Green Building Insulation: The Environmental Benefits

To meet green building standards for better thermal protection and energy performance from longer-lasting, environmentally benign building materials, more projects employ closed-cell spray polyurethane foam (ccSPF) insulation, which provides significant benefits contributing to green building performance and LEED certifications..

Executive Summary: The Use of Advanced Insulating Technology in High-Performance Green Building

For commercial and institutional buildings, sustainability has become an overarching and highly important project driver. Key attributes associated with high-performance green building – including high energy efficiency, occupant comfort, material durability and increased property values – have led to the adoption of best practices in construction materials and methods. Among those is the use of more efficient insulation systems, air barriers, and seamless monolithic roofing systems. One such system, closed-cell spray polyurethane foam (ccSPF) is the subject of this white paper. Closed-cell spray polyurethane foam has been shown to offer improved life-cycle analysis and environmental performance, in addition to superior control of the building enclosure and the indoor environment.

This paper reviews the current state of high-performance, advanced green insulation technology, and the key factors to consider when selecting, specifying and designing a green building insulation system. Attention is given to the selection criteria used for green building, including life-cycle analysis (LCA) and the U.S. Green Building Council's LEED systems.

After a discussion of the features and advantages of ccSPF insulation in this context, an overview is given on closed-cell spray foam products for use in the commercial building enclosure, including the roof, walls, floor slabs and foundation. Two case studies demonstrate the practical application of ccSPF in green building. The technical white paper concludes that ccSPF insulation provides significant benefits contributing to green building performance and LEED certifications.

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Green Building Drivers

Volatile and increasing energy prices, concern over environmental impact, and occupant health and comfort – these are the drivers of green building today. In fact, these trends have become of paramount importance for commercial and institutional building owners.

Many experts in building performance believe that the current state of energy consumption and carbon emissions in the United States requires a stark redirection of current design and construction approaches. "In the whole field of energy conservation and greenhouse gas emission, our industry has to stop, hold on, and see what we're doing wrong, as opposed to running to fix small things," says Dr. Mark Bomberg, a research professor in the Building Energy and Environmental Systems Laboratory at Syracuse University. "You really have to look where you can save energy – work on the demand side – before you address the supply side, and that's through the rehabilitation of existing buildings."

Industry's response to rising energy prices and increased environmental impact of building construction is apparent. The American Institute of Architects reports that although five years ago, less than half of architects were incorporating green building practices, it is estimated that 90 percent of architects will incorporate sustainable elements by 2012, and 88 percent have received some training in green building. In addition, the 2006 McGraw Hill Construction Survey noted that corporate respondents to the survey are willing to pay an average of 4 percent more for LEED certified buildings, with 31 percent willing to pay more than 5 percent more.

Despite increased demand for energy and environmental performance, quantifying the green building benefits of specific technologies and strategies is a complex process. It requires the evaluation of a long list of criteria in a full life-cycle analysis (LCA) to determine overall product performance (related to manufactured products) and full system performance (related to buildings as a whole).

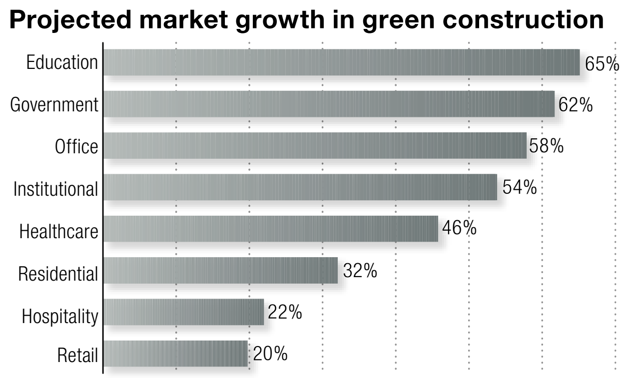
The LCA for ccSPF

Organizations such as Green Globes, owned and operated in the United States by the Green Building Initiative, have created tools to perform LCA for products. These methods include consideration of a complete range of environmental performance factors that impact overall product selection and application. These factors include: climate change potential; embodied energy; pollution and waste production; health factors; and other environmental risks.

A number of LCAs have been performed to date on specific formulations of closed-cell spray polyurethane foam (ccSPF), and all have reported favorable outcomes, in part because:

- **Installed performance.** Once installed, ccSPF materials are highly durable, energy-efficient, and protect buildings and their occupants from such issues as mold and poor indoor air quality (IAQ).
- **Manufacturing efficiencies.** The production and installation of ccSPF uses less or equivalent energy and raw materials to produce, transport and install as traditional insulation products. For example, one truckload of ccSPF material is equal to three

Significant market growth is projected for green building.



Source: 2006 McGraw-Hill Construction Survey

A study by Franklin and Associates published in 1992 - The Comparative Energy Evaluation of Plastic Products and Their Alternatives for the Building and Construction Industry – performed a pioneering life-cycle analysis of plastic products that concluded that in the building and construction industry, plastics use less energy from all sources than alternate materials. The study concluded that polyurethane foam insulation saved 3.4 trillion BTUs in manufacturing energy in 1992, as compared to fiberglass insulation. This is equivalent to 3.3 billion cubic feet of natural gas, or 580,000 barrels of oil.

to four truckloads of board stock insulation.

- **Material sourcing and transport.** In addition, some formulations use locally-sourced and both pre and post consumer recycled products, adding to the sustainability of the system.

Green Building Standards and Certifications

The practice of green building is becoming institutionalized by organizations such as the U.S. Green Building Council through their LEED Rating Systems. LEED stands for the Leadership in Energy and Environmental Design (LEED) Green Building Rating System™, which includes such categories as New Construction (LEED-NC) and the renovation of Existing Buildings (LEED-EB). These rating systems are highly influential, though they have only certified a small portion of the national building stock – roughly more than 1,250 buildings to date.

