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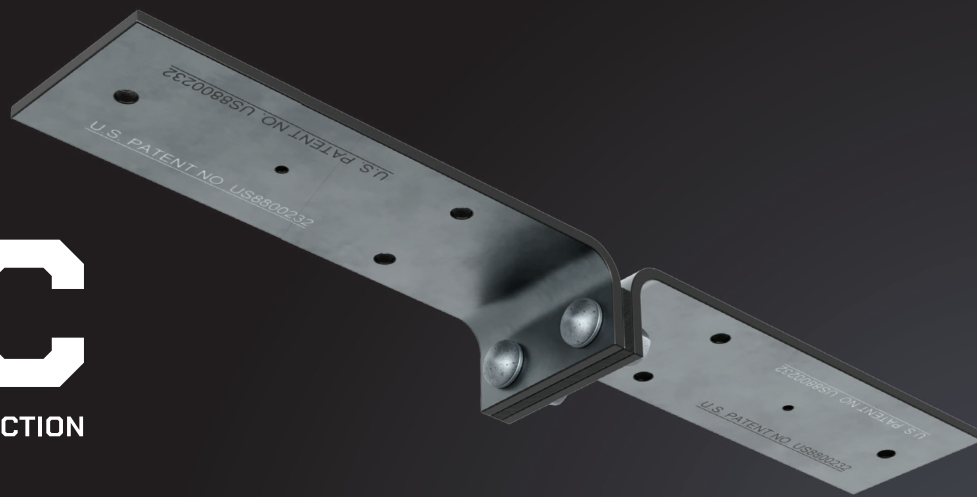

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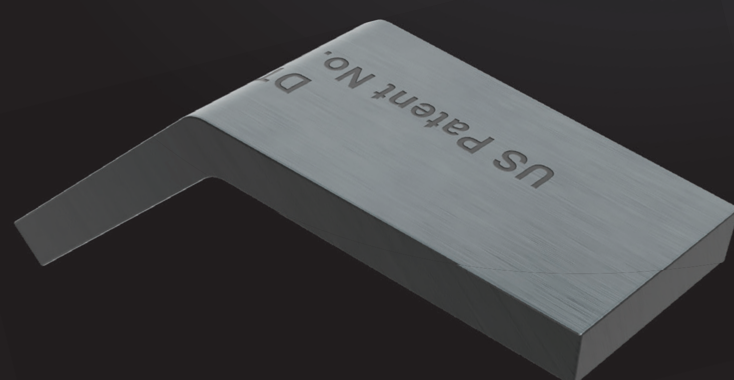

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Photo by Chris Bennett

ON THE COVER
Cascada by SolTerra in Portland's Alberta Arts District showcases striking modern architecture and a commitment to sustainability. The building features refined concrete floors, creating a durable and eco-friendly interior. Its innovative design blends seamlessly with the vibrant urban environment, redefining sustainable living.
See article on page 8.

CSI
123 North Pitt Street, Suite 450
Alexandria, VA 22314
Tel: (800) 689-2900
(703) 684-0300
Fax: (703) 236-4600
csi@csinet.org www.csiresources.org

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Production Offices
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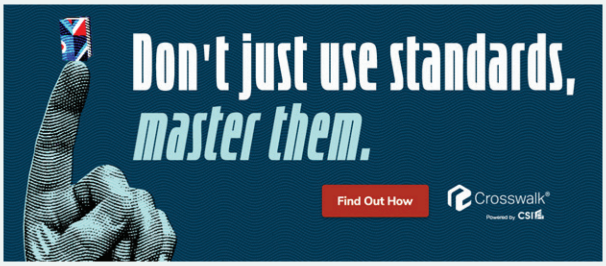
Join us in congratulating the following recipients: csiresources.org/communities/honorsandawards/awards79335 CS

CSI News & Notes



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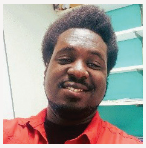
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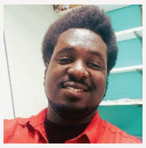
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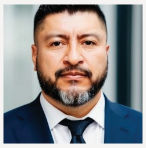

Hector Gamboa Corral


Ashely Tate

Refine Versus Shine

Defining and Defending Design Intent with Refined Concrete

By Kristina Abrams, AIA, LEED AP, CDT, CCS, Chris Bennett, CSC, iSCS, CDT, Bill DuBois, CSI, CCS, AIA, Melody Fontenot, AIA, CSI, CCCA, CCS, Kathryn Marek, AIA, CSI, CCCA, NCARB, SCIP, Keith Robinson, RSW, FCSC, FCSI, LEED AP, Ryan Stoltz, P.E., LEED AP, Vivian Volz, CSI, AIA, LEED AP, SCIP

Photo courtesy Tao Group Solutions

AFTER YEARS OF GRAPPLING WITH CLIENT CALLBACKS, LEGAL DISPUTES, AND FINANCIAL LOSSES FROM POOR POLISHED CONCRETE INSTALLATIONS, THE INDUSTRY HAS REACHED A BREAKING POINT: PROHIBIT POLISHED CONCRETE. THE CYCLE OF REPEATED FAILURES CAN NO LONGER CONTINUE, PROMPTING THE URGENT QUESTION—WHAT NOW?

Owners and design teams are not protected by today's inadequate and vague polished concrete specifications. From floors failing before substantial completion to skyrocketing change orders for never-ending densifier applications to the billions lost through delayed schedules, legal disputes, and contingency hemorrhaging, enough is enough.

What was once promised as a durable, low-maintenance flooring solution has been replaced by a patchwork of temporary sealers, densifiers, and polyureas—products that often require reinstallation almost immediately after application. Despite calls for clarity in specification language with accurate descriptions of work results, the definition of polished concrete has broadened to accommodate any floor finish that produces a shine. The industry urgently needs a specification framework that is measurable, verifiable, and defensible.

Without a quantifiable specification to convey contract requirements, project teams will continue to be handed polished concrete floors that are ripe for change orders and expensive to maintain. Contractors and design teams will continue to pay out contingencies without understanding what went wrong and how to protect themselves in the future. Thus, there is a need for a new solution to achieve a more reliable result that exceeds expectations. Building on straightforward material testing and proven project successes, the industry is making significant strides toward developing accountable language and precise definitions that can be

The refinement differences are clearly visible in this polished concrete image. It is likely that the benchmarks for this polishing scope were gloss-based and the design team had no way to protect the owner from this outcome.

Photo courtesy Vivian Volz

Despite this retail store being open for less than 18 months, the polished concrete finish has failed leaving an unsightly, pitted, unrefined concrete surface.

Photo courtesy Bennett Build

universally specified to address concrete floor challenges. The focus has shifted to demanding results—quantifiable, repeatable, and validated outcomes through physical testing of the finished product delivered to the client.

A new MasterFormat number and title are being proposed to establish a common language and eliminate the misinterpretations that led to the current challenges: 03 35 44–Refined Concrete Finishing. The remainder of this article will detail the key elements of the proposed new specification, highlighting significant differences and improvements over previous polished concrete sections. It will also examine suppliers' confusing and conflicting language, contributing to the misunderstandings and missteps that brought the industry to this point.

The polished concrete problem

The design industry has struggled with polished concrete for years. Contradictory weak specification language has left owners and design teams to simplify their aesthetic preferences based on photo representations and rely on marketing information about durability and low maintenance without proof. Inevitably, projects continue to have mixed results, where owners must accept problematic floors because they cannot be rejected contractually.

The language used to describe polished concrete lacks precision and clarity, making it difficult for owners to understand what they are purchasing, tough for designers to specify, and unclear for contractors to understand what they are required to build. Terms such as "high gloss," "reflective," "sustainable," and "durable" can be highly subjective and used differently by manufacturers. This ambiguity can lead to misinformed choices based on marketing rather than factual performance characteristics.

The categorization of polished concrete into various levels of sheen can confuse even veteran professionals, as the criteria is broad, and producer results can vary widely. The Concrete Polishing Council (CPC) provides four appearance levels using Distinctness of Image (DOI) gloss with Level 1: flat, Level 2: satin, Level 3: polished, and Level 4: highly polished with gloss and reflectivity as the measurement guideline. These levels, from CPC's Exposed/Polished Concrete Exposure Chart, are defined by image distinction, gloss value, and haze—characteristics based on reflection and lighting, not actual physical characteristics of the concrete.

There are countless floor finishes (*e.g.* grind and seals, burnished polish concrete, etc.) and many ways to achieve gloss levels. When the path to the work result is only gloss, contractors will seek out the most economical way to fit the definition of polished

Both refined concrete and polished concrete score high marks on aesthetics, but the cost of ownership increases with polished concrete while the cost of ownership decreases with refined concrete. Maintenance teams at Waco ISD are picking up the skills to measure, meter, and maintain exposed concrete surfaces without stripping and sealing.

Photo courtesy Bennett Build

concrete and meet the required DOI gloss level. Despite the design team's best efforts in using the specification guidelines provided by manufacturers, results often disappoint. Sometimes, that same spec language is used to defend the undesired outcome—rather than serving their intended purpose to ensure the desired quality results for the owner.

What is polished concrete, exactly?

According to CPC, polished concrete is "the act of changing a concrete floor surface, with or without aggregate exposure, to achieve a specified level of finished gloss." The definition further states there are different types of polished concrete: "Bonded Abrasive Polished Concrete, Burnished Polished Concrete, or Hybrid Polished Concrete."

CPC defines bonded abrasive polished concrete as "the multi-step operation of mechanically grinding, honing, and polishing a concrete floor surface with bonded abrasives to cut a concrete floor… to achieve a specified level of CPC-defined finished gloss." Burnished polished concrete is defined by CPC as "the multi-step operation of mechanical friction-rubbing a concrete floor surface with or without waxes or resins to achieve a specified level of CPC defined finished gloss." By definition, the burnished version of polished concrete can include coating the floor with waxes and resins. The CPC notes that this "yields a less durable finish and requires more maintenance than bonded abrasive polished concrete."

Hybrid polished concrete combines burnished polished concrete, bonded abrasive concrete, or anything in between that attempts "to achieve the specified level of CPC-defined finished gloss."

The emphasis on shine

This emphasis on achieving gloss (specular gloss, DOI gloss, etc.) has led to practices prioritizing aesthetic qualities over functional durability. The pursuit of shine in polished concrete usually involves the use of chemical sealers, sometimes called "guards," latex, acrylic, and various grouts, as well as solid epoxy tooling, which coats the floor as it is superheated and resin is transferred via friction rubbing to fill and hide scratches and imperfections with a thin shiny coating rather than correct the concrete surface. Whether a floor is refined without topical treatments or coated with resins and sealers, CPC classifies all these floor types as "polished concrete" if they achieve gloss—sometimes.

The glossary page of the CPC includes a definition for surface-coated concrete, indicating that "surface-coated concrete (waxes and resins) does not conform to the definition of polished concrete. It is the operation of applying a film-forming coating to a concrete floor surface to achieve a specified level of finished gloss." In other words, the defined end result of surface-coated concrete is essentially the same as burnished polished concrete. By definition, both aim to achieve a level of gloss. This means substitutions involving any cheap grind and seal or temporary burnished film-forming material contractually meet the design intent—despite not meeting the design intent. How can a specifier reject a work result that is both allowed and not allowed?

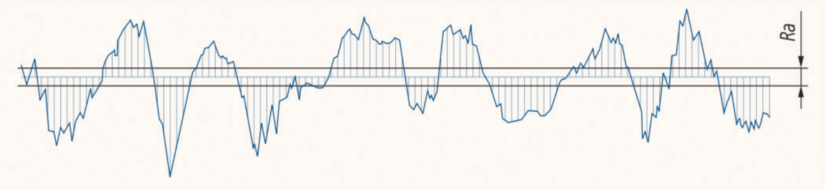
While concrete is inherently durable, an overly aggressive dry polishing process often compromises the material's integrity by destroying the finished slab's most durable top "skin," making it more susceptible to staining, scratching, and general wear. This degradation necessitates an initial grout coat and more frequent lifecycle refinishing and maintenance, contradicting initial claims of a problem-free floor. Thus, while the polished surface may initially appear appealing and shiny, its long-term viability (compounded by frequent coating applications) is questionable.

Concrete refining

The refining process is guided by initial measurements of average roughness (Ra) and Mohs hardness readings, which will be discussed in detail shortly. Refining includes wet mechanical refinement with power trowels or grinding equipment and chemical components that react with cement particles and free lime to stabilize and reshape the surface. Cement binds to form concrete. The unhydrated cement in the concrete tailings gets reincorporated to strengthen the surface concrete, and the newly exposed cementitious content has the opportunity to hydrate and strengthen the surface while it is in a malleable state, reworked back into itself, and then refined to provide an improved denser surface. Many professionals may be unaware that the top surface of a concrete slab can be reworked and refined after initial hardening, making refined concrete appropriate for a slab that is 40 years old or brand new.

The top 19 to 25 mm (0.75 to 1 in.) of a concrete slab is most susceptible to physical damage and the effects of nature. Decreased moisture content (MC) and lowered relative humidity (RH) from poor external curing practices also impact the durability of the top layer. This can significantly reduce the surface strength of concrete when the humidity drops below 80 percent as the hydration of the cement particles nearly stops below this level and does not restart when RH increases. The concrete refining process provides immense value and redefines the finishing and maintenance processes to help answer many of these issues.

A refined slab exhibits the same aesthetic capabilities of polished concrete (aggregate exposure levels, color, and DOI gloss) without coatings, sealers, and resinous grouts common with polished concrete. In fact, the concrete itself becomes the grout during the refinement process, addressing pop-outs, cracks, and other small voids. Refined concrete creates a measurable, monolithic floor slab with its surface integrity intact.



Microsurface benchmarks for refined concrete are measured in microinches (µin) or in micrometers (µm) by a device called a profilometer. Additional readings for gloss or gloss clarity may be taken in conjunction with surface micro texture readings after verification of physical refinement. Along with the Mohs scratch test, these measurements provide important contractual goals to describe design intent as well as defend against resinous diamond tooling, epoxy grouts, and other clear coat substitutions that do not provide the durability of refined concrete. Referenced from A New Concrete Glossary by Keith Robinson, Bill DuBois, Rae Taylor, Chris Bennett, and John Guill.

