Applying Recent Building and Energy Code Advancements for Durable and Energy-Efficient Building Enclosures

Jay H. Crandell, PE
Applied Building Technology Group
1236 Bast Lane, Shady Side, MD 20764
301-466-7420 • jcrandell@aresconsulting.biz

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ABSTRACT

Energy codes have advanced in recent years—in large part by requiring more efficient building thermal enclosures. This advancement typically requires more insulation or a more strategic and effective use of insulation, such as continuous insulation (ci) on exterior walls. Regardless of the insulation methods and materials used for compliance, this change has altered how water vapor and bulk water must be managed to maintain or even improve durability. Consequently, long-standing building code "rules" for moisture management are no longer reliable or, at best, are rendered incomplete. Fortunately, very recent building code advancements for water vapor control, including some related improvements for bulk water management, have answered this call to better coordinate with the prior energy code advancements. This paper and presentation will highlight and explain these coordinated energy code and building code advancements, including relevant substantiating research. It also will provide guidance for and examples of their effective application for design and construction of code-compliant, durable, and energy-efficient building enclosures.

SPEAKER

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, as well as research to address significant structural, energy, and building science challenges. His work has helped to propel many innovative technologies into the international codes and consensus standards. He is widely published on various engineering, construction, and building science topics.

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REVIEW OF RECENT ENERGY CODE ADVANCEMENTS

Climate Zones

The key to any building enclosure design starts with determining your climate conditions, and this is particularly true for a coordinated solution that complies with the energy code thermal insulation requirements and the building code moisture control provisions. The Climate Zone map used in the 2018 International Energy Conservation Code (IECC) is shown in *Figure 1* (ICC, 2018a). An updated map can be found in ASHRAE 169 and is used in the ASHRAE 90.1 standard (ASHRAE, 2013; ASHRAE, 2016). It shows a general "warming" trend in more recent climate data used to update the climate zones. However, the IECC is the focus of this paper, and it still maintains use of the older climate zone map (*Figure 1*).

Insulation Requirements

Based on the identified climate zone for a project, prescriptive requirements for building enclosure insulation are specified in accordance with the construction type (steel, wood, concrete/masonry, etc.) and the building occupancy and use classification. Prescriptive insulation provisions for walls from the 2018 IECC are shown in *Tables 1* and *2*. *Table 1* also includes some updates to expand insulation options for wood-frame walls that are expected to be a part of the 2021 IECC residential provisions based on pending code proposals. In levels of energy efficiency, these R-value requirements have changed little since the 2012 edition of the code and likely will remain very similar in the 2021 code edition, based on current code development status at the time of this writing. Note that while the various insulation options are equivalent from a thermal performance standpoint, they may not be equivalent in terms of moisture performance. This will become more obvious later.

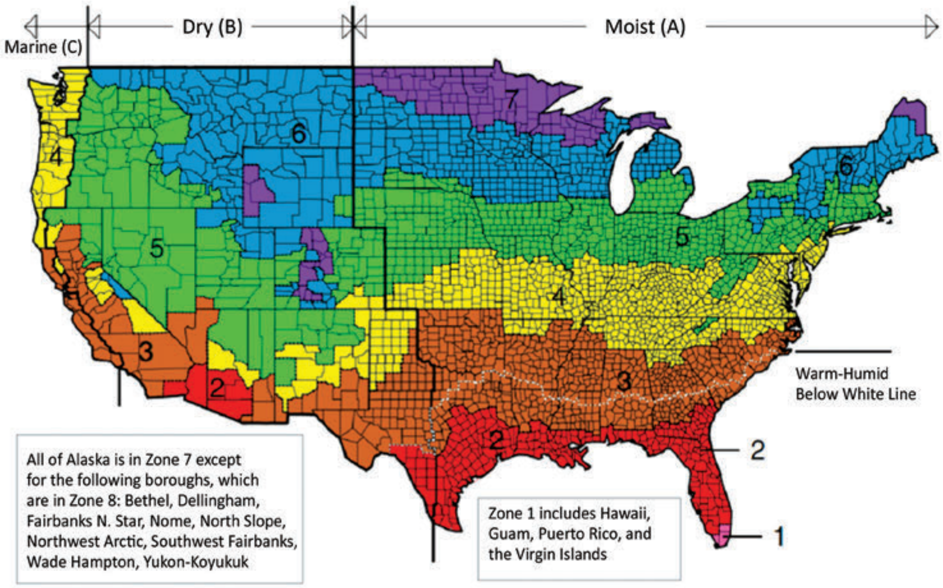

Figure 1 – U.S. Climate Zone Map used in IECC.

Climate Zone	Wood-Framed Wall R-value (16 in. oc)[a]	Steel-Framed Wall R-value (24 in. oc)[a]	Mass Wall R-value[b]
1	13+0ci or 0+10ci	0+9.3ci, 13+3ci, 15+2.4ci	3 / 4
2	13+0ci or 0+10ci	0+9.3ci, 13+3ci, 15+2.4ci	4 / 6
3	20+0ci, 13+5ci, or 0+15ci	0+14ci, 13+7.7ci, 15+7.1ci, 19+6.3ci, 21+5.9ci	8 / 13
4 except Marine	20+0ci, 13+5ci, or 0+15ci	0+14ci, 13+7.7ci, 15+7.1ci, 19+6.3ci, 21+5.9ci	8 / 13
5 and Marine 4	20+0ci, 13+5ci, or 0+15ci	0+14ci, 13+7.7ci, 15+7.1ci, 19+6.3ci, 21+5.9ci	13 / 17
6	30+0ci, 20+5ci, 13+10ci, or 0+20ci	13+11.5ci, 15+10.9ci, 19+10.1ci, 21+9.7ci, 25+9.1ci	15 / 20
7 and 8	30+0ci, 20+5ci, 13+10ci, or 0+20ci	13+11.5ci, 15+10.9ci, 19+10.1ci, 21+9.7ci, 25+9.1ci	19 / 21

a. The first value is cavity insulation R-value; the second value is continuous insulation (ci) R-value (e.g., cavity R-value + ci R-value). Where a value of "0" is indicated for either the cavity or ci component, that insulation component is not required. Summing of the indicated R-values is not permitted and will result in a non-equivalent solution. Alternate solutions must comply with a U-factor analysis method appropriate to the type of construction.

b. The first value applies where half or more of the insulation is on the exterior side of the mass wall; the second value applies where more than half of the insulation is on the interior of the mass wall.

Table 1 – Wall insulation requirements – IECC Residential (one- and two-family dwellings).