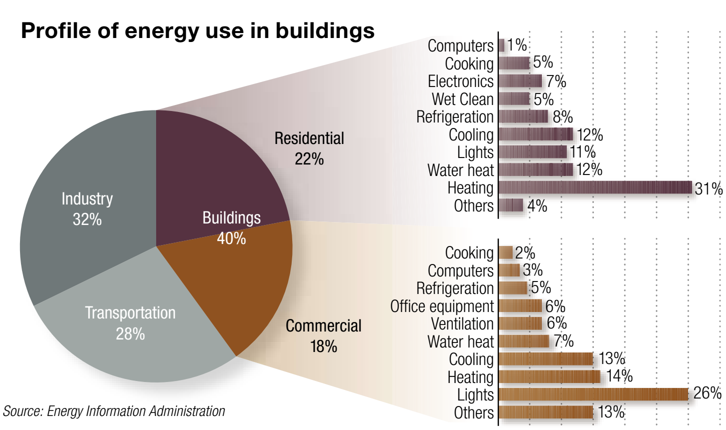
While it is not the only method employed to evaluate the sustainability of buildings, LEED provides a model that covers the significant issues associated with green building. These green building drivers – as they relate to the application of ccSPF – focus on:

Energy efficiency. According to the U.S. Department of Energy (DOE), buildings demand a growing and significant amount of energy – the total is about 40 quadrillion Btu (quads) per year, with commercial buildings accounting for more than 40 percent of overall energy use. In addition to energy consumption, buildings account for more than 40 percent of all CO_2 emissions in the United States – primarily because of their reliance on coal-fired electrical plants for electricity supply. (See Figure 1 on page 3)

These two factors, coupled with the rising cost of operating commercial and industrial buildings, makes energy efficiency a critical driver in sustainable design and construction – as well as in building operations. Green building criteria address energy efficiency by requiring significant energy improvements in existing buildings, and high performance ratings on new buildings. The LEED-NC rating system, for example, requires that buildings be built to meet the provisions of ASHRAE/IESNA Standard 90.1-2004 as a minimum level of energy performance. (ASHRAE is the American Society of Heating, Refrigerating and Air-Conditioning Engineers, and IESNA is the Illuminating Engineering Society of North America.)

Site selection and sustainability. In addition to general considerations about the building site – including the redevelopment of brownfields, the density of buildings and developments, availability of mass transit, and pollution reduction – green building drivers

Figure 1



Source: Energy Information Administration include the reduction of the heat island effect. According to the U.S. Environmental Protection Agency (EPA), this phenomenon describes "urban and suburban temperatures that are 2 degrees F to 10 degrees F hotter than nearby rural areas" due to the heating of buildings, roads, and other developed lands. "Elevated temperatures can impact communities by increasing peak energy demand, air conditioning costs, air pollution levels, and heat-related illness and mortality," the EPA adds.

Strategies to reduce heat island effects include the use of ccSPF highly reflective, or ccSPF vegetated, roof systems. The LEED-NC rating system requires that roof surface area be covered with at least 75 percent of material that has a Solar Reflectance Index (SRI) of at least 78 for low-slope roofs, or an SRI of 29 for steep-sloped roofs. (See Figure 2 on page 4)

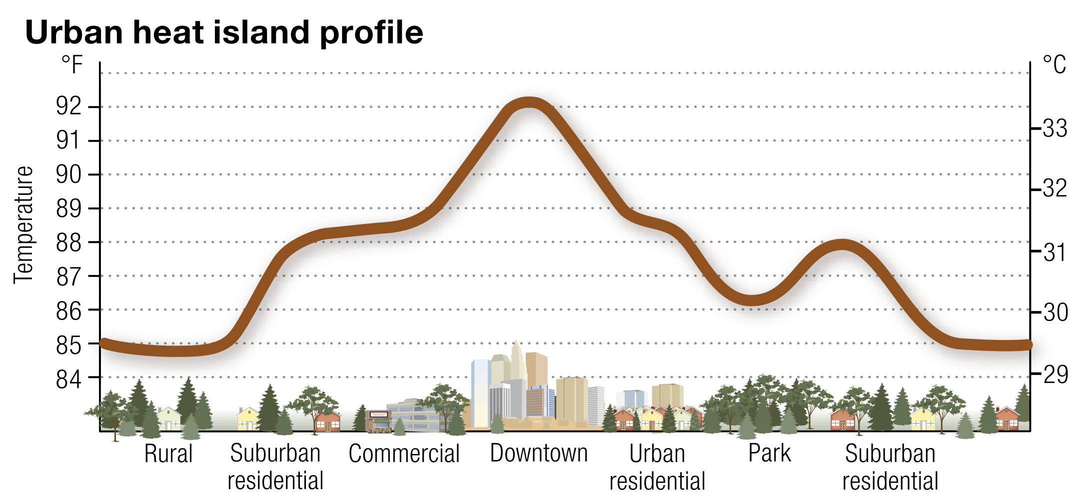
Material and resource use. According to the Environmental Protection Agency in 1996, more than 78 million tons per year of waste was generated from commercial building renovation and construction, accounting for more than 57 percent of overall construction and demolition debris. To significantly reduce the amount of material diverted to disposal, LEED-NC criteria allot credits for buildings that reuse a large percentage of the existing structure, rather than demolishing and reconstructing the building. Closed-cell SPF systems, particularly roofing systems, allow for recoating in lieu of complete system replacement, reducing demolition and reconstruction. Credit is also given for use of recycled, regional, and rapidly renewable materials. Some ccSPF formulations utilize recycled content, including the reuse of existing roof system materials, and qualify for this credit.

Indoor environment. Indoor environmental quality, or IEQ, is of paramount concern in green building, particularly in large buildings where occupant health and workplace productivity is critical. Issues in the indoor environment include indoor air quality (IAQ), comfort, effective operation and control of thermal and lighting systems, and adequate occupant exposure to daylight.

The importance of controlling these variables is crucial for green building. Some studies show a direct correlation between indoor pollutants and the accuracy of certain tasks, such as typing; they also show a certain correlation between perceived indoor pollutants and the performance of work tasks. Among other notable statistics from IEQ studies performed by Lawrence Berkeley National Laboratory (LBNL):

- By doubling ventilation rates in office buidlings, occupants showed a decrease in short-term absences of more than one-third.
- Buildings with above-average ventilation rates show significantly less sick-building syndrome (SBS) symptoms in workplace occupants, with reductions of

Figure 2



Source: U.S. Environmental Protection Agency

10 percent to 80 percent.

- Workplace performance decreases significantly in speed and accuracy when interior temperatures climb above, or fall below, 71 degrees Fahrenheit.
- Workplace performance increases in speed and accuracy when ventilation rates increase.

