

Insulation and Waterproofing for Metal Buildings & Metal Roof Systems

The case for using better insulating and waterproofing technologies in metal roof systems and metal buildings.



Executive Summary: The Use of Advanced Insulating and Waterproofing Technology in Metal Buildings and Metal Roof Retrofits

In this technical white paper, the use of closed-cell spray polyurethane foam (ccSPF) in metal buildings and metal roof retrofits and re-roofing projects is discussed, demonstrating the benefits of ccSPF for improving building energy efficiency, structural integrity, moisture resistance, and other key performance factors.

Closed-cell SPF has a significant history of use with metal building systems, including metal roofing and cladding assemblies. This paper reviews the application of ccSPF for roofing in new, retrofit and renovated building projects, and discusses the significant benefits associated with such practices – in particular, for high-performance insulation and moisture control.

Closed-cell SPF is ideally suited to metal building applications due to its light weight, durability, and conformability to virtually any surface geometry. More important, however, ccSPF adds a number of high-performance attributes to metal roofing and cladding assemblies, including: high R-value thermal insulation, good acoustical performance, and reduced uncontrolled air infiltration and exfiltration – which can lead to improved indoor air quality (IAQ). In addition, ccSPF is self-flashing and sealing, provides good wind uplift resistance, high compressive strength, increased racking strength, and lowered roof surface temperatures.

In terms of cost, the replacement of metal roofing and wall panels can cost \$10 to \$13 per square foot (sq. ft.). In contrast, a ccSPF application can range from below \$3 to \$5 per sq. ft. – less than half the replacement cost – while providing both additional insulation and waterproofing as well as other features and benefits to the building owner, discussed in the following pages.

Table of Contents

Executive Summary – Making Metal Buildings Better with Closed-cell Spray Polyurethane Foam (ccSPF).....	Page 1
Metal Building Challenges and ccSPF Solutions	Page 2
ccSPF Roofing Applications.....	Page 2
Severe Weather Resistance of ccSPF Roofing Systems.....	Page 8
ccSPF Insulation Systems	Page 9
Sustainable Construction Using ccSPF	Page 16
Conclusions: Inside or Out, Where Should ccSPF Be Installed?.....	Page 18
Credits and Sources.....	Page 18
Addendum: Building Code Requirements for Metal Buildings and ccSPF.....	Page 20

In this Commercial construction technical white paper, we examine general principles and some recommended practices for selecting, designing, and erecting hybrid metal building systems using ccSPF. Solutions for commonly used building systems are discussed, for both new construction and renovation applications. Attention is given to typical dimensions, materials, surface treatments, and construction approaches for these situations. Performance expectations are also outlined, such as durability, energy efficiency, sustainability considerations, and maintenance requirements. Finally, new developments in the codes and standards affecting ccSPF and metal construction are reviewed. Case studies are presented to highlight the real-world track record of ccSPF construction approaches for metal buildings.

Properly specified and applied, ccSPF is shown to provide significant benefits for new construction and renovation projects.

Metal Building Challenges and ccSPF Solutions

While it may surprise some, in 2004 metal buildings comprised more than 40% of all low-rise, nonresidential facilities constructed in the United States, according to the Metal Building Manufacturer's Association (MBMA). In 1999, MBMA reported more than 2 billion square feet per year of standing-seam roofing installed, and more than 50% of all commercial/industrial buildings utilized metal roofing systems or decking.

Properly designed, constructed and maintained, a metal building or roof assembly should last 15 to 30 years before serious maintenance is required. Yet, thousands of metal buildings and metal roofing assemblies are in need of retrofit or replacement long before their expected life span.

In fact, pressing concerns associated with metal buildings and metal roof systems now face building owners and specifiers. Factors that must be addressed in both new and retrofit construction include movement due to thermal expansion and contraction, moisture condensation, uncontrolled air movement, thermal bridging, radiant heat absorption, and energy efficiency. These factors are crucial for long-term energy efficiency and durability.

This commercial construction white paper addresses each of these factors, and demonstrates how ccSPF can be used cost effectively to solve many of these concerns.