Image courtesy Mitutoyo Bulletin No. 2229

"Unlike polished concrete, which may be a mix of resinous and cementitious materials, the single concrete matrix of refined concrete will accept color, react with humidity, and respond to its environment in more predictable and aesthetically pleasing ways," says Chris Bishop, president of the National Concrete Refinement Institute (NCRI).

Refining concrete eliminates topical impurities that have become standard with most "polished concrete" methodologies and results in more flexibility with the final finish, such as staining, dyeing, or even maintaining a truly refined concrete surface, but for much less money.

Refined concrete benchmarks

Physical readings from the concrete itself quantify performance benchmarks for refined concrete. Aesthetic benchmarks from the coating industry (DOI gloss, lumen levels, etc.) can also be used. Still, physical benchmarks ensure resilience, durability, simple maintenance, and a long service life that owners associate with exposed concrete floors. The three most important physical benchmarks are Ra, Mohs hardness, and dynamic coefficient of friction (DCOF).

Average roughness (Ra)

These microsurface benchmarks for refined concrete are measured in microinches (µin) or micrometers (µm) per the American Society of Mechanical Engineers (ASME) B46.1-2019 (R2019), *Standard for*

Architects, contractors, and material science students learning how to process concrete surfaces and achieve consistent refinement as measured through average roughness (Ra) at University of Alberta's campus.

Photo courtesy Keith Robinson

Surface Texture (Surface Roughness, Waviness, and Lay). This standard provides a practical method for measuring Ra on a surface.

Scott Langerman, P.E., of Langerman Engineering says, "Measuring the roughness average (Ra) provides input for concrete surface refinement. The Ra test is performed with equipment (profilometers) that measure the roughness/smoothness to the micro-inch. Data are then used to determine steps for the initial grinding process, minimizing surface micro fractures and maximizing refinement. After refinement is done, the Ra test is then performed again to determine that project specifications have been achieved."

Ra notes

- Ra is the numerical average of the total peaks and valleys across the length of a tested surface. It is also sometimes called the Center Line Average (CLA).
- A minimum specification benchmark for placement and finishing new concrete should be 2.54µm (100µin) or less.
- Minimum Ra benchmarks for refined concrete may include matte finish: 0.76µm [30µin] or less; semigloss: 0.50µm [20µin] or less; glossy: 0.254µm [10µin] or less. A tolerance of +/- 0.127µm [5µin] is acceptable in most cases.
- The NCRI provides education to architects and engineers and certification courses on surface measurement and refinement to installers.

Mohs

The Mohs test is a simple verification that can be performed on hardened concrete to help determine when the slab is ready to receive installation of a refined concrete finish and set minimum contractual benchmarks for the completed concrete surface. The ASTM standards referencing the Mohs hardness test are ASTM C1790-16 and ASTM C1895-20. These standards outline procedures for determining the hardness of a material using a scratch test, such as the Mohs hardness scale. While the Mohs test is a qualitative method originally devised in the early 19th century, these standards incorporate the Mohs principle and adapt it for specific industrial applications, including concrete and other materials that can be used to design and defend a minimum expectation of abrasion resistance.

Mohs notes

- The Mohs scale ranks materials based on their ability to scratch softer materials.
- It is a comparative scale, ranging from 1 (talc) to 10 (diamond).
- ASTM C1790-16 and ASTM C1895-20 emphasize controlled testing procedures to ensure reliability and repeatability.
- A minimum specification benchmark for a refined floor can be safely set at 7Mohs.
- 7Mohs is roughly equivalent to quartz. Natural concrete can achieve up to 8 and 9Mohs.

A large aggregate design style was selected for the second deck refined concrete floors at Cascada Portland.
Photo courtesy Tao Group Solutions

Dynamic coefficient of friction (DCOF)

Some film-forming coatings, such as epoxy and acrylic systems, can achieve a high gloss when burnished, creating a refined look to the floor. However, they also create a surface film that poses challenges for maintaining adequate traction and, consequently, a higher coefficient of friction (COF). With slips, trips, and falls constituting a significant percentage of workplace injuries, including 67 percent occurring on level surfaces, achieving and maintaining an appropriate COF is critical for user safety. DCOF is a measurement of the floor, similar to Ra and Mohs.

DCOF notes

- DCOF measures the resistance between two surfaces in relative motion.
- DCOF measures a surface already in motion, as opposed to the static coefficient of friction (SCOF), which measures resistance before motion begins (*i.e.* lawsuits and injuries from people slipping and falling are more directly related to DCOF, not static COF.).
- The NFSI is a resource that provides training and third-party testing and actively supports standards such as B101.1, B101.3, and B101.4.
- ANSI B101.4 includes updated metrics for bare-foot travel on hard surfaces.

Final set

While polished concrete can offer certain aesthetic and practical advantages, focusing on surface gloss or shine rather than lasting durability compromises the end result. The impacts of outdated topical treatments and resinous tooling used in current polishing practices, coupled with the lack of clear definitions and standards, present significant challenges for design teams and contractors. Clarity is power, but the confusing language surrounding polished concrete continues to breed errors, change orders, and deep frustration.

As the construction industry progresses, it is essential to emphasize transparency, precision, and authentic quality in flooring solutions, moving away from materials and methods that favor short-term aesthetics and financial gain over long-lasting performance and value.

It is time to move beyond the confusion surrounding polished concrete and set new standards by introducing “refined concrete” as a long-overdue solution. Measuring light reflected off a floor is not the same as assessing the quality and performance of the floor itself.

Refined concrete such as Cascada's can be installed on old concrete, existing polished concrete finishes, and within 24 hours on newly poured slabs if desired.

Photo courtesy Tao Group Solutions

Physical benchmarks addressing the performance of the concrete must more effectively anchor the design intent to deliver truly durable and sustainable finished concrete floors. Section 03 35 44–Refined Concrete Finishing is a step toward a more "concrete" exposed finish outcome. The next time a client considers a polished concrete floor, look closer at their expectations. Suppose their vision extends beyond mere shine to include durability, sustainability, and a maintenance schedule that avoids decades of reliance on petrochemical veneers. In that case, they may actually be looking for refined concrete. **CS**

Resources

To explore the relationship between friction coefficient and surface roughness of stone and ceramic floors, refer to this detailed study on ResearchGate, researchgate.net/publication/355344967_Relationship_between_Friction_Coefficient_and_Surface_Roughness_of_Stone_and_Ceramic_Floors

For insights into communicating effectively with project teams and redefining concrete language, visit *Construction Canada*'s article, constructioncanada.net/changing-the-language-of-concrete-communicating-clearly-with-the-project-team

To learn more about the ANSI/NFSI B101.2-2012 standard for walking surface safety, check out this comprehensive overview on the ANSI Webstore, webstore.ansi.org/standards/nfsi/ansinfsib1012012-1443377?gad_source=1&gclid=CjwKCAiA9IC6BhA3EiwAsbltOMdpSLzOzGmvpNFftUAYOxdihJoO1Mk9thL_7OhTGF-s2jOU-B-UDRoCQHIQAvD_BwE

For information on advancing concrete refinement practices, explore the National Concrete Refinement Institute's (NCRI) website, theNCRI.com.

To ensure safe walking surfaces on exposed concrete, consider reading this article from *The Construction Specifier*, constructionspecifier.com/ensuring-safe-walking-surfaces-exposed-concrete

For a discussion on polished concrete that goes beyond aesthetics, delve into this feature in *The Construction Specifier*, constructionspecifier.com/polished-concrete-not-just-shiny

To clarify terminology related to concrete polishing, consult the American Society of Concrete Contractors' (ASCC) glossary of terms, ascconline.org/polishing/glossary

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ADDITIONAL INFORMATION

Authors

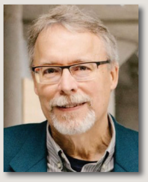
Kristina Abrams, AIA, iSCS, LEED AP, CDT, CCS, is an architect with more than 20 years of experience collaborating with design teams nationwide. As director of specifications at O'Connell Robertson, she focuses on establishing clear project terminology early in design to strengthen communication and improve contract documents. Abrams is passionate about bridging the gap between drawing and specification intent design intent.

Chris Bennett, CSC, iSCS, CDT, is a concrete consultant in Portland, Ore. He has trained thousands of architects, engineers, and contractors on how to produce better results and reduce risk in concrete. His firm, Bennett Build, leads project teams in lowering the economic and environmental costs of designing and implementing stronger concrete systems.

Bill DuBois, AIA, CSI, CCS, is an architect who is passionate about working with the entire construction project team, which includes owners, designers, constructors, and suppliers. DuBois strives to improve the decision-making processes necessary for efficiently implementing powerful design solutions and creating construction specifications to reduce risk and maximize value.

Melody Fontenot, AIA, CSI, CCCA, CCS, iSCS, SCIP, is a senior specification writer with Conspectus Inc., based in Portland, Ore. A licensed architect with more than 20 years of experience, she specializes in project management, construction documents, and contract administration. Passionate about product research and spec knowledge, she strives to improve communication across the architecture, engineering, construction, and owner (AECO) industry.

Kathryn Marek, AIA, CSI, CCCA, NCARB, SCIP is a specifier and an architect. She is the principal at KM Architectural Consulting and the current president of SCIP.



Keith Robinson, RSW, FCSC, FCSI, is an architect and specifier in Edmonton, Alberta, Canada. Robinson also instructs courses for the University of Alberta, acts as an advisor to several construction groups, and sits on many standards review committees for ASTM and the National Fire Protection Association (NFPA).

Ryan Stoltz, P.E., iSCS, LEED AP is a licensed structural engineer, LEED accredited professional, and associate principal at Structures, a North American engineering firm in Austin, Texas.

Vivian Volz, AIA, CSI, LEED AP, SCIP, is an independent specifier for commercial, public, and multifamily projects in California and beyond. Volz has served as a local and national leader in the Construction Specifications Institute (CSI) and is SCIP's immediate past president.

Key Takeaways

The polished concrete industry has long struggled with vague specifications, disappointing outcomes, and high maintenance demands. Floors often fail to meet promised durability and sustainability, relying on temporary treatments and resinous coatings. The proposed solution, "refined concrete," emphasizes measurable benchmarks like Ra, Mohs, and DCOF to ensure lasting performance. Unlike polished concrete, refined concrete uses a single concrete matrix to deliver durability, sustainability, and low maintenance without relying on petrochemical-based veneers. A new MasterFormat section, 03 35 44–Refined Concrete Finishing, aims to establish clarity and accountability. This approach prioritizes functional quality over superficial shine, providing a more durable and predictable result for clients seeking sustainable flooring solutions.

MasterFormat No.

03 00 00—Concrete

09 60 00—Flooring

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C2030—Flooring

Keywords

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Concrete specifications

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Protecting Sensitive Sites

Noise and Vibration Rules

By Todd Busch

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IN THE UNITED STATES AND CANADA, THREE PLACES ARE UNIQUELY REGULATED BY GOVERNMENT AUTHORITIES FOR CONSTRUCTION NOISE AND/OR VIBRATION. THESE INCLUDE THE CITY OF NEW YORK, THE STATE OF CALIFORNIA, AND THE CITY OF TORONTO. THE REGULATIONS REQUIRE STUDIES BEFORE CONSTRUCTION ACTIVITY AND/OR NOISE AND VIBRATION MONITORING DURING CONSTRUCTION. THE UNDERLYING OBJECTIVE OF THESE REGULATIONS REPRESENTS EITHER A COMMITMENT TO AVOIDING DAMAGE TO STRUCTURES IN PROXIMITY TO A CONSTRUCTION SITE OR THE REDUCED PROBABILITY OF PUBLIC ANNOYANCE.

The Province of Ontario has introduced an *Environmental Protection Act* (*EPA*) that defines a "contaminant" as any solid, liquid, gas, odor, heat, sound, vibration, radiation, or combination resulting directly or indirectly from human activities that may cause an adverse effect. As such, a statutory basis exists for extending the depth and breadth of regulation that applies to construction noise and vibration.

This is not just about the nuisance factor of industrial noise/vibration but also about the more overt health effects that may accrue from human exposure. Representative of such adverse effects are elevated blood pressure, heart rates, and sleep disturbances. Current regulations do not consider the potential for significant and adverse impacts on healthcare facilities, research laboratories, and microelectronics manufacturing operations, where

The City of New York has enacted a local law whose objective is citywide mitigation of construction noise.

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The *California Environmental Quality Act* (CEQA) defines "noise" as a part of the environment.

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sensitive instrumentation and equipment may be used. In these cases, the noise and/or vibration control requirements should often be much more restrictive.

City of New York

Local Laws of the City of New York for 2005, No.113, *Noise Control Code* and Construction Rule of January 18, 2007.

The City of New York has enacted a local law whose objective is citywide mitigation of construction noise.[2] To comply, every construction site with activity must submit a Construction Noise Mitigation Plan (CNMP) to the Department of Environmental Protection (DEP). The permit holder for construction work is expected to offer a formal noise mitigation training program to benefit supervisors.

The contents of the CNMP include a self-certification explaining that construction equipment has noise emissions that achieve the average manufacturer's operating specifications at peak loading. The DEP uses stipulated software for assessing noise complaints, the Federal Highway Administration (FHWA) Roadway Construction Noise Model (RCNM), published in January 2006. The RCNM and the Construction Rule's contents use a defined set of noise emissions for a wide range of construction equipment. Within the Construction Rule, authorized work hours range from 7 a.m. to 6 p.m. on weekdays, with the possibility of securing after-hours times through a permit. The DEP has the power to require additional noise mitigation. The contractor is expected to coordinate work hours to minimize the predicted noise impact on schools, hospitals, places of worship, and homes for the aging.