Climate Zone	Occupancy and Use	Construction Type			
		Mass	Metal Building	Metal Frame	Wood Frame and Other
1	Group R	R-5.7 ci	R-13+R-6.5 ci	R-13+R-5 ci	R-13+R-3.8 ci or R-20
	All Other	R-5.7 ci	R-13+R-6.5 ci	R-13+R-5 ci	R-13+R-3.8 ci or R-20
2	Group R	R-7.6 ci	R-13+R-13 ci	R-13+R-7.5 ci	R-13+R-3.8 ci or R-20
	All Other	R-5.7 ci	R-13+R-6.5 ci	R-13+R-5 ci	R-13+R-3.8 ci or R-20
3	Group R	R-9.5 ci	R-13+R-13 ci	R-13+R-7.5 ci	R-13+R-3.8 ci or R-20
	All Other	R-7.6 ci	R-13+R-13 ci	R-13+R-7.5 ci	R-13+R-3.8 ci or R-20
4 except Marine	Group R	R-11.4 ci	R-13+R-13 ci	R-13+R-7.5 ci	R-13+R-3.8 ci or R-20
	All Other	R-9.5 ci	R-13+R-13 ci	R-13+R-7.5 ci	R-13+R-3.8 ci or R-20
5 and Marine 4	Group R	R-13.3 ci	R-13+R-13 ci	R-13+R-7.5 ci	R-13+R-7.5 ci R-20+R-3.8 ci
	All Other	R-11.4 ci	R-13+R-13 ci	R-13+R-7.5 ci	R-13+R-3.8 ci or R-20
6	Group R	R-15.2 ci	R-13+R-13 ci	R-13+R-7.5 ci	R-13+R-7.5 ci R-20+R-3.8 ci
	All Other	R-13.3 ci	R-13+R-13 ci	R-13+R-7.5 ci	R-13+R-7.5 ci R-20+R-3.8 ci
7	Group R	R-15.2 ci	R-13+R-19.5 ci	R-13+R15.6 ci	R-13+R-7.5 ci R-20+R-3.8 ci
	All Other	R-15.2 ci	R-13+R-13 ci	R-13+R-7.5 ci	R-13+R-7.5 ci R-20+R-3.8 ci
8	Group R	R-25 ci	R-13+R-19.5 ci	R-13+R-17.5 ci	R-13+R-15.6 ci R-20+R10 ci
	All Other	R-25 ci	R-13+R-13 ci	R-13+R-7.5 ci	R-13+R-15.6 ci R-20+R10 ci

Table 2 – Wall insulation requirements for 2018 IECC Commercial ("Group R" residential and "all other" commercial buildings).

Enclosure Trade Offs

It is possible to arrive at different insulation designs by using enclosure trade-offs through the total building UA method or any of the performance path options (e.g., whole-building simulation for any building type or energy rating index for homes). But, the prescriptive R-value requirements in *Tables 1* and *2* for walls, together with the energy code's prescriptive requirements for insulation of roofs, floors, and foundations, provide a cost-effective benchmark for a minimum level of energy efficiency for an overall building enclosure with no "weak links." Greater energy savings and other benefits such as improved comfort and durability can be achieved by going beyond these code minimums. Conversely, trading off enclosure insulation can have negative consequences in terms of long-term performance, comfort, and durability. These consequences will become more evident in the next section and in later design examples.

The Renewable Energy and Energy Conservation Nexis

Finally, if the goal is to maximize the value of an on-site renewable energy system, such as rooftop solar panels, an efficient thermal enclosure is the first step to take before adding on-site renewable energy production. Conversely, using renewable energy production to justify weakening (i.e., trading off) the energy conservation purpose of a building enclosure does not conserve or reduce non-renewable energy use. Instead, the environmental benefits of the renewable energy system—particularly its ability to replace fossil fuel energy use and minimize carbon or pollutant emissions into the atmosphere—would be completely negated or severely diminished. This misuse of renewable energy production would then be nothing more than "greenwashing." Thus, energy conservation must come first and must not be sacrificed when making good use of renewable energy production technologies, whether on the building site or off site.

REVIEW OF COORDINATED BUILDING CODE ADVANCEMENTS

With a solid foundation for an energy-efficient enclosure established in the previous section, the next important step is to meet or exceed the moisture control requirements of the building code. In fact, this coordination intent is expressed in the following section of the 2018 IECC:

> **R401.1.1 Vapor retarder.** Wall assemblies in the building thermal enclosure shall comply with the vapor retarder requirements of Section 702.7 of the International Residential Code or Section 1405.3 of the International Building Code, as applicable.

Energy efficiency without moisture control is not durable, and a building that is not durable is not sustainable or resilient. Consequently, having an energy-efficient building that is not durable is ultimately not energy efficient (HUD, 2015). So, it is important (and not all that costly or complicated) to make sure you end up with an efficient and durable building enclosure as appropriate for a given project.

Important advancements in building codes are forthcoming to better coordinate moisture control requirements with the energy code requirements discussed in the previous section. This coordination is necessary because of the coupled hygrothermal nature of building enclosures. They must be designed to conserve energy and manage moisture, which are interrelated objectives that require careful attention to avoid one doing harm to the other. The physics are complex. But the forthcoming building code improvements have reduced this complexity to a reasonably simple table-driven or "menu" process.

The key design factors are the climate zone, the amount of insulation, where the insulation is located within an enclosure assembly, the interior vapor retarder selection to control vapor movement (seasonal drying and wetting), and specification of an appropriate water-resistive barrier (WRB), flashing, and cladding system to manage rainwater (minimize risk of wetting due to rainwater intrusion). This is clearly a system-based design problem, and each component of a building enclosure assembly must be viewed in relation to the other component parts of the assembly. This is why the energy code, the building code, and resulting design decisions must be carefully coordinated.

Water Vapor Control Improvements

Figure 2 is a representation of new building code provisions that are forthcoming in the 2021 editions of the International Residential Code (IRC) and International Building Code (IBC) (ICC, 2021a; ICC, 2021b). While only the IRC provisions are shown in *Figure 2*, the IBC provisions will be essentially the same. It is a complete reformat of the vapor retarder provisions, including some important technical improvements and additions. The reformatting better organizes the content into vapor retarder material classes (Table R702.7[1]) and basic vapor retarder specification requirements based on climate zone (Table R702.7[2]).

Two additional tables are provided for specific conditions identified in Table R702.7(2). First, Table R702.7(3) addresses use of Class III vapor retarders with either 1) vented claddings and vapor-permeable exterior building materials, or 2) continuous insulation. This table has been modified to address recent research findings and recommendations (ABTG, 2015; Crandell, 2017). In particular, Climate Zone 8 is treated separately from Climate Zone 7 to better address the more severe cold conditions of Climate Zone 8. In the IRC provisions shown in *Figure 2*, the application to Climate Zone Marine 4 remained unchanged (as a code development compromise); however, for the coordinated IBC provisions, the application of Table R702.7(3) was extended to all of Climate Zone 4 based on the available research (ABTG, 2015; Crandell, 2017).

