

# TRANSITIONS IN THE BUILDING ENVELOPE:

## Critical Issues and Considerations

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The built environment constitutes a significant portion of the consumption of nonrenewable energy in the United States. For this reason, it is crucial that a building envelope provide continuous resistance to air leakage, water penetration, and heat transfer in order to maximize facility performance. In response to this need, building codes are being revised and made stricter. This is a new paradigm as governing bodies realize that building envelope performance is linked to reducing energy consumption.

New codes are requiring increased performance levels from the exterior building envelope to resist air leakage, water penetration, and heat transfer, and to control the transmission of moisture in the form of water vapor. Stricter building envelope performance requirements force exterior envelope construction to be more complex.

The movement of heat, air, moisture vapor, and moisture water (HAMM) both into and out of a structure is con-

trolled by specifically designed systems that envelop the building across the foundation, roof, walls, doors, and windows. Although these are separate systems, they must work together to maximize the functionality of the exterior envelope. While these concepts seem self-evident at the macro level, the design, specification, detailing, and implementation of creating multiple systems within the building envelope can be challenging.

Based on the 2012 International Build-

ing Code® (IBC), this article will briefly describe some of the requirements, typical functions, materials, and components of building envelope systems that are designed to control the movement of heat, air, and moisture through the building envelope. It will then discuss the considerations that must be addressed when designing, detailing, specifying, and implementing the transition of these systems at the interface between horizontal and vertical components.

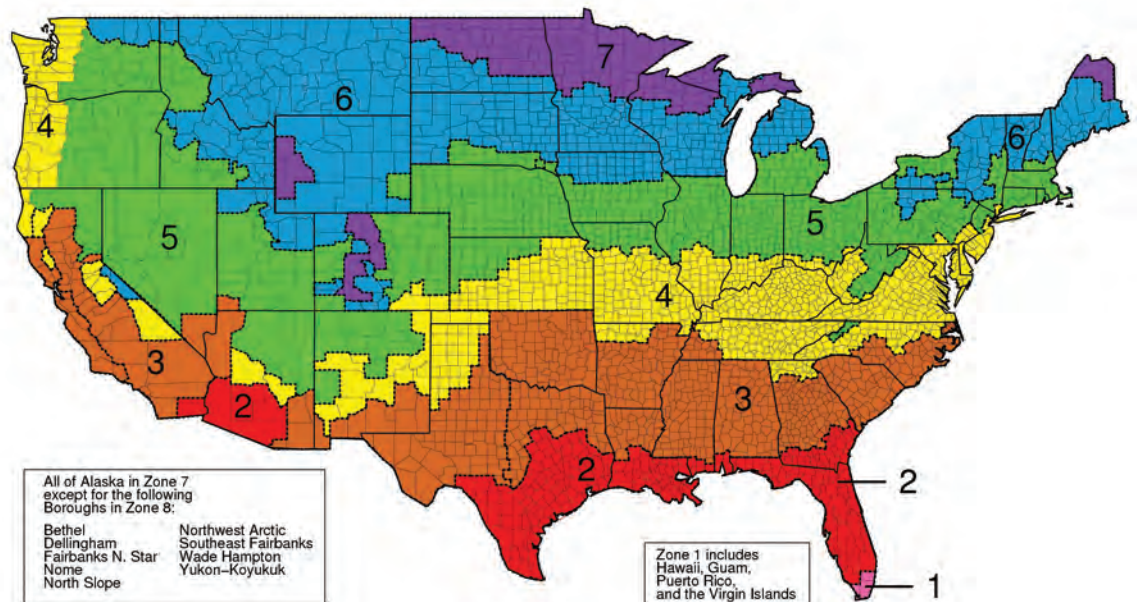


Figure 1 – 2012 IBC Climate Zone Map: Geographic climate zones, moisture regimes, and warm-humid designations.

