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PROCEEDINGS

SEPTEMBER 29-30, 2023
ORLANDO, FL

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Jennifer S. Hogan, REWC, RRO, CRE, LEED AP, Certified Passive House Consultant; Stephanie Robinson, P.Eng.

FENESTRATION REPLACEMENT: IDENTIFYING DESIGN SOLUTIONS FOR EXISTING BUILDINGS

ABSTRACT

When owners of existing buildings need to replace fenestration systems, designers and other project team members can improve project outcomes by proactively identifying potential obstacles during the design and construction phases. In this article, we discuss the challenges of fenestration replacement and identify project-specific design solutions to address them. We provide two case studies, using their distinctive conditions to illustrate fenestration replacement challenges and the lessons learned.

LEARNING OBJECTIVES

- Recognize building enclosure design best practices for detailing watertight enclosures, specifically regarding air and water leakage.
- Discuss when and how to use nondestructive testing procedures, such as air leakage and water penetration testing, to provide critical information for the overall design, including the need for window replacement.
- Develop an investigative opening plan to gather pertinent information, resulting in better preparation for varying existing perimeter conditions encountered during construction.
- Identify potential challenges that may arise during construction and design strategic solutions in advance to mitigate those challenges.

SPEAKERS



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Scott Bondi is a principal at Simpson Gumpertz & Heger. He has extensive experience in building enclosure design and specializes in building science and numerical analysis. Bondi consults on both new construction and historic renovation projects, from conceptual design through construction administration, applying his specific expertise in curtainwall and custom glazing systems. In addition, he is experienced in providing forensic engineering services and expert witness support for both building enclosure and mechanical systems. Bondi is also an adjunct professor at Cooper Union, where he has lectured and developed courses in mechanical engineering since 2007.

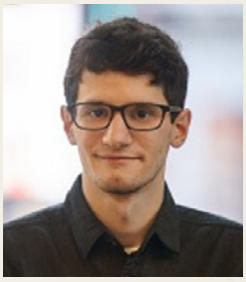


Leonidia M. Garbis, PE, LEED Green Associate
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Leonidia M. Garbis is a senior project manager specializing in building enclosures at Simpson Gumpertz & Heger. With 10 years of experience, she designs and evaluates new and existing building enclosures, focusing on custom curtainwall assemblies from design through construction administration. Her portfolio includes commercial, high-rise residential, and infrastructure projects. She is also skilled in enclosure forensic engineering, including curtainwall and custom glazing system investigations. Garbis has extensive knowledge of facade, roofing, and waterproofing systems. She actively participates in the Commercial Real Estate Women Network and the Association of Medical Facility Professionals, demonstrating her commitment to professional engagement.

AUTHORS:

Scott Bondi, PhD, PE, LEED AP
Leonidia M. Garbis, PE, LEED Green Associate
Michael Colella



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Michael Colella is a project consultant at Simpson Gumpertz & Heger and has four years of experience in the Building Technology Group. He specializes in design of new construction projects from conceptual design through construction administration. Colella uses advanced computer simulation tools, including computational fluid dynamics and finite element analysis, to support his design work. He has experience with several types of facade and roofing systems.

When fenestration reaches the end of its service life, and after attempts to patch and repair have been unsuccessful, replacement becomes necessary. Common indicators of failure include persistent air or water leakage, inadequate reduction of solar loads, condensation, occupant comfort complaints, and compromised functionality of operable units. Upgrading the units can enhance aesthetics, reduce air and water leakage, improve energy efficiency, and acoustics. Fenestration replacement may also lower building operation costs and upgrade expenses for other systems like mechanical equipment. Changes in interior programing are also ideal opportunities for considering window fenestration replacement.

Whatever the motivation for replacement, designers and owners must be prepared to tackle various challenges. These include ensuring proper support of the new fenestration within the existing wall assembly, meeting building codes and structural design requirements, and reconciling differences between past and present construction methods. The replacement design must also account for project-specific factors such as schedule limitations, the owner's performance criteria, and minimizing disruptions for occupants during construction.

BUILDING CODE AND STRUCTURAL CHALLENGES

Building owners have traditionally replaced aging fenestration in-kind with new off-the shelf systems, often without any consideration of engineering issues. However, current building codes have added complexity to fenestration unit replacement. For example, Chapter C503 of the 2021 *International Energy Conservation Code* (IECC)[1] mandates that all new building elements used in renovations must comply with the current code requirements. Local jurisdictions may impose stricter requirements than the model codes, further increasing the differences between existing and new fenestration. Specific aspects of building codes are discussed later in this article.

When planning the replacement of fenestration units, designers and building enclosure consultants should be aware of how contemporary construction methods and materials differ from the methods and materials used originally. For example, 50 to 100 years ago, mass masonry or transitional masonry were prevalent structural systems. Transitional masonry walls typically have less masonry with the addition of steel, which limits the mass to one or two wythes of masonry. Fenestration in older buildings was typically fabricated off site but glazed in place and windows were often installed using exterior scaffolding. In contrast, many newer buildings feature steel or concrete framing with engineered backup wall construction. If a brick masonry facade is used in a new building, the facade is typically a cavity wall. Windows in new buildings may be installed from the interior with limited exterior access.



FIGURE 1. Invasive and noninvasive investigative procedures. (A) Water testing; (B) Tracer fog air infiltration testing; (C) Invasive opening at masonry; (D) Invasive opening at steel framing.

To specify a suitable, cost-effective replacement system for a particular fenestration replacement project, the designer must determine whether design approaches for new buildings can be directly applied to the existing building or need to be modified to fit with the building's architecture, structural condition, or aesthetics. Also, as noted previously, project-specific considerations, such as occupancy during replacement, affect the ease of fenestration unit installation. Thorough investigation of the project conditions is therefore a critical step toward success.

INVESTIGATION CONSIDERATIONS

Identifying air drafts or water leaks within a fenestration unit is crucial to pinpoint issues with the fenestration or its interface with the adjacent wall assembly. Field investigations can be instrumental in determining the location and severity of such leakage. The methods used in such investigations can be classified as noninvasive or invasive procedures (**Fig. 1**).

ASTM E783[2] and ASTM E1105[3] present noninvasive methods that can be used to measure air and water leakage, respectively (**Fig. 1A**), without disturbing existing conditions. Techniques such as tracer fog (**Fig. 1B**) or pressurization can identify the source of leakage from either the fenestration unit itself or the adjacent wall assembly.

Invasive field investigations offer detailed insights into structural conditions surrounding fenestration units. Invasive investigations can also be essential to understand how the existing building was constructed (**Fig. 1C and 1D**). Many older buildings do not have the same level of construction documentation that is expected of a modern construction project.

Careful planning for invasive investigation, especially in areas without drawings, is necessary. Probed areas may contain hazardous materials, and prior coordination of a safety plan before the investigation begins is highly recommended.

DESIGN CONSIDERATIONS

Various design options exist for remediating fenestration issues, with no universal solution suitable for all buildings. Each option has its own complexities and considerations, warranting thorough evaluation to match project requirements. Important variables for designers to consider include the severity of problems, the project budget, and the anticipated life span of repairs or replacements.

Repairs and Modifications

Although this article focuses primarily on fenestration replacement, it is important to note that localized fenestration repairs are adequate for minor or limited issues. For example, deteriorated gaskets or failed sealant joints between the fenestration and the surrounding wall can be remedied with simple solutions such as new sealant joints (**Fig. 2A**) or silicone sheet patches (**Fig. 2B**). However, these types of repairs cannot fully resolve broad performance concerns such as insulating value or acoustic transmission. They should typically be considered as short-term solutions, and ongoing maintenance may be required. To effectively address air or water leakage problems, any repair plan should be supported by a field investigation to identify the specific leakage path and maximize the chances of resolving the issue.

In certain cases, modifying existing fenestration can be a more practical option than complete replacement. Storm windows, whether installed externally or internally, may offer a viable solution for underperforming windows (**Fig. 2C**). They add an additional layer of glazing, improving thermal and acoustic performance without removing the existing system. This approach is suitable for buildings where removing the current system is inconvenient or impractical due to aesthetic requirements or the need to maintain occupancy during construction.

However, adding storm windows introduces challenges that should be evaluated on a project-specific basis. The interstitial cavity created by storm windows can lead to condensation and increased maintenance costs due to additional glass surfaces requiring access and cleaning. Also, a storm window may not provide the same thermal performance as a high-performing replacement window, and proper integration of the storm window system with the surrounding wall system is crucial for achieving a



FIGURE 2. Design options for remediating fenestration issues. (A) New sealant joints; (B) Silicone sheet patches; (C) Storm window installation; (D) Window replacement; (E) Overcladding with curtain wall system.

balance of thermal and waterproofing performance.

Understanding and addressing potential leakage paths is highly recommended when considering storm windows. Neglecting this step may lead to unsatisfactory performance.

Replacement

Fenestration replacement provides an opportunity to start with a new, warranted system that can be properly integrated with the surrounding wall system (**Fig. 2D**). Improvements may include an effective air and water barrier, reduced air leakage, and enhanced thermal and acoustical performance. However, fenestration replacement brings its own challenges, such as the need to remove existing components and, especially for older buildings, the presence of unforeseen conditions that must be addressed during the project. Detailed project-specific planning and coordination are necessary to attain the desired performance outcomes.

Overcladding is an alternative to replacement that is often used in older high-rise office buildings with curtainwall systems (Fig. 2E). It provides an opportunity to renovate the building's appearance while simultaneously achieving performance improvements. The overcladding process, which typically necessitates a custom design approach, involves placing a facade system outboard of the existing facade system, possibly requiring new anchorage back to the primary structure. Vision areas, louver areas, and spandrel areas can be incorporated into the design. This approach is often used to minimize disruption inside the building by using the existing facade as a temporary weather barrier and means of occupant protection during construction. Existing attachments and framing members may need to be worked around during the process. The project team has an option to keep or remove the existing façade in the final configuration depending on how the system is designed. Overcladding may appeal to owners because it may allow for maintaining partial occupancy inside the building during the work—a crucial factor for the owner's revenue.

Code Requirements

As noted earlier, the need to meet building code requirements may be a considerable challenge in fenestration replacement projects. For example, to meet the IECC's thermal performance requirements, new fenestration units may need to be thicker and heavier than existing fenestration, and those differences can have implications for the design of the support systems. Similarly, windborne debris resistance may be mandated by codes and insurance

companies. While thermal performance can often be estimated by computation, windborne debris requirements necessitate physical testing rather than relying exclusively on analysis.

Code requirements can also influence various components of the glazing system. For example, triple glazing may be needed for energy code compliance, or laminated glazing may be specified for acoustic and/or windborne debris performance. Additionally, evolving jurisdictional requirements, such as those related to bird-friendly glass, can restrict glass coating types, locations, and fabricators. The product options that meet specific requirements may be limited, especially when physical tests are necessary, and that limitation can affect installation techniques and project costs.

System Integration into the Existing Building

One of the greatest challenges with a replacement fenestration system is how to best integrate it into the existing building (**Fig. 3**). Manufacturer's instructions and performance testing data are often available for fenestration systems. However, that information will not be specific to the particular project underway, so the designer will need to produce project-specific details to ensure the integration is effective.

A key design consideration is how to maintain a continuous air and weather barrier along the perimeter of the new fenestration unit. For many older buildings that rely on mass masonry, the existing masonry alone will not facilitate a continuous weather barrier.

The drainage system of both the fenestration unit and the adjacent wall assembly will dictate how to best waterproof the interface between the two systems. For example, if a new fenestration system has an internal drainage system, it is necessary to transition the waterproofing such that the drainage system is not blocked and can weep properly, while the rough opening in which the drainage system sits is fully waterproofed.

The characteristics of the surrounding wall system will considerably influence the placement of the waterproofing tie-in. Mass masonry walls may require full sill-pan flashing to catch any water that may bypass outer seals of the window-to-wall interface and drain that water to the exterior. In other cases, the replacement fenestration system is constructed of a stick-built curtainwall system and the waterproofing of the veneer cavity is directly tied into the glazing system.

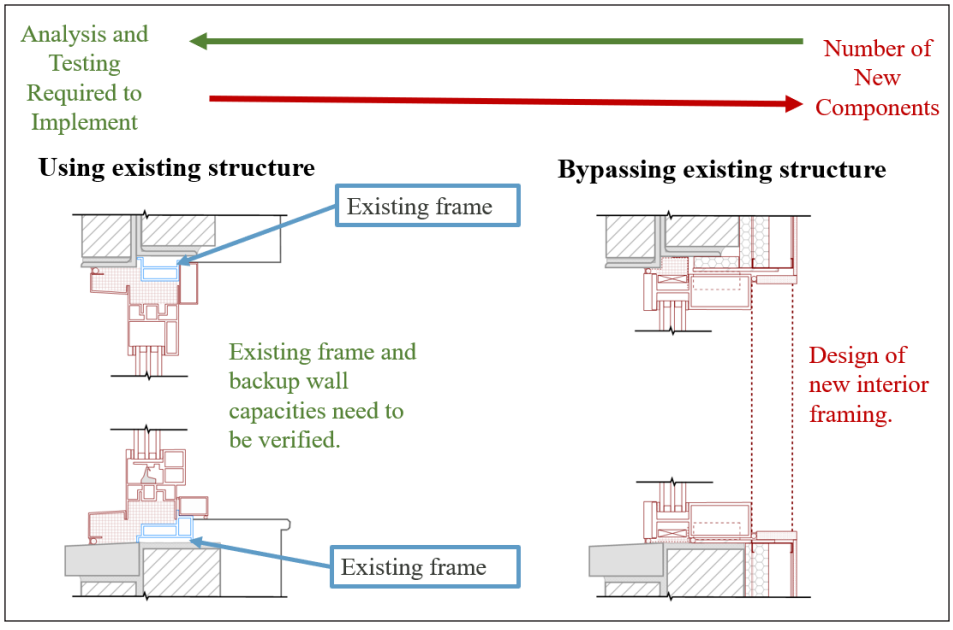


FIGURE 3. Considerations when interfacing a replacement fenestration system with an existing building.

Careful consideration is needed when selecting materials for waterproofing integration, with options including sealant or sheet membrane.[4] In our opinion a membrane is typically more reliable; however, implementation requires thorough planning.

The interfaces between fenestration and the surrounding wall may need additional elements for proper integration. In traditional window replacement projects, receptors can be used to simplify interior installation. Receptors are framing pieces that shrink the window opening to facilitate installation. They can accommodate prefabrication, interior installation techniques, and construction tolerances. However, depending on their configuration, the use of receptors can complicate waterproofing integration. In some cases, window receptors are fastened into the sill of the rough opening, which may complicate a sill-pan-flashing approach that aims to avoid any piercings. Overcoming this challenge requires careful planning and creative detailing approaches.

Verifying performance is always important. Drawings may not accurately reflect the actual project challenges. It is highly recommended that project teams conduct preliminary preconstruction mockup installation and testing, as well as quality assurance testing. These tests should include air and water infiltration testing according to AAMA 501.1[5] and 501.2[6] standards. Preconstruction testing offers the advantage of a "dry run" so that the entire team can address challenges before the actual construction begins.

Coordination among all stakeholders is paramount in a fenestration replacement project. The owner's schedule, budget, and occupancy-impact expectations will drive the design. The structural engineer evaluates primary and secondary structural members against the loads imposed by fenestration system attachments to the existing building. If the project includes interior refitment, the mechanical engineer assesses thermal performance requirements such as air infiltration, U-values, and solar heat gain coefficients. The contractor implementing the design

will also have input on appropriate installation methods and will inevitably discover during demolition that some existing conditions deviate from assumptions made during the planning stage. Successful outcomes depend on collaborative problem-solving by all team members.

CASE STUDIES

Senior Care Facility

Our first case study involves senior care facility housed in a 1970s building with vertical modules of bay windows. The existing windows and surrounding metal panels were steel-framed extending past the concrete building slabs. The exterior also had a textured cast-in-place concrete facade. The fenestration replacement project aimed to improve performance. The goal was to reuse the existing steel framing whenever possible.

The senior care facility needed to ensure occupant comfort and safety while remaining fully operational during construction. The project team's understanding of the installation process and its coordination with ownership and the contractor enabled a phased installation strategy (**Fig. 4)** to meet these requirements within an efficient timeline. The design process became iterative and collaborative, with the construction team influencing changes to perimeter detailing in certain areas.

The design team requested several invasive openings at the beginning of the design process to assess and verify the installed structural conditions, which varied. These openings facilitated calculations to determine the capacity of the steel framing members. To accommodate the inconsistent structural conditions of the existing building, new structural elements were added to create a uniform surface for window framing and waterproofing attachment.

For the opaque spandrel conditions of the building, the design solution involved installing new insulated metal panels with a continuous weather-resistive barrier over the existing metal cladding. Use of swing-stage access and this exterior installation method allowed the building to remain fully occupied during construction without the interior space being disturbed.

Sheet-applied waterproofing membrane was used to create a water-resistant transition between the windows and the surrounding cast-in-place concrete facades. Precise removal of textured concrete surface was necessary to create a flat surface for proper application and termination of the waterproofing membrane.

Unforeseen conditions in existing buildings often necessitate modifications to the project details. The design team collaborated with the contractor to create a guide for evaluating each window bay during the demolition phase. This guide helped identify and communicate conditions requiring design modifications. It included criteria such as maximum acceptable steel framing section loss, shimming heights, and minimum welding lengths. Preinstallation mock-ups were instrumental in verifying the viability of the drawn details and estimating the window replacement timeline. Successful project execution was facilitated by effective communication among the architect, contractor, and owner.

School Building

Our second case study is a 1950s school building with hung windows placed between expressed concrete fins. The spandrel areas beneath each window feature a concrete and brick masonry facade. After a thorough condition assessment and field investigation, which revealed multiple leaks and performance issues, the owner decided to replace the windows and rehabilitate the opaque exterior facades. This project involved recladding the brick and overcladding the concrete areas with an exterior insulation and finish system. The main challenge for the school was coordinating the active construction schedule within the limited time of a few months, aligned with the school calendar recesses.

Integrating replacement windows and spandrel cladding within existing concrete fins posed a design challenge. The exposed concrete fins relied on a barrier waterproofing approach.[4] To achieve the desired aesthetic, transition waterproofing had to be attached to the face of the concrete while remaining concealed. The window support design used an interior steel angle attachment to the concrete fins, allowing for waterproofing from the

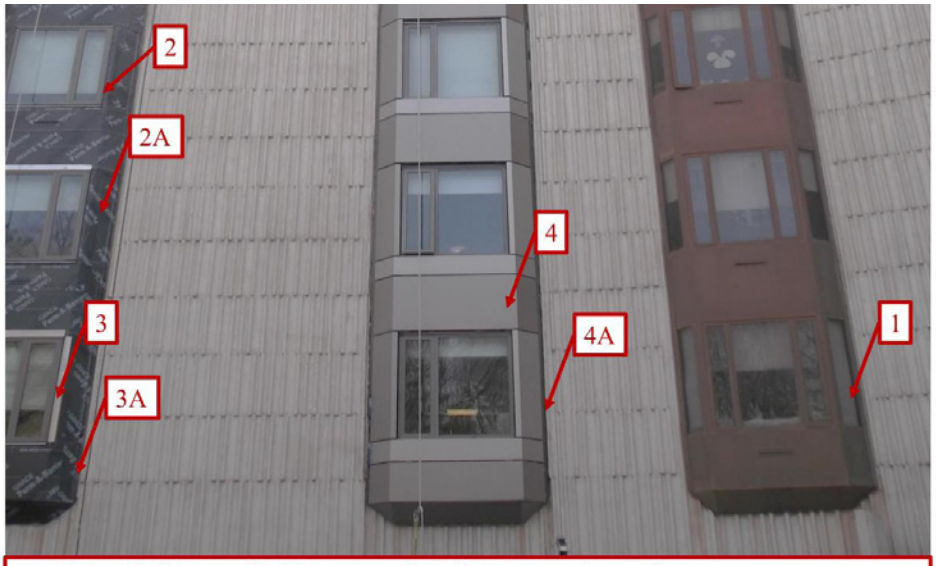


FIGURE 4. Phased installation of a fenestration system at a senior care facility.



FIGURE 5. Design options for remediating fenestration issues. (A) New sealant joints; (B) Silicone sheet patches; (C) Storm window installation; (D) Window replacement; (E) Overcladding with curtain wall system.

angle onto the concrete fin. Sheet-applied waterproofing was installed at the window jambs, concealed by the window frame, and sealed to the concrete with dual-stage sealant joints (**Fig. 5**). A metal sill-pan flashing system with end dams was used at the window sill, and reglet-set into the concrete fins to drain any water that penetrated the initial sealant line. Between spandrel zones, new concrete masonry units were designed to support the new windows and brick exterior, while also receiving face waterproofing. This approach facilitated cavity wall construction for the reclad facade. The window's sill pan flashing accommodated the offset between the window and the new brick masonry.

CONCLUSION

Fenestration replacement in existing buildings is a complex task requiring careful consideration and coordination. With an in-depth understanding of existing conditions, appropriate selection of replacement windows, and meticulous planning and execution, it is possible to significantly enhance the performance of the building, while minimizing disruption to the occupants and improving their comfort. The lessons learned from the projects described herein offer valuable insights for future fenestration replacement projects, contributing to the ongoing evolution of best practices in the field.

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4 Garbis, L. M., and C. C. Wowk. 2022. "Exploring the Dos and Don'ts of Curtainwall Transitions." *IIBEC Interface* 40 (8): 20-27.

5 Fenestration and Glazing Industry Alliance (FGIA). 2017. *Standard Test Method for Water Penetration of Windows, Curtain Walls and Doors Using Dynamic Pressure*. AAMA 501.1-17. Schaumburg, IL: FGIA.

6 FGIA. 2015. *Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls and Sloped Glazing Systems*. AAMA 501.2-15. Schaumburg, IL: FGIA.

EVALUATION OF VAPOR RETARDER IN ROOF DECKS BY HYGROTHERMAL SIMULATION

ABSTRACT

In natatoriums located in cold climates, high humidity and corrosive indoor environments can be associated with moisture condensation in roofs. The common practice is to employ at least a 0.1-perm vapor retarder on the warm side of the assembly to eliminate the risk of condensation. This study used hygrothermal modeling to investigate the role of a vapor retarder in a natatorium roof assembly in Climate Zone 7. A wood composite roof deck (*R*-value > 35 h·ft²·°F/BTU) with and without a vapor retarder in the assembly was used as a roofing candidate for the simulation. The moisture accumulation in the oriented strand board (OSB) of the composite deck over the years of exposure was used as an indicator of the roof's performance.

Even without a vapor retarder, the following simulation results were found: (a) maximum moisture content in the OSB did not exceed 11.6% (>20% is considered "risky"); (b) there was no risk of condensation in the assembly at any point in time; and (c) with the placement of a vapor retarder on the warm side, the maximum moisture content was reduced to 11.2%. These findings contradict the simple dew point analysis model that is commonly used to determine whether a vapor retarder for the roof assembly is needed.

LEARNING OBJECTIVES

- Explain the current steady-state methodology for determining the use of vapor retarders in roof assemblies.
- Describe the importance of various indoor and outdoor factors that determine the risk of condensation in roofs.
- Define a self-drying roof assembly and explain the conditions for a roof to be considered self-drying.
- Explain why the role of a vapor retarder in roof decks can be misunderstood.
- Discuss the need for acoustics in learning environments and the role of roof decks in achieving minimum reverberation time.

SPEAKER



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Gourish Sirdeshpande, PhD, is a senior principal scientist at STR Resources in Lancaster, Pennsylvania. Previously, he was a senior principal scientist in research and development at Armstrong World Industries Inc., with over 35 years of experience. His interests are in heat and mass transfer modeling, composite materials, building energy and indoor environment quality. He is the vice-chair of ASTM D22-05 on Indoor Air Quality and a member of the US delegation for ISO TC146-SC6 on Indoor Air Quality. He is a member of ASHRAE, ISIAQ, ASTM, and AIChE. He is also a member of ASTM-D08.

AUTHOR:

Gourish Sirdeshpande, PhD

In cold weather, high-humidity indoor environments such as indoor pools pose risks of moisture condensation in building enclosures, which in turn can cause mold, decay, buckling, corrosion, and eventually structural issues of durability. Most swimming pools are treated with chlorine, resulting in chloramines that off-gas into the pool's air space, irritating skin and eyes and creating respiratory hazards for swimmers and spectators. The chloramines also corrode building materials, especially metals. A good ventilation system[1] with effective air distribution and sufficient outdoor and exhaust air to remove toxic and corrosive chloramines is essential for the health and safety of swimmers, spectators, and other building occupants.

Acoustics and ambient noise are significant issues in natatoriums, as these spaces act as giant echo chambers. Most large community pools are considered learning spaces. Therefore, under the Acoustical Society of America (ASA)/ American National Standards Institute (ANSI) acoustic standards for physical education teaching environments,[2] these types of natatorium spaces are required to meet certain minimum reverberation times. To control indoor acoustics, pools require sound-absorbing materials that are widely and uniformly distributed throughout the natatorium. Both wall treatments and roofs must be sound absorbers. Moisture loads in a natatorium can be nearly two to three times per unit volume the loads in a typical building.[1] Therefore, moisture transport driven by vapor pressure differentials enhanced by temperature gradients across the enclosure is an important factor to consider in the proper design of the roofs.

