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High-density Polyiso Cover Boards

Enhancing the durability of low-slope roofs

by Justin Koscher

Photos courtesy Soprema

WHEN PLANNING FOR A ROOF ON A NEW BUILDING OR REROOFING AN EXISTING STRUCTURE, FINDING THE RIGHT PRODUCTS TO BALANCE COST AND PERFORMANCE IS A TALL ORDER. WHETHER IT IS

REPLACEMENT ON AN OLDER BUILDING OR NEW CONSTRUCTION, THE RIGHT ROOF SYSTEM CAN REDUCE INSTALLATION COSTS AND IMPROVE BUILDING PERFORMANCE.

Many architects, specifiers, and contractors include cover boards in conventional low-slope roof assemblies (with a roof membrane as the outermost component) to enhance overall system durability and lower long-term maintenance costs. A cover board is a thin substrate to which a roof membrane is secured. It can help extend the life of a roof assembly by providing a tough, resilient layer for improved wind uplift resistance, increased impact resistance from construction/service traffic, and high compressive strength.

In a conventional roof system, the cover board is installed on top of insulation (below the membrane). Many product types are available, ranging from traditional gypsum board, cement board, perlite board, asphalt/glass board, glass-based board, mineral wool, oriented strand board (OSB), polyurethane-based board, and wood fiber board to highly engineered, high-density (HD) polyisocyanurate (polyiso) cover boards.

Specifying polyiso cover boards

All HD polyiso cover boards are developed and tested to be part of a roofing system. Most HD polyiso cover boards are compatible with mechanically attached and fully adhered single-ply roof systems (*e.g.* thermoplastic polyolefin [TPO] or ethylene propylene diene monomer [EPDM]) and cold-applied modified bitumen (mod-bit) and built-up roof (BUR) applications.

When specifying cover boards, several factors should be considered, including roof-covering type and installation method, project/building location (which may govern wind uplift requirements), as well as anticipated service conditions (*i.e.* traffic or additional rooftop equipment such as photovoltaic [PV] panels). The designer, specifier, or contractor is encouraged to consult roof system manufacturers for guidance and assistance in specifying the system that best meets the needs of the project, design team, and/or building owner.

In Canada, HD polyiso cover boards may be designated as Type 4, 5, or 6 (depending on physical properties, including compressive, tensile, and flexural strength) in accordance with the Underwriters Laboratories of Canada (CAN/ULC) S704.1:2017, *Thermal Insulation*,

Many architects, specifiers, and contractors include cover boards in conventional low-slope roof assemblies (with a roof membrane as the outermost component) to enhance overall system durability and lower long-term maintenance costs.

Figure 1

Property	Physical Property Requirements					
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Compressive Strength, min., kPa	110	140	170	550	760	965
Flexural Strength, min., kPa	170	275	275	2750	2750	2750
Tensile Strength, min., kPa (perpendicular to the plane of the facer)	24	35	35	95	95	95

According to the Underwriters Laboratories of Canada (CAN/ULC) S704.1:2017, *Thermal Insulation, Polyurethane and Polyisocyanurate, Boards, Faced*, HD polyiso cover boards are categorized into different types.

Image courtesy Polyisocyanurate Insulation Manufacturers Association

Polyurethane and Polyisocyanurate, Boards, Faced. Type 4, 5, and 6 products have significantly higher requirements for physical properties as indicated in Figure 1. Type 1, 2, and 3 products are typically designated for roof insulation (installed above the roof deck and below the cover board).

The use of cover boards, although not required by the *National Building Code of Canada* (NBC), is a best building science practice as it offers added resiliency and durability to the roof system. An ongoing research consortium at the National Research Council Canada (NRC)

is focusing on evaluating the available cover board product types. The outcome of this research will pave the way for developing a Canadian standard for cover board products.

Benefits of HD polyiso cover boards

High-density polyiso cover boards are increasingly being used as they offer many benefits.

Lightweight

HD polyiso cover boards, on average, weigh 66 to 80 percent less than gypsum and cement products with the same thickness. Individual boards are light enough to be carried by a single worker, thereby reducing manpower requirements.

Water resistance

The water absorption by volume of HD polyiso cover boards is about four percent, lower than traditional options such as gypsum cover boards. Polyiso boards do not rot or dissolve and can maintain their integrity under adverse weather conditions.

Fewer truckloads

HD polyiso cover boards can be shipped with about three times more square foot per truckload requiring fewer trucks/hauls, leading to fuel and transportation savings as well as reduced traffic congestion on jobsites.

Reduced product staging time

These cover boards require less crane time with lower hoisting, loading, and staging costs. They are easier to carry and move around the roof. Pallets do not require breaking or redistribution as needed with the heavier cover board product types.

Ease of cutting

Unlike gypsum or cement cover boards that require heavy-duty saws or cutters to resize, HD polyiso product types can be easily scored



and cut using a utility knife. A single worker can measure and cut boards to size, increasing the roofing team's overall productivity.

Greater resistance to heat flow

Certain cover board products can enhance building energy efficiency by increasing the overall performance of roof assemblies. For example, HD polyiso cover boards contribute additional thermal resistance to the roof assembly and can provide as much as five times greater R-value than gypsum-based products of the same thickness. A 13-mm ($\frac{1}{2}$ -in.) HD polyiso cover board typically has an RSI value of 0.44 (2.5 R-value), whereas the RSI value of a gypsum cover board with the same thickness is about 0.11 and a cement cover board has an RSI value of about 0.07.

Dust free

HD polyiso cover boards are made of the same polyisocyanurate found in many insulation products and do not generate the dust produced by gypsum or cement products during cutting. The use of HD polyiso cover

The design team for dairy co-operative Agropur's headquarters in Longueuil, Québec, Canada, employed high-density (HD) polyiso cover boards to ensure the roof assembly is not damaged by heavy equipment or workers.

boards decreases jobsite dust and debris as well as potential for seam contamination during installation of the roof covering. Less mess equals better productivity for installers while the absence of silica particles in the air enhances worker safety.