**TABLE C402.2  
OPAQUE THERMAL ENVELOPE REQUIREMENTS\***

CLIMATE ZONE	1		2		3		4 EXCEPT MARINE		5 AND MARINE 4		6		7		8	
	All Other	Group R	All Other	Group R	All Other	Group R	All Other	Group R	All Other	Group R	All Other	Group R	All Other	Group R	All Other	Group R
<b>Roofs</b>																
Insulation entirely above deck	R-20ci	R-20ci	R-20ci	R-20ci	R-20ci	R-20ci	R-25ci	R-25ci	R-25ci	R-25ci	R-30ci	R-30ci	R-35ci	R-35ci	R-35ci	R-35ci
Metal buildings (with R-5 thermal blocks) <sup>a,b</sup>	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-25 + R-11 LS	R-25 + R-11 LS	R-30 + R-11 LS	R-30 + R-11 LS	R-30 + R-11 LS	R-30 + R-11 LS
Attic and other	R-38	R-38	R-38	R-38	R-38	R-38	R-38	R-38	R-38	R-49	R-49	R-49	R-49	R-49	R-49	R-49
<b>Walls, Above Grade</b>																
Mass	R-5.7ci	R-5.7ci	R-5.7ci	R-7.6ci	R-7.6ci	R-9.5ci	R-9.5ci	R-11.4ci	R-11.4ci	R-13.3ci	R-13.3ci	R-15.2ci	R-15.2ci	R-15.2ci	R-25ci	R-25ci
Metal building	R-13+ R-6.5ci	R-13+ R-6.5ci	R-13+ R-6.5ci	R-13+ R-13ci	R-13+ R-13ci	R-13+ R-13ci	R-13+ R-13ci	R-13+ R-13ci	R-13+ R-13ci	R-13+ R-13ci	R-13+ R-13ci	R-13+ R-13ci	R-13+ R-13ci	R-13+ R-13ci	R-13+ R-19.5ci	R-13+ R-19.5ci
Metal framed	R-13+ R-5ci	R-13+ R-5ci	R-13+ R-5ci	R-13+ R-7.5ci	R-13+ R-7.5ci	R-13+ R-7.5ci	R-13+ R-7.5ci	R-13+ R-7.5ci	R-13+ R-7.5ci	R-13+ R-7.5ci	R-13+ R-7.5ci	R-13+ R-7.5ci	R-13+ R-7.5ci	R-13+ R-15.6ci	R-13+ R-7.5ci	R-13+ R-17.5ci
Wood framed and other	R-13+ R-3.8ci or R-20	R-13+ R-3.8ci or R-20	R-13+ R-3.8ci or R-20	R-13+ R-3.8ci or R-20	R-13+ R-3.8ci or R-20	R-13+ R-3.8ci or R-20	R-13+ R-3.8ci or R-20	R-13+ R-3.8ci or R-20	R-13+ R-3.8ci or R-20	R-13+ R-7.5ci or R-20 + R-3.8ci	R-13+ R-7.5ci or R-20 + R-3.8ci	R-13+ R-7.5ci or R-20 + R-3.8ci	R-13+ R-7.5ci or R-20 + R-3.8ci	R-13+ R-7.5ci or R-20 + R-3.8ci	R-13+ R-15.6ci or R-20 + R-10ci	R-13+ R-15.6ci or R-20 + R-10ci

Figure 2 — Excerpts from Table C402.2 from the 2012 IECC provide opaque thermal envelope requirements for commercial buildings.

**HEAT**

The 2012 IBC cites the International Energy Conservation Code (IECC) for building envelope thermal performance requirements. The IECC identifies eight different climate zones in the United States. See Figure 1.

Zone 1 is located at the tip of Florida, and Zone 8 is located in boroughs of Alaska. The required thermal performance of the building envelope is based on the climate zone in which it is located. The thermal insulation requirements of the exterior vertical opaque walls of a metal frame structure in climate Zone 5 include cavity wall insulation rated at R-13 plus a layer of continuous insulation with a minimum thermal resistance rating of R-7.5 that is uninterrupted by the exterior wall framing. See Figure 2.

A thermal resistance of R-13 can be achieved with 3.5 in. of fiberglass batt insulation, while a thermal resistance of R-7.5 can be achieved with approximately 1.25 in. of rigid polyisocyanurate foam board insulation. Foam board insulation is generally not a structural sheathing and will not provide sufficient anchorage for exterior cladding. The thermal requirements for continuous insulation create the need for new ways to laterally brace the structure and attach the exterior cladding back to the edifice.

