Sustainability Characteristics of SPF Roofing and Insulation Systems

– A Review of Work to Date

By Mason Knowles

INTRODUCTION

Building owners have used spray polyurethane foam (SPF) as a roofing, insulation, and sealing product for many years. Recent research and performance studies on SPF applications demonstrate many sustainable characteristics of the material. This article is divided into two sections. The first section addresses SPF roofing and presents investigative research by René Dupuis and Dean Kashiwagi, Spray Polyurethane Foam Alliance (SPFA) sponsored projects at Factory Mutual and Underwriters Laboratory, cool roof research by Lawrence Berkeley Labs, and articles written by roofing experts such as Thomas Smith and Patrick Downey. Energy studies are courtesy of Texas A&M University.

The second section addresses SPF applications to the interior of a building. The article includes research by Mark Bomberg, W.C. Brown, Robert Alumbaugh, M.K. Kumaran, N.V. Schwartz, Anthony Woods, and others, in addition to SPFA sponsored projects with NAHB Research Center and Oak Ridge National Laboratories (ORNL) and field investigations by private companies.

SECTION 1

Roofing

Between 1983 and 1996, Dean Kashiwagi surveyed and documented the performance of more than 1,600 SPF roofing systems.[1] In 1998, René Dupuis published results of his inspection and evaluation of more than 160 SPF roofing systems in six different climates of the United States.[2] The surveys conducted by Dupuis and Kashiwagi are very similar in their conclusions that SPF roofing systems are highly sustainable. In Kashiwagi's 1996 report, the oldest performing SPF roofs were more than 26 years old, 97.6% did not leak, 93% had less than 1% deterioration, and 55% were never maintained. Kashiwagi and Dupuis also noted the physical properties of the SPF did not diminish over time and that more than 70% of the SPF roofs were applied over existing systems.[1, 2]

Energy Savings

Many large companies and institutions have documented energy savings from the use of SPF roofing systems. Texas A&M calculated the energy consumption of its buildings before and after the application of SPF roofing systems. According to the study of more than eight million square feet of SPF roofing, energy savings paid for the cost of Texas A&M's SPF roof applications in three to four years.[3] How do SPF roofs so dramatically show results of this type?

As shown on *Chart 1*, black-surfaced roofs have measured peak temperatures up to 190˚F on a 90˚F day. If the interior temperature is maintained at 78˚F, the resultant temperature difference is 112˚F.[4]