To address these concerns, green building criteria require that HVAC systems and the building envelope (insulation and airtightness) be designed to allow for optimal thermal control according to ASHRAE Standard 55-2004, which includes the factors of humidity, air temperature and speed, and radiant temperature. Adequate ventilation rates are required according to ASHRAE 62.1-2004 Ventilation for Acceptable Indoor Air Quality. In addition, low-emitting materials, including adhesives, sealants, paints, coatings, carpets, and wood or fiber products are required.

Fundamentally, in order to adequately control ventilation rates, indoor temperature and humidity, the building envelope must be tightly sealed to prevent uncontrolled air infiltration. A ccSPF system allows for superior air sealing, improving the controllability of the indoor environment.

How ccSPF Stacks Up to Green Building Criteria

Closed-cell spray polyurethane foam (ccSPF) insulation systems are self-adhering, two-component products that are spray-applied on site. The material is a rigid insulation system that, once cured, fills cracks, voids, and gaps and tenaciously bonds to most construction material substrates, including metal, wood, plastic, masonry, and the like.

In addition, ccSPF has been shown to provide superior thermal insulation performance – the highest among all commonly used insulation products. Typically, 2 lb/ft3 foam is used for walls and 3 lb/ft3 foam is used for roofs to provide increased strength. CcSPF performance shows a design R-value of 6.2 for ccSPF wall insulation with a density of 2-pounds per cubic foot at 75 degrees F. Similarly, at a mean temperature of 75 degrees, a design R-value of 6.7 is observed for ccSPF with a density of 3 pounds per cubic foot (lbs/cu. ft.), according to the standard ASTM C 518 04.

Excellent thermal performance, added structural strength, nearly zero air permeability and integral vapor retarding function makes ccSPF a superior green building product. The expansion of the product once it's sprayed on a surface – nearly thirty times the original volume – allows it to conform to the many irregular spaces that traditional materials cannot.

Overall, ccSPF systems are an excellent choice for green building, as ccSPF systems provide:

- Superior R-value as compared to all other insulation products.
- A complete air barrier, eliminating air infiltration, thus improving energy performance significantly beyond basic R-value and radically improving control of the indoor environment.
- Improved building durability because it is seamless and monolithic, reducing water and moisture intrusion and improving overall building strength.
- An overall favorable life-cycle analysis, thanks to: reduced manufacturing energy used; up to 40 percent operational energy savings; durability and long installed life span; and minimal waste of about 1/2 cubic yard per 10,000 square feet of application.
- Many green building rating system (such as LEED) credits for energy performance, reduced energy use in transport, recycled and renewable material content (see *Green Benefits of Spray-applied Barrier Systems* for more details).

Life-Cycle Analysis

The building systems incorporating ccSPF have been shown to provide superior performance in life-cycle analysis (LCA). Many manufacturers have commissioned LCAs for their specific products, and results vary based on the product formulation. However, generally speaking, LCAs performed show that ccSPF in comparison to other insulation systems:

- Increased energy efficiency by providing twice the R-value of traditional materials, along with an integrated air barrier and protection against thermal bridging commonly found in commercial buildings; energy consumption over the life of the building, which has been quantified as up to 40 percent lower than with other materials.

- Reduced landfill diversion and cost, as installation of ccSPF produces little waste to be diverted to landfill. This attribute also addresses requirements for reduced construction waste.
- Reduced transportation cost, as ccSPF is transported as the liquid precursors and is therefore compact and lightweight to transport.
- Increased durability when compared to traditional systems, as ccSPF provides superior protection against moisture and water vapor, as well as increased racking strength and wind resistance.
- Reduced health and risk potential, as less material must be produced and transported, less flammable primers are used, and there is less irritant potential than with many other common material choices.

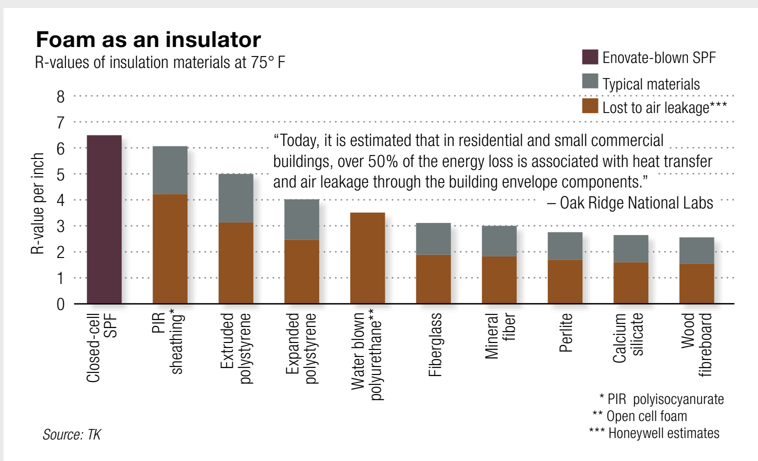
Dick West, President of West Roofing Systems and West Development Group, who has been producing and installing SPF roof systems for decades notes an important point in relation to the overall environmental impact of SPF systems. "When we send out a truckload of ccSPF," says West, "it's a truckload of drums. Let's say a truckload is 40,000 pounds of product per truckload. A truckload is equal to 120,000 board feet of insulation. It would take 3-4 truckloads of board stock to provide insulation for the same project that takes one truckload of ccSPF. The overall carbon footprint of a ccSPF roof is substantially lower than a comparable roof assembly simply because we're shipping it out as a fluid and it expands 30 times upon application."

Energy Efficiency – and the Building Envelope

Energy efficiency is a complex issue that involves nearly every individual system in a building, as well as consideration for the entire building as a whole system. However, engineers and designers versed in energy-efficient construction agree that efficiency begins with building envelope performance. A high-performance building envelope involves two significant factors: high levels of effective insulation, and a superior and consistent air-barrier system.