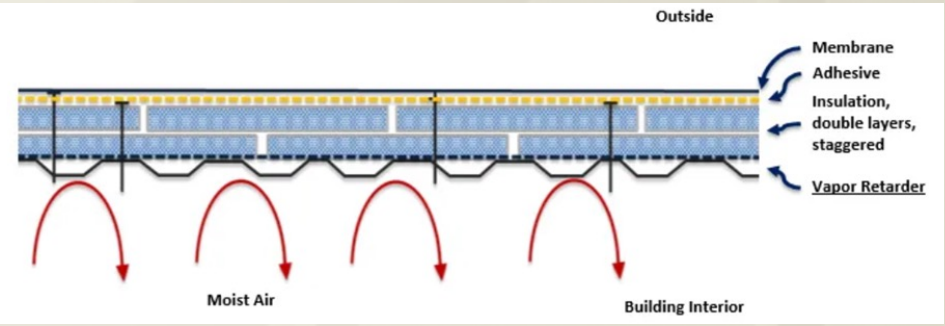


FIGURE 1. A typical metal roof deck assembly.

Current literature provides few guidelines for designing natatoriums to mitigate the risk of moisture condensation in roof decks. To avoid any risk of moisture condensation, design professionals frequently recommend a vapor retarder on the warm side of the roof assembly, presuming that a vapor retarder will safeguard the roof deck from condensation and moisture buildup.

Most roof installations in pools, irrespective of climate conditions, are perforated metal decks made of perforated metal, acoustic material, vapor retarder, insulation, roof decking material, and a roofing membrane (in that order, from inside to outside), as shown in **Figure 1**. The entire assembly is anchored by screws that hold the components together. This type of anchorage typically results in pinholes and tears in the retarder. Even when a vapor retarder is used, corrosion is a commonly occurring issue with metal roof decks in natatoriums. Such occurrences question the role of a vapor retarder in moisture buildup and condensation in these roof decks.

Although building enclosure consultants and roofing professionals may assume that there is minimal risk of condensation with the use of a vapor retarder, this assumption may be incorrect. The study presented herein used hygrothermal modeling to investigate moisture migration and condensation in composite roof decks with and without vapor retarders. In particular, the effectiveness of a vapor retarder to prevent condensation and moisture accumulation was highlighted in this investigation.

STEADY-STATE DEW POINT METHOD FOR ESTIMATING CONDENSATION

Most building enclosure professionals use the best-known simple steady-state design tool, the dew point method,[3] to evaluate condensation in roofs. This method assumes that steady-state heat conduction (under worst boundary conditions) and moisture diffusion govern heat flow and water vapor flow based on inside and outside temperatures and water vapor permeability of the assembly. Partial water vapor pressures in the roof deck are compared with saturation water vapor pressures based on calculated steady-state temperatures in the

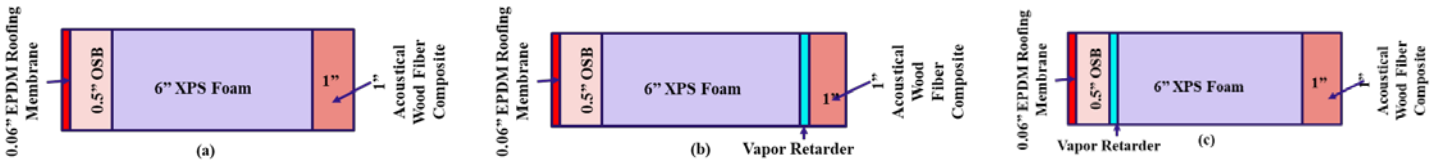


FIGURE 2. Roof deck assemblies: (a) without vapor retarder; (b) with vapor retarder after XPS foam installation; (c) with vapor retarder after the OSB installation. The exterior surface is on the left side in all cases. Note: EPDM = ethylene propylene diene monomer; OSB = oriented strand board; XPS = extruded polystyrene. 1" = 1 in. = 25.4 mm.

enclosure. If the calculated partial water vapor pressure is greater than saturation (estimated dew point), it is assumed that water vapor will condense in all parts of the roof assembly where the partial pressure is higher than the saturation pressure. The condensation rate is estimated based on the water vapor permeability of the assembly.[4]

The applicability of this method is severely limited by its assumptions about steady-state heat conduction and vapor diffusion. In reality, boundary conditions of temperature, humidity, wind, and radiation are in constant flux. Furthermore, water vapor permeances and thermal conductivity may vary with the relative humidity, temperature, and moisture content of the roof components. Nevertheless, many designers rely on the dew point method to select vapor retarders. Typically, a Class I vapor retarder with less than 0.1 perm is used in all metal roof decks.

TRANSIENT MODELING WITH HYGROTHERMAL SIMULATION MODEL

The features of a complete moisture analysis model include transient heat, air, and moisture transport formulations. Dynamic indoor and outdoor conditions as established by ANSI/ASHRAE Standard 160[5] should be used for simulation. Extensive data on material properties are available in published literature.[6]

In this study, simulations were conducted on one of the types of roof decks recommended by the ASA/ANSI standard,[2] a composite roof deck assembly for high-humidity environments, to assess the performance of the selected type of roof deck in cold climates and the role of vapor retarders in that performance. The simulations were modeled with WUFI.[7] This hygrothermal simulation model has been developed over the past three decades by Fraunhofer Institute of Building Physics and Oak Ridge National Laboratory to perform transient hygrothermal calculations to evaluate the long-term thermal and moisture performances of building enclosures, including roofs. (WUFI is an acronym for *Wärme und Feuchte Instationär* [heat and moisture transiency].) The model has been validated repeatedly over the past two decades and has an extensive database of material properties and exterior climates from all U.S. climate zones.[8, 9]

Figure 2 presents the schematic of the roof assemblies studied for transient heat and moisture flow. The basic assembly (from inside to outside) consisted of a wood-fiber-cement composite, extruded polystyrene (XPS) insulation, oriented strand board (OSB), and an ethylene propylene diene monomer (EPDM) roofing membrane. A vapor retarder (0.032 perm) was installed at two different locations, one on the warm side (**Fig. 2b**), and the other after the OSB (**Fig. 2c**). A retarder with a very low perm-rating (< 0.1 perm) was chosen to overstate the role of the vapor

TABLE 1. Thermodynamic and transport properties of roof components.

Properties	EPDM roofing membrane (0.06 in.)	OSB (0.5 in.)	XPS foam (6 in.)	Wood-fiber board (1 in.)	Vapor retarder (0.25 in.)
Bulk density, lb/ft^3	53.1	34.5	1.79	18.7	54.6
(kg/m3)	(851)	(553)	(28.7)	(300)	(875)
Porosity	0.001	0.64	0.99	0.8	0.001
Specific heat capacity, BTU/lb°F	0.45	0.33	0.35	0.334	0.38
(kJ/kg·K)	(1.88)	(1.38)	(1.46)	(1.4)	(1.6)
Thermal conductivity, BTU/h ft°F	0.12	0.07	0.014	0.29	0.87
(W/mK)	(0.66)	(0.12)	(0.024)	(0.5)	(1.5)
Permeability, perm-in.	0.0014	0.96	1.3	10.3	0.008

NOTE: EPDM = ethylene propylene diene monomer; OSB = oriented strand board; XPS = extruded polystyrene. 1 in. = 25.4 mm.

retarder. (The general understanding is that the lower the perm rating of the retarder, the less chance there is of condensation in the assembly.) The wood-fiber composite inside the pool space provided acoustical absorption, which is one of the requirements for good indoor environmental quality (IEQ) in the space. **Table 1** lists the primary transport properties of each of the components. The rest of the properties—moisture- and temperature-dependent transport properties and the equilibrium moisture content for each element—were obtained from the database provided in WUFI.

Fargo, North Dakota, in Climate Zone 7, was chosen for the location to simulate the roof performance. Table 2 presents the boundary conditions and the main surface transfer conditions.

The hygrothermal simulation software includes the actual hourly averages of outside temperature, humidity, rain, wind, and the solar (short- and long-wave) radiation used in the simulation. To simulate a high moisture load in the natatorium, the inside conditions ranged from 40% to 65% relative humidity and 68°F to 80°F (20°C to 31.1°C).[5] For all components, the initial moisture content was assumed to be equilibrated at 50% relative humidity. The roof deck assembly had a total *R*-value of 37 ft²·h°F/BTU (6.52 m²K/W). To emulate realistic conditions, an air leak at the rate of 0.99 ft³/h ft² (0.084 L/s·m² @ 50 Pa) was included in the model.[5] The air leak was introduced at the interface of OSB and insulation, and it was set to start from the wood composite (inside) up to the EPDM layer for all the three cases. The stack height was set to 23 ft (7 m), and there was no mechanical ventilation overpressure. Air leaks (typically due to static pressure difference) can result in significant moisture transport from the pool space to the outside. A no-coating option for permeance was selected on the left side, and a permeance of 10 perm was selected for the right side. The short-wave radiation absorptivity coefficient is an important variable when determining the outside surface temperature.[10] The roof deck had a dark roofing membrane (short-wave radiation absorptivity = 0.8) to absorb incident solar radiation, which would significantly elevate the daytime (and summer) surface temperatures since the pool was located in Climate Zone 7. Typically, white roofs are used in Climate Zones 1 through 3 to save energy (by lowering surface temperatures). If a white roofing membrane is used in a colder climate, the likelihood of exceeding a moisture content of 20% will be very high.[11] The simulation was carried out from 2000 to 2020.

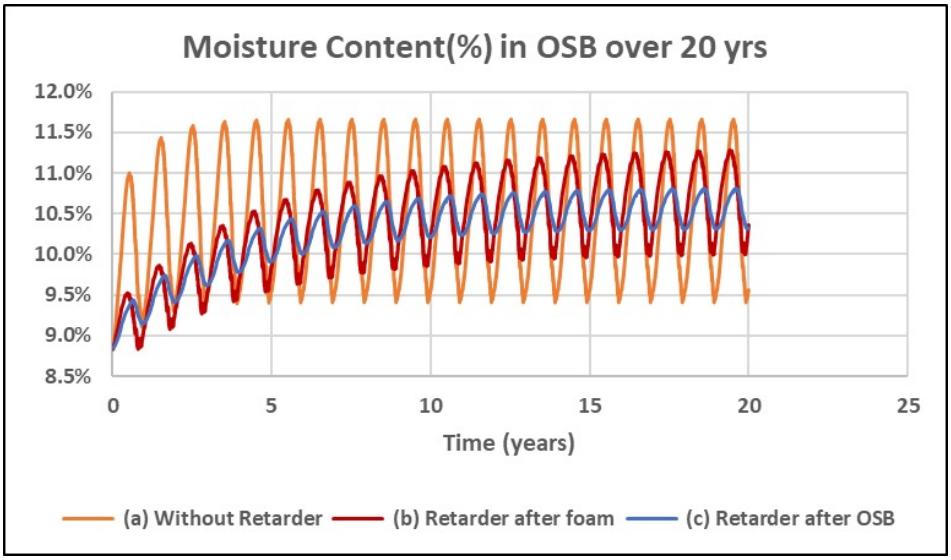


FIGURE 3. Moisture content in the oriented strand board, 2000–2020.

SIMULATION RESULTS AND DISCUSSION

Moisture Accumulation in OSB

The primary concern regarding the roof's long-term performance would be moisture condensation and accumulation in the OSB over its service life. Decay and rot in wood occur when its moisture content exceeds 30%.[3] However, to provide an adequate margin of safety, it is preferable to not exceed more than 20% moisture saturation.[12] **Figure 3** presents the simulation results for moisture content in the OSB for the three cases.

As seen in **Fig. 3a**, in the roof assembly without a vapor retarder, the average moisture content in the OSB reached a dynamic steady state in 5 years, and the maximum accumulation of water in the OSB did not exceed 11.6%. Therefore, there would be no risk of rot or decay since the percentage of moisture was well under 20%. With the use of a vapor retarder on the warm side of the roof assembly (after the installation of foam), the maximum moisture content in the OSB was reduced to 11.3% (**Fig. 3b**). With the vapor retarder installed after the OSB, the maximum moisture content was around 10.8% (**Fig. 3c**). The vapor retarder primarily minimized the magnitude of the swing in moisture accumulation between winter and summer months without significantly affecting the average moisture accumulation over the 20-year period. These results show that using a vapor retarder in the roofing assembly offered no significant advantage, thus contradicting popular assumptions. The simulations indicate that, even in Climate Zone 7, a roof assembly without the retarder could perform just as well as the one with the vapor retarder so long as there were a sufficient number of summer days with warm temperatures (where the temperature gradients cause the vapor drive from outside to the inside). In these conditions, the moisture content would reach a dynamic steady state, with the accumulation of moisture during the winter months being equal to the "drying" of the OSB during the summer months. This concept of a "self-drying roof" has been recognized by previous investigators.[12, 13]

Notably, the simulation shows that the vapor retarder in the roof assemblies had minimal effect on moisture accumulation. Although the simulation illustrated the performance of a wooden composite deck, the

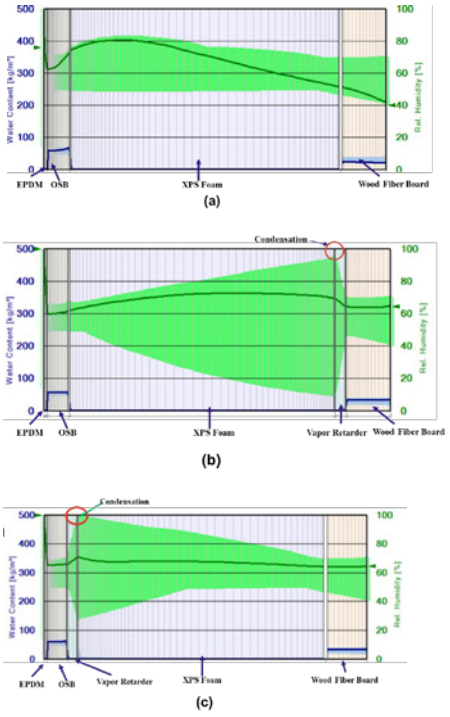


FIGURE 4: Moisture distribution profiles in the roof assemblies, 2000–2020: (a) without vapor retarder; (b) with vapor retarder after the installation of XPS foam; and (c) with vapor retarder after installation of the OSB. The green regions represent the range of the relative humidity profiles in each component of the roof deck. These profiles are calculated based on partial vapor pressure corresponding to the equilibrium moisture content in each component at a given instant. The green lines represent the instantaneous relative humidity profiles. The blue lines represent the moisture content in each component (primary axis). Note: EPDM = ethylene propylene diene monomer; OSB = oriented strand board; XPS = extruded polystyrene. 1 kg/m^3 = 0.062 lb/ft^3.

conclusions on the role of the vapor retarder also hold true for a metal deck.

Moisture Profiles in the Assembly

The development of moisture profiles across the roof assembly provides insight into the dynamics of moisture migration and buildup inside the roof during the 20-year study period. **Figure 4** shows the distribution of the moisture profiles through each layer during the 20 years of simulated life. It is important to note that when the roof deck assembly did not have a vapor retarder (**Fig. 4a**), the maximum relative humidity reached in the assembly did not exceed about 80%. However, when the roof deck assembly had a vapor retarder (**Fig. 4b and 4c**), the maximum relative humidity at the foam-retarder interphase reached about 100%, indicating that moisture condensation was quite likely to occur at that location. While the vapor retarder lowered the moisture flux from inside to the outside during winter, its presence inside the assembly retarded the downward (from outside to inside) moisture flux through the foam during the drying cycle (summer). With the occurrence of condensation at the foam-retarder interface, there would be a risk of mold or mildew buildup in the assembly. In case of a metal roof deck, with the retarder on the warm side, condensation would be associated with an increased risk of corrosion of the metal as the condensed water could seep through pathways created by screws and other anchoring hardware. Therefore, in general, using a vapor retarder would pose a higher risk and would not provide the intended safety of preventing condensation in the roof assembly in cold climates. These conclusions, which contradict common understanding and practice, can be generalized for natatorium roofs in Climate Zones 1 through 7.

In general, in addition to the roof deck attributes mentioned in this article, a good basis for natatorium roof design should include the following: (a) a continuous air barrier, (b) appropriate HVAC design and operation,[3] and (c) minimization of stack pressure by fan control.

TABLE 2. Primary boundary and surface conditions

	Conditions
Exterior climate (left side)	Fargo, ND; ASHRAE Year 1
Roof orientation/inclination	North/2 deg.
Heat resistance, ft2h °F/BTU (m2K/W)	0.3 (0.053)
Short-wave radiation absorptivity	0.8
Long-wave radiation absorptivity	0.9
Interior (right side)	EN 15026, high moisture load
Heat resistance, ft2h °F/BTU (m2K/W)	0.7 (0.123)

CONCLUSION

The steady-state dew point analysis model used by many practitioners of roof deck design does not accurately characterize moisture transport in roof decks. As a result, its use can lead to suboptimal design. Hygrothermal modeling can accurately predict roof deck performance. Simulation results of a roof deck assembly in a natatorium in Climate Zone 7 derived from a widely used hygrothermal simulation model show that—contrary to the assumptions behind common practice—a vapor retarder does little to affect moisture transport and condensation in a roof deck assembly in the long run. In Climate Zone 7, despite a high-moisture load in the natatorium, the roof deck assembly with or without a vapor retarder can be self-drying, with the moisture content in the OSB maintained below the "at-risk" level of 20%. Furthermore, this study shows that a vapor retarder can increase the risk of condensation by hindering the downward drying (outside to inside) and thus increase the risk of corrosion in a metal roof deck. Thus, contrary to common belief, a vapor retarder provides a false sense of safety (with regard to moisture transport and condensation) as it does not prevent or reduce the risk of moisture condensation and buildup in roof decks in cold climate zones.

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DESIGN IMPLICATIONS OF ENCLOSURE BACKSTOPS IN ENERGY CODES

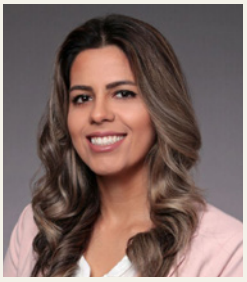
ABSTRACT

In the drive for increased energy efficiency, recent energy codes are putting increased focus on the thermal performance of enclosure assemblies. One increasingly popular concept is the introduction of envelope backstops to limit the traditional energy codes' approach of accommodating a shortfall in the thermal performance of the enclosure using efficiencies from other building systems. We will contrast the UA (system U-factor times its area) restriction approach to envelope backstops adopted in the latest City of Seattle Energy Codes and other US jurisdictions with the TEDI (thermal energy design intensity) approach adopted by the British Columbia Step Code and other Canadian jurisdictions. We outline the particular challenge this presents for enclosure design of high-rise buildings. Examples from BC Housing's *Building Envelope Thermal Bridging Guide* will be used to illustrate the current limitations of traditional unitized glazing systems when it comes to accounting for the impact of thermal bridging on enclosure thermal performance. We will conclude with a couple examples of how manufacturers are adapting the design of unitized glazing systems to meet this new challenge.

LEARNING OBJECTIVES

- Assess the design implications for the design of enclosure backstops in US and Canadian energy codes.
- Discuss the special challenges enclosure backstops pose for high-rise buildings, especially for the spandrel assemblies in unitized glazing systems.
- Review the Building Enclosure Thermal Bridging Guide and the effective performance of spandrel assemblies commonly used in current unitized glazing system design.
- Explore recent developments to improve the thermal performance of spandrel assemblies.
- Interpret how the increasing focus on accounting for thermal bridging can be reconciled with the concept of envelope backstops.

SPEAKERS



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Sadaf Mansour is a building science specialist with a passion for building enclosure design and energy-saving solutions. She holds a bachelor of architecture and a master of building science degree from Ryerson University in Toronto, Canada. With a strong background in both design and technical aspects of buildings, Sadaf is committed to promoting sustainable and energy-efficient practices in the built environment. Currently working at Morrison Hershfield in Seattle, she brings her expertise to various projects, focusing on developing innovative solutions for high-performance building envelopes.



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Jaydon Chun is a building science consultant with Morrison Hershfield's Seattle office. Jaydon's bachelor of architectural science degree is from Toronto Metropolitan University (formerly Ryerson University). With a diverse background spanning across Ontario, Alberta, and Saskatchewan, and currently based in Seattle, Washington, Jaydon brings a wealth of experience that includes consulting, commissioning of building enclosures for new construction projects, rehabilitation efforts, thermal modeling, and performance testing. Jaydon's expertise is focused on ensuring that high quality and performance are achieved with building enclosures.

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Energy consumption within the residential and commercial sectors accounts for 40% of energy utilization in the U.S.[1] Among the various energy uses, space heating and cooling activities are responsible for more than 50% of this energy consumption.[2] Canada also faces a similar concern, prompting regulatory authorities to explore alternative approaches. To mitigate energy consumption, both the United States and Canada are increasingly turning to more rigorous energy standards at the state and provincial levels, respectively. These energy codes have progressively become more stringent over the past few years. The underlying principle is that nationwide regulation will ultimately support each country in achieving its national sustainability targets. However, some jurisdictions are moving ahead of national standards in pursuit of higher performance.

Many western and northeastern states have already adopted the latest energy codes, emphasizing their commitment to sustainability and environmental preservation. Notably in the Northwest, Washington and British Columbia have implemented some of the most rigorous energy building codes. These jurisdictions, along with others such as Massachusetts, Vermont, Rhode Island, New York, and the City of Toronto, have gone one step further and implemented a strict requirement known as an "envelope backstop." The type of restriction imposed by each jurisdiction varies based on their respective targets, but the ultimate goal remains the same: to construct resilient and sustainable enclosures.

The envelope backstop requirement restricts a design team's ability to substitute energy efficiencies from internal systems (e.g., HVAC, hot water, lighting, etc.) against envelope energy efficiency shortfalls within the performance path to compliance. The traditional performance-path methods based on whole-building energy modeling have provided designers with considerably greater flexibility compared with the prescriptive path, as they permit the utilization of certain components that may not independently satisfy the prescriptive requirements. This allowance is permissible due to the requirement for other components to exhibit higher performance levels, resulting in a building that performs as well as or better than one designed using the prescriptive approach for each component. It is worth noting that the terminology associated with these requirements may vary across states and can be used interchangeably. However, this trade-off approach has often been used to justify lower-performing enclosures.

The following section briefly contrasts two approaches taken by Washington State in the U.S. and British Columbia in Canada, focusing on how these individual jurisdictions have implemented additional limitations on enclosure performance trade-offs to accelerate progress toward their sustainable building goals.

A CLOSER LOOK AT JURISDICTIONAL APPROACHES

The 2018 *Washington State Energy Code*,[3] which took effect on February 1, 2021, introduced envelope backstop as part of its energy performance path to compliance alongside traditional compliance methods and the prescriptive path (including prescriptive method and envelope component trade-off method). This new requirement imposes a limitation on the building enclosure's total heat loss coefficient UA calculated through the building envelope trade-off method. Per the *Washington State Energy Code*, the calculated UA must not exceed 20% higher than the level specified in the prescriptive code for Washington state. The City of Seattle, which has its own version of the *Washington State Energy Code*, has adopted a more stringent threshold set at 10%. The UA approach to envelope backstop is also found in other jurisdictions, such as Massachusetts and New York City.

In contrast, the British Columbia Energy Step Code4 compliance path requires new constructions to meet higher energy-efficiency standards beyond the requirements of the previous British Columbia building code, with the aim of transitioning to net zero energy–ready buildings by 2032. For instance, under step 3 of the Step Code, which came into effect on May 1, 2023, all new buildings must achieve a 20% improvement in energy efficiency compared to the previous code minimum.[4] The Step Code introduced new energy performance targets through a new performance metric, thermal energy demand intensity (TEDI), in combination with the traditional energy use intensity (EUI). TEDI focuses on enhancing building enclosure and space conditioning equipment performance, while EUI targets the overall energy consumption of all building systems. TEDI quantifies the annual heating load per unit of floor area, taking into account factors such as exterior surface area, thermal transmittance of building envelope components, airtightness, solar radiation, internal gains, heat recovery, and ventilation. However, TEDI does not include factors such as lighting and domestic hot water, despite their interaction with the building systems. In essence, TEDI can be perceived as a subset of EUI, and their combined application offers a comprehensive representation of overall building energy usage.[5]

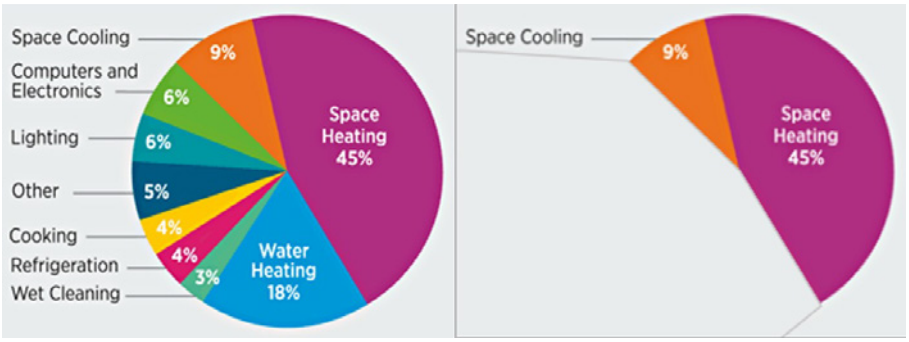


FIGURE 1. TEDI can be perceived as a subset of EUI.