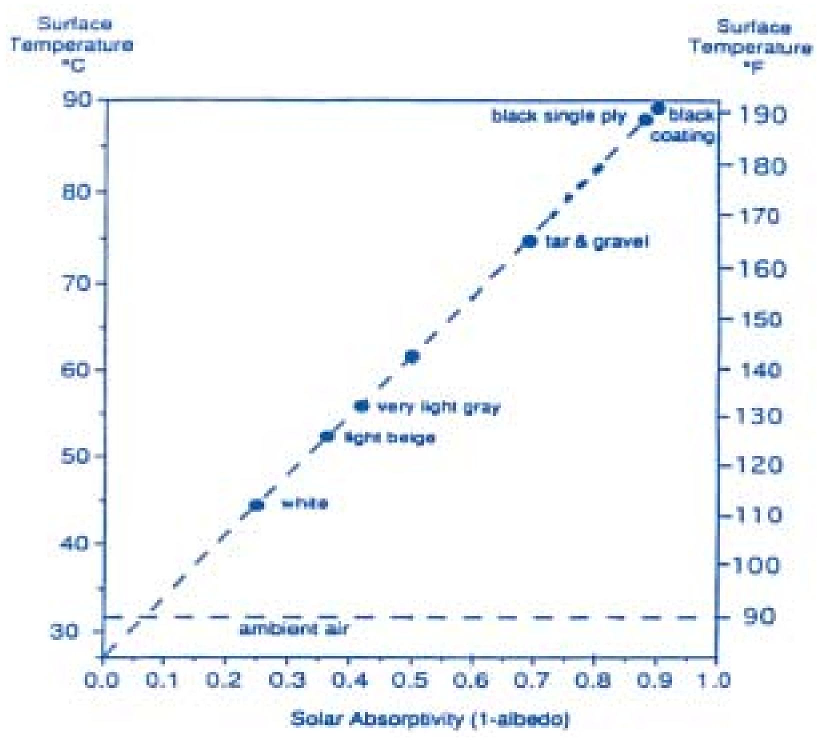
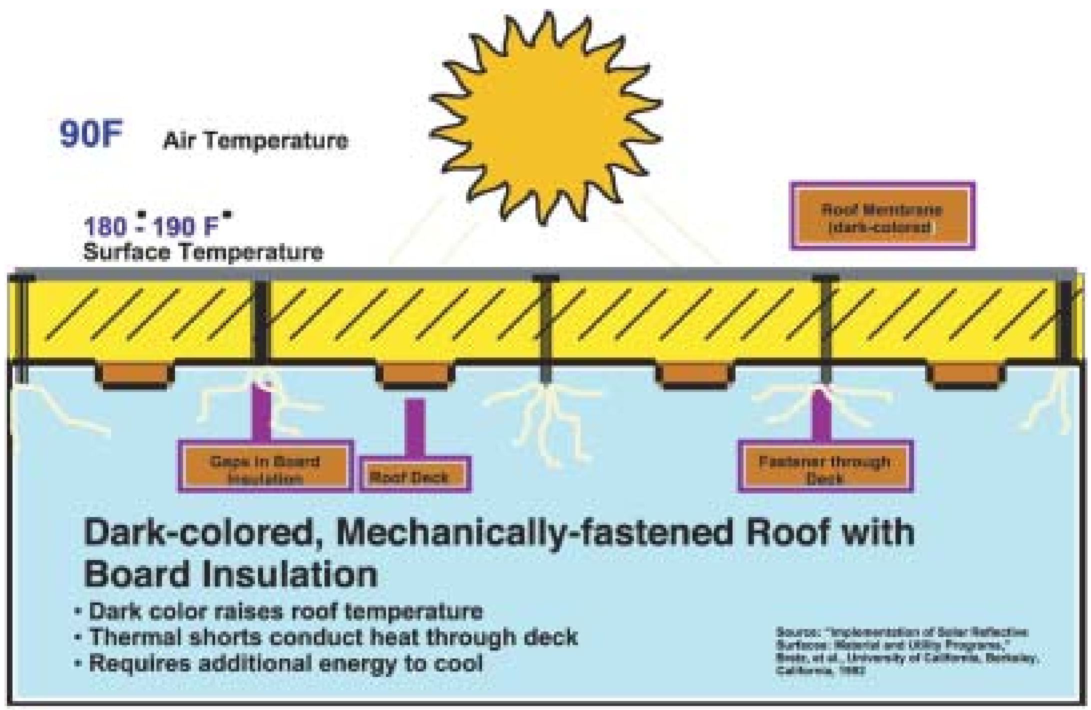


Chart 1: Solar absorbtivity.

According to figures reported by Mike Watts in 1996, fasteners alone can reduce the effective insulation value between 1.5% to 31.5%, depending on the number and type of fasteners.[6]

Detail 1 shows what happens to a typical roof on a hot summer day. Dark-colored membranes absorb radiant heat. The roof's surface temperature rises. Thermal bridges such as fasteners and gaps in insulation boards transport the heat within the building.

