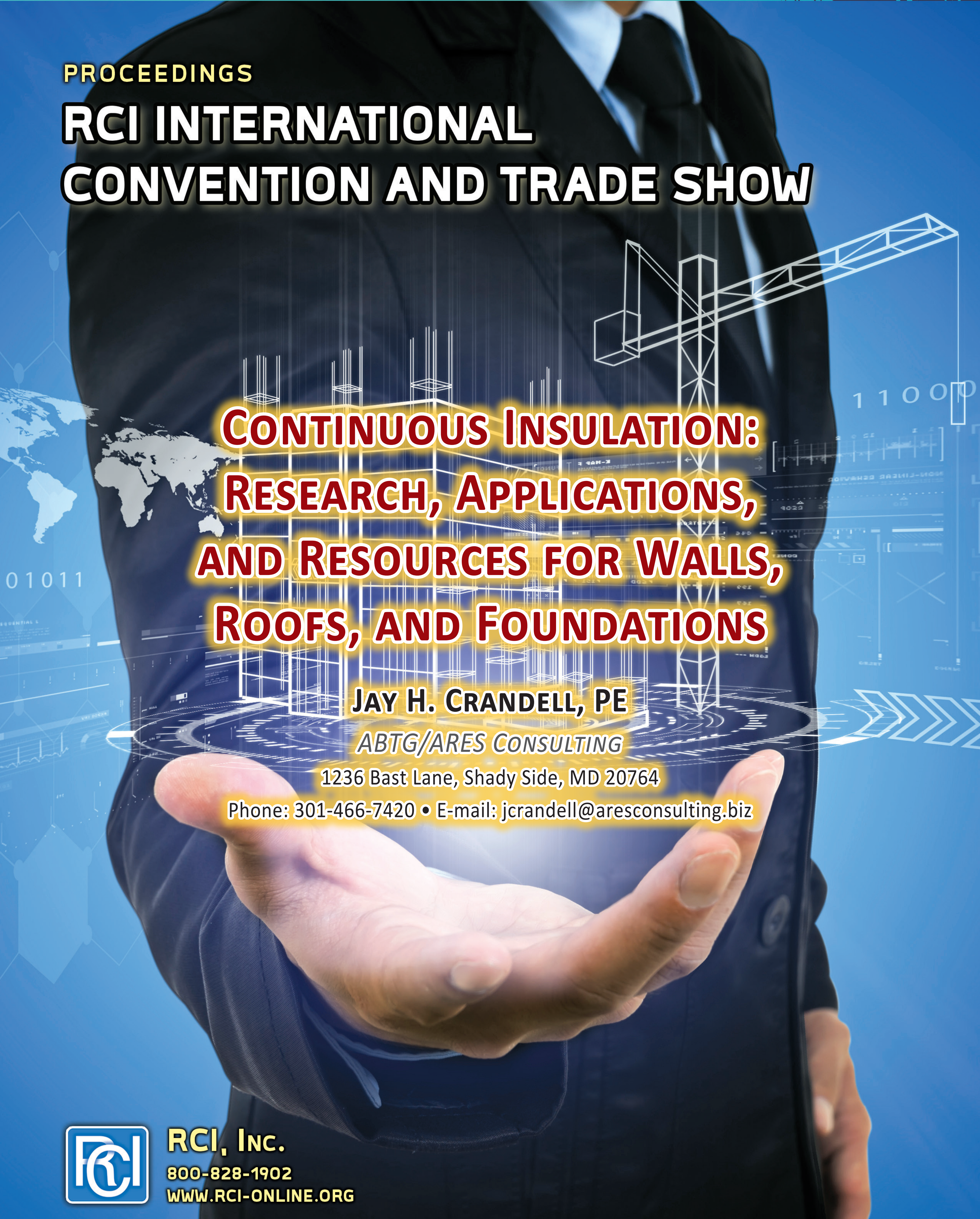

PROCEEDINGS

RCI INTERNATIONAL CONVENTION AND TRADE SHOW

CONTINUOUS INSULATION: RESEARCH, APPLICATIONS, AND RESOURCES FOR WALLS, ROOFS, AND FOUNDATIONS

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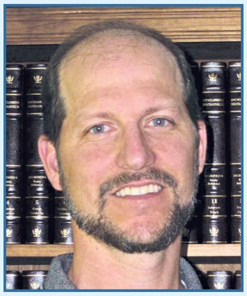
ABSTRACT

Continuous insulation (CI) is used on foundations, exterior walls, and roofs. Primarily, CI provides maximum thermal performance by minimizing thermal bridging caused by framing and structural details such as floor–wall or roof–wall intersections. When properly coordinated with climate and vapor retarder specification, it provides assemblies that dry and also minimizes seasonal moisture variations, creating a stable and durable environment for the building structure and interior. Various CI products also provide one or more functions, such as thermal insulation, water-resistive barriers, and air barriers (some composites even add a wall-bracing function or roof ventilation function). Hybrid envelope assemblies that strategically use CI in combination with other materials can optimize cost effectiveness and performance. While the options and opportunities are significant, the application must be done correctly to accommodate cladding installation, fire performance requirements, and other matters important to overall constructability and code compliance for energy-efficient and resilient building envelopes. This presentation addresses these topics based on a comprehensive body of building science research and knowledge resulting in recent building code and energy code advancements, as well as design guides, calculator tools, construction details, and installation resources available to support appropriate and competitive use of CI (refer to http://www.continuousinsulation.org/).

SPEAKER

Jay Crandell – Applied Building Technology Group and ARES Consulting – Shady Side, MD



JAY CRANDELL has over 30 years of experience in construction, engineering, and innovative building technology research for private- and public-sector clients. He has conducted benchmark studies of major natural disasters and done research to address significant structural, energy, and building science challenges. His work has helped propel many innovative technologies into the international codes and consensus standards. He is widely published on various engineering, construction, and building science topics.

CONTINUOUS INSULATION: RESEARCH, APPLICATIONS, AND RESOURCES FOR WALLS, ROOFS, AND FOUNDATIONS

INTRODUCTION

This paper provides an overview of the various applications of continuous insulation (CI), while identifying important design and construction considerations, options, and resources available to maximize the value and performance of CI applications on code-compliant walls, roofs, and foundations. Its content relies on a comprehensive body of building science research and knowledge available at http://www.continuousinsulation.org/. This resource has supported recent building code and energy code advancements, as well as design guides, calculator tools, construction details, and installation resources for appropriate use of CI.

While there are numerous materials that could be used as CI, this paper focuses on the various types of foam plastic insulating sheathing (FPIS), also known as rigid foam board or simply, foam sheathing. These products include expanded polystyrene (EPS), extruded polystyrene (XPS), and polyisocyanurate (PIR). The R-values are among the highest of available CI materials, with R-per-inch values varying from about R-4/in. to R-6/in., although various manufacturer formulations and types provide unique values. A wide range of compressive strengths, water resistance, water vapor resistance, facers, and other properties or features are available. These products are manufactured in accordance with ASTM C578 and ASTM C1289 (ASTM, 2018; ASTM, 2017), which provide a foundation for complying with various building code and energy code provisions that govern their use in residential and commercial building construction (ICC, 2018a; ICC, 2018b; ICC, 2018c; and ASHRAE, 2016).

BACKGROUND

CI is not a new concept. In the days of balloon-frame construction and prior to the advent of energy codes in the U.S., horizontal or diagonal wood board sheathing was recognized for its insulation value of about R-1/in. (HUD, 2001; HEW, 1931). At that time, insulation was not required, and air barriers (ABs) were not appreciated, although an undated National Bureau of Standards document of that era indicated that it is probably not worth installing tarred felt paper unless installed over wood board sheathing as a solid backing to help prevent air leakage between the lap joints. Buildings were drafty, cold in the winter, hot in the summer, and they consumed a lot of coal, wood, or fuel oil for heating.

By the early 1900s, wood-based fiberboard was being commercially produced in the U.S. as a derivative of the paper-making process (Suchsland and Woodson, 1986). It may be considered as a precursor to modern CI sheathing materials. It is still used today and has an insulation value of about R-2.6/in. (or R-1.3 for a typical ½-in.-thick sheathing panel).

As stated by the author of a historical review of insulation materials, "The appearance of plastic foams (polystyrene, polyurethane) created a huge revolution in the market of insulation materials in the 1940s and 1950s" (Bozsaky, 2010). This revolution was accelerated by the 1970s oil crisis. The technology and applications of foam plastic insulations have continued to advance in the regulated building construction market. Foam plastics have insulation values typically ranging from about R-4/in. up to R-7/in. and provide a wide range of properties and functions, as mentioned previously. Consequently, these products are commonly used to insulate building foundations, walls, floors, and roofs as a means to comply with modern energy conservation codes.

