Spray Polyurethane Foam Insulation and Passive Houses

Introduction

With insulation and air tightness being critical factors in the design and construction of Passive Houses, questions have arisen about the use of spray polyurethane foam (SPF) insulation. Spray polyurethane foam is typically a highly effective insulator and air sealant material. While installation of SPF insulation may be a leading choice for attaining current insulation levels associated with standard housing, the increased insulation thicknesses typically required to meet Passive House certification may not justify its use given its current high embodied energy, its carbon footprint and other important factors, relative to other insulation choices.

This article provides information about spray polyurethane foam insulation to assist Passive House designers to make well-informed decisions about its use. While this paper is focused on polyurethane spray-applied foam insulation, PHIUS recommends the use of any material be examined in the light of the Passive House movement's drive to reduce the overall environmental impact of buildings.

What is SPF insulation

There are two basic types of SPF insulation - open cell and closed cell. These are also referred to as "low density" and "medium density", respectively [1]. Low-density foam may also be called "half pound" SPF [2], [1].

Low density, open cell SPF has a density between 0.4 to 0.7 pounds per cubic foot when fully cured and has an open cell structure [1]. Given the open cell structure (i.e. the cells are generally connected to each other), the cells are filled with air. It is spray applied to a substrate as a liquid and expands approximately 100 - 150 times its original volume using a reactive blowing agent (typically water) to form a semi-rigid/flexible, non-structural SPF insulation. Low density SPF is permeable to moisture and may need a vapor retarder in cold climates [1].

Medium density closed cell SPF, typically refers to polyurethane foam that has a density between 1.7 to 2.3 pounds per cubic foot when fully cured [3], [1] . It is spray applied as a liquid to a substrate, using a fluorocarbon blowing agent and expands approximately 35 to 50 times its original volume to form a rigid, structural SPF insulation with a compressive strength between 15 to 25 PSI [1]. It has a closed cell structure with 90% or more of the cells closed (i.e. disconnected) and filled with the fluorocarbon gas. As such, it is resistant to water absorption and has a relatively high resistance to water vapor and air [1].

An extension of medium density SPF, high density SPF is specifically designed for exterior insulation of building roofs and has a density of 2.5 to 4 pounds per cubic foot when fully cured and is highly rigid, strong and water impermeable. This SPF is often called "three pound" SPF [1].

Open-cell foam has an R-value of approximately 4 per inch of thickness and closed-cell has an R-value of approximately 6 per inch of thickness based on available literature for various products [2], [1]. Open cell foam is less air permeable than fibrous insulation materials (fiber glass, etc.), and at certain thicknesses can act as an air barrier [1]. Closed cell foam is stiff, can provide structural strength, and seals out air and moisture.

According to the Center for the Polyurethanes Industry (CPI) of the American Chemistry Council (ACC), SPF insulation has numerous benefits [4]:

> *SPF insulation helps keep homes warm in the winter and cool in the summer. Because it is sprayed directly into the gaps, cracks and other surfaces that contribute to heat loss, it both insulates and air seals, offering one of the easiest and most effective ways of weatherizing existing homes and new construction. When installed following proper safety and handling guidelines, SPF:*

- *Helps save on energy bills.*
- *Resists heat transfer better than many other insulation materials.*
- *Because SPF insulation minimizes air infiltration, it assists in preventing moisture vapor from entering and escaping the home, which in turn reduces the load on heating and cooling systems.*
- *Reduces heating and air conditioning unit size. HVAC sizing can be reduced as much as 35% without the loss of efficiency and comfort.*
- *Reduces drafts, noise and increases comfort*
- *Is an effective air barrier.*
- *Is commonly used to prevent drafts from windows, doors, attics and floor boards creating a more comfortable indoor environment.*
- *Helps minimize air-borne sound transmission.*
- *Impedes entry of insects and pests. Sealing gaps with SPF from the outside provides a barrier against insects and other pests.*
- *Minimizes air infiltration that can generate condensation and result in mold growth.*
- *Resists settling due to its general stability. Typically not subjected to structural deterioration/decomposition.*

The Spray Polyurethane Foam Alliance (SPFA) lists the following additional benefits and provides a number of successful case studies on its website [5]. SPF:

- *Is environmentally friendly, contains no formaldehyde and reduces the use of fossil fuels, thereby reducing global warming gases.*
- *Contributes little to the waste stream.*
- *A single product that can take the place of three-four other products, including insulation, air barriers, sealants, vapor retarders, and weather barriers.*
- *Reduces convective currents in walls and attics.*
- *Eliminates wind washing.*
- *Effective at low and high temperatures.*
- *Closed cell SPF adds structural strength and glues a building together, thereby making it more resistant to racking events, such as hurricanes and high winds.*
- *Helps maintain a comfortable, constant, temperature throughout the building, from room to room and floor to floor.*
- *Contributes LEED credits for sustainable, green construction.*
- *Can help reduce structural damage caused by high winds.*
- *Contains no formaldehyde or ozone depleting substances.*

SPF insulation, both open and closed cell, when applied in large quantities (high pressure applications) such as for insulating a building, is done by using an onsite chemical mixing and application process using two liquid compounds to create the polyurethane foam material. Specialized equipment is used to heat and pressurize the ingredients and pump them through hoses to the installation point within a structure where the two components are mixed together, then sprayed onto the surface of the structure, be it a wall cavity, between attic rafters, on rim joists, etc. where the insulation is intended. The foam mixture is very adhesive, causing it to adhere to surfaces it comes in contact with. As the foam components react, the material expands to fill cracks, crevices and other openings giving it its air sealing characteristics. The exothermic chemical reaction releases heat.

In smaller quantities (low pressure applications), such as for sealing small cracks, or for sealing around newly installed windows, SPF insulation comes pre-mixed in small aerosol cans with low pressure propellants added. By pressing the valve on the can, the blended ingredients are released, expand and form the foam within seconds.