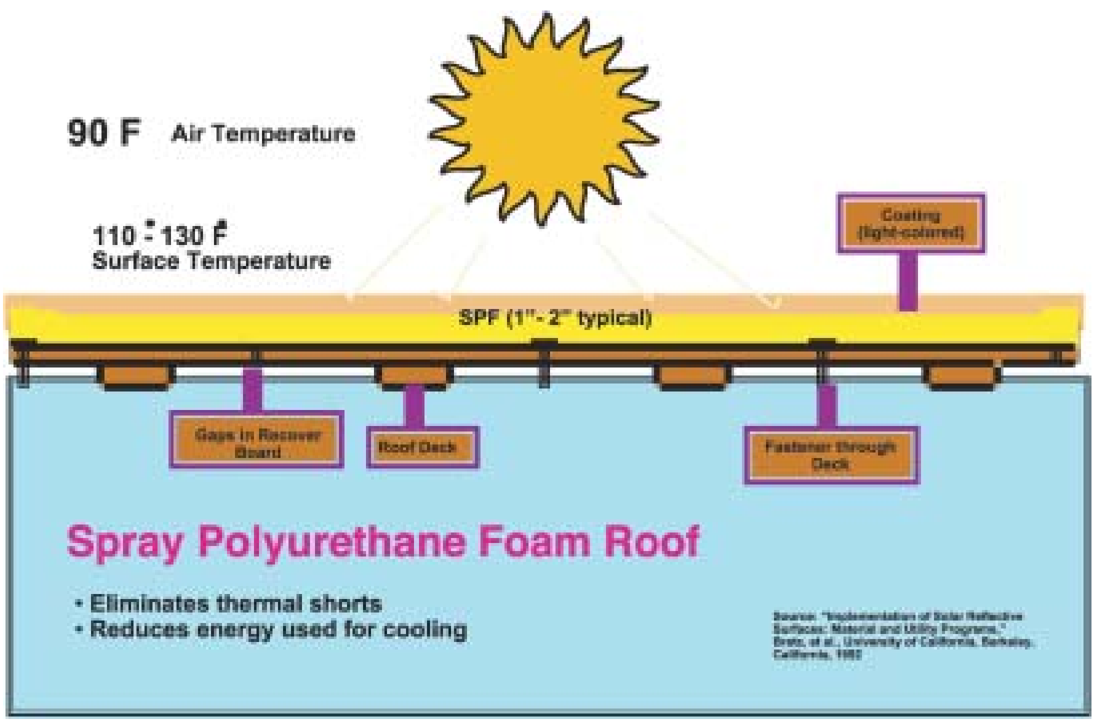


Detail 1

How does SPF reduce energy costs?

As shown in *Detail 2*:

- SPF roofing systems are applied above the roof deck.
- SPF eliminates thermal bridging by providing a continuous layer of insulation over existing thermal bridges in the roof deck and/or roof assembly.
- SPF has a very high aged R-value of between 6 to 7 per inch.
- SPF roofing systems typically are coated with light-colored, reflective coatings.



Detail 2

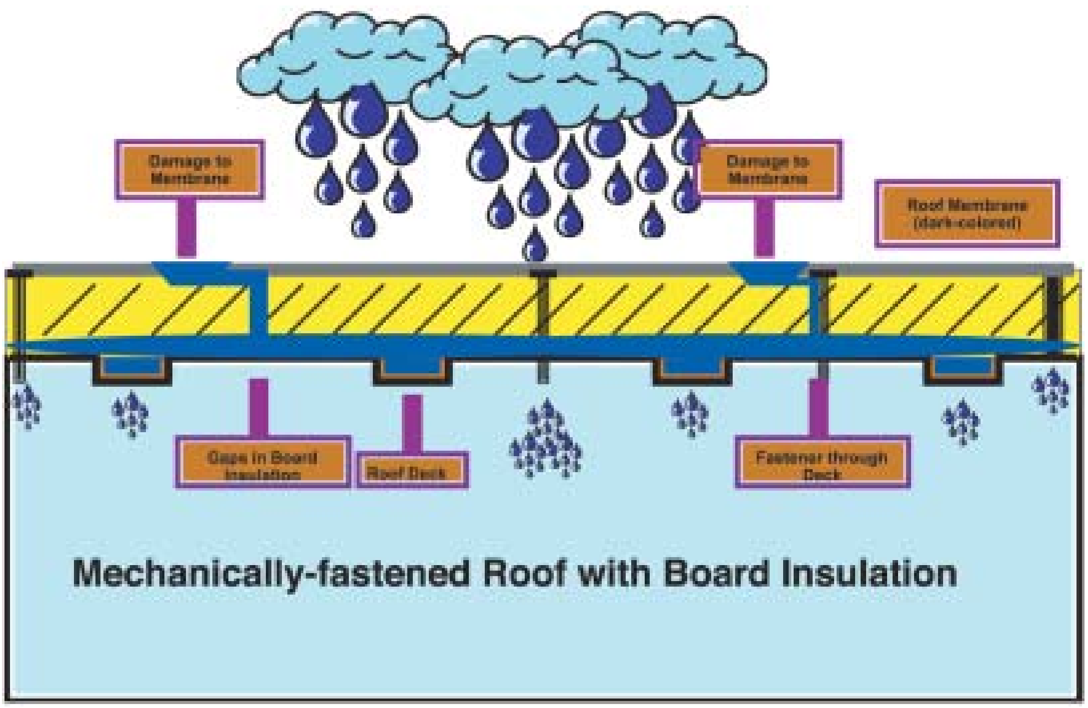
Durability

Performance studies and research suggest that SPF roofing systems can last 30 years or more. Additionally, they require low maintenance, are resistant to leaks caused by hail and wind-driven debris, are resistant to high wind blow-off, can add structural strength, and minimize moisture damage within the building envelope.[7]