In particular, the use of foam plastics as CI has grown in significance as energy conservation codes increasingly recognize the value of insulation strategies that mitigate thermal bridging caused by structural materials and details. Structural materials that bridge through insulation can severely degrade the effective thermal resistance of insulation materials. This thermal bridging condition occurs when insulation is placed discontinuously in cavities between framing and within cores of masonry block. It also occurs at floor slabs, beams, and columns, or other structural elements that penetrate the building thermal envelope. Because cavity insulation also provides sound transmission control (and some spray foams can provide air leakage control and vapor control within cavities), a common approach is to use both cavity insulation and CI as a "hybrid" assembly.

Where practical, placing all the insulation continuously on the exterior provides the ideal CI strategy to insulate the structure and protect it and the interior environment from the outdoors. This is most commonly done for low-slope roof systems with above-deck roof insulation. It is also commonly done for floor slabs on grade (particularly heated slabs). It can also be done for foundation walls and above-grade walls, but current practice tends to prefer the hybrid approach. When these practices are linked together with appropriate construction detailing and assembly interfaces, they create a continuous thermal envelope and minimize thermal bridging effects that can severely degrade energy savings, increase condensation potential, and cause discomfort to occupants.

The advancement of foam plastic insulation materials and their use as CI has not been without parallel consideration of fire safety, moisture control, and other matters related to building performance and building code compliance. Consequently, the energy-saving benefits of foam plastic CI must be coordinated with building code requirements to result in durable and safe construction. Energy efficiency and building durability and safety are not incompatible. In fact, they should be viewed as complementary. The key is to make sure the many useful advancements in codes, material technology, and practical building science knowledge are properly implemented in the design, construction, and code enforcement for modern buildings, and particularly their envelopes. This paper and the accompanying presentation are intended to help promote that objective where foam plastic insulating sheathing is used as CI.

CI APPLICATIONS AND FUNCTIONS

Thermal Control With CI

The operative definition for CI in U.S. model energy codes and standards is as follows (ASHRAE, 2016; ICC, 2018c):

> **Continuous insulation (c.i.):** insulation that is uncompressed and continuous across all structural members without thermal bridges other than fasteners and service openings. It is installed on the interior or exterior or is integral to any opaque surface of the building envelope.

While the definition allows some limited thermal discontinuity to occur for attachment of building components such as cladding and fenestration, the value of CI is in its generally high R-value and its location on a building assembly such that heat loss/gain through structural framing and details is minimized. This value is easily demonstrated by comparing the effective R-value of some example frame wall assemblies with and without CI, but with the same overall nominal R-value of insulation components.

Table 1 shows that for both wood frame and cold-formed steel frame assemblies, the use of CI (even when the total nominal amount of insulation in the assembly is unchanged) results in a significant improvement in thermal performance. For the wood frame wall examples, the R-20+5 wall has an effective R-value of 21.6, which is a more than a 20% improvement over the R-25 wall, with an effective R-value of 17.5. The difference is even more significant for the steel frame wall. The R-13+6 steel frame wall has an effective R-value of 15.7, which is a more than 40% improvement over the R-19 wall. This is why CI is required in modern energy code prescriptive compliance paths in colder climates for wood framing and in essentially all climates for cold-formed steel framing. For buildings reaching beyond minimum code performance levels, the use of CI becomes even more advantageous.

The examples in *Table 1* also dispel a common misuse of "energy code math" whereby simply adding insulation component nominal R-values (without regard to the location and continuity of the insulation) is used to inappropriately compare alternative insulation strategies. In reality and as intended by the code, R-25 does not equal R-20+5, and R-19 does not equal R-13+6. The energy code designation of "R(cavity) + R(ci)" was never meant to be taken literally as a math equation. It is merely a symbolic way of specifying insulation components and amounts in different locations of an assembly. Correct comparisons of alternative insulation strategies must use energy code math correctly.

Wall Construction & Insulation Strategy	2x6@16 in. oc Wood Frame Wall		Cold-formed Steel Stud Wall	
	R-25 (cavity insulation only)	R-20+5 (cavity + CI)	R-19 (6-in. stud @ 24 in. oc; CI only)	R-13+6 (4-in. stud @ 24 in. oc; cavity + CI)
Total nominal R-value of insulation components	R-25	R-25	R-19	R-19
Insulation Material and Building Component R-values				
Outside air film	0.17	0.17	0.17	0.17
Siding	0.6	0.6	0.6	0.6
Continuous insulation	0	5	0	6
Structural sheathing	0.6	0.6	0.6	0.6
Stud	6.6	6.6	n/a	n/a
Cavity insulation	25	20	19	13
Gypsum wallboard	0.45	0.45	0.45	0.45
Interior air film	0.68	0.68	0.68	0.68
Computed U-factor and Effective R-value of Assemblies[a]				
Stud path R-value	8.5	13.5	n/a	n/a
Cavity path R-value	26.9	26.9	n/a	n/a
Framing factor	0.25	0.25	n/a	
Cavity correction factor	n/a	n/a	0.45	0.55
Cavity + framing corrected R-value	n/a	n/a	8.55	7.15
R-value of interior + exterior layers	n/a	n/a	2.5	8.5
U-factor	0.0573	0.0464	0.0905	0.0639
R – effective	**17.5**	**21.6**	**11.1**	**15.7**

[a] The computations for the wood frame walls follow the parallel path method in Chapter 27 of the ASHRAE Handbook of Fundamentals (ASHRAE, 2017), and computations for the cold-formed steel frame walls follow the cavity correction method in Section C402.1.4.1 of the 2018 IBC (ICC, 2018c).

Table 1 – Comparison of insulation methods and effective R-values.

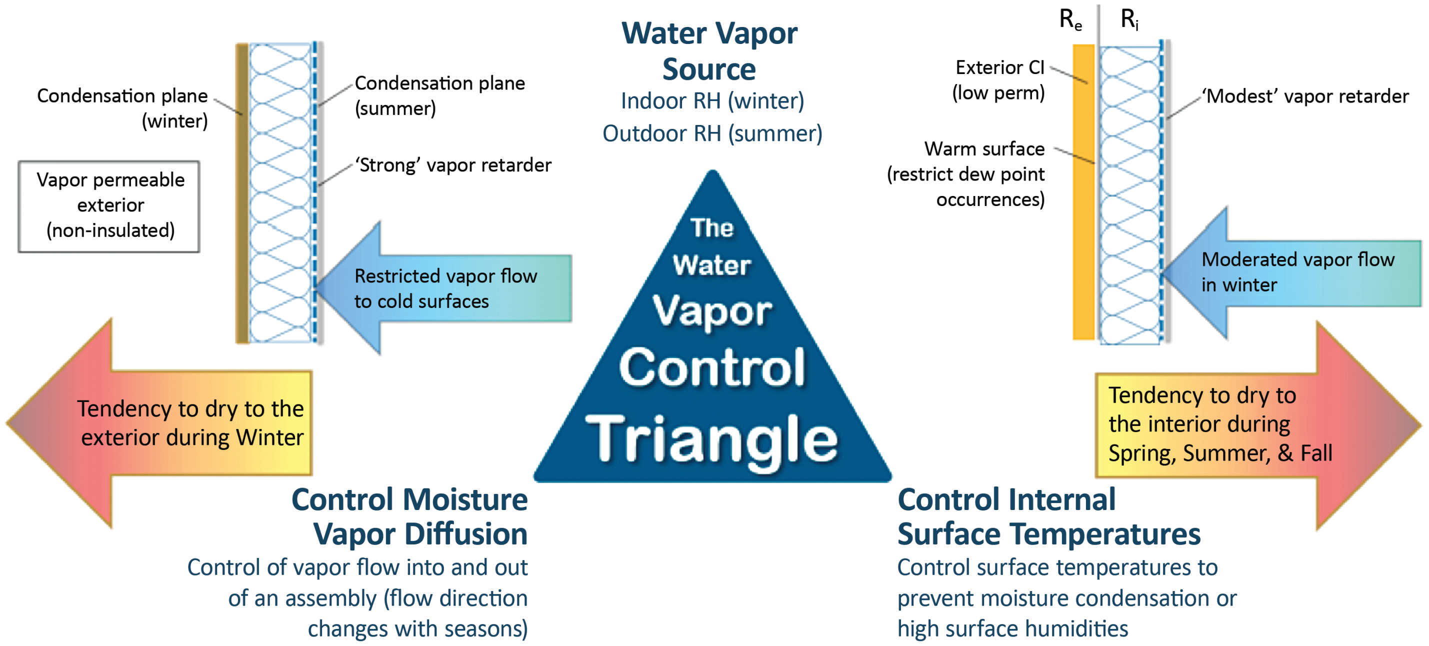


Figure 1 – Permeance and temperature-controlled design approaches for water vapor management.