A roof system in Climate Zone 5 is required to have a minimum thermal resistance rating of R-25, and the insulation must be continuous. This will require 5 in. of insulation with a thermal resistance rating of R-5 per in. The transition from wall to roof needs to accommodate the variation and placement of the insulation types and quantities, and still provide adequate insulation so there is no heat loss at the transition.

**AIR LEAKAGE**

Controlling the movement of heat energy through the building envelope is very important. Estimates indicate that air leakage contributes to almost 40 percent of the energy lost in a building. Air leakage can also transport a significant amount of moisture through the building envelope, helping to create uncomfortable indoor conditions. Moisture in a facility is also

thought to cause health risks for visitors and occupants. Air leakage may occur through unsealed voids in exterior sealant, poorly fitting window gaskets, plumbing penetrations, or unsealed mechanical vents.

Air leakage is caused by a differential pressure across the exterior envelope. This differential pressure may be caused by wind, the stack effect, or mechanical equipment.



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Wind creates higher pressures on the windward side of a building. This causes air to enter the structure and result in areas of low pressure on the leeward sides and roof, which forces air to exit the structure.

The stack effect is caused by the fact that hot air is more buoyant and tends to rise, while cooler air is denser and sinks. This creates areas of high air pressure at the top of a facility and low pressure at its foundation, which can contribute to air leakages.

Another cause of differential pressure across the building envelope can be attributed to mechanical equipment. Imbalances in the air intake and exhaust systems can create positive or negative pressures within a building. The imbalances may be intentional or caused by a lack of proper commissioning. These imbalances can cause air to enter or exit a facility.

To be effective, air barrier systems must be:

- Continuous across the entire building envelope
- Structurally sound to be able to resist the positive or negative pressures created from wind, the stack effect, or mechanical systems
- Durable to exist within the exterior envelope, as repair could require the removal and replacement of either interior or exterior finishes
- Able to impede the flow of air through the exterior envelope to an amount consistent with the code-specified rates

A facility's air barrier system consists of all of the assemblies in the building envelope that are united to create a continuous barrier to air leakage. Assemblies can include roofs, windows, and opaque walls or doors. Assemblies are made of qualified materials such as glass, roof membranes, and polyethylene plastic. The code specifies minimum air penetration performance levels for materials, assemblies, and entire buildings. A qualified air barrier material cannot allow the passage of more than 0.004 cubic feet per minute (cfm) of air per sq. ft. at a static pressure differential of 0.3 in. of water across the material. Similarly, a qualified air barrier assembly such as a window cannot allow the passage of more than 0.004 cfm of air per sq. ft. at the same differential pressure. This increase in the allowable air leakage through an assembly over a material is to allow for increased air

leakage at joints between materials. The code allows a total of 0.4 CFM of air leakage per sq. ft. at the same differential air pressure for the entire building envelope. This increased amount of allowable air leakage is to allow for the additional joints created by uniting numerous air barrier assemblies to create an entire building system.

#### MOISTURE WATER

The 2012 IBC calls for the exterior wall envelope to be designed to prevent the accumulation of water within the wall assembly by providing a resistive barrier behind the exterior veneer as well as a way to drain water that enters the assembly to the exterior. The code defines a water-resistive barrier as a material behind an exterior wall covering that is intended to resist liquid water that has penetrated behind the exterior covering from further intruding into the exterior wall assembly. Water barrier systems are generally constructed of liquid-applied membranes, self-adhered sheets, or mechanically fastened membranes of EPDM, butyl rubber, or polyethylene.

The code language clearly defines a system to collect, control, and conduct water that may have penetrated through the exterior wall surface back to the exterior.

This is not a new concept in construction. Typical masonry, cavity wall construction includes a drainage plane with flashing and weep holes. Masonry will allow water penetration through cracks and areas of debonded mortar. Window systems are also designed with internal drainage and weep holes to collect water that may have penetrated the primary seals and conduct it back to the exterior of the system.