Mold

These cover boards resist mold growth when tested in accordance with industry standards such as ASTM D3273, *Standard Test Method for Resistance to Growth of Mold on the Surface of Interior Coatings in an Environmental Chamber*.

Resiliency

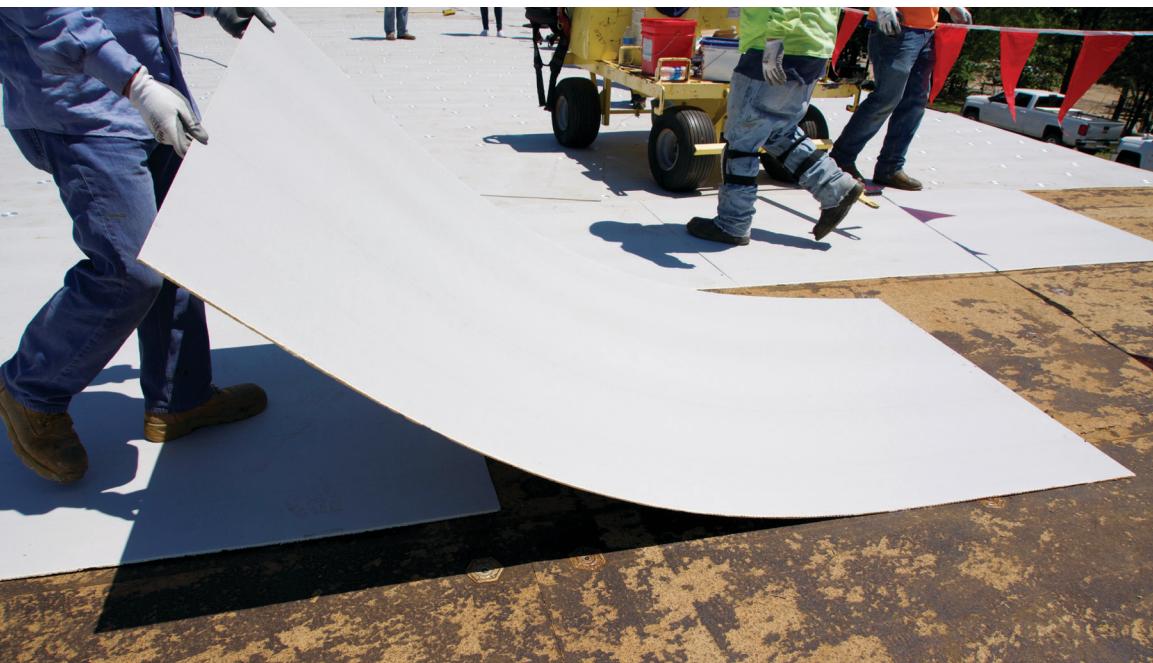
Higher compressive strength and flexibility in HD polyiso cover boards with coated glass mat facers (CGF) improve a roof's resistance to wind uplift and imparts greater resistance to impact from hail, as well as various construction and service activities (*i.e.* damage from foot traffic, heavily loaded carts, and construction tools).

Versatility

High-density polyiso cover boards can be used in new construction, reroofing, and recover applications. They are suitable in mechanically attached, adhered, and ballasted roof assemblies. HD polyiso cover boards are manufactured using the same process as polyiso board insulation. However, cover boards are produced to have a higher density, thus, higher physical properties such as compressive, flexural, and tensile strength. The product is typically produced in 13-mm (½-in.) thick boards using a continuous manufacturing process. The final product can then be cut and delivered to the jobsite in either 1.2 x 1.2 m (4 x 4 ft) or 1.2 x 2.4 m (4 x 8 ft) board sizes.

Additional considerations when selecting a cover board

Prior to installation, roofing contractors should protect HD polyiso cover boards from exposure to moisture and keep them safe from other hazards like open flames. The product is typically delivered to the jobsite



in manufacturer wrapped bundles. Like all roofing materials stored on the jobsite or roof, care should be taken to ensure cover boards are properly protected and stored to prevent materials from blowing off the roof. For additional information on recommended storage and handling procedures, it is advisable to consult the Polyisocyanurate Insulation Manufacturers Association's (PIMA's) Technical Bulletin 109, *Storage and Handling Recommendations for Polyiso Roof Insulation*. Additionally, it is best to install the quantity of roofing material (insulation and cover board) that can be covered the same day by a roof-covering material. HD cover boards are tested to meet the applicable product and roof assembly standards for fire performance. For information on evaluated assemblies including HD cover boards, interested parties are encouraged to review the

HD polyiso cover boards offer additional thermal resistance to roof assemblies, thereby increasing the buildings' energy efficiency.

Photo courtesy Johns Manville

third-party roof assembly listings from accredited testing agencies such as Underwriters Laboratory (UL) and Factory Mutual (FM).

Finally, like polyiso insulation products, HD cover boards are manufactured using a blowing agent with low global warming and zero ozone depleting potential. Products sold with a thermal resistance value (R-value) should be tested in accordance with industry standards. R-values for closed-cell foam products are reported as aged-values to reflect the loss of any blowing agent.

Case study

In 2016, the dairy co-operative Agropur opened its new, two-storey office building in Longueuil, Québec, Canada, that earned a Leadership in Energy and Environmental Design (LEED) certification from the Canada Green Building Council (CaGBC) in 2017. The project allowed Agropur to consolidate four existing offices into a single, unified 23,226-m² (250,000-sf) campus in a heavily wooded environment. The new campus is adjacent to its existing distribution centre and quality assurance (QA) labs.

The campus offers a state-of-the-art office environment, underground parking for 700 cars, as well as amenity areas, such as a cafeteria, gymnasiums, and relaxation and conference rooms. The building was designed in a series of narrow wings, with many windows to allow natural light and continuous views of the surrounding forest.

The building was designed by Le Groupe Architex, and the roof was installed by Truchon Roofing. Since the exterior of Agropur's building is glass, regular window washing is a must. The roof needed solid bases to protect it from the heavy equipment and accompanying workers who would launch from the roof.

