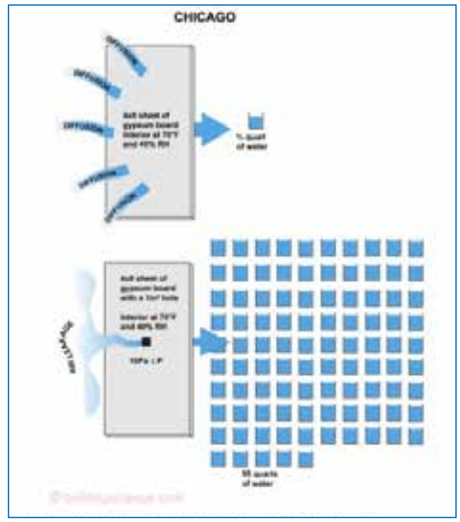

FIGURE 3. Diagram showing the difference between air- and vapor-transported moisture.[2]

While all three mechanisms of transport are important to understand, a common misconception in the roofing industry is that vapor diffusion transports more moisture than moisture-laden air. In reality, it is moisture-laden air movement that overwhelmingly drives moisture infiltration and premature failure.

Moisture is transported by vapor diffusion when high relative humidity or high vapor pressures drive the vapor. Vapor is transported through the materials of the roof enclosure by vapor diffusion. This process happens much more slowly than moisture transported by air, as shown in **Fig. 3**.

HOW DOES AIR MOVE THROUGH A ROOF ENCLOSURE?

Temperature differences drive natural convection (stack effect). Exterior temperature and climate vary by location. As an example, the temperature differences during the five cold winter months in the climates of Chicago, Illinois, and Atlanta, Georgia, are different. These temperature differences drive natural convection and the pressure differences between the interior and exterior of a building. Joseph W. Lstiburek’s 2024 paper discusses these two differing climates and their average winter temperatures, providing a 0.00145 psi (10 Pa) pressure difference for Chicago’s climate and a 0.00058 psi (4 Pa) difference for Atlanta’s climate.[2] Climate does impact air transport, though even in a moderate climate, such as Atlanta's, a 1 in. (25.4 mm) hole transports 100 times more moisture than vapor diffusion in a painted 32 ft² (2.9729 m²) sheet of gypsum board (Class II vapor retarder at 0.5 g/ft²•hr•inHg). Chicago's climate can transport 200 times more moisture through that 1 in. hole than vapor diffusion.

HOW MUCH AIR-TRANSPORTED MOISTURE ENTERS THE ROOF ENCLOSURE?

In a typical roof enclosure (**Fig. 4**), staggered polyiso rigid insulation boards are used to slow airflow. Properly staggered polyiso insulation restricts direct air leakage by 60% to 80%, leaving an approximate 20% to 40% pathway for moisture-laden air to penetrate the assembly components.

The perimeter of a typical (4 × 8 ft [1.2192 × 2.4384 m]) polyiso insulation board is 24 ft (288 in. [7,315.2 mm]). Assuming a 0.0625 in. (1.5875 mm) shared gap between adjacent boards, we would have an effective gap size of 0.03125 in. (0.79375 mm) per board. Multiplying the perimeter (288 in.) by the gap per board (0.03125 in.) yields 9 in.² (5,806.44 mm²) of gap per board. If we assume that the staggered polyiso insulation board restricts air leakage up to 80%, 20% of the airflow would still be allowed through the 9 in.² of gap. For overlapping polyiso boards, we have 1.8 in.² (1,161.29 mm²) of gap that allows air movement.

Using the calculations from Joseph W. Lstiburek's 2024 paper, the amount of moisture transported by air through a 1 in (25.4 mm) hole in Atlanta is 7.5 gal. (28.39 L) Applying this to 9 in.² (5,806.44 mm²) surrounding staggered polyiso boards equates to 67.5 gal. (255.52 L) of water. Using the reduction for overlapping polyiso insulation boards of 20% of airflow, we get 13.5 gal. (51.1 L) of water accumulation per board per spring, summer, and fall combined. For the average low-slope roof of 20,000 ft² (1,858.06 m²) (625 polyiso insulation boards), you are allowing 938 gal. (3,550.72 L) of air-transported moisture per month into the roof system. When it transports through the gaps in the polyiso boards, and this moisture-laden air reaches dew point, it condenses in the roof assembly.

