THE USE OF SPRAY POLYURETHANE IN POST-FRAME BUILDINGS: AN OVERVIEW

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Spray polyurethane foam insulation has been used in the United States since the 1970s. Although a number of challenges accompanied its early use (e.g., fire issues, moisture problems), improvements in SPF formulation have been made, and a better understanding of its use and applications now exists. This article discusses the basic characteristics of SPF insulation, addresses some of the controversial issues regarding its use and presents some post-frame building applications for SPF.

SEALANT VERSUS INSULATION

A sealant is used to seal joints, cracks or openings between wood, metal, masonry or other construction components. Types of sealants available include, but are not limited to, caulk, neoprene, silicone and foams. SPF is one of the foams used as a sealant to control air leakage, and it can also be used as building envelope insulation in exterior walls, insulated ceilings or insulated roof systems. This article focuses on the use of SPF as building envelope insulation and not on its use as a sealant.

Several resources discuss building envelope insulation from a variety of perspectives. The website www.insulationinstitute.org, developed by the North American Insulation Manufacturers Association, has technical information on insulation benefits, insulation type comparisons and basic installation information. This site can provide technical information on building envelope insulation for post-frame buildings even though post-frame buildings are not specifically discussed.

WHAT IS SPRAY POLYURETHANE FOAM INSULATION?

Spray polyurethane foam, as defined by Spray Polyurethane Foam Alliance (www.sprayfoam.org), is "a foamed plastic material formed by the reaction of an isocyanate and a polyol and employing a blowing agent to develop a cellular structure. SPF may be a two-component reactive system mixed at a spray gun or a single-component system that cures by exposure to moisture. SPF can be formulated to have physical properties (such as density, compressive strength, closed cell content and R-value) appropriate for the

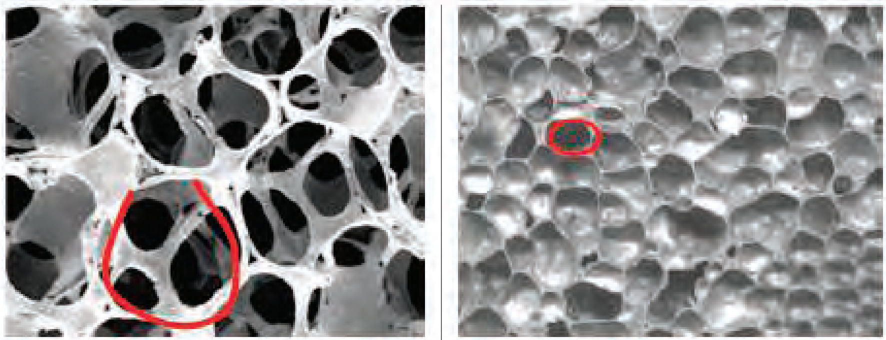

FIGURE 1. Close-up images of open-cell and closed-cell SPF insulation. Source: *SPF Builders Handbook.*

TABLE 1. CHARACTERISTICS OF SPRAY POLYURETHANE FOAM INSULATION BY CATEGORY

Open-Cell Spray Polyurethane Foam (ocSPF)	Closed-Cell Spray Polyurethane Foam (ccSPF)
Open-cell, low density	Closed-cell, medium density
Soft, flexible foam	Rigid, hard foam
Density = 0.5–0.8 pounds per cubic foot	Density = 1.8–2.3 pounds per cubic foot
Still air is the primary insulation medium (like fiberglass and cellulose).	Smaller, closed cells trap an insulating gas (a blowing agent), which has a lower thermal conductivity than still air.
R-value is typically 3.6–4.5 per inch.	R-value is 5.8–6.9 per inch.
Serves as an air barrier because, unlike fiberglass and cellulose, its fine cell structure makes it air-impermeable at certain thicknesses	Naturally works as an air barrier
Can and will absorb moisture	Is water resistant and moisture resistant
Can retain liquid water	Has been approved by FEMA as flood-resistant material
Provides no structural value	Has been demonstrated to provide structural enhancement to certain framed buildings

FEMA = Federal Emergency Management Agency.
Note: It is important to consider the properties of each foam type for each application.

application requirements." SPFA provides technical and educational resources for the spray foam industry. The basic chemical composition of two-component SPF is discussed in more detail in the publication *Insulation Facts #83: Spray Foam Insulation Industry and Federal Agencies Agree on Product Stewardship Measures* (NAIMA, 2010).