Both the UA and TEDI approaches exemplify distinct envelope backstop trade-off paths established by jurisdictions to pursue sustainable goals. The UA approach exclusively concentrates on the building enclosure itself, excluding other building parameters that could potentially compensate for deficiencies in the building envelope, such as mechanical systems. Conversely, the TEDI approach offers greater flexibility compared with the UA approach, permitting the offset of any *U*-value shortcomings in the building enclosure by employing efficient mechanical systems. This mitigates the burden on the envelope to fulfill the entire energy-reduction requirement. However, it is important to note that the TEDI approach incorporates more rigorous measures in building envelope thermal bridging calculations, accounting for thermal transmittance through interface details such as wall-to-roof interfaces, intermediate floors, at-grade to below-grade parking garages, and other similar elements. This level of meticulousness is not extensively considered in the UA approach, which predominantly focuses on thermal bridges within the assembly itself.

The implementation of building envelope backstop requirements has the potential to significantly impact building envelope design. Addressing the design challenges in low-rise buildings with a low ratio of vertical enclosure area to horizontal enclosure area is easier to achieve, enabling the potential offset of UA shortfalls through the use of high-performance roofing systems. Low-rise construction also lends itself to a wider range of high-performance exterior opaque wall assemblies.

However, challenges arise when transitioning to high-rise buildings, where the ratio of vertical enclosure area greatly exceeds the horizontal area. This renders it impractical to compensate for UA shortfalls through increased performance of the roof assemblies. In such cases, the primary focus lies in increasing the efficiency of the vertical enclosure, including both opaque walls and fenestrations. Furthermore, solely increasing the *R*-value of fenestrations does not significantly enhance overall performance. For instance, upgrading from double-glazing fenestration to a triple-glazing system would result in an increase of only two to four *R*-value units, which fails to compensate for the shortfall in the 70% opaque wall coverage of the building enclosure.[6] While high-performance opaque wall options, such as sandwich insulated concrete panels or stud walls with continuous exterior insulation, are viable options, they are not as popular as unitized glazing systems for taller buildings due to cost, speed of construction, and

TABLE 1. Default *U*-values for spandrel systems (Table C303.1.5 of the 2018 *Washington State Energy Code*)

			Rated *R*-value of insulation between framing members							
			None	R-4	R-7	R-10	R-15	R-20	R-25	R-30
Frame type	**Spandrel panel**		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Aluminum without thermal break	Single glass pane, stone or metal panel	1	0.360	0.242	0.222	0.212	0.203	0.198	0.195	0.193
	Double glass with no low-e coatings	2	0.297	0.233	0.218	0.209	0.202	0.197	0.194	0.192
	Triple or low-e glass	3	0.267	0.226	0.214	0.207	0.200	0.196	0.194	0.192
Aluminum with thermal break	Single glass pane, stone or metal panel	4	0.350	0.211	0.186	0.173	0.162	0.155	0.151	0.149
	Double glass with no low-e coatings	5	0.278	0.200	0.180	0.170	0.160	0.154	0.151	0.148
	Triple or low-e glass	6	0.241	0.191	0.176	0.167	0.159	0.153	0.150	0.148
Structural glazing	Single glass pane, stone or metal panel	7	0.354	0.195	0.163	0.147	0.132	0.123	0.118	0.114
	Double glass with no low-e coatings	8	0.274	0.180	0.156	0.142	0.129	0.122	0.117	0.114
	Triple or low-e glass	9	0.231	0.169	0.150	0.138	0.127	0.121	0.116	0.113
No framing, or insulation is continuous	Single glass pane, stone or metal panel	10	0.360	0.148	0.102	0.078	0.056	**0.044**	**0.036**	**0.031**
	Double glass with no low-e coatings	11	0.297	0.136	0.097	0.075	**0.054**	**0.043**	**0.035**	**0.030**
	Triple or low-e glass	12	0.267	0.129	0.093	0.073	**0.053**	**0.042**	**0.035**	**0.030**

logistical constraints. To address the speed and cost challenges associated with high-rise construction, unitized panelized systems have become the dominant approach. However, the spandrel assemblies in these unitized systems often fall short of the target *U*-value for the opaque walls. Traditionally, mechanical systems have been employed to compensate for this shortcoming, but the envelope backstop limits the flexibility of such trade-offs.

In the context of high-rise towers with panelized glazing systems, opaque assemblies are often glazed spandrel assemblies integrated into aluminum-framed, panelized construction. The amended energy code in Washington State started including default *U*-values for spandrel assemblies for various types of insulation thicknesses and the configuration of the spandrel system in Table C303.1.5.[3] The table of default spandrel U-values originates from California Title 24, Appendix JA4-42, Table 4.3.8.[7] The default *U*-values are mandated to be used, unless the designer can demonstrate the thermal performance of the proposed spandrel assembly with either thermal modeling or guarded hotbox testing. Of these default *U*-values, the only spandrel configuration that meets the prescriptive thermal performance in colder climate zones requiring R-15 performance is a system without any framing member, which is generally not feasible in most unitized glazing systems (**Table 1**). This characteristic makes it necessary for a truly continuous insulation to be provided either inboard or outboard of the facade system, uninterrupted by framing members. The typical industry practice to address this has been to introduce insulation inboard of the glazing system. This approach, however, presents a significant risk in colder climates. By insulating inboard of the glazing system, the dewpoint is moved inward, increasing the risk of condensation inboard of the now-colder framing.

It is also important to recognize the existing methods of determining thermal performance of such spandrel systems. Traditionally, NFRC 100, *Procedure*

TABLE 2. Comparison of guarded hotbox test results with two- and three-dimensional thermal modeling

		IGU with air	IGU with argon	Combined IGU with VIP	VIP unit	VIP without backpan insulation
Hotbox test results	Total *U* (W/m² K)	0.89	0.87	0.56	0.50	0.60
	Total *U* (Btu/hr ft² F)	0.156	0.153	0.097	0.088	0.105
	Total *R* (hr ft² F/Btu)	**6.40**	**6.52**	**10.23**	**11.36**	**9.52**
2-D thermal Modeling—NFRC 100 approach	Total *U* (W/m² K)	0.65	0.63	0.43	0.34	0.47
	Total *U* (Btu/hr ft² F)	0.114	0.111	0.076	0.059	0.082
	Total *R* (hr ft² F/Btu)	**8.74**	**8.98**	**13.08**	**16.96**	**12.14**
	Delta *R*	**-2.34**	**-2.46**	**-2.85**	**-5.6**	**-2.62**
	Delta %	**-26.77%**	**-27.39%**	**-21.79%**	**-33.02%**	**-21.59%**
3-D thermal modeling	Total *U* (W/m² K)	0.90	0.87	0.57	0.51	0.59
	Total *U* (Btu/hr ft² F)	0.158	0.153	0.101	0.089	0.103
	Total *R* (hr ft² F/Btu)	**6.40**	**6.54**	**9.94**	**11.20**	**9.68**
	Delta *R*	**0**	**-0.02**	**0.29**	**0.16**	**-0.16**
	Delta %	**0%**	**-0.31%**	**2.92%**	**1.43%**	**-1.65%**

NOTE: 2-D = two-dimensional; 3-D = three-dimensional; IGU = insulating glass unit; VIP = vacuum-insulated panel.

for Determining Fenestration Product U-Factors,[8] included a two-dimensional, area-weighted modeling approach to assess thermal performance of glazed systems including opaque spandrel systems. The modeling approach as per NFRC 100 is intended mostly for glazed fenestrations and allows for insulated spandrels to be assessed the same way. However, it was later found that the same approach, when used for spandrel systems, lacks accuracy when verified against guarded hot-box test results.[8] In comparison, two-dimensional modeling of insulated spandrel systems results in higher *R*-values, with a margin of error as high as 33%. It has been found that three-dimensional modeling is the most accurate in simulating the effective thermal performance of spandrel systems. The three-dimensional modeling results are verified to be accurate, with minimal discrepancy from the guarded hot-box test results (**Table 2**). NFRC has been developing a proposed methodology specific to the modeling of spandrel assemblies that better accounts for these discrepancies.

In a typical unitized curtain wall system, the vertical mullions would typically be a singular extrusion that spans between the vision glass and spandrels. The added insulation on the spandrels makes the mullions colder, but because the concealed mullion is a singular component that is also exposed on the vision portion of the panel, a significant amount of heat flows along these vertical members. As the frame components are typically highly conductive materials such as aluminum, it creates a vertical thermal bridging effect. The intermediate horizontal mullions between the vision and the spandrel also experience increased heat loss across the mullion with the added insulation. This issue takes place by the same mechanism that makes the internal of the spandrel colder, leading to additional heat flow into the spandrel assembly. In general, aluminum extrusions are more susceptible to this risk, as aluminum is a highly conductive material. When insulated inboard, the mullions start to form a grid of thermal bridges, further negating the

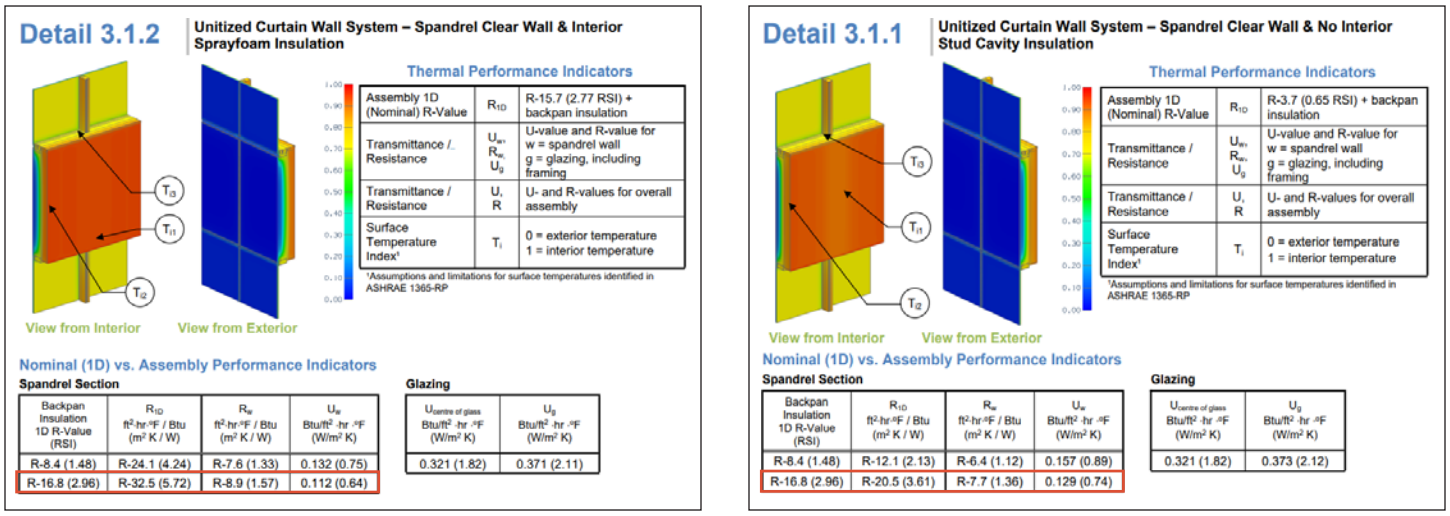


FIGURE 2. Comparison of thermal performance of unitized curtain wall system with and without interior insulation. Data reproduced from Morrison Hershfield Ltd. (2014).

effectiveness of the continuous insulation. This reinforces the importance of continuity of thermal insulation. As an example, unitized curtain wall system with R-17 backpan insulation and nominal assembly R-20.5 yields effective R-7.7 (62% derating). An addition of R-11.5 continuous insulation inboard of the curtain wall increases the nominal assembly *R*-value to R-32.5, but it only improves the effective *R*-value of the system by R-1.2, to R-8.9 effective (73% derating), as per **Fig. 2.**[10]

The 2021 International Energy Conservation Code (IECC) as adopted by Washington State and the City of Seattle under Commercial Energy Efficiency takes this one step further by including section C402.2.9, which requires alignment of the thermal break of vertical fenestration to be positioned within 2 inches laterally of either face of the continuous insulation.[10] In the context of recent trends with unitized glazing systems in the industry, this new provision will create challenges to using the interior layer of continuous insulation as a way to improve the thermal performance of aluminum-framed unitized glazing systems. In order to meet this new requirement, the industry will need to revisit the design of thermal-barrier continuity within curtain wall systems for greater efficiency. A similar requirement is up for adoption in the upcoming 2024 IECC.

One emerging design solution to overcome this challenge is the vacuum-insulated panel (VIP). These high-density insulation panels provide a high *R*-value, which makes them an ideal material for use in typical aluminum-framed glazing systems, as insulating capacity is limited to the depth of the facade system. The thinness of the VIP also makes it possible to place the insulation in the same plane as the thermal break of the framing member, which is a better placement of insulation in aluminum-framed unitized glazing systems, potentially eliminating the need for standard backpan insulation other than for fire staffing at the floor line. VIP can be integrated into a unitized curtain wall system either skinned with finished sheet metal, or in an insulating glass unit (IGU) assembly replacing the air cavity. The former system with 1 inch VIP with nominal assembly *R*-value of 39.1 can yield R-16.6/U-0.060 effective (58% derating), whereas the latter system with glass does not perform as effectively due to the need for a traditional IGU spacer along the perimeter, as per **Fig. 3**.[10, 12] Although this modeled configuration still does not comply with the minimum prescriptive code requirement, it is a significant improvement in the effectiveness of metal-framed facade systems.[12]

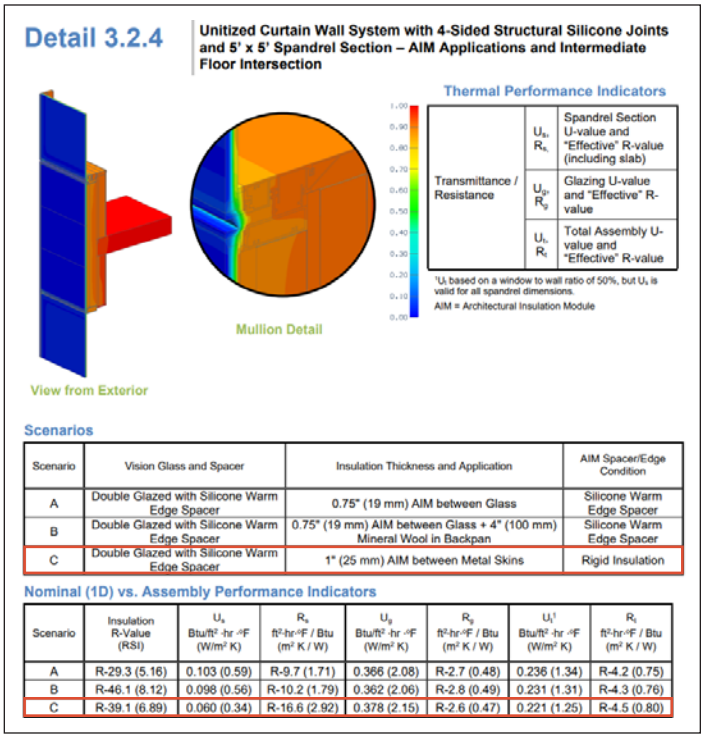


FIGURE 3. Three-dimensional modeling results of unitized curtain wall with architectural insulation module (vacuum-insulated panel). Data reproduced from Morrison Hershfield Ltd. (2014).

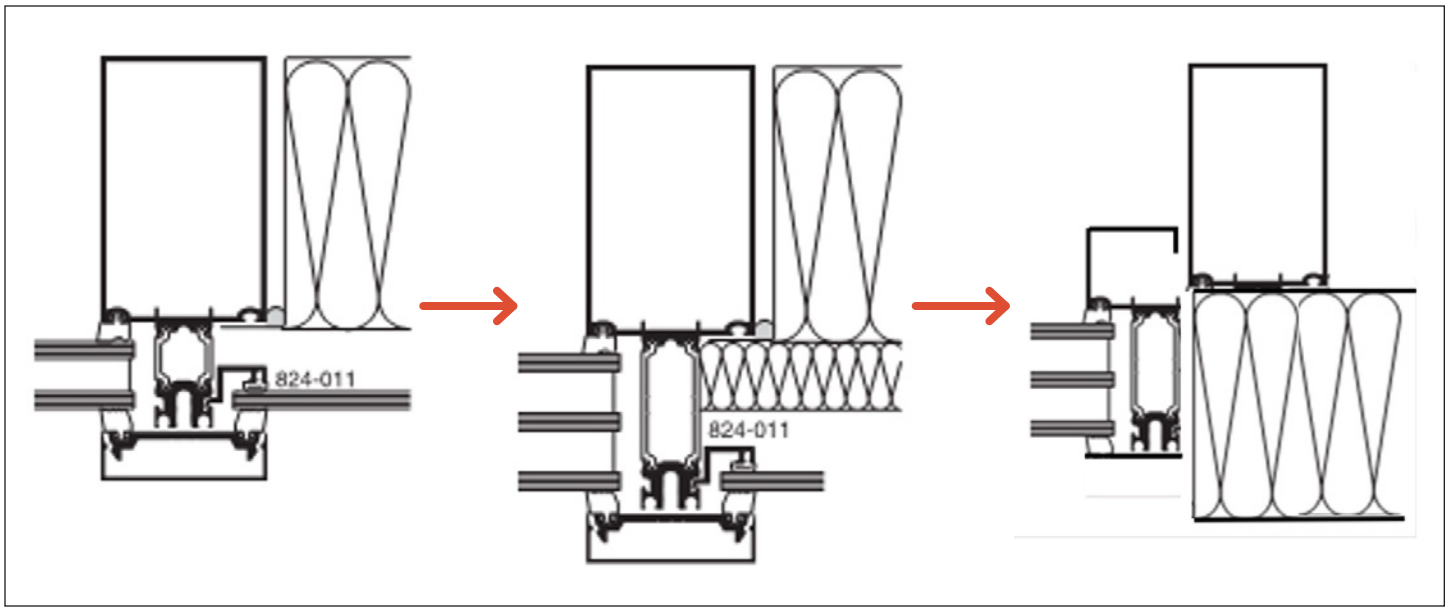


FIGURE 4. Evolution of insulation placement in unitized curtain wall system.

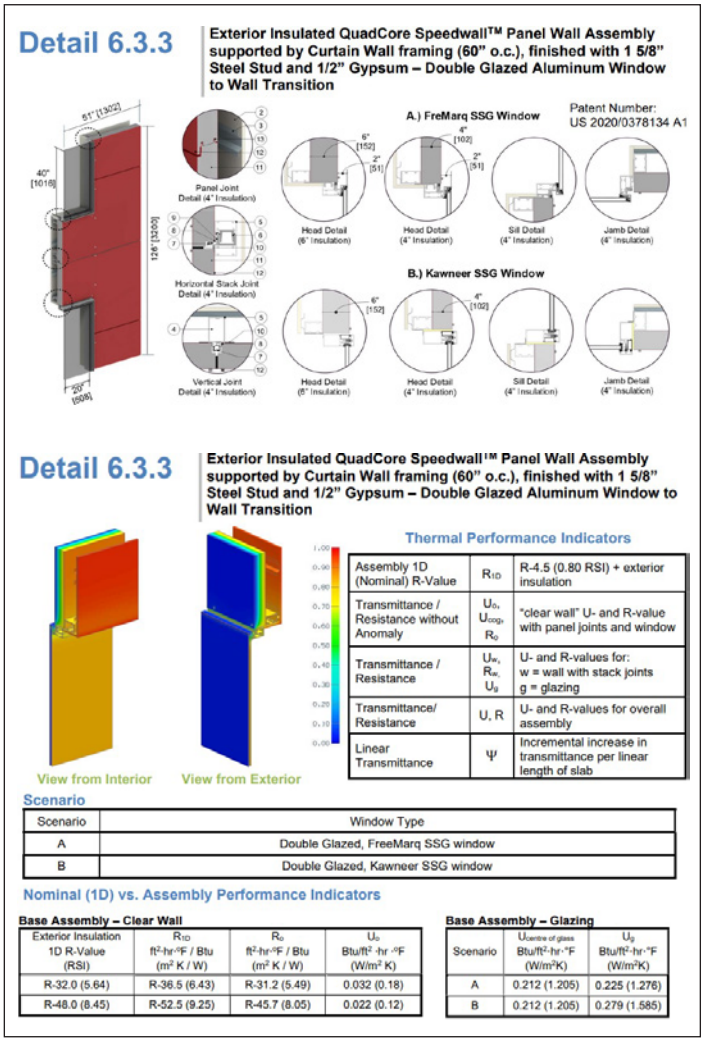


FIGURE 5. Example of exterior insulated facade system. Data reproduced from Morrison Hershfield Ltd. (2014).

The optimal continuous insulation placement in a unitized glazing system is the exterior of the framing, which also complies with the aforementioned IECC requirement. More recently developed glazing systems offer the possibility of maintaining continuous thermal insulation exterior to the framing system. This type of system is founded upon the same design principles of fully glazed facade systems, where the frame members are utilized as the carrier/chassis on which continuous insulation panels can be placed. Transparent glazing components also no longer have to be integrated into the mullions, but rather can be installed as an independent window system where the thermal break and the insulated glass units can be placed in the same plane as the continuous insulation panels. As an example of this type of system, a facade system that allows for 6-inch-thick insulated metal panel installed over the mullions with nominal system *R*-value of R-52.6 can yield an effective *R*-value of R-45.7 (derating of 13%), as per **Fig. 5**.[10]

CONCLUSION

The implementation of envelope backstop requirements in energy codes has the potential to significantly impact envelope design, especially for high-rise buildings. These new requirements place increased focus on building envelope thermal performance, necessitating innovative solutions. Incorporating continuous exterior insulation within unitized glazing systems is a promising alternative, but it adds complexities depending on the placement relative to the facade systems. With the newly updated energy code, this will require the continuous insulation outboard of the facade systems. The strict energy code drives innovation, leading to more resilient and sustainable building envelope designs. Ongoing efforts to refine these requirements will shape the future of energy-efficient building practices, reducing energy consumption and promoting environmental sustainability.

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REVIVING A HISTORIC LANDMARK: ASSESSMENT AND MONITORING OF "DETROIT'S LARGEST ART OBJECT," THE ICONIC FISHER BUILDING

ABSTRACT

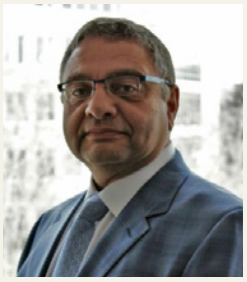
Restoring a national historic landmark that is considered a unique and exemplary piece of art deco architecture and an iconic beacon for the city of Detroit may seem a daunting task. Utilizing a combination of state-of-the-art, three-dimensional laser scanning (LiDAR) and traditional, hands-on examination techniques, the author developed a multipronged approach to understand the unique challenges facing the Fisher Building and develop a full restoration plan.

This article discusses the facade maintenance/restoration program of a 28-story building with a marble-clad exterior. It begins by providing an overview of the hands-on inspection and make-safe repairs that were performed at the building elevations. The second part of the article discusses how LiDAR technology has been employed to remotely monitor and detect movement by comparing laser scan data captured at six-month intervals.

LEARNING OBJECTIVES

- Detail how a large-scale hands-on facade inspection was performed with a summary of the lessons learned.
- Describe remediation techniques and the unique challenges encountered during the stabilization of this iconic marble-clad facade.
- Discuss the capabilities and limitations of LiDAR when utilized to remotely monitor a building facade.
- Examine the process of working within the standards for historic restoration.

SPEAKER



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Ziad Salameh, PhD, PE, principal-in-charge at ZS LLC (ZS), a multidisciplinary consulting engineering firm, brings more than 30 years of professional experience in the engineering and construction industry. Salameh is active in structural designs, structural failure investigations, building enclosure assessments, historic restoration, and laser scanning to building information modeling (BIM) technology. For the Fisher project, Salameh acted as the project executive and was responsible for the multiple assignments that ZS LLC was assigned for the project.