Costs and Considerations

Properly designed and installed, ccSPF can provide a solution for metal building and metal roof concerns. The material is sprayed onto a surface as a liquid. Within seconds, the foam – while still in a fluid-like state – expands 30 to 40 times its original volume to form a lightweight insulation. In this way, the material fills in cracks, crevices and areas that are difficult to reach with other materials.

There are two ways to effectively use ccSPF in metal buildings:

- (1) installed as a roofing system or insulated exterior wall covering, or
- (2) installed to the interior walls and ceiling of the metal building.

Each of these options has distinctive benefits, and a number of factors determine which system to use for a specific metal building project.

In all cases, however, the use of ccSPF can be highly cost-effective. According to RS Means cost data, replacing metal roofing and wall panels can cost \$10 to \$13 per square foot (sq. ft.), whereas a ccSPF application can range from below \$3 to \$5 per sq. ft.

ccSPF Roofing Systems

As a roofing system, ccSPF installed upon a standing-seam metal roof or metal roof-deck system consists of the application of ccSPF at a nominal density of 3 pounds per cubic foot (lb/ft³), with an elastomeric coating or single-ply membrane. The foam is sprayed directly onto a properly prepared surface – it should be clean, dry, and free of contaminants – in lifts averaging approximately 1-2 inches in thickness. Its total installed weight is normally between 1-2 lbs. per sq. foot.

The foam sets up in minutes and is then typically coated with an elastomeric coating – usually an acrylic, silicone, or polyurethane that protects it from ultraviolet (UV) rays. Some

fleeced-backed fully-adhered and other single-ply systems specifically designed for SPF can also be installed over ccSPF insulation systems. The foam is self-flashing around most penetrations, parapet walls, and the like, and the material is flexible enough to withstand some structural building movement, generally deflections of less than 1/2 inch.

Application Guidelines – and Solutions

Many organizations, such as the National Roofing Contractors Association (NRCA), the Spray Polyurethane Foam Alliance (SPFA), and SPF manufacturers, have developed application guidelines and standards on ccSPF roofing systems. **Table 1** on page 3 lists some of the better-known guidelines available to the design community. The guidelines and standards listed include the minimum physical properties of ccSPF that a Building Team would expect in exterior applications. **Table 2** on page 4 identifies those properties.

It is valuable to note that ccSPF roofing systems can address numerous challenging conditions associated with metal building and roof assemblies. All roof installations are quality inspected by the manufacturer or accredited third party before the warranty is issued. The following is a partial list of those items and the solutions offered by the use of ccSPF roofing systems:

1. Movement due to thermal shock expansion and contraction. Metal expands and contracts with varying ambient temperatures, causing fasteners to wear and pull out, flashing to delaminate and separate, metal panels to separate, and welds to break loose – which can cause roofs to start leaking. Serious water damage and loss of structural integrity can be the result.

Installed in a roofing system, ccSPF eliminates thermally induced movement by providing a continuous layer of a highly effective insulation above the roof deck. Metal is an effective heat conductor. Lawrence Berkeley National Laboratories has measured dark-colored roof substrates up to 190 degrees F on a 95 degree F day, and up to 160 degrees F on a dark, gray-colored surface (the color of most metal roofs). Research conducted by Dr. Mark Bomberg of Syracuse University demonstrates that the application of a seamless, continuous insulation on top of the metal roof deck and metal framing members reduces the temperature differential between the roof metal deck and the interior temperatures. This in effect “puts the roof to sleep,” minimizing thermal expansion and contraction caused by varying temperature.

Spray polyurethane foam also offers additional sound reduction from building movement and outside noise.