Businesses in the construction industry, commercial, cultural, and manufacturing establishments producing plainly audible sound above the sound of the immediate vicinity should become familiar with Local Law 113: *Noise Code*. The Construction Rule provides a set of stipulations for noise mitigation in conjunction with the presence of any of five defined classes of construction equipment:

- Impact equipment:
  - Pile drivers, jackhammers, hoe rams, blasting
  - Earth moving devices: Vacuum excavators
- Construction trucks: Dump trucks
- Stationary devices: Cranes, auger drills, street plates, backup alarms
- Manual devices: Concrete saws

For each of these classes of construction equipment, the stipulations include source controls, such as quieter models, mufflers and/or silencers; noise pathway controls, such as noise barriers, enclosures and/or curtains. Noise barriers, both permanent and temporary, must be built to achieve a sound transmission class (STC) rating of 30 or greater, with a general expectation that noise levels at sensitive receptors will be reduced by 5 dB or more. The Construction Rule even recommends specific construction equipment makes and models as the preferred options. Local Law 113 does not establish specific noise-level limits for construction activity. Rather, as described above, it prescribes mitigation of various kinds and sets a general expectation on the effectiveness when techniques are implemented.

State of California

California Environmental Quality Act (*CEQA*) 1970.

The *CEQA*[3] is legislation that defines "environment" as the physical conditions that exist within the area which will be affected by a proposed project, including land, air, water, minerals, flora, fauna, noise, or objects of historic or aesthetic significance (*CEQA* 21060.5). It defines "noise" as a part of the environment. Both the long-term operations of projects and short-term construction activity are subjected to study before a project begins through the preparation of a comprehensive environmental impact report (EIR) that is subject to review by a lead agency, such as a state, county, or city, along with the opportunity for public review and input.

A range of feasible alternatives defines a "project" within an EIR, each potentially requiring different mitigation. One of these is designated as the preferred alternative. In the case of construction noise and vibration, the objectives of an EIR are to document whether there is a "significant effect on the environment" when considering a quantitative "threshold of significance." Where there is a significant effect (*i.e.* "impact"), mitigation will be developed to prevent or minimize environmental damage. The resulting project is then defined to include the required mitigation, and a "mitigation monitoring plan" will be implemented during construction.

The following excerpt from a *CEQA* checklist is typically applied when assessing whether project noise or vibration would result in either "no impact," "less than significant impact," "less than significant impact with mitigation," or a "potentially significant impact" by asking whether the project would result in:

- Exposure of persons to the generation of noise levels higher than standards established in the local general plan, noise ordinance, or applicable standards of other agencies.
- Exposure of persons to or generation of excessive ground-borne vibration or ground-borne noise levels.
- A substantial temporary or periodic increase in ambient noise levels in the project vicinity, above levels existing without the project.

Unlike comparable jurisdictions in Canada and the U.S., Toronto has had a vibration municipal code chapter since May 27, 2008.

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Although *CEQA* is very comprehensive regarding the required analysis of construction noise and vibration prior to short-term construction and long-term operation, the lead agency would need to stipulate all acceptable significance thresholds for determining impact due to construction activity. Similarly, the project sponsor's development of mitigation will rely upon the defined thresholds of effects. The extent to which the definition of a threshold of impact can depend upon a noise ordinance would vary with jurisdiction.

Overview of regulations City of Toronto

Toronto Municipal Code, chapter 363, Building Construction and Demolition, Article 5, Construction Vibrations.

Unlike comparable jurisdictions in Canada and the United States, Toronto has had a vibration municipal code chapter since May 27, 2008.[1] This regulation was recently updated as of March 1, 2023. There are no stated restrictions on the times of day when construction vibration may be created. However, they are described in Chapter 591. There are no descriptions within the bylaw of exemptions for different types of construction activity and/or allowable vibration. Section 591-2.3. provides the following restrictions on noise:

No person shall emit or cause or permit the emission of sound resulting from any operation of construction equipment or any construction that is clearly audible at a point of reception:

(1) from 7 p.m. to 7 a.m. the next day, except until 9 a.m. on Saturdays; and
(2) all day on Sundays and statutory holidays.

The construction equipment is assessed for vibration concerns within a "zone of influence" (ZOI), defined by a radius away from construction activity where

In all three jurisdictions, the studies and analysis are generally assigned to consultants retained by a project proponent, such as the project owner.

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Distilled to its simplest message, the best solutions in the future include better and quieter equipment, better processes and better barriers for noise and vibration.

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the vibration amplitudes are excessive. Within this ZOI, the municipal code chapter defines "prohibited construction vibrations" to be those exceeding a stipulated peak particle velocity of 8 mm/s (0.31 in./s) below a frequency of 4 Hz, 15 mm/s (0.60 in./s) from 4 to 10 Hz, and 25 mm/s (0.98 in./s) for a frequency range above 10 Hz. An applicant for a permit must submit a vibration control form that relies upon a preliminary study prepared by a professional engineer. The vibration control form identifies the places where the ZOI extends beyond the boundaries of the construction site and identifies any buildings designated or listed under the *Ontario Heritage Act*. It also must describe sensitive structures or infrastructure in the ZOI. Where necessary, mitigation is recommended.

Chapter 363 requires pre-construction consultation with owners within the ZOI, which will be included in the form. Thus, the owner of a vibration-sensitive facility has an opportunity to state their maximum vibration limit. This is one mechanism whereby site-specific conditions may mandate lower vibration limits than the default values.

One potentially problematic aspect of dealing with vibration-sensitive facilities involves selecting appropriate vibration impact criteria. In most cases, the owners/operators of such facilities will not have in-house expertise in this area. They may have to retain experts to defend their facilities from intrusive construction activities.

The municipal code chapter requires a monitoring program to document compliance. The mitigation and monitoring program must be described in the documentation submitted for a construction work permit. A professional engineer must investigate complaints.

Lessons learned

To summarize, the following can be learned by considering the regulations in place for these two cities and a state:

- Construction noise is subject to pervasive mitigation requirements in the City of New York, but there is no comparable regulation of construction vibration. This omission extends statewide. Federally, within the Department of Transportation (DOT), guidelines are offered to address construction noise and vibration by the Federal Highway Administration (FHWA), Federal Railroad Administration (FRA), and Federal Transit Administration (FTA). These guidelines are only applied when projects are undergoing assessment via the *National Environmental Protection Act* (*NEPA*). Other projects are exempt.
- Construction noise and vibration are subject to environmental study before project approval and permitting in the State of California. Quantitative thresholds of significance for construction noise and vibration are developed on a case-by-case basis by the project sponsor, with the lead *CEQA* agency agreeing to them.
- Construction vibration is subject to quantitative limits in the City of Toronto, whereas construction noise is addressed within a municipal code chapter in less strict terms.
- Documentation of the possible environmental effects before project construction is as follows for these three places:
  - City of New York: Construction Noise Mitigation Plan.
  - State of California: Environmental Impact Report.
  - City of Toronto: Preliminary study and vibration control form.

In all three jurisdictions, the studies and analysis are generally assigned to consultants retained by a project proponent, such as the project owner. In the case of the City of Toronto, the requirements include credentials for the person(s) undertaking the work, including licensing as a professional engineer (P.Eng.). The resulting deliverables are typically subject to review and approval by regulatory authorities before permitting a project.

Conclusion

In the three cases cited in this article, the expectation is for construction/demolition contractors to comply with the regulations and produce documentation before and during work periods at a site. (The time to comply with regulations is long before the actual building process begins.) The engineering expertise required to generate such documentation is generally outside the expertise of a construction contractor—to deliver quality projects on time and on budget—which is why outside assistance is usually required and highly recommended.

Distilled to its simplest message, the best solutions in the future include better and quieter equipment, better processes and better barriers for noise and vibration. Some companies that design and manufacture construction equipment have acoustical engineers among their staff who presumably can exert some influence over noise emissions and vibration characteristics. Specialists maintain an inventory of state-of-the-art instrumentation to measure construction noise and vibration and experienced, professional staff to help clients achieve regulatory compliance. Such instrumentation for monitoring may be prudent in situations not explicitly considered by regulations, including, for example, healthcare facilities, research laboratories and microelectronics manufacturing.

The project proponent would typically bear the cost of such monitoring. In some cases, owners/operators of vibration-sensitive facilities may already have such instrumentation to support quality-control activities. **CS**

Author's note: This article documents the author's first-hand experiences working with regulatory requirements in several jurisdictions that govern allowable construction noise and vibration. The observations may be of interest to consultants seeking methods of assessment and/or those in a position to amend noise/vibration regulations in other jurisdictions.

Notes

[1] Review New York City's local law at nyc.gov/html/dep/html/noise/index.shtml

[2] See *California Environmental Quality Act* at oag.ca.gov/environment/ceqa

[3] Learn more about Toronto's municipal code chapters at toronto.ca/legdocs/municode/1184_363.pdf and toronto.ca/legdocs/municode/1184_591.pdf

ADDITIONAL **INFORMATION**

Author

Todd Busch is an invited committee member for the Canadian Board for Harmonized Construction Codes (CBHCC) sound and vibration task force. He has extensive experience as an acoustical consultant, senior engineer, and senior project manager. He has a master of applied science degree in mechanical engineering focusing on acoustics and an additional certificate in construction management. He is the owner of Todd Busch Consulting. Busch has been involved in various projects across many sectors, including environmental noise analysis and mitigation, offices, research facilities, exhibition and convention centers, auditoriums, commercial, hospitality, educational institutions, highways, railways, aviation, etc. In the last 28 years of his career, he has worked on various technical tasks covering architectural acoustics, mechanical noise and vibration, construction noise and vibration, and ground-borne vibration. Busch is affiliated with the Institute of Noise Control Engineers USA, the Audio Engineering Society (AES), and other international organizations. He has published more than 50 articles through various media outlets, including conference proceedings, peer-reviewed journal articles, and magazines.

Key Takeaways

This analysis examines unique construction noise and vibration regulations in New York City, California, and Toronto. These regulations mandate pre-construction studies and/or monitoring to prevent structural damage and public annoyance but often overlook impacts on sensitive facilities such as healthcare, research labs, and microelectronics manufacturing.

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13 48 00—Sound, Vibration, and Seismic Control

UniFormat No.

F1030.10—Sound and Vibration Control

Keywords

Division 13 | Regulations
Noise | Vibration

Internally Cured Bridges STAND THE TEST OF TIME

By Darren Medeiros

Photos courtesy Holcim

EARLY-AGE CRACKING IN BRIDGE DECKS AND STRUCTURAL ELEMENTS CAN SIGNIFICANTLY REDUCE THE FUNCTIONAL LIFE OF A BRIDGE, NECESSITATING FREQUENT REPAIRS AND PREMATURE REPLACEMENT. CRACKED AND OTHERWISE MORE PERMEABLE CONCRETE STRUCTURES CAN REPRESENT A HIGH COST TO DEPARTMENTS OF TRANSPORTATION (DOTs), THEIR CONSTITUENTS, AND THE ENVIRONMENT. PROJECT STAKEHOLDERS CAN MITIGATE THESE ECONOMIC AND ECOLOGICAL COSTS BY USING LESS PERMEABLE, MORE DURABLE AND MORE RESILIENT CONCRETE MATERIALS TO EXTEND A BRIDGE'S SERVICE LIFE.

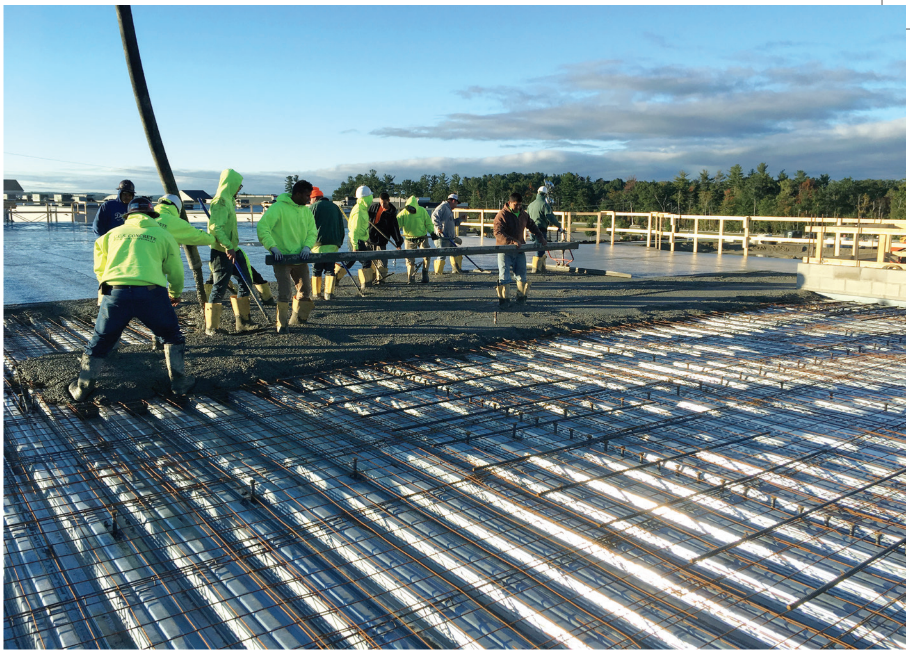
Internally cured concrete has been shown to reduce instances of both autogenous and dry shrinkage to decrease the potential for early-age cracking. This supports a concrete that is less permeable and, thereby, more resistant to chloride attack than traditionally cured mixes. Additionally, when internal curing is facilitated through pre-saturated lightweight aggregates, such as expanded shale, clay, and slate (ESCS), it can produce a denser cement microstructure,[1] supporting less permeable concrete. This is especially true for concretes with high fly ash or other cementitious materials, which can reduce chloride permeability by as much as 50 percent.[2] Further, using prewetted ESCS to facilitate internal curing can benefit bridge repair and construction projects in hotter climates by reducing the thermal stresses concrete experiences during curing, thereby delaying and minimizing the risk of cracking.[3]

The discussion around more resilient infrastructure is timely as the construction industry nears 2030's sustainability goals, considering the present state of the country's highways, bridges, and roads. In the 2021 Infrastructure Report Card, the American Society of Civil Engineers (ASCE) stated that 42 percent of highway bridges are more than 50 years old, the expected end of the service life for most bridges in the United States. Hence, engineers, specifiers, and other project stakeholders are at a critical juncture in designing more resilient bridges. Internally cured concrete can be an essential step in realizing this goal. As less permeable concrete, it can contribute to longer-lasting bridges that need fewer repairs over their service life—especially in locations near saltwater or ones where salt-based deicers are used. This reduces the total cost of ownership of a structure and contributes to improved infrastructure.