For mass construction (concrete/masonry walls), CI has a potential for a dual benefit in thermal performance. First, it mitigates major thermal bridges at areas such as floor slab and wall intersections that cannot otherwise be easily avoided with traditional application of insulation to the interior side of mass wall construction. The interior insulation is interrupted at the floor slab of each story. This common insulation strategy creates a massive linear thermal bridge extending around the entire perimeter of a building at every floor level. It can significantly degrade the overall effective R-value of the opaque wall envelope by 33% or more. Unfortunately, this loss in thermal performance is usually ignored or inadequately accounted for in assessing energy code compliance.[1] Continuous insulation placed on the exterior can significantly reduce this impact. Second, by placing CI on the exterior (and continuously across floors), the thermal inertia effect of mass buildings is maximized such that even greater thermal performance benefit is realized. This benefit also is typically ignored or underappreciated when assessing energy code compliance following the prescriptive path because the energy code assumes that the insulation is placed on the interior (or, at best, half on the exterior), not all or most on the exterior. Whole-building energy models, however, can account for this benefit of exterior CI on mass wall assemblies.

The use of foam sheathing for CI not only supports efficient compliance with thermal insulation requirements of the energy code, but it also provides opportunities to cost-effectively leverage other benefits in complying with other required building code functions, such as water vapor control, weather resistance, and air leakage control. While much more could be said about the thermal insulation and thermal bridging mitigation benefits of CI, the reader is referred to additional information and resources at http://www.continuousinsulation.org/thermal-insulation and http://www.continuousinsulation.org/prevent-thermal-bridging.

Water Vapor Control With CI

CI provides a means to thermally insulate a structure and also to protect it against the ill effects of improperly controlled water vapor movement. Water vapor condenses on surfaces that are colder than the dew point temperature and causes high humidity on the surface of materials that are near to the dew point (causing the materials to accumulate moisture and potentially support mold growth). When properly used, CI keeps the interstitial or interior surfaces of building envelopes above the dewpoint temperature. Thus, it provides a means to mitigate condensation or high-humidity conditions in assemblies, resulting in lowered risk of unacceptable moisture accumulation within or on materials, material damage (rot/corrosion), material expansion/contraction effects, and mold. This approach to controlling water vapor is known as a "temperature-controlled" design approach (*Figure 1*). The application and benefits of this approach are discussed later.

Traditional methods of water vapor control have attempted to rely exclusively on use of a designated vapor retarder (e.g., permeance-controlled design) without fully considering the permeance of other materials on the opposite side of the assembly or the temperature of those materials. The traditional rules of thumb for specification of interior vapor retarders as still found in modern U.S. building codes do not work reliably or consistently for the modern assemblies of today with different material properties and increased insulation requirements. For walls without CI, it is important to consider both the interior vapor retarder selection and also the net water vapor permeance of all material layers on the exterior side of the assembly. The permeance of materials on the exterior side of assemblies, however, is often unreliably known because this is often not a controlled design property for many building materials. Also, in some cases, the common practice of "more permeance is better" is not always true (see later discussion on inward vapor drives). Thus, the simplified rules of thumb for vapor retarder specification may work in some cases, but not so well in others.

For walls with CI, the permeance of the exterior materials becomes less important because the selection of an interior vapor retarder and the amount of CI provide a dual means of controlling water vapor to properly balance seasonal wetting and drying for a given climate and also moderate the resulting season change in moisture levels of materials within an assembly.

So, how does water vapor control work for CI? It's really pretty easy and boils down to two steps:

1) Identify the climate zone (*Figure 2*).
2) Select the appropriate interior vapor retarder and insulation ratio (*Table 2*).[2]

A wide range of frame wall assemblies can be designed using this approach (*Figure 3*), and the same process can be applied to roof systems that use CI, such as above-deck roof insulation commonly used with low-slope commercial building roofs. As with any reasonable approach to managing water vapor, one must also adequately control air leakage into and through assemblies (although assemblies designed using the temperature-controlled design approach tend to be less affected by moist air leakage) and take appropriate action to prevent rainwater intrusion (e.g., proper water-resistive barrier and flashing installation, including use of pan flashings at windowsills and door thresholds). Buildings or portions of buildings with high indoor moisture generation (e.g., pool rooms or saunas) require additional consideration.

For example, assume the energy code requires an R20+5 wall in Climate Zone 6 per *Figure 2*, and assume the project is located in Climate Region A (moist). Does this meet the insulation ratio requirement to control water vapor, and what interior vapor retarder should be used? Per *Table 2*, a Class I, II, or III vapor retarder could be used. However, footnote 'e' limits use of a Class I or II (e.g., polyethylene film) vapor retarder to use only in Dry 'B' climate regions per *Figure 2*. However, if Kraft paper-faced batt insulation is used in the cavity, the Kraft paper is a Class II vapor retarder that is a "smart" vapor retarder (vapor permeance changes with humidity), and it meets the requirement of footnote 'e' such that adequate interior drying potential is maintained. With use of a Class II Kraft smart vapor retarder (or other equivalent smart vapor retarder product), *Table 2* requires a minimum insulation ratio of 0.2 for Climate Zone 6. The R20+5 wall has an insulation ratio of 5/20 = 0.25, which exceeds the 0.2 minimum.

The above example shows that as exterior insulation amount increases relative to cavity insulation amount (e.g., increasing insulation ratio), the wall performs better and better at controlling moisture. At the extreme where essentially all of the insulation is placed on the exterior, then no interior vapor retarder is required at all because the entire wall assembly is located interior to the insulation and thus is connected

Climate Zone (Figure 2)	Maximum Heating Degree Days (65°F basis)	Interior Vapor Retarder (VR) Class			
		Class I[e]	Class II[e]	Class III	No VR[f]
1	N/A	NP	NP[g]	R-2 CI minimum	R-2 CI minimum
2	N/A	NP	NP[g]	R-2 CI minimum	R-2 CI minimum
3	3,600	NP	R-2 CI minimum	R-2 CI minimum	0.4
4	5,400	NP	R-2 CI minimum	0.2	0.9
5	7,200	0.2	0.2	0.35	1.3
6	9,000	0.2	0.2	0.5	1.7
7	12,600	0.35	0.35	0.8	2.3
8[h]	16,200	0.5	0.5	1.1	2.8

For SI: 1 heating degree day (65°F basis) = 0.56 heating degree days (18°C basis).
NP = Indicated vapor retarder class is not permitted in the indicated climate zone.

a. Insulation ratio (IR) is the exterior CI R-value (Re) divided by the cavity insulation R-value (Ri). For example, a wall with R-20 cavity insulation and R-5 CI (e.g., R-20+5 CI) has an insulation ratio of IR = Re/Ri = 5/20 = 0.25.

b. Interpolation of insulation ratios using a site-specific heating degree day value shall be permitted.

c. For light-frame cold-form steel wall construction, the tabulated minimum insulation ratio shall be increased by adding 0.1.

d. In addition to the vapor retarder, spray foam with a maximum permeance of 1.5 perms at the installed thickness, applied to the interior cavity side of the exterior sheathing, shall comply with the tabulated insulation ratio or minimum R-value for CI and shall be permitted to be added to the R-value of FPIS CI on the exterior for the purposes of compliance with the water vapor control purposes of this table.

e. Class I and II vapor retarder use is limited to the indicated climate zones and should be used only in the dry climate region B of those climate zones as shown in *Figure 2*. Where used in climate regions A or C, Class I and II interior vapor retarders shall be permitted in the indicated climate zones, provided the Class I or II vapor retarder has a vapor permeance of greater than 1 perm as measured in accordance with ASTM E96 water method (Procedure B). Kraft paper (Class II vapor retarder) shall be deemed to comply.

f. "No VR" refers to the case where there is no interior vapor retarder and water vapor control relies entirely on the amount of exterior insulation used to control temperature, humidity, and condensation conditions within the assembly. Where there is no cavity insulation, the R-value of any material layers, air space, and air film to the interior side of the exterior CI shall be used to determine the insulation ratio in accordance with footnote 'a.' In no case shall the value of Ri be taken as less than R-5 in determining the insulation ratio (Re/Ri) for the "No VR" case. The water vapor permeance of the exterior CI, facer on the interior face, or other material layer located to the interior side of the exterior CI shall not exceed 1 perm in Climate Zones 4-8.

g. In Climate Zones 1 and 2, a Kraft paper vapor retarder or other Class II vapor retarder shall be permitted where the WVP of the vapor retarder is greater than 1.5 perms as measured in accordance with Method B (wet cup) of ASTM E96.

h. The insulation ratio requirement for Climate Zone 8 is based on a maximum 16,200 heating degree days (65˚F basis) [9,000 heating-degree days (18˚C basis)]. Where this heating degree day limit is exceeded, a design shall be required to determine the insulation ratio.