Table 1: ccSPF Exterior Application Standards and Guidelines

Organization	Guidelines or Standards			
SPFA	AY 104, Guideline to New and Remedial Roofing using SPF	AY, 134, Guideline to Insulating Metal Buildings with SPF	AY 102, Guideline to Elastomeric Coatings Used in SPF Roofing	AY 122, Guideline for Renewal of SPF Roofing Systems
NRCA	Low Slope Waterproofing Manual	Quality Control Guidelines for the Application of Spray Polyurethane Foam Based Roofing Systems		
ASTM	D 5469, Standard Guide for the Application of SPF Roofing Systems	D 6705, Standard Guide for the Repair and Recoat of SPF Roofing Systems	C 1029, Standard Specification for Spray-Applied Cellular Polyurethane Foam	
CSI	CSI Monograph on SPF Roofing Systems			
AIA	AIA MasterSpec on SPF Roofing Systems			

Among the organizations that have developed applications guidelines and standards on ccSPF roofing systems are the Spray Polyurethane Foam Alliance (SPFA), the National Roofing Contractors Association (NRCA), the American Society of Testing and Materials (ASTM), the Construction Specifications Institute (CSI), and the American Institute of Architects (AIA).

Table 2: ccSPF Physical Properties Used in Exterior Applications

Properties	ASTM Test	Value
Density (sprayed-in-place)	D-1622	2.5-3.0 lbs/ft ³
Compressive Strength	D 1621	40 psi min
Closed Cell Content	D-2662	90% min.
R-Value	C 177 C-577 C-1363	6.0 aged at 180 days
Flammability	E-84	75 or less
Smoke	E-84	450 or less

Listed in the table are the minimum physical properties of ccSPF that a building team would expect in exterior applications.

* Note: ccSPF roofing systems can be approved as a Class A, Class B, or Class C roof covering in accordance with UL 790 or by FM as a class I roof covering.

2. Condensation. Metal is a good conductor and will promote condensation if the exterior climate and interior climate collide on the metal surface, creating dew point conditions. Proper installation and use of vapor retarders, continuous insulation, and effective air barriers can help prevent condensation. In practice, however, the many angles, tight corners, irregular surfaces, cracks and crevices on a typical roof can make it difficult to install these climate-control measures properly. Poorly insulated and sealed metal buildings will experience a significant amount of sweating, especially if the buildings are climate-controlled. The moisture condensation can cause water damage to the interior of the building and premature corrosion of the metal. Corrosion to a metal roof decking system can be a major safety hazard for anyone that has to access the roof for roof top service or repairs.

As shown by the dew point calculations in **Table 3** on page 4, condensation can easily form inside a poorly insulated metal building with interior humidity as low as 20%. With a ccSPF roofing systems sprayed to the existing roof deck, a continuous layer covers fasteners, metal roof panels, and penetrations through the roof (such as pipes and supports) and completely separates metal beams, joists, purlins, and the metal roof deck panels from contact with outside temperature and humidity. This thermal break eliminates the potential for condensation.

3. Air movement within the building. Metal buildings are hard to make airtight. Metal panels typically do not have good continuous air seals along the intersections of walls, roofs, and floors. For that reason, large amounts of air can travel into and out of metal buildings unless an effective air-barrier system is installed. Peel-and-stick membranes can be difficult to install in these buildings. The tight, irregular-shaped edges, corners, and junctions make it challenging to apply the membranes effectively as an air seal.

The National Institute of Standards and Technology (NIST) estimates that effective air-barrier systems could save up to 83% of air leakage in nonresidential buildings, which would save more than 40% on gas bills and more than 25% on electrical consumption.

As described earlier in this paper, ccSPF is sprayed onto the roof surface as a liquid and expands 30 to 40 times its original volume to form a lightweight insulation that fills in cracks, crevices, and voids. It completely air-seals around and through roof protrusions such as vents, pipes, stacks, structural supports, parapet walls, drains, and the like. Combined with an interior

Table 3: Dew point Based on Varying Temperature

Inside Temperature	Inside Humidity	Dew point	Outside Temperature	Condensation
70° F	20%	27° F	20° F	Yes
70° F	20%	27° F	30° F	No
70° F	30%	37° F	30° F	Yes
70° F	40%	44.6° F	40° F	Yes

Dew point calculations show that condensation can easily form inside a poorly insulated metal building with interior humidity as low as 20%.

air-barrier system on the walls and floors of the building, ccSPF can completely control air leakage within a metal building.