Internal curing and early-age cracking mitigation

Generally, internal curing is curing concrete from the inside out. Since 2013, the American Concrete Institute (ACI) has defined internal curing as "a process by which the hydration of cement continues because of the availability of internal water that is not part of the mixing water" and has outlined specific standards in ACI 308.1.

Prewetted ESCS fine aggregate supplies additional water throughout the concrete mix to continue hydration after the concrete is set. As the concrete cures, it draws the water out of the pores to keep the mix internally hydrated. The extra hydration reduces shrinkage until the concrete gains enough strength to minimize cracking, a common cause of chloride penetration. In a 2009 study, researchers stated using lightweight fine aggregates contributes to a 67 percent reduction of autogenous shrinkage at 28 days and a 37 percent reduction in drying shrinkage at 90 days.[4] Given shrinkage can be a significant contributing factor to cracking, lowering the amount of shrinkage that occurs can be a practical step towards mitigating the number and size of cracks compared to conventionally cured concrete, which results in a less permeable material. Without cracking and microcracking, concrete has a smaller chance of corrosion due to chloride attack, which can prolong the lifespan and durability of the material.



Construction workers pour and finish internally cured concrete to ensure durability and reduce early-age cracking on a bridge deck.

In addition, ESCS can help concrete mixes overcome some limitations associated with using concretes with high fly ash content. According to the Federal Highway Association (FHA), this material, along with other supplementary cementitious materials (SCMs), can help concrete become less permeable and improve its resistance to chemical ingress. However, high fly ash content can make concrete more prone to shrinkage and cracking.[5] Saturated lightweight aggregate contributes to slower hydration of concretes with high fly ash content, allowing pozzolanic reactions to occur, thereby improving the density of the cementitious mix and mitigating instances of autogenous shrinkage and early-age cracking. As such, ESCS lightweight aggregates can be instrumental in reducing factors that contribute to early-age cracking while supporting generally less permeable concrete mixes.

A less permeable concrete means lower risks of chloride attack

Concrete structures that experience less cracking during curing and are generally less permeable tend to have longer lifespans than average because they can protect steel reinforcements from corrosion caused by the ingress of chloride and other chemicals. It is estimated that chloride attack is responsible for 40 percent of concrete failures.[6] As a result, producing concrete that guards against the penetration of corrosive chemicals is a vital first step toward creating longer-lasting, more resilient bridges.

This is especially true in locations near saltwater or where salt-based deicers are frequently used. In both circumstances, chlorides are diluted into water—a danger compounded in areas that experience rapid freeze-thaw cycles. If concrete structures in these locations are cracked, chloride-

Construction crew installs pre-cast bridge deck panels reinforced with rebar, ensuring durability and safety in a challenging mountainous environment.

rich water can infiltrate, leading to rapid corrosion of the rebar. When the steel corrodes, the concrete structure experiences a reduction in tensile strength and load-bearing capacity. This, in turn, can make a bridge deck more prone to failure. While cracks represent a more substantial means for chloride attack, generally, more permeable concretes can also be vulnerable to chemical penetration.

Concrete with a lower risk of cracking and a denser cementitious mix can withstand the elements longer, reducing the need to repair, replace, or rebuild structures. In a 2013 study, the Indiana Department of Transportation (DOT) constructed four bridges with internally cured concrete and compared the performance of these bridges to traditionally cured ones.[7] The results of this study indicate that internally cured concrete bridges have the potential to more than triple the service life of a typical bridge deck in Indiana due, in part, to the material's ability to reduce early-age autogenous shrinkage by more than 80 percent. Likewise, the New York DOT used internally cured concrete in multiple bridges across the state to quantify the benefits of this curing technique. Experimental results show a 70 percent reduction in cracking, including several multi-span bridges that showed no cracking. The decrease in cracks supports improved resiliency in bridge construction.

Further, internal curing is also achieved when concrete uses ESCS to meet structural lightweight concrete (SLC) parameters. In addition to reducing early-age cracking, SLC made with ESCS enhances the bond between the aggregate and the surrounding cementitious matrix. The stronger bond between the aggregate and binder further reduces cracking and other forms of permeability to support a more durable and resilient concrete. This, in turn, extends the material's lifespan and reduces the environmental impact of structural maintenance over the building's service life.

Examples of internally cured bridges supporting resilience

The benefits of internally cured concrete bridges extend beyond Indiana and New York. DOTs from Utah to Louisiana have used this method of curing to support longer-lasting bridge decks and structures. Often, internal curing begins as a small field test that is studied. Once a DOT has data that quantifies how internal curing can support its bridge projects, it uses this type of concrete on a large scale.

For example, in 2012, researchers at Brigham Young University evaluated bridge decks across multiple Utah locations. These decks used both traditional and internal curing techniques. They found that, on average, the conventionally cured

A pre-cast lightweight concrete bridge deck panel is carefully lifted into place as part of a resilient infrastructure project in a mountainous setting.

bridge decks had between four and 21 times as much cracking as the internally cured decks at five and eight months. In addition, the cracks on the traditionally cured decks were located throughout the bridge, whereas those in the internally cured decks were mainly found on the deck ends.

Similar results were shown in Louisiana. The engineering department of the Lafayette Consolidated Government first used internal curing on a small five-span bridge on West Congress Street at the west end of the parish. Of the project, Tyson Rupnow, Ph.D., P.E., associate director of research at the Louisiana Transportation Research Center (LTRC), says, "Internal curing helps reduce concrete cracking, thus allowing us to increase the service life of our deck structures and reduce overall maintenance costs."

As a result of this small project, the Lafayette Consolidated Government modified its bridge specifications to require internal curing on exposed concrete elements—diaphragms, deck surfaces, guard rail walls, and approach slabs—to improve the return on investment (ROI) of taxpayer dollars.

It is important to note internal curing also supports non-bridge pavements. In 2005, a paving project in Hutchins, Tex., used internal curing to minimize cracks. Due to the improvements this curing technique provides, lightweight aggregate was used in more paving projects throughout the Dallas Fort Worth area. A report on this project states internal curing resulted in the mitigation or elimination of plastic and drying shrinkage cracking and limiting the effects of self-desiccation—an important factor given the extreme heat of Texas summers. Contractors reported the concrete was also easier to work and consolidate, which reduced the total placing time. Similarly, the Kansas DOT used internally cured concrete to support pavement design in a 24-km (15-mile) paving project just south of the Kansas City metropolitan area. The project showed benefits similar to those of the Texas project.

A pre-cast double T girder, designed for durability and load-bearing efficiency, ready for transport to a construction site.

Internally cured concrete extends service life

These examples and experimental data demonstrate internally cured concrete can be a viable first step

Stockpiles of pre-wetted lightweight aggregate, essential for internal curing of concrete, ready for use in high-performance construction projects.

toward improving the nation's infrastructure. This method of curing significantly reduces the potential for early-age cracking in multiple climates and conditions. It also enhances cracking resistance in concretes with high fly ash content. These benefits result in bridges that can outlast the service life of traditionally cured bridge decks and structures.

Longer-lasting bridges not only represent a way to stretch taxpayer dollars for needed infrastructure repair and replacement, but they also support a more ecologically conscious approach to construction as fewer materials, fuel, and waste will be generated throughout the service life of internally cured concrete bridges. Considering the data from infrastructure projects across the United States, the question becomes whether internal curing will improve a concrete bridge and to what degree internal curing will enhance concrete bridge decks and structures both in the present and future. **CS**

Notes

[1] See "Internal Curing Improves Concrete throughout its Life." Concrete In Focus by Bentz, D., Castro, J., Henkensiefken, R., Haejin, K., Weiss, J.

[2] Review "Permeability of concrete containing large amounts of fly ash," Cement and Concrete Research, 24(5), pages 913–922.

[3] "Cracking Tendency of Lightweight Concrete," Highway Research Center by Byard, B. and Schindler, A.

[4] "Internal Curing of Engineered Cementitious Composites for Prevention of Early Age Autogenous Shrinkage Cracking." Cement and Concrete Research, 39(10), pages 893–901.

[5] "Application of Internal Curing for Mixtures Containing High Volumes of Fly Ash." Cement and Concrete Composites, 34(9).

[6] "Evaluating effect of chloride attack and concrete cover on the probability of corrosion." Frontiers of Structural and Civil Engineering. Pages 379-390. 10.1007/s11709-013-0223-9.

[7] Documentation of the INDOT experience and construction of the bridge decks containing internal curing in 2013 (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2015/10).

ADDITIONAL **INFORMATION**

Author

Darren Medeiros is a regional technical salesperson at Holcim Lightweight Aggregates—Utelite Plant. He has two decades of experience in the lightweight aggregate industry and is active in several Expanded Shale, Clay, and Slate Institute (ESCSI) committees involving the use of lightweight concrete.

Key Takeaways

Internally cured concrete, achieved through pre-saturated lightweight aggregates such as expanded shale, clay, and slate (ESCS), offers a durable solution to early-age cracking in bridge decks. This technique reduces autogenous and drying shrinkage, producing less permeable concrete that withstands chloride penetration—a critical factor in concrete corrosion and failure. Studies show that internally cured concrete triples bridge deck longevity, with Department of Transportation (DOT) projects across states such as Indiana, New York, Utah, and Louisiana demonstrating significant crack reduction. This approach enhances structural resilience and reduces environmental impact by lowering maintenance needs and extending service life. As the U.S. infrastructure ages, internal curing presents an effective strategy to build longer-lasting, cost-effective, and environmentally sustainable bridges.

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03 05 00—Common Work Results for Concrete (aggregate)

UniFormat No.

G2010—Roadways

G2060.70—Site Bridges

Keywords

Division 03

Cast-in-place concrete

Concrete curing

Fabricated roadway bridges

Lightweight structural concrete

Rigid roadway pavement

Roadway pavement

Structural concrete

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The Structural Complexity of Shelf Angles

By Mark D. Hagel, Ph.D., P.Eng.

Photo by Klassen Photography/courtesy Jackson Masonry

THE INVENTION OF SKELETON FRAME CONSTRUCTION, WHICH CREATES THE BUILDING'S PRIMARY LOAD-BEARING ROLE USING A CONCRETE OR STEEL FRAME "SKELETON," LED TO THE REMOVAL OF THE LOAD-BEARING FUNCTION OF MASONRY IN THE LATE 19TH CENTURY. THE FIRST BUILDING TO USE A STEEL-FRAME SKELETON IN NORTH AMERICA WAS THE HOME INSURANCE BUILDING IN CHICAGO, COMPLETED IN 1885. IT IS ALSO CONSIDERED THE WORLD'S FIRST SKYSCRAPER (FIGURE 1).

The removal of the load-bearing function of multiple wythes of masonry, as seen in Figure 2a, was accompanied by reducing the masonry to a single wythe of non-load-bearing veneer and a backup wall, as seen in Figure 2b, which required support of its weight using concrete brick ledges or steel shelf angles.

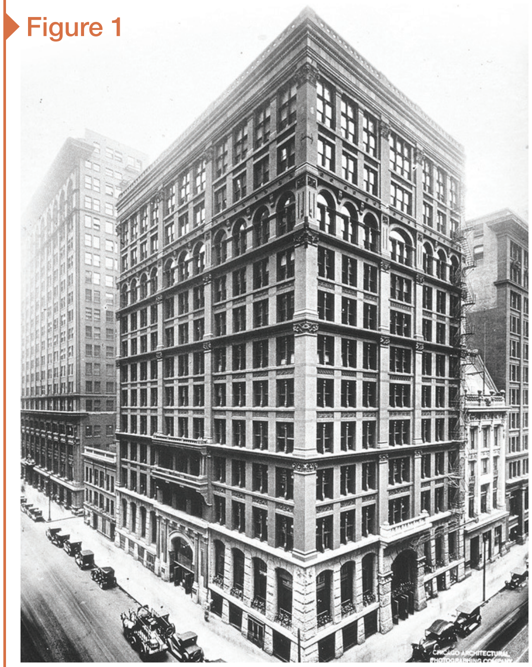
Shelf angle design represents the intersection of masonry design and steel design, and depending on the building's primary structural system, concrete, steel, or wood design. Therefore, shelf angle design has often been regarded as a "steel" design or a "concrete" design problem rather than a "masonry design" problem. For this reason, very little literature has been published on shelf angle design.

The design of steel shelf angles is not as simple and intuitive as it might first appear. Interactions between the tied masonry veneer and the steel angle and beam behavior from the brick veneer spanning between anchor bolts can be complex to capture with models simple enough for hand calculations. This often leads to oversizing shelf angles and the stand-offs for shelf angles when continuous insulation (c.i.) is used. Overdesign of these steel elements can lead to unnecessary increases in thermal bridging, carbon footprint, and cost of a masonry veneer. This article provides examples and discusses strategies for a more efficient design of steel shelf angles that support the weight of full-bed masonry veneers.

Beam effect and restraining force of masonry ties

The deep beam behavior (action) of the brick veneer spanning between anchor bolts is challenging to capture with simple models for hand calculations. As a result, the beam action of the brick veneer identified by McGinley[2] is often ignored when using a simplified hand calculation. The impacts of the masonry ties lead to a statically indeterminate

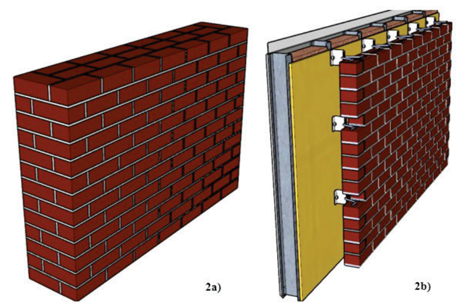
Figure 1



Home Insurance Building in Chicago.[1]

See note 1.

Figure 2a and 2b



2a) Multi-wythe load-bearing brick wall (veneer and structure).

2b) Single-wythe brick veneer with steel stud load-bearing wall.