The architect chose HD polyiso cover boards to ensure the roof materials installed below the board are not damaged by additional loads. Unlike other types of cover board, HD polyiso offers the added thermal resistance, which contributes to improved energy efficiency.

Commercial low-slope roof systems are expected to perform during the service life of a building, so understanding and utilizing products to

help enhance the roof's performance and longevity is advisable when planning for one. Selecting products offering performance benefits as well as ease of installation is a win for both the contractor and building owner. With proper installation, HD polyiso cover boards provide versatile and resilient low-slope roof system solutions. Whether it is exposed to severe weather or maintenance personnel servicing rooftop equipment, a long-lasting roof system means satisfied building owners.

CS

Note

¹ For more information, visit www.buildgp.com/product/densdeck-prime.

This article originally appeared in the June 2019 issue of Construction Canada.

ADDITIONAL INFORMATION

Author

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Abstract

Many architects, specifiers, and contractors include cover boards in conventional low-slope roof assemblies (with a roof membrane as the outermost component) to enhance overall system durability and lower long-term

maintenance costs. A cover board is a thin substrate to which a roof membrane is secured. It can help extend the life of a roof assembly by providing a tough, resilient layer for improved wind uplift resistance, increased impact resistance from construction/service traffic, and high compressive strength.

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B1020—Roof Construction

Key Words

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Cover boards	Manufacturers Association
Insulation	Roofing
Polyisocyanurate	



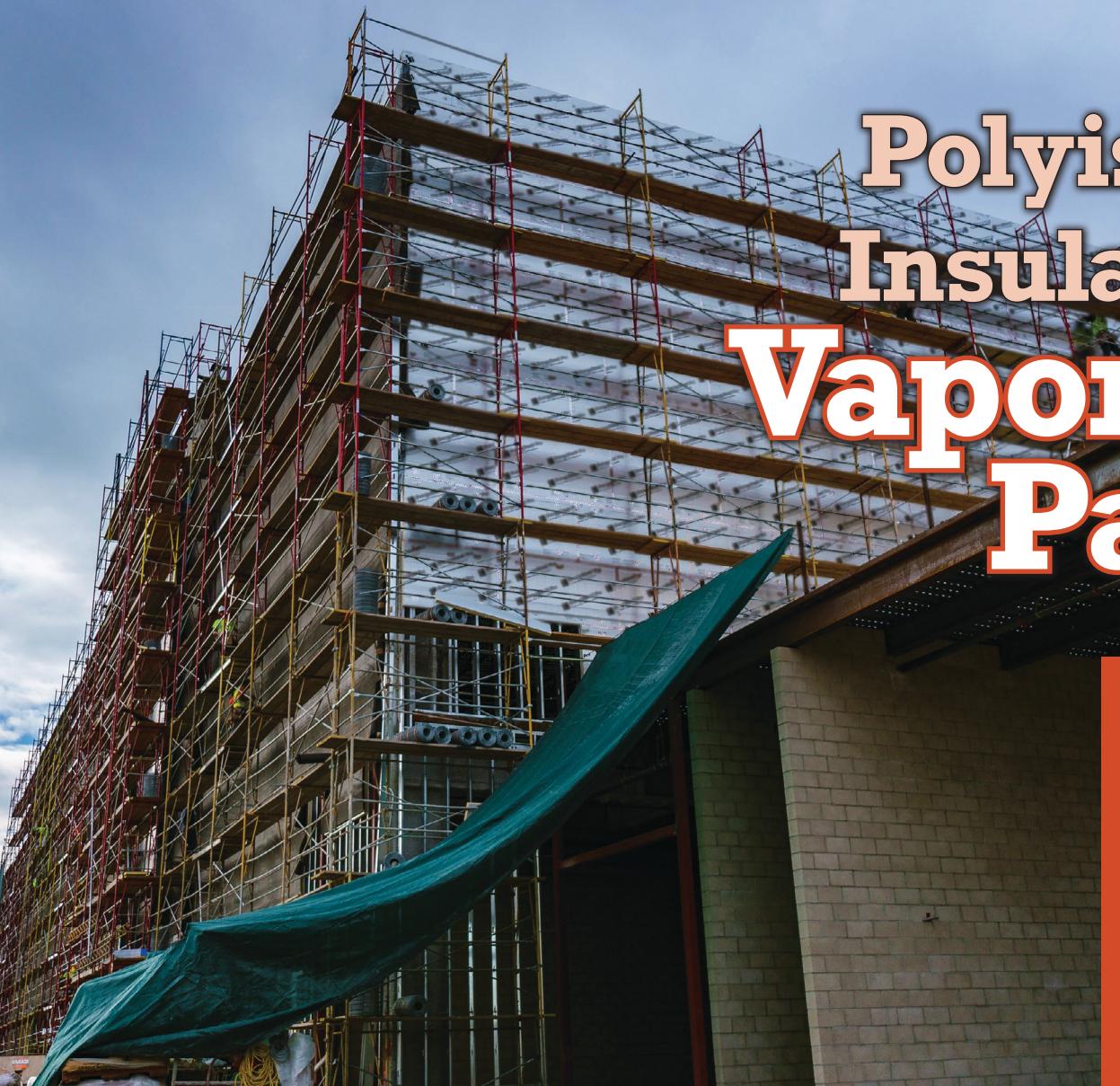
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Polyisocyanurate Insulation and the **Vapor Retarder Paradox**

by Tom Robertson

Photos courtesy Atlas Roofing Corporation

THE WORLD OF CONSTRUCTION IS FILLED WITH CONTRONYMS—WORDS HAVING TWO COMPLETELY OPPOSITE MEANINGS. HAS A BUILDING WEATHERED MANY SEASONS, OR IS IT FALLING APART BECAUSE IT IS SO WEATHERED? IS THE CONTRACTOR PROVIDING GOOD OVERSIGHT, OR DID AN OVERSIGHT SET OFF AN ANGRY CLIENT? ANYONE IN THE CONSTRUCTION INDUSTRY CAN VOUCH THAT ALMOST NOTHING IS EVER QUITE AS STRAIGHTFORWARD AS ONE MIGHT HOPE.