4. Thermal bridging. Thousands of fasteners and welds intersecting with hundreds of metal beams and metal panels conduct heat into and out of metal buildings, causing insulation to be less effective. As demonstrated in **Table 4** on page 5, 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% to 31.5%, depending on the number and type of fasteners.

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

5. Solar absorptivity and the “urban heat-island effect.” The typical gray-colored metal roof can reach up to 160 degrees F on a 90-degree day. The resulting heat transmitted into the building makes the HVAC equipment

work harder to cool the building. The situation becomes worse if metal roofs are coated with darker coatings, thereby absorbing additional heat that is transmitted to the interior. Dark-colored roofs, parking lots, and roads collectively contribute to an increase of temperature in an urban area, causing what scientists call the “urban heat-island effect.”

Commercial ccSPF roofing systems can cover dark-colored roof planes with continuous insulation that is then covered typically with a high-reflective and low-emissivity (low-E) cool roof coating. The combination of a radiant energy-refracting insulation with a reflective coating significantly reduces rooftop temperatures. ccSPF Energy Star rated systems are available, so consult the specific manufacturer and Energy Star for more details.

Illustration 1 and **Illustration 2** on page 6 demonstrate the energy-saving characteristics of ccSPF roofing systems from thermal bridging and radiative heat absorption. The first illustration shows an insulated membrane roof over a metal deck with numerous thermal bridges through

Table 4: 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		
	Assumed	Calculated	Loss %	Assumed	Calculated	Loss %	Assumed	Calculated	Loss %
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.

Illustration 1: Effects of Radiant Heat on Metal Roof Decks

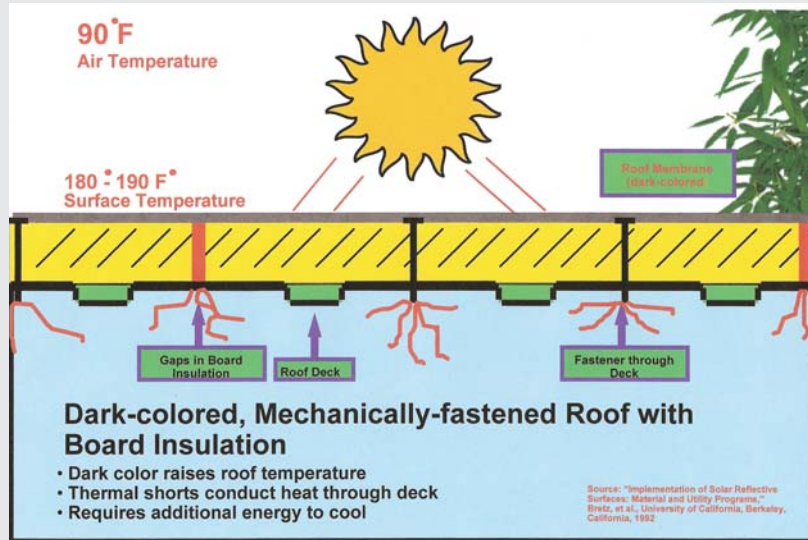
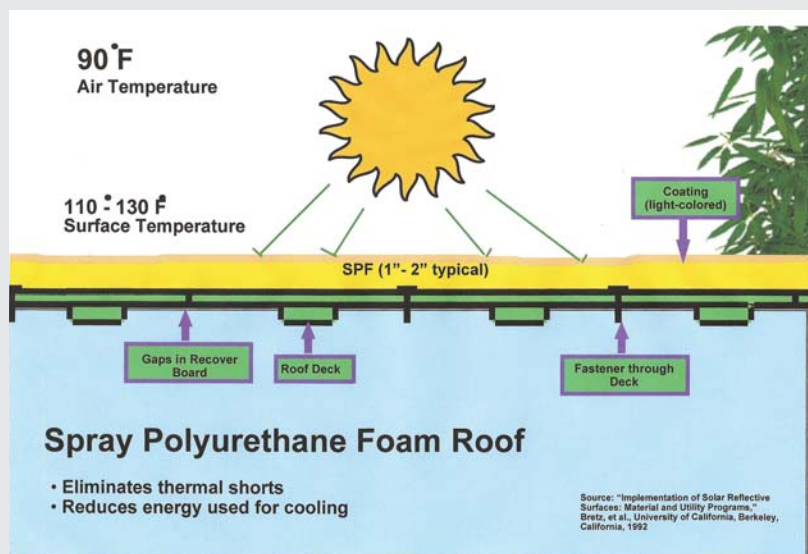


Illustration 2: ccSPF Roofing Systems Affecting Radiant Heat Energy of Metal Roof Decks.