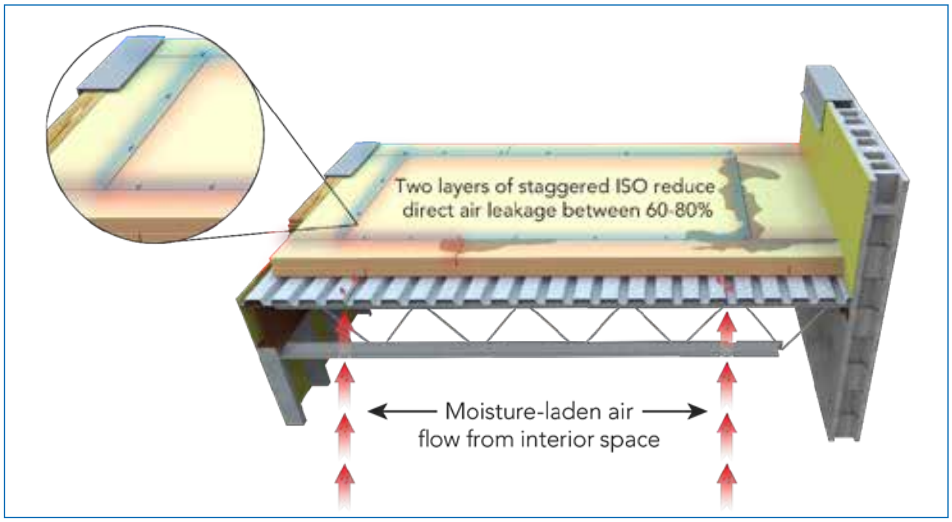

FIGURE 4. Typical low-slope commercial roof showing moisture movement through the staggered layers of polyisocyanurate rigid insulation boards. *Note: ISO = polyisocyanurate.*

HOW DOES THIS AFFECT THE ROOF ENCLOSURE?

As we see above, the amount of moisture transport without an air barrier can be quite large, affecting the components of the roof enclosure. The continued moisture buildup damage to roof decks can be quite extensive, as shown in **Fig. 5**. The ingress of air-transported moisture becomes more of an issue with the cool roof, reducing inward drying due to the cooler roof. Any moisture within the insulation also affects the *R*-value, reducing its heat resistance.

Wind uplift can also move air-transported moisture into the roof system and tear the roof membrane from the surface, as shown in **Fig. 6**.

FIGURE 5. Severely deteriorated plywood a few years after replacing an old cap sheet built-up roof with a white single-ply roof.[7]

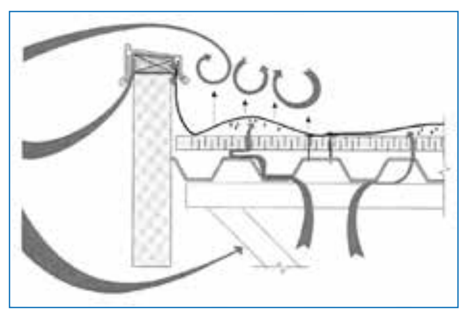

FIGURE 6. Wind uplift, pumping moisture-laden air into the roof system, is due to the lack of an internal air barrier.[8]

PERMEABLE VAPOR RETARDERS AND BALANCED MOISTURE CONTROL

While traditional vapor retarders and barriers are designed primarily to limit vapor diffusion, modern building assemblies incorporate permeable vapor retarders based upon interior and exterior environments to balance moisture control and drying potential. Permeable vapor retarders restrict the movement of moisture-laden air while still allowing any moisture accumulation in the assembly to dry inward.

