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Sealing the Envelope with SPF Insulation

by Jim Lambach

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IN A TIME OF EVER-RISING ENERGY COSTS AND INCREASING CONCERNS OVER THE CARBON FOOTPRINT, BUILDING OWNERS AND DESIGNERS WANT FUNCTIONAL, ENERGY-EFFICIENT STRUCTURES AS WELL AS AESTHETICS. FURTHER, INCREASINGLY STRINGENT CODES ARE PUSHING DESIGN PROFESSIONALS TO MODIFY AND RE-EXAMINE BUILDING ENVELOPE CONSTRUCTION.

New code requirements focus on improving the envelope by prescribing higher R-values, recognizing the importance of continuous insulation and the inclusion of air barrier systems. The thermal envelope, along with air and moisture movement through the building envelope, has a significant impact on the structure's performance. New building materials and construction techniques are being evaluated.

Closed-cell sprayed polyurethane foam (ccSPF) insulation has been used in roof systems since the 1960s. The material is continuously applied on the assembly's exterior, thereby mitigating thermal bridging. The SPF roof system serves as continuous insulation, waterproofing, and an air barrier. With routine maintenance, the properly installed system provides an energy-efficient covering that can last 20 years or more between recoats—and this is for a system that has direct exposure to the sun and the elements.

Figure 1

ASHRAE Climate Zone 2 Changes (Walls)	Non-residential		Residentail		Semi-heated	
Above-grade Walls	< 2004	2007	< 2004	2007	< 2004	2007
Mass	NR	5.7 ci	R-5.7 ci	R-7.6 ci	No Requirement	NC
Metal Buildings	R-13	No Change	R-13	No Change	R-6	R-13
Steel-framed	R-13	No Change	R-13	R-13 + R-7.5 ci	No Requirement	R-13
Wood Frame	R-13	No Change	R-13	No Change	No Requirement	R-13

ASHRAE 90.1, *Energy Standard for Buildings Except Low-rise Residential Buildings*, minimum insulation requirements for energy-efficient building designs in high-rise buildings (Climate Zone 2).

Images courtesy Bayer MaterialScience LLC

Figure 2

ASHRAE Climate Zone 3 Changes (Walls)	Non-residential		Residentail		Semi-heated	
Above-grade Walls	< 2004	2007	< 2004	2007	< 2004	2007
Mass	5.7	7.6 ci	R7.67 ci	R-9.6 ci	No Requirement	No Change
Metal Buildings	R-13	No Change	R-13	R-13 + R-13 ci	R-6	R-13
Steel-framed	R-13	R-13 + R-3.8 ci	R-13 + R- R-3.8 ci	R-13 + R-7.5 ci	NR	R-13
Wood Frame	R-13	No Change	R-13	No Change	R-13	No Change

ASHRAE 90.1 requirements for energy-efficient building designs in high-rise buildings (Climate Zone 3).

Thermal envelope

In any energy-efficient structure, a well-designed thermal envelope is key to building performance. Closed-cell SPF insulation has many facets that give design professionals a large degree of creative license. The fluid-applied, self-adhering nature of the product can be used for irregularly shaped buildings, and helps ensure continuity of the thermal envelope.

Performance metrics are a major factor in envelope materials selection; ccSPF insulation offers high R-value compared to other common insulation products. While these values vary between manufacturers, an aged R-6.5 per 25.4 mm (1 in.) is fairly common.

In 2007, American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) implemented the first wholesale increases in R-value since 1989. With energy prices fairly cheap in the 1990s, there was little incentive to increase energy efficiency. However, in the 2000s, energy prices started steadily rising. Model building codes reflected the need for higher R-values along with the need for continuous insulation on the structure's exterior. ASHRAE 90.1, *Energy Standard for Buildings Except Low-rise Residential Buildings*, outlines the minimum requirements for energy-efficient designs in high-rise buildings. Figures 1, 2, and 3 show changes to ASHRAE 90.1 for Zones 2, 3, and 4, respectively.[1]

These changes represent increased R-values up to 50 percent in some cases. The *International Building Code* (*IBC*) and *International Residential Code* (*IRC*) have recognized the raised ASHRAE 90.1 standards. This will put greater pressure on state and local municipalities to adopt more stringent requirements. Using ccSPF, it is

A spray-applied polyurethane foam (SPF) roof, prepared for photovoltaic (PV) cells.