These images demonstrate the energy-saving characteristics of ccSPF roofing systems from thermal bridging and radiative heat absorption. Illustration 1 shows an insulated membrane roof over a metal deck with numerous thermal bridges through gaps and fasteners. Illustration 2 shows the energy-saving characteristics of ccSPF installed over the existing roof covering and metal deck. The ccSPF completely covers the fasteners and gaps while providing a heat reflective surface reducing the roof top temperature.

gaps and fasteners. The second illustration shows the energy-saving characteristics of ccSPF installed over the existing roof covering and metal deck. The SPF completely covers the fasteners and gaps while providing a heat reflective surface reducing the

roof top temperature. "Energy Star Heat Island" effect is measured in ALBEDO NUMBER - for roofs and the number must be higher than 0.65 and above 0.50 for 3 yr. aged roofs. Many ccSPF polyurethane coatings achieve a number of 0.77 or above and an

aged value of 0.63 or above - well above the requirement".

6. Preventing leaks and sealing irregular surfaces and junctions.

With metal roofs and buildings, it can prove challenging and costly to identify and locate water leaks due to the irregular surfaces and angular corners and junctions. Flashings tend to move, increasing the potential for water leaks that may be hard to detect and to stop.

On the other hand, ccSPF conforms to the irregular surfaces, corners, and junctions, forming a fully adhered, seamless waterproofing membrane that helps eliminate leaks. The closed-cell physical properties of the ccSPF material prevent water leaks from penetrating through the foam and traveling laterally.

In terms of analyzing vulnerability to wind or hail damage, a recent report sponsored by the National Roofing Foundation (NRF) surveyed 140 ccSPF roofs ranging from new to 27 years old. The NRF research discovered that where roofs had experienced hail strikes, the damage was localized to the upper surface of the foam. Most roofs were repaired rather than replaced which is often the case with other types of roofing systems..

Illustration 3 and **Illustration 4**, on page 7, show that the closed-cell foam inhibits water from traveling laterally, even if the foam surface is damaged. Repairs can be easily made with sealant or foam packs.