#### MOISTURE VAPOR

As building envelopes become tighter, it is increasingly important to incorporate systems to control the passage of moisture vapor. Uncontrolled moisture vapor can collect inside the building envelope and cause premature deterioration such as corrosion, rot, or biological growth. The movement of moisture vapor through a wall is controlled with a vapor retarder system. The material that makes up a vapor retarder is rated in perms (units of measure that quantify the amount of water vapor that passes through a sq. ft. of material at a static pressure of one inch of mercury.) One U.S. perm = 1.0 grain/ft<sup>2</sup>/hr./in. Hg).

The code defines three different classes of vapor retarders in terms of perms:

- Class 1: <0.1 perms—materials such as sheet polyethylene, nonperforated aluminum foil
- Class 2: 0.1 to 1.0 perm—materials such as Kraft-faced fiberglass batts or paint with a perm rating greater than 0.1 and less than or equal to 1.0
- Class 3: 1.0 to 10 perms—materials such as latex or enamel paint

The proper location of a vapor retarder depends on the climate zone, the occupancy, and the thermal properties of the building envelope. Locating a vapor retarder should be done using a thorough hygrothermal analysis of the building envelope.

Control of heat, air, and moisture is important for the building envelope to perform successfully for the long term. From a roofing point of view, one must consider how heat, air, and moisture are controlled. These same considerations must be addressed when designing, detailing, specifying, and implementing the transitions of the roof system and at the interface between the horizontal and vertical components of a structure.

#### DESIGN: ROOF AS ASSEMBLY

A roof incorporates many different elements, including parapets, flat edges, skylight scuttles, drains, vent stacks, posts, columns, penetrations, and curbs. However, the roof's performance—and by extension, building envelope performance—is dependent on the whole system rather than its parts. The transition between the roof and other systems in the building directly affects weatherproofing as well as thermal-resistive, air barrier, and vapor retarder systems. When selecting a roof, designers tend to look at product information over system information.

#### EXAMPLE 1

If the project requirements call for an R-value of 25 for a roof, depending on the conditions, a designer may select two layers of 2-in.-thick polyisocyanurate rigid insulation as the insulation layer. On the surface this may be a good product choice because it includes two layers of insulation that can have staggered joints, but it is not completely accurate to identify the R-value of the roof based on its basic construction.

Penetrations and transitions are a large portion of the roof. They generally do not add to the R-value of the roof assembly, since they usually interrupt the insulation

layers. To determine the actual R-value of a roof assembly, one cannot simply add up the R-value of the two insulation boards.

#### EXAMPLE 2

A 400-sq.-ft. wall of a single-story house may contain four windows and a door. The windows constitute 25% of the wall area, and the door adds another 5%. If the wall has R-13 batts between the studs and R-12 rigid board continuous insulation, the actual R-value of the assembled wall is not the sum total of the R-values of the insulation of the opaque wall. Twenty-five percent of the wall area is made up of the windows that have an R-value of 4. Simple averaging of R-values based on relative square footage yields a weighted average R-value of just below 20.

However, the above calculation is still inaccurate. The R-value and area of the wood framing have not been accounted for. Four-inch nominal wood framing has an R-value of about 4. The framing typically constitutes approximately 10% of the wall. Using the weighted average calculation, the R-value of a wood frame wall assembly with

R-13 batt insulation and 4-in. nominal wood framing at 16 inches on-center stud assembly has an R-value of 12. The inclusion of the wood framing reduces the R-value of the cavity wall insulation from R-13 to R-12.

To obtain a true representation of the R-value of the exterior wall assembly, the continuous insulation at the exterior of the framing should be evaluated similarly to the cavity wall insulation. Rigid foam board insulation assemblies have board joints and a fastening system. Poorly butted insulation with unmated joints can allow considerable thermal energy movement through the open joints. Metallic fasteners create thermal bridges unless their heads are thermally protected. What is the loss of assembly R-value because of the board joints, fasteners, and installation quality? In many cases, the R-value of the continuous insulation layer should be reduced to an R-value of 10 or 11.