Long term thermal resistance for cellular plastic insulations*

This issue actually pertains not just to closed-cell spray foam but to other cellular plastic insulation as well. There is good news and bad news.

The good news is that the reporting of R-values is subject to Federal regulation. It has been since 1979, as we can read in volume 44 of the U.S. Federal Register, page 50219 (more compactly referred to as [44 FR 50219].) The rules were most recently reviewed in "Labeling and Advertising of Home Insulation: Trade Regulation Rule" a Rule by the Federal Trade Commission on 5/31/2005. [70 FR 31258-31276] This ruling amends and explicates the relevant section of the actual Code of Federal Regulations, which is Title 16, part 460 (more compactly referred to as [16 CFR 460] [6],[7].

According to the 2005 Ruling (emphasis added) [70 FR 31275]:

> *§ 460.8 R-value tolerances.*
>
> *If you are a manufacturer of home insulation, no individual specimen of the insulation you sell can have an R-value more than 10% below the R-value shown in a label, fact sheet, ad, or other promotional material for that insulation.* ***If you are not a manufacturer, you can rely on the R-value data given to you by the manufacturer, unless you know or should know that the data is false or not based on the proper tests.***

However, the ruling also explains [70 FR 31262]:

> *"Certain types of cellular plastics insulations (polyurethane, polyisocyanurate, and extruded polystyrene boardstock insulations) are manufactured in a process that results in a gas other than normal air being incorporated into voids in the products [encapsulated in the closed cells]. This gas gives the product an initial*

* In this section we quote a number of passages from the U.S. Federal Register and the U.S. Code of Federal Regulations, and use the style of references native to those documents for their own cross-referencing.

R-value that is higher than it would have if the product contained normal air. The aging process causes the R-value of these insulations to decrease over time as the gas is replaced by normal air through diffusion. The length of this process depends on whether the product is faced or unfaced, the permeability of the facing, the thickness of the product, and other factors."

Even so, it is reassuring to read [70 FR 31262]:

"The current Rule addresses this aging process by requiring that R-value tests be performed on specimens that 'fully reflect the effect of aging on the product's R-value.' "

The bad news is that there is disagreement as to which type of long-term thermal resistance testing should be utilized [70 FR 31263]:

"The comments on aging tests for cellular plastic insulations reveal continued divisions among industry members. Some commenters urged the Commission to incorporate the newer slicing and scaling tests (i.e., ASTM C 1303-00 or Can/ULC-S 770), while others urged the Commission not to do so because of concerns with the adequacy and scope of the new procedures."

Also, looking at the original 1979 regulatory language, one can conclude the goal was to provide information for consumers to make valid comparisons, not necessarily to provide valid data for quantitative energy modeling (then in its early days). Quoting again from the Federal Register [44 FR 50225], with **emphasis added**.

"While §460.2 specifies which products are covered under the Rule, §460.4 indicates when the Rule appliesThe Rule must be followed whenever a covered person imports. manufactures, distributes, sells, installs, promotes, or labels home insulation. The Rule also applies to the supplying of written information forand the preparation and use of, home insulation labels, fact sheets, ads, and other promotional materials ***for consumer use****. The relevant limitation here is that the written materials must be "for consumer use."* ***The Commission recognizes that insulation manufacturers often prepare detailed, technical data for building industry professionals, such as architects These professionals should already be sufficiently informed concerning insulation performance characteristics, and manufacturers may wish to provide them with information that differs from that required under the Rule.*** *The Commission has therefore concluded that its Rule should not apply to such materials."*

As we read farther we find the following, again **emphasis added** [44 FR 50227-50228]:

"c. Aging of cellular plastics insulations. As discussed in Section I.C.3 of this statement, a chemical aging process peculiar to certain cellular plastic materials causes their R-value to decrease over a period of time after manufacture. This aging process affects polyurethane. polyisocyanurate, and extruded polystyrene insulations. ***It lasts a variable length of time, sometimes as long as several years. and can have a significant adverse impact on the R- values of these products****. As a consequence, failure to account for this aging effect in the testing of these products results in R-value claims that are inflated and misleading to consumers.*

With ASTM C1303 being questioned [70 FR 31263], the two mainstay test procedures remain in place. The first is from an old General Services Administration purchase specification for rigid board insulation, from 1971.

Quoting again from the 2005 FTC ruling [7]:

Section 460.5(a)(1) of the Rule allows the use of the "accelerated aging" procedure in paragraph 4.6.4 of GSA Purchase Specification HH-I-530A (which was in effect at the time the Commission promulgated the Rule) as a *permissible "safe harbor" procedure, but also allows manufacturers to use "another reliable procedure." (See 44 FR at 50227-50228). The "accelerated" procedure was designed to age these insulations in a shorter period than they would age under normal usage conditions.* [70 FR 31262]

Footnote 21. The Commission understands that GSA Specification HH-I-530A may have limited availability. The R-value Rule, however, only references one paragraph which states: "4.6.4 Thermal conductivity. The thermal conductivity of insulation board shall be determined by the guarded hot plate method described in ASTM C 177 or by the heat flow method described in ASTM C 518. Tests shall be conducted on a 1-inch thick product at a mean temperature of 75 degrees F (23.8 degrees C) after 30 days and 90 days of conditioning at 140 degrees F (60 degrees C) dry heat."

This is the "accelerated aging test". There is another. Again emphasis added:

GSA amended its specification in 1982 to allow the use of an optional aging procedure (in addition to the "accelerated" method) under which test specimens are aged for six months ("180 days") at 73 °F ± 4 °F and 50% ± 5% relative humidity (with air circulation to expose all surfaces to the surrounding environmental conditions). ***The staff cautioned, however, that manufacturers of insulations faced with materials that significantly retard aging may need to age test specimens for a longer period of time, and that the staff would consider whether the alternative procedure was acceptable for specific products on a case-by-case basis.***

We expect that often, the information from these regulated tests will be the best information available.