7. Energy efficiency.

There is great potential for poor energy efficiency

Illustration 3: Water Leaks in Membrane Roofing on Metal Deck

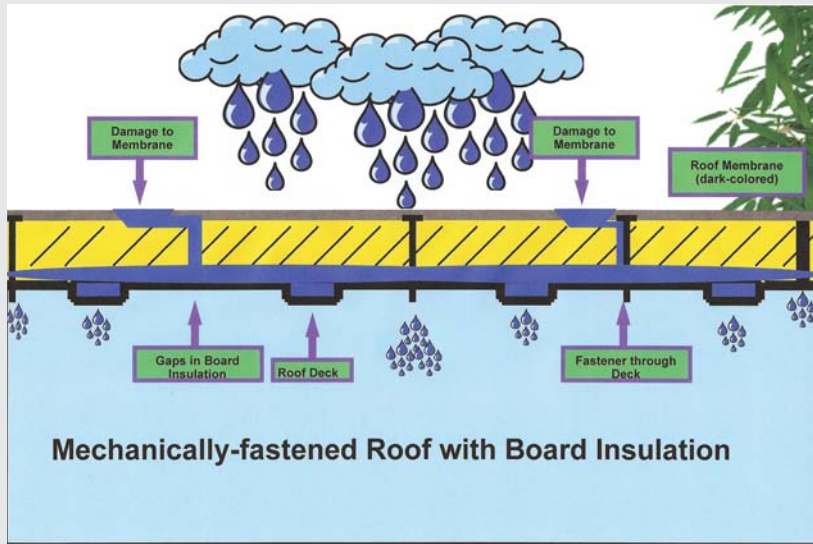
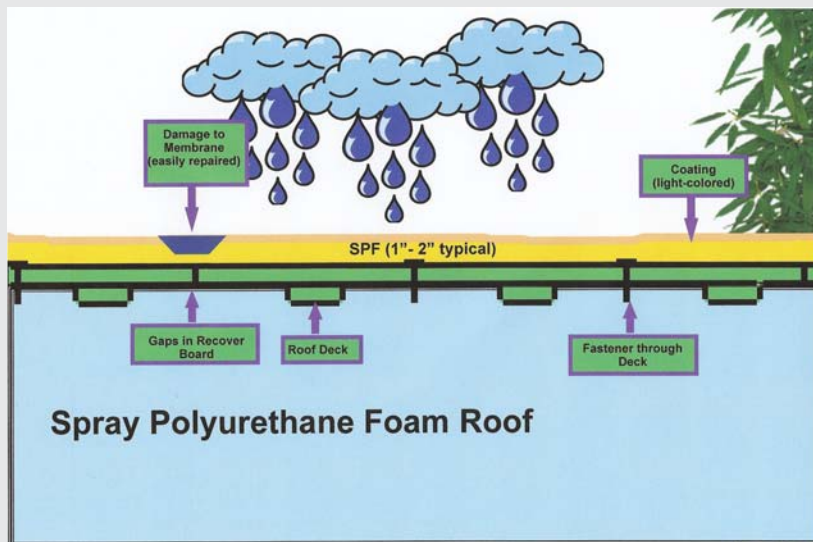


Illustration 4: ccSPF Preventing Water from Traveling Laterally and Through Metal Deck



As these illustrations show, the closed-cell foam of ccSPF roofing does not allow water to travel laterally even if the foam surface is damaged. Repairs can be easily made with sealant or foam packs.

in metal buildings if factors such as air infiltration, radiation, and thermal bridging are not adequately addressed. Traditional insulation techniques provide poor solutions to controlling these factors; for that reason, the forces of convection, conduction, and radiation heat transfer rob many metal buildings of their energy efficiency.

On the other hand, ccSPF roofing systems increase energy efficiency in metal buildings four ways:

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

Research compiled by Dr. Mark Bomberg on the energy efficiency of ccSPF roofing systems confirms that the roofing system can dramatically increase the energy efficiency of metal buildings and metal roof assemblies. The Davis Energy Group has used Dr. Bomberg's data to create the "SPF Roof Energy Calculator," shown on page 8.

For example, the calculator estimated that fiberglass batt insulation installed to the underside of a metal roof in a conditioned warehouse would provide negligible insulation value, while ccSPF installed as a roofing system would provide a

Illustration 5: Comparing Energy Performance of ccSPF Roofing to a Metal Roof Decks with Insulation on the Underside of Roof Deck


Project Editor



EPMT

Exit Project Envelope HVAC **Roof** Calculate Results

Project Name: **metal roof, 1**

Roof Age: 15

 New Roof

	Existing Roof	SPF Roof Spec. 1 	SPF Roof Spec. 2 
Membrane			
Material:	Metal	Metal	Metal
Color:	Grey	Grey	Grey
Reflectivity (%):	40	40	40
Additional Insulation			
Material:	None	None	None
Thickness (in):			
Roof Insulation			
Material:	None	SPF	SPF
Thickness (in):		2	3
Fasteners/Board:	None	None	None
Gaps Between Boards:	<input type="radio"/> Yes <input checked="" type="radio"/> No	<input checked="" type="radio"/> Yes <input type="radio"/> No	<input checked="" type="radio"/> Yes <input type="radio"/> No
Moisture Effect:	<input type="checkbox"/>		
Roof Deck			
Material:	Vented Metal	Vented Metal	Vented Metal
Thickness (in):			
Framing			
Material:	Metal	Metal	Metal
Dimension:	4x2.5 12g	4x2.5 12g	4x2.5 12g
Spacing (in):	16 on-center	16 on-center	16 on-center
Ceiling Insulation			
Material:	R-19 Batt	R-19 Batt	R-19 Batt
Thickness (in):			
Location:	Direct to Deck	Direct to Deck	Direct to Deck
Attic Air Space (ft):	0	0	0
Vented Attic:	<input type="radio"/> Yes <input checked="" type="radio"/> No	<input type="radio"/> Yes <input checked="" type="radio"/> No	<input type="radio"/> Yes <input checked="" type="radio"/> No
Dropped Ceiling:	None	None	None
Assembly R-Value:	1.8	18.3	22.6
	Save	Cancel	