Like a cononym, here is another word that causes plenty of headaches—vapor retarder. In a given application, it can have opposite effects depending on its properties and conditions of use. Employed correctly, it can help keep structures dry, and when used incorrectly, it can contribute to moisture accumulation and prevent structures from drying. This creates a paradox of sorts because some vapor retarder materials, like polyisocyanurate (ISO) insulation, may be perceived as a problem. In reality, such materials can provide a simple and effective solution to water, air, vapor, and thermal control for building enclosures. The solution is proper application in coordination with the climate conditions and the overall design of any building envelope assembly (*i.e.* above-grade walls, below-grade basement and crawlspace walls, and roofs).

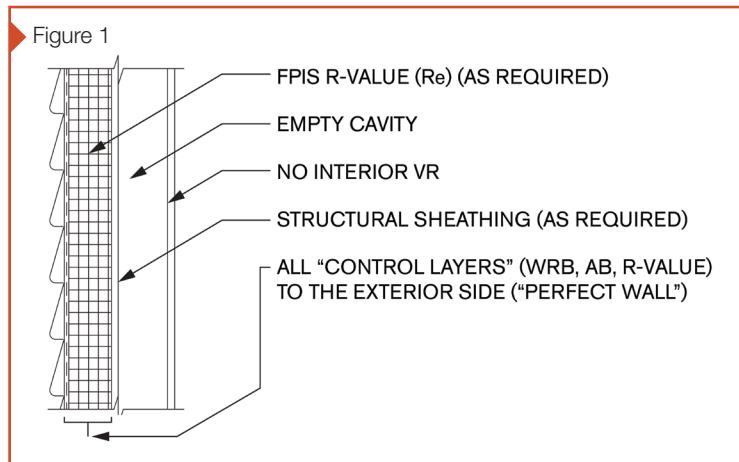
In its different forms (liquid, vapor, and solid), water is the great enemy of long-lasting, efficient construction. Water can cause sound structures to crumble from corrosion, rot, and rust. It can provide an environment for harmful mold that can be difficult and expensive to eradicate. It can completely ruin a building's aesthetics. Water is, quite literally, a relentless force of nature for good or bad. This natural dichotomy is why it must be managed or controlled in any reasonable design approach and can never be completely eliminated.

Above-grade vapor control methods

The ideal wall is one that provides an uninterrupted thermal barrier to keep the building envelope protected and ensures long-term energy efficiency. To that end, a building must be resistant to water and air, manage vapor, and limit heat transfer, prioritized in that order, as detailed by Dr. Joseph Lstiburek of Building Science Corporation in his description of ‘the perfect wall.’¹ As shown in Figure 1, the perfect wall has all of the control layers (water, air, thermal, and vapor) located on the exterior side of the building envelope assembly and thus entails the use of continuous insulation (ci) materials like ISO. For example, an interior vapor retarder is not required and instead the vapor control layer is provided on the exterior side (*e.g.* by the



A construction project in California utilizing polyisocyanurate (ISO) insulation to protect against vapor and moisture intrusion.



‘The perfect wall’ has all of the control layers (water, air, thermal, and vapor) located on the exterior side of the building envelope assembly and thus entails the use of continuous insulation (ci) materials like polyisocyanurate (ISO).

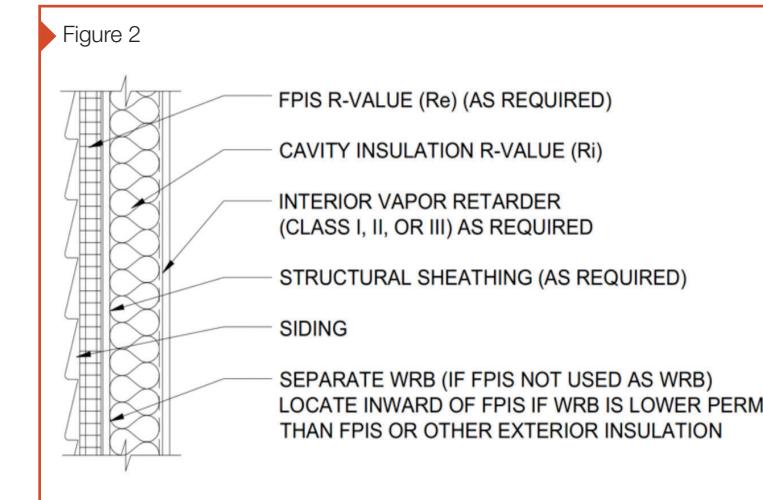
Images courtesy Applied Building Technology Group

inner facing of the foil-faced ISO). This maximizes the ability of the assembly to dry to the interior. While the perfect wall may indeed be the ideal solution, there are other wall configurations that will perform well for a given application.

One example of an ‘optimal’ variant from the perfect wall is an above-grade wall with a combination of cavity insulation and exterior ci for thermal control to satisfy the energy code. This is also known as a hybrid wall (Figure 2). A key design consideration is the insulation ratio which compares the exterior ci R-value to the cavity insulation R-value—material properties that are readily available and familiar to building professionals. When exterior ci materials like foil-faced ISO are used for this purpose, it provides thermal control, thereby, saving energy and preventing thermal bridging through wall framing. It also prevents moisture accumulation by shielding the wall from outdoor water-vapor sources in the humid summer while keeping the interior of the wall warm during the winter to prevent condensation or high humidity. This is particularly true when the ci is also approved for use as a water control layer (*i.e.* water-resistive barrier [WRB]) and air barrier. For any wall design, it is of primary importance to control water and air movement. In other words, it is pertinent to never overlook the perfect wall priorities mentioned earlier, even if specifying a variant like the hybrid wall.