Table R702.7(4) is a new table to specifically address appropriate use of a Class II vapor retarder (e.g., traditional kraft paper interior vapor retarder) on walls with ci on the exterior side (see also footnote 'c' of Table R702.7[2]). This table provides direction for additional options for use of ci and, in some cases, is a more efficient means to comply with energy code insulation requirements with good moisture control performance as demonstrated in research and various field studies (ABTG, 2015; Crandell, 2017). It also is consistent with practices that have been used

R702.7 Vapor Retarders. Vapor retarder materials shall be classified in accordance with Table R702.7(1). A vapor retarder shall be provided on the interior side of frame walls of the class indicated in Table R702.7(2), including compliance with Table R702.7(3) or Table R702.7(4) where applicable. An approved design using accepted engineering practice for hygrothermal analysis shall be an alternative. The climate zone shall be determined in accordance with Section N1101.7 (R301.1) [See Figure 1].

Exceptions:

1. Basement walls.
2. Below-grade portion of any wall.
3. Construction where accumulation, condensation or freezing of moisture will not damage the materials.
4. A vapor retarder shall not be required in Climate Zones 1, 2, and 3.

R702.7.1 Spray foam plastic insulation for moisture control with Class II and III vapor retarders. For purposes of compliance with Tables R702.7(3) and R702.7(4), spray foam with a maximum permeance of 1.5 perms at the installed thickness applied to the interior side of wood structural panels, fiberboard, insulating sheathing or gypsum shall be deemed to meet the ci moisture control requirement in accordance with one of the following conditions:

1. The spray foam R-value is equal to or greater than the specified ci R-value.
2. The combined R-value of the spray foam and ci is equal to or greater than the specified ci R-value.

TABLE R702.7(1)
VAPOR RETARDER MATERIALS AND CLASSES

CLASS	ACCEPTABLE MATERIALS
I	Sheet polyethylene, nonperforated aluminum foil, or other approved materials with a perm rating of less than or equal to 0.1.
II	Kraft-faced fiberglass batts, vapor retarder paint, or other approved materials applied in accordance with the manufacturer's installation instructions for a perm rating greater than 0.1 and less than or equal to 1.0.
III	Latex pain, enamel paint, or other approved materials applied in accordance with the manufacturer's installation instructions for a perm rating of grater than 1.0 and less than or equal to 10.0.

TABLE R702.7(2)
VAPOR RETARDER OPTIONS

CLIMATE ZONE	VAPOR RETARDER CLASS		
	CLASS I[a]	CLASS II[a]	CLASS III
1, 2	Not Permitted	Not Permitted	Permitted
3, 4 (except Marine 4)	Not Permitted	Permitted[c]	Permitted
Marine 4, 5, 6, 7, 8	Permitted[b]	Permitted[c]	See Table R702.7(3)

a Class I and II vapor retarders with vapor permeance greater than 1 perm when measured by ASTM E96 water method (Procedure B) shall be allowed on the interior side of any frame wall in all climate zones.

b Use of a Class I interior vapor retarder in frame walls with a Class I vapor retarder on the exterior side shall require an approved design.

c Where a Class II vapor retarder is used in combination with foam plastic insulating sheathing installed as ci on the exterior side of frame walls, the ci shall comply with Table R702.7(4) and the Class II vapor retarder shall have a vapor permeance of greater than 1 perm when measured by ASTM E96 water method (Procedure B).

Figure 2** - (continued on page 6) **Forthcoming Vapor Retarder Provisions for the 2021 I-Codes (IRC shown).[1]

TABLE R702.7(3)
CLASS III VAPOR RETARDERS

CLIMATE ZONE	CLASS III VAPOR RETARDERS PERMITTED FOR:[a,b]
Marine 4 [or all of 4 for 2021 IBC]	Vented cladding over wood structural panels.
	Vented cladding over fiberboard.
	Vented cladding over gypsum.
	Continuous insulation with R-value ≥ 2.5 over 2 x 4 wall.
	Continuous insulation with R-value ≥ 3.75 over 2 x 6 wall.
5	Vented cladding over wood structural panels.
	Vented cladding over fiberboard.
	Vented cladding over gypsum.
	Continuous insulation with R-value ≥ 5 over 2 x 4 wall.
	Continuous insulation with R-value ≥ 7.5 over 2 x 6 wall.
6	Vented cladding over fiberboard.
	Vented cladding over gypsum.
	Continuous insulation with R-value ≥ 7.5 over 2 x 4 wall.
	Continuous insulation with R-value ≥ 11.25 over 2 x 6 wall.
7	Continuous insulation with R-value ≥ 10 over 2 x 4 wall.
	Continuous insulation with R-value ≥ 15 over 2 x 6 wall.
8	Continuous insulation with R-value ≥ 12.5 over 2 x 4 wall.
	Continuous insulation with R-value ≥ 20 over 2 x 6 wall.

a Vented cladding shall include vinyl, polypropylene, or horizontal aluminum siding, or brick veneer with a clear airspace as specified in Table R703.8.4(1), or other approved vented claddings.

b The requirements of this table apply only to insulation used to control moisture in order to permit the use of Class III vapor retarders. The insulation materials used to satisfy this option also contribute to but do not supersede the thermal enclosure requirements of Chapter 11.

TABLE R702.7(4)
CONTINUOUS INSULATION WITH CLASS II VAPOR RETARDER

CLIMATE ZONE	CLASS II VAPOR RETARDERS PERMITTED FOR:[a]
3	Continuous insulation with R-value ≥ 2.
4, 5, and 6	Continuous insulation with R-value ≥ 3 over 2 x 4 wall.
	Continuous insulation with R-value ≥ 5 over 2 x 6 wall.
7	Continuous insulation with R-value ≥ 5 over 2 x 4 wall.
	Continuous insulation with R-value ≥ 7.5 over 2 x 6 wall.
8	Continuous insulation with R-value ≥ 7.5 over 2 x 4 wall.
	Continuous insulation with R-value ≥ 10 over 2 x 6 wall.

a The requirements of this table apply only to insulation used to control moisture in order to permit the use of Class II vapor retarders. The insulation materials used to satisfy this option also contribute to but do not supersede the thermal enclosure requirements of Chapter 11.

Figure 2 - (continued from page 5) Forthcoming Vapor Retarder Provisions for the 2021 I-Codes (IRC shown).[1]

successfully in Canada for many years as also addressed in the National Building Code of Canada since the 1995 edition.

Other important advancements are recognized in footnotes 'a' and 'b' of Table R702.7(2). First, footnote 'a' recognizes that not all Class I or II vapor retarders are equal. Some act as "responsive" vapor retarders that are also known as "smart" vapor retarders. The vapor retarder classes are based on a permeance rating from use of only the "dry cup" or desiccant method of ASTM E96. This classification is over-simplified in that it does not consider that some materials (such as kraft paper or proprietary smart vapor retarders) increase in water vapor permeance as the humidity they experience increases. When used on the interior side as a vapor retarder, they promote inward drying by "opening up" in periods or seasons where inward vapor drives occur (most prominent during spring and summer months). In the winter, they "close up" to restrict water vapor from moving into the assembly when outward vapor drives are the strongest and most persistent.