SPF exists in one of two categories of materials: open-cell spray foam and closed-cell spray foam. A close-up image of both open-cell and closed-cell SPF insulation can be found in **Figure 1**. SPF in both categories is made using almost identical chemical reactions. The major difference between the two categories concerns the blowing agent used when the foam is applied. Open-cell SPF typically uses air or carbon dioxide to create the bubbles in the foam. These bubbles generally do not remain intact during the application and curing processes, so the resulting foam resembles a sponge. In closed-cell SPF proprietary gas mixtures are typically used as the blowing agent to create the bubbles in the foam. These bubbles of gas remain intact during the application and curing processes. The bubbles, which trapped gas with more thermal resistance than air, result in the closed-cell SPF having a higher thermal resistance than open-cell SPF. The intact bubbles create the stiffness and rigidity common with closed-cell SPF compared to the soft and more pliable open-cell SPF. The inherent differences between the physical properties of installed open-cell and closed-cell SPF often determine which product category is chosen for a particular project. **Table 1** compares the two categories of SPF. Another source on the basics of SPF insulation is part of the U.S. Environmental Protection Agency's "Design for the Environment" effort, a publication titled "Information on the Various Spray Polyurethane Foam Products" (U.S. EPA, n.d.).

IS SPRAY POLYURETHANE FOAM INSULATION A GOOD OPTION FOR MY PARTICULAR APPLICATION?

When considering SPF insulation, one must realize the importance of matching a particular product with a specific application. The following sections discuss aspects of SPF insulation that should be considered when determining whether SPF can be used for a given application, and if so, which SPF insulation product will be better suited.

SPF INSULATION AND MOISTURE

The two categories of SPF insulation respond differently to moisture and water, as indicated in Table 1**.** Open-cell spray foams respond to moisture in a way very similar to the way that fiberglass and cellulose type insulations respond. If the building envelope system is not protected from moisture vapor penetration, in some applications of open-cell spray foams vapor can (or will under certain conditions) condense inside the SPF layer, resulting in water forming and soaking the SPF insulation. Because open-cell SPF will retain the liquid water, the insulation value is basically lost, and structural moisture problems can occur. Open-cell spray foams used in building envelope systems need to be designed and constructed for vapor transmission just as with fiberglass- or cellulose-type insulations. SPFA provides a detailed discussion of moisture vapor transmission within SPF insulation (SPFA, 2015a).

Closed-cell spray foams are water and moisture resistant. Closed-cell spray foams do not need to be protected from vapor transmission and do not retain water. Closed-cell spray polyurethane foams are sometimes called closed-cell plastic foams. The U.S. Federal Emergency Management Agency has recognized closed-cell SPF products as acceptable materials for use in flood damage–resistant construction. SPF insulation (closed-cell types only) is the only acceptable insulation for flood-resistant construction (U.S. FEMA, 2008).

SPF INSULATION AS AN AIR BARRIER

An air barrier controls the movement of air into and out of a building. Maybe more important, an air barrier keeps warm, moist inside air from entering post-frame structural cavities, where the moisture carried by the air can condense and result in moisture problems within those cavities. All SPF insulations can naturally serve as an air barrier. The minimum thicknesses of SPF insulation intended to serve as an air barrier are 3.5 to 5.5 inches of open-cell SPF insulation and about 1.5 inches of closed-cell SPF insulation. (See SPFA, 2015b, 2015c for more information about using SPF insulation as an air barrier.)

Spray polyurethane foam insulation has been criticized as being an ineffective air barrier because of foam shrinkage, which results in cracks and separation from other building members. These kinds of failures have been documented but normally are a result of improper installation of the SPF insulation. As with any air barrier system, attention to detail is critical during installation. More information about using SPF insulation and other materials as effective air barriers is available from the Air Barrier Association of America (www.airbarrier.org). The purpose of ABAA is to provide knowledge and education on the need for and applications and installation of air barriers in buildings.

FIRE PROTECTION ISSUES FOR SPF INSULATION

Fire protection has been and still is a controversial issue in the use of SPF insulation. The three most-discussed fire-related aspects of a material are flame spread, thermal barriers and ignition barriers. Flame spread is defined by the American Society for Testing and Materials in ASTM E-84 *Test for Surface Burning Characteristics for Building Materials.* The flame spread index of SPF has been decreased to 25 or less (Class I) using flame retardants. Check with the manufacturer for the flame spread index of a particular product.