The Davis Energy Calculator was used to estimate the energy performance of a ccSPF roofing system and a metal roof deck with fiberglass insulation on the underside of the deck. The batt insulation provided negligible insulation value for the conditioned warehouse, while the ccSPF roofing system provided a higher R-value performance than the rated R-value of the foam.

higher R-value performance than the rated R-value of the foam.

Severe Weather Resistance of ccSPF Roofing Systems

Severe weather is the toughest test for any building system or component. High winds, airborne projectiles, wind-driven water, sea surges, flooding, hail, and snow are among the hazards that threaten buildings and their occupancies. Most buildings fare poorly in moderate weather, let alone severe conditions. The record for U.S. property insurance tells the story: Annual claims for hail damage alone, for example, average \$1.94 billion. Wind damage claims tally hundreds of millions of dollars. (The numbers for water damage are very high also, but much water damage incurred annually is not due to severe weather events.)

With a vested interest in how buildings perform during severe weather, the insurance industry carefully tracks how much of the losses can be attributed to which specific materials and assemblies. Not surprisingly, roofing has been found to be the primary contributor to disaster-related insured losses. Roofing is the culprit behind escalating insurance premiums for building owners, which has pressured architects, engineers and contractors to specify, detail and construct roofing systems with proven

resistance to wind effects, hail, and other severe weather effects.

At first glance, metal roof systems and assemblies would appear to have good resistance against severe weather. But high winds can find the weak spot in any roof assembly. In metal roofs, the weak spot would be a poor weld, rusted panel, or a fastener that has started to back out. Once the weak spot gives, the wind peels the rest of the metal panel back, exposing the interior. Wind-driven debris and hail typically don't cause leaks to metal roofs, but they can leave unsightly dents that cannot be easily remedied.

Solutions for Severe Weather

Hurricane investigations by NIST, NRCA, the Roofing Industries Committee on Weather Issues (RICOWI), and other groups show that ccSPF assemblies have a remarkable track record of performance in severe weather situations. Highlighting the effectiveness of ccSPF roofing during severe weather, many manufacturers of ccSPF building assemblies now offer an “UNLIMITED WIND WARRANTY.” The first of its kind, these warranties assure that the ccSPF roofing membranes will not blow off, regardless of wind speed.

When it comes to protecting roofs against natural disasters, especially hurricanes, ccSPF roof systems have shown remarkable resistance to high wind uplift and blow-off, a characteristic attributed to its spray-applied application, strong adhesion, without the need for fasteners and absence of joints or edges for the wind to grab onto. Furthermore, ccSPF is resistant to progressive peeling failure due to missile impact, deck failure, and peeling failure at the roof edge, not to mention preventing water infiltration following missile impact.

In fact, laboratory testing of ccSPF systems found that the foam's wind uplift resistance actually exceeded the capacity of Underwriters Laboratories (UL) equipment. In addition, the UL noted that ccSPF applied over BUR and metal increased the wind-uplift resistance of those roof coverings. FM Global's testing showed similar results over concrete, metal, and wood and enabled FM to approve ccSPF roofing systems for an I-250 wind rating over metal and an I-990 rating over concrete.

RICOWI's Hurricane Katrina Investigation Team 1 documented more than 2 million sq. ft. of ccSPF installed

to metal roof decks and metal buildings that survived the 2005 storm with minimal damage when buildings next to them were seriously damaged from pressurization and high winds. In terms of hail damage, the NRF report of 140 ccSPF roofs discovered that “one unique aspect of SPF roofs ... is that they are not in immediate danger of leaking, provided the penetration does not extend all the way through the foam.”