Table 2 – Minimum insulation ratio or continuous insulation R-value for light-frame walls where exterior CI is used.

to the indoor environment. However, the requirements of footnote 'f' (*Table 2*) must be satisfied regarding placement of control layers on the exterior side of the assembly.

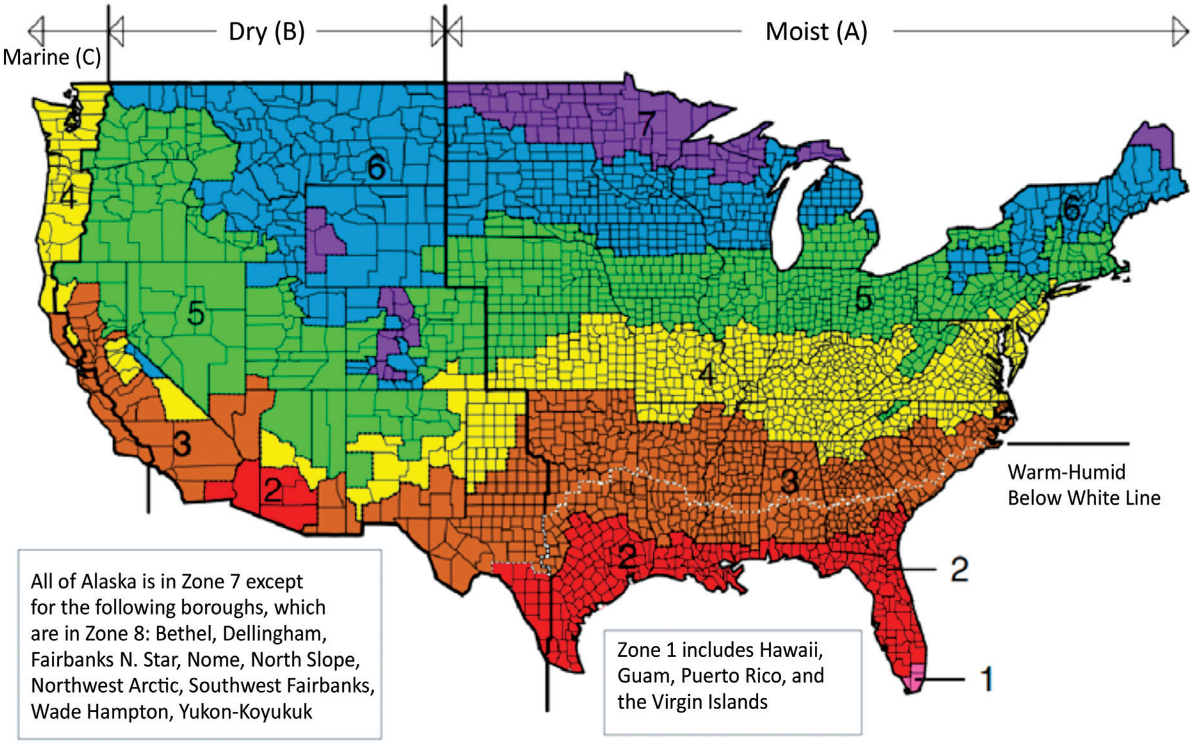


Figure 2 – U.S. climate zone map.

Water vapor is not just something that is a concern with moisture seeking its way out of a building during the winter. During the summer (and particularly for air-conditioned buildings), the reverse is true, although the inward vapor drives are generally not as severe as the outward vapor drives in the winter. Nevertheless, there is a special case where inward vapor drives can be significantly greater than winter outward vapor drives. This pertains to reservoir claddings that absorb rainwater; and then when drying (particularly when exposed to the sun), significant amounts of water vapor are driven inward into the wall assembly. We've known about this for a long time, and that's why the code requires a ventilated air space behind claddings such as anchored brick veneer. Other reservoir claddings, however, such as stucco and adhered masonry veneers, are often directly applied to the wall substrate and over a water-resistive barrier with high water vapor permeance without a ventilation air gap or even a gap sufficient for free drainage of bulk water. This has worked in dry climate regions, but in moist climate regions, it can contribute significantly to wetting of walls such that condensation forms on interior vapor retarders, and exterior sheathing substrates experience sustained or repeated wetting episodes as water vapor is driven into the wall. Thus, such walls may accumulate moisture in the winter (as typical and in tolerable amounts), but then experience additional accumulation in the summer with no sustained opportunity to dry. Consequently, U.S. model codes are beginning to require a ventilated air space behind stucco and adhered veneers when used in moist climate regions (refer to Section 2510.6 of the 2018 International Building Code [IBC]), although this improvement has not yet been adopted in the International Residential Code (IRC) where it perhaps is most needed (ICC, 2018a; ICC, 2018b).

So, how does this inward vapor drive issue relate to foam sheathing? Foam sheathings generally have a water vapor permeance of less than 10 perms and commonly less than about 1 perm. As such they provide a block to inward water vapor movement from reservoir claddings and as generally occurs in hot-humid climates. Coupled with use of a properly selected vapor retarder that permits inward drying (see previous discussion), foam sheathing controls both inward vapor drives during the summer and outward vapor drives during the winter in any climate zone. Thus, placing foam sheathing behind a reservoir cladding is an

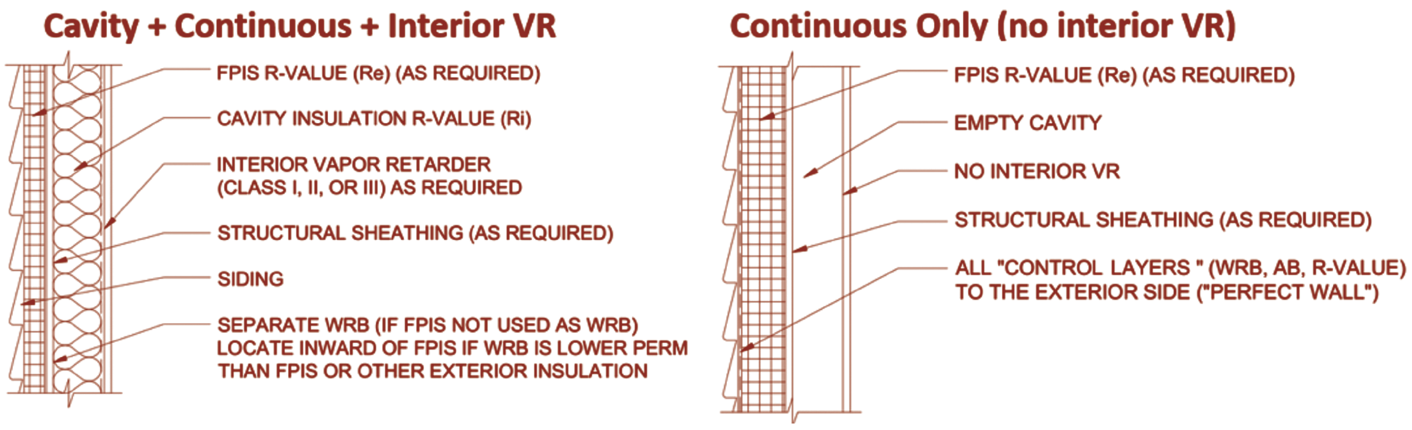


Figure 3 – Example of assemblies with CI (temperature-controlled design).[3]

alternative to (or in addition to) providing a ventilated air space and gives protection against inward and outward vapor drives.

In summary, water vapor control is a balancing act. Foam sheathing provides a simple and versatile approach to striking the optimal balance to protect walls from various wetting episodes that occur due to water vapor movement in the summer and winter or due to the use of reservoir claddings. This can all be done while maintaining drying potential with coordinated vapor retarder specification such that the wall assembly experiences a dry and stable environment. For more information and design guidance on use of foam sheathing CI to control water vapor, refer to http://www.continuousinsulation.org/topical-library/water-vapor-control. Also, an extensive review of research serving as the basis for the design guidance presented above has been summarized in an ASTM symposium paper (Crandell, 2017).

Water-Resistive Barrier (WRB) Application of CI

Foam sheathing applied as CI on the exterior of a building can also be used as the water-resistive barrier (WRB) when successfully tested and approved for that purpose. Foam sheathing WRB systems are tested as installed systems, with some of the most stringent water-resistance testing requirements using ASTM E331 (ASTM, 2016; ICC-ES, 2012). These tests include weatherization preconditioning to ensure durability.