AUTHOR:

Ziad Salameh, PhD, PE

The Fisher Building, an iconic example of art deco architecture, stands as a National Historic Landmark and a symbol of Detroit's rich architectural heritage from the golden age of the automobile. Although it is often called Detroit's "largest art object", neglect and deferred repairs have taken a toll on its magnificent facade in recent years. In response, a new owner group has stepped forward, dedicated to the restoration of this architectural landmark. This article presents a summary of the findings and recommendations derived from a comprehensive facade assessment program, highlighting the utilization of LiDAR (light detection and ranging) technology in conjunction with high resolution photography to monitor facade movement.



FIGURE 1. The Fisher Building

OVERVIEW OF THE FISHER BUILDING COMPLEX

The Fisher Building complex encompasses a 30-story tower, two 11-story wing structures, the Fisher Theatre, and an attached parking structure. The complex as a whole encompasses an entire city block along Grand Avenue in the city's New Center district.

Each component within the complex possesses distinct structural framing and exterior wall construction. The tower and wings feature steel-framed and transition masonry walls. Steel framed/transition masonry walls consist of structural steel framed columns and spandrel beams that are fully encased with masonry construction or poured concrete. The inner wythes (backup) of the walls typically consist of brick masonry or extruded clay tile blocks that infill the plane of the main building structural system. The inner wythes are header bonded to each other (i.e. bonded masonry construction). The exterior wythe of the walls is supported by rolled steel shapes attached with lateral tie anchors into the inner wythes' construction.

The parking garage and theatre are composed of transition mass masonry walls. The parking garage exterior wall cladding varies along the elevations and consist mainly of either granite, stone ashlar/decorative cut units, or clay brick. The granite cladding is present at partial height of the first floor on the north elevation of the garage. The remaining garage elevations is clad with limestone, which turns the corner for a partial bay width on the west elevation. The remaining portion of the garage west elevation is primarily a solid brick wall. The Fisher Theater walls consist of granite-face brick for a partial height of the first floor of the west wall. The remainder of the west facade as well as the south and east facades are stone ashlar units with glazed brick features. The north facade is brick with the limestone from the west facade turning the corner for a small width.

EXTERIOR WALL COMPOSITION AND CLADDING MATERIALS

At the tower and wings, the walls' cladding (i.e. exterior wythe) type varies along the elevations and consists mainly of either marble, granite, or stone ashlar/decorative cut units. The granite cladding is mainly present on the first 3 floors. The remaining floors above are either clad with marble or limestone. All

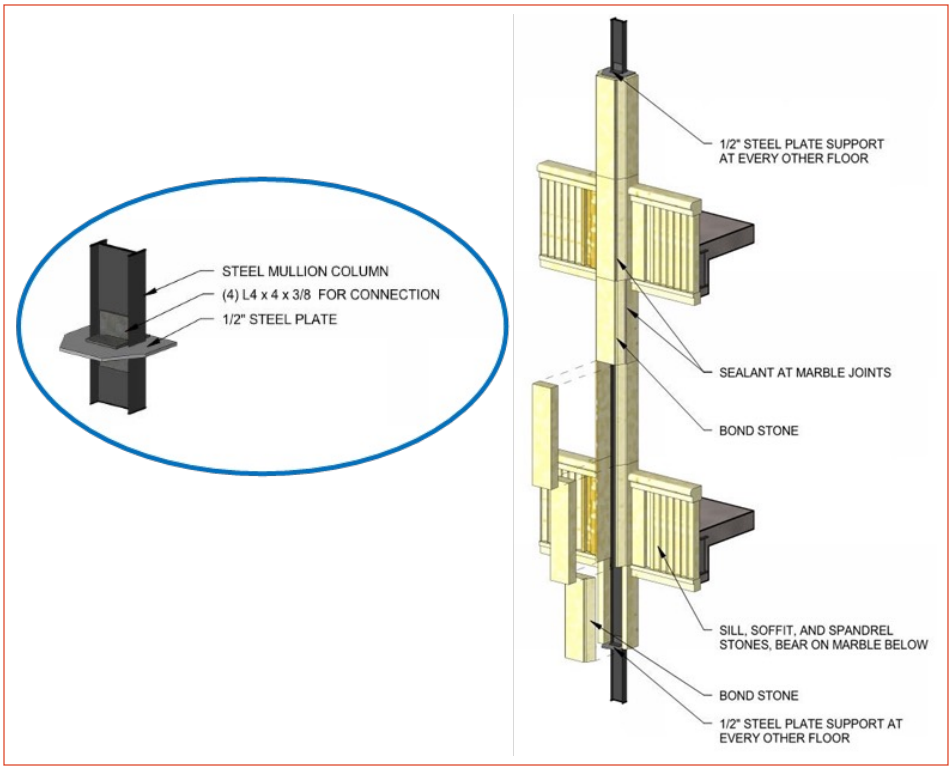


FIGURE 2. Exterior Walls Composition.

the walls are articulated with numerous changes in plane with the main feature being alternating mullions and piers of various depth, width, and articulation. Other main features include bronze statues, dentils, carved ornaments, various types of granite and marble insets, stone soffits, carved brackets, carved figures and metal spandrels.

The size and thickness of the ashlar/decorative cladding units varies significantly and include units that are as large as 5 feet x 5 feet x 24 inches thick to units as small as 16 inches x 16 inches x 3 inches thick. The exterior walls back-up construction consists of bonded clay brick/clay tile block construction or concrete encased framing. The marble, granite and stone cladding is gravity supported using embedded steel plates and shelf angels that are connected mechanically to the backup wall construction. In addition, the cladding is laterally tied to the backup wall construction using brass Z-shaped dowels at the marble and granite elevations and mild steel anchors/dowels at the stone elevations. Adorned with intricate marble cut details such as mullions, piers, statues, dentils, and carved ornaments, the facade exemplifies the meticulous craftsmanship of its era.

ASSESSMENT PROCESS

To evaluate the condition of the exterior walls, a combination of three-dimensional laser scanning, high-resolution photography, and hands-on examinations were employed. ZS' 3D laser scanning approach utilized a high speed, infrared laser (coupled with a high-resolution photography) to quickly obtain millions of three-dimensional measurements. The scans were then registered so that each individual scan is aligned within a group of scans to form a "point cloud." For this project, ZS generated a composite point cloud model that accurately depicted the as- built/as-existing conditions of all elevations. ZS then utilized the point cloud model to generate as-built elevation plans that depicted and quantified all observed exterior walls distress conditions. These same elevation plans will then be used in the future to prepare the repair construction documents. Additionally, through the use of the state-of-the-art scanner and supporting software, subsequent laser scan point clouds can be generated and utilized to perform facade monitoring via future plane deviation analysis for each exterior wall elevation. This analysis technique can detect out of plane movement as small as 1 inch and will enable remote monitoring and movement/displacement detection at areas of localized distress. The results of this analysis will then enable the owner to strategically prioritize and phase locations that require repairs.

ZS also performed a hands-on/close-up examination and condition documentation of a 60 foot wide by full building height area that is clad with marble and granite at the lower floors and located at the north end of the east wing. A swing stage was utilized for access at this location. The hands-on examination included sounding (i.e. hammer) testing to

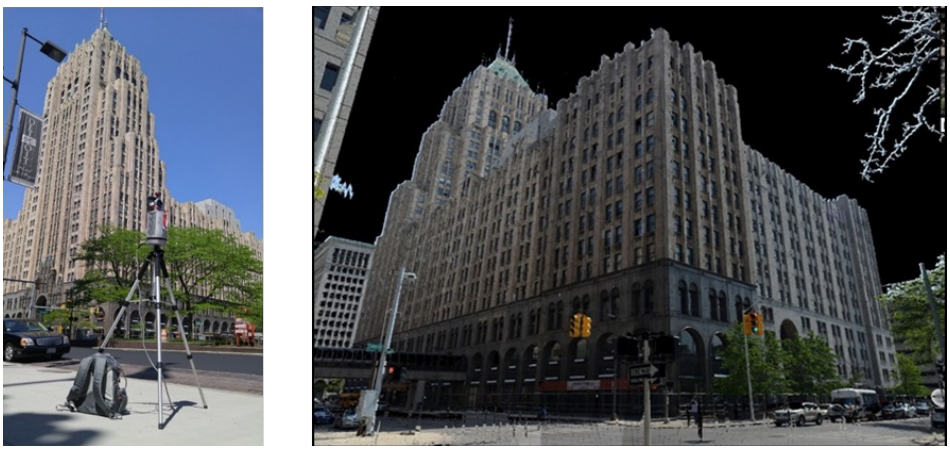


FIGURE 3. Laser Scanning utilized during assessment.

determine loose/delaminated material, sample measurements of level/plumb, and inspection of joints and connections at each level at different areas of the building elevation. A rappelling subcontractor was utilized for performing a hands-on/close-up examination and condition documentation of 2-15 feet wide by full building height area that is clad with marble and located at the south east corner of the tower. Originally the rappelling access was planned at 6 more additional tower locations, however, the activities of a pair of Peregrine Falcons that have a nest with fledglings — located behind a bronze sculpture at the 5th level above the south elevation main entrance door — endangered the rappelling personal and resulted in ending the hands-on examination of the tower structure. It is important to note that the presence of the falcons and their endangered species status must be considered in planning and scheduling all exterior wall restoration efforts. ZS also performed three invasive wall examination openings to examine and document the condition of the exterior wall backup construction.

ASSESSMENT FINDINGS

The comprehensive assessment uncovered various types of distress and classifications for each cladding material. These distresses included damaged/spalled units, failed repaired units, unsafe/ready-to-fall units, displaced units, cracked units, deteriorated coping units, failed mortar joints, failed sealant joints, unsafe cladding and supports at bronze sculptures, and deteriorated brick-clad areas. The extent and severity of these issues were meticulously documented on as-built facade elevations, created from laser scans and converted into digital twins using Scan to BIM (building information modeling) technology.

The distresses observed and documented included, but were not limited to, the following:

- Previously replaced marble ashlar units with matching marble units.
- Temporary stabilized/anchored marble and limestone units. Five temporary repair details were observed as follows:
  - A strapping technique using steel wires, wood blocking, turn buckles and round eye anchor rods.
  - Steel anchor rods that are drilled into the face of a displaced unit and grouted in place.
  - Bent steel plates or shelf angles placed at the sides of a displaced unit and anchored with bolts to adjacent units.
  - Plywood sheets anchored into the wall back-up construction at the north elevation at a location where two stone units have been removed.
  - Netting anchored into adjacent units.

  The previous repair records did not reveal when these measures were installed, however, most of the measures appear to be more than 10 years old. Additionally, there are no engineering design or detailing records available to review the load capacity or predict the useful life of the installed temporary repairs.
- Damaged/spalled marble/limestone/granite units.
- Previously repaired damaged/spalled marble/limestone/granite units.
- Unsafe/ready to fall damaged/spalled marble/limestone/granite/brick units. The observed unsafe damaged/spalled units and areas are occurring at locations that are in direct contact with (or near) embedded steel elements which indicate that the damage was primarily caused by corrosion of embedded steel. To protect the public, building users, and pedestrian traffic from the falling hazard of these units and areas, the owner has erected a pedestrian protection canopy along the building street facing elevations.
- Displaced/out of plane movement at marble/limestone/granite/brick units. The majority of the displaced units are located near embedded steel units and exhibited signs of active movement (i.e. split open vertical sealant joints, visible out-of-plane movement and plane deviation).
- Low severity cracked marble and limestone units.
- Unsafe/ready to fall cracked marble and limestone units.
- Deteriorated/damaged/displaced marble/limestone coping units.



FIGURE 4. Examples of Cladding Distress Observed.

- Deteriorated/failed mortar joints repaired with multiple layers of sealant/caulk products.
- Unsafe/damaged cladding and supports at bronze sculptures.
- Unsafe deteriorated brick cladded areas.

CAUSES OF DAMAGE AND INSTABILITY

The observed damage and instability of the facade cladding primarily resulted from the corrosion of embedded steel elements, such as shelf angles and tie anchors. Furthermore, previous improper repair campaigns, including inadequate patching, incorrect removal of spalls, anchoring unstable damaged cladding with mild steel supports, and the improper application of sealant to repair cracks or mortar joints, contributed significantly to the ongoing deterioration.

RECOMMENDATIONS FOR RESTORATION

The assessment report proposed a comprehensive make-safe campaign, involving a yearly 100% hands-on inspection to remove or stabilize damaged cladding areas. This included hammer sounding and removal of all ready-to-fall masonry pieces and spalls, installation of engineered netting systems at displaced and cracked units, and installation of engineered shoring systems at projecting elements. In addition to the locations identified by examination of the laser scan point cloud, ZS engineers marked the locations of all new make-safe measures on building elevation sheets in real time during hands-on inspections. These elevation sheets created from the point cloud served as a record of work for construction crews with easily verifiable locations and extents. Final certification inspection was performed using these sheets for comparison.

Additionally, ZS recommended semiannual laser scanning of the cladding to detect out-of-plane movement using point cloud–to–point cloud analysis. The initial laser scans have been archived as a baseline model to serve as a point of comparison. Through the use of state-of-the-art scanner and supporting software, subsequent laser scan point clouds can be generated and utilized to perform cloud-to-cloud deviation analysis for each exterior wall elevation. This analysis technique uses software that automatically colors the new point cloud data using the least squares method based on the distance from the prior cloud data. Subsequent scans will reveal significant local movement in the building street facades. Any new critical repairs can thus be identified and performed in a timely manner. The recommended repair schedule and exterior wall classification can also be continually evaluated and adjusted during the planning phase for long term repairs.

A phased restoration effort was suggested to address the distresses and ensure the long-term preservation of the Fisher Building's exterior walls. The integration of advanced scanning technology with hands-on examinations provided invaluable data for the formulation of long term restoration plans. The primary repair construction elements recommended for permanent repairs include the following:

1. At select damaged/spalled/cracked/displaced cladding locations along all elevations of the building, and as directed by engineer, perform the following:
   a. Carefully remove and salvage the cladding units/areas as necessary to expose the embedded supporting steel elements (i.e. plates and shelf angles).
   b. Replace unsalvageable embedded support elements with corrosion resistant steel elements and install waterproofing/through-wall

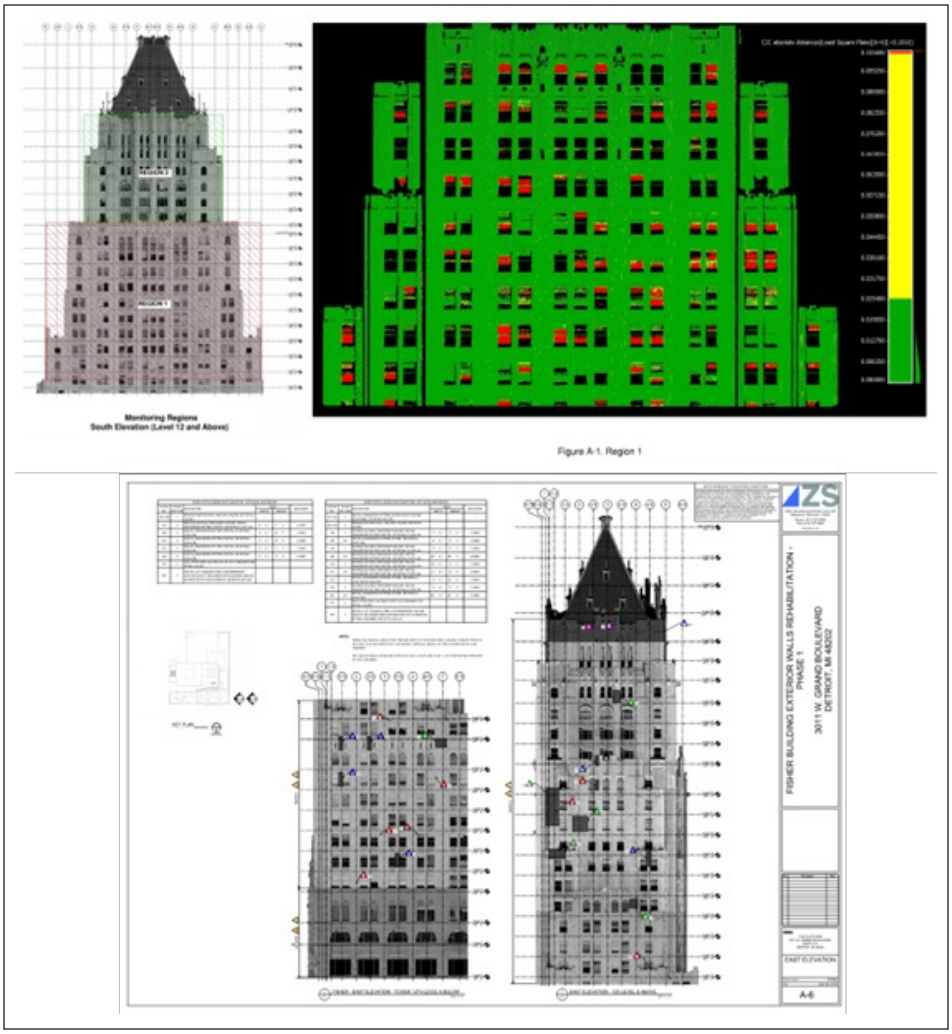


FIGURE 5. Laser Scanning Monitoring Plots.

flashing where required and as directed by engineer.

c Clean, repair, prepare and paint all salvageable steel elements and install waterproofing/through-wall flashing where required and as directed by engineer.

d Reinstall salvaged cladding units with corrosion resistant lateral ties/anchors.

e Replace unsalvageable cladding units with matching units.

2. Remove sealant installed at all marble and granite mortar joints. Grind and tuckpoint the joints with new mortar.
3. Grind and tuckpoint deteriorated mortar joints at select areas at all elevation as directed by engineer.
4. Remove, salvage and reinstall select coping units at all elevations. Reinstall the coping units with new engineered stainless steel anchors and copper flashings.
5. Rebuild localized areas of brick wall construction with matching brick units in color and size and stainless steel lateral ties and as directed by engineer. Where exposed, replace embedded support steel shelf angles with corrosion resistant steel elements and install waterproofing/through-wall flashing where required and as directed by engineer.

Performing this phase repairs completely, should give the building exterior walls up to 50 years of additional life, excluding the windows, and assuming proper maintenance.

CONCLUSION

By adhering to the recommendations put forth by the comprehensive facade assessment program, the new owner group can embark on a journey to restore the Fisher Building to its former grandeur. With a meticulous approach to addressing the identified issues and implementing appropriate rehabilitation measures, this architectural masterpiece can continue to serve as a cherished symbol of Detroit's grandeur and a tangible vision of the Motor City's storied history.

LESSONS LEARNED FROM BUILDING ENCLOSURE DELEGATED DESIGN DISASTERS

ABSTRACT

With the evolution of the building enclosure and construction practices, building design is demanding higher-performing, well-coordinated, effective, and efficient implementation from their waterproofing, facade, fenestration, and roofing systems. For new construction, many modern enclosures may include delegated designs to a specialty trade that is not a part of or under the responsibility of the building's design team. Existing buildings are being reimagined and updated for modern use, often including significant modifications to the enclosure "skin" on the existing structure "bones". Both new and adapted existing buildings present challenges for the design professional to ensure that the enclosure design is properly executed and coordinated with the building structure when the building is in service.[1]

This paper and presentation will review the types of building enclosure systems and related components impacted by delegated designs or significant existing building enclosure modifications. Case studies (from the authors' personal experience) for unitized curtainwall, architectural precast concrete, and reroof or roof adaptations will be reviewed. Finally, recommendations for inclusion into building enclosure design will be provided to mitigate risks associated with delegated design and related design coordination of building enclosure systems.

LEARNING OBJECTIVES

- Review the types of delegated design systems and related performance requirements.
- Analyze the limitations of a delegated designer's responsibility and the associated risks.
- Discuss the lessons learned resulting from delegated design deficiencies and impact field deviations.
- Assess the project scope and design provisions that help mitigate potential delegated design issues.

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Amy Peevey, PE, REWC, RRO, CDT, is a building enclosure engineer with over 24 years of experience in the new design, investigation/evaluation, and restoration of building envelope systems and related structural components. She is a registered professional engineer who provides project advisory and expert litigation support for below-grade and plaza waterproofing, cladding, fenestration, roofing systems, and related structural components. She is a seasoned presenter and published member of several technical trade associations and an active contributor to the building enclosure community. Peevey is the current IIBEC president on the Executive Committee.

AUTHORS:

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INTRODUCTION

As a means of achieving higher quality control, expedited installation, and adapting buildings for their next phase of use, more and more building enclosure systems are prefabricated and consolidated, and their designs require higher performance than ever before. Simply put, the building enclosure is no longer simply keeping water (liquid and vapor) out and achieving the overall exterior aesthetic while other systems manage the thermal, structural, and hygrothermal aspects of the overall building performance. The modern building enclosure has evolved into a complex design that not only manages and transfers structural loads while accommodating the permanent and dynamic main frame structural and thermal movements. The enclosure systems are also controlling the transfer of water vapor, managing liquid water, achieving the thermal performance to ensure occupant safety and comfort, all whilst providing an aesthetically beautiful, sustainable, and durable building enclosure.

For complex building enclosure systems, their overall design is often delegated to trades with specialized expertise and is typically performed under the trade responsible for their installation.[2] Common delegated-design systems include architectural precast panels, curtainwall systems, dimension stone cladding, metal or composite wall panels, fabric membrane roof systems, panelized roof systems, green/blue/purpose roof systems, etc. As the delegated design is independent from the coordinated building design that is performed under the supervision of the Designer-of-Record (DOR), the DOR does not assume the responsibility of the proper integration of the system's design with other systems of the building. Therefore, the system's delegated design is responsible for the integration with the other building systems. In most jurisdictions, only a portion of the actual delegated design requires a licensed design professional. As a result, an engineer contracted under the specialty trade typically provides structural design, which includes thermal and other movement accommodations. However, the other performance requirements, such as water-penetration and air-infiltration management, hurricane resistance, and specialty performance (such as fire, flood, and blast protection), are not the responsibility of a licensed professional. Instead, system performance testing (manufacturer or project specific) is compared to the performance requirements established by the building's DOR, and if it meets or exceeds them, then the system is accepted for incorporation into the building design.[3]

Herein lies a fatal flaw. Ultimately, the system's delegated design does not have a licensed professional responsible for its overall performance. The delegated-design engineer is typically only responsible for a portion of the system's design; however, the entire system's performance is critical to the health and safety of the occupants and the public.[4] In addition, the trade responsible for efficient and effective system installation to achieve the project cost and schedule is also responsible for the system's design, resulting in a conflict of interest and requiring additional design coordination. Further, modification of a tested standard system or customization of a tested fabrication/installation that deviates from the standard means and methods must be vetted to understand possible impact on the system's previously tested performance. If system customizations and modified means and methods are not integrated within the delegated design, then there can be significant consequences, the direst of which are structurally unstable systems or systems that don't meet the DOR's design requirements. This paper discusses the complexity of modern building enclosure design and the possible problems resulting from complex delegated designs and their increased expectations for installation and performance through a series of case studies from the authors' personal experience.

CASE STUDY 1

Located in Texas, this building is a 32-story luxury residential high-rise with a concrete-framed structure containing 274 apartments. To meet an accelerated project schedule, prefabrication was considered for the building cladding and fenestration systems. As it was not feasible to prefabricate the traditional brick cavity wall veneer required for construction in the historic district where the building was located, the decision was made to prefabricate the exterior cold-formed metal stud (CFMS) framed walls, exterior sheathing, and air barrier, as well as the punched windows and window-wall systems. Therefore, once the prefabricated exterior backup walls and fenestrations were in place, the building would be dried in to accelerate the finish-out process.[5] However, as the delegated design of each prefabricated system was left to its respective team (the curtainwall contractor and the

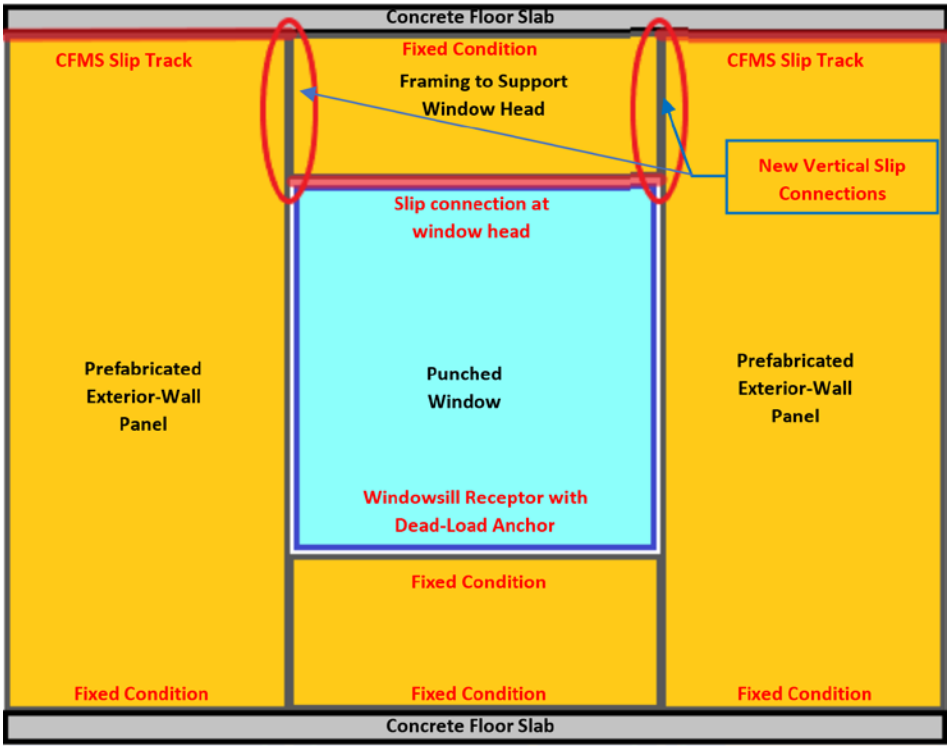


FIGURE 1. Configuration of typical premanufactured exterior wall framing panel and punched windowbetween floor lines with resulting unresolved vertical differential movements (circled).