Photo © Central Coating Co. Photo courtesy Bayer MaterialScience LLC

> To effectively manage moisture, the building envelope must be designed and constructed so that bulk moisture from rain and snow can drain off the structure and away from the foundation.

Figure 3

ASHRAE Climate Zone 4 Changes (Walls)	Non-residential		Residential		Semi-heated	
Above-grade Walls	< 2004	2007	< 2004	2007	< 2004	2007
Mass	5.7	9.5 ci	R-9.5 ci	R-11.4 ci	No Requirement	No Change
Metal Buildings	R-13	R-13 + R-13 ci	R-13	R-13 + R-13 ci	R-10	R-13
Steel-framed	R-13	R-13 + R-7.5 ci	R-13 + R-7.5 ci	No Change	R-13	No Change
Wood Frame	R-13	No Change	R-13	R-13 + R-3.8 ci	R-13	No Change

ASHRAE 90.1 requirements for energy-efficient building designs in high-rise buildings (Climate Zone 4).

Images courtesy Bayer MaterialScience LLC

possible to meet these newer prerequisites without significant changes to the wall design.

ASHRAE 90.1-07 changes also showed greater recognition for the importance of continuous insulation. Its R-value requirements were added to building components, though not previously mandated. Higher R-values for continuous insulation values were implemented, especially in northern climate zones. Using data from ASHRAE 90.1-07, Table A3.1D (Figure 4, page 68), the effectiveness of continuous insulation is clear.

For common metal stud construction, the elimination of thermal bridging across the stud is highly effective in improving the wall's thermal performance. In this example, when insulation is placed in the stud cavity, the R-value maxes out at around R-5. However, if the insulation is placed on the outside of the wall, as continuous insulation, the wall's R-value increases linearly with the insulation R-value.

To further illustrate this point, one can consider a steel-framed building in Zone 4 and refer to Figure 3. When built to ASHRAE 90.1-04, R-13 insulation is installed between the studs, and according to Figure 5, that overall wall section performs as R-4.7. If the same structure is built according to the 2007 standard, it requires another R-7.5 of continuous insulation outboard of the stud wall, which equates to a 58 percent increase in the amount of installed insulation. However, the impact of that added insulation is far greater—the wall section now performs as R-12.2. For a 58 percent increase in installed insulation, the wall's insulating effectiveness is increased by 160 percent. This is a great payback in performance.

In the photo above, SPF has been applied under a cantilevered wall section.

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Air leakage

The next critical factor in energy-efficient design is control over air infiltration and exfiltration. According to the U.S. Department of Energy (DOE), in 2011, buildings used about 40 percent of the energy in the U.S. economy, costing more than $400 billion.[2] Further, air leakage can contribute to associated issues with:

- moisture management;
- noise;
- dust;
- pollutants;
- insects; and
- rodents.

One solution to this problem is to use a properly designed air barrier system.

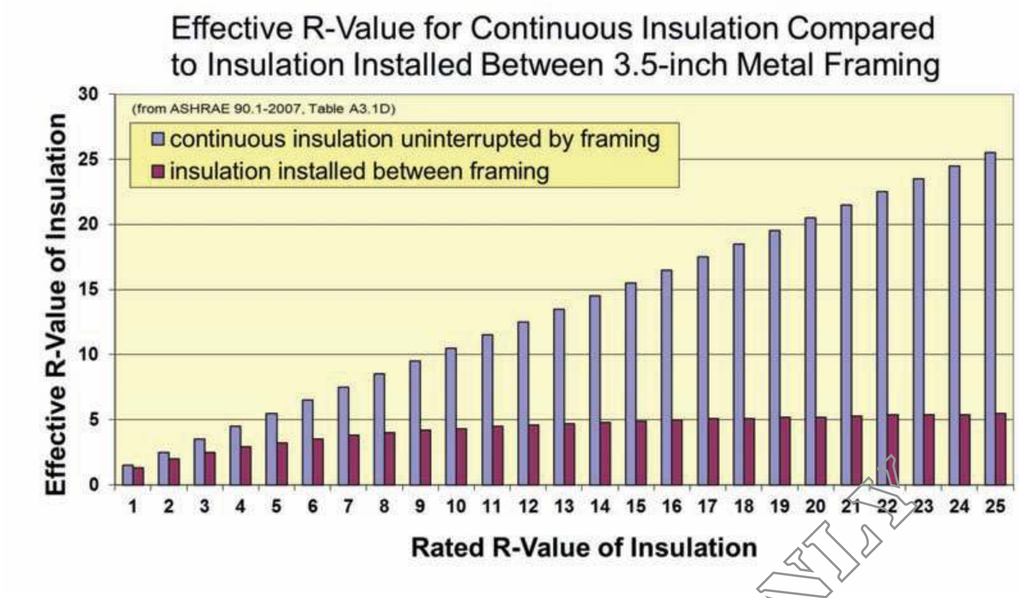
An air barrier system is a collection of air-impermeable materials assembled together for the purpose of forming a continuous boundary separating indoor (*i.e.* conditioned) air from the outdoor (*i.e.* unconditioned) air.[3] Air-impermeable components are defined by the building code as materials with air infiltration and exfiltration rates of less than 0.02 L/s•m^2 (0.004 cfm/sf) when tested at a pressure differential of 75 Pa (1.57 psf), in accordance with ASTM E2178, *Standard Test Method for Air Permeance of Building Materials.* A 75-Pa pressure differential simulates a 40-km/h (25-mph) wind. Most rigid foam insulations easily meet this requirement.