Not only does ccSPF provide the highest R-value per inch of any insulation system, but it also acts as an integral air barrier. In commercial buildings, this performance is particularly significant. "Oftentimes in commercial buildings you're dealing with steel studs, and steel conducts energy and heat about 1,000 times faster than wood or vinyl," says Steve Easley, a California-based building-science consultant specializing in the commercial sector. According to the Denver American Association of Architects Committee on the Environment, thermal bridging in steel framed buildings can reduce the effectiveness of insulation systems by 30-50 percent. The reduced insulation effectiveness can lead to lower wall cavity temperatures, which, in turn, can lead to condensation and building envelope moisture problems. The Department of Energy recommends using "thermal blocks" to eliminate issues with thermal bridging, which can be done by utilizing ccSPF as an insulation system, as ccSPF will continuously cover existing thermal bridges. In addition, because ccSPF

Figure 3



systems don't require fasteners, thermal bridging is naturally eliminated. (See Figure 3 on page 6)

Site Selection and Sustainability

According to LBNL's Heat Island Group, the urban heat-island effect is a considerable issue in metropolitan areas, where the lack of vegetated ground cover can lead to temperature differentials of 6-8 degrees Fahrenheit. This temperature increase dramatically impacts energy use, mechanical system operation, IAQ, and comfort. LBNL studies to reduce heat island effect have focused largely on cool roofs – systems that use light colored, reflective roof coatings that can reduce energy use by up to 40 percent and, if widely used, can greatly reduce the increase in temperatures in urban areas.

Roofing systems using ccSPF provide an excellent commercial cool-roof solution because they can be combined easily with high reflectivity, low-emissivity (low-E) roof coatings. They can also be used effectively under vegetated roofs to reduce roof surface temperature and increase building performance. In addition, because ccSPF roofing applications are an extremely effective strategy for re-roofing over existing standing seam metal and other (built-up, modified bitumen, or single-ply) roof systems, the material provides a sustainable solution for existing buildings.

Material and Resource Use and Durability

A significant factor in green building is reducing or diverting construction waste, and with this comes the issue of durability of materials. The EPA has estimated that construction- and renovation-related waste generated in the United States accounts for 25 percent to 40 percent of the country's solid waste. Because ccSPF is applied on site by qualified professionals who use only as much material as is needed, construction waste is eliminated or significantly reduced.

More significantly, increasing the life of a building system reduces the need for new resources to replace it. Surveys conducted by Dr. Dean Kashiwagi, a teaching professor at the Del E. Webb School of Construction at the University of Arizona, have documented the exceptional durability of ccSPF roofing systems. The studies have evaluated thousands of ccSPF roofing systems in six U.S. climate zones and concluded that of all the roofs:

- 97.6 percent did not leak
- 93 percent had less than 1 percent deterioration
- 55 percent were never maintained
- 70 percent were applied over existing roofs.

The oldest performing roofs were more than 26 years old. Fundamentally, the studies proved that the physical properties of the roofs did not diminish over time. This conclusion highlights the sustainability of ccSPF roof systems.

Indoor Environment

HVAC system design and performance, human activities, and off-gassing of toxic compounds from building components and furnishings have a dramatic effect on the quality of indoor air. The performance of the building envelope is paramount to good air quality. A poorly insulated, leaky envelope creates the perfect conditions for condensation and mold growth, as well as the invasion of outside contaminants into the conditioned space – not to mention reductions in energy efficiency.

The use of ccSPF helps to improve IAQ because it acts as an integral air barrier, reducing air infiltration to provide a more controllable conditioned space. This also reduces the incidence of moisture intrusion and moisture-related damage, even providing an insulation value that reduces condensation within the wall cavity or on building surfaces. These features reduce the growth of mold and mildew and allow for improved ventilation and mechanical system operation, improving indoor air quality.

Finally, ccSPF is considered a low-emitting material by LEED-NC because it doesn't produce toxic contaminants that affect the indoor environment. As critical to indoor air quality is control of space conditioning. The high R-value of ccSPF – and its performance as an air barrier – allows HVAC systems to work to the best of their expected performance.

Selection Criteria and Industry Standards for Green Building

The past decade has seen a huge need to measure and quantify the performance of green products, and green buildings. "I use the term high-performance buildings," says Syracuse University's Dr. Mark Bomberg, "because nobody understands what the word 'green' means." In fact, the advertising and publicity associated with green building and sustainable design in the construction and remodeling industry is seen as nebulous, ill-defined, and unregulated by experts. In response, the Federal Trade Commission held a working group to determine how to provide concrete guidance on the acceptable use of marketing terms associated with green building. These recommendations will be incorporated into the FTC's Green Guides in 2009, making it unlawful to market using unsubstantiated (and unmeasured) claims about building or building product performance.

The technical standards to which a "green building" must be built have also long been in contest. This need has driven the development or adaptation of a variety of standards for commercial construction by organizations such as ASHRAE, the Green Building Initiative (GBI), and the U.S. Green Building Council (USGBC). Recently, the USGBC and GBI both became accredited as Standards Developing Organizations (SDO) by the American National Standards Institute (ANSI), and they both have developed standards that apply to buildings and building systems.

- **The U.S. Green Building Council:** USGBC's LEED for New Construction and LEED for Existing Buildings provide a comprehensive certification program. In addition, LEED provides a LEED for Core & Shell rating system that focuses specifically on the performance of the structure, envelope, and HVAC system only.
- **Green Building Initiative:** The Green Globes Assessment and Rating System and associated tools provide a comprehensive rating system for new and existing buildings, a certification process and analysis tools. Their software tools allow for building and full life cycle analysis.
- **GreenGuard:** Created by the GREENGUARD Environmental Institute, GREENGUARD certification assures that products and buildings that go through frequent testing to ensure particle and chemical emissions that meet guidelines for acceptable indoor air quality.
- **Green Seal:** Run by a not-for-profit group, Green Seal tests and certifies products that have been evaluated over their full life cycle, starting from material extraction through manufacturing and consumer use, all the way to disposal and recycling.

Green Insulation Choices and Tradeoffs

Based on the industry-accepted standards and criteria for high-performance, sustainable buildings outlined above, a number of attributes, including full product life-cycle analysis, must be weighed when selecting sustainable insulation materials. In addition to using an LCA for product evaluation, effective energy performance and overall air barrier effectiveness must be considered critically.

Effective energy performance. In addition to choosing a system with the highest possible effective R-value based on the field performance of commonly installed insulation products, the overall energy performance of a building is significantly affected by issues associated with insulation system selection and installation. It is important to note that studies have shown that the real-world (effective) performance of insulation systems simply doesn't match up to labeled R-value. Installation errors, wind drift/wash, mechanical fasteners, joints and gaps along with other factors radically reduce thermal performance of insulation as measured in commonly installed scenarios.