How much difference would ASTM C1303 make? We don't know in general but here is a specific example: Demilec Heatlok Soya. (not the 200 or the 500.) According to this data sheet it is R 6.6 aged by the old method and R 6 by CAN/ULC s770. [8]

We assume that most Passive House projects would have design lives of 70 years or more. Over such time frames, would all the special blowing agent gas diffuse away, and the increased R-value with it? For an order of magnitude estimate we could use the diffusion coefficient D measured by Schwartz et al of about 6e-11 m^2/s for gas diffusion in rigid cellular plastics [9] and the basic formula for mean square displacement distance x^2 by diffusion in one dimension over time t.

$$x^2 = 2Dt \quad (1)$$

For t=70 years or 2.2 billion seconds, x=0.5 meters. This is greater than the typical SPF insulation thickness suggesting much of the gas would escape. Alternatively we could estimate characteristic diffusion times for typical applied thicknesses of spray foam. That works out to 1.5 years for 3 inches, 4.2 years for 5 inches, and 8.3 years for 7 inches.

Given the foregoing we have some doubt about the aging tests. Nevertheless, for the time being:

Aged R-values determined in accordance with the 2005 U.S. Federal Trade Commission Rule on Labeling and Advertising of Home Insulation [70 FR 31258-31276], and CAN/ULC S770 are acceptable to PHIUS for energy modeling for project certification in the USA and Canada respectively, if the manufacturer can document that the aging test was performed by a qualified

3rd party. If such documentation is not available, use the typical values found in the 2009 ASHRAE Handbook of Fundamentals, Chapter 26, Table 4 [10].

Almost all SPF insulations have evaluation service reports from independent product evaluation organizations (ICC-ES, IAPMO) that evaluate thermal data from independent laboratories performed to ASTM standards.

Another phenomenon to be aware of is that typically the R per inch does decrease with thickness. [16 CFR 460.20]

> *§ 460.20 R-value per inch claims.*
>
> *In labels, fact sheets, ads, or other promotional materials, do not give the R-value for one inch or the "R-value per inch" of your product. There are two exceptions:*
>
> *(a) If an outstanding FTC Cease and Desist Order applies to you but differs from the rules given here, you can petition to amend the order.*
>
> *(b) You can do this if actual test results prove that the R-values per inch of your product does not drop as it gets thicker.*
>
> *You can list a range of R-value per inch. If you do, you must say exactly how much the R-value drops with greater thickness. You must also add this statement: "The R-value per inch of this insulation varies with thickness. The thicker the insulation, the lower the R-value per inch."*
>
> *[44 FR 50242, Aug. 27, 1979, as amended at 70 FR 31276, May 31, 2005]*

Nisson & Dutt explain [11]:

> *"Evidently the first inch of two of a fibrous insulation is the most effective because it absorbs or scatters most of the infrared radiation. Successive inches of insulation absorb less radiation and therefore have lower effective R-values per inch."*

Based on available data, it appears other kinds of insulations are also subject to this phenomenon. For example, the ICC Evaluation Service Report for Heatlok Soy 200 shows an R-value of 7.4 at one inch thickness, but only 26.6 at four inches thickness, that is, 6.6 per inch [12]. Under ICC's test protocol AC377, samples are tested at both one inch thickness and at 3.5 inch thickness, and interpolated and extrapolated to other thicknesses [13].

Passive House consultants should therefore take care to calculate appropriate R/inch values for the specific assemblies they are modeling.

PHIUS certification of projects using SPF

PHIUS will certify projects using SPF, but will be developing a protocol for limiting its use. It is in PHIUS' mission to "promote the Passive House Building Energy Standard, … which has been established based on global carbon reduction needed to avert the climate crisis…" In light of this mission, the current high global warming potential of closed-cell foam blowing agents is a matter of particular concern. This concern extends also to extruded polystyrene rigid insulation [3].

The framework for that protocol will be the global warming impact metric implemented in the calculator developed by Building Science Corp and Right Environments [14]. As such, as the GWP of SPF or other cellular plastic insulations decreases over time with new materials and procedures, the viability to use these products in Passive House projects may increase.

According to the introductory notes for v1.2 of the calculator [14]:

> "This tool calculates total global warming potential (GWP) of various insulation materials. Total impact is defined as the embodied GWP of the insulation plus GWP of heating energy demand. It does not consider other important environmental impacts, such as resource depletion, habitat loss, toxicity, eutrophication, acidification, etc; nor does it consider other financial costs."

Our preliminary assessment of the formulas used is that they are reasonable and appropriate to our purpose, except that only the heating season is considered. We believe an additional term should be added to the impact equation to account for the benefit of insulation during the cooling season as well.

As a first step, effective immediately, for projects seeking certification, which propose to use spray polyurethane foam or extruded polystyrene, PHIUS will require disclosure of the blowing agent. If it is HFC-134a, -152a, -245fa, or -365mfc, we encourage submitters to proactively investigate the impact and share this information with PHIUS to help us quantify effects. Again, at this time we are establishing the framework for evaluating the impact, but not yet setting precise criteria or limits.

The super-insulated context – assemblies with massively thick insulation layers

The impact calculations mentioned above typically produce a U-shaped curve of impact versus insulation thickness: when the insulation is thin the impact is high because the assembly allows more energy to migrate across it over its life. From a thin starting point it is easy to bring the impact down by adding insulation. But as the thickness is steadily increased, the embodied GWP impact also steadily increases, while the energy savings show diminishing returns. Beyond some thickness the life impact stops decreasing and starts going up again. Using current published values an 8-inch staggered-stud wall in a cold climate, insulated with SPF only, would be beyond the minimum-impact thickness (See Figure 1 below).