Thermal barriers or ignition barriers are required by building codes to allow sufficient time for occupants to escape from the building during a fire. A thermal barrier protects the SPF insulation from temperature rise during a fire for a selected amount of time to allow occupants to exit a building before the SPF insulation starts burning as a result of the temperature increase. Thermal barriers must pass temperature rise tests like *ASTM E 119. Test Methods for Fire Tests of Building Construction Materials* and a fire integrity test like the National Fire Protection Association's NFPA 286, using specific acceptance criteria as defined by the International Building Code, International Residential Code, UL 1040 or FM 4880. The most commonly cited thermal barrier is half-inch gypsum wallboard. Approved equivalent materials must perform as well as or better than half-inch gypsum wallboard.

Ignition barriers are more complicated because of variations in interpretation by different entities. Also, no specific tests quantifying what makes a good ignition barrier were located. Building codes permit the use of ignition barriers in place of thermal barriers in locations like attics, where access is limited. Some potential ignition barriers include 1½-inch-thick mineral fiber insulation, ¼-inch-thick wood structural panel and corrosion-resistant steel having a minimum base metal thickness of 0.016 inch. The challenge is to find what, if any, ignition barrier will be allowed by the local code authority. (See SPFA, 2015d, for a more complete discussion of thermal barriers and ignition barriers.)

CODE COMPLIANCE AND SPF INSULATION

IBC Section 2603 and IRC Section R316 specifically address SPF while focusing on aspects of fire protection. Code compliance for SPF insulation must address three main areas: fire protection, moisture control and building energy use. Following the manufacturer's recommendations for a given SFP product is a critical first step for code compliance. A thermal barrier, such as half-inch gypsum wallboard, is required between the SPF insulation and an occupied space. For open-cell SPF, a vapor barrier will be required according to the same criteria used for fiberglass or cellulose insulation. If open-cell SPF is not protected with a vapor barrier, moisture problems occur that are similar to those occurring when a vapor barrier is not used with fiberglass or cellulose insulation. It is well recognized that SPF insulation can be used to help meet various energy efficiency codes and requirements. When properly installed at adequate minimum thicknesses, SPF insulation can provide both thermal resistance and air barrier capabilities to a building envelope assembly. A final check with local code authorities will help ensure that the proposed materials and application methods will be approved. Following manufacturer's recommendations is typically a part of code compliance.

FIGURE 2. A typical spray polyurethane foam insulation application. The worker applying SPF needs complete personal protective equipment, including an air respirator, eye protection, chemical-resistant clothing and chemical-resistant gloves.

WORKER PROTECTION ISSUES FOR SPF INSULATION INSTALLERS

The variety of chemical compounds in SPF insulation raises a number of safety concerns, and worker protection is a major concern. Many SPF insulation suppliers provide applicator safety instructions and recommendations for proper installation of their specific products. A typical scene for SPF insulation application can be seen in **Figure 2**. Workers applying SPF insulation should have the following personal protective equipment: air respirator, eye protection, chemical-resistant clothing and chemical-resistant gloves. Satisfying these requirements ensures that the person applying the SPF product has no exposed skin and has clean air to breathe. A source for more general installation or application safety is the EPA's Web page "Spray Polyurethane Foam (SPF) Insulation and How to Use It More Safely" (www.epa.gov/saferchoice/spray-polyurethane-foam-spf-insulation-and-how-use-it-more-safely). Ventilation of the application area is critical to safe SPF application (see the EPA's "Ventilation Guidance for Spray Polyurethane Foam Application" at www.epa.gov/saferchoice/ventilation-guidance-spray-polyurethane-foam-application).

Details on safe reentry after application are specific to the manufacturer and product used. The communication between the client and the contractor is a critical aspect when SPF insulation is being used (see "Contractor-Client Communications Checklist for Spray Polyurethane Foam" at www.epa.gov/saferchoice/contractor-client-communications-checklist-spray-polyurethane-foam-spf-incluyendo-la). Some products require a 24-hour period after application before anyone enters the space where SPF insulation was applied without using personal protective equipment.