Because the effective performance of insulation systems is so critical to the performance of the entire building system, Oak Ridge National Laboratory (ORNL) conducted a study in 1998 to evaluate the actual R-value performance of insulation products when installed, as compared to the labeled R-values. Striking results showed that fiberglass batt insulation labeled at an R-value of 19, showed an R-value of 17 when correctly installed. When installed as commonly found in walls after installation, the R-value was 13.7 (ORNL 1998). (See Figure 4 on page 9)

As demonstrated in Table T.K on page T.K., reflecting research by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) and the Oak Ridge National Laboratories (ORNL), fasteners alone can reduce the effective insulation value between 1.5 percent to 31.5 percent, depending on the number and type of fasteners.

SPF eliminates thermal bridging by providing a continuous, fully adhered layer of insulation over existing thermal bridges in the roof deck and/or assembly.

Significant impacts on energy performance. Thermal drift, thermal bridging, air movement, and moisture all dramatically impact whole building performance.

- **A thermal bridge** is an assembly or component in the building envelope that transfers heat at a significantly higher rate than the surrounding insulated area. Thermal bridging is created by fasteners, joints, and gaps. Thermal bridging can be a significant cause of heat loss and underperformance of insulation assemblies in commercial buildings, particularly in metal-framed buildings and decking systems.
- **Air movement** (infiltration and exfiltration) account for a significant amount of energy loss in commercial buildings. According to a 2005 study by the National Institute of Science and Technology (NIST), an energy savings of up to 62 percent can be realized by undertaking specific measures to improve airtightness. In addition to energy loss, infiltration reduces occupant comfort, interferes with efficient operation of mechanical systems, reduces indoor air quality and contributes to condensation and moisture damage in the building envelope system. Air movement can be most effectively limited by the use of ccSPF as compared to other type insulation systems.

Moisture considerations. Issues related to moisture penetration and

Figure 4: Labeled R-value vs. Installed R-values Attic Thermal Testing at Oak Ridge National Laboratory

Insulation	Test Number	Insulation Temerature	Labeled R-Value	Tested R-Value (C 1363)	% Labeled
Blown Fiber Glass @ 14 incehes	1a (low temp)	38.01	38	17.7	47
	1b (low temp)	38.03		17.7	47
	1c (avg temp)	51.75		29.0	76
	1d (high temp)	88.97		20.2	53
Low-Density SPF @ 5.5 inches	2a (low temp)	32.61	19.8	14.7	74
	2b (low temp)	32.73		14.7	74
	2c (avg temp)	48.49		13.6	69
	2d (high temp)	93.00		12.1	61
High-Density SPF @ 4.0 inches.	3a (low temp)	32.89	27	22.8	84
	3b (low temp)	33.01		22.7	83
	3c (avg temp)	48.79		19.8	73
	3d (high temp)	93.07		18.1	67
Source: Oak Ridge National Laboratory, 1998					

R-value Loss Due to Fasteners in Metal Roof Deck Assemblies

Board Insulation	**1 fastener per 4 sq ft**			**1 fastener per 2 sq ft**			**1 fastener per 1 sq ft**		
Insulation Thickness	Comparison Results: Assumed System Resistance & U-Value vs. Actual System Resistance and U-Value								
	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	31.20
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
According to research by ASHRAE and ORNL, fasteners alone can reduce the effective insulation value of metal buildings between 1.5% to 31.5%, depending on the number and type of fasteners.									

control go hand in hand with improving energy performance in buildings. The reason is that systems improving energy performance in the building envelope can prevent bulk water and water vapor from entering and damaging building assemblies. Insulation, moisture barriers, and air barriers are critical parts of the high-performance building envelope. These systems are instrumental to energy performance, but also to helping prevent water vapor from entering the envelope assembly, where it can condense and turn into liquid water – a key ingredient in corrosion and mold growth. The properties of ccSPF address the functions of all of these systems, combined.

Air barrier performance. Generally speaking, air barriers are intended to keep air from moving through building assemblies – walls, roofs, foundations – throughout the entire building envelope. Although air-barrier and insulation systems often involve several components and installations, the entire air-barrier assembly, fully installed and connected, must be tested for air leakage to quantify the performance of the installed system. This testing is done using ASTM E 2357 guidelines, and the results reflect the total amount of air that passes through the envelope. The acceptable air leakage of assemblies, components, and the entire building envelope is the same, and cannot exceed 0.2 liters per second per square meter (L/s/m2) at 75Pa, or 0.004 cubic feet per minute per square foot (cfm/ft2) at 1.57 psf. In relation to individual air barrier materials that may comprise an air barrier system or assembly, the material must have the requisite air leakage rate when measured in accordance with ASTM 2178.

In addition to evaluating the performance of specific systems in a laboratory-testing environment, overall performance targets for the entire building must be considered. Though many building codes do not contain adequate language to govern the design and construction parameters for air barriers in commercial buildings, new standards are being developed and implemented. For example, ASHRAE is in the process of making revisions to Standard 90.1 that will require the inclusion of a continuous air barrier. As previously stated, the material must have the requisite air leakage rate when measured in accordance with ASTM 2178.

Figure 5: R-Values of common Insulation Materials

Insulation Type	R-Value per inch of thickness
Fiberglass blanket or batt	2.9 to 3.8 (avg. 3.2)
High performance fiber glass blanket or batt	3.7 to 4.3 (avg. 3.8)
Loose-fill fiber glass	2.3 to 2.7 (avg. 2.5)
Loose-fill rock wool	2.7 to 3.0 (avg. 2.8)
Loose-fill cellulose	3.4 to 3.7 (avg. 3.5)
Perlite or vermiculite	2.4 to 3.7 (avg. 2.7)
Expanded polystyrene board	3.6 to 4 (avg. 3.8)
Extruded polystyrene board	4.5 to 5 (avg. 4.8)
Polyisocyanurate board, unfaced	5.6 to 6.3 (avg. 5.8)
Polyisocyanurate board, foil-faced	7
Spray polyurethane foam	5.6 to 6.3 (avg. 5.9)
Source: U.S. Department of Energy/Oak Ridge National Laboratory, July 2007	

For more information on air barriers, see Insulation Energy Saving: Key Issues and Performance Factors [ADD LINK TO BD+C PAPER HERE, as follows:] (www.ncfionline.com/uploads/Insulation percent20Energy percent20Savings percent20Final.pdf).