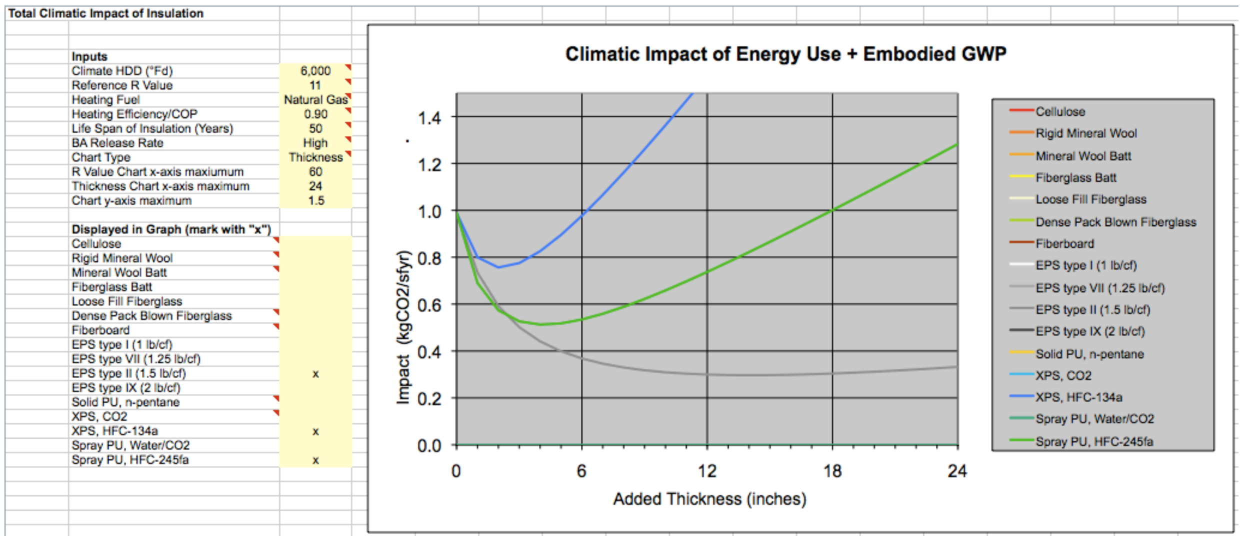

Figure 1. Total Climate Impact of Insulation, example calculation for XPS, SPF, EPS.

Flash-and-batt applications

'Flash-and-Batt' is the process of installing a thin layer of spray foam insulation followed by a relatively thick layer of semi-rigid or blown fibrous insulation. The main driver to this approach is typically reduced capital cost at the installation stage. Flash-and-batt is a value-engineering response – the idea being to use a minimum amount of SPF to gain the air-sealing benefit, and lower-cost insulation to provide most of the thermal resistance. This technique can introduce significant problems within a super-insulated wall assembly. Some examples of problems with this approach are, but not limited to:

(i) creation of a vapor retarder on the 'cold' side of the insulation (this problem becomes more prevalent when moving towards a heating-dominated (i.e. cold) climate).

(ii) dimensional instability leading to bulk air leakage routes. Thin layers of spray foam may have less adhesive capability to resist differential movement between structural elements (e.g. wood studs or sheet materials) and the foam itself As a result, the air barrier can become compromised. Further, bulk movement of warm, moist air may result in significant levels of interstitial condensation within the wall.

Achieving the .6 ACH50 necessary for Passive House Certification

One of the Passive House design principles is that there is one defined and carefully detailed air barrier layer throughout the building enclosure. Theoretically, any air barrier product/material has the ability to meet the required 0.6 ACH50 criteria. PHIUS' opinion is that the most important aspect of achieving the Passive House required air-tightness lies in the project-specific detailing and the project-specific installation practice. Another key issue for any air barrier system is the long term performance. The long term performance of SPF as an air barrier has not been well documented. Research of this nature is necessary to quantify SPF's performance for long term use. To this day, we are not aware of any certified Passive House projects relying solely on SPF as the air barrier system.

Retrofit applications

Not only does the information described above change between new and retrofit applications, the above information changes between each and every project. In terms of global warming impact, the calculator mentioned above embodies an assembly-centered view (wall, roof, or floor) as opposed to whole-project. Nevertheless it should be possible to include the impact of spray-foamed “edges” and “spots” in addition to “areas”, within the same framework.

How SPF is made

In order to create SPF insulation in large quantities under high pressure, a chemical reaction of the two component parts, commonly referred to as "Side A" and "Side B", has to occur. In commercial SPF systems, the A and B sides are mixed in a 1:1 volumetric ratio [1]. In large-scale applications, these two components are typically stored separately in 55 gallon drums.

Side A contains chemicals known as isocyanates. Side B primarily contains a polyol, which reacts with isocyanates to make urethane. The most common isocyanate compound used in SPF is methylene diphenyl diisocyanates (MDI) [2].

Side B is a proprietary blend of chemicals in addition to the polyol that allow formulators to tailor the performance properties of the final polyurethane. Other materials contained in Side B normally include [2]:

- Blowing agents
- Flame retardants
- Amine or metal catalysts
- Surfactants

Since Side B is a proprietary blend of chemicals, the identity of some of these chemicals is not known, nor are the proportions, except to the manufacturers and formulators. The best available information indicates that the flame retardant most commonly used in spray polyurethane foam insulation is TCPP (Tris (1-chloro-2-propyl) phosphate) (1). TCPP is combined with a reactive brominated compound to form a polymeric brominated flame retardant [1]. TDCPP (Tris (1,3-dichloro-2-propyl) phosphate) is also used as a flame retardant.