The ‘warm wall’ design approach described above is simple to implement and robust in the field. It controls the temperature of the assembly and promotes drying to the interior through the selection of an appropriate interior vapor retarder, such as interior latex paint, kraft paper, or various types of ‘smart’ vapor retarders. The warm wall design is based on a temperature-controlled design approach and, as such, removes the headache of attempting to control moisture purely by a traditional ‘water vapor permeance’ design approach. The downfall of the traditional method is it requires careful specification of the vapor retarder properties of each material layer on the interior and exterior of the assembly. For many materials, this property may be unknown or uncertain. It also attempts to walk a fine line

The ideal wall is one that provides an uninterrupted thermal barrier to keep the building envelope protected and ensures long-term energy efficiency.



Hybrid wall assembly (cavity and ci).

between outward (wintertime) and inward (summertime) water vapor movement, which ends up cycling the assembly through seasonal periods of higher and lower moisture. Conversely, a warm wall design results in a stable and dry assembly year-round.

As energy codes continue to advance, the traditional vapor retarder design approach has become more and more challenging to reliably implement. Increasing cavity insulation levels can worsen the vulnerability to condensation or moisture accumulation by causing wood or gypsum sheathing materials to become colder (not warmer), resulting in condensation on surfaces.

However, the use of ci for a warm wall design completely changes this challenge into an opportunity to leverage newer energy code insulation requirements in a way that also improves moisture performance. Fortunately, energy codes always afford specifiers the ability to use ci (alone, as in the perfect wall, or together with cavity insulation) whether it is offered in the code as a prescriptive option or not. Also, building codes are in the process of updating vapor control provisions to better coordinate with advancements in the energy code, such as in the case of the upcoming 2021 editions of the *International Building Code* (IBC), *International Residential Code* (IRC), and *International Energy Conservation Code* (IECC).²

Below-grade vapor control methods

The discussion so far has been focused on above-grade wall applications, but what about below-grade walls? Well, the same principles apply, but in many ways, basements are easier because the climate below-grade does not change as much with the seasons. Basically, the ground is always moist and moderates the outside temperature year-round. The result is water vapor drives are always inward. Of course, the same high priority for liquid water control applies. All high performing basement walls start with:

- proper drainage of surface water (slope of grade away from building);
 - drainage to remove any liquid water in the soil away from the foundation; and
 - waterproofing the below-grade outside surface of the basement wall.
- Nearly 90 percent of basement moisture problems are related to the failure to provide or maintain one or more of these crucial features.

For basements, the perfect wall concept also applies as the ideal solution. This simply requires the use of ci on the exterior side of the basement wall. However, for practical reasons, it is often optimal to use ci on the interior side of the assembly together with the water control strategies discussed above. These practical reasons include the need to protect the insulation (particularly above-grade portions) and the need to retrofit an existing basement (like the case study addressed in the



next section). When insulating and finishing a basement on the interior side, it is important to be mindful of where the vapor retarder layer is placed. Ideally, vapor retarder should be layered directly on the interior surface of the block or concrete wall and should be water-resistant and insulating, like ISO ci, in order to protect moisture-sensitive materials. Consequently, wood framing, furring, gypsum, and water-absorbing insulation materials should be placed on the inside of the ci layer. This approach is consistent with the U.S. Department of Energy's (DOE's) Building America Program best practices for foundations.³

Real-world application

Understanding the principles and methods for controlling water vapor is all well and good, but how does it work in a practical application?

Nearing completion, this project in California includes ISO to protect against the elements and meet building codes.

Photos courtesy Atlas Roofing Corporation

A recent residential project in Marietta, Georgia, provides a good example of how ISO insulation helps control moisture issues.

Homeowners Jon and Rachel recently remodeled their basement to create a comfortable suite for Jon's mother. The previous structure of the basement made it difficult to comfortably control the basement temperature, and condensation issues had led to a strong, musty odor. The couple had already decided to install a second HVAC unit to help control the basement temperature, though they were concerned about increasing energy usage. They also knew they needed a better way to control moisture to rid the area of its musty smell.

Jon and Rachel decided to incorporate a better insulation solution to create a comfortable environment. They installed foil-faced continuous ISO insulation on the interior side and directly to the basement walls. Since the foil-faced ISO insulation is vapor impermeable and the basement is below grade, wood framing and drywall were placed on the interior side of the ISO. This protected the wood and interior finishes from moisture moving inward through the basement wall. There was no additional vapor retarder placed behind the finish on the wood frame, as the foil-faced ISO provided for insulation and a properly located vapor retarder for the basement wall. In the end, this approach solved their moisture-control issues and created a healthier, cleaner environment. As an added bonus, Jon and Rachel have noticed little change in their energy costs because the new basement space is so energy efficient.

In the case of this application, the insulation method was a simple and effective way to control moisture issues with few compromises. While each project requires builders to consider a variety of factors, such as the thickness of the wall design, extreme climate, or the client's budget, the insulation method can be applicable in a variety of both residential and commercial applications.

Conclusion

While every project and its specifications will be different, the vapor control and insulation methods described above are available and

generally applicable to optimize wall performance and minimize moisture issues.⁴

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Notes

¹ Visit www.buildingscience.com/documents/insights/bsi-001-the-perfect-wall.

² For more information on the design approaches, vapor retarders, continuous insulation (ci), and an online wall design calculator to help with proper specification, refer to www.continuousinsulation.org.

³ See www.energy.gov/eere/buildings/building-america.

⁴ See Note 2.

ADDITIONAL INFORMATION

Author

Tom Robertson is an experienced thought leader in the continuous insulation (ci) industry, developing and executing strategy as business unit manager for the Atlas Wall CI division. He oversees the wall insulation business unit including marketing, sales, product development, and customer relationships. Robertson holds a master's degree from the Georgia Institute of Technology and has 20 years of experience in insulated wall design and products including insulations, weather barriers, and façade finishes. Robertson can be contacted via e-mail at trobertson@atlasroofing.com.

Abstract

The 'warm wall' design is based on a temperature-controlled design approach and, as such, removes the headache of attempting to control moisture purely by a traditional 'water vapor permeance' design approach. As energy codes continue to advance, the traditional

vapor retarder design has become more and more challenging to reliably implement. However, the use of continuous insulation (ci) for a warm wall design creates an opportunity to leverage newer energy code insulation requirements in a way that also improves the building's moisture performance.