Green Insulation Options for Commercial Construction

The Insulation Contractors Association of America (ICAA) recognizes the following categories of insulation in their publication Recommended Design Considerations and Guide Specifications for Commercial Building Insulation:

- Rigid and semi-rigid foam board insulation.
- Thermal batt and blanket insulation.
- Spray applied polyurethane foam insulation.
- Spray applied fibrous insulation.
- Loose fill insulation.

Many products within these categories can be used to achieve green building guidelines, but as seen in the sections above, foam board and spray foam insulation provide significantly higher R-values than other insulation types, and ccSPF provides an integral thermal, moisture and air barrier that dramatically improve actual energy savings performance.

In addition to energy, moisture and air barrier considerations, GREENGUARD lays out the following emissions criteria for a product to be labeled under their GREENGUARD Indoor Air Certification Program for Low-emitting Products (see Figure using minimal additional resources and diverting very little material to landfills.

- Provides superior thermal performance, including unparalleled air-sealing which, in turn, improves overall building envelope thermal performance and reduces energy used by HVAC systems. Lower energy use in buildings in turn reduces carbon emissions.
- Provides moisture protection, reducing IAQ issues and increasing durability.
- Adds structural integrity to the building, further increasing building durability.
- Is renewable, particularly in applications like commercial roofs where ccSPF can be recoated vs. tear-off and replacement of traditional roof system every 10-20 years.
- Is durable, as ccSPF has a serviceable life of more than

Figure 6: GreenGuard Emission Criteria

For use with GreenGuard Certification Program℠ for Low Emitting Products

Insulation-Applicable to: Building insulation, Basic mechanical insulation and Air handling (HVAC) insulation

Properties	ASTM Test	Value
Individual VOCs[1]	< 0.1 TLV	< 0.1 TLV
Formaldehyde	< 0.05 ppm	< 0.025 ppm
Total VOCs[2]	< 0.5 mg/m³	< 0.25 mg/m³
Total Aldehydes[3]	< 0.1 ppm	< 0.05 ppm
Respirable particles (for HVAC ductwork)	< 0.5 mg/m³	< 0.5 mg/m³
Listing of measured carcinogens and reproductive toxins as identified by California Proposition 65, the U.S. National Toxicology Program (NTP), and the International Agency on Research on Cancer (IARC) must be provided.		
Any pollutant regulated as a primary or secondary outdoor air pollutant must meet a concentration that will not generate an air concentration greater than that promulgated by the National Ambient Air Quality Standard (U.S. EPA, code of Federal Regulations, Title 40, Part 50).		

[1] *Any VOC not listed must produce an air concentration level no greater than 1/10 the Threshold Limit Value (TLV) industrial work place standard (Reference: American Conference of Government Industrial Hygeinists, 6500 Glenway, Building D-7, Cincinnati, Ohio 45211-4438).*

[2] *Defined to be the total response of measured VOCs falling within the C_6-C_{16} range, with responses calibrated to a toluene surrogate.*

[3] *Defined to be the total response of a specific target list of aldegydes (2-butenal; acetaldehyde; benzaldehyde; 2.5-dimethylbenzaldehyde, 2-methylbenzaldehyde; 3-and /or 4-methylbenzaldehyde; butanal; 3-methylbutanal; formaldehyde; hexanal; pentanal; propanal), with each individually calibrated to a compound specific standard.*

Source: GreenGuard Environmental Institute

30 years and can be recoated easily, at a minimal cost, using minimal additional resources and diverting very little material to landfills.

- Is sometimes made with recycled materials, and with materials that are "locally sourced" and manufactured.
- Rates very well in life-cycle analysis.

Joseph Lstiburek, Ph.D., P.Eng., a principal of Building Science Corporation and an internationally renowned building scientist believes that insulation products capable of achieving green building standards need to handle water, air, vapor and thermal control in one material. "All of these factors," says Lstiburek, "are very important in the fundamental performance

> **"It's the only product available in the industry that can provide four of the major fundamental control functions of the building enclosure."**

of a building. You want a water, air, and vapor control layer coupled with a thermal control layer. A lot of technologies are able to collapse three of those four functions, whereas ccSPF can actually collapse all four into one application. In other words, normally you have a water control membrane that's also an air and a vapor barrier and you install insulation over it. With ccSPF, that one layer of foam sprayed on the outside of the building actually does all four things. It's a product that's unique like no other – the only product available in the industry that can provide four of the major fundamental control functions of the building enclosure."

This fundamental fact is the cornerstone and unique value of ccSPF to green building – ccSPF systems address all of the core issues associated with energy, moisture, and durability performance of buildings in one system, in addition to providing added benefits that can be used to achieve other points in green rating systems.

Achieving USGBC LEED for New Construction credits using ccSPF

Closed-cell spray polyurethane systems provide benefits that can allow designers to qualify for points in the USGBC LEED rating systems. The following table outlines the areas where it may be possible to achieve points using ccSPF:

Closed-Cell Spray Polyurethane Foam: Green Attributes and Applications

For those wanting more detail, following is an overview of the attributes and applications of ccSPF. Briefly, ccSPF is an insulating foam that is sprayed in or onto construction assemblies. When it contacts the application surface, it immediately increases in volume by as much as 30-40 times.