Second, footnote 'b' of Table R702.7(2) limits the use of a so-called "double vapor barrier" wall (i.e., having Class I vapor retarder materials on both sides of the assembly). These types of walls have performed well in some conditions of use such as cold-dry climates with use of appropriate weather protection and application of sufficient exterior ci. However, there are also many cases where they have not performed well, such as moist climates coupled with poor weather protection practices and lack of exterior ci or inappropriate use of interior vapor barrier in warm-humid climates. Consequently, a design is required to justify the use of a double vapor barrier assembly with very limited inward and outward drying potential to ensure that wetting potential is appropriately minimized as appropriate to a given climate. In essence, the code is promoting a good thing by favoring the provision of either inward or outward drying potential, or both. Having some drying potential in at least one direction is important for all types of walls, regardless of insulation strategy or construction type. The approach used depends on the climate as well as the exterior cladding materials (see later discussion on reservoir claddings).

Reservoir Cladding Improvements (Controlling Inward Vapor Drives)

The previous section dealt with code advancements related mainly to outward vapor drives during the winter, provision of adequate drying potential, and avoiding misuse of interior vapor retarders in the warm-moist climates. It acknowledges that walls must balance wetting and drying potential appropriate to a given climate. But there is another factor that has a significant effect on water vapor drives into assemblies (remember we are dealing with a "system," where any one component can have an effect on the design or performance of other components of the assembly). Reservoir claddings, such as portland cement (conventional) stucco and adhered masonry veneers, can absorb and store significant amounts of rainwater. When drying after a rain event—particularly with the aid of energy from direct sunlight—the inward vapor drives can readily exceed the magnitude of outward vapor drives experienced during the winter. Thus, in this case, some additional considerations are necessary for a complete water vapor control strategy. Namely, this inwardly driven water vapor must be blocked (by a low-vapor-permeance outer layer, such as foam sheathing ci) or vented out of the assembly by providing at least some nominal air gap behind the assembly, or both. Recent code changes have been put forward to address this issue, with the final result for the 2021 IBC and IRC editions still pending at the time of this writing. One of these stucco proposals is identical for both the IRC and IBC and is shown in *Figure 3*.

The pending code change represented in *Figure 3* does two very important things. First, it allows traditional practices to be continued where they have been successful in the dry climate zones (see *Figure 1* and Section 2510.6.1 option #1 in *Figure 3*). It also clarifies that the nebulous "non-water absorbing layer" has always been intended to apply to materials such as foam plastic insulating sheathing placed behind stucco (see Section 2510.5.1 option #2 in *Figure 3*). In addition, the WRB requirement in option #2 (i.e., 60-minute Grade D paper or material with at least equivalent water resistance) can include alternative use of other materials such as foam sheathing where approved for WRB applications. In this case, a separate bond-break or non-water-absorbing layer must be applied over the foam sheathing (i.e., the foam sheathing is used as the WRB, not as the non-water-absorbing layer). Foam sheathing also provides a block to inward water vapor movement from stucco, which can further enhance moisture control performance.

2510.6 Water-resistive barriers. Water-resistive barriers shall be installed as required in Section 1403.2 and, where applied over wood-based sheathing, shall comply with Section 2510.6.1 or Section 2510.6.2.

2510.6.1 Dry climates. One of the following shall apply for dry (B) climate zones:

The water-resistive barrier shall be two layers of 10-minute Grade D paper or have a water resistance equal to or greater than two layers of water-resistive barrier complying with ASTM E2556, Type I. The individual layers shall be installed independently such that each layer provides a separate continuous plane and any flashing, installed in accordance with Section 1404.4 and intended to drain to the water-resistive barrier, is directed between the layers.

The water-resistive barrier shall be 60-minute Grade D paper or have a water resistance equal to or greater than one layer of water-resistive barrier complying with ASTM E2556, Type II. The water-resistive barrier shall be separated from the stucco by a layer of foam plastic insulating sheathing or other non-water absorbing layer.

2510.6.2 Moist or marine climates. In moist (A) or marine (C) climate zones, water-resistive barrier shall comply with of one of the following:

1. In addition to complying with Item 1 or 2 of Section 2510.6.1, a minimum 3/16 inch (4.8 mm) space shall be added to the exterior side of the water-resistive barrier.
2. In addition to complying with Item 2 of Section 2510.6.1, a space with a minimum drainage efficiency of 90% as measured in accordance with ASTM E2273 or Annex A2 of ASTM E2925 is added to the exterior side of the water-resistive barrier.

Figure 3 – Pending IRC and IBC advancements for stucco (2021 IBC proposed change shown).

Second, the pending code change proposal represented in *Figure 3* provides enhanced requirements for use of stucco in the moist climate zones (see *Figure 1* and Section 2510.6.2 in *Figure 3*). There are two options for compliance: 1) use of a prescribed minimum 3⁄16-in.-thick drainage space to the exterior side of the WRB (behind the stucco) or 2) a space with a minimum drainage efficiency of 90% as measured in accordance with two commonly used ASTM standards. This provides a simple prescriptive solution and performance-based solutions allowing use of proprietary drainage materials and methods such as grooved foam sheathing, drainage mats, or building wraps that provide adequate drainage space or drainage performance. This practice will help to mitigate moisture issues that have occurred behind stucco and adhered veneers (e.g., reservoir claddings) in moist regions of the U.S.

It should be noted, however, that these provisions only apply where wood-based sheathing is used on the exterior side of a wall supporting the stucco (consistent with prior editions of the IBC and IRC). Thus, for all other sheathing materials (regardless of their moisture sensitivity), the only thing the code continues to require is a WRB behind the stucco (without a drainage space) in any climate and irrespective of the amount of rain or moisture hazard. For other types of sheathing that are sensitive to moisture (such as gypsum sheathing), it is recommended that the provisions aimed at wood-based sheathing be used, even though it is not required by the code.

Water-Resistive Barrier (WRB) and Flashing

Without appropriate means to prevent rainwater intrusion, all of the above practices (no matter how well executed) can be readily nullified. This reality has been borne out in experience without exception. Control of rainwater intrusion involves proper specification and application of a WRB and its interface (flashing) with other wall components such as windows, doors, roof-wall intersections, and other penetrations or discontinuities. There are many choices of materials for this purpose.

Forthcoming code changes to WRB and flashing provisions (at least in the IRC) are seeking to make continual improvements,

> Having some drying potential in at least one direction is important for all types of walls, regardless of insulation strategy or construction type. The approach used depends on the climate as well as the exterior cladding materials.