A key component to the use of any sheathing material as a WRB system (or any WRB for that matter) is the joint treatments. Typically, adhesive joint tapes or flexible adhered flashings are used for this purpose, and this approach is not all that different from the use of sealed joints on low-slope membrane roof systems. When installed properly using approved materials in accordance with the manufacturer's installation instructions, foam sheathing WRBs provide a high level of resistance to rainwater penetration. Again, critical considerations include detailing of flashing wall penetrations such as windows and doors. Use of pan flashing is highly recommended as a redundant means of draining any intruded moisture around windows and doors (this applies to all types of walls).

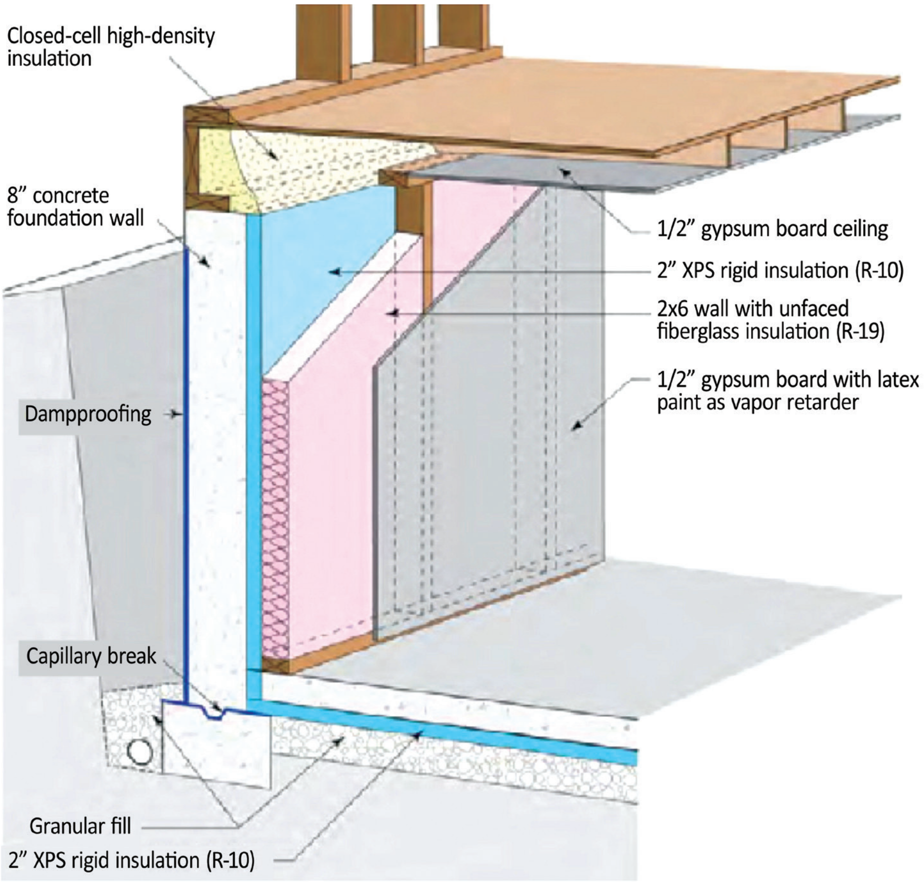


Figure 4 – Example of foam sheathing application as CI on a basement foundation for dry, comfortable, and energy-efficient basements.

For additional information on WRB applications of foam sheathing and approved materials, refer to http://www.continuousinsulation.org/topical-library/water-resistive-barrier.

AB Application of CI

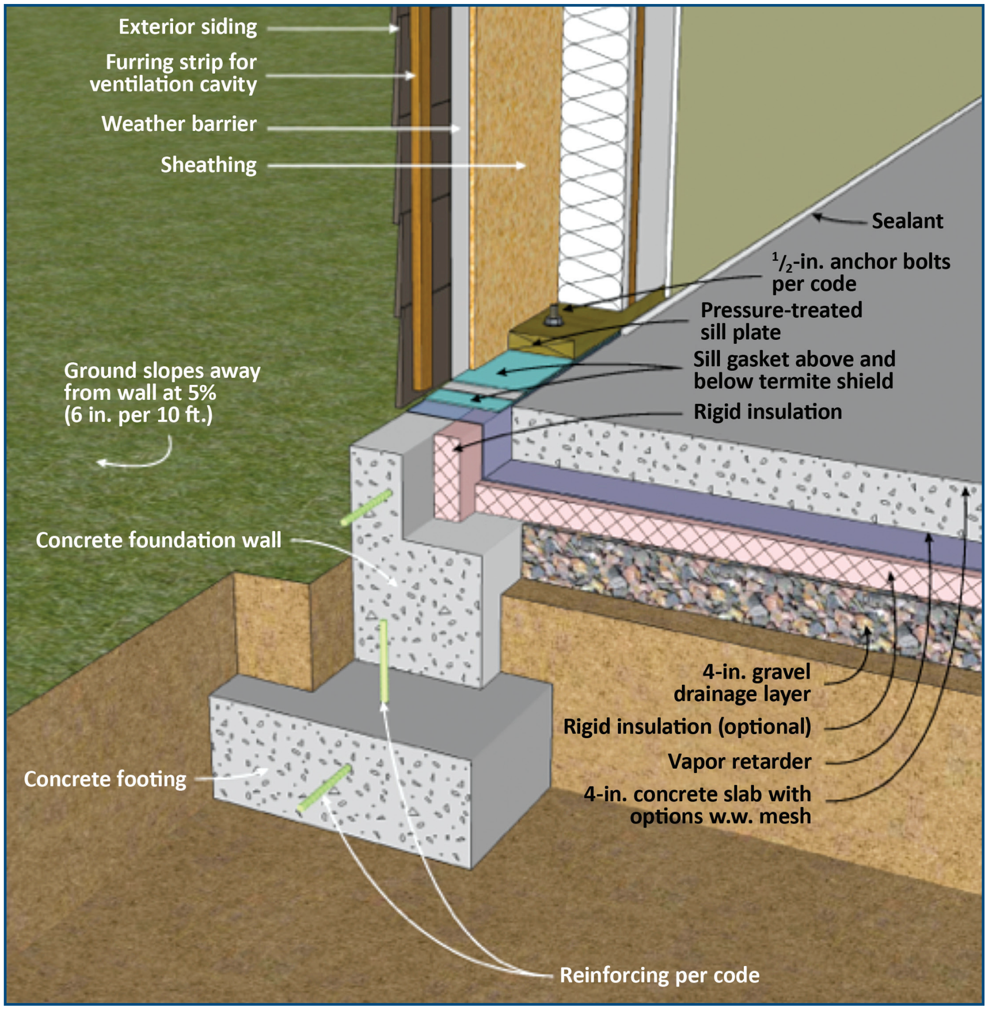
Foam sheathing materials are also capable of serving as an AB material and require sealed joints for this application in a manner as described above for WRB applications. This application uses foam sheathing on roofs and walls. As with any effective AB system, the terminal edges of the CI at junctures between buildings assemblies (e.g., wall–roof or wall–foundation) and building components (e.g., wall–window) must be detailed to maintain continuity of the air control layer. This can be achieved by use of compatible sealants. For additional information on AB applications of foam sheathing and approved materials, refer to http://www.continuousinsulation.org/air-barrier.

Foundation Insulation and Frost Protection

Use of foam sheathing as CI on foundations has thermal, moisture control, and even frost protection and foundation cost-reduction benefits that can all be leveraged as needed by design. For example, the Department of Energy's (DOE's) Building American program recognizes the use of foam plastic insulation on basement walls (alone or together with other insulation materials to the interior side of the foam sheathing) as an important component of a "hall of fame" innovation in the insulation and construction of energy-efficient and moisture-resistant basement walls. The two key factors noted for keeping basements dry and warm are: 1) choosing the right insulation and 2) installing it the right way. One example is shown in *Figure 4* (refer to https://www.energy.gov/sites/prod/files/2014/01/f6/1_1a_ba_innov_basementinsulationsystems_011713.pdf).

For slab-on-grade construction, effective use of foam sheathing CI provides comfortable and energy-efficient concrete floors that are not prone to cold surface temperatures and condensation, which can

Figure 5 – Slab-on-grade application of foam sheathing CI.



cause mold underneath or warping of finish flooring materials. One example of such construction is shown in *Figure 5* (refer to https://foundationhandbook.ornl.gov/handbook/section4-2.shtml). This detail works for both heated and unheated slabs—mainly because the slab is fully insulated. The minimum amounts of insulation required are governed by the energy code; however, the energy code does not fully account for the effect of insulation location and placement on the effective thermal performance of the foundation. Important features include full slab insulation and its continuity with the wall insulation at the perimeter of the slab. Installed correctly, foam sheathing CI mitigates major thermal bridges at the perimeter of foundation slabs-on-grade.