In small applications, when pressurized 16 oz. cans are used, the SPF components are pre-mixed in controlled amounts along with a propellant. However, some "do-it-yourselfer" supplies now come in the separate two part formulations, typically in 5lb, 10lb, 40lb, or greater, low pressure cylinders.

SPFs made with soy or other natural or bio-based ingredients

SPF is made primarily from petroleum derived chemicals. Some SPF may be advertised as being “green”, "natural" or, "environmentally friendly", due to having been partially made from natural ingredients, such as soy bean oil, castor oil, and other bio-based oils, etc. However, these oils may only be a low percentage of the Side B mixture and still be advertised as green or natural [15]. Current technology limits the use of natural oil polyols to about 1/3 of the total polyols, as excessive use of natural oils can affect the dimensional stability of SPF [1]. Typically, the balance of the polyol used in Side B is still petroleum derived, as are the isocyanates in Side A - 50% of the total mixture.

Recently, the U.S. Department of Agriculture (USDA) proposed new regulations requiring at least 51% of the total product formulation be from natural ingredients in order for a product to be called bio-based [16]. If finalized, this new regulation would prevent SPF from being labeled "bio-based".

Human health/indoor air quality concerns with SPF

There can be health risks from exposure to isocyanates and some of the other ingredients, used to manufacture SPF insulation [4], [2], [5]. The primary health risks are from exposure during the installation stage while the foam insulation is being sprayed [4], [2], [5]. Health risks are of most concern for spray foam workers, and possibly other workers in the spraying area, especially if they are not properly protected [4], [2], [5].

However, homeowners or building occupants may also be at risk if certain precautions are not taken [4], [2], [5]. More recently, there have been reports from homeowners of incorrect installations of spray foam that have triggered health problems and indoor odor issues [17], [18]. Researchers and manufacturers are looking into these incidents as well as currently investigating any long-term health effects associated with the product [1].

Isocyanates, the primary ingredient in SPF, are well known inhalation and dermal "sensitizers" that can trigger a severe or fatal asthma attack in some people who become sensitized, even at very low levels [2]. A sensitizing chemical is one that after multiple repeat exposures, may cause the human body to react in an abnormal or over-reactive way, even to extremely low doses, when initial exposures may not have had an impact. The more the body is exposed to the chemical the more it has a negative reaction to it. In some cases, certain individuals can quickly become sensitized to these types of chemicals such that there are no safe levels of exposure [2], [19].

Isocyanates are the leading attributable cause of work-place related asthma [2], [19]. SPF insulation also contains potentially hazardous amine catalysts, blowing agents, flame retardants and other constituents [2].

With the widespread and increasing use of SPF insulation, unnecessary exposure for SPF applicators and other trade workers or other building occupants (e.g., homeowners, children, office workers, etc.) may occur if proper precautions are not taken during the spray applications and shortly after.

While applying SFP, aerosols and vapors are generated that can be inhaled or come in contact with the eyes or skin. Potential sensitization may occur through exposures on the skin as well as through inhalation [2]. Individuals, in particular installers of SPF as well as homeowners, with a history of skin conditions, respiratory allergies, asthma, or prior isocyanate sensitization should carefully review product information when considering the use of SPF products and may want to consider other insulation alternatives. This especially applies to high pressure applications but also to low pressure applications. With low pressure applications, which mechanically mix the A and B side chemicals inside a nozzle, instead of impingement mixing of aerosolized chemicals in high-pressure foams, the amount of vapors and aerosols tends to be lower, but they are still generated during installation [1].

Manufacturers who have prepared complete and accurate SPF Material Safety Data Sheets (MSDS) typically recommend in the MSDS that individuals undergo medical surveillance prior to working with these materials, and individuals with a history of medical conditions such as asthma, be restricted from working with isocyanates [20].

The following were noted in the 2006 National Institutes of Occupational Safety and Health (NIOSH) Alert -- *Preventing Asthma and Death from MDI Exposure during Truck Bed Liner and Related Applications* [19]. NIOSH issued this, and a 1996 Alert, in follow up to worker deaths after exposure to isocyanate containing polyurethane automobile paint and exposure to isocyanates in polyurethane foam manufacturing. NIOSH concluded that the potential for exposure to isocyanates from spraying polyurethane foam insulation is very similar to these prior incidents [19].

- *"Isocyanates have been reported to be the leading attributable chemical cause of work-related asthma,.*
- *Exposure to isocyanates can cause contact dermatitis, skin and respiratory tract irritation, sensitization, and asthma.*
- *Both skin and inhalation exposures can lead to respiratory responses.*
- *Isocyanates can cause "sensitization," which means that some people may become allergic to isocyanates and could experience allergic reactions including: itching and watery eyes, skin rashes, asthma, and other breathing difficulties. Symptoms may also be delayed up to several hours after exposure. If you are allergic or become sensitized, even low concentrations of isocyanates can trigger a severe asthma attack or other lung effects, or a potentially fatal reaction.*
- *Some workers who become sensitized to isocyanates are subject to severe asthma attacks if they are exposed again. Death from severe asthma in some sensitized persons has been reported.*
- *Sensitization may result from either a single exposure to a relatively high concentration or repeated exposures to lower concentrations over time.*
- *Even if you do not become sensitized to isocyanates, they may still irritate your skin and lungs, and many years of exposure can lead to permanent lung damage and respiratory problems.*
- *All skin contact should be avoided since contact with skin may lead to respiratory sensitization or cause other allergic reactions.*
- *Appropriate Personal Protective Equipment (PPE) should be used during all activities that may present exposure to any isocyanate compounds to avoid sensitization."*

As mentioned above, Side B contains a blend of proprietary chemicals that provide unique properties to the foam, and may vary from manufacturer to manufacturer. Given this, it is difficult to precisely identify all potential health effects of the Side B components, but the following is reported [2].