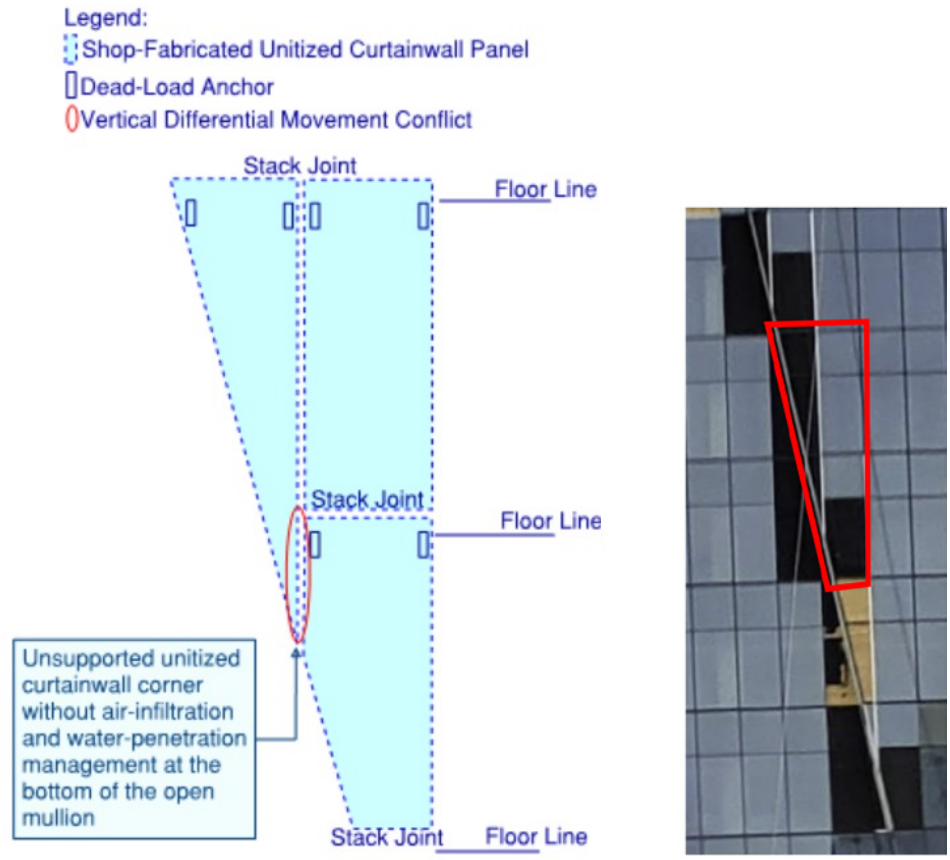


FIGURE 2. Unitized curtainwall panelization layout on the left showing a triangular panel bypassing the floor line where the typical panel stack joint accommodates the installation tolerance and movements (see the resulting movement conflict along the two-part mullion circled). Photograph of the missing bypass panel on the right.

framing contractor), there was a lack of coordination that resulted in conflicts related to system performance and ultimately caused schedule delays for the project. Both the prefabricated exterior walls and fenestration systems were designed to accommodate movement as well as construction installation tolerance with movement joints along each floor line. The premanufactured framed exterior-wall panels (**Fig. 1**) were designed to fit between the floor lines with allowance for movement and construction tolerance at the head condition. For the punched windows, the same provisions were provided at the window heads. As the premanufactured components were submitted as two separate submittals, it was not apparent that the provisions for each conflicted with one another and resulted in a design issue that was not discovered until installation was underway. Specifically, it became apparent that to achieve proper load transfer from the punched windows, the framing supporting the window head required anchorage to the base of the overlying slab. However, the adjacent exterior-wall framing at each side was supported at the slab below. As a result, there was no provision for movement between the prefabrication framed panels and the framing supporting the window heads. To address the resulting movement between the two locations within each level, a new vertical slip joint at each side of the window head framing was required (circled in **Fig. 1**). The resulting redesign and rework to accommodate the coordination oversight between the adjacent systems caused increased project costs and schedule delays. This first case study provides an example of how independent delegated designs require proper integration to ensure the overall building enclosure performance.

CASE STUDY 2

This is a 19-story Class A office building in Texas, constructed as a part of a master-planned business district which includes aluminum and glass curtainwalls, metal panels, and architectural precast-concrete cladding systems with a signature angled feature on each building. The new tower consists of a concrete-framed

structure clad with a unitized curtainwall system and metal wall panel accents, with an attached parking garage clad with architectural precast-concrete panels. The signature angled accents on three elevations are outset from the building face and supported by concrete framing and supplemental steel. The unitized curtainwall was a standard system by a large manufacturer that was customized to achieve the angled accent features and was modified by the installer for field-erection means and methods. The design was delegated to the curtainwall installer who retained an engineer to perform the structural design for the system. The engineer reviewed the curtainwall system shop drawings produced by the curtainwall installer to provide the associated framing and connection design. No fabrication or erection drawings were provided to the engineer. However, the curtainwall installer intended to splice adjacent units together side by side and across floor lines to achieve their desired panel erection layout. The result was unsupported/discontinuous triangular units that were omitted from the delegated design and were not coordinated with the adjacent components, supporting structure, building movements, and thermal expansion/contraction (**Fig. 2**) to achieve the project requirements. In addition, twin-span units were fabricated under the direction of the curtainwall installer to address constructability issues but were also omitted from the delegated design. Finally, the building design included entrance canopies, balconies, a garden roof plaza, and other horizontally intersecting features through the curtainwall. Like Case Study 1, floor-to-floor movements and thermal expansion/contraction changed between adjacent floor slabs at and adjacent to these features, resulting in conflicts for the continuity of vertical displacement between floor lines.

Other consequences resulted from the separation of the delegated design from the design team to that of the installer. The triangular glass units along the angled building features were not coordinated with the glass manufacturer's minimum dimensional production requirements. As a result,

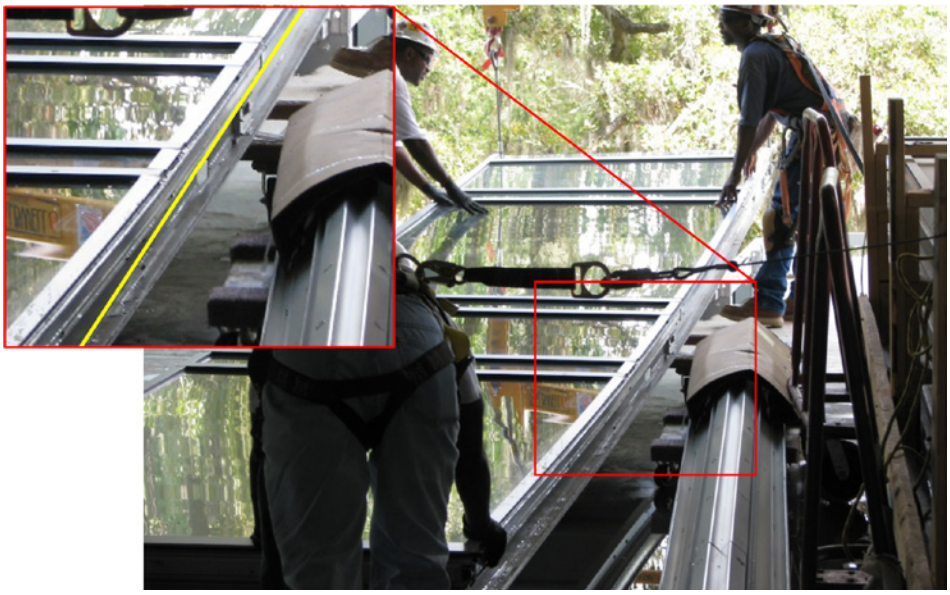


FIGURE 3. Excessive deflection of twin-span unitized curtainwall during erection.

metal panels were utilized in lieu of glazing, which significantly impacted the overall building aesthetic along the signature angled features of the building facade. Also, the cut framing elements at the triangular units resulted in open and discontinuous framing intersections that did not conform to the manufacturer's tested curtainwall assembly for air-infiltration and water-penetration management of the standard curtainwall system. Finally, where the triangular panels were spliced to panels at the overlying or underlying floor, the triangular panel was laterally unsupported and obstructed the adjacent continuous stack joint's movement and drainage above the floor line.

Finally, the engineering requirements for the maximum framing spans, cantilevered framing distances, connection requirements, and fastener requirements were not coordinated between the engineered calculations and the field installation. As a result, following curtainwall installation, every framing span/cantilever, connection, and anchor required inspection for the entire project. Subsequently, many conditions were outside of the tolerance of the engineering requirements and required field modifications.

The delegated-design engineer was solely focused on the structural performance of the curtainwall without an understanding of the unit fabrication and erection layout, building features, and the corresponding structural movements and thermal expansion/contraction. Additionally, because the installer failed to coordinate between the installation and engineering requirements, field conditions did not meet the engineering requirements. Extensive repair design and field alterations were required to remediate the curtainwall system, which led to significant project cost and schedule overruns. This resulted in an unvetted, custom system that no longer resembled the standardized manufacturer system (that met the project requirements), and the curtainwall aesthetics did not meet the architect's and owner's desired intent for an integrated aesthetic of the master-planned business district. This case study serves as an example that delegated designers are responsible for the overall system design. The lack of coordination between the installer and its delegated designer can result in design deficiencies and construction defects that fail to meet the design intent.

SAMPLE STUDY 1: TRANSPORT AND INSTALLATION

In addition to design considerations for shop fabrication and field installation, the process of transportation, handling, and erection may also impact the delegated design of prefabricated

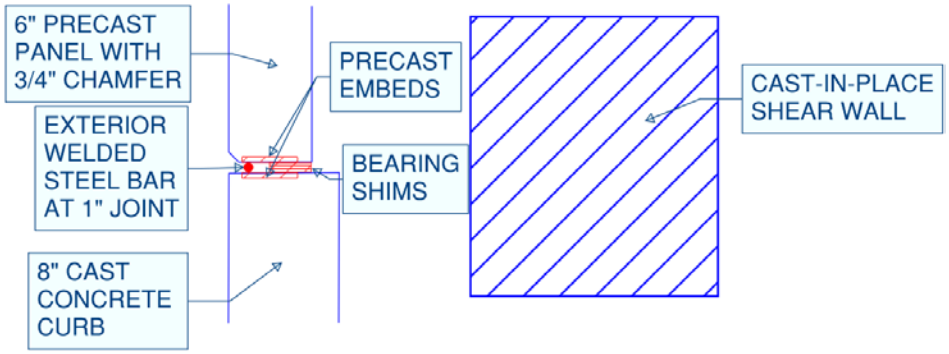


FIGURE 4. Excessive deflection of twin-span unitized curtainwall during erection.

building enclosure systems. For example, twin-span precast unitized curtainwall undergoes significant loading during transport and erection (**Fig. 3**). These loads can result in excessive deflections that can cause permanent deformation or breakage of the unit's components.

For architectural precast concrete and other large unitized components (such as mega panels), the engineered panel size and layout must be coordinated with the erection methods, including crane capacity. Crane weight limitations may limit panel shapes and sizes, which can impact the overall aesthetic; therefore, coordination is necessary before the finalization of the delegated design. Another aspect commonly requiring delegated-design coordination is for installation of other adjacent systems. For example, large structural elements such as continuous concrete shear walls that bypass several floor and column lines will obstruct access for installation of the interior continuous-insulation and air-barrier systems. Also, the placement of panel structural connections should undergo review prior to finalizing the delegated design. Often, the delegated designer is more focused on the constructability and structural performance of the system and less concerned with the impact on the air- and water-management performance. Therefore, if not coordinated properly, flashing or integration between systems may be negatively impacted. A common example is with perimeter dual-joint sealants that are obstructed or discontinuous as a result of structural embed or connection placement. These examples illustrate that while delegate designers are not part of the design team, their designs still require coordination with the overall design.

SAMPLE STUDY 2 – ROOF DECKS

During standard planned reroofing operations of a major hospital campus in the Texas Medical Center, review of the existing roof deck confirmed that while the new roof system was a manufacturer-tested assembly complying with the latest code-required wind-uplift pressures, the existing roof deck, which had been in place for over 50 years, was unable to meet the same requirements. Further engineering review confirmed that the metal roof decks throughout the campus required significant modification to accommodate the increased uplift capacity of modern codes; however, many of the roofs had already undergone replacement in the recent past. As a result, retrofit of the existing roofs at metal roof deck locations was required to enhance the roof deck capacity at corner and sometimes perimeter zones. On another Texas Medical Center reroof project, an evaluation for the removal of abandoned rooftop equipment confirmed that the incorporation of so many rooftop penetrations had compromised the shear diaphragm capacity of the roof deck. The evaluation also revealed significant areas of roof deck corrosion requiring replacement. The result was complete roof deck replacement and additional support at corner and perimeter zones, significantly impacting the overall project scope, budget, schedule, and hospital operations. These projects serve as a lesson learned that routine maintenance should include an engineer review to ensure that the roof deck or components supporting the roof system are able to meet the increased demands of modern building codes (and insurance requirements).

RECOMMENDATIONS

The following provisions, when properly coordinated and integrated with the project scope, have proven successful to mitigating delegated-design disasters.

1. Include building envelope commissioning within the project scope from the conceptual design phase forward.
2. Incorporate specialty engineering design peer review for complex building enclosure delegated designs.
3. Perform third-party special inspections at the fabrication facility and in the field to support installer quality control and quality assurance (if not already required by the authority having jurisdiction).

Incorporate the following project requirements to ensure that the delegated design is comprehensive and coordinated with the other project requirements.

1. **Loads:** In addition to dead, wind, seismic, and other project-in-service loads, include the following:
   - a. Transport- and erection-load analysis reflecting dynamic transport and erection methods
   - b. Maintenance loads including at intermittent stabilization anchors and along horizontal projecting elements (such as sunshades)
   - c. Sufficient load transfer and accommodation of movement across movement/expansion joints
   - d. Inclusion of associated requirements, such as those for supplemental framing
2. **Delegated-design engineering package:** Professional engineer–sealed, coordinated, and comprehensive set including structural calculations (framing, glazing, and structural-sealant glazing), shop-fabrication drawings and instruction, and field-elevation panelized layout and installation

instructions. The field-elevation panelized layout should include the outline of each panel (single span, twin span, spliced-multiple wide units, etc.), dead-load and live-load anchor locations, clear indication for each starter and stack joint locations, etc.).

3. **Delegated-design requirements:** Coordination with other performance requirements, including but not limited to the following:
   a. Structural-engineering movements (creep, dead loads, live loads, etc.)
   b. Structural-engineering or wind-tunnel components and cladding pressures
   c. Review of complete and final delegated design to ensure system meets specified requirements (water management, air management, thermal, energy, fire, sound, etc.).
   d. For existing buildings, confirmation of as-built construction with updated code-required loads and associated requirements (area of openings, projectile risk, increased loads/pressures, etc.)
4. **Manufacturer's certification letter:** Project-specific letter from the manufacturer (framing, glazing/infill system, structural-sealant glazing, etc.) certifying their review of the delegated-design engineering package to ensure that the system will meet the specified project requirements.
5. **Site-inspection requirements for existing buildings:**
   a. Confirmation of as-built construction
   b. Confirmation of existing conditions (distress, damage, etc.)
   c. Evaluation of as-built, existing capacity and coordination with requirements (including additional requirements such as shear diaphragm, shear walls, etc.)

Finally, during construction, include the following provisions.

1. **Delegated-design meeting(s):** Between the delegated-design team (specialty trade/installer and their engineer), owner, general contractor, structural engineer, architect, building enclosure consultant (prior to fabrication), and related manufacturers.
2. **Field-erection set:** Provide a set of field-installation/erection drawings that include the actual layout, dimensions, spans, anchor types, anchor requirements. The set should include the following:
   a. Maximum spans and cantilever framing lengths (anchor to stack/parapet/soffit hang-down, etc.) per system type/component type
   b. Connection requirements, including maximum eccentricity (of anchors/hooks), maximum shim depth/height, etc., for each connection and/or anchor (embedded versus field installed) type
   c. Fastener requirements, including minimum edge distances, minimum embedment depths, required torque, minimum thread engagement, etc.
   d. Allowable field modifications (such as cutting of lifting lugs) to accommodate setting of units
3. **Quality control and quality assurance:** Pre-fabrication laboratory performance mockup testing for custom or modified standard systems:
   a. Shop-fabrication inspections, including compliance with manufacturer's requirements
   b. Field verification of structural dimensions prior to installation (spans, embed locations, etc.)
   c. Pre-setting inspection of units (for proper unit fabrication and confirming no damage)
   d. Post-setting inspection of units (for proper integration between units, stack/starter seal installation, etc.)
   e. Fastener inspections to ensure compliance with requirements
   f. Field air-infiltration and water-penetration testing
4. **As-built set:** Provide as-built record set, including all field fixes and supporting documents.

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THROUGH THE LENS OF TIME: A LONGITUDINAL REVIEW OF ENERGY EFFICIENCY

ABSTRACT

In the last few decades, many studies have been conducted on ways to achieve sustainable building enclosures. A thorough literature review was conducted of 77 studies to document the solar reflectance and albedo effect on energy efficiency for various types of roofs. This study offers a valuable resource about how roofing systems affect the energy efficiency of buildings. It also provides insight into other study parameters to evaluate when considering the impact of roofing systems on energy efficiency and suggests areas for future research.

LEARNING OBJECTIVES

- Assess the impact of increasing reflectance and albedo value of roofing membranes on energy efficiency and energy savings.
- Assess energy efficiency impacts in differing regions and how roof assembly design impacts design decision-making in various climatic regions.
- Recognize the role of investigation on life-cycle analysis and how the roof design impacts the calculations of energy savings in dollar value.
- Apply the study's findings in the decision-making for the design of the building enclosure to achieve long-term sustainability goals.

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The United Nations' *Sustainable Development Report 2022*[1] ranks the United States 41st out of 163 nations based on the 2022 SDG Index Rating Score of 74.6 (SDG Index is an assessment of the country's overall performance on the 17 Sustainable Development Goals, giving equal weight to each goal). The country that was ranked first had a score of 86.5 whereas the country that was ranked 163rd had a score of 39. This report emphasizes the significance of having a sustainable building enclosure as a goal and area for progress for sustainable cities and communities.[1] The building sector has a detrimental influence on the environment since it is the biggest user of raw resources and waste production.[2] For example, nearly 40% of the total energy used in the United States is used by residential and commercial buildings with both low-slope and steep slope roofs.[3]

The energy used during the operation and maintenance of buildings includes the energy required for lighting, heating, cooling, and ventilation systems, as well as the energy used by electronics, appliances, and other equipment. Strategies to decrease energy consumption include improvements to building insulation, effective heating and cooling systems, and efficient building enclosures. According to Costanzo et al.,[4] roofs comprise 20% to 25% of building surfaces in urban settings. Furthermore, roof systems are essential for a building's thermal performance because they can account for up to 50% of the structure's overall thermal load.[5] Modifications to the roof's surface such as coating the roof surface to change the albedo value and the use of materials that alter the reflectance of the roof's surface are some of the ways to improve the energy efficiency of building enclosures.[6]

Key factors in the energy efficiency of roofing systems are solar reflectance and albedo. Solar reflectance is the roofing system's ability to reflect solar energy into the atmosphere and is measured using the Solar Reflectance Index (SRI) on a scale from 0 to 100. ASTM E1980-11 standards state that SRI = 100 for standard white surface and SRI = 0 for a standard black surface.[7] In this study, the terms solar reflectance and solar reflectance index have been used interchangeably. Albedo is the percentage of incident radiation reflected off a surface (such as the surface of a roof).[8] The building's temperature will rise as the building absorbs solar radiation that the roofing system does not reflect. A surface with an albedo value of 0 absorbs 100% of solar radiation, whereas a surface with an albedo value of 1 absorbs 0% of solar radiation.

To assess how changes in the solar reflectance and albedo of roofing systems affect energy efficiency, we collected and analyzed data from relevant studies published from 1990 to 2019. The goals of this study were to (a) conduct a systematic literature review of studies documenting the impact of a roofing membrane's solar reflectance and albedo on a building's energy efficiency; (b) synthesize the data and findings from the various studies; and (c) suggest areas where further research is warranted.

METHODOLOGY

A systematic literature review entails conducting a thorough search to find pertinent material. Databases, journals, conference proceedings, and other sources can be used in this type of review. In this study, we initially identified literature published between 1990 and 2019 with the following keywords: roof, energy efficiency, temperature, albedo, reflectance, and insulation. To narrow these results, we then followed up with content and comparative analysis, in which we used various approaches to search dedicated words and word associations, such as narrative summary, content analysis, case, survey, and comparative analyses.[9]

Table 1 shows the results of a search that was run on 12 databases using the keywords and their Boolean logic combinations to identify potentially relevant publications across various databases.[9, 10] This initial search retrieved 1,691 articles. **Table 2** summarizes the process for selecting the relevant articles. The inclusion criteria were (a) only peer-reviewed publications; (b) articles with data on various types of roofing systems and the impact of system type on energy efficiency as measured by cooling/heating energy usage, dollar savings, and temperature reductions; (3) cases from anywhere in the world; and (4) authenticity of the source.[11] Studies either compared the same type of roofing system for different locations or compared the same type of roofing system for varying albedo and reflectance values.

The factors that were extracted from the literature review included

TABLE 1. Search results and database keywords.

Database	No. of articles found	No. of papers included in review
Engineering Village	178	12
ProQuest	287	3
ACM [Association for Computing Machinery] Digital Library	1	0
Web of Science	234	7
Business Source Complete	20	2
Academic Search Complete	97	10
Springer Link	172	2
Institute of Electrical and Electronics Engineers	32	1
Wiley Online Library	71	2
Office of Scientific and Technical Information	121	5
Clemson Library	313	27
Other sources	165	6
Total	**1,691**	**77**

TABLE 2. Selection of relevant articles.

Step	Results
Step 1: Initial identification based on keywords	1,691 articles identified
Step 2: Refinement of selection based on inclusion criteria and study design	747 articles selected
Step 3: Review of articles and abstracts to identify articles relevant to the aims of the literature review	325 articles eligible
Step 4: Review of articles that include the effect of roofing systems on energy efficiency in the main body	77 articles included

TABLE 3. Search results and database keywords.

Location	Climates	Sample size for low-slope roofs	Sample size for steep-slope roofs	Total Sample Size
United States	Temperate, subtropical	202	65	267
Asia	Temperate, subtropical, subequatorial	79	15	94
Europe	Temperate, subtropical	64	27	91
Other	Tropical, subtropical, equatorial, subequatorial	50	36	86
TOTAL		**395**	**143**	**538**

the sample size (number of roofs investigated), study locations and climates, the albedo of the roof membranes, the solar reflectance of the roof membranes, the types of roofing systems, relative energy savings from an original roof versus a modified roof, study limitations, and conclusions.

The sample size discussed in **Table 3**, representing the individual instances of roofs included in the studies was 538, of which 395 were low-slope roofs and 143 were steep-slope roofs. 52% of the sample size evaluated existing roof membranes that were coated afterwards. In comparison, 19% measured the effect of change in the albedo value of the roof by applying a coating or modification to the membrane. 12% of the studies documented the effect of change in insulation, while 9% recorded baseline cases comparing different types of roofs. The distribution of studies across the climatic zones is listed in **Table 3**.

Albedo and solar reflectance values of the original roof and of the modified roof were documented. Energy efficiency is defined as the percentage change in energy usage between the original roof and the modified roof. The charts were then plotted using the above-recorded data points to interpret the relationship between solar reflectance or albedo of the modified roof with the energy efficiency calculated as a percentage difference.

RESULTS AND DISCUSSION

A systematic literature review was conducted to examine how reflectance and albedo affect a building's ability to use energy efficiently. To accomplish this goal, 77 publications on the topic, including scholarly articles, technical reports, two literature reviews, and other pertinent publications were evaluated.

Data Sample

This study included published studies from the United States, Asia, Europe, Australia, Africa, and South America. **Table 3** and **Fig. 1** show the sample sizes and the geographical distribution of studies, respectively. The studies were evaluated for the

energy savings between the original roof system installed (those without any modifications, such as coating, membrane color, or changing *R*-value) and modified roofing systems.