R703.2 Water-resistive barrier. Not fewer than one layer of water-resistive barrier shall be applied over studs or sheathing with flashing as indicated in Section R703.4, in such a manner as to provide a continuous water-resistive barrier behind the exterior wall veneer. Water-resistive barrier materials shall comply with one of the following:

1. No. 15 felt complying with ASTM D226, Type 1
2. ASTM E2556, Type I or II
3. ASTM E331 in accordance with Section R703.1.1, or
4. Other approved materials in accordance with the manufacturer's installation instructions.

No.15 asphalt felt and water-resistive barriers complying with ASTM E2556 shall be applied horizontally, with the upper layer lapped over the lower layer not less than 2 inches (51 mm), and where joints occur, shall be lapped not less than 6 inches (152 mm).

Figure 4 – Forthcoming 2021 IRC code change to clarify WRB requirements and options.

R703.4.1 Flashing installation at exterior window and door openings. Flashing at exterior window and door openings shall extend to the surface of the exterior wall finish or to the water-resistive barrier complying with Section 703.2 for subsequent drainage. Mechanically attached flexible flashings shall comply with AAMA 712. Flashing at exterior window and door openings shall be installed in accordance with one or more of the following:

1. The fenestration manufacturer's installation and flashing instructions, or for applications not addressed in the fenestration manufacturer's instructions, in accordance with the flashing manufacturer's instructions. Where flashing instructions or details are not provided, pan flashing shall be installed at the sill of exterior window and door openings. Pan flashing shall be sealed or sloped in such a manner as to direct water to the surface of the exterior wall finish or to the water resistive barrier for subsequent drainage. Openings using pan flashing shall incorporate flashing or protection at the head and sides.
2. In accordance with the flashing design or method of a registered design professional.
3. In accordance with other approved methods.

Figure 5 – Forthcoming 2021 IRC code change to reorganize flashing requirements.

even if in the form of clarifications. *Figure 4* gives an example of a forthcoming code change for the 2021 IRC related to specification of WRBs. *Figure 5* is a reorganization of flashing requirements in the IRC, mainly to distinguish fenestration flashing practices from those used for other applications.

There are so many possible variations of materials and methods for WRBs and flashing that the code cannot possibly keep up with specific details. Therefore, it is imperative that a design fill in the gaps where the code and even individual product manufacturer instructions may be incomplete or silent. For example, window manufacturers' instructions may not include installation and flashing provisions where walls include ci. WRB manufacturers may only provide flashing details for certain generic or commonly used fenestration types. ASTM standard guides or practices may be similarly limited in scope. For foam sheathing panel-type WRBs[2] and "other approved materials" (see *Figure 4*, item 4) used as a WRB system, the WRB specification and installation must carefully follow the manufacturer's installation instructions as required by code. These instructions typically include important material and installation specifications for joint sealing and flashing.

Air Barriers

Generally, air barriers have been considered only as an energy code requirement because they have the potential to significantly reduce energy use by limiting whole-building air leakage and are necessary to achieve whole-building air leakage requirements. But air barriers are also very important to the water vapor control strategies in the building code, as discussed earlier. A water vapor retarder can only work as intended if moist air is prevented from leaking around or bypassing the vapor retarder. While walls with increasing amounts of exterior ci are less impacted by this concern because they can be ultimately designed with no interior vapor retarder (e.g., the "perfect wall" with all moisture and thermal control layers on the exterior side of the structural assembly), walls without exterior insulation that instead rely solely on throttling water vapor by use of vapor retarders must increasingly be concerned with moist air leakage into the assembly around the vapor retarder. For this reason, code changes have attempted to marry the use of vapor retarders with the need for air leakage control through installation of the vapor retarder as an air barrier or provision of a separate air barrier as required by the energy code.

An example proposal for the 2021 IRC is shown in *Figure 6*. It requires vapor retarders to be installed in accordance with the manufacturer's instructions or an approved design. An approved design allows for alternative installation solutions based on a design that is approved by the code official. But the key added feature of this proposal is the requirement to install the vapor retarder as an air barrier with sealed joints or to separately install an air barrier in conjunction with the vapor retarder. At the time of this writing, it was unlikely that this pending proposal would become part of the 2021 IRC.

702.7.4 Installation. Vapor retarders shall be installed in accordance with the manufacturer's instructions or an approved design. The vapor retarder shall be installed as an air barrier or in conjunction with an air barrier.

Figure 6 – Pending 2021 IRC code change proposal to coordinate vapor retarders and air barriers.

EXAMPLE APPLICATION FOR EXTERIOR WALLS

This section provides examples that focus mainly on the water vapor control code improvements discussed in the previous section (see *Figure 2*). It applies to wood-framed walls and coordinates the water vapor control strategy with the energy code insulation requirements presented at the beginning of the paper (see *Tables 1* and *2*). This focus is not intended to diminish the importance of the other pending building code advancements discussed in the previous section related to stucco, WRBs, flashing, and air barriers. As shown in the subsequent examples, the process of selecting an appropriate vapor retarder for a frame wall that is insulated to comply with the energy code is reasonably simple (and much more reliable than could be achieved by use of older, oversimplified "rules of thumb" in the code). For more comprehensive guidance on moisture control for wood- and steel-framed walls and a step-by-step design check worksheet that allows for a wider range of code-compliant solutions and considerations, refer to ABTG Research Report No. 1701-01 (ABTG, 2017).

Example 1 – Residential (One- and Two-Family Dwelling)

Given: In Climate Zone 6, the energy code provides the following equivalent prescriptive wood-framed wall insulation options (see *Table 1*), where the first value is for cavity insulation (i.e., insulation located between wall framing or studs), and the second value is for continuous insulation (ci):

30+0 ci, 20+5 ci, 13+10 ci, or 0+20 ci

Find: For each of the wall assembly insulation options above, what vapor retarder options are appropriate in accordance with the building code (see *Figure 2*).

Solution: A vapor retarder must be ("shall be") provided in accordance with Section R702.7 (*Figure 2*). In Climate Zone 6, any of the following vapor retarder options are permitted in accordance with Table R702.7(2) as highlighted in *Figure 7*.

The application of Table R702.7(2) to determine a specific vapor retarder option depends on the insulation strategy used to comply with the energy code as shown subsequently.