Illustrations and photos courtesy Alberta Masonry Council

problem and, as such, are frequently overlooked so the design can be reduced to a more easily solved statically determinate problem.

Reviewing the definitions of statically determinate and statically indeterminate structures can help one better understand the problem's complexity. In 2D, there are three equations of equilibrium. Static equilibrium requires these equations to be equal to zero; in other words, the external forces acting on the structure are resisted by equal and opposite reactions. If the equations were not equal to zero, the structure would move.

A statically determinate structural condition occurs when three unknown reaction forces hold the structure in static equilibrium, and three equilibrium equations are used to determine these forces. Simply put, three equations and three unknowns.

In contrast, with a statically indeterminate structure, there are more reactions than equations of equilibrium. Since there are only three equilibrium equations in 2D, if there are four reactions on a structure, then there are four unknowns and only three equations, creating a statically indeterminate structure with one degree of static indeterminacy. If there were five reactions, the degree of static indeterminacy would be two and so on. Finding a solution for a statically indeterminate structure involves creating additional equations (or relationships) between the forces acting on the structure and the reactions. This is often accomplished by examining the structural deflections/displacements and internal forces within the structure.

Now that the definitions have been reviewed, the brick veneer system, as illustrated in Figure 3 (page 30), is typically reduced to a statically determinate structure, as seen in the free body diagram of the system in Figure 4 (page 30). The simplification of the system by ignoring the restraining force of the ties results in only three unknowns, Tf, Vf, and Cf, which can be easily determined from the equations of equilibrium. However, this can lead to an overestimation of the forces acting on the anchor bolts and increased deflection of the shelf angle, resulting in an unnecessary increase in the size and cost of the shelf angle and an increase in the size and frequency of the anchor bolts. Technical aids that use the statically determinate method to design shelf angles already exist.[3] These technical aids conclude that to support the weight of 9 m (30 ft) of traditional 90 mm (3.5 in.) brick veneer, an L102 x 102 x 13 mm (L4 x 4 x 0.5 in.) steel shelf angle is required to meet the maximum deflection of 0.24 mm (0.009 in.) of the L/480 recommended deflection limit. In addition to this, 16 mm (0.6 in.) diameter post-installed anchor bolts spaced at 305 mm (12 in.) on center horizontally would be required to meet the tension and shear forces on the anchor bolts resulting from the weight of the brick veneer.

On the other hand, based on field experience of buildings with brick veneers, shelf angles that are half that thickness have been observed to support 9 m (30 ft) of brick veneer without the cracking of mortar joints that can be indicative of excessive movement in brick veneers.

Figure 5a (page 30) illustrates the impact of both the beam effect and the restraining force of the ties on a brick veneer in situ. In Figure 5a, the approximately 20-ft (6-m) span of shelf angle supporting the veneer has fallen to the ground due to anchor bolt withdrawal on the 30-year-old brick veneer. A horizontal crack developing into step cracking (Figure 5b, page 30) has formed due to the absence of support for the weight

Figure 3

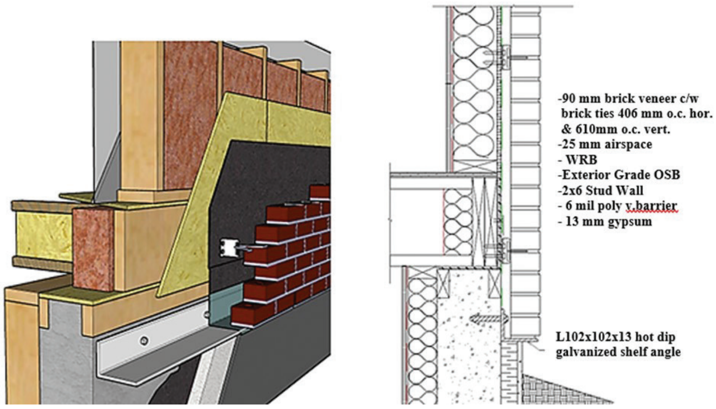


Figure 4

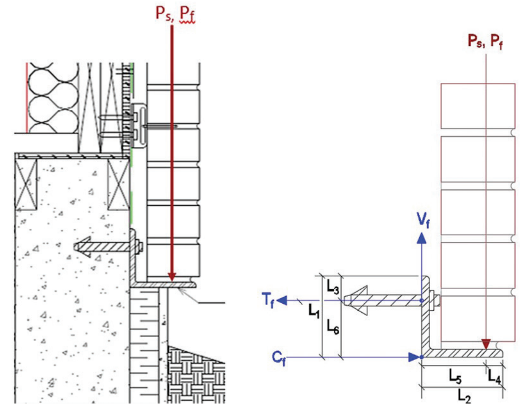


Figure 5a

Figure 5b

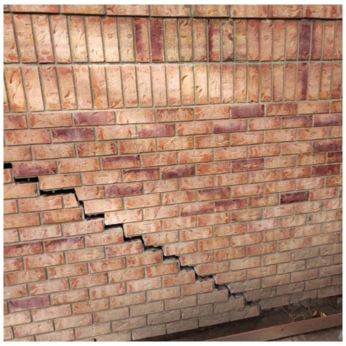


Figure 3: Brick veneer with wood stud backup foundation detail, 2D and 3D.

Figure 4: Free body diagram of shelf angle at the foundation—statically determinate.

Figure 5a and 5b: Failed shelf angle anchor bolts—illustration of beam action and masonry tie impacts on brick veneers.

of the veneer. However, the veneer remains attached to the wall, and no brick units have fallen to the ground. The combined action of the brick veneer appears to create deep beam behavior between the two remaining supports. At the same time, the masonry ties continue to laterally anchor the veneer to the wall.

A new design approach is proposed, which more accurately accounts for the interaction between the tied masonry veneer and the shelf angle. The proposed design method more accurately reflects field observations of masonry veneer where an L102 x 102 x 6.4 mm (L4 x 4 x 0.25 in.) can support 7 to 9 m (24 to 30 ft) of 90 mm (3.5 in.) clay brick veneer without evidence of structural distress in brick veneers from excessive deflection that is typically identified by mortar joint cracking. The "as-built" performance of masonry veneers in Figure 6 (page 32) shows that the deflections and load distribution on a shelf angle are less than what is typically produced with current simplified, statically determinate shelf angle design methods.

The proposed design method employs the use of the force method in combination with virtual work to solve the one-degree statically indeterminate system that results from the introduction of tie restraining force, R_{TIE}, at the first course of ties as depicted in the free body diagram of the system in Figure 7 (page 32).

From Figure 8 (page 32), the following parameters are required to use the force method and virtual work:

P = Unfactored (service load) of masonry veneer and shelf angle (N) per meter

= (20.8 kN/m^3) (9.144 m) (0.0921 m) (1 m) + 0.098kN/m = 17,614 N (3,960 lbf)

Pf = Factored load of masonry veneer and shelf angle (N) per meter

= 1.4 (17,614 N) = 24,659 N (5,544 lbf)

R_{TIE} = Reaction force in the brick ties at the first course of ties (kN) per meter

V = Reaction force in the brick ties at the first course of ties (kN) per meter

T = Reaction force in the brick ties at the first course of ties (kN) per meter

C = Reaction force in the brick ties at the first course of ties (kN) per meter

L1 = Vertical leg length (mm)

L2 = Horizontal leg length (mm)

L3 = Vertical distance to the center of the bolt hole = 38 mm (1.4 in.)

L4 = Centroid of brick veneer (typically 45 mm [1.6 in.] for metric modular 90 mm [3.5 mm] brick)

L5 = Eccentricity of veneer load = Air space + (veneer thickness / 2) = (25.4 + 46.1)

= 71.5 mm (2.8 in.)

L6 = L1 – L3 (mm)

L7 = Max 300 mm (11.8 in.) from base support (typically 272 mm [10 in.] + thickness of the shelf angle to meet the joints of the brick coursing)

L8 = Vertical distance between the ties and the center of the bolt hole

L9 = Total length of horizontal leg = Air space + veneer thickness = 25.4 + 92.1

= 117.5 mm (4.6 in.)

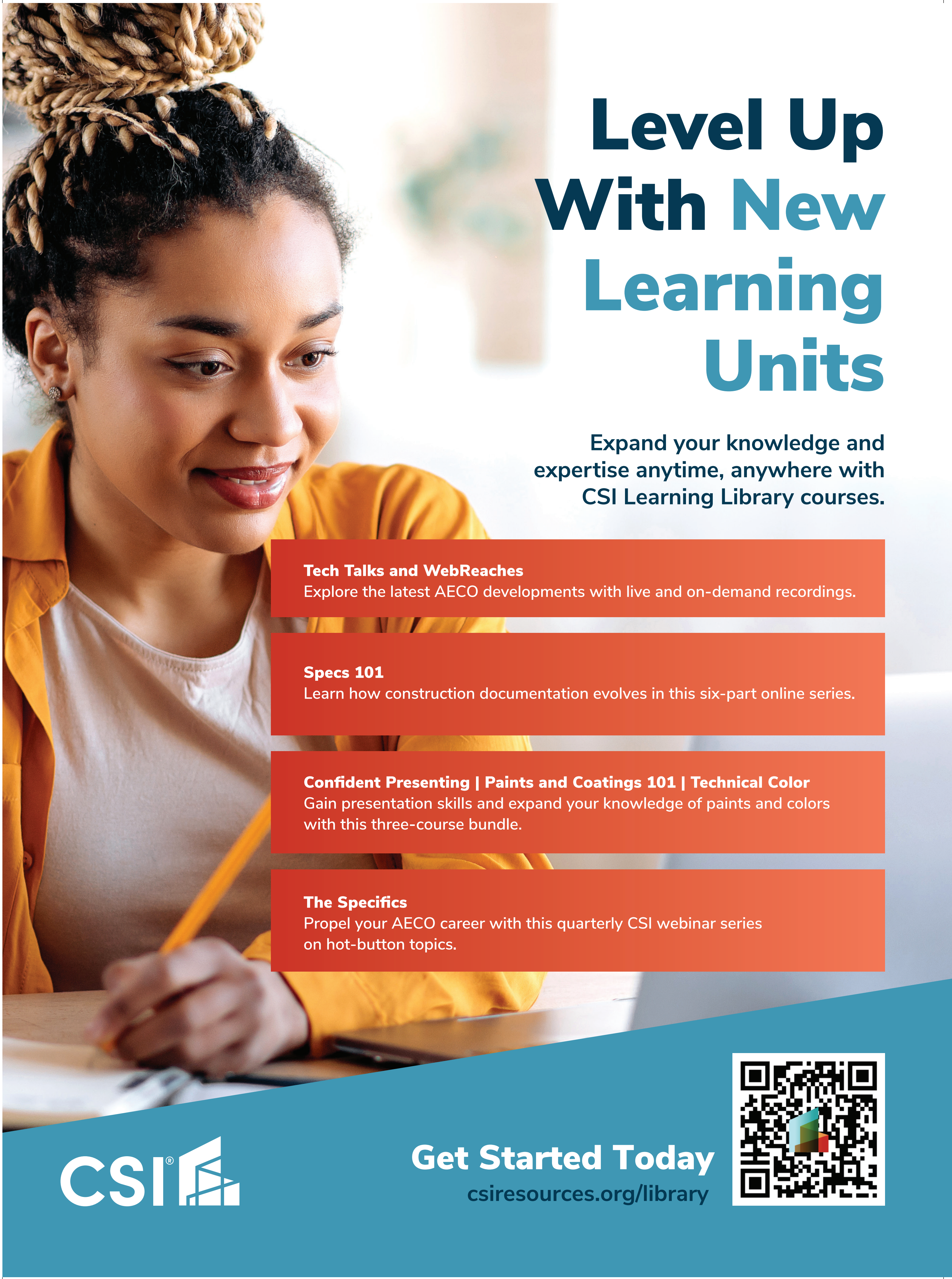

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Figure 6

Figure 7

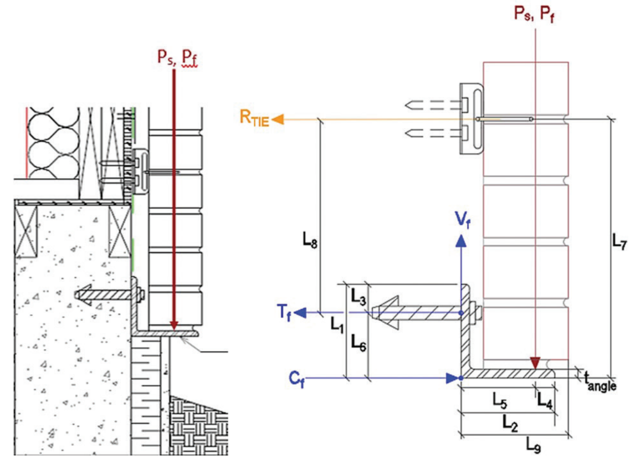
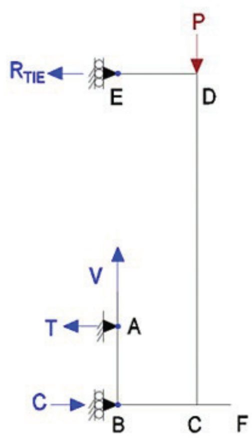


Figure 8



$$R\_tie := \frac{\dfrac{L5 \cdot L6 \cdot P \cdot (L8+L6)}{3 \cdot Es \cdot I\_angle} - \dfrac{L5^2 \cdot P \cdot (L8+L6)}{2 \cdot Es \cdot I\_angle}}{\dfrac{L7 \cdot (L8+L6)^2}{3 \cdot Em \cdot I\_veneer} + \dfrac{L6 \cdot (L8+L6)^2}{3 \cdot Es \cdot I\_angle} + \dfrac{L5 \cdot (L8+L6)^2}{Es \cdot I\_angle}}$$

$$V := P$$

$$C := \frac{(P \cdot L5 + R\_tie \cdot L8)}{L6}$$

$$T := -(C + R\_tie)$$

Figure 9

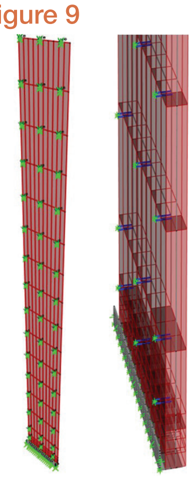


Figure 8: Statically indeterminate free body diagram and solved reactions.