Unlike Class I, II, or III vapor retarders defined by Method A of ASTM E96, *Standard Test Methods for Water Vapor Transmission of Materials*, permeable vapor retarders typically have higher perm ratings—exceeding 10 perms—placing them outside the conventional classification system. This higher permeability allows assemblies to "breathe," enabling incidental moisture that enters the system to dry toward the conditioned space.

In a properly designed enclosure, the air barrier and vapor control layers must work together but not necessarily perform the same role. Whereas an air barrier must meet stringent air permeance criteria (less than 0.004 cfm/ft² at 1.57 lb/ft², per ASTM E2178, *Standard Test Method for Determining Air Leakage Rate and Calculation of Air Permeance of Building Materials*), a permeable vapor retarder is optimized to limit vapor drive without trapping moisture. This distinction is crucial: even small air leaks can transport significantly more moisture than vapor diffusion, so air control must remain continuous. The permeable vapor retarder then provides the secondary function that supports drying.[9]

The use of vapor-permeable air barriers is especially important in advanced roofing systems that experience varying temperature and humidity gradients. These materials support dynamic moisture equilibrium by blocking the flow of humid air while maintaining the capacity for controlled vapor diffusion. This balanced approach minimizes the risk of mold, corrosion, or insulation degradation, ensuring long-term durability. The overall influence of vapor control layers can be evaluated by hygrothermal modeling. In many cases, the use of a low-permeance vapor barrier does not necessarily enhance hygrothermal performance and may increase the likelihood of moisture accumulation within the system. By contrast, airtight permeable vapor retarders provide a more adaptive solution, maintaining both moisture control and drying potential in response to real-world environmental variations.[10]

CONCLUSION

Condensation control in low-slope commercial roofing requires more than simply meeting code requirements—it demands a deep understanding of how air, vapor, and heat interact within the roof assembly. As this paper has shown, moisture-laden air movement, not vapor diffusion alone, is the dominant cause of internal condensation and premature roof system failures. Traditional low-permeance vapor barriers, once considered essential, can in many cases exacerbate moisture problems by trapping water within the roof enclosure rather than allowing it to dry.

Modern building performance demands have outgrown legacy design assumptions. With evolving climates, reflective roof technologies, and more complex interior conditions, resilient roofing assemblies must integrate solutions that both restrict air leakage and enable controlled vapor diffusion. Permeable vapor retarders represent the next generation of moisture control—providing a balanced approach that blocks air-transported moisture while permitting the roof system to dry. When paired with continuous air barriers and appropriate detailing, these materials help maintain dynamic moisture equilibrium, improve hygrothermal performance, and extend the roof service life.

Ultimately, the key to designing durable, high-performance low-slope roof systems lies in tailored moisture management strategies aligned with the building's climate, occupancy, and assembly design. By applying building science principles, leveraging advanced materials, and prioritizing air and vapor control, roofing professionals can prevent condensation-related failures, preserve energy efficiency, and safeguard both the roof system and the building interior. A proactive, performance-based approach to condensation control not only enhances roof resilience but also supports long-term sustainability, occupant comfort, and operational continuity.

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Navigating the High-Risk World of Community Association Projects: Essential Strategies for Building Enclosure Professionals

ABSTRACT

Community associations, including condominium associations (CAs) and homeowners' associations (HOAs), represent the largest claim category for architects, engineers, and consultants. This presentation provides critical knowledge for consultants who typically do not work with CAs and those seeking a community association refresher to protect their practice and achieve successful project outcomes. This presentation will examine legal and insurance considerations unique to HOA projects, including third-party ownership structures and associated liability challenges; critical documents such as declarations of covenants, bylaws, and other instruments, and their impact on project parameters; and extended statutes of limitations specific to condominium projects. Additionally, community association–specific implications for professional liability insurance coverage will be discussed. Attendees will gain practical applications, such as valuable insights into strategic approaches for evaluating and undertaking community association work as well as the identification of common "pain points" experienced by community associations. Actionable strategies for successful collaboration with CA boards and property managers, along with risk management techniques specific to the community association sector, will be provided. This session will deliver essential knowledge for building enclosure professionals seeking to navigate the complex community association environment while minimizing risk exposure and maximizing project success.