When designing an air barrier system, it is critical to be mindful of the differences between an air barrier assembly and an air barrier material. Air leakage rates for wall assemblies are determined by ASTM E2357, *Standard Test Method for Determining Air Leakage of Air Barrier Assemblies.* This measures air leakage across a pressure gradient with and without penetrations. The generally accepted value for good wall design is air leakage of less than 0.2 L/s•m^2 (0.04 cfm/sf) at 75 Pa pressure differential, which is an order of magnitude above the requirement for an air barrier material.[4]

Using ccSPF insulation, it is possible to achieve very low ASTM E2357 values with common wall types such as exterior gypsum board and concrete masonry unit (CMU) block walls. Other building insulation products, such as board stock, are able to achieve the necessary values in testing using tape to seal the joints and flashings around penetrations. Closed-cell SPF offers the advantage of being liquid-applied, expansive, and self-flashing. These properties allow it to more fully fill voids and odd junctions.

Building airtightness is measured using a blower door test. A professional energy auditor conducts the test by first closing all windows and exterior doors, and turning off the HVAC unit and all exhaust fans. The auditor then mounts the variable speed blower door fan in an entry door, and uses it to create a pressure differential in the building. This forces air through all holes and penetrations in the building enclosure.

Figure 4



Rated R-value for cavity fill insulation versus continuous insulation in metal stud construction.

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The tighter the building (*e.g.* fewer holes), the less air is needed from the blower door fan to create a change in building pressure. Typically, the blower door hardware converts fan pressure measurements directly to fan airflow values. The result can be expressed in numerous ways, but one common practice is to express the result in terms of the number of air exchanges per hour (ACH) the structure undergoes at a defined pressure—typically 50 Pa (1.04 psf).

More codes have changed in the United States to recognize the importance of air barriers. The movement started in Massachusetts and Minnesota, with both states mandating air barriers in their commercial building codes. The 2012 *International Energy Conservation Code* (*IECC*), Section R402.4, "Specific Insulation Requirements (Prescriptive)," mandates all homes be blower-door tested, and the air leakage result must be ≤ 5 ACH 50 for Zones 1 and 2, and ≤ 3 ACH 50 for Zones 3 to 8. Although many new homes are not yet built to this version of model code, approximately 25 percent of housing starts were built to Energy Star standards in 2010. Most Energy Star homes are blower-door tested for air leakage, and in the current Energy Star version, blower door testing is mandatory.