Foam sheathing CI applied to crawlspace foundation walls offers some important design opportunities. First, it allows the crawlspace to be enclosed and conditioned such that the floor above does not require insulation, and it provides for a dry crawlspace and comfortable suspended floor above. It also allows ductwork to be enclosed in conditioned space. This crawlspace construction method is recognized in modern U.S. building codes. One example of an unvented/conditioned crawlspace construction is shown in *Figure 6* (refer to https://basc.pnnl.gov/resource-guides/unvented-insulated-crawlspaces).

One foundation construction approach recognized as an innovation by *Popular Science* magazine uses foam sheathing CI in strategic placement to satisfy the energy code and also to “trick” the ground into thinking it is in a warm climate. Consequently, shallow foundations can be built in areas with extreme seasonal frost depth, but without permafrost. This affects the northern half of the U.S. The technology saves thousands of dollars in initial construction cost (reduced excavation and foundation material and labor costs) and continues to pay dividends in energy savings. Rarely is there a design technology that saves energy over the life of the building while also reducing initial construction cost. Designs using this technology are supported in U.S. model codes (IRC and IBC) and in ASCE Standard 32 (ASCE, 2001). It applies to unvented crawlspace and slab-on-grade foundations. It can be used for housing, low-rise commercial buildings, and many other applications where ground-bearing con-

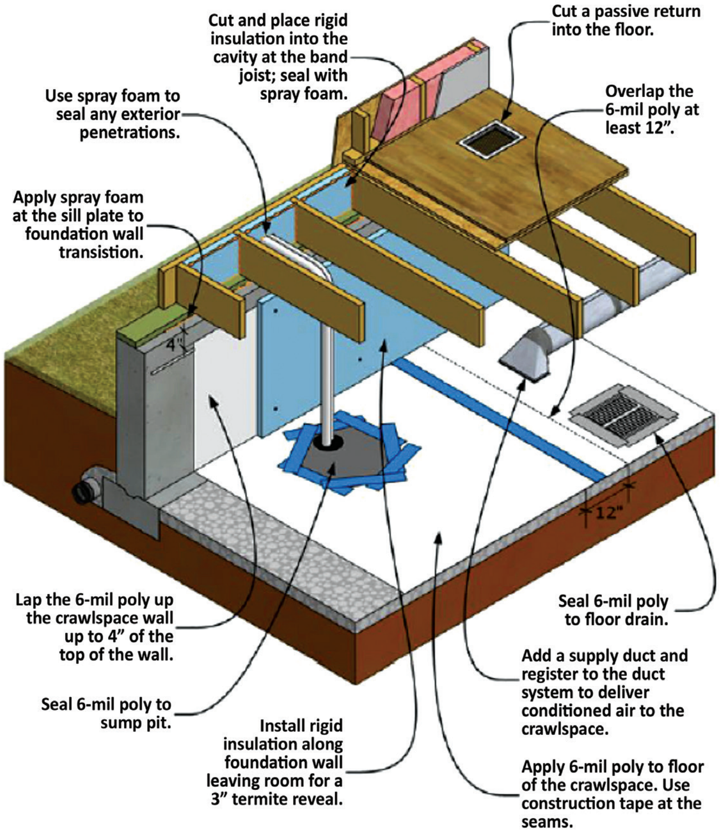


Figure 6 – One example of unvented/conditioned crawlspace construction using foam sheathing CI on the perimeter.[5]

Figure 7 – Example of a frost-protected shallow foundation using foam sheathing CI (16-in.-deep thickened-edge slab built in Fargo, ND).

ditions allow for shallow perimeter footings or grade beams. An example application under construction is shown in *Figure 7*.

For more information and resources addressing applications of foam sheathing on commercial and residential building foundations, refer to http://www.continuousinsulation.org/.

Floor Applications of CI

Floors that are exposed to the exterior or unconditioned (vented) crawlspaces can be insulated and protected from moisture in the same way that walls and roofs are protected by appropriate use of foam sheathing CI. While the bottom sides of floors are much more sheltered from the weather, they can also be exposed to persistently high humidity (e.g., vented crawlspaces in spring and summer). Placing foam sheathing CI on the bottom side of such floors, and also using it as an air barrier and vapor retarder to prevent moist air intrusion and vapor diffusion, provides a means for energy-efficient, comfortable, and dry floor assemblies. One such application on a wood frame floor is shown in *Figure 8* (refer to https://basc.pnnl.gov/code-compliance/sealing-and-insulating-existing-floors-above-unconditioned-spaces-code-compliance). This practice is even more beneficial for exposed floors constructed using high-thermal-conductivity structural materials (e.g., steel joists or concrete).

Roof Applications of CI

Roof applications of foam sheathing CI are most widely known and used in commercial building low-slope roof construction. These roof systems typically use "above-deck" roof insulation located underneath a single-ply or multi-ply roofing installation. But some insulation materials can also be used above the roof membrane in what is known as a protected membrane roof (PMR) system. In this case, pavers or ballast is used over the insulation material to secure it and protect it. Thus, the insulation material and the roof membrane are protected from direct exposure to the weather and ultraviolet radiation. This is similar to the manner in which wall claddings protect the WRB and exterior CI. A common application of above-deck roof insulation is shown in *Figure 9*.

This above-deck roof insulation technology also is applicable to steep-sloped roofs and offers some worthy design benefits. For example, with above-deck insulation of a

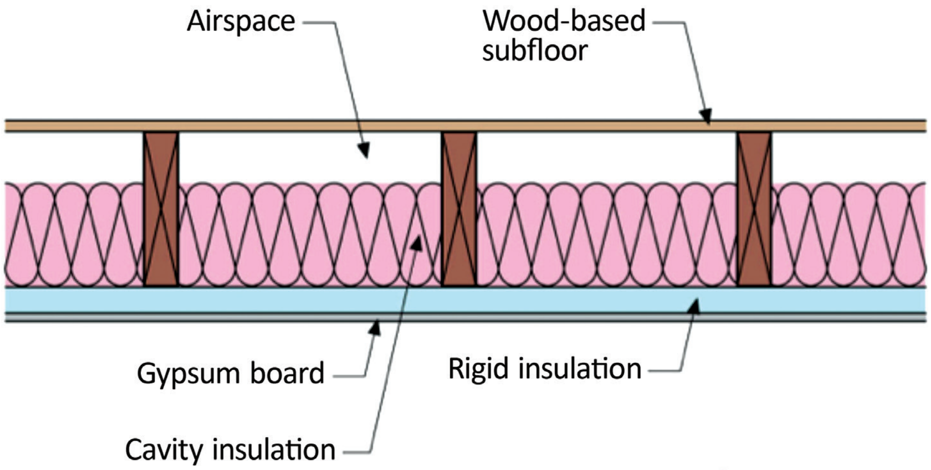


Figure 8 – Raised floor system over unconditioned space (e.g., garage) or exposed to exterior (e.g., vented crawlspace or floor overhang).

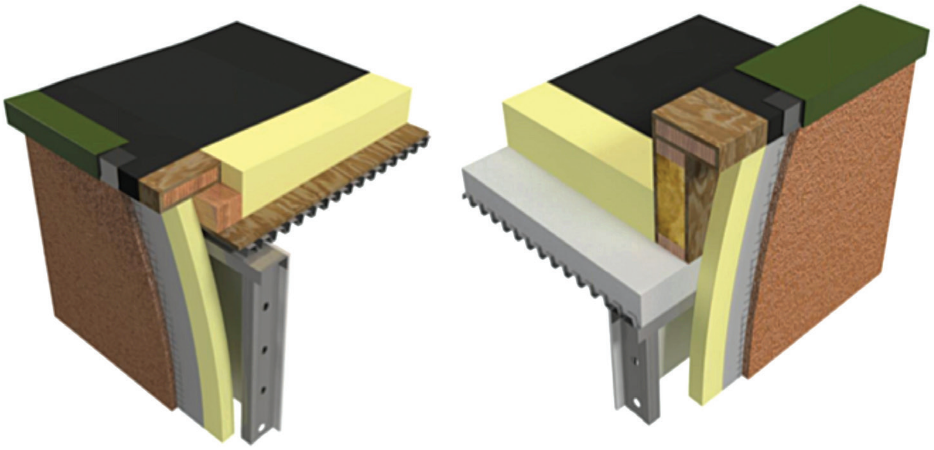


Figure 9 – Example applications of low-slope roof with above-deck insulation (variations of these details can provide even greater continuity of insulation at the roof–wall intersection).

steep-sloped roof using foam sheathing CI, the attic space can be unvented and becomes conditioned such that it is more usable space, and it has the benefit of putting any attic HVAC equipment and ductwork into the conditioned space of the building, creating significant energy savings and comfort benefits. This practice is particularly useful for cathedral ceiling construction where provision of ventilation and depth of rafters for sufficient insulation may be difficult to achieve. This approach is enabled in Section 806.5 of the 2018 IRC and is equally applicable to commercial buildings per the IBC. Vented and unvented foam insulation panels with a nail-base surface for roofing attachment are also available for steep-slope roof applications. One example of several similar products of this type is shown in *Figure 10* (refer to https://cornellcorporation.com/docs/ThermaCal_Nail_Base_Roof_Insulation_Panels_Product_Brochure.pdf).