30+0 ci Wall Assembly

For this wall with R-30 cavity insulation only, the cavity insulation is assumed to be vapor permeable (i.e., fiberglass, cellulose, open-cell spray foam, etc.) and not a vapor retarder itself. The vapor retarder options include Class I, II, or III as defined in Table R702.7(1) in *Figure 2*. Each option is considered as follows:

Class I – The use of Class I vapor retarder (i.e., polyethylene) would likely be the best code-compliant choice for this assembly for winter conditions in Climate Zone 6 (to avoid moisture accumulation in the exterior non-insulating sheathing). But, if the building is air-conditioned, the use of a Class I vapor retarder may result in condensation forming on the vapor retarder on the interior side of the assembly during the summer. While the code doesn't require it, this concern could be resolved by use of a "smart" or responsive Class I vapor retarder as described in footnote 'a' of Table R702.7(2). Even so, if the exterior side of the assembly contains a material layer or combination of layers that have a low permeance, the use of exterior ci may be necessary to protect the exterior layers from condensation or moisture accumulation during the winter. Unfortunately, the code updates shown in *Figure 2* did not go so far as to address this important concern (i.e., vapor permeance of the exterior side) for walls with vapor-permeable cavity insulation only in cold climates. Refer to ABTG (2017) for specific design guidance related to this concern to ensure that the permeance ratio of interior and exterior layers is in proper balance.

Class II – A Class II vapor retarder is also permitted for this assembly; however, it will allow even more water vapor to reach the cold sheathing in the winter than the use of a Class I vapor retarder (see discussion above). Available field data have consistently indicated that a typical kraft paper vapor retarder may result in excessive sheathing moisture contents in the winter in Climate Zones 5 and greater; however, a Class II vapor retarder would permit more inward drying in non-winter seasons. While a Class II vapor retarder is a code-compliant solution, it would be "safer" to use a Class I responsive vapor retarder for this assembly in Climate Zone 6 as recommended above.

Class III – A Class III vapor retarder is also permitted and requires compliance with Table R702.7(3) as shown in *Figure 2*. However, this table requires that, for an assembly without exterior ci, the cladding must be a "vented cladding" (see *Figure 2*, Table R702.7(3), footnote 'a'), and the exterior sheathing choices are limited to fiberboard or gypsum. Wood structural panels are not permitted in Climate Zone 6 because they are less permeable than fiberboard or gypsum and would certainly accumulate too much moisture due to outward vapor drives. This relates to the "permeance ratio" issue discussed above. So, if the cladding is not a vented cladding or if wood structural panels are used, a Class III vapor retarder for the cavity-insulation-only assembly is not permitted.

An attempt was made to address the concerns or recommendations mentioned in the above solutions related to management of water vapor in highly insulated walls without exterior ci (i.e., vapor-permeable cavity insulation only) in previous code development cycles, but consensus was not achieved. For more complete guidance on effectively addressing these concerns on walls without exterior ci, refer to Model Moisture Control Guidelines (ABTG, 2017) and wall design calculators at www.continuousinsulation.org/calculators.

Recommendation: Use a Class I vapor retarder that is "smart" (responsive) for the 30+0 assembly insulation strategy where vapor-permeable cavity insulation only is used. It is important that meticulous air sealing is applied, and the Class I "smart" vapor retarder should be installed as an air barrier to avoid moist indoor air bypassing the vapor retarder. Alternatively, it is possible to use closed-cell spray polyurethane foam (ccSPF) in the cavity (together with vapor-permeable insulation to the interior side) together with a Class II interior vapor retarder (see Section R702.7.1 in *Figure 2*). If the cavity is completely filled with ccSPF, this would potentially allow use of a 2 x 6 wall instead of a 2 x 8 or double-stud wall to achieve the R-30 cavity insulation requirement, and it may also serve as the Class II vapor retarder.

20+5 ci Wall Assembly

Class I – For this wall assembly, a Class I vapor retarder is permitted, but only if the R-5 ci on the exterior side (or other material layers on the exterior) is not a Class I vapor retarder as required by footnote 'b' of Table R702.7(2) in *Figure 2*. Many foam sheathing materials used as ci have a low vapor permeance (are not vapor permeable at thicknesses used) and some have facers (such as foil) that result in low vapor permeance. Therefore, as a conservative measure for any type of exterior ci with any level of vapor permeance, only the Class II and Class III vapor retarder options are discussed for this 20+5 ci wall assembly as described herein.

Class II – According to Table R702.7(2) in *Figure 2*, a Class II vapor retarder is permitted, but footnote 'c' applies in this case. Footnote 'c' requires two things: 1) compliance with Table R702.7(4), and 2) the Class II vapor retarder must have a vapor permeance of greater than 1 perm when measured by ASTM E96 water method (Procedure B), which is also known as the wet cup method. This defines and effectively requires use of a "smart" or responsive vapor retarder, such as conventional kraft paper, which is a Class II vapor retarder that meets this requirement. Other proprietary smart vapor retarders may be classified or rated as Class I or II vapor retarders and also meet the minimum 1 perm requirement under ASTM E96 wet cup test conditions. For compliance with Table R702.7(4) as shown in *Figure 2*, the following options are permitted for Climate Zone 6:

ci with R-value ≥ 3 over 2 x 4 wall

ci with R-value ≥ 5 over 2 x 6 wall

Because R-20 cavity insulation is used, a 2 x 6 wall cavity is required for typical vapor-permeable cavity insulation materials. For the 2 x 6 wall, a minimum of R-5 ci is required by Table R702.7(2) for moisture control when using the Class II "smart" vapor retarder (e.g., kraft paper). The 20+5 ci wall meets this requirement.

Class III – Table R702.7(2) permits use of a Class III vapor retarder, but it requires compliance with Table R702.7(3) when using this option. Table R702.7(3) requires the following for this wall assembly with ci in Climate Zone 6:

ci with R-value ≥ 7.5 over 2 x 4 wall

ci with R-value ≥ 11.25 over 2 x 6 wall

Again, with R-20 cavity insulation, this typically requires a 2 x 6 wall. For a 2 x 6 wall, Table R702.7(3) requires a minimum R-11.25 ci for moisture control. Consequently, for use of a fairly vapor-open Class III vapor retarder in Climate Zone 6, this 20+5 ci assembly does not provide a great enough exterior ci R-value-to-cavity insulation R-value ratio to address moisture control. Therefore, the code does not permit use of a Class III vapor retarder with the 20+5 ci assembly in Climate Zone 6.

It is possible to use a Class III vapor retarder, however, following the provisions of Section R702.7.1 (see *Figure 2*) with a sufficient R-value of ccSPF in the stud cavity in combination with the R-5 ci on the exterior. For example, using R-5 ci plus a 1-in.-thick flash coat of ccSPF in the cavity (with a minimum R-value of R-6.25) would result in a net R-value of at least 11.25 for the moisture control purposes of Section R702.7. But adding R-values of cavity and ci is not permitted for energy-code-compliance purposes. Instead, the minimum R-6.25 ccSPF in the cavity is added to a remaining cavity insulation of R-15 (high-performance 2 x 4 fiberglass batt) to achieve a cavity insulation value of R-21.25 (which slightly exceeds the R20 requirement of the energy code for the cavity portion of the 20+5ci assembly).