STRUCTURAL INTEGRITY AND SPF INSULATION

A fair amount of information on the structural benefits of SPF insulation is available. Much of the information focuses on roofing systems using SPF insulation. The benefit of using SPF in roofing systems is the uplift resistance: SPF insulation tends to bond roofing materials together, providing more uplift resistance. Some sources mention the stiffening of stud-based structural frames that occurs when the space between studs is filled with closed-cell SPF insulation. Data reported by the National Association of Home Builders (1996) indicated that stud frames filled with closed-cell insulation had more racking resistance. The average maximum racking load for a metal stud frame at 16 inches on center with oriented strand board sheathing increased from 4,800 pounds when R-19 fiberglass insulation was used to 6,000 pounds when 3-inch-thick closed-cell SPF insulation was used. An earlier study by the

National Association of Home Builders Research Center (NAHB, 1992) found the average maximum racking load increased from 2,890 pounds for a wood stud frame at 16 inches on center with plywood sheathing to 5,300 pounds for a wood stud frame at 16 inches on center with plywood sheathing and closed-cell SPF insulation. However, none of the articles found provided data that could be used to determine a stiffness factor in post-frame building design procedures. Closed-cell SPF insulation is rigid and would naturally provide some structural stiffness. If this stiffness was known, closed-cell SPF insulation could provide another method for developing a diaphragm to be used in a post-frame building system. Data are not available providing an allowable deflection for SPF insulation incorporated into a structural system. If closed-cell SPF insulation was used as an air barrier in a post-frame building and the deflection exceeded the allowable SPF insulation deflection, this closed-cell SPF insulation could crack or pull away from building components, resulting in a failed air barrier. Closed-cell SPF insulation is therefore probably not as valuable a product for post-frame buildings unless in a location where flood-resistant construction is required. Open-cell SPF insulation is soft and flexible, so it should work very well as an air barrier in a post-frame building system.

QUALITY CONTROL AND APPLICATION PROBLEMS

Along with the safety concerns discussed above, installation of SPF insulation involves a number of technical concerns. Specific installation instructions for a given SPF product need to be obtained from the manufacturer. To ensure a high-quality application of SPF insulation, these details must be addressed: substrate preparation, application equipment, application practices (i.e., the thickness of the foam as it is applied in each layer) and weather (temperature and humidity). The substrate typically needs to be in ready-to-paint condition before SPF is applied. The equipment pressure and gun-nozzle configuration need to be correctly set for the specific product to be applied. The temperature during application typically needs to be at least 55 degrees Fahrenheit for proper installation. Check the manufacturer's literature for proper application temperature ranges. SPF should not be applied when the dew-point temperature is within 5 degrees Fahrenheit of the ambient air temperature. High humidity levels can result in the applied SPF's absorbing too much moisture during application and giving a poor final result. All conditions and preparations must be correct and the equipment properly set and operated if a good SPF insulation application is to be obtained (see Knowles, 2010, for more information, including photos of problems with SPF and probable causes of the problems).

A given application must be sampled and tested to verify a high quality. A 29-page document titled "Spray Polyurethane Foam: Guidance on Sampling Techniques for the Inspection of Installed SPF" (American Chemistry Council, 2013) provides photos of problems and good applications. The topics covered include general observations and visual surface inspection, thickness testing, sampling and qualitative examinations.

POTENTIAL IDEAS FOR SPRAY POLYURETHANE FOAM INSULATION IN POST-FRAME BUILDING SYSTEMS

This section provides a few ideas for the use of SPF insulation in post-frame building systems based on the limited technical information available. First, open-cell SPF can provide another option for building envelope insulation. Open-cell SPF has a thermal resistance similar to that of other fiberglass- or cellulose-based options. Second, open-cell SPF can be incorporated into a post-frame building envelope to provide a reliable air barrier in an exterior wall system. The open-cell SPF must be properly applied, and care must be taken by the applicator to fill all cracks and gaps in the post-frame structure. The open-cell SPF should have the necessary flexibility to remain as an intact air barrier when it is part of a wall system. The interior wall liner should have the needed fire-protection characteristics to minimize concerns about code compliance issues. Third, closed-cell spray foam insulation could provide the needed insulation in the lower portion of a wall section when flood-resistant construction is required or when the lower part of a wall is expected to be exposed to wet conditions in the proposed use. The closed-cell SPF insulation is water- and moisture-resistant, as discussed earlier. The base of an exterior wall in a post-frame building typically does not have significant deflection due to loading conditions, so cracking or breaking the relatively stiff closed-cell SPF insulation should not be a major concern. Fourth, closed-cell SPF may provide for another diaphragm option in the future. However, research will be required to determine a stiffness factor for closed-cell SPF to be used in design procedures.

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