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07 26 00—Vapor Retarders

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B20—Exterior Vertical Enclosures
B2010—Exterior Walls

Key Words

Division 07	Polyisocyanurate
Building envelope	Vapor retarder
Continuous insulation	Warm wall design
Insulation	

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Energy Code Math for Commercial Walls



How polyiso continuous insulation can help

by Timothy Ahrenholz

Photo © Johns Manville

IT IS AN EASY MISTAKE TO MAKE. FOR EXAMPLE, WHEN ONE COMES ACROSS THE R 13 + 7.5 CI WALL INSULATION REQUIREMENT IN THE *INTERNATIONAL ENERGY CONSERVATION CODE (IECC)* COMMERCIAL PROVISIONS, IT CAN BE TEMPTING TO JUST ADD THE TWO R-VALUES AND INSTALL R-20.5 RATED INSULATION IN THE CAVITY WITH THE ASSUMPTION BEING THAT THE SAME PERFORMANCE CAN BE ACHIEVED WITH FEWER STEPS. HOWEVER, BY EMPLOYING JUST R-20.5 CAVITY INSULATION, ONE WOULD BE ACCEPTING A 16 PERCENT DECREASE IN THERMAL PERFORMANCE IN A WOOD-FRAMED WALL, OR A 40 PERCENT DECREASE IN A STEEL STUD WALL, WHEN COMPARED TO THE ENERGY CODE REQUIREMENT.

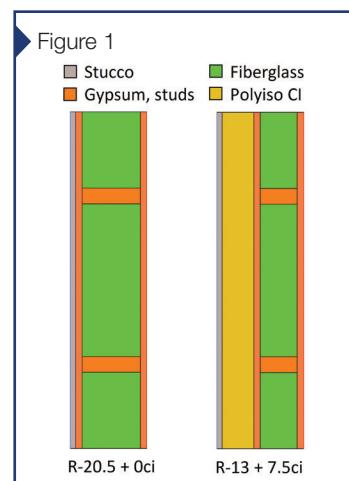
Continuous insulation (ci) and cavity insulation products are both sold with R-value ratings, but the way these two products are used in wall construction means they do not have the same effectiveness.¹ Cavity insulation is interrupted by framing members, which let heat through the insulation layer. On the other hand, ci, as the name suggests, is uninterrupted (except at fasteners and service openings, as defined by IECC). So a layer of cavity insulation is less effective than a layer of ci of the same R-value.

This can easily be seen with thermal modeling software. Figure 1 shows a cross-section of two walls. The left wall is the R-20.5 + 0 ci, and the right is R-13 + 7.5 ci. When these two are subjected to a temperature differential—such as winter outside and room temperature inside—heat flows through the wall from the warm to the cold side. Figure 2 shows the temperature flux, or rate of change, through these walls. As one can see, there is high flux through the wall studs. In the wall without ci, the studs act like a ‘heat highway,’ allowing heat an easy route around the cavity insulation—out of the wall in cold climates and into the wall in hot regions. When ci is added, the highway ends, and heat is forced to slowly seep through the last layer of insulation.

The real math problem of determining a wall assembly’s overall R-value is not nearly so simple as just adding the nominal R-values of the different insulation components (e.g. R 13 + 7.5 ci = R 20.5). Depending on whether wood or steel framing is being employed, different procedures for calculating the assembly R-value of a wall are laid out in the American Society of Heating, Refrigerating and Air-conditioning Engineers’ (ASHRAE’s) 2017 *ASHRAE Handbook-Fundamentals* and *IECC*. This article will discuss both the methods. But first, let us look at some of the terms.

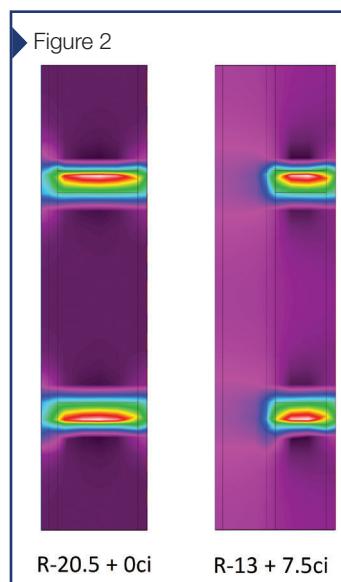
R-values and U-factors

In this article, the u-factor (or C-factor) of a component or an assembly refers to its thermal conductance. A u-factor is given in units as W/m².K (Btu/h·F·sf). One way of understanding these units is the rate of heat



A cross-section of two walls. On the left is the R-20.5 + 0 continuous insulation (ci) wall, and the R-13 + 7.5 ci wall is on the right.

Images © Timothy Ahrenholz



Thermal modeling reveals there is high temperature flux through the wall studs.

transfer (W) through a material with a given u-factor is proportional to the temperature difference on both sides of the material (K) and the surface area available (m²).

The R-value of a component or assembly is the inverse of its u-factor. The R-value describes an object’s thermal resistivity, and the units for R-value are simply the inverse of the u-factor: K.m²/W (sf·F·h/Btu). Therefore, good conductors have low R-values and high u-factors, and good insulators have high R-values and low u-factors. If one knows the R-value of a layer or an assembly, one can find its u-factor by simply calculating the inverse. R-value and u-factor requirements mentioned in this article are taken from *IECC*.

While any layer of material can be described by its R-value, U.S. energy codes only refer to the R-values of insulation layers in the prescriptive R-value compliance path. Conversely, while any layer or assembly also has a u-factor, energy codes only discuss the u-factors of entire wall assemblies. When this is done, a capital 'U' is used. For the remainder of this article, a capital 'U' will be employed when discussing assembly U-factors.

If an R-value and a u-factor are just two sides of the same coin, why would the energy codes include both as separate compliance paths? This is because the R-values of individual components like cavity insulation and ci can be easier to work with and understand than assembly U-factors. Many people can picture an R-13 insulation batt whereas a wall assembly with a U-factor of 0.064 is not an intuitive notion. One must delve into some math to understand what this means.