The overall wall assembly R-value calculation needs to take into account the stud wall (75% of the wall), which has an R-value of 23, and the windows (25% of the wall),

having an R-value of 10. Simple averaging means an overall wall assembly R-value is approximately 18.

These examples demonstrate why it is common for mechanical engineers to over-size units, and why the concept of R-value for roofing assembly is crucial to the overall design team, especially mechanical-system designers. The heating and cooling systems should be balanced to the level of building envelope thermal design, and this includes more accurate predictions of R-value for the roof as part of the building envelope. Accurate numbers are crucial to have more efficient mechanicals based on a full-perspective, 3-D-type approach.

The same concepts can and should be used when designing and predicting the R-value of a roof. The R-value of skylights and roof scuttles is 4-5. If the design of the roof area includes nearly 5% skylights, then it is necessary to reduce the R-value of the overall roof assembly.

Consider a case where a roof has three drains down the center, six mechanical units, and 12 skylights on a condo or strip mall. The quantity and type of roof penetra-



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tions vary greatly from roof to roof. After one has accounted for the “major” penetrations, what about the roof system itself? Does the design include thermal bridges—meaning, how many metal fasteners are in the roof assembly? Do they penetrate full thickness? Or is there insulation above the plate and fastener head? How many layers of insulation are there? Are the board joints offset? Research shows that as much as 18% of R-value can be lost with single-layer insulation and fasteners that act as thermal bridges.

Going back to Example 1, if a roof is 70 ft. by 100 ft., the perimeter is 340 ft., the skylights are 60 sq. ft., the drains are less than 10 sq. ft., and the HVAC units are about 50 sq. ft., then the R-value at these locations is really 0 to 4. This means roughly 5% to 7% of the roof has little or no insulation. The total R-value now drops to just under 24. If the roof included fasteners through the full thickness of insulation, the R-value decreases another 5% to 10%,

bringing the assembly R-value down to 22 or 23. A 10% loss in R-value may seem minimal, but consider large-footprint, one-story structures. Most building professionals would be happy with a 10% improvement in energy efficiency with any building design. That’s when the roofing industry does its commissioning—during design and installation. Roof commissioning is not done after installation.

There are quite a few other materials used for insulation or within the thermal layer, such as phase change materials. Each material type has its own characteristics that should be accounted for during thermal design and calculation. No matter the type(s) of material used, the insulation as an assembly approach to design still holds true.

#### AIR BARRIERS

A thermal layer is great to reduce the transfer of heat via conduction, but what

about air-transported heat and water? Air barriers are critical because moisture transferred by air moves at 30 times the rate of diffused moisture. Air can also be hot or cold, so there is plenty of heat exchanged when air passes through a building envelope.

The roof membrane is inherently an effective air barrier. A low-slope roof membrane does not allow air to freely pass through it. But where the roof membrane is penetrated or ends, the continuity of the air barrier becomes critical. Most often, the penetration is also through the air retarder or barrier. A vent stack or a drain is an air barrier from the perspective of the roof assembly. The wall of the vent pipe is the air barrier. What travels through the vent stack is the designer’s issue. The air barrier within the roof system needs to be connected to the penetration. That can happen at the membrane level with a fully adhered flashing, or it can happen at the deck level if the air barrier is located at that level. From a roofing perspective and in most cases, where air can enter, so can water.

At the perimeter of a roof, the roof membrane (when used as the air barrier) can be transitioned from membrane to deck level by inserting an air barrier at a board joint in the insulation layer. The air barrier is continuous from the roof membrane to the air barrier located at deck level. The deck-level air barrier is the air barrier that transitions from the horizontal to the vertical.

Alternatively, materials can be stacked to create an air retarder/barrier location. More components mean extra interfaces and, inherently, a greater chance of error. At an overhang with block/brick walls and steel joists/steel deck, there are many



Figure 3 – Billowing, mechanically fastened roof system over a pressurized building.



Figure 4 – Positive pressure in this facility’s mechanical system causes membrane to billow.

locations for air to pass. The air barrier in the wall needs to be connected to the air barrier in the roof (be it the roof membrane or another layer), using the steel deck as a portion of the air barrier (as necessary). The wall air barrier needs to connect to the bottom of the steel deck—likely with spray-applied foam; and the top of the steel deck needs to connect to the roof air barrier—with spray-applied foam or by taping/adhering the air barriers to each other.