Data Synthesis and Analysis

Figures 2 and 3 plot the effects of solar reflectance and albedo on the energy efficiency of buildings, where energy efficiency is defined as the percentage change in energy usage between buildings with the original roofing system and a modified roof roofing system. Energy usage was measured in Gj (gigajoules) per year and KWh (kilowatt-hour) per time or area (e.g., KWh per sq.m. or KWh per day). Out of 77 studies, only 4 studies investigated utility bills while 58 studies were modeled for energy usage. **Figure 2** includes data on low-slope roofing systems of all colors, and **Fig. 3** includes data on steep-slope roofing systems of all colors. For every 10-unit change in solar reflectance, energy efficiency increases by 4.5% for low-slope roofs and 1.5% for steep-slope roofs. For every 0.1-unit change in albedo, energy efficiency increases by 2.2% for low-slope roofs and 5.5% for steep-slope roofs. Based on the study, changing the albedo value of the roof, and altering the reflectance value of the roof has a different effect on energy efficiency on a low slope roof vs. a steep slope roof. Higher energy efficiency is observed in low-slope roofs with a change in reflectance of the roof. In contrast, higher energy efficiency is observed in steep-slope roofs with a change in the albedo value of the roof.[12]

Table 4 identifies the parameters of the roofing system that the 75 studies (excluding the two literature reviews studies) considered to be integral influences on energy efficiency. The table shows the number of studies that included or excluded each of the parameters. Notably, while all studies considered "location" to be a critical factor, only 36% of the studies considered "insulation" as a key parameter. Further, 32% of the studies included "albedo" as an important factor, whereas 70% of the studies considered "reflectance" as an integral parameter.

TABLE 3. Search results and database keywords.

Location	Climates	Sample size for low-slope roofs	Sample size for steep-slope roofs	Total Sample Size
United States	Temperate, subtropical	202	65	267
Asia	Temperate, subtropical, subequatorial	79	15	94
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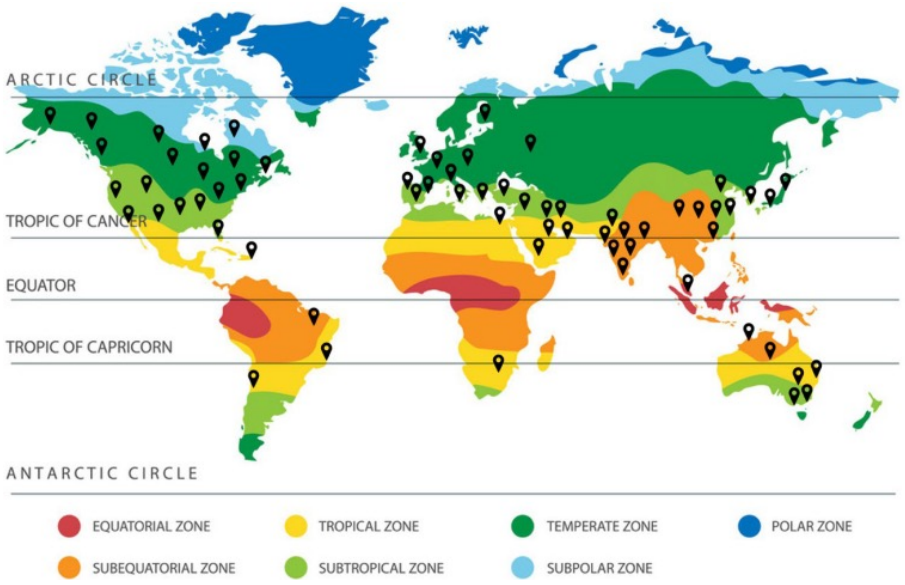
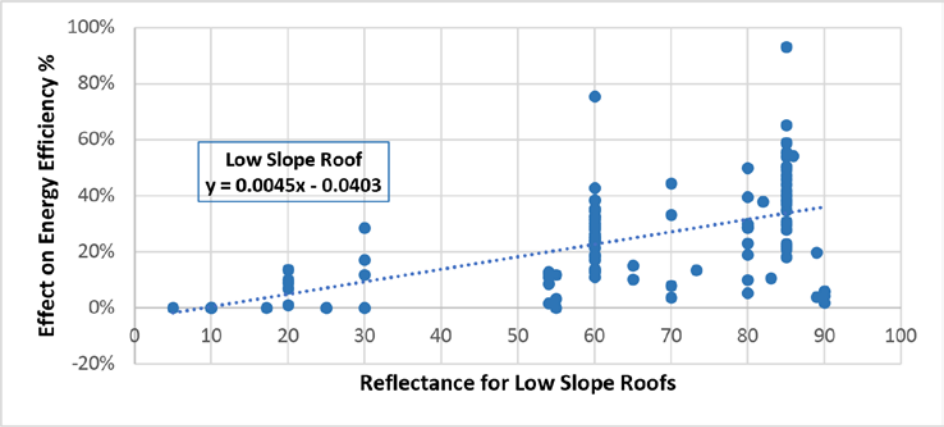


FIGURE 1. Geographical distribution of studies in the literature review.

CONCLUSION

The main objective of this study was to conduct a systematic literature review to offer a thorough examination of the roofing sector by synthesizing the results of past investigations. The literature review demonstrated that significant energy efficiency research has been conducted for different types of roofing systems. The findings of this systematic literature review indicate that as solar reflectance and albedo increase, energy efficiency also increases. The systematic literature review also identified other parameters that were included in the studies that impact building's energy efficiency.

Time of data capture was one of the parameters identified. Some of the observations from the literature review illustrate the need to evaluate the roofing system's effects on energy performance over the entire year, rather than on data from specific months in the year. Additionally, the *R*-value of the insulation needs to be considered which is essential because it can minimize heat energy loss in colder climates and reduce heat gains in hotter ones. A higher balance of real-world studies is also necessary vis-à-vis simulation/energy-modeled-based studies. For meaningful comparison in dollar value,



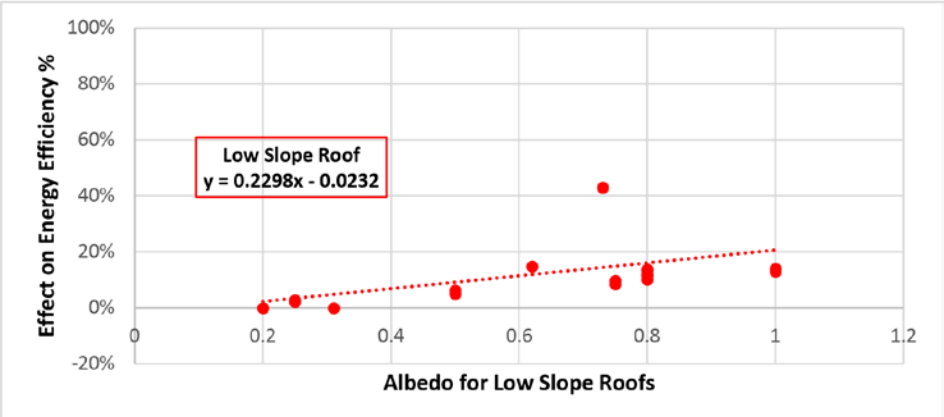
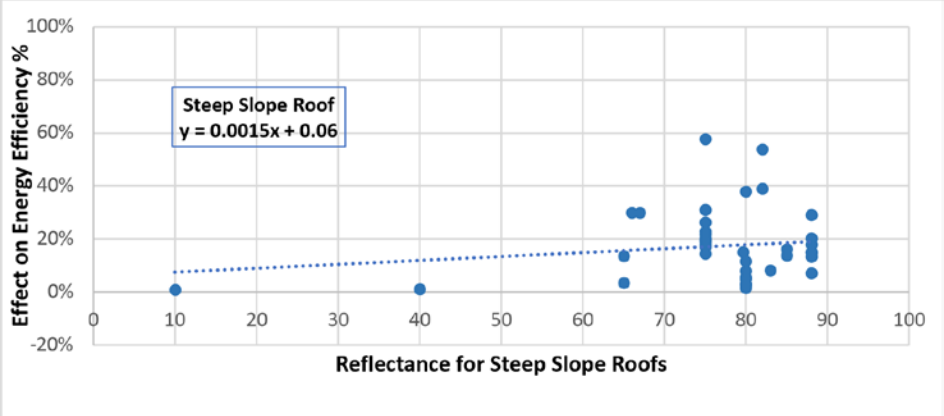


FIGURE 2. Effects of solar reflectance and albedo for low-slope roofs on energy efficiency.



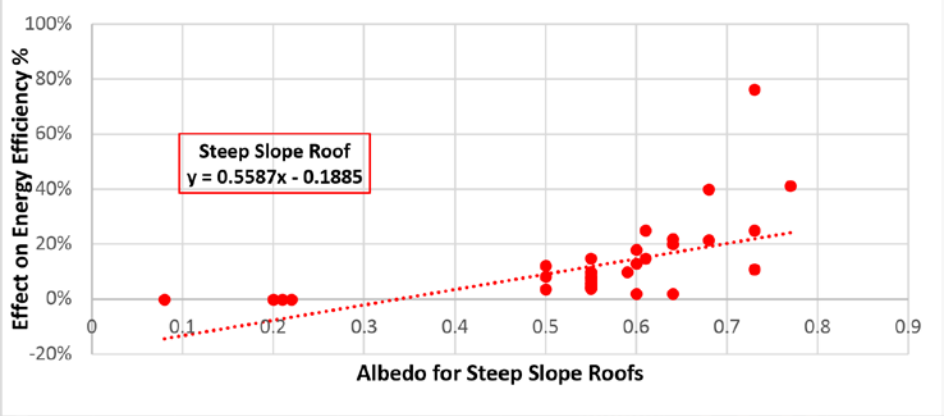


FIGURE 3. Effects of solar reflectance and albedo for steep-slope roofs on energy efficiency.

the cost savings need to be normalized for different regions because electricity prices can differ substantially from one place to another. Roofing systems also need to be compared in climate zones with similar climatic conditions to better assess the energy efficiency. In summary, along with solar reflectance and albedo value, it is recommended to consider other parameters such as the months in the year when the study was conducted, insulation *R*-value, energy costs, and different climate zones to better assess the effects of roofing systems on energy efficiency. Life-cycle analyses would also be interesting to discover appropriate roofing materials and designs and evaluate energy savings throughout the life cycles of roofing systems.

This study acknowledges the breadth of research that has already been conducted in the roofing industry on the topic of energy efficiency. This study suggests a path forward for the roofing industry to direct and design future studies on energy efficiency that benefit the industry, buildings, and the environment.

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TABLE 4. List of Parameters Used to Study the Effect on Energy Efficiency.

Parameter	Parameters included, no. of studies	Parameter not included, no. of studies	N/A*
Sample size (average) = 7.17			
Properties of roof			
Color of roof	48	27	
Area of roof	54	21	
Insulation	27	48	
Solar reflectance	52	23	
Albedo	24	51	
Study design			
Real-world study	17	58	
Simulation-based study	58	17	
Hot weather	53	0	22
Cold weather	14	39	22
Location	75	0	
Duration of data capture	53	0	22

**N/A represents the simulation-based studies in which data was simulated for effect on energy efficiency for the whole year*

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CHANGES TO THE WIND LOAD PROVISIONS AND HOW TO IMPLEMENT STRATEGIES IN A RE-ROOFING PROJECT DESIGN

ABSTRACT

ASCE 7-16 contains significant changes from ASCE 7-10 in the areas of seismic design, wind design, snow design, and more. A brand-new chapter on design against tsunami loads has been added. Several of the seismic chapters have been extensively rewritten. Since ASCE 7 eventually becomes law through adoption by the *International Building Code* (IBC) and then through adoption of the IBC by legal building codes of local jurisdictions, a practicing engineer has no choice but to keep up with these changes. In the East Coast of the US the wind design controls most of the roofing design of a building, understanding how to interpret and use ASCE 7-16 wind provision will help consultants and design professional to perform their job properly, but the design of a re-roof starts in the correct roof assessment collecting the necessary data to do a complete evaluation. A case study of a six- (6) story building located on the East Coast of Florida within the High Velocity Hurricane Zone will help us to understand the entire process, from assessment and data collection to evaluation, design to specification.

LEARNING OBJECTIVES

- Describe the process of performing an assessment of an existing roof system.
- Review the changes and wind-resistance requirements from ASCE 7-10 to ASCE 7-16
- Assess the design parameters in accordance with the new ASCE 7-16 code guidelines.
- Review a case study for a step-by-step wind design analysis for a building located in a high velocity wind zone.

SPEAKERS



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Tarcisio Noguera, PE, LEED AP, WMI, THLV2 is an engineer and senior project manager in the Miami Walter P. Moore Diagnostics group. He has more than 20 years of domestic and international experience in the field of building enclosure and forensic engineering. His expertise includes assessing and designing repairs for distress related to moisture management, roofing systems, and below-grade waterproofing on concrete substrates. He has participated in the roof design and construction administration for international projects, such as Montevideo Uruguay International airport and five (5) FIFA 2014 soccer world cup stadiums in Brazil.



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Noah Doukas, EI, LEED Green Associate, is a graduate engineer in our Orlando Diagnostics Group, with experience in structural engineering, building envelope consulting, and forensic consulting. His expertise includes evaluating, assessing, and designing repairs for structural systems and building envelope components. He develops work scopes, repair details, repair procedures, and technical specifications for concrete and steel restoration, waterproofing, and stucco rehabilitation projects. He has been involved in many large and complex projects across the Southeastern United States.

AUTHORS:

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Noah T. Doukas, EI, LEED Green Associate

INTRODUCTION

The fields of structural engineering and building enclosure consulting are continuously evolving to meet the demands of a rapidly changing world. As buildings reach new heights, extreme weather events become more frequent, and technological advancements are rapidly reshaping the industry. Engineers must adapt their practices to ensure the safety and resilience of structures. At the forefront of this adaptation is the American Society of Civil Engineers (ASCE) 7-16 standard, a critical resource that guides structural engineers in designing for wind loads.

ASCE 7-16 serves as a vital tool for design professionals as they navigate the complexities of wind design. It outlines the criteria for determining wind loads on structures and provides essential guidelines for developing durable designs. This article aims to introduce changes from ASCE 7-10 to the newer code ASCE 7-16 is utilized by structural engineers in the wind design process.

Some factors that have influenced the changes made to ASCE 7-16 include continual modifications to state legislation, local building code changes, improvement in industry practices, and the continued development of improved building science technology. Due to legal mandates, ASCE 7-16 has undergone revisions to ensure compliance with the latest regulations, however, it is up to individual states and counties to modify their building code provisions according to how they see fit.

These changes reflect the ongoing commitment to safeguarding the built environment and addressing potential liabilities associated with structural failures. Over time, as scientific knowledge and engineering practices evolve, building codes must be updated to incorporate new findings. ASCE 7-16 considers advancements in wind engineering, incorporating the latest research and insights into its design provisions.

CHANGES FROM ASCE 7-10 AND ASCE 7-16

The 2016 version of this standard has several significant changes from 2010:

- Enclosure Classification
- Basic Wind Speed
- Ground elevation above Sea Level
- Edge Zones
- Rooftop Equipment
- Design Wind loads on circular bins, silos, tanks
- Wind loads on Rooftop Solar Panels
- Design wind pressures component cladding – loads on roofs with h <= 60 ft
- Attached canopies on buildings with h <= 60 ft
- Tornado Limitations

Enclosure classification has a new condition "Partially Open Building" with a GCpi (+0.18 / -0.18) labeled as moderate internal pressure. Correspond to a building that do not comply with "Enclosed", "Partially Enclosed", or "Open" Classifications.

Wind maps and wind speeds were updated in ASCE 7-16. Wind speeds for large parts of the country have been reduced for each Risk Category. While Category III and IV buildings were addressed on a combined map in ASCE 7-10, ASCE 7-16 has a separate these Risk Categories to individual wind speed maps.

New wind speed map for Risk Category IV Building (Essential Facilities) with a mean recurrence interval 3,000 years. (1.6% probability of exceedance in 50 years)

External pressure coefficients for components and cladding (C&C) have increased. Hip and gable roofs are separated. In most cases, the factors are going up, causing design wind loads to generally increase. Part 1 and 2 of Chapter 30 – Roof Component and Cladding Pressure Coefficient (GCp) for Enclosed and Partially Enclosed. Buildings with h <= 60 ft.

A Ground Elevation Factor has been added in ASCE 7-16 to account for variations in air density at different altitudes and amends the wind velocity pressure equation ASCE 7-16 26.10-1.

$q_z = 0.00256 K_z K_{zt} K_d K_e V^2$ (lb/ft²); V in mi/h (ASCE 7-16 26.10-1)

CASE STUDY INTRODUCTION

For the remainder of this article, we will explore a case study on a residential condominium building located in Hillsboro Beach, Florida. This project is in Broward County, Florida exposed to the highest wind design speeds in the United States. The building is considered a Risk Category II, Surface Roughness D for the site, with design wind speeds of 170 miles per hour (mph) per ASCE 7-16 wind. The six-story (51ft eave height) condominium complex was constructed around 1974,

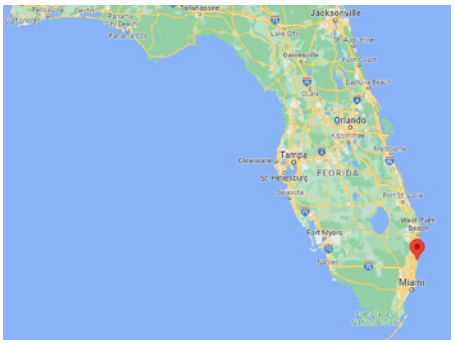





FIGURE 1. Six-story condominium building in Hillsboro Beach, Florida in Broward County located along the Atlantic Ocean. Subject of the re-roofing design case study.

with CMU walls, reinforced concrete cast-in-place slabs, and framing.

ROOF ASSESSMENT OF EXISTING BUILDINGS – WHAT TO LOOK FOR

A detailed visual inspection of the roof system can serve as an effective way to begin assessing an existing roof. Key parameters needing to be identified include the type of membrane system, insulation type, existing drainage pattern and slope, structural deck type, and how the roof system is adhered to the structure. Typical signs of deterioration for roof assemblies include punctures or wear in the top membrane, persistent staining along the roof system indicative of insufficient drainage from lack of slope or drain placement, soft spots in the roof assembly's insulation, and documented sources of water intrusion observed along the underside of the roof. Information about property specific roof replacement history can usually be found usually on county permitting websites, which serve as a useful resource in identifying the system in place.

Additional items to look for during this visual inspection would include locations where specific flashing details will be required for the re-roofed assembly like at roof penetrations for mechanical equipment or supports. An understanding of the roof geometry such as parapet heights, slope of roof, and location of mechanical systems will become imperative in determining the design wind pressures for the roof assembly. Finally, determining the layout of the roof drainage system, dimensions of the wall scuppers, and whether additional sloping will be necessary will provide useful information in adequately draining the roof.

Non-destructive testing techniques, such as infrared thermography or ground-penetrating radar, may offer insights into the underlying structure and potential attachment methods without requiring construction documents. These methods can detect temperature variations, material thicknesses, or hidden attachment elements providing indirect evidence of the attachment mechanisms used.

In parallel with non-destructive testing, destructive testing can be useful at selective locations to provide a reasonable insight into the overall condition of the existing roof. Methods such as coring or exploratory openings offer a more intrusive look at the conditions of the roofing assembly's components and give the evaluating engineer a chance to confirm the in-situ roof assembly at the testing location.

Case Study: Data Collection

At the six-story condominium building focused in the case study, a detailed visual assessment was performed by the engineering team. According to the County's permitting website, the roof was replaced back in 2007, with a Built-Up Roof (BUR) system using (1") perlite insulation board installed by hot mop directly to the concrete deck. This was followed by two ply (2) fiberglass mats in hot mop material and a torch-applied granular cap sheet.

The BUR with acrylic coatings applied over the years was exhibiting signs of deterioration consistent with its age which included cracking of the asphaltic membrane, ponding water, staining and debris accumulation, and deterioration of the flashing members around the parapet walls. Additional distress conditions around the mechanical equipment in place included corrosion staining around equipment curbs, improperly fastened flashing members, mechanical penetrations with voids, and undersized roof scuppers. Prolonged and worsening of these conditions could result in rapid deterioration of the subsequent layers and create the potential for wind uplift damages.

The roof did not have appropriate slope, the slope measurements taken on site using a digital level indicated less than 1% slope, and ponding water at many locations confirmed this finding.

Case Study: Non-Destructive Testing

Thermography scanning was performed along the roof after sunset using a FLIR E60 thermographic camera. Thermography measures surface temperatures by using infrared cameras. These tools identify light that is in the heat spectrum. Images on the video or film record the temperature variations of the building's skin, ranging from white for warm regions to black for cooler areas. The resulting images help the auditor determine whether insulation is needed.

Infrared scanning allows for checking the effectiveness of the insulation in a building's envelope, and it is a qualitative measure for any leaks in the membrane. Because wet insulation conducts heat faster than dry insulation, thermographic scans of roofs can often detect possible roof leaks.

The thermography scan performed along the roof indicated high heat transfer through the concrete slab due to water ponding. Some isolated wet insulation was detected however multiple locations with ponding water on top of the membrane, were due to the lack of proper slope drainage. Detecting wet and loosely packed layers of insulation provide useful information in identifying possible locations for failures to occur in high wind events.

Case Study: Destructive Testing

Results obtained from roof cores confirmed the roofing system consisted of a concrete deck with a BUR system and 1" thick hot mopped perlite board, followed by two plies of hot mopped fiberglass roofing and a two granular cap sheets, all coated in an acrylic topping. At select locations, this acrylic coating has been recoated with a silicone coating due to deterioration caused by long-term ponding water.

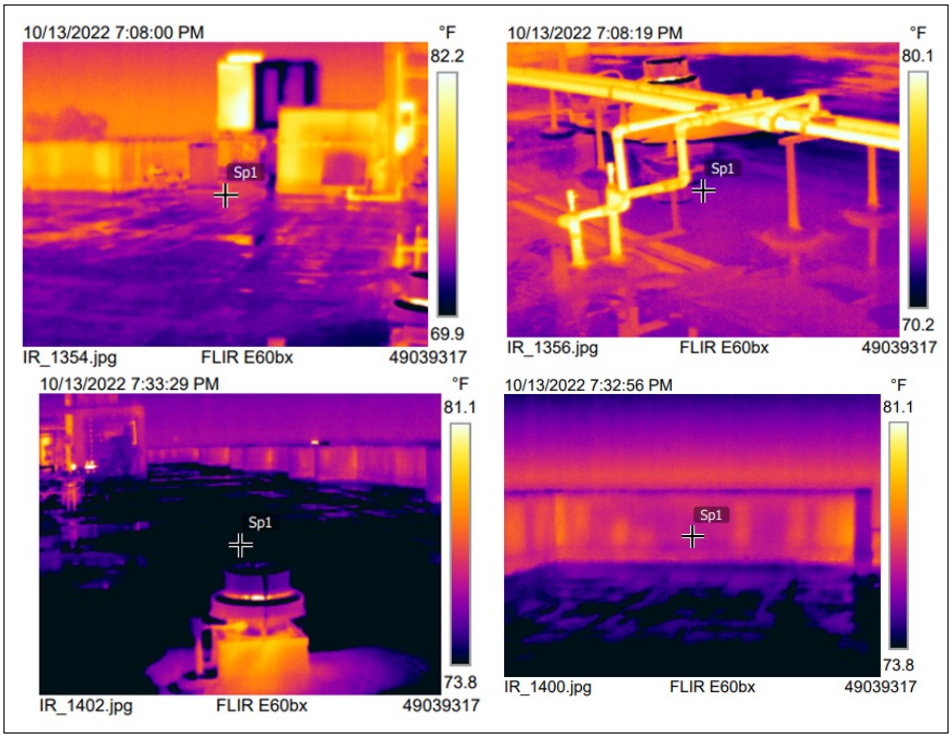


FIGURE 2. Thermography images taken from the roof of condominium building. Including overview of roof, mechanical penetrations, and parapet walls.

EVALUATION OF ROOF CONDITIONS

With the data accumulated during the visual assessment, non-destructive testing, and destructive procedures a more thoughtful approach to the re-roof design can begin. With the age of the roof and deteriorated conditions, lack of proper drainage contributing to the owner's selection for replacement, it was time to begin evaluation of what roof system would be best applicable for the replacement.

Before moving forward with identifying the type of roof to be utilized, it was important to put together a list of typical details needing to address conditions throughout the roof. Terminations at walls, flashings around mechanical openings, scuppers and roof drain inserts would be important to have adequately detailed.

The starting point taken for evaluating the case study's intended wind design pressures was to obtain the ASCE 7 Hazard Tool. This tool allows for the address of the building to be input, along with its risk category and soil class, to receive an ASCE 7 Hazard Report



FIGURE 3. Roof core exploratory opening showing BUR assembly is just under 2" thick, consisting of 1" hot mopped perlite board, two-ply fiberglass. BUR and two mopped granular cap sheets and an acrylic coating layer over top.