ORNL reported, "The principal causes of premature roof failure are moisture intrusion and lack of wind resistance. Moisture accumulation in roofing systems leads to dripping, accelerated failure of the insulation and membrane, roof structure deterioration, depreciation of assets, and poor thermal performance. [See *Detail 3*.] Similarly, the loss of a roof during a major windstorm not only causes structural damage but also exposes the building contents to the elements. The insurance industry identifies roofing as the primary contributor to disaster-related insured losses."[8]

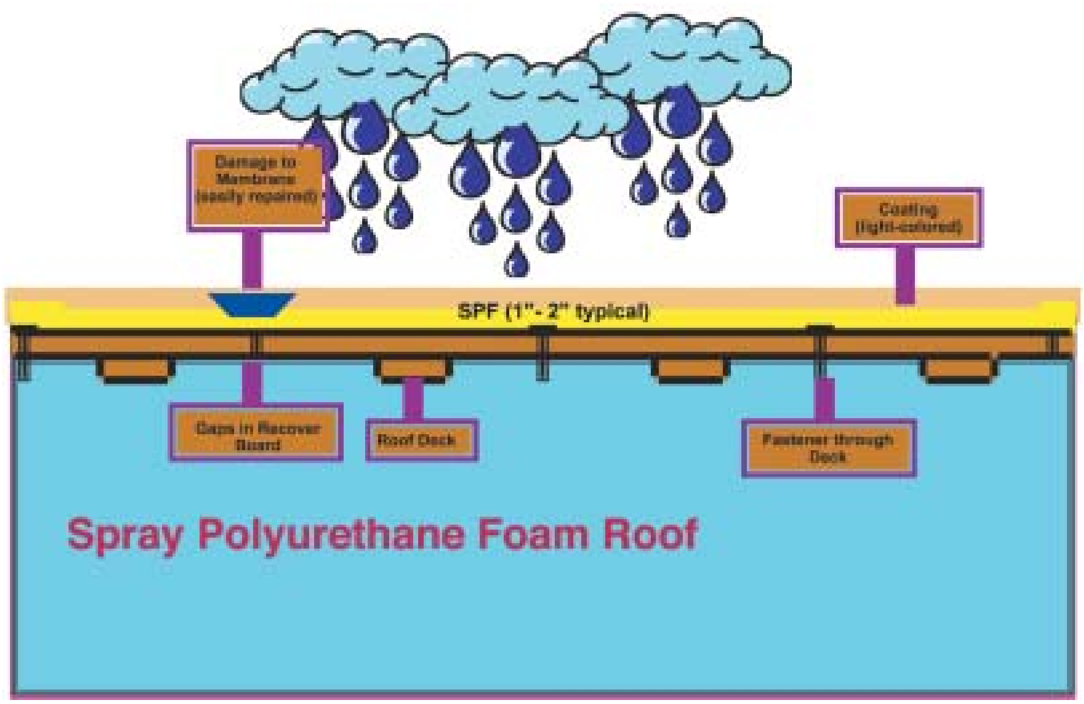
SPF roofing systems limit moisture intrusion because of their 90% closed cell properties. Damage to the system typically does not cause leaks into the building, and moisture intrusion is isolated to the areas of damaged foam cells (see *Detail 4*). As reported by Dr. Dupuis, "One unique aspect of SPF roofs...is that they are not in immediate danger of leaking, providing the penetration does not extend all the way through the foam."[2]

SPF roofing systems have exceptional wind uplift resistance. Field observations of SPF performance during Hurricanes Allen, Hugo, and Andrew led the industry to conduct laboratory testing of SPF systems at Underwriters Laboratories and Factory Mutual. SPF's wind uplift resistance exceeded the capacity of UL's testing equipment. UL also observed that SPF roofs applied over BUR and metal increased the wind uplift resistance of those roof coverings. Factory Mutual's testing showed similar results over concrete, metal, and wood.[9, 10]