- Catalysts may be amine or metal catalysts. Amine catalysts in SPF can be sensitizers and irritants that can cause blurry vision (halo-effect) [21], [22].
- Flame retardants, such as halogenated compounds, can be persistent, bioaccumulative, and/or toxic chemicals (PBTs). Some examples include:
    - TCPP -(Tris (1-chloro-2-propyl) phosphate)

- TEP -(Triethyl phosphate)
- TDCPP (Tris (1,3-dichloro-2-propyl) phosphate)

- Blowing agents may have adverse health effects, as well as be green house gases.
- Some surfactants may be linked to endocrine disruption [2].

Recently, the State of California released a study indicating that TDCPP has a carcinogenic effect in laboratory test rats [23].

Potential for exposure to these chemicals

Exposures to SPF chemicals may occur through a variety of ways depending on whether it is the SPF applicator(s) and other workers, or the owner or resident of a building that is being SPF insulated.

When SPF installation is ongoing, the work site should be restricted to only trained persons wearing appropriate Personal Protective Equipment (PPE) [4], [2], [5]. NIOSH (and the industry represented by CPI and SPFA) recommend that PPE for SPF workers include [4], [19]:

- Full-face supplied-air respirator (with a pump/filter/hose supplying fresh air).
- Face mask, with a peel-off shield for clear visibility as foam aerosols will coat the mask after a duration of spraying.
- Full body suit and chemical-resistant gloves and boots.
- All exposed skin must be fully covered.
- A ventilation system to ventilate the work area, during and after spraying.
- NIOSH also recommends a containment structure or enclosure for the area where spraying is occurring.

During spraying, vapors and aerosols of isocyanates and the other components are generated. Research data indicate that inhalation exposures without PPE to isocyanates during SPF installation will typically exceed OSHA occupational exposure limits (OELs) [19]. In addition, vapors and aerosols can migrate through a building if the spray area is not isolated and properly ventilated. After application, vapors may linger in a building until properly ventilated. This supports current practice to vacate the premises during installation and for a specified period of time following installation.

Cutting or trimming the foam after it hardens may generate dust and particles that contain unreacted isocyanates and other chemicals [2]. After application, foam dust may linger in a building until properly ventilated and thoroughly vacuumed.

Unprotected (without PPE) homeowners or residents should not be present when a high pressure foam application is ongoing in the house. A homeowner or resident could also be exposed to isocyanates and the other chemicals if they re-enter the structure too soon after application [2], [24], [25].

Another important factor relating to the potential exposure to isocyanates and the other components is the time it takes for the SPF to cure. Curing of SPF means that the chemicals in the product are reacting to produce polyurethane foam. SPF may appear hardened or "tack-free" within a range of a few seconds to a few minutes after application. However, at this stage, the foam is still curing and still contains unreacted SPF chemicals and may still be off-gassing these chemicals [2].

Some estimates indicate that it can take approximately 24-72 hours after application for the foam to fully cure for the two-component high pressure "professional" SPF systems, and approximately 8 to 24 hours to cure for one component foam available in the small cans, but more research is needed to account for the potential variability of curing rates. [4], [2], [5]

The curing time may vary depending on the type of SPF product (open or closed cell), product formulation, applicator technique, foam thickness, temperature, humidity and other factors, which will impact re-occupancy time. Temperature and humidity play a critical role in the curing of SPF ingredients as does proper installation (applicator training, technique and maintenance and quality of the equipment that is used). More research is needed to understand the role these variables play in future potential off-gassing.

A homeowner who is erroneously advised they can stay in a house without PPE while the SPF is being installed, can be exposed to unhealthful levels of the spray foam chemicals. Or, if they return to the house too soon after spraying, may also be exposed to high levels. Likewise, if something went wrong during the installation and the foam has yet to cure, or never does fully cure, then exposures can also occur when the home is re-occupied.

The US EPA states, if home or building occupants have concerns that they may be exposed to residual SPF chemicals, potential off-gassing, or continue to smell odors, they should contact their SPF contractor to ensure proper procedures and clean-up were followed [2]. If their concerns are not resolved, affected parties should contact their local or state consumer protection office or contractors' licensing board. Consumers can also file an online Consumer Product Incident Report with the U.S. Consumer Product Safety Commission on the SaferProducts.gov website [2].

Additional pathways of exposure to SPF chemicals for homeowners and residents, as well as workers, after the foam insulation is installed may include heat-generating processes such as drilling, welding, soldering, grinding, sawing, or sanding on or near SPF insulation [2]. This may generate a range of airborne degradation chemicals including isocyanates, amines, carbon dioxide, carbon monoxide, hydrogen cyanide, or nitrogen oxides [2]. These potential releases raise possible concerns for future renovations, alterations and even demolition.

Fires involving SPF may release isocyanates, hydrogen cyanide, amines, and other highly toxic chemicals into the air. Fire departments have issued advisories and require the use of full supplied air respirators for firefighters when fighting fires with burning polyurethane foam insulation [2].

Reported problems with the use of SPF

Since 2009, homeowners or others have been reporting spray polyurethane foam insulation problems to the Consumer Product Safety Commission (CPSC) [17]. A review of the reporting at the time this article was written, reveals there have been at least six cases reported to

CPSC where homeowners have become sick after installation of SPF insulation in their homes [17].

A recent paper in the Journal of Occupational and Environmental Medicine reported the first documented case of SPF isocyanate-induced asthma in two otherwise healthy homeowners who were allowed to return to their home too soon after the attic was spray foamed [25].

There are also numerous other reports of spray foam off-gassing causing health problems on consumer-sponsored spray foam websites and in green building blogs [26], [18], [27]. Health effects such as headaches, chest pains, eye, and throat irritation, rashes and coughs and asthma-like symptoms are reported.