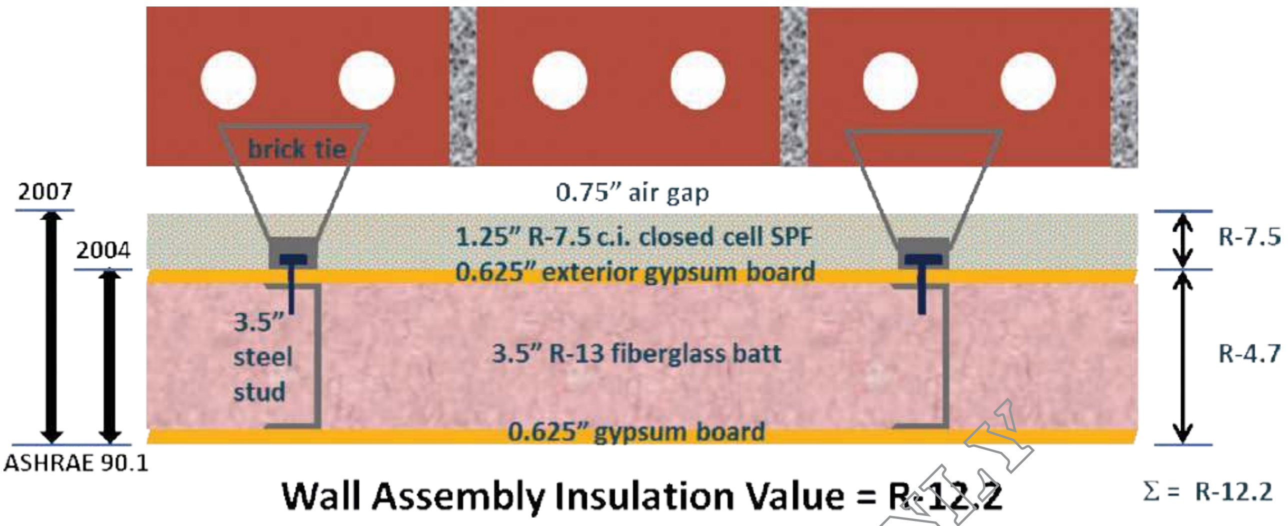
As homes and commercial structures become better sealed, the amount of air exchange that occurs naturally through air leakage pathways is greatly reduced. However, some level of air exchange is needed to flush out stale indoor air and replace it with fresh outdoor air. ASHRAE 62.1, *Ventilation for Acceptable Indoor Air Quality*, and 62.2, *Ventilation and Acceptable Indoor Air Quality in Low-rise Residential Buildings*, were written to define the minimum amount of ventilation recommended for commercial and residential structures, respectively, to maintain acceptable indoor air quality (IAQ). For well-sealed structures, this minimum level of ventilation is achieved by mechanical means. Air is exchanged through engineered openings in the structure versus incidental leakage pathways.

Moisture management

A well-constructed building envelope effectively manages heat, air, and moisture transfer across the boundary from inside out and from outside in. Mismanagement or misalignment of the heat and air boundaries can cause significant impact to energy efficiency and occupant comfort, but design flaws in the moisture boundary can lead to more significant problems. Water is the common ingredient leading to wood rot, metal corrosion, efflorescence, and foundation movement. Moisture can seriously threaten the building's long-term integrity and durability, and is also a contributor to mold formation that can threaten occupant health.

Water that is in the building envelope develops from a number of sources. A primary cause is bulk moisture from rain and snow that leaks through holes and cracks in the building envelope, or penetrates through surfaces that have not been adequately waterproofed. To effectively manage moisture, the building envelope must be designed and constructed so bulk moisture from rain and snow drains off the structure and away from the foundation. Exterior claddings like brick or vinyl siding are designed to screen the majority of the rain and snow.

Figure 5



Difference in insulation between the 2004 and 2007 editions of ASHRAE 90.1 for Climate Zone 4 in steel-framed walls.

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A drainage plane must be located behind the cladding for incidental water that leaks behind. It must not trap water, but allow it to flow down the wall, where it can drain away from the structure. Building wraps and membranes—such as spunbonded olefin—are typically used as the drainage plane; however, ccSPF functions as its own drainage plane, making an additional building membrane unnecessary. Closed-cell SPF is naturally resistant to water penetration, so the water simply drains off.

Condensation from contact with surfaces below the dewpoint is the second significant source of liquid water infiltration; this is most apparent when there is a large temperature difference between the outside environment and the conditioned space. The amount of water that can be deposited in the building envelope due to condensation from air leaks is more consequential than many people realize.

Consider this example from a hot-humid climate. Assume 28.3 L/min (150 cfm) of air at 37.7 C (100 F) and 70 percent relative humidity (RH) leaks into a space conditioned to 21 C (70 F). Over a 12-hour period, 98.4 L (26 gal) of water is transported into the building from air leakage. As the air cools to 21 C, it can only hold 56.8 L (15 gal) of water (at 100 percent RH). What happens to the 41.6 L (11 gal) of excess water? Some of it condenses on cool surfaces in the building envelope as the air leaks into the building. The rest mixes with the interior air, driving the indoor humidity level up and impacting building occupants' comfort. This also taxes the ability of the HVAC unit to remove the excess humidity over time as latent heat.