Recommendation: As a simple code-compliant solution, use a Class II "smart" vapor retarder, such as kraft paper, in Climate Zone 6 for the 20+5 ci wall assembly.

It should be noted that the R-5 ci is a minimum requirement for moisture control. Increasing the ci R-value will result in increasing moisture control because the wall, in combination with a code-compliant vapor retarder specification, becomes increasingly "warmed" by the exterior insulation and less prone to internal moisture accumulation or condensation. This is evident in the following assembly insulation options that increasingly rely on exterior ci to achieve equivalent energy code compliance.

13+10 ci Wall Assembly

This wall assembly follows the same code compliance process as discussed above for the 20+5ci assembly. The Class II and Class III vapor retarder options are discussed for this 13+10ci wall assembly as follows:

Class II – In this case, the use of R-13 cavity insulation implies the use of a 2 x 4 stud wall. Consequently, Table R702.7(4) requires a minimum of R-3 ci for this assembly to satisfy moisture control requirements of the building code. So, the energy code option to use a 13+10 ci insulation strategy provides a more moisture-resistant solution because the ratio of exterior insulation R-value to cavity insulation R-value is increased (yet it has the same energy efficiency as the other wall assemblies discussed above). For design guidance on the use of "insulation ratio" to design energy-efficient and moisture-resistant walls with more options than just those shown in Table

R702.7(4), refer to ABTG (2017) and wall design calculators at www.continuousinsulation.org/calculators.

Class III – For this continuously insulated assembly with R-13 cavity insulation, Table R702.7(3) requires a minimum R-7.5 ci. Because R-10 ci is provided for compliance with the energy code, this wall exceeds the minimum requirements of the building code for water vapor control.

Recommendation: Use a Class III vapor retarder for this 13+10 ci wall assembly to maximize inward drying.

0+20 ci Wall Assembly

This wall assembly also follows the same code compliance process as discussed above for the other two continuously insulated assemblies. However, in this case, all of the insulation is ci and there is no cavity insulation. This wall provides the highest insulation ratio and, therefore, is the most water-vapor-resistant of all of the above assemblies, even though it is equivalent from an energy-code-compliance standpoint. It readily complies with use of a Class II "smart" vapor retarder and is best used with a Class III interior vapor retarder (simply use latex paint on drywall) to maximize inward drying capability. In fact, if the R-20 ci material is a Class I or II vapor retarder or has a facer on its interior side that is a Class I or II vapor retarder, no separate vapor retarder on the interior side of the assembly is required at all, but this useful design nuance is not specifically included in the updated code language of *Figure 2*. For more information and design guidance on this type of wall assembly, which is known as "the perfect wall," refer to ABTG (2017) and wall design calculators at www.continuousinsulation.org/calculators.

Recommendation: Use a Class III vapor retarder (latex paint on gypsum wallboard) for this 0+20 ci wall assembly.

Example 2 – Commercial Building (Group R Residential)

Given: In Climate Zone 5 for a Group R building, the energy code provides the following prescriptive wood-framed wall insulation options (see *Table 2*):

R-13+R-7.5 ci
R-20+R-3.8 ci

Find: For each of the assembly insulation conditions above, what vapor retarder options are appropriate in accordance with the building code (see *Figure 2*)? Although *Figure 2* is for the IRC (one- and two-family dwellings), it is used in this example as a matter of convenience because a similar set of provisions will be included in the IBC for commercial and residential (Group R) buildings with frame walls.

Solution: First, in Climate Zone 5, a vapor retarder is required for both of the wall assembly insulation options in accordance with Section R702.7 of *Figure 2*. Any of these options (also shown in *Figure 7*) are permitted in accordance with Table R702.7(2).

As with Example 1, the application of the table to determine specific vapor retarder options depends on the insulation strategy used to comply with the energy code.

R-13+R-7.5 ci

The code compliance evaluation process is the same as for the continuously insulated assemblies discussed previously in Example 1. This assembly complies with Table R702.7(4) for use of a Class II "smart" vapor retarder (e.g., kraft paper) in Climate Zone 5. It also complies with the minimum R-5 ci requirement in Table R702.7(3) for use of a Class III vapor retarder in Climate Zone 5 with a 2 x 6 wall. In this case, the energy code insulation prescription allows multiple vapor retarder options in compliance with the building code.

Recommendation: Use a Class II "smart" vapor retarder (e.g., kraft paper) or a Class III vapor retarder (interior latex paint on gypsum wallboard) with this R-13 + R-7.5 ci wall assembly.

R-20+R-3.8 ci

Again, the code compliance evaluation process for this wall is similar to the previous examples. However, this particular energy-code-prescribed insulation option presents some moisture control challenges (for use in Climate Zone 5) due to its low insulation ratio. These challenges go away for warmer climate zones 1–4.

For use of a Class II "smart" vapor retarder (e.g., kraft paper), Table R702.7(4) requires a minimum R-5 ci for a 2 x 6 wall assembly with R-20 in the cavity. Similarly, for use of a Class III vapor retarder, Table R702.7(3) requires minimum R-7.5 ci for a 2 x 6 wall assembly. Thus, the R-20+R-3.8 ci assembly is not compliant with either of these vapor retarder options. This leaves two alternatives:

1) Redesign the wall assembly with an increased insulation ratio (e.g., increase the ci R-value to R-5 ci or R-7.5 ci) so that a Class II "smart" or Class III vapor retarder can be used. This will result in a wall that exceeds the energy code requirements (unless the cavity insulation is decreased and exact energy code compliance is achieved through use of U-factors); refer to ABTG (2017) and wall calculators found at www.continuousinsulation.org/calculators.

TABLE R702.7(2)
VAPOR RETARDER OPTIONS

CLIMATE ZONE	VAPOR RETARDER CLASS		
	CLASS I[a]	CLASS II[a]	CLASS III
1, 2	Not permitted	Not permitted	Permitted
3, 4 (except Marine 4)	Not permitted	Permitted[c]	Permitted
Marine 4, 5, 6, 7, 8	Permitted[b]	Permitted[c]	See Table R702.7(3)

a Class I and II vapor retarders with vapor permeance greater than 1 perm when measured by ASTM E96 water method (Procedure B) shall be allowed on the interior side of any frame wall in all climate zones.

b Use of a Class I interior vapor retarder in frame walls with a Class I vapor retarder on the exterior side shall require an approved design.

c Where a Class II vapor retarder is used in combination with foam plastic insulating sheathing installed as continuous insulation on the exterior side of frame walls, the continuous insulation shall comply with Table R702.7(4) and the Class II vapor retarder shall have a vapor permeance of greater than 1 perm when measured by ASTM E96 water method (Procedure B).

Figure 7 – Table R702.7(2), vapor retarder options.