The Spray Polyurethane Foam Alliance (SPFA) notes that the various SPF formulations provide a broad range of physical properties that are suitable for a variety of applications and climates. Closed-cell SPFs (ccSPFs) are suitable for both interior and exterior insulation because of significantly higher structural integrity and waterproofing characteristics. Foam

Sustainable Sites	
SS Credit 6.1-6.2: Storm water Design: Quantity and Quality Control	Use of vegetated roof systems over ccSPF roof systems can qualify projects for points by minimizing impervious surfaces.
SS Credit 7.2: Heat Island Effect: Roof	Use of highly reflective roof coatings over ccSPF roofs, in addition to vegetated roof systems, can qualify for points by reducing roof surface temperatures and thereby decreasing the urban heat island effect.
Energy and Atmosphere	
EA Prerequisite 2: Minimum Energy Performance Required EA Credit 1: Optimize Energy Performance	Use of ccSPF significantly increases energy performance in buildings through superior R-value and air barrier performance. Points may be gained for overall building energy performance because of improved building envelope performance. In addition, ccSPF is a non-Ozone depleting technology, ccSPF roofs can to integrated into photovoltaic solar energy systems , and there is reduced energy in manufacturing ccSPF as compared to traditional systems.
Materials and Resources	
MR Credit 1.1 - 1.2: Building Reuse: Maintain 75% - 95% of Existing Walls, Floors & Roof	Use of ccSPF roof systems allows for application of new coatings instead of complete roof tear-off once the system's useful life is reached. Points may be gained for reuse and recoating of the existing roof structure.
MR Credit 4.1-4.2: Recycled Content	Some ccSPF formulations utilize recycled content and may qualify for points.
MR Credit 5.1 -5.2: Regional Materials	Some ccSPF formulations utilize regionally sourced and produced materials and can qualify for points.
MR Credit 6: Rapidly Renewable Materials	Some ccSPF formulations utilize agricultural products, such as soy, and sugar based polymers that are rapidly renewable.
Indoor Environmental Quality	
EQ Credit 4.1: Low-Emitting Materials: Adhesives & Sealants	CcSPF is not considered a volatile organic compound (VOC) by the U.S. government, and its use reduced the use of caulks and adhesives.
EQ Credit 7.1: Thermal Comfort: Design	CcSPF can help building envelopes meet the requirements of ASHRAE Standard 55-2004, Thermal Comfort Conditions for Human Occupancy
ID Credit 1–1.4: Innovation in Design	CcSPF foam can contribute to innovation credits for acoustical performance, reducing construction waste while being sustainable and durable.

used in exterior applications must be covered for both UV and protection from the weather.

Because ccSPF shows little degradation over time, SPF roofing systems have been in place for as long as 30 years and are easily renewable after that time by just re-coating the surface which provides UV protection. Cracks or punctures in ccSPF roof systems up to 3 inches in diameter can be fixed using simple elastomeric sealants or caulk; damage of a larger size can be resolved with reapplication of the spray foam in the affected area. The combination of ccSPF roof insulation and waterproofing system with elastomeric, aggregate, or vegetated coverings to protect the ccSPF against UV ratings provide and highly desirable green-roof solution.

Several types of ccSPF are used for building envelopes – *high-density closed-cell SPF* that is extremely resistant to water intrusion and foot traffic, *medium-density closed-cell SPF* for interior applications.

Views on Spray-Foam Insulation by Green Building Experts

Bill Rose, a research architect at the University of Illinois at Urbana-Champaign's Building Research Council, has conducted significant research into thermal and moisture performance of buildings, and served as a consultant on historic buildings and museums. For obvious reasons, his work in museum projects has focused on the critical building performance factor of indoor temperature and humidity control. According to Rose, "There is simply no way to control temperature and particularly humidity in a building that's leaky. Especially for larger museums, the effort to improve the indoor climate and make it more stable hinges on the ability to prevent air leakage."

Rose's experience shows that existing buildings can have significant issues in air leakage that can't be solved using traditional materials. These leaks pose significant problems to energy and indoor environmental performance. "As far as I can tell," says the research architect, "there really isn't any product that compares to spray-applied urethane foams for blocking air leakage. The first thing we do is look at the wall roof junction. Often where the wall goes up the roof engages the parapet continues up from that – it's just a giant chimney for air leakage. The question of making the indoor environment workable or not comes down to the question – can we foam these holes shut?"

Syracuse University's Dr. Mark Bomberg believes that spray foam will play a significant role in reducing energy demand and environmental impact of buildings. Bomberg's decades of experience with buildings and building performance research, as well as the spray foam industry, has made him passionate about systems that behave as a system, rather than component products and materials. "Spray foam is a material for now and the future, not for the past, because in the past we were dividing building and materials and everyone was selling miraculous solutions called product A, B, or C. Now because we are looking at energy, durability, sustainability – all these green things – we have to deal with building as a system. Spray foam's future is secure because it allows tailoring to whatever needs you have in your system."

Related Green Benefits of SPF

Though not directly measured by commonly accepted green building criteria, the following related benefits of using ccSPF systems should be considered in any green building or remodeling project:

- **Safety:** ccSPF insulation and waterproofing systems add structural integrity to any building – particularly in roof systems that are impacted by wind uplift in severe weather areas. In fact, a 2007 study at the University of Florida's Department of Civil and Coastal Engineering showed that ccSPF roof systems have the potential to increase wind uplift capacity by more than three times that of traditional construction using a continuous layer of ccSPF on the underside of the roof deck.
- **Highly reflective (cool) roof surface:** Heat on a low-slope black roof surface can surge to 190 degrees Fahrenheit in the summer. Much of the heat generated in summer months is absorbed into the building, radically impacting efficiency by impact to heating and cooling loads. Highly reflective, low-E roof coatings and membranes are now widely available for the U.V surfacing of ccSPF roof systems, and have proven to reduce roof temperatures to a few degrees above ambient temperature on common roof assemblies. In addition, highly reflective ccSPF roof systems have been shown to reduce the energy needed

to cool a commercial building by as much as half. As an alternate green-roof strategy, a vegetated-roof system can be installed on top of a ccSPF roof system.

- **Solar photovoltaic roof SPF systems:** Once energy conservation measures are employed and the building consumes as little energy as possible, generating power onsite from renewable energy sources is an excellent green building strategy. A ccSPF roof system that employs highly reflective coatings, coupled with roof-mounted photovoltaic (PV) panels can provide efficient operation and offset energy costs. The ccSPF roofing systems create a waterproof, monolithic, and lightweight roof structure that allows for the addition of PV systems without concerns about roof weight.
- **Vegetated roof systems:** Vegetated or "true green" roof systems employ vegetative roof cover to replace a bare membrane, gravel, shingle, or tiles. A vegetated roof system can provide significant benefits, including stormwater runoff management and urban heat island effect reduction. Although a vegetated roof system can be installed on any type of low-slope commercial roof, ccSPF systems are ideal, because they:
    - Provide significant insulation value, reducing the likelihood of water on the roof from cooling the building during the winter or heating it during the summer.
    - Are lightweight. Any additional systems placed on the roof of a building add weight to the structure, and the lightweight nature of ccSPF may allow designers to specify vegetated roof systems without the need to reinforce the roof to account for additional weight.
    - Are continuous, monolithic, self-flashing and are easily tapered to slope and drain properly ensuring that water from the vegetated roof system doesn't enter the building envelope.
    - Are durable and have a compressive strength of (45-50psi) - double that of polyisocyanurate board stock at (20-25psi). This added durability improves the roof's ability to withstand foot traffic and abuse.
    - Adhere to irregular surfaces and fill penetrations unlike any other product, ideal when a vegetated roof system design uses stanchions or other structural assemblies.