LEARNING OBJECTIVES

- Apply approaches to evaluate and prioritize community association projects based on legal, insurance, and other considerations.
- Identify operational challenges faced by community associations and their impact on building enclosure projects.
- Demonstrate communication techniques that improve condominium association board and unit owner relationships.
- Consider and develop risk assessment protocols for interacting with community associations.

SPEAKERS

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Community associations, including condominium associations (CAs) and homeowners' associations (HOAs), represent the largest claim category for architects, engineers, and consultants (A/E/Cs). This paper provides critical knowledge for consultants who typically do not work with CAs and those seeking a community association refresher to protect their practice and achieve successful project outcomes.

DEFINING THE PROBLEM: WHY ARE CAS PROBLEMATIC FOR A/E/CS?

A/E/Cs depend upon their professional liability insurance to protect their practices against claims relating to their professional practice. CAs represent specific concerns regarding professional liability insurance, including the following:

- High claim severity. For most firms, CA work represents a small percentage of their firm's overall fees, with CA work representing a disproportionately high percentage of claims and claim costs. Per XL Insurance, less than 1% of policyholder fees come from CA work, but 9% of professional liability claim dollars are attributed to CA work.
- High density of units. Most CA properties involve fewer buildings with a correspondingly large number of units or owners. If problems become litigious, litigation often involves multiple plaintiffs and owners. Further, most of these are third-party plaintiffs that may not be a party to the terms of the A/E/C's dispute resolution process defined in the contract between the A/E/C and the CA.
- Building enclosure defects are one of the highest claims made by CAs.
- CA claims often include claims for economic loss, loss of use of primary residence, rents, and other related claims.
- CA-driven claims. CAs are often managed by inexperienced, member-staffed boards of directors (BODs), which are often driven to hire lawyers and experts to find problems. This can be exacerbated as properties get closer to the expiration of the statute of repose.
- Associations are often underfunded and unable to pay for unexpected expenses and repairs, except through levying special assessments. Special assessments are almost always a contentious issue with unit owners and can create significant problems for BODs.
- Most CA owners and BODs assume the A/E/C can or will provide a guaranty or warranty for any work completed. In contrast, A/E/C professional liability insurance specifically prohibits A/E/Cs from providing warranties for their work.

WHERE IT STARTS

By the time a building enclosure A/E/C is hired by an association, there is already a sour taste. Typical situations include oversight of very involved and intrusive repairs or replacements, and at this time, it is often discovered through invasive evaluation that the developer created a litany of issues. The BOD does not want to deal with a similar situation down the road, wants repairs to be performed correctly, and is hiring an A/E/C to provide professional services to ensure all work is performed properly.

In the US, the time period for which a CA can take action against a developer for defects varies by state. For instance, in Wisconsin, there is a battle between the statute of limitations and the statute of repose.

In Wisconsin, the statute of limitations and statute of repose for construction defect cases involving CAs are governed by *Wis. Stat. § 893.89*.[i] The statute of repose establishes a 7-year "exposure period" following the substantial completion of the improvement to real property. If damage occurs between the 5th and 7th year after substantial completion, the time to commence an action is extended by 3 years from the date the damages occurred. However, this extension does not apply to actions for contribution unless the underlying action is extended under this provision. No action may be commenced after this period for damages arising from deficiencies or defects in the design, construction, or materials used in the improvement, except under specific circumstances outlined in the statute. These circumstances include fraud, concealment, or misrepresentation. *Wis. Stat. § 895.072* and *Wascher v. ABC Ins. Co., 2022 WI App 10* further clarify that the statute of repose cannot be extended or revived by the notice of claim process required for construction defect claims.[ii,iii] This means that even if a claimant provides the required notice under *Wis. Stat. § 895.07(2)*, it does not extend the statute of repose.[ii]