Figure 9: SAP 2000 model using shells for angle/veneer and frames for ties.

In addition to these dimensions, the force method and virtual work require material parameters and assembly dimensions to establish relative stiffnesses. The other values that were required to complete the calculations were:

t_angle = thickness of the horizontal leg of the angle

b = 1,000 mm (1 m of wall design length)

veneer_thick = thickness of the masonry veneer = 92.1 mm (3.6 in.)

V-tie diameter = 2.4 mm (0.09 in.)

f'm = the compressive strength of the masonry veneer

Em = Modulus of Elasticity of the masonry veneer = 850 f'm

Es = Modulus of Elasticity of structural steel = 200,000 MPa

The proof of the following equations is beyond the scope of this paper but can be determined by applying the force method and virtual work to the free body diagram in Figure 8.

For illustration purposes, the proposed method was applied to the design of a shelf angle anchored to a concrete foundation with post-installed anchor bolts that support a 9-m (30-ft) clay brick veneer. The SAP 2000 structural design software created a 3D finite element model using frame and shell elements. The model was used to compare the accuracy of the 2D force method/virtual work hand calculation to a 3D model that captures the interaction of the ties and the brick with the shelf angle. Figure 9 illustrates the 3D finite element model.

Table 1 compares the tie reaction, anchor bolt and foundation loads using the statically determinate method, the proposed force method/virtual work method and the SAP 2000 3D model. The proposed force method/virtual work method and SAP 2000 have excellent agreement in reaction forces and deflections, with a difference of approximately 3.6 percent and 9.4 percent, respectively. This demonstrates the force method/virtual work method better represents interactions between the tie and shelf angles and brick

Table 1

Model	Tie Reaction $R_{Tie,f}$ lbf./m (kN/m)	Anchor Bolt Loads V_f lbf./m (kN/m)	Anchor Bolt Loads T_f lbf./m (kN/m)	Foundation Load C_f lbf./m (kN/m)	Max. Deflection in. (mm)
Statically Determinate	N/A	24.66	27.75	27.75	1.544
Force Method/ Virt. Work	3.911	24.66	10.81	14.72	0.2298
SAP 2000 - Shells	3.776	25.07	8.384	12.63	0.2101

Comparison of model results for a shelf angle supporting 9 m (30 ft) of brick veneer.

Table 2

Model	Air Space in. (mm)	Distance to bolt hole in. (mm)	Shelf Angle Size Imperial (metric)	Anchor Bolt Diameter in. (mm)	Anchor Bolt Spacing in. (mm)
Statically Determinate	1 (25.4)	1.5 (38.1)	4"x4x"x½" (102x102x13)	5/8 (15.9)	12 (305)
Force Method/Virtual Work	1 (25.4)	1.5 (38.1)	4"x4"x¼" (102x102x6.4)	5/8 (15.9)	16 (406)
SAP 2000 - Shell elements	1 (25.4)	1.5 (38.1)	4"x4"x¼" (102x102x6.4)	5/8 (15.9)	16 (406)

Comparison of designed shelf angle size and anchor bolt spacing.

and shelf angles captured with a 3D finite element model. Table 1 also illustrates the difference in the deflection and loads when using the statically determinate method versus the force method/virtual work method. The difference is approximately 157 percent greater Tf, acting on the anchor bolt, and 572 percent greater deflection in the shelf angle.

Table 2 demonstrates the design results of the shelf angle, anchor bolt size, and anchor bolt spacing when using the three different design approaches. In Table 2, the shelf angle thickness was reduced from 13 mm (0.5 in.) when using the traditional approach[6] to 6.35 mm (0.25 in.) when using the proposed force method and maintained an acceptable deflection less than L/480. In addition, as estimated by the proposed force method, the reduction in forces acting on the anchor bolt translates to an increase in bolt spacing from 305 to 406 mm (12 to 16 in.), reducing the number of anchor bolts required. Depending on the wall length, the cost savings are approximately one percent. **CS**

Author's note: I would like to thank Jordan Kuntz and Lyndsey Jackson of Jackson Masonry Ltd. for their insights from their field experience with shelf angle installations and performance. Without these insights, the results of these findings would not have been possible.

Notes

[1] Refer to en.wikipedia.org/wiki/Home_Insurance_Building

[2] See the article by McGinley, M., "Design of Shelf Angles for Masonry," *Structure Magazine*, structuremag.org/article/design-of-shelf-angles-for-masonry-veneers

[3] Review "Shelf-Angle and Brick Ledge Design for Brick Veneer On Mid-Rise Wood-Frame Buildings," Alberta Masonry Council, Canadian Wood Council, Masonryworx, by Hagel, M.D., Moses, D.., Jonkman, R. (2019). See albertamasonrycouncil.ca/wp-content/uploads/2022/09/Tech-Aid-1-Shelf-Angle-and-Brick-Ledge-November-2019.pdf

ADDITIONAL **INFORMATION**

Author

Mark D. Hagel, PhD, P.Eng., is the executive director of the Alberta Masonry Council. He holds a bachelor of science in actuarial science and applied mathematics, a bachelor of science in civil engineering, and a doctor of philosophy in civil engineering. Hagel's fields of expertise include thermal and hygrothermal modelling of building systems, corrosion modelling, Life-cycle Cost Analysis (LCCA), structural analysis and design, and the durability of building components. In 2018, he served on the National Research Council of Canada (NRC) working group that developed the Guideline on Design for Durability of the Building Envelope and in a working group on the CSA-S478-2019 Durability in Buildings. Hagel can be reached at markhagel@albertamasonrycouncil.ca.

Key Takeaways

With masonry reduced to a single, non-load-bearing veneer, steel shelf angles or brick ledges became necessary to support its weight. Shelf angle design combines masonry, steel, and the building's primary structural material (concrete, wood, or steel) and is often treated as a "steel" or "concrete" design challenge rather than a masonry issue. Consequently, the literature on shelf angle design is limited. Designing steel shelf angles is complex due to interactions between the masonry veneer and structural elements, which are difficult to model by hand, often resulting in overdesign. This can increase thermal bridging, carbon footprint, and costs. This article presents examples and strategies for more efficient shelf angle design to support full-bed masonry veneers.

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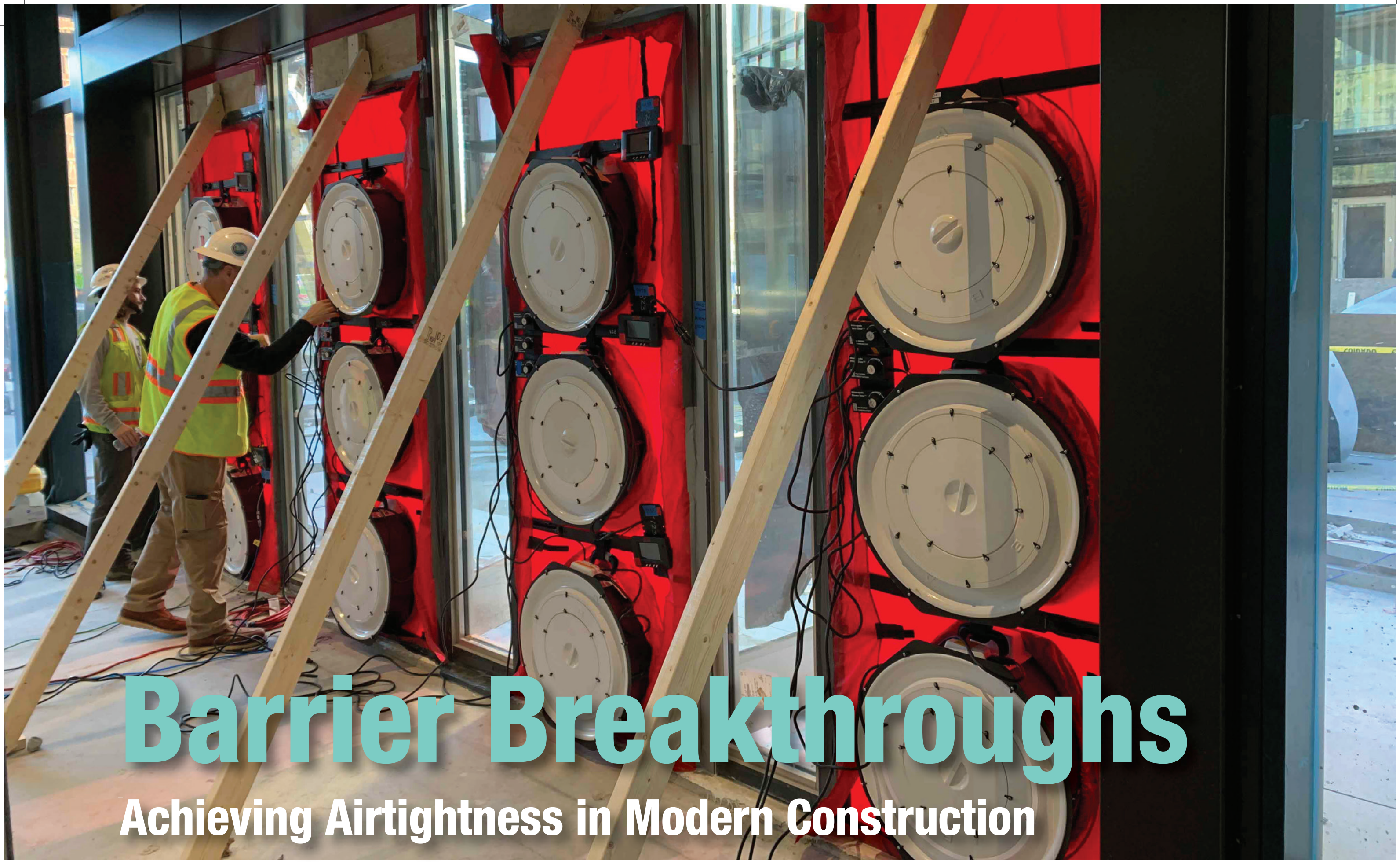


Barrier Breakthroughs

Achieving Airtightness in Modern Construction

By Matthew Ridgway, P.E.

Photo courtesy Intertek

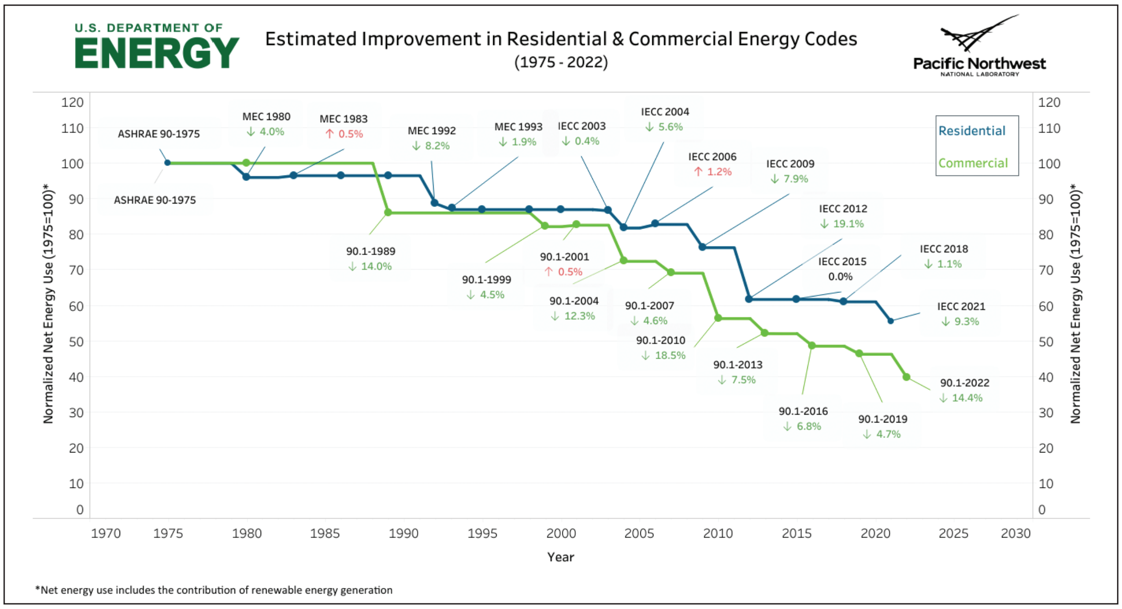
AS BUILDING CODES AND STANDARDS EVOLVE, THE DEMAND FOR AIRTIGHT, ENVIRONMENTALLY FRIENDLY BUILDING ENCLOSURES INCREASES AMONG BUILDING OWNERS, INSURERS, AND DESIGN PROFESSIONALS. THESE STRICTER REGULATIONS AIM TO REDUCE ENERGY CONSUMPTION AND ENHANCE OVERALL BUILDING PERFORMANCE, MAKING AIR BARRIERS A KEY ELEMENT IN TODAY'S CONSTRUCTION PRACTICES.

Air barriers are essential for maintaining the integrity and performance of building enclosures. By preventing uncontrolled air movement between conditioned and unconditioned spaces, they help regulate indoor temperatures, control moisture, and improve energy efficiency. When designed and installed correctly, air barriers contribute to the long-term durability of a building. However, if an air barrier fails, it can lead to significant problems in both new and existing buildings, including reduced insulation effectiveness, resulting in higher energy bills and moisture intrusion, potentially allowing for the development of toxic mold, and even premature failure of building components.

Role of air barriers

Modern building enclosures are designed to maintain a stable indoor climate by separating conditioned spaces from external or semi-conditioned areas. While their primary function is to control air at a pressure boundary, air barriers can also help control water, vapor, and radiation, depending on the materials used and how they function in combination with other building components. All of these factors, along with thermal resistance, define the performance of a building enclosure assembly.

Though there is a historical context for controlling air infiltration through the building enclosure, historical methods and requirements have been ad hoc and mostly material-based until the modern era of construction. Drafty building enclosure assemblies of past eras contributed to higher energy use to keep occupants comfortable but have also played a role in maintaining the long-term durability of a building by helping to address issues related to poor water and vapor control (*i.e.* drafty buildings dry more readily).