This example is for hot-humid climates; however, the condensation from air leakage in cold climates is also an issue. This phenomenon is operative when warm, humid air from inside the building leaks through the envelope to the outside. Water condenses on cold surfaces in the building envelope as the humid air encounters cold surfaces below its dewpoint. Condensation in cold climates can also occur without air leakage if thermal bridging across the building envelope allows for some surfaces in the conditioned space to fall below dewpoint. Interior air conditioned to 21 C and 40 percent RH has a dewpoint of 7.2 C (45 F). Therefore, condensation occurs when the outside temperature is cold, and there are thermal bridges in the wall design that cause some of the inside surface temperatures to be less than 7.2 C.

The third water source is moisture accumulation in the wall assembly due to vapor diffusion. Water vapor can diffuse through materials with high vapor permeance and increase their moisture content (MC). At moisture contents in the high teens, wood and oriented strandboard (OSB) become susceptible to rot. Building codes recognize that vapor diffusion can be a significant source of moisture in the building envelope in cold climate zones, so a vapor retarder is required on the inside surface to minimize the potential for dewpoint condensation from vapor diffusion. Typically, this would be a polyethylene film, or some other vapor-impermeable membrane. However, ccSPF has very low vapor permeance, and typically qualifies as a vapor retarder at thicknesses less than 51 mm (2 in.). One should see individual manufacturer's technical data sheets to confirm the thickness

Insulating Material	R-value/inch (typical) ASTM C518
Closed-cell Sprayed Polyurethane Foam (ccSPF)	6.5
Open-cell SPF (ocSPF)	3.7
Fiberglass batt (3.5-in. standard)	3.2
Fiberglass batt (3.5-in. dense)	3.6
Blown-in cellulose	3.6
Packed cellulose	3.2
Extruded polystyrene (XPS)	5.0
Expanded polystyrene (EPS)	3.8
Polyisocyanurate (Polyiso)	6.8

Common insulation values.

at which the product qualifies as a Class II vapor retarder. If that minimum thickness is achieved, no additional vapor retarder is required.

WUFI is a sophisticated modeling program jointly developed by Oak Ridge National Laboratory (ORNL) and the Fraunhofer Institute for Building Physics (IBP) in Holzkirchen, Germany. It is used by building scientists, architects, and engineers to test theoretical performance of wall assemblies with regard to moisture transportation and condensation. WUFI models the performance of a conceptual wall assembly constructed in the software. The program uses climate data files from various areas throughout the United States so the wall assembly can be virtually placed into any climate to model temperature and moisture profiles throughout a typical weather year.

Figure 3 shows a stud wall with ccSPF continuously applied to the exterior. By placing insulation outboard of the studs, instead of between them, thermal bridging from wall components is eliminated, leaving the stud cavity-free for electrical service and utilities. The outside surface of the ccSPF functions as the drainage plane, and because the sprayfoam is continuously applied, it functions as both the air barrier and vapor retarder.

This wall assembly was modeled in WUFI for a cold winter day in Merrill, Wisconsin. The temperature profile through the assembly is indicated by the purple line. At the interior interface of the SPF insulation/air/vapor barrier element, the wall assembly's temperature is above the dewpoint temperature, indicating this will not be a condensing surface.

Another example, from a WUFI training class, shows the dramatic impact different wall assembly materials and details have on building performance. The project—a 1860s warehouse in Cleveland, Ohio—had a double-wythe brick exterior wall assembly and a heavy timber structural frame.

A blower door test can help determine air leakage.

Photo courtesy Austin Spray Foam

One trial wall assembly maintained the original brick exterior by applying 51 mm of 32-kg/m^3 (2-lb/cf) ccSPF on the interior side of the wall. A 92-mm (3.6-in.) steel stud wall covered the insulation and had R-13 un-faced batt insulation in the stud wall cavity. This was covered with a 16-mm (⅝-in.) gypsum board.

The WUFI model showed the polyurethane foam insulation had sufficient resistance to water vapor transmission to effectively block moisture flow across the original brick. The only direction for the brick to dry was to the exterior. Per the WUFI modeling, within three years, the original brick started to decay due to the freeze–thaw cycle and moisture trapped within the wall. With further study, this problem could be remedied by installing additional weeps at higher portions of the brick wall and over higher windows and selective locations.