Within the field of the roof, air barriers are required at many locations. Details include roof-to-wall configurations, vent stacks, and small pipes. Skylights and scuttles are a difficult group because of the window effect—they are operable, so they rely on gaskets and compression, which can be problematic over time. Regardless, the roof system needs to be tied to the penetration with tapes or spray-applied foams in order to maintain the air barrier transition from roof to penetration.

Virtually all buildings are designed to provide a positive pressure. Many conditioned spaces—certainly those with air conditioning—can have interiors that are pressurized and, therefore, are likely pushing air into the roof system by finding ways through the roof deck and/or ceiling construction.

Figures 3 and 4 are representative of the positive pressure of a facility's mechanical system making its way under the roofing membrane due to lack of continuity of the air barrier at this transition location. There is likely to be a lack of continuity through the transition condition from roof to wall.

#### **DIFFERENCES BETWEEN AIR AND VAPOR RETARDERS AND BARRIERS**

Before moving on to vapor retarders, it is worth pointing out some key differences between air retarders/barriers and vapor retarders. Vapor retarders do not need to be continuous. The laps don't need to be perfect. Vapor retarders are located within a wall based on the climate/vapor drive and materials used for construction. Vapor retarders do not need to be strong.

In contrast, air barriers need to be continuous, and the laps/joints are critical. An air barrier can be located anywhere within an assembly; ease of installation and detailing are most important. An air barrier needs to be strong to resist positive and negative air pressures.

#### **VAPOR RETARDERS AND BARRIERS**

The roofing industry is more familiar with vapor retarders and has been installing them for years, especially in colder climates. Vapor barriers used in roofs typically are located above the roof deck and below the insulation to keep moisture from entering the roof system.

Vapor retarders used in a roof system include polyethylene sheets or adhered bituminous membranes. A polyethylene sheet with fastener holes and untaped seams is a good vapor retarder but is not a good air barrier. Diffused moisture will not get into the roof system, but air-transported moisture can. This is important to note. A bituminous sheet that is adhered (and does not have fasteners through it) will be a good vapor retarder and a good air barrier.

There are products that can be air barriers but not good vapor retarders. Take plywood decking as an example. If the joints and penetrations are taped, the plywood deck becomes an effective air barrier. However, we recognize plywood will allow vapor to diffuse through it, so it's not an effective vapor retarder.

Air and vapor retarders can be specific to a formula. Spray polyurethane foam (SPF) is a good air and vapor barrier when high-density, closed-cell formulations are used. The high-density, closed-cell SPF is typically used for roof systems. Open-cell, lower-density SPF is a good air retarder but not a quality vapor retarder. This product is more commonly used for wall insulation because it allows the wall to dry out.

There are a number of computer models that can assist the designer. WUFI, by Oak Ridge National Laboratory (ORNL)/Fraunhofer IBP, is a hygrothermal analysis tool that calculates the transient coupled one-dimensional heat and moisture transport in multilayer building components exposed to weather elements. It is based on the latest findings about vapor diffusion and liquid transport in construction materials. The system has been authenticated by detailed comparison with measurements found both in the lab and through outdoor testing.


The NRCA EnergyWise® Roof Calculator can be used to assist vapor retarder placement. However, much of the design of the thermal, air, and vapor retarder layers is based on a designer's careful approach to continuity at the transitions. Most analysis tools do not address the complexity and variation of three-dimensional construction details.



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## CONCLUSION

The transitions from roof to wall, roof to penetration, and roof to perimeter are critical to the effective control of heat, air, and moisture. New codes are demanding buildings reduce energy use and perform more efficiently. Stricter building envelope performance helps facilities meet this criterion. It is crucial for the build environment to learn and adapt to the new codes.

When it comes to designing and implementing, it is incumbent upon roof system designers to understand the needs of the building, the design of the roof system, and the details—whether code-driven or simply by necessity—so that transitions between a building's components are continuous, effective, and installable. 

## SOURCES

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