If there are several unbroken layers of different materials forming a wall assembly, the R-value of the entire assembly can be found simply by adding the layers:

$$R_{\text{total}} = R_1 + R_2 + R_3 + \dots$$

With u-factors, it is not so simple. Since a u-factor is the inverse of an R-value, to find the overall u-factor, one needs the following equation:

$$1/u_{\text{total}} = 1/u_1 + 1/u_2 + 1/u_3 + \dots$$

(Which, by the way, is the exact same equation. Since a material's R-value is just the inverse of its u-factor, the author just replaced each R-value with the inverse of the u-factor.) Now one can take the inverse of the entire equation to find the overall u-factor:

$$u_{\text{total}} = 1/(1/u_1 + 1/u_2 + 1/u_3 + \dots)$$

As mentioned earlier, this only applies to the part of a wall with unbroken layers, such as the wall cavity. To account for the framing in the wall, a separate u-factor calculation must be done, and then the

Figure 3

Layer	R20.5 + 0ci Wall (2x6)		R13 + 7.5ci Wall (2x4)	
	Framing Path	Cavity Path	Framing Path	Cavity Path
Outside Air Film	R-0.17	R-0.17	R-0.17	R-0.17
Stucco	R-0.08	R-0.08	R-0.08	R-0.08
CI	---	---	R-7.5	R-7.5
16 mm (5/8 in.) Gypsum	R-0.56	R-0.56	R-0.56	R-0.56
SPF Stud	R-6.875	---	R-4.375	---
Cavity Insulation	---	R-20.5	---	R-13
16 mm (5/8 in.) Gypsum	R-0.56	R-0.56	R-0.56	R-0.56
Inside Air Film	R-0.68	R-0.68	R-0.68	R-0.68
Total	R-8.925	R-22.55	R-13.925	R-22.55

two u-factors can be combined to get an overall value for the entire assembly. If one tries to do this using R-values, the answer will be wrong. R-values of different heat flow pathways through an assembly cannot be added together, averaged, or area-weighted to get the overall assembly performance.

Energy codes have tried to make compliance possible without doing any math because the math is not intuitive. This is why they have provided tables listing just a required insulation R-value (and in many cases, an accompanying required ci R-value).

How can this be fair or accurate? It is easy to see a wall's overall rating depends on a lot more than just the insulation. What about the air films, cladding, structural sheathing, framing, and interior finish? Well, it turns out *IECC* has assumed the following R-values for all of these layers in a wall in commercial construction:

- exterior air film: R-0.17;
- cladding: stucco, R-0.08;
- sheathing: 16 mm (5/8 in.) gypsum, R-0.56;

A list of the layers for each path heat can take through the walls and their R-values.

- interior finish: 16 mm gypsum, R-0.56; and
- interior air film: R-0.68.

When one uses these assumptions to compute the overall U-factor for the prescriptive R-value wall assemblies, they match right up with the U-factor requirements. To see this correspondence in action, one needs to go through the approved U-factor calculation procedures.

Good energy code math

For wood walls, the “parallel path” method is appropriate, (see for example, the “R 20.5 + 0 ci” and “R 13 + 7.5” wall assemblies in Figure 1, page 18). This method of calculation can be applied to any combination of ci and cavity insulation required for wood-framed construction (whether commercial or residential). The first step is to determine the R-value for each “path” heat can take through the wall. There are two paths—through the framing (studs and headers) and cavity. In Figure 3 (page 18), the layers for each path and their R-values are listed. The totals are obtained by summing the R-values for each layer in each path.

One can see while both walls have the same cavity path R-value, the R 13 + 7.5 ci wall has a higher R-value for the framing path (even with a smaller thermal contribution from the thinner 2 x 4 wall framing), thanks to the ci.

The next step is to combine the R-values of the two paths to get an overall value for the entire wall assembly. To do this, the author assumes the wall assemblies are 25 percent framing (21 percent studs and 4 percent headers) and 75 percent cavity by area, which is typical for 406 mm (16 in.) o.c. framing. Then the U-factor for each wall can be obtained with the following formula:

$$U = ff_{framing} * 1/R_{framing} + ff_{cavity} * 1/R_{cavity}$$

where ff is the framing factor (25 percent for framing and 75 percent for cavity). Once the U-factor is found, the assembly R-value is just the inverse of the U-factor. This calculation gives us the assembly U-factors and R-values found in Figure 4.

For wood walls, the “parallel path” method is appropriate. This method of calculation can be applied to any combination of ci and cavity insulation required for wood-framed construction (whether commercial or residential). The first step is to determine the R-value for each “path” heat can take through the wall. There are two paths—through the framing (studs and headers) and cavity.

Figure 4

	R20.5 + 0ci Wall	R13 + 7.5ci Wall
Effective U-factor	0.061	0.051
Effective R-value	R-16.393	R-19.608
Qualifying Climate Zones	5	6, 7
Climate Zone Required Effective U-factor	0.064	0.051
Climate Zone Required Effective R-value	R-15.625	R-19.608

The U-factors and R-values for the wall assemblies.

Clearly, with complete energy code math, an R 20.5 + 0 ci wall (effective R-16.393) is not equivalent to an R 13 + 7.5 ci wall (effective R-19.608). Further, it becomes obvious the R 20.5 + 0 ci wall complies with and slightly exceeds the R-value requirements only in climate zone five for IECC residential provisions. On the other hand, the R 13 + 7.5 ci wall complies in climate zones up to seven. It is easy to see the location of the insulation makes a big difference (cavity vs. continuous).



A wall with polyiso ci can achieve the code-required, minimum R-value with thinner materials than other products.

Photo courtesy Rmax

Since the math is covered, let us explore a few more comparisons. For instance, how much cavity insulation would one need to achieve performance equivalent to an R 13 + 7.5 ci wall? As demonstrated in Figure 5, R-24 cavity insulation would be required. In most cases, this would require using 2 x 8 studs, since cavity insulation greater than R-21 is generally thicker than the cavity in a 2 x 6 wall. By using ci, the wall is kept to half the thickness it would be otherwise, saving lots of valuable interior floor space.