Lingering, irritating odors that smell sweet, fishy with a chemical-like or ammonia-like aroma that won't dissipate, even with extended ventilation, have been complaints in a number of these cases. The SPF industry attributes lingering odors to the amine catalysts [1].

In some cases, homeowners or residents who reported having no respiratory problems or symptoms prior to the foam installation, reported they began experiencing burning throats, irritated eyes, difficulty breathing and other various symptoms immediately after, or within a day or two after, foam installation when they re-entered their house. In some cases, the homeowners or residents indicated they experienced a relief of the symptoms after they spent time away from their homes. Some homeowners reported having to move out of their homes because of the concern for their health. In a growing number of cases, homeowners report having the spray foam insulation completely removed from their homes in an attempt to remediate the situation and to be able to return to their house [18], [27].

The cause of these incidents is unclear. Although more evidence needs to be gathered to determine patterns and commonalities between the cases, the most likely cause of problems with the SPF insulation is an incorrect installation since industry representatives have data to show that when SPF insulation is properly formed and it has fully cured, there is no residual off-gassing of any of the chemical components. In some instances of improper installation, the SPF manufacturer has, or is initiating, the removal of installed SPF insulation as a way to remediate the odors and health concerns of homeowners.

As discussed above, numerous variables can affect whether high pressure SPF insulation installation is done correctly, and most of these variables are controlled by the SPF installation contractors on-site at the time of application.

It is important to note installing SPF insulation in a house or building is an on-site chemical manufacturing process in a location that will be occupied shortly thereafter (by workers or owners), and continuously for years on end. If anything goes wrong during the process the effects are experienced on-site, rather than at a factory as with other insulations. There has been discussion on a green building website that with an incorrect SPF installation, the chemical ingredients of the foam can even be absorbed by the building materials with which it comes into contact [18].

The most likely variable that is leading to these incidents is human error. Human errors in knowledge and performance, which can lead to incorrect mixtures of the chemical components, incorrect temperatures and pressures during the spraying, poorly maintained spray equipment, or spraying when ambient temperatures or building substrates are too cold, or humidity is too high for a proper chemical reaction and proper curing.

One error that has been reported is applying too thick of a layer of SPF in one pass. The proper procedure for applying closed cell foam insulation is to spray 2 inch (maximum thickness) layers, allow time to cure, and then applying additional 2 inch (maximum thickness) layers if more insulation has been specified. In one reported case an entire 6-8 inch layer of closed cell foam was applied at once by the applicator who did not follow the recommended application procedures provided by the SPF manufacturer.

In addition, there have been reports of house fires spontaneously starting after the installation of SPF due to excessive heat build-up from the exothermic reaction of the foam [28].

Environmental impact of SPF blowing agents

SPF insulation is made using two types of blowing agents: reactive and physical [1]. Water is the reactive blowing agent and is used primarily to make open cell SPF. Physical blowing agents, or fluorocarbon gases, are used to make closed cell SPF [1].

When water is the blowing agent, the water reacts with the MDI to create CO2 gas that expands the foam. With closed cell SPF, the fluorocarbon gases are contained as a B-side ingredient which when combined with the A-side (MDI), creates an exothermic reaction [1]. This exothermic reaction converts the blowing agent into a gas which forms the cells. The fluorocarbon gas is retained within the foam cells, giving the SPF increased thermal resistance [1].

History

In the past, the blowing agents used for closed cell SPF were typically ozone depleting substances (ODSs). The old ODS blowing agent family of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) consisted of CFC-11, CFC-12, CFC-114, HCFC-22, HCFC-141b, and HCFC-142b. CFCs and HCFCs are not only ODSs, but also have very high global warming potential (GWP) values, thousands of times greater than CO2 [29], [3].

While CFCs are now banned, manufacturers had to eliminate their use of HCFC-141b, a common SPF blowing agent, by January 1, 2003. Manufacturers of closed-cell (high-density) spray polyurethane were given an extension for the transition to non-ozone-depleting blowing agents. HCFC-141b for spray polyurethane was not sold after December 31, 2004, though polyurethane installers were allowed to use inventoried HCFC-based chemicals until July 1, 2005 [29], [3].

Although HCFC-22 and HCFC-141b did have lower ozone depleting values than the CFCs, both still had ozone depleting characteristics and high global warming potentials with GWP values of 1810 and 600, respectively (that is 1810 and 600 times that of CO2). Given this, both were phased out in 2008 and 2003, respectively [29], [3].

Current

More recently spray polyurethane foam insulation companies have been using third generation blowing agents -- liquid hydrofluorocarbons, including HFC-134a (1,1,1,2-tetrafluoroethane), HFC-245fa (1,1,1,3,3,-pentafluoropropane) and HFC-365mfc (1,1,1,3,3-pentafluorobutane). While significantly more expensive than HCFC-141b and the earlier blowing agents, the resultant foam achieves similar energy performance. The ozone depletion potential of HFC-245fa is zero, but the global warming potential of HFC-134a is still 1300 and that of HFC-245fa is 950 [29], [3].

Future

Since blowing agents currently in use have global warming potential, manufacturers of blowing agents are now working on fourth-generation blowing agents which include both liquid and gas versions [1],[3]. These are being designed to have no ozone depleting value and less than a 15 GWP. Two examples include the hydrofluoroolefins (HFOs) HFO-1234yf and HFO-1233zd. Both have a GWP of 7 [3].

Some open-cell polyurethane foams are produced with water as the blowing agent thereby having no global warming potential from the blowing agent per se. A possible alternative- hydrocarbon blowing agents - are avoided with spray polyurethane foam because of flammability concerns.