Estimated improvements in residential and commercial energy codes, 1975–2022.

Illustration courtesy Department of Energy (DOE) Building Energy Codes Program

Within the AEC industry, research focuses on predicting and quantifying the impact of air leakage. Using energy models and computational fluid dynamics, experts can analyze air distribution and how air leaks affect energy consumption at the building, assembly, and individual component levels.

Empirical evidence from physical testing and energy bill analysis confirms that reducing air leakage through a building enclosure can save on fuel used to air condition a building. As buildings become more airtight to save on these fuel costs, reducing air leakage can prevent other potential building performance issues arising from uncontrolled airflow in an otherwise high-performing building.

Improving building enclosure performance

While energy efficiency might initially suggest well-insulated walls and efficient HVAC systems, controlling air leakage can be just as critical. Uncontrolled air movement through penetrations in the building enclosure can increase energy costs as HVAC systems work harder to condition the air. At a building level, uncontrolled air leakage may also lead to issues with stack effect, which can have a compounding impact on building performance. Also defined as the "chimney effect," stack effect is the natural propensity for hot air to rise. In multistory buildings, especially in winter, cold air rushes into lower levels while warm air is exhausted through the top of the building.

A continuous air barrier system also protects the building structure by reducing the risk of localized condensation or moisture accumulation. An air barrier that also performs as a weather barrier, or an air weather barrier (AWB), acts as a shield and stabilizer, protecting the building enclosure from external elements while optimizing internal energy performance.

Financial benefits

One driving force behind the increasing demand for high-performing and airtight buildings is the combined efforts of industry and government to reduce energy consumption. While carbon reduction from embodied energy is an environmental benefit, for this purpose, the focus is solely on the fuel costs associated with conditioning buildings.

According to the U.S. Energy Information Administration, residential and commercial buildings account for approximately 27.6 percent of the total energy consumption in the United States. Space heating is the largest single energy end-use in commercial buildings, consuming 32 percent of energy, followed by ventilation at 10 percent.

The ongoing evolution of building codes has continued to drive energy reductions. By implementing stricter energy efficiency standards, these codes have incentivized the construction of higher-performing buildings.

A high-performance building is one that optimizes building performance to ensure long-term durability and resilience. Such attributes including energy efficiency, lifecycle and serviceability enhancements, IAQ, sustainability targets, and reductions in embodied carbon.

An aluminum-faced, impermeable air barrier with a rubberized asphalt adhesive applied to a fiberglass mat gypsum sheathing. The sealant is applied at several lap joints in the field of the air barrier installation to ensure continuity.

Photos courtesy Intertek

Following reports of difficulty managing interior temperatures in a medical office at Level 3 of a new high-rise clad in unitized curtain wall, diagnostic testing revealed air leakage sites at stack joints and within column enclosures exasperated by some stack effect. Further investigation revealed missing shop-applied seals at several units.

These high-performance buildings offer several advantages, including a longer lifespan and reduced energy demands. Savvy building owners recognize that airtight buildings minimize the financial risks of future repairs or major renovations. Additionally, properly constructed air barriers result in lower operating costs. In certain regions, high-performing buildings have become a marketing tool to enhance property value and tenant occupancy.

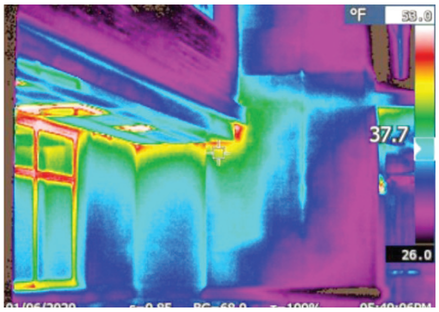
Testing, design, and regulatory compliance

Several ASTM tests are commonly used in the construction industry to ensure the performance and durability of air barriers. Quantitative and qualitative methods are used during testing to assess how well the system works.

Quantitative testing measures the air leakage rate, showing how effectively the air barrier controls airflow through the building enclosure. Qualitative methods help identify specific areas where air leakage might occur, allowing for targeted repairs before construction is completed.

Quantitative methods include:

- ASTM E1827, *Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door*. This method evaluates a building's airtightness by creating a pressure differential with a blower door. It offers two options: a single-point test (usually at 50 Pa [1 psf] for dwelling units) and a two-point test (using two pressure levels) to measure air leakage. Commonly used in residential and commercial buildings, it helps identify air barrier weaknesses and improve energy efficiency.
- ASTM E779, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*. This multi-point test uses a blower door to pressurize or depressurize a building and measure air leakage. The air leakage rate is calculated by the airflow required to maintain a pressure difference, typically 75 Pa (1.5 psf), and reported as cubic feet per minute (CFM) per square foot (sf) of building enclosure area. This method is used in new and existing buildings to assess airtightness and identify areas for improvement in the air barrier system.
- ASTM E3158, *Standard Test Method for Measuring the Air Leakage Rate of a Large or Multizone Building*. This method was developed from the Air Barrier Association of America's (ABAA) *Standard Method for Building Enclosure Airtightness Compliance Testing* and refines the above methods.
- The U.S. Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes. This protocol establishes a standardized method to measure air leakage in building enclosures, particularly in military and government buildings. It combines quantitative tests such as ASTM E779 with qualitative methods such as infrared scanning and smoke tracing from ASTM E1186. Using blower doors to pressurize or depressurize buildings, it evaluates air leakage at standardized pressure levels, typically 75 Pa (1.5 psf), to ensure compliance with airtightness standards, enhancing energy efficiency and durability.



Air leakage at a soffit-to-wall transition due to discontinuity of the air barrier at structure-to-wall penetrations within the masonry cavity pictured with thermography during ASTM E1186, *Air Leakage Site Detection in Building Envelopes and Air Barrier Systems*, Practice 4.2.1, Infrared Scanning with Depressurization/Pressurization.

Qualitative methods include:

- STM E1186, *Air Leakage Site Detection in Building Envelopes and Air Barrier Systems.*
- Practice 4.2.1—Infrared Scanning with Depressurization/Pressurization. A blower door creates a pressure differential, and infrared cameras detect temperature variations, pinpointing leaks in insulation and around windows or doors.
- Practice 4.2.2—Smoke Tracer with Depressurization/Pressurization. Smoke is released near potential leak sites, and its movement reveals gaps in the air barrier system, especially around windows, doors, and utility penetrations.
- Practice 4.2.3—Airflow Measurement (Anemometers). Anemometers measure airflow at suspected leakage points during depressurization or pressurization, identifying areas with significant air leaks.
- Practice 4.2.4—Sound Detection. Low-frequency sound is generated in the building, and detectors identify leaks by picking up sound variations through the building enclosure.
- Practice 4.2.5—Tracer Gas. A tracer gas, such as sulfur hexafluoride, is released and detected to identify leaks by measuring gas concentration differences inside and outside the building.

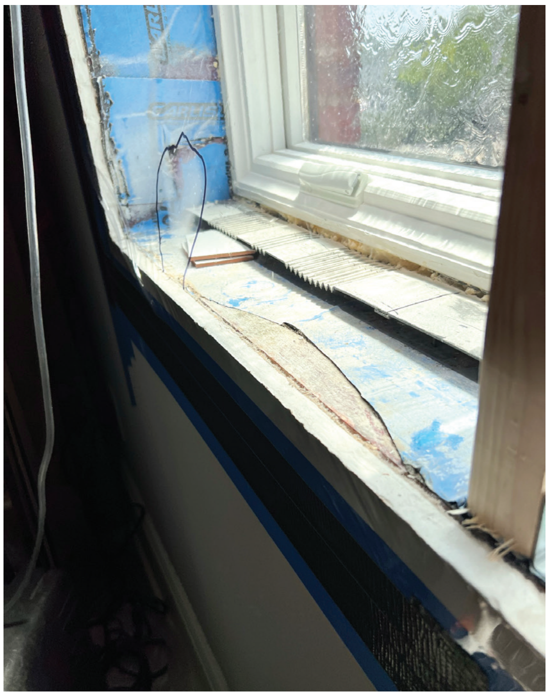
Mock-ups are also frequently used in the pre-construction phase to confirm air barrier systems can be installed properly and perform as expected in real-world situations. Pre-construction testing is essential to check for proper adhesion of the air barrier and air leakage resistance at penetrations and transitions of air barrier assemblies, reducing the chance of issues arising during construction and after the building is occupied.

Durability across climates

Air barriers must be durable in all climates to withstand each region's unique environmental challenges. Factors such as temperature fluctuations, humidity, wind, construction type, and exposure must be carefully considered when designing and installing air barrier systems. Climate considerations and the location of insulation in a wall assembly might dictate a need for vapor-permeable air barriers to accommodate vapor drive. Regions with harsh winds or extreme temperatures may require barriers with varying adhesive or facer properties.

When designing air barriers, consider the specific climate conditions of the region, as well as the type of construction, wall assembly, and project timeline. The chosen air barrier system must withstand the environmental conditions it will face throughout its service life. Air barriers now vary widely in chemistries and applications, including systems integrated with sheathing, fluid-applied, spray-applied, sheet-applied, and self-adhered (SA) options, each offering different advantages depending on the climate, building type and use case.

Performance characteristics such as water penetration resistance, vapor permeability, adhesion, and fire resistance are also crucial for durability. Construction practices, including the quality of installer training and regional installation preferences, significantly impact an air barrier's success. Exposure limitations, such as UV, wind, or rain sensitivity, must be managed carefully during installation to prevent premature failure. The air barrier must also resist building movements and be designed for continuity across movement joints and transitions between other exterior wall assemblies and openings.



Following reports of interior staining and some joint failures at the window trim of a newly constructed multifamily residential building, an investigation revealed discontinuity in the air seals under the sill pan of a window, allowing warm, moist air to condense on window trim within the rough opening of the window during the summer cooling season. Note the correlation of staining on the trim to the air leakage site (noted by condensation forming on the interior vinyl sheet during diagnostic testing). Proactive investigation and air sealing allowed the unit to be remediated before becoming a more significant issue.

The design and installation of air barriers and other building enclosure systems can also influence the 'right-sizing' of mechanical equipment. Building energy use, influenced by climate zone-specific code guidelines and building owner decisions, directly impacts mechanical system designs. Mechanical design and energy modeling typically rely on minimum criteria defined by ASHRAE for heating and cooling degree days, which measure the average outdoor temperatures compared to a standard temperature, typically 18 C (65 F) in the United States. The 2021 version of the *International Energy Conservation Code* (*IECC*) revised its climate zone map to reflect rising average temperatures across the U.S. due to climate change and added additional requirements for air barrier assurance.

Impact of failed air barriers

Failures in air barrier systems can lead to uncontrolled air leakage, often worsened by building pressurization or depressurization. This forces HVAC systems to work harder to maintain indoor temperature set points and can have severe consequences for moisture control within the building's components and assemblies. The amount of moisture that can enter a building due to a discontinuity in the air barrier is greater than what occurs through vapor diffusion alone. Defects in air control layers can allow moisture to accumulate within the building's walls, resulting in several problems, including reduced effectiveness of thermal insulation, the potential for biological growth, and even structural failure within the wall assemblies.

Air leakage becomes even more problematic when there is a significant difference between indoor and outdoor temperatures. In such cases, condensation can occur when moisture within the ambient air condenses on surfaces at or below the dew point temperature. In winter, cold outdoor air infiltrates the building enclosure and causes interior surfaces to cool, which can lead to condensation of ambient interior warm, moist air. Similarly, warm, humid air can infiltrate an air-conditioned building in summer, causing condensation on cooler ambient surfaces.

Condensation, especially in areas with poor ventilation, can accelerate mold growth, material rot, and risk of structural damage. The long-term effects of air barrier failures are detrimental to both the performance and durability of the building, as well as the occupants within.

Preventing common failures

Many failed whole-building airtightness tests can be attributed to relatively simple issues that could have been addressed during the design or construction phases. Common problem areas include transitions between soffits to walls, parapet transitions to roofs, and window terminations to the air barrier. Mock-ups and testing of these transitions during construction can be worth the extra effort and cost.

Construction-related issues often stem from poor quality control or work performed out of sequence, such as making roof or wall penetrations after roofing or cladding installation, which can limit the ability to properly terminate air barriers to ducts, piping, or electrical conduits. Some of the most complex challenges in air barrier design and application are related to the interior compartmentalization of buildings. Issues such as malodor, stack effect, and condensation are among the most common problems identified during diagnostic and forensic testing of whole buildings.

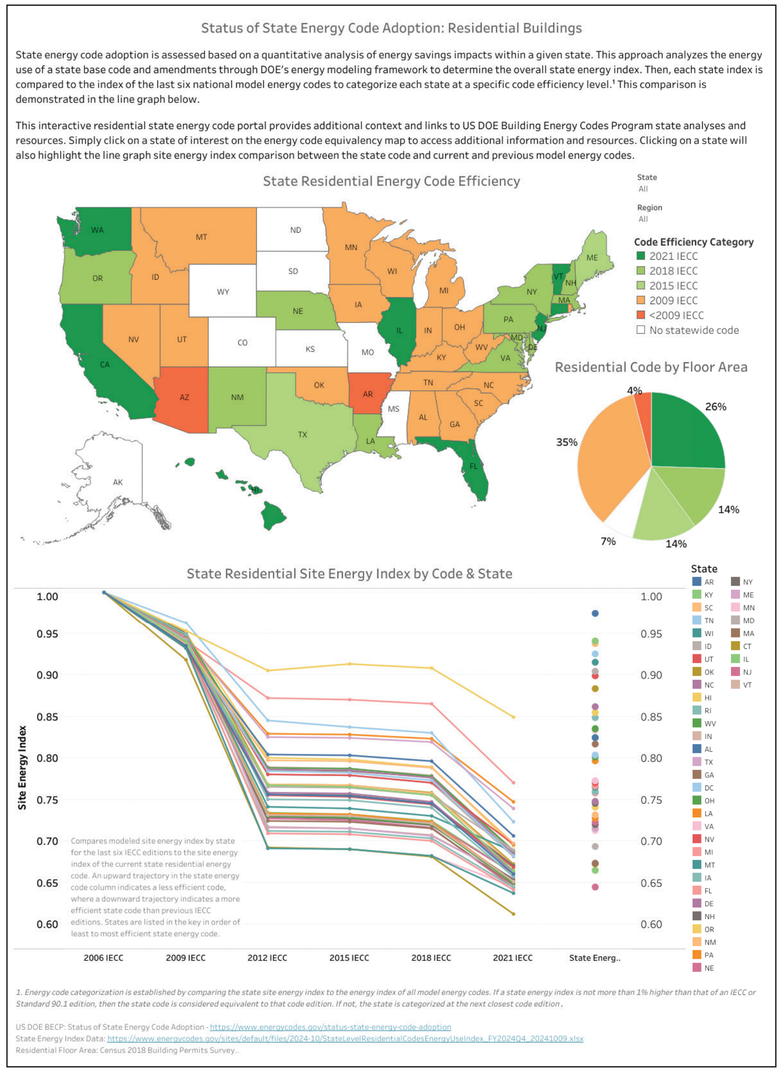
Additionally, the industry still faces challenges in maintaining air barrier continuity at the sills of curtain walls, storefronts, and flanged windows. Designing an air barrier to be continuous, even with the complexities of structural and drainage requirements, is critically important but not impossible with proper coordination.