The benefits of ci ought to be clear for timber-framed structures, but for cold-formed steel framing, the impact is even more significant. Steel conducts heat more efficiently than wood, so the thermal bridging effect is much more pronounced. In this type of structure, ci is absolutely necessary for adequate performance. The calculation method provided in IECC for commercial steel-framed walls is arguably simpler to implement than the parallel path method for wood walls.

Essentially, the code treats the cavity/stud layer of the wall assembly as a single layer with its own R-value, and provides a correction factor to compute the appropriate R-value. For example,

Figure 5

R24 + 0ci Wall		
Layer	Framing Path	Cavity Path
Outside Air Film	R-0.17	R-0.17
Siding	R-0.08	R-0.08
16 mm (5/8 in.) Gypsum	R-0.56	R-0.56
SPF 2x8 Stud	R-9.0625	---
Cavity Insulation	---	R-24
16 mm (5/8 in.) Gypsum	R-0.56	R-0.56
Inside Air Film	R-0.68	R-0.68
Total	R-11.1125	R-26.05
Effective U-factor	0.051	
Effective R-value	R-19.608	

An R-24 cavity insulation would be needed to achieve performance equivalent to an R13 + 7.5 ci wall.

Figure 6

Layer	R13 + 7.5ci Wall	R8 + 10ci Wall
Outside Air Film	R-0.17	R-0.17
CI	R-7.5	R-10
Stucco	R-0.08	R-0.08
16 mm (5/8 in.) Gypsum	R-0.56	R-0.56
Corrected Cavity Insulation	R-13×0.46=R-5.98	R-8×0.46=R-3.68
16 mm (5/8 in.) Gypsum	R-0.56	R-0.56
Inside Air Film	R-0.68	R-0.68
Assembly R-value (sum)	R-15.53	R-15.73
Assembly U-factor	0.064	R-0.064

The advantage of ci over cavity insulation is more obvious in steel-framed walls. Adding just R-2.5 of ci more than makes up for removing cavity insulation worth R-5.

in climate zone six, IECC commercial provisions require a wall u-factor of 0.064 or less. The correction factor for climate zone six with steel studs at 406 mm (16 in.) o.c. is 0.46. Another way of saying this is a layer of cavity insulation contributes only 46 percent of the listed R-value to the overall wall performance. Consider the two qualifying walls in Figure 6.

The advantage of ci over cavity insulation is more obvious in steel-framed walls. In this comparison, adding just R-2.5 of ci more than makes up for removing cavity insulation worth R-5. With deeper 152- and 203-mm (6- and 8-in.) steel studs, the disparity only grows. The full list of correction factors is shown in Figure 7.

Though there are many choices when it comes to ci products, polyisocyanurate (or simply polyiso) stands out for its high R-value per inch of 6 (or more, when layers 76 mm (3 in.) or thicker are used). Polyiso ci is available in thicknesses from 6.35 to 114 mm ($\frac{1}{4}$ to 4.5 in.) or more. For the R-7.5 ci requirement, just over an inch of polyiso would be needed. An additional incentive is most polyiso is sold with a foil facer on one or both sides. This is important as polyiso ci can serve as an air- and water-resistive barrier, saving labor and materials costs, if the facer is properly taped, sealed, and integrated with flashing at penetrations. Additionally, polyiso is manufactured without the use of global-warming-causing blowing agents, making it an attractive choice. Thus a wall using polyiso ci can achieve the code-required, minimum R-value with thinner materials than other ci products, thereby providing more saleable floor space.

If one would like to further explore proper wall design for thermal behavior, visit the wall calculator developed by the Applied Building Technology Group.² This tool uses the approach the authors have outlined to compute the effective R-value and U-factor of a wood-framed wall, and depending on climate zone, determines whether the wall is code-compliant. Additionally, the calculator handles moisture code compliance, another tricky area in design. A version of the calculator for steel walls taking the same approach is in the works. **CS**

Notes

¹ The article assumes design according to U.S. energy codes. However, the concepts presented here are applicable in all territories, as the underlying science does not change.

² Visit www.appliedbuildingtech.com/fsc/calculator for the wall calculator.

Figure 7

Stud Depth	OC Stud Spacing			
	406 mm (16 in.)		610 mm (24 in.)	
Cavity Insulation	Correction Factor	Cavity Insulation	Correction Factor	
89 mm (3.5 in.)	R-13	0.46	R-13	0.55
	R-15	0.43	R-15	0.52
152 mm (6 in.)	R-19	0.37	R-19	0.45
	R-21	0.35	R-21	0.43
203 mm (8 in.)	R-25	0.31	R-25	0.38

A list of correction factors.

Image © Timothy Ahrenholz

ADDITIONAL INFORMATION

Author

Timothy Ahrenholz is a special projects engineer with the Applied Building Technology Group. In this role, he develops design solutions for foam sheathing products. Ahrenholz has been involved with standards development and code change proposals for the I-codes and the *National Building Code of Canada (NBC)*. He holds a master's degree in civil engineering with a structural focus from the University of Illinois, and bachelor's degrees in physics and mathematics from Covenant College. He can be reached at tahrenholz@qualtim.com.

Abstract

The use of continuous insulation (ci) systems on building walls is changing the way specifiers, design professionals, and builders look at the building envelope. The correct approach for determining a wall assembly's overall R-value is not nearly as simple as adding the nominal R-values of the different insulation components. The actual procedure as laid out in the American Society of

Heating, Refrigerating and Air-conditioning Engineers' (ASHRAE's) 2017 *ASHRAE Handbook—Fundamentals* is known as the parallel path method. The article also explains how polyiso insulation allows designers and builders to meet energy code requirements with either thinner wall assemblies or more energy efficient wall assemblies with the same amount of material as compared to traditional insulation approaches.

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Continuous insulation	R-value
Insulation	

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