A critical note for green building systems such as solar photovoltaic and vegetated roof systems is made by Dick West. "You're taking a part of a building that's basically designed to insulate and waterproof the structure, that's it. Anything you put on that roof is detrimental to that goal – so when you start putting rooftop mounted equipment up there and you have penetrations going through the roof to support the solar collectors – each one of those penetrations is a vulnerable point for water intrusion. Because ccSPF is self-flashing and conforms very easily to irregular shapes and penetrations, the cost of the roof assembly doesn't go up as a result of all of the additional assemblies and penetrations needed to support a PV system. The other reason that ccSPF lends itself to these additional systems is the fact that ccSPF is probably the lightest weight roof assembly you can install on a building. A building's roof capacity is limited. If you want to make the load capacity greater, you have to beef up the structure itself, which is expensive. If you're going to add PV or vegetated roof systems, thus adding weight and can add a lighter weight roof system instead of reinforcing the building, that's a clear benefit."

Green Building Case Study: Mississippi Coast Coliseum

Building: Mississippi Coast Coliseum
Location: Biloxi, MS
Profile: Biloxi, Mississippi is a tough place to be a building, particularly a roof. Since 1979, Biloxi has been hit by more than 15 hurricanes, with high wind speeds between 110 mph and 115 mph. According to the National Oceanic and Atmospheric Administration (NOAA), 28 significant hail events with golf-ball-sized hail, 28 tornadoes, and 100 high-wind storms have braced the area. All told that equates to more than 175 days of severe weather since 1979.

Built in 1977, the Mississippi Coast Coliseum was constructed with an ccSPF roof. After Hurricane Katrina, the coliseum was still standing with little damage to the SPF roof system. Contractors removed a ½ inch of the SPF and replaced it, along with a new elastomeric coating. A NIST report titled

> **"A number of spray polyurethane foam (SPF) roofing systems were observed … Some of these roofs were estimated to be about 20 years old. With one minor exception, all were found to have sustained Hurricane Katrina extremely well without blow-off of the SPF or damage to flashings."** *– NIST*

Performance of Physical Structures in Hurricane Katrina and Hurricane Rita: A Reconnaissance Reports showed that SPF roofs performed significantly better than average in hurricane conditions.

The increased durability of SPF roof systems provides a sustainable solution for commercial buildings, reducing the need for replacement or significant maintenance and maintaining building performance attributes over time.

According to sources such as the Oak Ridge National Laboratory and Franklin & Associates, durability is a key component of life-cycle analysis, or LCA – a key component of green building. Providing good wind uplift resistance and enhanced structural strength of building assemblies, ccSPF has been shown to contribute to sustainability over the long term.

Green Building Case Study: Texas A&M University

Building(s): Texas A&M University
Location: Biloxi, TX
Profile: With over 7 million square feet of ccSPF roofing system on their buildings, Texas A&M may be the best example of proven sustainability and energy efficiency of SPF systems.

In the 1970s, the university's physical plant department was looking for alternatives to their traditional built-up roof systems, which had suffered significant leaks after only a few years of service.

SPF roof systems were used on many of the Texas A&M buildings, with energy savings being monitored on 27 buildings that had been retrofitted with SPF roofs between 1980 and 1984. Results showed a payback in energy savings of an average of 4.5 years.

The systems, many still in place today, boast high energy savings, low maintenance and replacement costs, and minimal disruption in occupant productivity, as the systems can be applied without disrupting the building interior.

Action Plan: Using ccSPF for Green Building – New Construction and Renovations

Use of ccSPF systems for green buildings will become more commonplace as building designers and owners seek cost-effective means to achieve new building codes and green building program requirements. For that reason, we recommend the following:

1. Focus research and solutions development and measurements on whole-systems solutions, rather than component parts. Syracuse University's Bomberg believes that the industry should strive for systems solutions that are measured and verified as whole systems, rather than component parts.

2. Understand and evaluate the application and performance of different ccSPF formulations for specific applications. There are many different types of foams and applications and building teams must evaluate the performance of each formulation and application. As Bomberg reflects, "A tailor can use very different textiles to make different pants. He's not saying I use only one textile to make all pants. The foam industry needs to look at their products in a similar way."

3. Further verify the performance of ccSPF systems according to traditional LCA models. While life-cycle analysis has been performed on ccSPF systems that reflect good performance, additional evaluations are forthcoming that will further strengthen the case. Clearly, in such areas as energy conservation and durability, ccSPF is a good life-cycle choice.

4. Push the requirement of high thermal and air-barrier performance in the design and construction of all buildings. Fundamentally, building codes and standards are not stringent enough to create a solution to building-related contributions to greenhouse gas emissions, unsustainable energy consumption, and significant negative environmental impact. New codes and legislation should be developed and enacted that reduce consumption and improve positive environmental impact.

Sources and References

The following groups have been cited or quoted in the development of this White Paper. Building Design + Construction thanks these groups for their work.

Mark Bomberg, Syracuse University
BASF
Steve Easley, Steve Easley & Associates
Environmental Protection Agency
Green Building Initiative
Honeywell
Lawrence Berkeley Laboratory
National Institute of Standards & Technology
National Oceanic and Atmospheric Administration
Oak Ridge National Laboratory, Buildings Technology Center
Bill Rose, University of Illinois at Urbana-Champaign
Spray Polyurethane Foam Alliance
U.S. Department of Energy
U.S. Green Building Council

Corporate Sponsor Honeywell

Honeywell has been a key supplier of fluorocarbon insulation for more than 40 years. Throughout this time, Honeywell has been a global leader in developing and commercializing products that meet the needs of the global foam market, as well as the most comprehensive technical, regulatory, health, safety, and environmental support, which is critical in ensuring safe and effective use of these products.

Honeywell