Detail 3

According to Dr. Dupuis and other industry experts such as Thomas Smith and Richard Fricklas, SPF is a very good impact absorbing material. Hail and wind-driven missile damage rarely cause leaks in an SPF roof. The damage typically can be repaired at a later date without compromising the long-term performance of the SPF roofing system.[11] One of the most famous examples is the New Orleans Superdome. A severe hailstorm damaged areas of the SPF roof in 1978. For the next 10 years, the city debated how best to repair the damaged roof. Finally, in 1992, the roof was repaired and re-coated. However, prior to the repairs, the roof never leaked from the hail damage. (Some leaks were reported that were actually caused from bullets fired at the roof during Mardi Gras.)[12]



Detail 4

SPF Reduces Construction Debris

ORNL also reported, "The need for multiple roofs makes roofing one of the largest contributors of solid waste."[8] According to the National Roofing Contractors 1999 Survey, more than 68.5% of the 11.3 billion dollar low slope re-roofing market includes tear-off and replacement of the existing roof membrane.[13] SPF roofing systems have excellent adhesion to a variety of substrates, including BUR, modified bitumen, concrete, wood, asphalt shingles, clay tile, and metal. Since SPF adds little weight and can be applied in various thicknesses to add slope and fill in low areas, SPF roofing systems are often used as a recover system over existing roofs without tear-off. Therefore, the application of SPF roofing systems over existing roof coverings greatly reduces the amount of construction debris in our landfills.[7]

So to conclude this section, SPF roofing systems demonstrate significant sustainable characteristics. SPF roofing systems have a long life, are renewable, save energy, add durability to buildings, control moisture in buildings, and contribute very little to the waste stream. SPF roofing systems greatly reduce tear-offs in many reroofing projects, which also decreases the amount of materials entering the waste stream.

SECTION 2: INSULATION AND AIR BARRIER SYSTEMS

"Environmental control within a building envelope depends on strong interaction [among] heat, air, and moisture transport collectively." In order to control these factors, there must be "effective air barriers, rain screens, weather barriers, and thermal insulation of a continuous nature so that gaps do not compromise the climate control design."[14]

"The durability of a material in a building envelope depends on the outdoor and indoor climate, type of construction, and conditions of service. A small change in one of these variables may result in material failure during the first year or a flawless performance for forty years."[15]

The use of SPF systems can significantly affect the durability and climate control of a building. Three SPF systems are used within the building envelope: high density (1-1/2 to 2 lb/ft^3), low density (less than 1/2 lb/ft^3), and sealant foams. High density SPF is used when strength, high moisture resistance, and high insulating value are desired. Low density SPF is used when insulation, air barrier, and sound control are desired. Sealant foams are used to caulk around windows, doors, sill plates, and other locations to seal against unwanted air infiltration.

R-Value

SPF's aged R-value varies, depending on the formulation, type of blowing agent used, and type of application. Aged R-values of SPF used in insulation and roofing applications with a density ranging from 1-1/2 to 3 lb/ft^3 typically range between 6 and 7.5 per inch. Factors affecting the R-value include: thickness of application (the thicker the foam the better the aged R-value), and the substrate and covering systems used (the lower the perm rated covering and substrate, the higher the aged R-value).[15] Low-density (1/2 lb), open-celled SPF typically has a stable, aged R-value ranging from 3.4 to 3.6 per inch *(Chart 2)*.

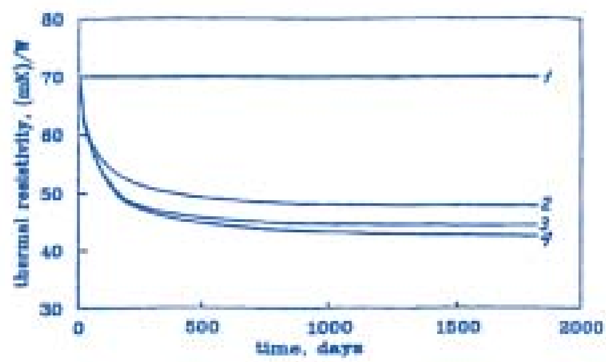


Chart 2: SPFR value aging curve.