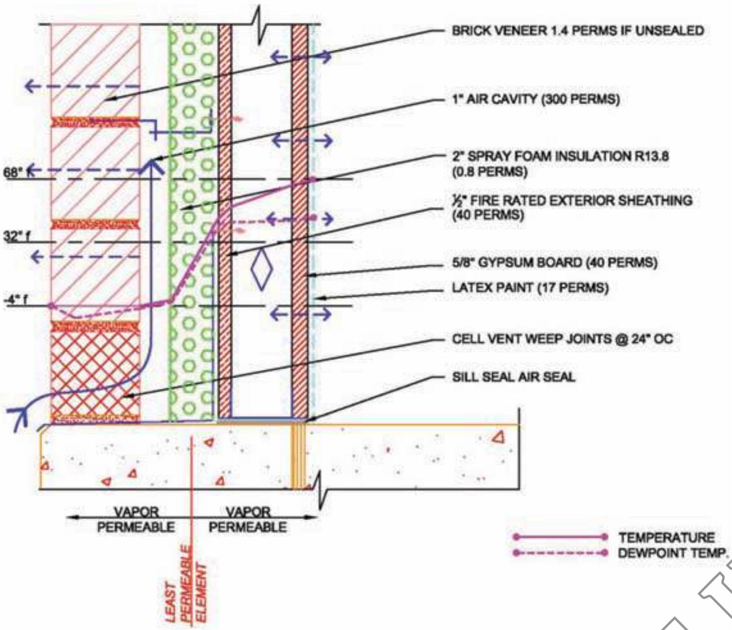
Conclusion

Buildings do not have to be the energy hogs they have been in the past. As building science is increasingly integrated into building materials and design and construction techniques, the energy consumption of residential and commercial facilities can be brought well within compliance of local and national codes being put into place.

At the earliest design phases, architects and engineers must look holistically at the building and energy performance goals. From there, an understanding of how Mother Nature's forces of temperature, wind, and water act on a building can drive even higher performance metrics. A continuous thermal envelope such as that provided by closed-cell sprayed polyurethane foam insulation will not only help meet ASHRAE 90.1 requirements, but it also provides a monolithic seal around building penetrations and affords designers great

> With routine maintenance, a properly installed SPF roof system provides an energy-efficient covering that can last 20 years between recoats.

Figure 6



Brick veneer assembly with SPF insulation.

Image courtesy Bayer MaterialScience LLC and Trinity Consultants

flexibility. A properly designed air barrier system is the single biggest factor for controlling unwanted air infiltration and exfiltration.

Understanding how bulk moisture, condensation, and vapor diffusion occur is a major step toward moisture management on the building envelope. Science and the environment can peacefully co-exist in today's high-performance buildings. **CS**

Notes

[1] See ASHRAE 90.1, *Energy Standard for Buildings Except Low-rise Residential Buildings.*

[2] For more, see U.S. Department of Energy's (DOE's) "Better Buildings." Visit www1.eere.energy.gov/buildings/betterbuildings.

[3] See the Air Barrier Association of America's (ABAA's) "Information for Design Professionals." Visit www.airbarrier.org/views/design_e.php.

[4] For more information, see ABBA's "Air Barrier Materials, Components, Assemblies, and Systems" at www.airbarrier.org/materials/assemblies_e.php.

ADDITIONAL **INFORMATION**

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Jim Lambach is Industrial Marketing Manager for Bayer MaterialScience LLC. He is responsible for identifying and developing new business opportunities for polyurethanes in the Building and Construction segment. Lambach has been with Bayer 25 years. He is currently a board member for the Energy & Environmental Building Alliance. Lambach earned a Bachelors in Chemistry from University of California San Diego and a Masters in Polymer Engineering and Science from University of Tennessee Knoxville. He can be reached at james.lambach@bayer.com.

Abstract

New building code requirements focus on improving the building envelope by prescribing higher R-values, recognizing the importance of continuous insulation and the inclusion of air barrier systems. The thermal envelope, along with air and moisture movement through the building envelope, has a significant impact on the structure's performance. New building materials and construction techniques are being evaluated. Closed-cell sprayed polyurethane foam (ccSPF) is a multi-functional product that can perform as continuous insulation, an air barrier component, and waterproofing.

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