Codes and standards

IECC and ASHRAE 90.1 standard are primarily referenced for compliance with a commercial building's energy performance and verification. While the 2021 *IECC* is not yet required in all jurisdictions, it is gaining adoption, and several states and cities have implemented local codes, often referred to as "stretch" codes, which include stricter requirements for both testing and/or other prescriptive requirements to ensure airtightness of buildings.

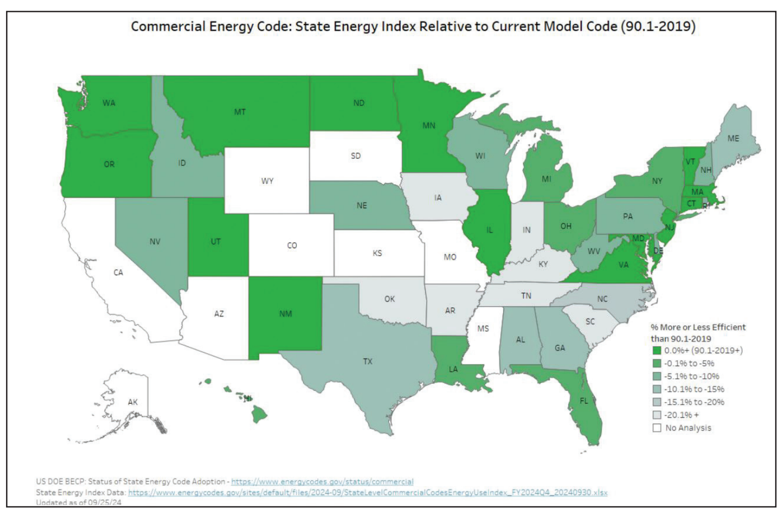
For commercial buildings, the 2021 *IECC* now includes a requirement to comply with ASHRAE 90.1–2019 and requires buildings to have a posted a Thermal Envelope Certificate. This certificate must include R-values of insulation installed across the building enclosure and ducts outside-conditioned spaces of the building, U-factors and solar heat gain coefficients (SHGC) of fenestrations, and the results of any building enclosure air leakage testing performed on the building.

The 2021 *IECC* also requires the installation of a continuous air barrier, which must be verified by a qualified professional such as a code official, design professional, or an approved agency. A final report detailing any deficiencies and corrective actions is required. Residential requirements include the building or dwelling unit enclosures must be tested in accordance with ASTM E779, ANSI/RESNET/ICC 380, ASTM E1827, or another equivalent method approved by the code official, with air leakage not exceeding 0.0079 $m^3/(s \times m^2)$ [0.28 CFM/sf] at 0.2 inch w.g. (50 Pa). Similarly, commercial requirements include that the whole building thermal envelope (building enclosure) must be tested according to ASTM E779, ANSI/RESNET/ICC 380, ASTM E3158, ASTM E1827,

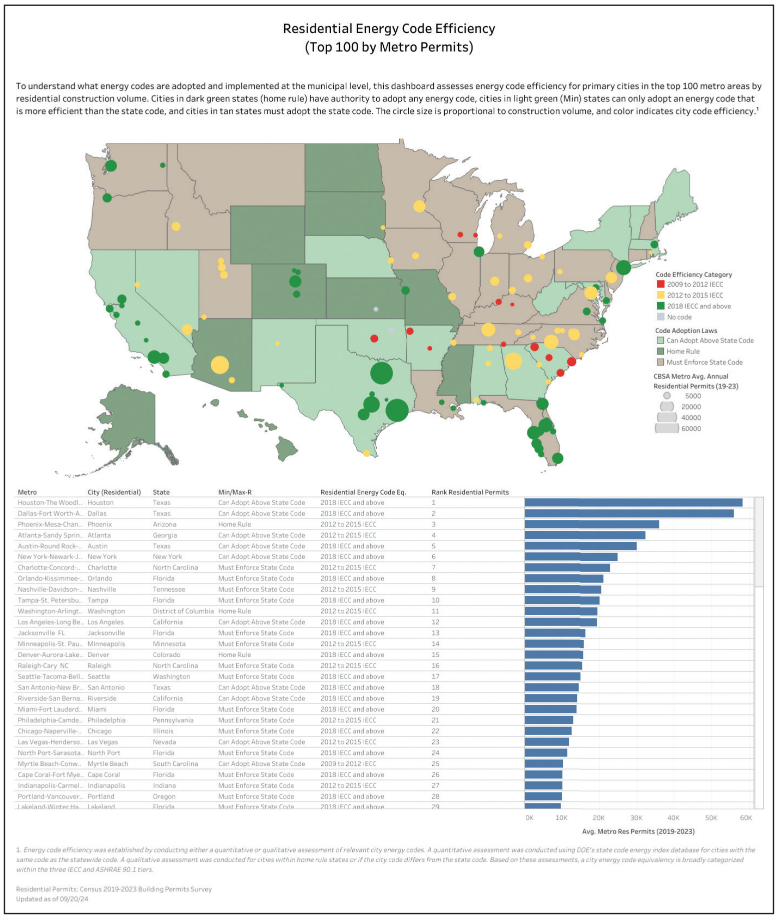


Residential energy code adoption by state.

Illustrations courtesy Department of Energy (DOE) Building Energy Codes Program



Commercial energy code: State energy index relative to current model code.



Residential energy code efficiency by metro markets.

or an equivalent method approved by the code official, with air leakage not exceeding 2.0 L/s x m^2 (0.40 CFM/sf) at 0.3 inch w.g. (75 Pa).

Technological advancements

Recent technological advancements have significantly improved the design and testing capabilities of air barrier systems. Hardware and software packages, which have become more affordable, now include compatible fans, manometers, and Wi-Fi-enabled software packages. These improvements streamline the process of conducting airtightness tests and allow for real-time data collection and analysis, making it easier to assess and adjust air barrier performance.

Diagnostic tools for detecting air leakage, such as infrared scanners and smoke tracers, have also improved and become more affordable, helping identify leaks more accurately and quickly. However, there is still room for further advancements, particularly in developing higher-powered blowers to test larger buildings and reducing setup times for testing procedures.

Additionally, as air-tightness requirements improve via codes and standards, other non-compulsory programs continue to aim for even

ADDITIONAL **INFORMATION**

Author

Matthew Ridgway, P.E., is an architectural engineer with 20 years of experience specializing in building enclosure systems. As the Northeast director of Intertek's building and construction division, Ridgway leads the building science solutions consulting group and provides technical oversight of several regional laboratories. Ridgway's design work includes building enclosure consulting and historic restoration. His passion is investigative and forensic work which has focused on building performance issues including water intrusion, building instrumentation, air leakage and condensation analysis for modern and historic roofing, waterproofing, fenestration, and opaque walls. He has also conducted in-depth investigations into manufacturing defects of prefabricated systems. His experience in commercial and institutional project planning and repair prioritization informs his professional practice.

Key Takeaways

As building codes become more stringent, the demand for environmentally friendly, airtight buildings is increasing. The 2021 *International Energy Conservation Code* (*IECC*) and related standards are key drivers of this trend, leading to more rigorous testing standards for building enclosures and airtightness. A well-designed air barrier system must be structurally sound and durable in all climates. When an air barrier fails, it can cause serious issues such as reduced insulation effectiveness, unwanted air infiltration, mold growth, and premature failure of building components. ASTM tests play a critical role in validating the performance of air barrier systems, while the 2021 *IECC* has significantly impacted building codes nationwide. This has heightened the focus on energy efficiency and airtightness, making whole-building inspections and airtightness testing for new construction more common.

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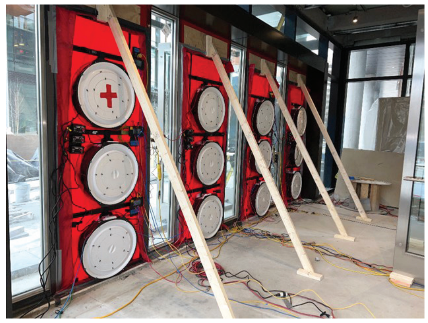
higher performing buildings. Programs such as Phius' Passive House, and Net Zero Standards can only be achievable with improvements in energy recovery and air filtration in order to minimize the energy use required for ventilation.

Involving a consultant

Involving a qualified building enclosure consultant in the air barrier design and installation process is important due to their specialized expertise. They possess in-depth knowledge of air barrier design, materials, installation techniques, and testing procedures. They stay current with evolving building codes and regulations, guaranteeing the project complies with all requirements. Building enclosure consultants also can identify potential problem areas early on and suggest solutions that prevent costly issues later. By overseeing the construction process, they can ensure the air barrier is installed correctly and meets performance standards before code-required testing.



Fan array for a whole building airtightness test.

Photo courtesy Intertek

Conclusion

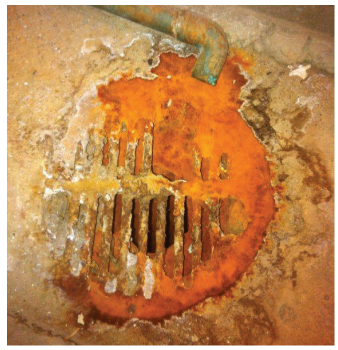
Air barrier systems offer many benefits beyond compliance with building codes. Investing in a well-designed and properly installed air barrier system can improve energy efficiency, enhance indoor comfort, protect building components, increase property value, and reduce environmental impact. Air barriers are not merely a compliance requirement but a strategic investment that can deliver long-term benefits for building owners and occupants. By prioritizing air barrier performance, project teams can ensure a building is comfortable and sustainable for years. **CS**

CLASSIFIEDS

Understanding the Emerging Acidic Condensate Issue

Kyle Emmons is the president of JJM Alkaline Technologies, which designs and manufactures condensate neutralizers for the heating and plumbing industries. He focuses on sales, marketing, and product development. Emmons holds a bachelor of business administration in finance from Texas Christian University and an MBA from the Kellogg School of Management at Northwestern University.

Today's high-efficiency, gas-fired heating appliances (*e.g.* boilers, furnaces, and water heaters) offer a variety of critical benefits, from reducing a building's energy consumption to minimizing its environmental footprint. These types of condensing appliances are well-suited for most new construction and retrofit installations.



Improperly managed acidic condensate from high-efficiency gas-fired appliances can corrode plumbing infrastructure, as shown in this severely damaged floor drain.

Photos courtesy JJM Alkaline Technologies

Corrosion caused by untreated acidic condensate can compromise pipe integrity and lead to costly system failures, as seen in this rusted and leaking setup.

Key factors driving the adoption of high-efficiency appliances include new regulatory mandates. In late 2023, the Department of Energy (DOE) established a standard for residential gas furnace efficiency, set to take effect in late 2028. This rule mandates that non-weatherized gas furnaces and those in mobile homes achieve an annual fuel utilization efficiency of at least 95 percent. To comply, gas furnaces will need to utilize condensing technology, which uses a secondary heat exchanger to recover combustion gases and capture more heat. The DOE states this standard is "readily achievable by modern condensing furnaces."

Despite their reputation as a game-changing innovation, high-efficiency, gas-fired heating appliances produce acidic condensate (pH 2.9-4.0). If discharged without being properly treated, this acidic residue can corrode plumbing, concrete foundations, floor drains, septic systems, and other wastewater infrastructure. It can also potentially contaminate groundwater and the environment.

A typical residential, high-efficiency gas-fired heating appliance produces about 7.6 L (2 gal) of acidic condensate per hour, leading to an estimated 39.6 billion L (9 billion gal) annually across the U.S. This poses significant risks to properties and the environment. The solution is straightforward: install condensate neutralizers with every high-efficiency gas-fired heating appliance.

Condensate neutralizers are specialized filtration devices that connect to appliances and contain a neutralizing media like magnesium hydroxide to treat acidic condensate. The acidic condensate drains from the appliance and is piped to the gravity-fed neutralizer, where it interacts with the media, raising the pH between five and 9.5. This process neutralizes the condensate, rendering it safe to be discharged into the building's plumbing and wastewater system. These devices are essential for preventing damage from acidic condensate.

A properly installed condensate neutralizer can effectively function in high-efficiency systems for years if routinely inspected and its neutralizing media regularly replaced. Maintenance is crucial; neglecting it is akin to not having a neutralizer at all. Factors like condensate acidity and volume affect media longevity. Service technicians should regularly test the pH of the treated condensate to ensure adequate treatment. The service technician should replace the media if the pH drops below five (or the minimum level per the local authority). Generally, the media should be replaced at least every 12 months. Incorporating this service into a preventative maintenance program for gas-fired, high-efficiency appliances is recommended.

Ultimately, condensate neutralizers are a must-have accessory for every condensing installation in a building or home to ensure the gas-fired heating appliance operates safely, achieves code compliance, and fulfills its environmental promise. **CS**