Comparison Results: Assumed System Resistance & U-Value vs. Actual System Resistance & U-Value

Insulation Thickness	R-Value		Loss	R-Value		Loss	R-Value		Loss
	Assumed	Calculated	%	Assumed	Calculated	%	Assumed	Calculated	%
1.0 in.	5.85	5.18	11.5	5.85	4.66	20.27	4.7	3.45	26.49
1.5 in.	8.35	7.34	12.08	8.35	6.57	21.3	6.62	4.75	28.19
2.0 in.	10.85	9.51	12.4	10.85	8.48	21.86	8.54	6.05	29.13
3.0 in.	15.85	13.83	12.73	15.85	12.29	22.44	12.39	8.66	30.13
4.0 in.	20.85	18.16	12.9	20.85	16.11	22.75	16.24	11.26	30.66
5.0 in.	25.85	22.49	13.01	25.85	19.92	22.94	20.08	13.86	30.98
6.0 in.	30.85	26.81	13.08	30.85	23.74	23.06	23.93	16.46	31.2
7.0 in.	35.85	31.14	13.13	35.85	27.55	23.15	27.77	19.06	31.36
8.0 in.	40.85	35.47	13.17	40.85	31.36	23.22	31.62	21.67	31.48

Source: Mike Watts, "Thermal Conduction Based on Isothermal Planes (Series-Parallel Path) Analysis," *Interface*, May 1996.

Chart 3

Roof Connection Comparisons: Fully Adhered Membrane vs. Mechanically Fastened Membrane

System Design	Fasteners @1 per 4 sq. ft.	Fasteners @ 1 per 2 sq. ft.	Fasteners @ 1 per 1 sq. ft.
Insulation Type	Extruded	Extruded	Extruded
Fastener Type	Deck Screw @ 1/4" dia.	Deck screw @ 1/4" dia.	Deck screw @ 1/4" dia.
Fastener Conductivity	365	365	365
Fastener Area	490.87 sq. in.	981.75 sq. in.	1,963.50 sq. in.
Roof Area	5,760,000 sq. in.	5,760,000 sq. in.	5,760,000 sq. in.
Insulation Conductivity	0.2	0.2	0.26
Deck Conductivity	365	365	365
Open Deck Area	0.00 sq. in.	0.00 sq. in.	0.00 sq. in
Surface Resistance	0.85	0.85	0.85
Deck Thickness	0.14 in.	0.14 in.	0.14 in.

Source: Mike Watts, "Thermal Conduction Based on Isothermal Planes (Peries-Parallel Path) Analysis," *Interface*, May 1996.

Chart 4

In 1997, ORNL performed whole and clear wall testing of SPF between metal stud walls. Three quarters of an inch of high density SPF was applied between studs and 1/2" over the metal studs. Results confirmed that the use of SPF greatly reduces the thermal bridging effect of the metal studs.[18]

Typical SPF roof.

By controlling moisture infiltration, SPF also provides greater durability to buildings. The number one cause of building deterioration is moisture within the building envelope. Building performance in hurricanes and other catastrophic events can be adversely affected by moisture damage.[19]

Structural Strength

SPF can add structural strength to buildings. Testing conducted by the National Association of Home Builders Research Center showed that SPF insulation between wood and steel stud wall panels increased rack and shear by a factor of 2 to 3 when sprayed onto gypsum board and vinyl siding and increased racking strength 50% when sprayed onto OSB. According to the NAHB Research Center, "During a design racking event (such as a hurricane), there would be less permanent deformation of wall elements and possibly less damage to a structure that was braced with SPF filled walls."[20]

Providing a continuous air barrier, preventing moisture infiltration through air leakage, minimizing condensation within the building, avoiding thermal bridging, resisting heat movement in all directions, and providing reliable performance under varying climatic conditions, SPF provides better climate and moisture control.[16] Better climate control saves energy and makes the building more comfortable. Better moisture control reduces building deterioration, increasing the life of the building. SPF's climate control

SPF conforms to unusual substrate configurations.

attribute enables a downsizing of the heating and cooling equipment of a building, further reducing energy use. Side-by-side energy efficiency comparisons have shown up to 40% energy savings by using SPF over the commonly specified insulation materials.[17] The use of high density SPF within the building can add significant structural strength, minimizing damage from building movement and racking events.