Life Cycle Assessment (LCA) considerations of SPF

Taking into account the life cycle assessment (LCA) of a building product is useful for making decisions about its use. A life cycle assessment analyzes a product's environmental impact throughout its 'cradle-to-grave' life span. This involves a holistic look at the 'big picture'— the energy consumed, the raw materials used, and the extent of environmental impact at various stages of a product's manufacture, use, and end-of-life [30]. Considerations that factor into a life cycle assessment of SPF could include the following.

- Insulates well and will save energy - long term energy savings will need to be calculated on a case-by-case basis.
- Made primarily from petrochemicals.
- Uses blowing agents with global warming potential.
- Needs flame retardants to suppress combustibility.
- Given its high adhesion characteristics, SPF would be difficult to remove from walls, rafters or other spaces in any sizable portions that could be re-used when renovating or demolishing a structure and might also render the attached wood unfit for reuse.
- Demolition could also release particles.
- Recycled foam could possibly be used as a packing material.
- SPF does not biodegrade rapidly. (It does weather and photo-degrade, but that is more likely to happen in service than in a landfill.)
- Expended drums, tanks and other containers for the raw SPF ingredients need to be disposed and not re-used according to Material Safety Data Sheets.
- Wastes must be tested using methods described in 40 CFR Part 261 to determine if they are hazardous.
- Disposal of surplus and non-recyclable products must be via a licensed waste disposal

contractor if deemed hazardous.

- SPF chemicals must not be allowed to runoff, to contact soil or enter waterways, drains and sewers.
- Energy is consumed to manufacture SPF raw materials, and how much energy is required to transport and install SPF into structures.
- What and how many types of pollutants (air and water) are generated during SPF raw materials manufacturing.
- Installation consumes disposable materials and equipment including personal protective equipment. Health implications:
    - o Cutting, sawing and sanding may release particles that could be inhaled.
    - o Incidental burning, such as when soldering water pipes, could release isocyanate fumes.
    - o Home renovations that disturb the foam would need to control dust and particle releases.

Clearly, it could take a lot of work to do a full life cycle assessment. Even so, appeals to take such a holistic view have an undeniable logic. For a comparative listing of some of these life cycle assessment factors for SPF, relative to other insulation materials, see the article entitled; *Green Chemistry* prepared by the Green Policy Institute [31].

Federal agencies and SPF

In 2009, the U.S. EPA in cooperation with the Consumer Products Safety Commission (CPSC), the National Institutes of Occupational Health and Safety (NIOSH) and the Occupational Safety and Health Administration (OSHA), formed the Federal Inter-Agency Workgroup on spray polyurethane foam insulation. During 2009 to 2010, the Federal Inter-Agency Workgroup worked extensively with CPI and SPFA to improve the dissemination of health and safety information to SPF workers and consumers. Since that time, EPA also established a website providing health and safety information on SPF, and the CPSC encouraged reporting of SPF insulation problems.

Also in 2009, at the request of the Federal Workgroup, both CPI and the SPFA initiated a spray foam stewardship program, developing training materials on health and safety for spray foam workers, and general health and other information for consumers [32].

On April 13, 2011, EPA released a Chemical Action Plan to address the potential health risks of methylene diphenyl diisocyanate (MDI) and related compounds, which are used in SPF insulation. The plan identifies a range of actions the Agency is considering under the authority of the Toxic Substances Control Act (TSCA).

In addition, EPA recently revised requirements for insulation manufacturers to participate in ENERGY STAR with the "Seal and Insulate with Energy Star" program. To do so, it is now required that spray foam manufacturers provide:

- Clear and specific safe installation practices and personal protective equipment listed on containers.
- Specific information on chemical reactants.

- Cure times and safe re-entry times after installation.
- MSDSs for chemical reactants with complete hazard information listed.
- All products must be 3rd party certified for R-values and flame/smoke spread.

Related International Activities

European Union (EU)

In 2005, Belgium completed, on behalf of the European Union, a risk assessment report on methylenediphenyl diisocyanate (MDI) isomers and mixtures. The risk assessment identifies risks to human health for both workers and consumers and the need for risk reduction measures that will ensure protection of workers and consumers from eye, skin, and respiratory tract irritation, respiratory and skin sensitization and lung effects induced by short-term repeated exposure [2].

The EU Commission adopted amendments to Marketing and Use Directive (76/769/EEC) on December 16, 2008, to address concerns about the use of MDI- containing consumer products that were raised in the EU Risk Assessment Report. Effective December 27, 2010, all consumer products manufactured and imported into the EU containing concentrations of 0.1 percent or more MDI must include protective gloves which comply with certain EU safety requirements and specific warnings and use instructions [2].

In a separate activity, as a result of a recommendation from the Technical Committee for Classification and Labeling, the EU Commission adopted amendments to its classification and labeling regulations for MDI. The European Commission, in Commission Directive 2008/58/EC, added a "limited evidence of carcinogenicity" designation to its existing classification and labeling requirements for MDI, on August 21, 2008. This designation is based on limited evidence of carcinogenicity in animal studies only [2].

Links to additional information on SPF

EPA:

http://www.epa.gov/dfe/pubs/projects/spf/spray_polyurethane_foam.html

http://www.epa.gov/dfe/pubs/projects/spf/federal_related.html

Foam blowing agents global warming potentials:

http://www.epa.gov/ozone/geninfo/gwps.html

http://www.epa.gov/ozone/downloads/EPA_HFC_ConstFoam.pdf

CPI/SPFA:

http://www.polyurethane.org/s_api/sec.asp?CID=884&DID=3560

http://www.polyurethane.org/s_api/sec.asp?CID=885&DID=3561

Health Effects:

http://www.epa.gov/dfe/pubs/projects/spf/health_concerns_associated_with_chemicals_in_spray_polyurethane_foam_products.html

http://www.cdc.gov/niosh/topics/isocyanates/

http://www.cdph.ca.gov/programs/hesis/Documents/iso.pdf

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