For breach of contract claims related to construction defects, the applicable statute of limitations is 6 years under *Wis. Stat. § 893.43(1)*, which may apply if it is shorter than the statute of repose.[iii,iv]

In Wisconsin, a CA can be at a disadvantage when the original developer maintains control of the association. The end result is that the statute of repose is typically 7 years, and the statute of limitations for a breach of contract is 6 years; however, the developer can control the association for up to 10 years. For community associations, such as HOAs in Wisconsin, there is no required turnover period, so turnover of the association could occur well after the 10-year expiration of the statute of repose.

In other US states, associations may not be at such a disadvantage, but typically there is not much time to determine the severity of construction defects and hold the developer accountable.

A/E/C ROLE AFTER DEVELOPER TURNOVER

The collapse of the Champlain Towers South condominium in Surfside, Florida, prompted significant legislative and regulatory changes. These include structural inspection requirements for aging cooperative and condominium buildings that are three or more stories tall. The legislation in Florida now mandates milestone inspections at specific intervals to ensure structural integrity and safety.

There has been a push to mandate reserve studies for CAs. At least eight US states have already passed legislation requiring a reserve study to be performed at some interval. The reserve study, which needs to be performed by an engineer or someone with significant experience who is capable of evaluating the property, provides an evaluation of the component parts of the association's building(s) with estimates on how much the association should save in their reserve fund to adequately address any issues or the end of the useful life of a system or component part.

For the bigger projects, such as the replacement of siding, roofs, or other larger items, A/E/Cs are hired as project managers to oversee the work. There is an expectation that the A/E/C hired will ensure the work is done properly. If an A/E/C is being paid to oversee a project, the expectation is that the engineer will guarantee the work is performed to industry standards.

DIFFICULTY WITH INDIVIDUAL OWNERS

The community association setup is unique, provided the association is represented by the BOD to act in the best interest of all members. Since unit owners are paying into the association, some are inclined to believe they should have a say in larger projects and the ability to file lawsuits against vendors. This is simply not the case. Associations have recognized that interference with a vendor is a growing concern. However, there is case law that suggests a unit owner suing the CA and various professionals, including public adjusters, hired by the CA lacks a right of action against these professionals, as there is no contractual duty owed to the individual unit owner. The court emphasized that the duty of professionals hired by the CA, such as public adjusters, is owed solely to the insured association and not to individual unit owners.[v]

Furthermore, associations have begun to enact restrictions against membership to prevent interference with vendors, including A/E/Cs. Such interference can be a fineable offense, as long as it is indicated as such in the association's governing documents, including the rules and regulations.

WHAT CAN A/E/CS DO TO PROTECT THEIR PROFESSIONAL LIABILITY COVERAGE?

Most A/E/C firms, particularly small firms, have a relatively low value in comparison to the liability they incur and the fees they charge. Actual collateral or physical assets are often little more than computer equipment, office furniture, some testing equipment, and maybe a vehicle or two. Without insurance, most firms are worth very little on paper and cannot survive the impact of a major claim against them.

Given this reality, most firms need to diligently work to maintain and protect their professional liability (PL) coverage. Following are a few suggestions:

- Start with assessing the project, the CA BOD and representatives, and the project risk, and above all, trust your gut. Be objective and beware of optimism bias, which is a "cognitive bias that causes people to overestimate the likelihood of positive events happening to them."

Like optimism bias, going into a potential project "needing the work" can also result in problems for a firm by committing to items they would not normally agree to, reducing their fees, or ignoring their gut.

- Ensure you have a strong contract reviewed by a construction law attorney and your insurance broker.
- Develop a very clear scope of service. Define exactly what you will do, what is not included, and what might be extra.
- Ask the CA to indemnify and defend you from suits raised by individual owners. Most CAs will not agree to this, but they certainly will not do it if you do not ask. Essentially, you are asking the association itself to defend you against suits brought by their individual owners.
- Require a percentage of owners to agree to be a party to your dispute resolution agreement. While this can be as simple as copying these terms from the contract with the CA to create a stand-alone clause or document, having this clause developed and reviewed by your insurance representative and attorney is the best.