REVIEW OF DESIGN PARAMETERS

Design wind loads are derived using American Society of Civil Engineers (ASCE) standard ASCE 7-16, "Minimum Design Loads and Associated Criteria for Buildings and Other Structures," Chapter 30—Wind Loads—Components and Cladding (C&C), Envelope Procedure, Part 2: Low-rise Buildings (Simplified) and Part 4: Buildings with 60ft < h ≤ 160ft (Simplified). ASCE 7-16 is a widely recognized consensus standard and is referenced in and serves as the technical basis for wind load determination in the 2020 Florida Building Code.

ASCE 7-16 specifies wind design procedures for buildings and organizes them into two categories: main wind force-resisting systems, and component and cladding elements. Main wind force-resisting systems are the structural elements assigned to provide the support and stability for the overall building. C&C are elements of the building envelope that do not qualify as part of the main wind force-resisting system. Roof systems and edge-metal flashing systems are considered C&C.

ASCE 7-16 is used to determine minimum wind pressure design requirements for buildings and can be considered as loads acting on the building when factored using the load combination in ASCE 7-16 Chapter 2. Design wind load calculations determined by the Envelope Procedure, Part 2: Low-rise Buildings (Simplified) method result in strength design values. ASCE 7-16, Part 2: Low-rise Buildings (Simplified), and, therefore, Roof Wind Designer apply to only buildings that are classified as Enclosed.

Utilizing ASCE 7-16 for designing the roof system as C&C will entail utilizing Chapters 26-30. These chapters of the ASCE 7-16 standard are intended to account for the directional procedure, envelope procedure, directional procedure for building's structures (such as roof overhangs and parapets), and the wind tunnel procedure. Individual factors determined from the surrounding condition are identified and included in the final wind velocity pressure at the given height of the building (q_z) formula below:

$q_z=0.00256K_zK_{zt}K_dK_eV^2$ (lb/ft²); V in mi/h (ASCE 7-16 26.10-1)

Ground elevation factor (K_e) can be determined from the ASCE 7 Hazard Report which provides the elevation of the condominium building at 0ft. Therefore, K_e is 1.0. the topographic factor is dependent on the parameters outlined in Figure 26.8-1, for this scenario the K_{zt} is 1.0.

The directionality factor (K_d) had been determined by Table 26.6-1 in ASCE 7-16, is 0.85. It's also necessary to identify the level of exposure the building will have. Since the condominium building resides next to the ocean, it will be considered as Surface Roughness D and Exposure D, as identified in ASCE 7-16 Chapter 26.7.3. Further detailing on the directional procedure is detailed in Chapter 27 of ASCE 7-16. The exposure classification influences the velocity pressure coefficient (K_z) based on Table 26.10-1. Since the height of the condominium building was 51ft, K_z is 1.27. With all these coefficients identified, our wind velocity pressure can be calculated, as q_z to be 80.2 psf.

The enclosure classification of the building helps determine the internal pressure coefficient (GC_{pi}) for the structure. It is dependent on the relationship between the total area of openings (A_o), gross area of the wall (A_g), the sum of the areas of openings in the building envelope (A_{oi}), and the sum of the gross surface areas of the building envelope (wall and roof) (A_{gi}). Since the condominium building has windows and sliding glass doors on all sides calculations as described in ASCE 7-16 Table 26.13-1 would be considered a partially enclosed building, per. This "high" classification of the internal pressure coefficient (GC_{pi}) is +/-0.55.

Design wind pressures for partially enclosure buildings are determined in Chapter 27 in ASCE 7-16 are determined from using the above-mentioned coefficients in the following equation:

$p= qGC_p-q_i(GC_{pi})$; in lb/ft² (ASCE 7-16 27.3-1)

Similarly, for the parapet walls and staircases a design wind pressure can be obtained using:

$p_p=q_p(GC_{pm})$ (ASCE 7-16 27.3-3)

Depending on the directionality of the wind, uplift pressures exerted on the windward and leeward side can be positive or negative. ASCE 7-16 Chapter 30 details the pressure zones for the C&C and provides specific roof uplift pressures zones based on the type of roof orientation. Since the roof system for the condominium building was a flat roof, Table 30.6-2 zones 1-3 were needed at the corners, perimeter, and center of the roof. The GC_p coefficient varies depending on the location considered. Therefore, the design wind pressures for each zone varied as shown in the below figure. The wind uplift pressures felt on in zone 3 are the highest throughout the roof and should be considered as the minimum design pressure (MDP) needing to be met.

This process results in Design Wind Pressures for each roof zone and determines the dimensions for each of the zones. Providing this information on the construction documents ensures the contractor and manufacturer can provide an appropriate roof system with tested capacity.

FINAL PRODUCT – CONSTRUCTION DOCUMENTS AND SPECIFICATIONS

With the design wind pressures identified in for the three zones along the roof, it will be possible to begin selecting the roof assembly intended to be installed as a replacement. Since this case study is in Broward County Florida, there needs to be a Florida Building Code (FBC) including High-Velocity Hurricane Zones (HVHZ) approved assembly selected to meet the design wind pressures.

Specific manufacturers have approved assemblies available that have been tested to exceed the design wind pressures. Since the selection of a 0.60" TPO membrane was already identified as a system intended for this re-roof project, the roof assembly will be selected based on this requirement for highest wind uplift pressures at the corner zones.

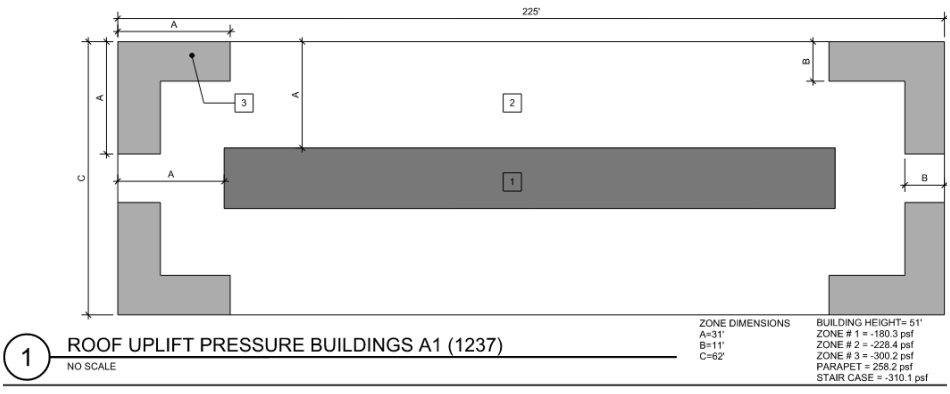


FIGURE 4. Roof uplift pressures, wind zones, and edge zone dimensions for the condominium building roof replacement..

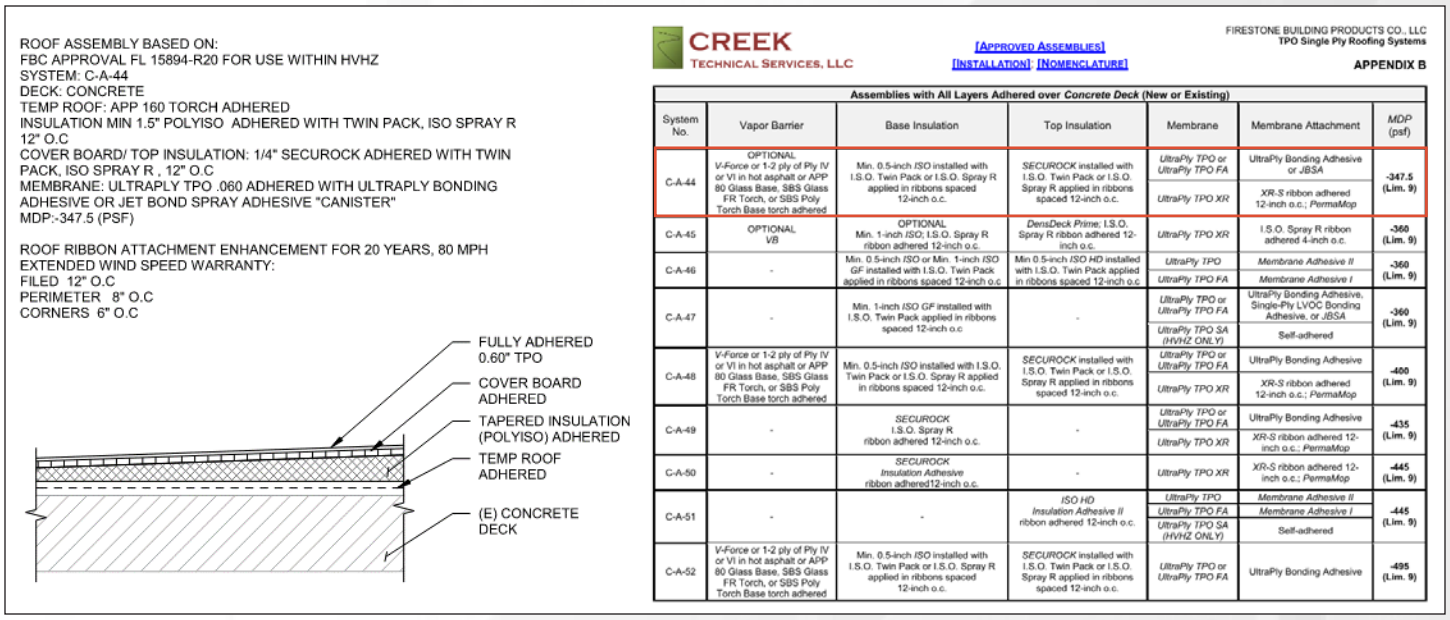


FIGURE 6. Roof assembly diagram and selection criteria identified by Creek Technological Services, LLC showing the assembly meets MDP of -347.5 psf.

Depending in the location of the project the roof assembly is selected based on previously tested and approved systems. Since the project is in Miami Dade County, the roof assembly much meet Miami Dade NOA (Notice of Approval), and Florida Approvals. The approved system details the type of rood membrane, insulation attachment method, and design uplift pressure resistance. From the verbal description of the roof assembly system, the construction documents can graphically show the assembly as a typical detail.

Additionally, specific details for the terminations at the drains, mechanical equipment pads, penetrations through the roof deck, and mechanical equipment supports would have to be detailed to meet the manufacturer's specifications. On the construction documents, locations where each applicable detail will be installed are called out and allow the bidding contractors to get quantities for conditions needing to be met.

With the above figure and finalized roof assembly ready to be provided for bidding documents, this concludes the procedure for evaluating and designing a re-roof system utilizing the ASCE 7-16 standard. The new roof system will be able to resist some of the highest wind uplift pressures experienced in the continental United States respective to this building's size, while keeping in mind serviceability and adequately drain water.

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MIND THE GAP: WATERPROOFING CONSIDERATIONS IN PROPERTY LINE CONSTRUCTION

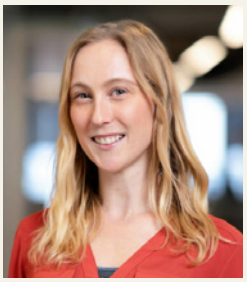
ABSTRACT

For urban infill construction projects, designers and contractors are challenged with designing and constructing the exterior enclosure mere inches from neighboring buildings. All components of the exterior enclosure require special consideration, from below-grade waterproofing selection to exterior-wall type and construction methods, tolerances, seismic-gap requirements, and the top-of-wall joint coverings. This presentation will explore the challenges, pitfalls, and successes of waterproofing in property line construction.

LEARNING OBJECTIVES

- Present a variety of approaches to interacting with existing neighboring construction with limited access.
- Review below-grade waterproofing considerations and installations that abut existing neighboring buildings.
- Explore alternate exterior wall types: concrete/concrete masonry unit, framed tilt-up wall, or shaft wall assemblies.
- Review exterior enclosure detailing considerations to maintain continuity of the air and water barrier between walls and adjacent finishes.

SPEAKERS



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Oakland, CA

Caitlyn Kallus is a consultant at Simpson Gumpertz & Heger (SGH) with over six years of experience in commercial building envelope consulting work in the San Francisco Bay and Los Angeles areas, including new design consultation, rehabilitation, investigations, inspections, and condition assessments. Her project experience spans various systems, including below-grade waterproofing, plaza deck waterproofing, exterior-cladding systems, exterior curtainwalls, window assemblies, and roofing systems.



Jesse Sipes, PE
Simpson Gumpertz & Heger
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Jesse Sipes is a senior consulting engineer at Simpson Gumpertz & Heger with more than seven years of building enclosure consulting experience in the San Francisco Bay Area. At SGH, he has experience with investigation, consultation, litigation, and inspection work on new and existing multi-unit and single-family residential, commercial, and institutional projects. His design and investigation work includes below-grade waterproofing, plaza deck coatings, wall cladding assemblies, and roofing systems.

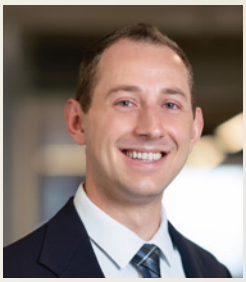
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The iconic "Painted Ladies" in the sitcom *Full House*, brownstones in New York City, and row houses along the Venetian canals are all famous examples of property line construction. Construction along property lines has been done successfully for centuries, yet modern performance requirements and construction practices of lighter and thinner assemblies challenge designers and contractors with forming the exterior enclosure mere inches from neighboring buildings.

In modern construction, building code requirements and performance expectations form the basis of design of the exterior enclosure. Key building code requirements that affect property line design include fire resistance, design for earthquake displacement, occupancy classifications, height and area limitation, hazardous material considerations, and water drainage. Each component of the exterior enclosure, from below-grade waterproofing, along the building separation, and at the exterior wall (**Fig. 1**), requires additional considerations on a project-by-project basis.

Project-specific key parameters that affect property line design and construction are:

- Agreement (or disagreement) between neighbor and owner.
- Condition of the neighboring building (i.e., lightwells, existing leaks, deteriorated cladding, encroachment beyond the property line, open air garages, etc.).
- Future-proof requirements: Anticipating whether a neighboring building is to be constructed or slated to be demolished concurrently with the new building's construction.
- Separation size: Size of the separation is defined by the design earthquake displacement of both the new construction and neighboring building (ASCE 7-22, Section 12.12.2). Whether the separation is too narrow for a person to enter (approximately 12 in. or less) or wide enough for construction access (approximately 24 in. minimum) impacts the design, construction, and maintenance considerations.

All the above parameters affect the infill building's design, yet the neighboring agreement, the condition of the neighboring building, and future-proof requirements are beyond the control or jurisdiction of the design team for the infill building. The design team should be aware that all design details that interface with the neighboring building may be subject to change at any time due to unexpected field conditions, updates or revisions to the neighboring agreement, or lack of information from the neighboring building owners.

We will conceptually discuss the below-grade waterproofing, the strategy along the building separation, and the exterior-wall implications for construction along the property line, followed by how key parameters from the neighboring building can potentially foil each strategy.

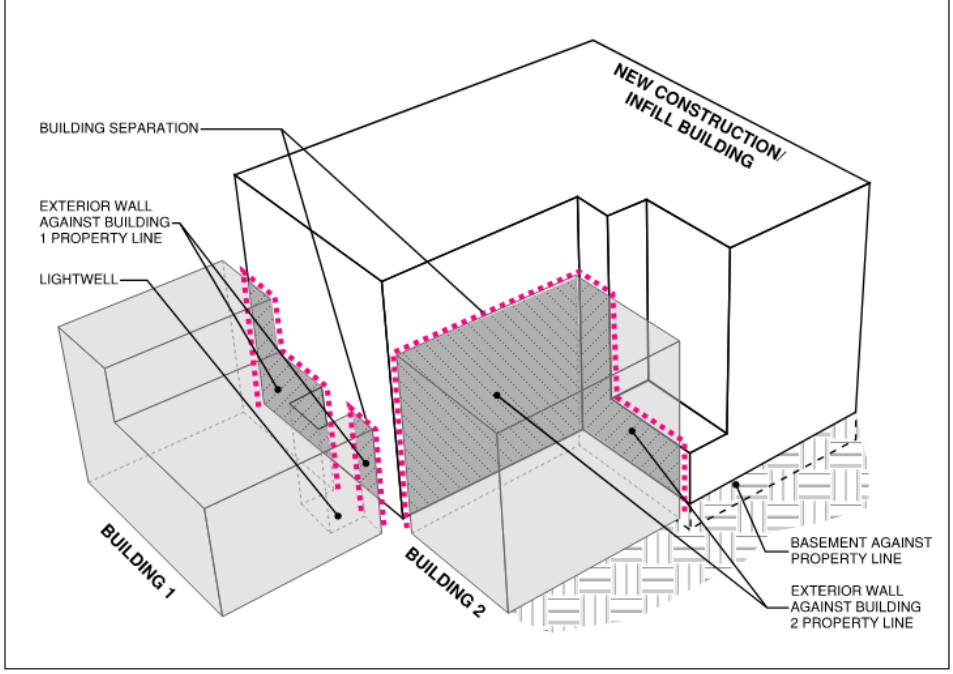


FIGURE 1. Building separation diagram of a new construction building along the property line of neighboring buildings.

BELOW-GRADE WATERPROOFING

Due to the lack of access to over-excavate at a property line wall, pre-applied "blind-side" below-grade waterproofing is required along the property line and all the considerations common to blind-side waterproofing apply.

One additional below-grade waterproofing membrane consideration along the property line is when the neighboring building also has a basement. During construction of the new building's basement, the neighboring building's basement wall may be exposed as part of the excavation. The owner must be cognizant of the risk of exposing and potentially damaging the neighboring building's below-grade waterproofing. For the infill building, a key consideration is that the backfill at the below-grade separation between the two buildings may not be compacted due to the limited space or purposely filled with geofoam to provide a separation layer. There is a family of below-grade waterproofing membranes designed to swell, such as those with bentonite clay, that rely on confining pressure which non-compacted fill or foam may not provide. The project team should review the backfill requirements with the waterproofing membrane manufacturer if the specified below-grade waterproofing membrane relies on confining pressure.

Along the property line, the below-grade waterproofing must be terminated with limited access to the exterior, and often there is no access to install a traditional termination bar. Instead, the membrane may need to be folded into the concrete wall at a pour joint or terminated onto a sheet-metal flashing inserted into the concrete pour joint (**Fig. 2**). Since the detailing affects the concrete pour joint, especially if the termination occurs at a concrete shear wall, the structural engineer must review the structural impact. Furthermore, it is critical that the future backfill height be finalized to locate the waterproofing termination detail at the correct elevation.

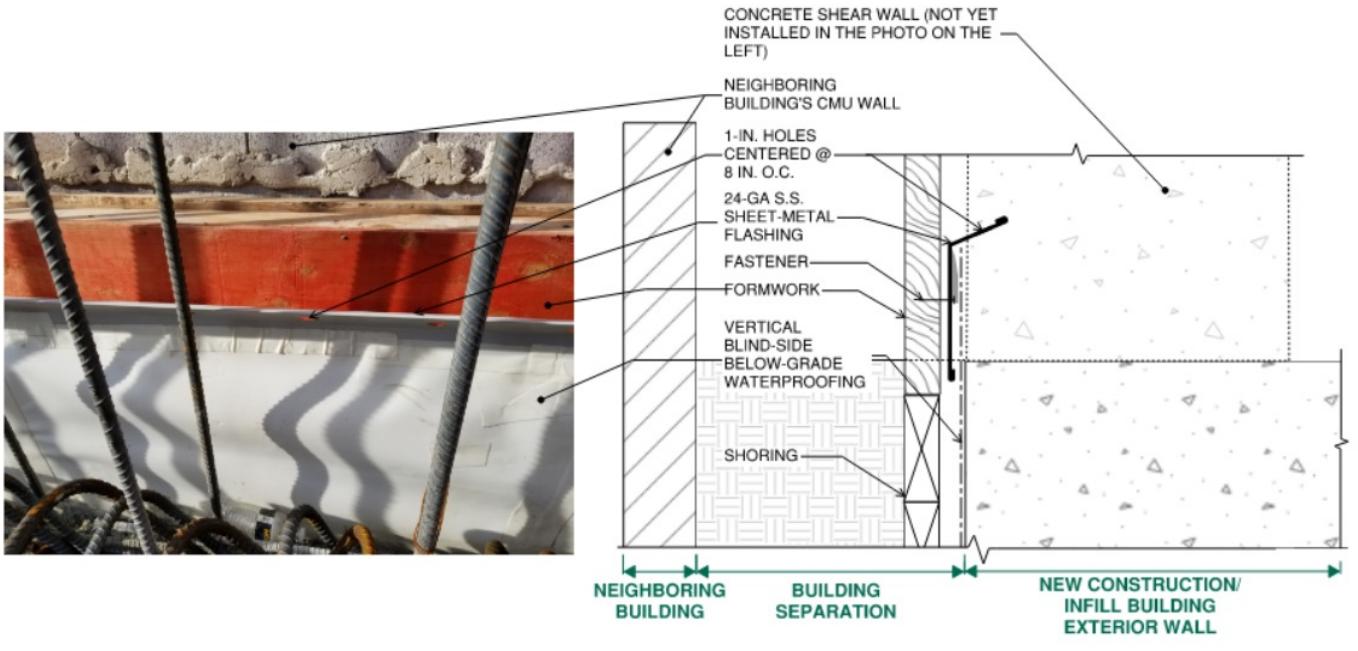


FIGURE 2. Below-grade waterproofing along property line construction.

AT THE BUILDING SEPARATION ABOVE GRADE

At the building separation along the property line, the three strategies are (1) do nothing, (2) provide bulk-water diverter flashings, and (3) provide watertight flashings.

1. Do Nothing

Doing nothing simply means treating the interface as if there is no adjacent neighboring building. This may seem like a simple solution, but in practice, it requires consideration for risk management, site drainage, exterior-wall design (see "Exterior Walls" section below), and overall building maintenance.

Risks

The code-required property line separation between the two buildings creates an open space within the gap. Any gap less than approximately 12 in. in an urban environment prompts a maintenance challenge since a person is unlikely to fit into this gap. By doing nothing at the building separation, the gap along the property line cannot be accessed to retrieve debris or deter vermin from entering or nesting.

When the interface between the two buildings is treated as if there is no adjacent building, rainwater that reaches the wall surface drains down to the ground. Exactly how the water is managed once it arrives at the ground has proven to be tricky and complicated on numerous projects. The slope for site drainage along a property line between two buildings is to match the finish grade at the end of the buildings. By the time finish grading is scheduled toward project completion, the infill building is nearly complete and access within the gap is very limited.

Based on past projects where the new construction did not have a basement, most of the gaps are not graded and are left with a combination of native soil and construction debris. Instead of directing the rainwater out of the neighboring gap, the rainwater percolates down to the soil. A key risk management consideration for ownership, especially if the neighboring building has below-grade space, is that the change in the condition along the property line created by the construction of the infill building could be attributed by the neighboring property owner to their leakage. It can be contentious and difficult to determine whether this leakage already existed but went unnoticed or whether this is new leakage due to increased weather exposure and accumulation.

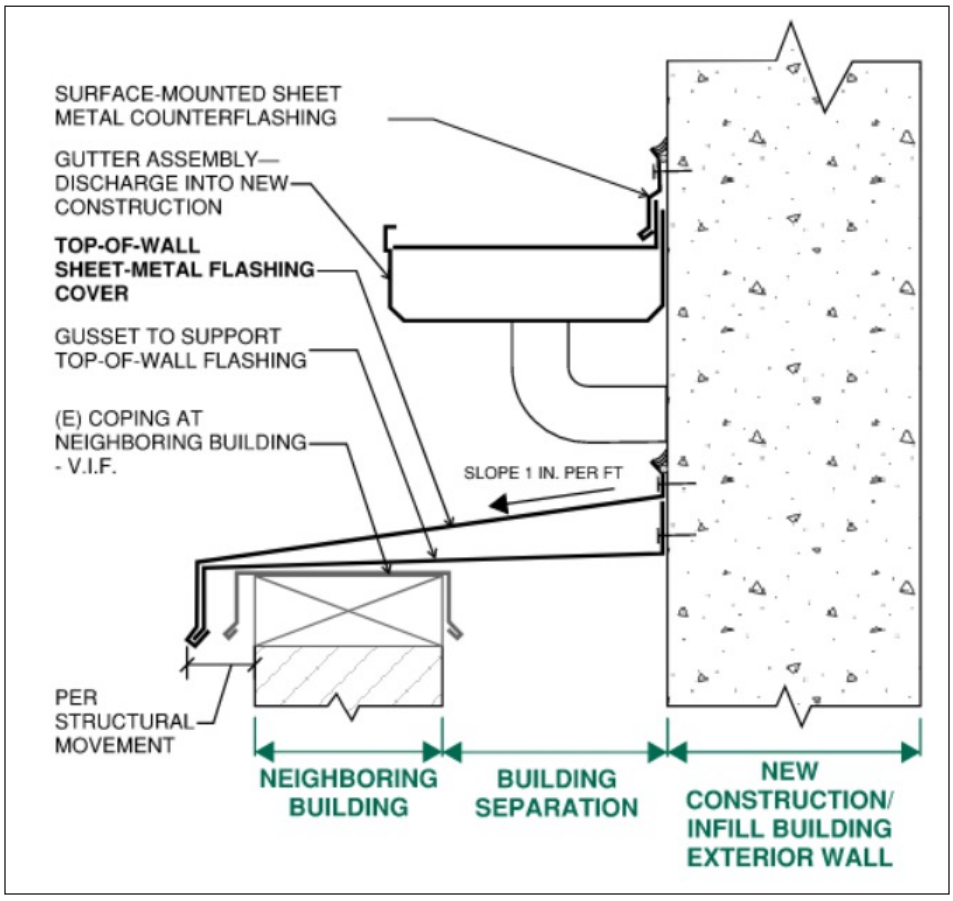


FIGURE 3. Top-of-wall bulk-water diverter flashing.