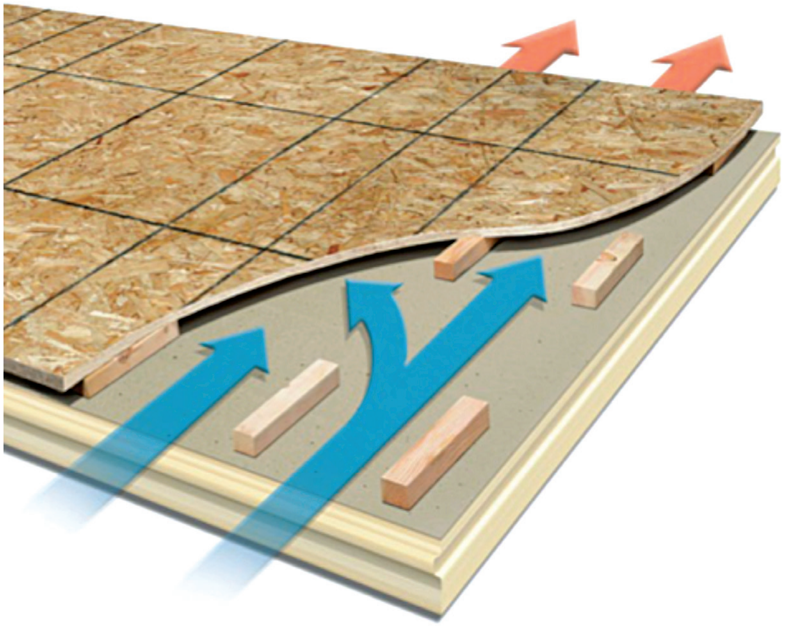
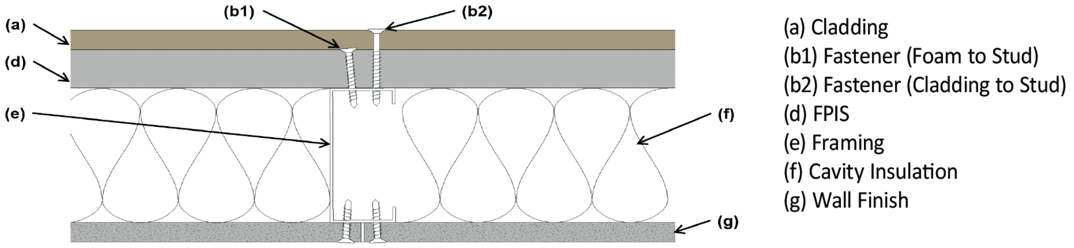


Figure 10 – Example of steep-slope roof panel with vented nail-base roof deck laminated to CI (image courtesy of GAF).

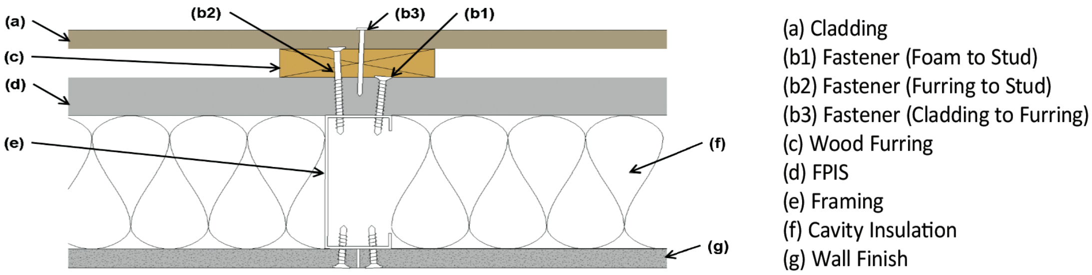
COORDINATION WITH OTHER BUILDING CODE REQUIREMENTS

Cladding Installation

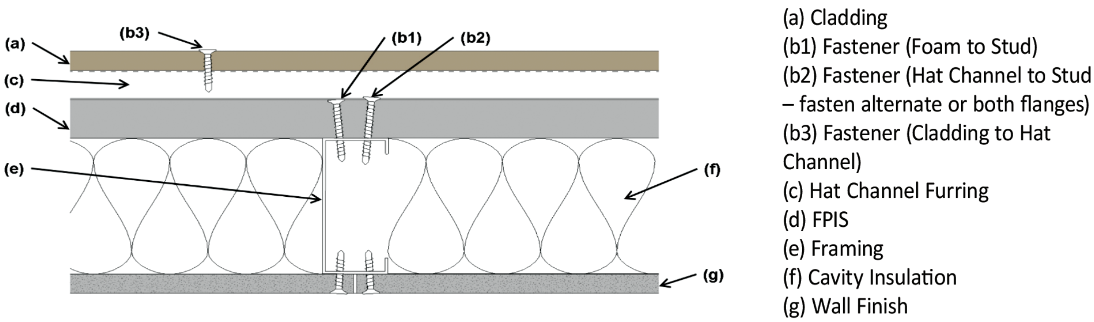
Where cladding is installed over CI, it must be fastened through the CI layer (refer to *Figure 11*). Fortunately, provisions have been added to U.S. model building codes to specify fasteners for cladding or furring attachments through foam plastic insulation to cold-formed steel and wood framing (2018 IBC, Sections 2603.12 and 2603.13; and 2018 IRC, Sections R703.15 and R703.16). In addition, Table R703.3.3 of the 2018 IRC provides attachment of cladding directly to wood structural panel sheathing through foam sheathing up to 2 in. thick, provided the cladding weight is not more than 3 psf (e.g., typical wood sidings, fiber cement siding, and vinyl siding). When properly specified, fasteners are able to support cladding weights up



(a) Plan View – Direct Cladding Attachment Through FPIS

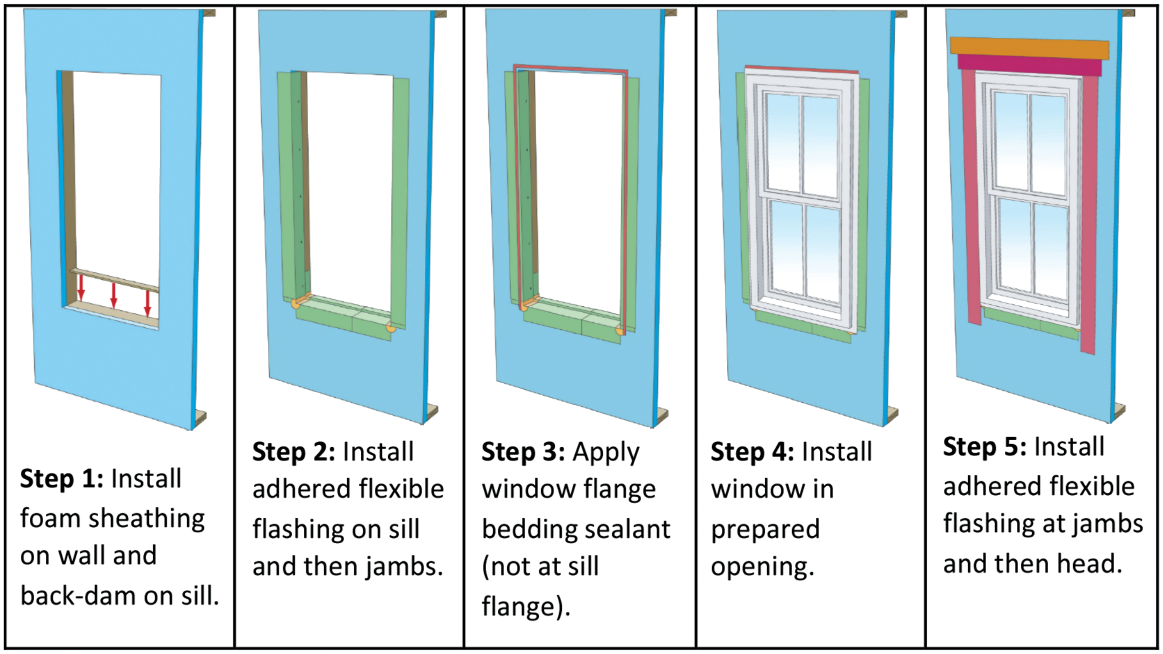


(b) Cladding Attachment Through Wood Furring Aligned Parallel to Studs



(c) Cladding Attachment Through Hat Channel Furring Aligned Perpendicular to Studs

Figure 11 – Illustration of cladding attachments through foam sheathing.