TABLE R702.7(2)
VAPOR RETARDER OPTIONS

CLIMATE ZONE	VAPOR RETARDER CLASS		
	CLASS I[a]	CLASS II[a]	CLASS III
1, 2	Not Permitted	Not Permitted	Permitted
3, 4 (except Marine 4)	Not Permitted	Permitted[c]	Permitted
Marine 4, 5, 6, 7, 8	Permitted[b]	Permitted[c]	See Table R702.7(3)

a. Class I and II vapor retarders with vapor permeance greater than 1 perm when measured by ASTM E96 water method (Procedure B) shall be allowed on the interior side of any frame wall in all climate zones.

b. Use of a Class I interior vapor retarder in frame walls with a Class I vapor retarder on the exterior side shall require an approved design.

c. Where a Class II vapor retarder is used in combination with foam plastic insulating sheathing installed as ci on the exterior side of frame walls, the ci shall comply with Table R702.7(4) and the Class II vapor retarder shall have a vapor permeance of greater than 1 perm when measured by ASTM E96 water method (Procedure B).

Figure 8 – Table R702.7(2), vapor retarder options.

2) Alternatively, Section R702.7.1 could be used with an appropriate amount of ccSPF in the cavity to achieve compliance with the R-5 ci or R-7.5 ci requirement for use of a Class II "smart" or Class III vapor retarder, respectively.

Example 3 – Commercial Building ("All Other" – Nonresidential)

Given: In Climate Zone 2 for a nonresidential metal-frame building, the energy code provides the following prescriptive wall insulation options (see *Table 2*):

R-13+R-5 ci

Find: For each of the assembly insulation conditions above, what vapor retarder options are appropriate in accordance with the building code (see *Figure 2*). Although *Figure 2* is for the IRC (one- and two-family dwellings), it is used in this example as a matter of convenience because a similar set of provisions will be included in the IBC for commercial and residential (Group R) buildings with frame walls.

Solution: First, in Climate Zone 2, only a Class III vapor retarder is permitted (see highlight in *Figure 8*). The additional requirements of Table R702.7(3) for use of a Class III vapor retarder in colder climates do not apply. Footnote 'a' of Table R702.7(2) in *Figure 2* would permit the use of a Class I or II smart vapor retarder, but the simple solution is to use a Class III vapor retarder. The assembly requires both R-13 cavity insulation and R-5 ci. There is no minimum insulation ratio requirement as required for colder climates (see Examples 1 and 2), so no design check for this concern is required. While any type of exterior ci could be used, the use of a lower permeance variety of ci (such as various foam sheathing materials) provides for low vapor permeance to block the predominantly inward vapor drive in warm-humid climates such as Climate Zone 2. With a Class III vapor retarder (e.g., latex paint) on the interior side of the assembly as gypsum wall board finish, a significant inward drying potential is provided, which is ideal for warm-humid climates.

Recommendation: Use a Class III vapor retarder with the required R-13+R-7.5 ci assembly.

CONCLUSIONS

As presented in this paper, major advancements are expected in the next (2021) I-Codes to provide better coordination of energy code insulation requirements with the water vapor and moisture control requirements of the building code for frame walls. Current energy code provisions were discussed, as well as various proposed and pending building code changes. The application of the energy code and the expected newer building code requirements were illustrated in three examples evaluating a variety of insulation and vapor retarder options for warm and cold climates. While more work is needed to continue to improve the energy code and building code, much progress has been made to help coordinate the energy code and building code for energy-efficient and durable building enclosures.

The following are some key take aways from this paper:

1. Compliance with the energy code requires careful coordination with upcoming water vapor control building code provisions.
2. Together with climate, the insulation materials and strategy selected for compliance with the energy code govern the specification of an optimal vapor retarder material and location in compliance with upcoming building code provisions (or vice versa).
3. For any climate, the application of ci provides a robust and simple means to control moisture, provided a proper minimum insulation ratio is achieved in combination with the selection of an interior vapor retarder that promotes inward drying.
4. For any climate, walls without ci (see Item 3) require careful consideration of vapor permeance properties of materials located on the inside and outside (or cavity) of the assembly. However, traditional water vapor control practices included in building codes typically

While more work is needed to continue to improve the energy code and building code, much progress has been made to help coordinate the energy code and building code for energy-efficient and durable building enclosures.

focus only on specification of an interior vapor retarder (or its avoidance in warm-humid climates).

5. For reservoir claddings, such as conventional portland cement stucco or adhered masonry veneers, it is very important to provide adequate back-ventilation in moist (rainy) climates or at least a clear drainage pathway. Use of foam plastic ci also can help block inward vapor flows during episodes of high inward vapor drives from a reservoir cladding.
6. Regardless of the wall assembly and strategy employed for energy code and building code compliance, it is extremely important to minimize rainwater wetting potential by use of a carefully specified, detailed, and installed integration of WRB materials, flashing materials, and wall components.
7. Similarly, for any wall assembly, it is important to minimize wetting potential by use of a carefully specified, detailed, and installed air barrier system.

REFERENCES

Applied Building Technology Group. "Assessment of Water Vapor Control Methods for Modern Insulated Light-Frame Wall Assemblies." Research Report No. 1410-03. November 25, 2015. www.appliedbuildingtech.com

Applied Building Technology Group. "Model Moisture Control Guidelines for Light-Frame Walls: A Building Code Supplement for Builders, Designers, and Building Officials." Research Report No. 1701-01. December 26, 2017. www.appliedbuildingtech.com.

J.H. Crandell. "Assessment of Hygrothermal Performance and Design Guidance for Modern Light-Frame Wall Assemblies." *Advances in Hygrothermal Performance of Building Envelopes: Materials, Systems and Simulations*. ASTM STP1599. P. Mukhopadhyaya and D. Fisler, Eds., ASTM International, West Conshohocken, PA, 2017. pp. 362-394, http://dx.doi.org/10.1520/STP159920160097.

ASHRAE. 2013. Standard 169, *Climate Data for Building Design Standards*. Atlanta, GA. www.ashrae.org.

ASHRAE. 2016. Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta, GA. www.ashrae.org.

International Code Council. 2018a, International Energy Conservation Code, International Code Council, Inc. www.iccsafe.org.

International Code Council. International Building Code. Pending publication.

International Code Council. 2021b. International Residential Code. Pending publication.

U.S. Department of Housing and Urban Development. 2015. *Durability by Design*. 2nd Edition. Washington, DC (prepared by Newport Partners and ARES Consulting). www.huduser.org. www.newportpartnersllc.com, www.aresconsulting.biz.

FOOTNOTES

1. Online calculators to help implement and automate the moisture control provisions of *Figure 2* can be accessed at https://www.continuousinsulation.org/calculators.
2. For additional information on the use of foam sheathing as a WRB (including standard flashing details for windows), refer to https://www.continuousinsulation.org/topical-library/water-resistive-barrier.