2. Bulk-Water Diverter Flashing

Bulk-water diverter flashings trace the perimeter of the building-to-building separation to cover the gap. The flashing occurs both vertically and horizontally along the sides and tops of walls. An example of a top-of-wall bulk-water diverter flashing is shown in **Fig. 3**. A flashing at the higher wall spanning across the gap and capping over the top of the lower wall has numerous advantages compared to the "do nothing" option. The bulk of the water flowing down the upper wall is either collected by a gutter above the flashing or directed by the flashing onto the lower roof instead of flowing down the wall and into the soil below. The exterior enclosure below the top-of-wall flashing is exposed to incidental water, but no direct weather or sunlight. The vertical flashing has a similar effect.

Sheet-metal flashings are commonly used as bulk-water diverters. The sheet-metal gauge is sized to span the building separation and can be oversized to accommodate differential building movement based on the size of the separation.

Complications

A prerequisite for a top-of-wall flashing is an agreement between the neighboring owners allowing for a flashing that spans across the two properties. Without an agreement in place, a top-of-wall flashing is an encroachment.

The top-of-wall detailing is straightforward when the infill building is taller than the neighboring building. The infill building walls are



FIGURE 4. Integration of bulk-water diverter flashing with the neighboring building

designed to accommodate flashing attachment requirements. However, ASCE 7-22, Section 8.4 requires the new construction to contain a water collection system (such as a gutter) to prevent discharging its water onto the existing roof unless the existing roof is evaluated.

If the existing neighboring building is taller than the infill building, the flashing must be attached to the existing building, which can become complex due to the current condition of the existing building's cladding. Non-veneer masonry walls such as concrete, concrete masonry unit (CMU), and brick cavity walls are suitable exterior cladding for attaching the new top-of-wall flashing directly to the surface (i.e., "surface mount"). A surface-mounted flashing is the simplest solution to a top-of-wall flashing and should be utilized where possible. However, light-gauge metal- and wood-framed exterior-wall claddings including veneer masonry, rainscreens such as metal, fiber cement, or terracotta panels are often not suitable for surface-mounted flashings because the cladding alone does not have the structural capacity to support the flashing, and the weather barrier behind the cladding should be weather lapped over the flashing. To ensure the flashing is properly attached to studs and to mitigate water leakage risk, the neighboring building existing cladding must be locally removed to expose the underlying weather barrier (**Fig. 4**). Having access to studs ensures the flashing is solidly attached to a suitable substrate and allows the installation of new waterproofing membrane to tie in with the existing weather-resistive barrier to direct water onto the top-of-wall flashing and out of the wall assembly.

3. Watertight Flashings

Watertight flashings can be pre-manufactured expansion-joint assemblies or enhanced sheet-metal wall flashings that shield 100% of weather exposure from the cladding below. The enhancements to make sheet-metal flashing watertight require either an underlayment below the flashing or additional flexible seals at the flashing's joinery.

If the flashing along the perimeter of the building separation is 100% watertight, the walls below are not weather exposed, so they can be designed and constructed like fire-rated interior walls, thus reducing the cost of the project. Just as previously discussed for bulk-water diverter flashing, the complexity and efforts required for watertight flashings are based on the existing conditions of the neighboring building.

Complications

An agreement between neighboring owners is also required to allow for potential modifications to the existing building to create a watertight flashing between buildings. Conditions that make a watertight flashing challenging include but are not limited to:

- **Non-watertight neighboring wall:** The discussion thus far has focused on the neighboring building wall being either exterior weather-exposed masonry or framed wall. However, the neighboring building wall could be a parking garage with openings or a rooftop terrace with a screen wall or planters. These are some examples of non-watertight neighboring conditions that make a watertight flashing impossible unless a portion of the neighboring wall is reconstructed.
- **No parapets:** If the neighboring building does not have a parapet, such as with a gravel stop detail, the top-of-wall flashing from the infill building will have to float above the existing roof membrane instead of capping over it. Water may be able to flow between the flashing and the roof and into the gap. Creating a watertight condition requires modification of the existing roofing membrane detailing.

The decision along the building separation to do nothing, add bulk-water diverter flashing, or add watertight flashing is complicated by legal terms, risk management, and existing condition of the neighboring building. To add to the complexity, the decision at the top-of-wall area also affects the exterior-wall assembly along the property line.

EXTERIOR WALLS

The Venetian row houses and New York City brownstones are masonry construction, allowing the installer to construct the masonry wall within the

TABLE 1. Common Shaftwall Waterproofing and Cladding Ideas and Pitfalls.

Proposed Shaftwall Waterproofing Strategy	Pitfall(s)
Unroll sheet-applied membrane and hang cladding from the level above.	Insufficient Anchorage: Waterproofing membrane and cladding are only attached at the top of each floor.
Pre-apply the weather-resistive barrier and cladding. Install sealant into the flanges of the shaftwall stud immediately prior to inserting the sheathing into the flange.	The installation method is solely reliant on smash seals with no means of tooling the sealant or field quality control.
Pre-apply the weather-resistive barrier and cladding. Install a strip of self-adhered waterproofing membrane centered at the shaftwall stud from the edge of the exterior sheathing prior to installing the next shaftwall stud (i.e., reach over 16 or 24 in., depending on stud spacing, to add waterproofing membrane over the in-place shaftwall stud).	This method for installing the waterproofing membrane has been successfully implemented on a project, but the building code at the time was ambiguous for the requirement of exterior cladding. Traditional exterior-cladding installation is unachievable due to limited access.
Provide a 100% watertight flashing at the top-of-wall area to eliminate weather exposure. Leave the shaftwall without cladding and waterproofing.	See discussion above regarding the challenges of 100% watertight flashings. It is also important to note this approach is not future-proof; that is, if the neighboring building is ever demolished, the shaftwall will immediately become exterior exposed and susceptible to leakage.

property line without exterior access. The lack of exterior access along the property line at contemporary framed walls creates constructability challenges, as these are typically constructed from the exterior.

A very simple solution to constructing an exterior wall along the property line is to do what the Venetians did hundreds of years ago and build it out of masonry. Masonry walls can be constructed from inside the property line, comply with code requirements for fire resistance, and are not required to have a weather-resistive exterior-wall envelope when designed in accordance with code standards. This makes it the ideal wall type to construct along a property line. Unfortunately, masonry walls weigh more than contemporary framed walls, and this additional weight impacts the structural gravity and lateral system designs. Reducing overall building weight optimizes the building's structural systems, and that can become the deciding factor for framed walls along the property line. The options of constructing a framed wall without exterior access include (1) shaftwalls and (2) pre-assembled walls.

SHAFTWALLS

Having access available to only one side of a framed wall is a common occurrence in elevator shafts, mechanical shafts, and air ducts. Numerous manufacturers have shaftwall assemblies that are intended to be constructed from one side and meet the code-required fire resistance. Framed walls along the property line are complicated due to being an exterior wall requiring a weather-resistive barrier and, depending on the governing code requirements, exterior-wall cladding. Both the weather-resistive barrier and the exterior-wall cladding must be installed from the interior, without exterior access. **Table 1** summarizes ideas often explored for waterproofing a shaftwall, along with the pitfalls.

A traditional shaftwall solves the challenge of constructing a wall with only one-sided access, but the need for a complete exterior wall with a weather-resistive barrier and exterior cladding requires alternative solutions.

PRE-ASSEMBLED WALL

Precast concrete, unitized curtainwall, and panelized exterior insulation and finish systems (EIFS) are all examples of pre-assembled exterior-exposed walls. The concept of pre-assembled exterior walls can be adopted and modified for tilting a pre-assembled wall in place from the interior. These pre-assembled "tilt-up" walls are non-load-bearing walls that span between floor slabs (**Fig. 5**) and between load-bearing columns on either side. These pre-assembled tilt-up framed walls are not to be confused with typical tilt-up construction which are load-bearing exterior walls. Each tilt-up wall panel includes the framing, exterior sheathing, weather-resistive barrier, and exterior cladding. The size of each pre-assembled wall section is constrained by the installers' ability to manually lift and tilt the wall into place.

The detailing for pre-assembled framed walls at the top of slab, bottom of slab and between panels requires special consideration for the one-sided construction from a fire resistance and waterproofing perspective. The designer must recognize that the tilt-up panel-to-panel joints are unconventional with two studs back to back (**Fig. 5B**) and must obtain approval for the fire-resistant detail for the joinery from the authority having jurisdiction. In addition, the panel-to-panel joint requires a seal in the weather-resistive barrier that must not interfere with the fire resistance requirements. When exterior cladding is not required by the governing code, the installer can reach from the adjacent panel or from the floor above to seal the panel joint. When exterior cladding is required, the weather barrier seal will be a blind smash seal that relies on sheet-metal flashing at the slab above to shield the joint from exposure and

deflect surface water. **Figure 5** provides an example of a tilt-up wall assembly and the corresponding details that were approved and executed on a project that has been in service for several years with no reported issues.

CONCLUSIONS

For urban infill construction projects, designers and contractors must design and construct the exterior enclosure mere inches from neighboring buildings. Understanding the condition of the neighboring building is critical to the owner and designers of the infill building to evaluate the available options for a well performing exterior enclosure along the property line.

REFERENCE

ASCE (2022). *Minimum Design Loads for Buildings and Other Structures*, Standard ASCE/SEI 7-22. American Society of Civil Engineers (ASCE), Reston, VA.

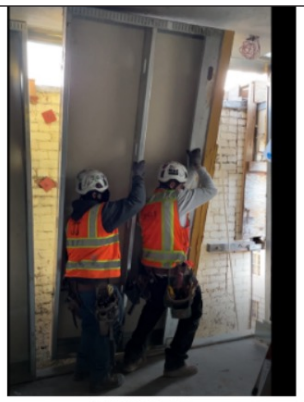


FIGURE 5A

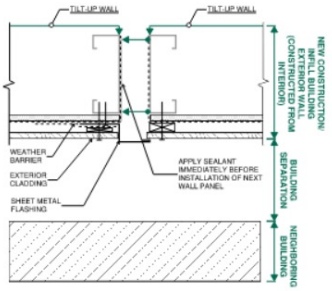


FIGURE 5B

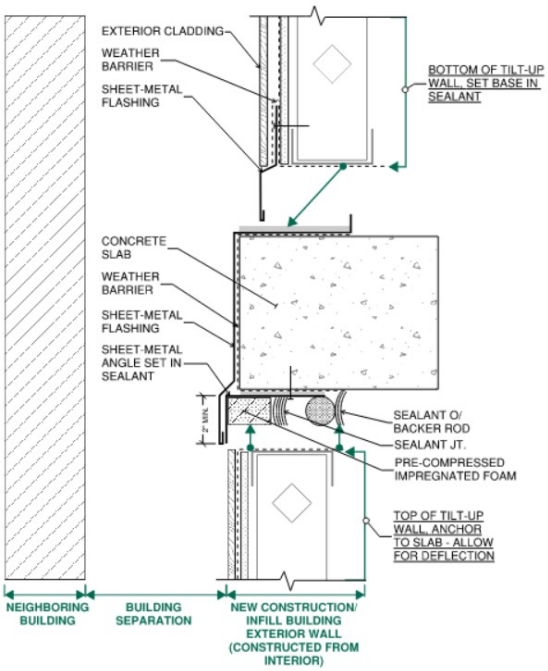


FIGURE 5C

FIGURE 5. Figure 5A: Contractors lifting tilt-up panel into the property line wall opening. Figure 5B: Plan section detail at tilt-up wall. Figure 5C: Section detail at tilt-up wall.

ADHERED MASONRY SEISMIC TESTING

ABSTRACT

This article focuses on adhered masonry with commercial buildings, not Residential buildings. This research was confirmed via our consortium of partners including architects, structural engineers, enclosure consultants, industry manufacturers, and masonry organizations over three years of research.

The scope of this paper is to summarize the testing completed for adhered masonry, specifically the seismic aspects of this code.

The principal findings include a suggested limit of height that is safe to apply adhered masonry above occupied levels based on physics and test results. Other key findings include test methodology created, adhesive type, and details. Unrelated, we also discovered verification of IGU (insulated glazing units) compliance in vinyl windows.

LEARNING OBJECTIVES

- Identify the current requirements of the national code in relation to adhered masonry (installed with other cladding / glazing systems) in resisting seismic events.
- Explain how to test and determine if adhered masonry cladding complies with the national seismic code.
- Discuss why the national seismic code requirements were developed and are applicable across various regions in the United States.
- List four challenges (with corresponding solutions) each practitioner is likely to encounter while researching, developing, and designing cladding systems to comply with the national code.
- State the simple rule of thumb that can be applied to any adhered masonry building to determine if the installation meets code.

SPEAKER



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With 26 years of experience working as an enclosure-focused architect, building scientist, and University of Oregon professor, Sean Scott has made a habit of contributing to the building industry field of knowledge and educating the industry regarding enclosures. He is known as a "process-driven" high value member of the enclosure field in the Pacific Northwest. With his clear, concise communication style, he leads his firm of almost 300 staff for enclosures through consulting, research, and education. He has served on the Portland Building Enclosure Council and has been an enclosure professor at the University of Oregon.

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This research consortium included Mike Baker, Heidi Clark, John Gallup, Tonia Neal, Monka Nain, David Aronson, Peter Dusika, Harold Friberg, Bob Duke, Tony Fuller, and Sean Scott. Compliance with the prescriptive aspects of the code (TMS 402/602) is one aspect of the code. Other aspects include the *International Building Code's* (IBC) chapter 16 referencing chapter 14, which requires compliance with ASCE (American Society of Civil Engineers) 7, chapter 13, which requires cladding, architectural components, and other aspects to stay on the building during the design seismic event. Specifically, 1401.1 is the charging language stating that all content in chapter 14 applies to exterior walls and "exterior wall coverings" which are both defined in chapter 2 to include assembly of materials on the exterior side of exterior walls providing weather-resisting barrier, aesthetics, including veneers. 1403.1 states exterior walls need to comply with Chapter 16. 1601.1 is the charging language stating all content in chapter 16 applies to portions of building regulated by code (which includes exterior walls and exterior wall coverings), as both are listed in code definitions. There is charging language and requirement language for both terms. 1613.1 states earthquake loads need to be accommodated per ASCE 7, chapters 11–13, 15, 17, 18. ASCE 7 chapter 13 is for nonstructural components (like cladding). 13.5.1 is the charging language stating all architectural components and their supports and attachments shall satisfy the requirements of this section. 13.5.3 states exterior non-structural wall elements and connections shall be designed to accommodate seismic relative displacement. 13.5.3 states such elements shall be supported by means of positive and direct structural supports or by mechanical connections and fasteners in accordance with the following requirements. The following requirements contains a reference to Table 13.5.1, which contains "wall elements" as an "architectural component." The code does not state a shake test is required and allows alternative methods which shake tests are included. Authorities having jurisdiction (AHJs) are not required to catch issues and have limited liability. Design Professionals have the responsibility to create designs that meet all aspects of the codes.

The TMS 402/602 prescribes loading to be transferred from veneer and into the structural backing wall. The structural backing wall needs to be designed to adequately provide resistance and meet deflection limits when subjected to the code-prescribed loadings. TMS 402/602 further clarifies flexural tensile stresses are not to be transferred to the veneer. Design and detailing are required to consider differential movement between veneer and backing.

Since seismic activity varies across the United States, and not every building has adhered masonry, and the design seismic event is not common, we don't see this liability in lawsuits frequently related to SEISMIC issues for adhered masonry.

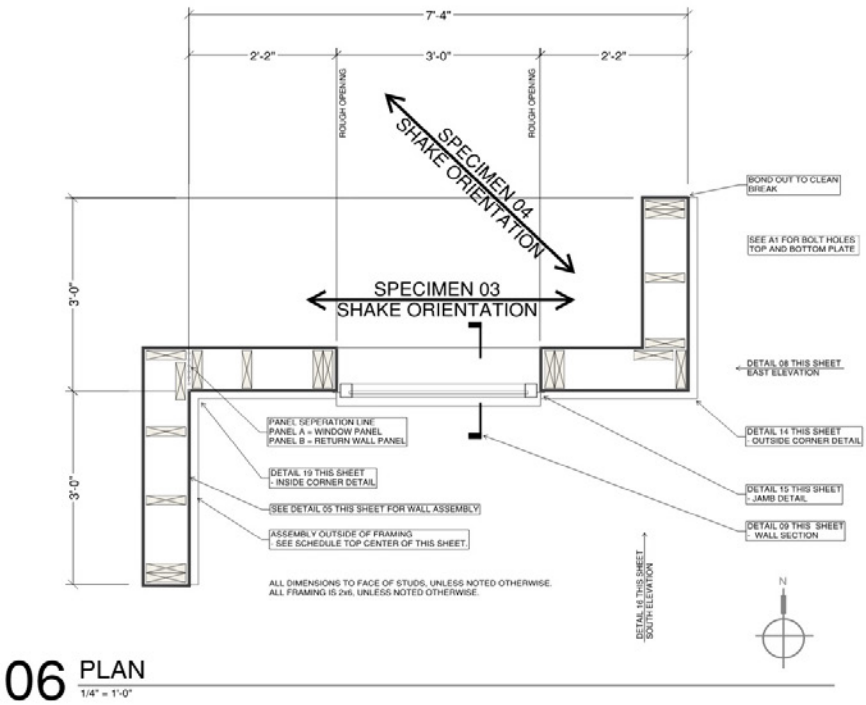
However, we are seeing common adhered masonry failing by falling from buildings between seismic events. It even occurs with attached masonry. Adding seismic events on these failures, and in some regions, this is a *large* movement.

Additional testing is encouraged to help establish protocols in the industry. As of this writing, there are ASTM International committees considering this research to start the process of making the methodology utilized in this research part of an ASTM standard. This testing is for framed core wall structures only as the behavior would be vastly different with mass walls that are more rigid and tend to rack less in elevation.

While meeting TMS 402 / 602 it is presumed the system meets adhesion requirements between backing and adhered units to meet shear strength, it does not mean the system can be confirmed to resist the design seismic event with mechanics alone. The reason is each building has varied joint locations, geometries of facades or openings, products, and assemblies. This is the reason the consortium wanted to test to include variables noted above as we could not be certain it met the design event without testing. TMS 402 / 602 does have seismic weight requirements of 12 psf maximum.

TESTING

Testing included the three most common framed assemblies at Portland State University by the Masonry Consortium of Manufacturers, Engineers, Architects, and Façade Engineers. Assembly 1 is wood framed direct applied. Assembly 2 is wood framed wood furring. Assembly 3 is metal framed metal clip and rail girts. Shake Protocol FEMA (Federal



06 PLAN
1/4" = 1'-0"



Emergency Management Agency) 461 was utilized as the most appropriate among the 12 available in the industry because it focused on architectural components. The other 11 are available to be reviewed but do not pertain to this paper. Each mockup built contained an outside corner, inside corner, and window, with stone lower and brick upper of a 10-foot high series of walls platform framed as seen in plan and image above.

Drift of the code maximum 2.0% (2.4 inches) was utilized without acceleration per the FEMA 461 protocol. Two complete mockups (specimens) were built for each of three assemblies for a total of six tests.

Rather than a pass/fail criteria, we adopted a more of a greyscale feedback, meaning the results related to how high up on the building above occupied level the system could be installed relating weight of falling object from test specimen to the height of the building using a simple formula. Height on building in feet = 96 / Weight of heaviest falling object from specimen in oz. The inverse formula works as well. W = 96/H or H=96/W.

Test results are for the assembly, geometry, products tested. This is reasonable to propose to the industry as a new ASTM International because it's similar to any fire test for a fire rated assembly or detail or NFPA (National Fire Protection Agency) 285 or Curtain wall bypassing a floor.

RESULTS

The results showed all assemblies without limit to height, except wood framed wood furring yielding a 69-foot-zero-inch height limit above occupied space (sidewalk or occupied roof below). This is because a 1.4 oz piece was the heaviest that fell from that specimen, and the equations above result in 69-feet-zero-inches height limit from that weight.

Specimen 2 with wood frame and wood furring had a 5.2 oz piece that fell after the code limit of 2.0% story drift that would have limited it to 18.5=foot if it fell one cycle earlier. 2.0% is the limit from the structural code. How it is applied to all our specimens may illustrate what this means. Our top of floor to top of floor height is 120 inches. 120 x 0.02 = 2.4 inches maximum drift horizontally of the top floor vs the floor staying still as a zero point reference.

As of early 2023, TMS 401/402 2022 has published 13.3.2.5, b limiting prescriptive heights to 60-feet-zero-inches but that won't be adopted by the model code or other states until 2025.

The results offer the first seismic adhered masonry testing that contains built conditions and/or induces shear into the adhesive plane (meaning testing the adhesive strength in the adhesive plane). We learned joint spacing from corners is critical. We learned the IGU (insulated glazing unit) did not break due to the ½-inch pocket inside the window frame and the window frame coming apart at 45 degrees in elevation at window frame corners.

APPLICATION

To apply the found information, it is reasonable for an architect on an adhered masonry building to match the tested assemblies, geometry, and products within the extensions offered in the test reports. The extensions allowed by the structural engineer

overseeing this testing include those listed below are changes designers could have in their built solution that do not (in their professional opinion) change the level of safety from conditions tested. The extensions include the changing the following.

1. Size, depth and spacing of wood or metal studs
2. Grade of wood studs
3. Thickness of metal stud material
4. Adhered veneer type and size provided weight was less than maximum allowed via prescriptive code and adhesion is equal to that tested
5. Sheathing manufacturer substituted has the same structural properties
6. Wall membrane and opening membranes substituted products when adhesive is NOT adhered to membrane
7. Flashing configuration around window substituted to any configuration
8. Sealant products changing with the same movement capabilities
9. Window manufacturer substituted has the same movement capabilities
10. Insulation manufacturer substituted has the same compressive strength

Test reports are necessary to provide test results that can be applied to built conditions to prove that designs being built meet the intent of the code. The other option is to ask the structural engineer for an "equivalency letter" stating to the architect the design is just as safe as what was tested (including extensions). In that letter, all changes should be taken into account beyond test conditions or extensions. For example, if the design has less than 2.0% code maximum interstory drift, that would reflect well for the design vs what was tested. This is the same methodology used on NFPA (National Fire Protection Agency) 285 testing, curtainwall floor bypass testing, or any fire rated testing in that a fire engineer is engaged to give an equivalency letter to the architect stating the design is just as safe as the conditions tested.

Following ASTM International C 1063 that several masonry institutes (Masonry Institute of Oregon, Masonry Institute of Washington, International Masonry Institute, and others) have published is another recommendation of this article, as noted below to locate movement joints made of backer rod and sealant joints through masonry and adhesive.

- 144-square-foot maximum area of each panel in elevation between joints
- 18-foot maximum horizontal or vertical distance between joints
- 2.5:1 maximum height to width ratio in elevation
- Change in height or backup materials
- Opening edges (at least one edge if not both)

It is also recommended to add a standard of a vertical running movement joints within 24 inches of outside and inside corners.

Better seismic performance was found to be higher when using cementitious polymer-modified adhesives instead of Type S mortar. Type S mortar does not have the adhesive qualities that adhesive does.

CONCLUSIONS

This testing focused on the three most common assemblies built, and it allows many extensions. Architects are responsible to be sure their design meets code. One way to accomplish this with adhered masonry is to get an equivalency letter from their structural engineer stating the design is just as safe as the tested conditions with extensions if the products and design does not match what is tested (just like any fire testing). Some structural engineers may not be willing since it's not based on a standardized test yet. This research also pioneered a testing methodology that is being considered for future ASTM International publications. TMS (The Masonry Standard) 402/602 – 2022 published in 2023 now has a height limit of 60 feet. This testing showed unlimited height except wood frame wood furring showing 69-feet limit. Meeting 402/602 prescriptive does not alleviate the architect from the requirement of meeting the rest of the code, requiring compliance with ASCE 7, which requires cladding, glazing, roofing to stay on the building during a seismic event.

REFERENCES

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