Step 1: Install foam sheathing on wall and back-dam on sill.

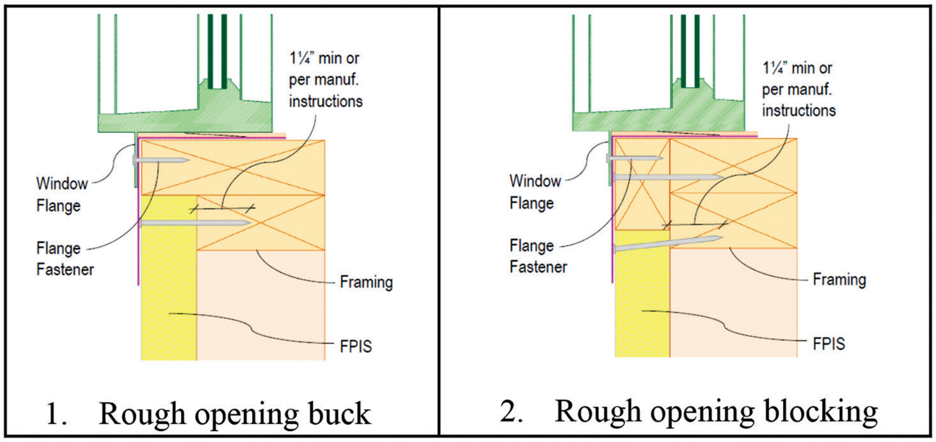
Step 2: Install adhered flexible flashing on sill and then jambs.

Step 3: Apply window flange bedding sealant (not at sill flange).

Step 4: Install window in prepared opening.

Step 5: Install adhered flexible flashing at jambs and then head.

Figure 12 – Standard window installation detail on foam-sheathed wall (foam sheathing shown as the WRB).



1. Rough opening buck

2. Rough opening blocking

Figure 13 – Rough opening buck or block as used for fenestration support with thick foam sheathing or as required for window/door anchorage conditions.

to 25 psf through foam sheathing thicknesses of up to 4 in., dependent on the cladding weight and fastening schedule. This fastening approach complies with the definition of CI mentioned earlier.[3] Conversely, if furring is installed continuously through the CI layer, then such an installation does not comply, and the effect of the furring on the U-factor or effective R-value of the assembly must be considered (see earlier discussion on energy code math).

For more complete guidance on fastening of cladding or furring through foam sheathing, refer to https://www.continuousinsulation.org/cladding-attachment.

Window/Door Installation

Window and door installation practices for walls with CI vary depending on many factors. Typically, integrally flanged windows and doors are used for "punched" openings in wood or cold-formed steel wall assemblies. This is good because the integral flanges not only provide a means to mount and support the fenestration unit, but they also provide a means to flash/seal the window to the WRB, and this is ideal when foam sheathing is used as both CI and the WRB. While some fenestration manufacturers are beginning to develop installation instructions and proprietary devices for applications with CI, many do not address this common condition. Fortunately, some good installation details and recommendations are available.

A standard installation procedure that applies to foam sheathing generally not exceeding 1½- to 2-in. thickness is shown in *Figure 12*. This is feasible because foam sheathing materials have substantial compressive strength (minimum 15 psi is recommended), and fasteners through this thickness of foam provide adequate anchorage and support when length is specified to accommodate the thickness of foam. Where additional fasteners are required through the frame of windows or hinges of doors, it is imperative that the thickness of foam used and width of the fenestration frame allow the fasteners to penetrate rough framing members. If not, alternate support methods must be designed or the extension buck method used. For thicker foam applications (e.g., 2 in. or greater), it becomes necessary to consider various types of window or door rough opening extension bucks. *Figure 13* features an opening extension buck using 2x lumber. Use of 2x blocking in a picture frame around the rough opening has also been used. In some cases, the blocking may be placed only at the threshold to provide adequate support at the base of the window or door. Where blocking or bucks are used, the flashing procedure remains similar to those shown in *Figure 12*.

Many installation variations from those shown in *Figures 12* and *13* are possible, provided adequate anchorage and support of the fenestration unit is maintained. Continuity of the fenestration's plane of water resistance at its interface with the wall's WRB system (e.g., at the flange of the window) also must be maintained with effective flashing and sill drainage. For additional information, details, and guidance, refer to https://www.continuousinsulation.org/window-installation.

Wall Bracing

Conventional foam sheathing is not a structural wall-bracing material. It must be coordinated with use of other code-approved or designed bracing methods. Typically, foam sheathing is used as over-sheathing (i.e., is placed over the structural sheathing). However, some foam sheathing products are laminated to a structural sheathing material, and these proprietary structural insulating sheathing panels are qualified as code-approved bracing methods through the code evaluation process. Refer to the product manufacturer for code approval data, design guidance, and installation instructions.

Wind Resistance

For foam sheathing materials that are used as under-sheathing (placed underneath a structural sheathing layer) or as over-sheathing, or otherwise affixed to a solid surface capable of resisting the design wind load, no structural wind resistance is required of the foam sheathing. However, if fixed directly to open stud cavities without another structural layer, then the foam sheathing material must be rated for wind load resistance in accordance with the ANSI/SBCA FS 100 standard (SBCA, 2012). This standard is referenced in the IBC and IRC building codes. While foam sheathing materials typically rely on cladding and furring attachments for permanent securement to resist wind loads, the FS 100 standard also provides a means to qualify connection of foam sheathing to resist the permanent wind load. This is typically achieved by use of mechanical fasteners and specialty washers. Adhesives can also be used for this purpose, as is commonly done for EIFS cladding installations.

Fire Safety and Use of Foam Sheathing

Last and certainly not least, foam sheathing must be used in a way that complies with stringent fire safety requirements for use of foam plastics in buildings. These provisions vary in important ways for commercial building construction and one- and two-family dwellings. The applicable requirements are found in Section R316 of the IRC and Chapter 26 (Section 2603) of the IBC. Some basic fire safety requirements are fairly consistent across various building applications, such as use of thermal barriers, ignition barriers, and material flame spread and smoke development limits. There also are important requirements, such as full-scale exterior fire spread tests in accordance with NFPA 285 when foam plastics are used on exterior walls of many commercial building types (except Type V wood frame construction). Furthermore, special foam plastic sheathing products and formulations that pass appropriate full-scale fire tests may be allowed for use in some applications without a thermal or ignition barrier. For product-specific information, refer to the product manufacturer for code compliance data. For general information on fire safety requirements and qualified FPIS materials and assemblies, refer to http://www.continuousinsulation.org/fire-performance.

CONCLUSION

This paper has surveyed various applications and requirements related to the code-compliant use of foam plastic insulating sheathing materials on commercial and residential building envelopes. These applications revolve around the primary function of foam plastic insulation on foundations, walls, floors, and roofs as CI to meet or exceed the minimum requirements of energy conservation codes and standards. However, once present, the many additional functions of foam sheathing can be leveraged—such as use as a WRB, AB, means of controlling water vapor, foundation frost protection, and others. When coupled with appropriate methods for attachment of claddings and compliance with fire safety provisions of building codes, these applications of foam sheathing products contribute to buildings that are energy efficient, comfortable, durable, and resilient.

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FOOTNOTES

1. For more information on the implications of thermal bridging at the interface of various types of building assembly interfaces and details, and how to account for them, refer to BC Hydro (2018), Building Envelope Thermal Bridging Guide, v1.2, https://www.bchydro.com/news/conservation/2014/building-envelope-thermal-bridging.html .
2. Where the vapor retarder also is intended to serve as an air barrier, the continuity of its installation and the material air permeance must also be considered as required by energy codes for air barriers.
3. While the definition of CI permits fastener penetrations, fasteners do impact the effective R-value of an assembly, depending on the fastening schedule, type of fastener (e.g., carbon vs. stainless steel), length of fastener, the thermal properties and arrangement of materials fastened, and other factors. For more information on the impact of fasteners on the thermal performance of building assemblies, refer to ABTG (2018).
4. Where CI only is used on the exterior side, see Table 2 footnote ‘f’ regarding arrangement of material layers on the exterior side of the assembly.
5. Foam sheathing exposed to a crawlspace requires an ignition barrier covering the surface, unless the foam sheathing is approved for exposure without an ignition barrier.