Ozone Depletion and Global Warming

There are still some groups that consider SPF harmful to the environment due to the blowing agents used in the higher density foams. The following information should dispel that concern.

Before 1992, most high density SPF used CFC 11 as the main blowing agent. From 1992 to the present, HCFC 141b has been the main blowing agent used in SPF. HCFC 141b will be phased out in the next couple of years. The most likely blowing agent candidates are blends of HFC 245fa, Pentane, or water.

"The HCFCs and HFCs are considered environmentally superior to CFCs because they are largely destroyed in the lowest region of the atmosphere. The HFCs do not contain chlorine and have no potential to deplete ozone. HCFCs, however, do contain chlorine, but only a small percentage of that chlorine can affect the ozone layer; this is because most of the HCFCs released at ground level are destroyed in the lower atmosphere before they reach the stratospheric ozone layer."[21]

The global warming potential of a material is calculated by its total environmental warming impact (TEWI). The TEWI of a material is the total effect of the combination of direct (chemical) emissions and indirect (energy-related) emissions on global warming. In the case of insulation systems, the direct effect equals the total greenhouse gases released into the atmosphere. The indirect effect is calculated by estimating the equivalent carbon dioxide emissions based on how long the system remains in place before replacement and the total amount of fuel consumed. Because of the world's dependence on fossil fuels for primary energy needs and the predominant contribution of carbon dioxide to future global warming, energy efficiency is crucial in minimizing contributions to these issues.[22]

SPF helped to seal repairs made to this existing roof.

From 1980 to 1990, carbon dioxide contributed 55% of greenhouse gases that affect future global warming. CFC blowing agents (which were used at that time in SPF insulation) contributed 17% of greenhouse gases during the same time period. Replacing CFC blowing agents in foam insulation with HCFCs reduced the global warming potential of SPF insulations by 92%. SPF's exceptional insulation quality reduces the amount of energy required for heating and cooling, thereby significantly reducing the amount of carbon dioxide released into the atmosphere.

The global warming potential of a gas is calculated from its energy absorbing properties over a specified length of time. The longer it takes for a gas to be purged from the atmosphere, the worse its global warming potential. It takes more than 500 years for carbon dioxide emissions to be purged from the atmosphere. Even after 500 years, 19% of carbon dioxide survives to affect global warming. Most HCFC 141b and HFC 245fa blowing agents have left the atmosphere within 10 years.[22]

While most roofs are replaced within 15 years, the wall insulation systems typically remain in place until the building is remodeled or demolished. The longer the insulation system remains in place, the more reduction to global warming. SPF roofing systems are not replaced as often, thereby increasing their effectiveness in reducing global warming. Utilized as an insulation system, SPF's ability to provide effective air barriers and control moisture increases its effectiveness in reducing global warming.

SPF and Energy Costs of Production

Franklin and Associates Ltd.'s study, "Comparative Energy Evaluation of Plastic Products and Their Alternatives for the Building and Construction and Transportation Industries," compares the total energy requirements for the manufacture of plastic products to the total energy requirements for the manufacture of the alternatives. The unique feature of this type of analysis is its focus on all the major steps in the manufacture of a product, raw material extraction from the earth, fabrication, and even transport, rather than a single manufacturing step.[23]

The study concludes that plastic products in the building and construction industry use less energy from all sources than the alternative materials. According to the Franklin and Associates' study, polyurethane foam insulation saved 3.4 trillion BTUs in manufacturing energy over fiberglass insulation in 1990. One trillion BTUs are equivalent to almost 170,000 barrels of oil and one billion cubic feet of natural gas.

As mentioned earlier, SPF helps reduce tear-off debris in roofing applications. SPF's on-site application process generates very little debris and waste. A typical 10,000 square foot roofing project produces less than 1/2 cubic yard of scrap SPF, tape, and plastic (used for masking) and from one pint to three gallons of waste solvent (depending on the type of protective covering used). Compare this to the typical 10,000-square-foot re-roofing project that produces more than 10 yards of construction debris from tear-off and application waste. At the present time, so little scrap SPF is produced that recycling of the material is not practical.[9] ■

Roof mounted HVAC units should be raised and curbed, but typically don't require additional counterflashing.

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SPF is custom made for roofs with lots of penetrations.

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