  This is not an attempt to restrict owners from filing a claim or a suit but rather to have them agree to the terms of your dispute resolution process. Obviously, the more owners you have who agree to and sign your agreement, the better your position. However, in the past, the consultant author's insurance company has been satisfied with 75% of unit owners agreeing to these terms.
- Vet the client—have they previously sued developers, contractors, or design teams? How many other A/E/Cs have they contracted with and are no longer utilizing? The consultant author recently declined to work with a CA after they sent two previously commissioned studies and reports from local, well-known, and respected firms. It became apparent the CA simply did not like the answers (and likely the estimates of cost) they received from the other firms.

SUGGESTIONS FOR DEALING WITH CAS

- Use the initial meeting to assess the CA itself as well as the potential project. In addition to determining whether the project and personalities involved are a good fit, remember that if the CA cannot afford your fee, they probably cannot afford to complete a project.
- Use any meetings of the membership to assess the overall mood, individuals with clear objections to your project or even your involvement, and any other gut reactions you might have.
- Propose services in at least two distinct phases:
  1. Initial assessment, diagnostics, etc., followed by meetings with the BOD and owners. This provides a few things:
     a. Usually less liability (but not completely free from liability) in offering your opinion regarding existing conditions.
     b. Gives you an "out" in case things go sideways before proceeding with a more expensive project with significantly higher project liability.
  2. Design and construction administration phases. Do not split off construction administration into a separate or optional phase—you must protect your design and position in the project. If you provide a design, you must include construction administration.
- Request and review any and all documentation available regarding the issue in question. Look for previous activities, assessments, and recommendations by other firms, contractor involvement, etc.
- Stipulate one point of contact, preferably on the BOD. Insist all communications go through this point of contact. Be very careful about having discussions outside of the BOD, as you will see in the next point.
- Have an appreciation for BOD politics. There are usually some people in full support of the BOD, there are usually people vehemently opposed to what the BOD wants to do, and most are somewhere in the middle.
- Recommend a full, thorough scope of work that you are very confident in. This is not the time to say, "You might be able to get away with something less." Remember, your name and reputation are on the line. Do not hesitate to make a firm stand—it is your way or the highway, so to speak.
- Do not imply that your work has any warranty or guaranty—protect your PL insurance! Stress that you specify the project warranties the contractors will provide. If there is a design problem, they can initiate a claim.
- Be conservative in budgets and initial estimates of construction costs you may provide. Be wary of underfunded CAs and underfunded projects. Understand the CA's funding mechanism if/when work is approved. Recommend healthy contingencies, and that contingencies be held until confident they are not needed—that is, do not release contingencies if/when the initial bid and contract come in lower than expected.
- Remember that you are working on people's homes—someone is always around, and people can be very particular and often have very unrealistic expectations. Further, most owners are not familiar with commercial construction, working with (even professional) contractors, general contractors, A/E/Cs, etc.

Community association projects present both significant opportunities and substantial risks for building enclosure professionals. By understanding the unique legal landscape, including statutes of limitations and repose, developer turnover challenges, and the complex dynamics of BOD governance, A/E/Cs can position themselves for successful project outcomes while protecting their practices. The strategies outlined in this presentation—from thorough client vetting and robust contract development to clear communication protocols and conservative budgeting—provide a framework for navigating these challenging engagements. As reserve study mandates expand across more states and aging building stock continues to require professional attention, the demand for qualified building enclosure consultants will only grow. Those practitioners who approach CA work with appropriate caution, clear boundaries, and a commitment to thorough documentation will find this sector both professionally fulfilling and financially sustainable. Ultimately, success in community association work requires balancing technical expertise with an appreciation for the human dynamics at play, recognizing that behind every project are homeowners invested in protecting what is often their most significant asset.

ENDNOTES

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