According to roofing industry experts, ccSPF is a very good energy impact-absorbing material compared to other type roofing systems. Hail and wind-driven missile damage rarely cause leaks in a ccSPF roof. The damage typically can be repaired at a later date without compromising the long-term performance of the ccSPF roofing system.

Building Code Considerations

Other standards and codes affect the specification and application of ccSPF. Key building codes include the International Building Code (IBC) and the International Energy Conservation Code (IECC). (A discussion of relevant codes and standards is provided in the Addendum on page 20.)

Key codes for Building Teams to review include: standard specifications for ccSPF and its protective coatings, roof covering tests, and general code compliance for exterior insulation systems and R-value requirements. Other important and applicable codes include sections on R-value requirements and vapor retarders. Many of these are given in the IBC and IECC.

ccSPF Insulation Systems

Typical ccSPF interior wall or ceiling insulation systems consist of the application of spray foam at a nominal density of 2 lbs. per cubic ft. onto a properly prepared surface – clean, dry, and free of contaminants – it is applied in lifts averaging approximately 1-2 inches in thickness to the desired thickness and R-value required. The foam sets up in minutes and is then covered with an application of a thermal barrier (in interior spaces) or an ignition barrier (in walls, attics or crawl spaces). The foam is self-flashing around most penetrations, parapet walls, and the like.

Table 6: ccSPF Guidelines and Standards for Interior Applications

Organization	Guidelines or Standards			
SPFA	AY 112, Guideline to SPF Used in the Building Envelope	AY, 134, Guideline to Insulating Metal Buildings with SPF	AY 118, Moisture Vapor Transmission	AY 126, Thermal Barriers for the SPF Industry
ASTM	C 1029, Standard Specification for Spray-Applied Cellular Polyurethane Foam			

The material is also flexible enough to withstand most structural building movement – less than 1/2 inch typically.

As for guidelines and standards for specifying the application of ccSPF in interior applications, **Table 6** and **Table 7** on page 10 list the applicable documents that will be useful in ensuring a successful project.

As with ccSPF exterior roofing applications, ccSPF used in interior insulation applications can significantly benefit conditions found in metal buildings.

Specifically, the use of ccSPF in metal buildings can help provide better climate control leading to decreased energy usage, reduced air infiltration, better moisture control, and improved indoor air quality (IAQ). The applied ccSPF can improve the durability of metal buildings as well, providing some structural enhancements.

Movement and Structural Integrity

Metal buildings tend to move due to thermal effects, in some cases causing fasteners to back out and welds to loosen. These dynamic effects can lead to water leaks, corrosion, and premature failure of the metal panels. In severe weather, high winds can peel the fatigued metal panels from their structural supports and framing.

Application of ccSPF can increase the structural strength of existing metal buildings. The degree of hardening depends primarily on the strength of the building to begin with. For example, a post-frame constructed building with 29 gauge corrugated metal panels will benefit from an interior application of ccSPF to the building considerably more than an I-beam modular constructed metal building with a 22 gauge metal panel.

Table 7: ccSPF Physical Properties Used in Interior Applications

Properties	ASTM Test	Value
Density (sprayed-in-place)	D-1622	1.5 - 2.0 lb/in ²
Compressive Strength	D 1621	15 -25 psi
Closed Cell Content	D-2662	90% min.
R-Value	C 177 C-577 C-1363	6.0 aged 180 days
Flammability	E-84	75 or less
Smoke	E-84	450 or less

These guidelines and standards can be used to specify the application of ccSPF in interior applications. They list the minimum physical properties of ccSPF that a builder or designer would expect in exterior applications.

Once installed, ccSPF “glues” the metal assembly together, reducing the potential for movement by adding a tensile strength average of 15 psi to 25 psi. The spray foam also provides a secondary barrier against water and moisture intrusion, reducing the potential for corrosion caused by water leaks into the building.

Supporting the strengthening capabilities of ccSPF, racking performance tests conducted by the Spray Polyurethane Foam Alliance (SPFA) in 1992 and 1996 and at Architectural Testing Inc., York, PA. (ATI) in 2007 demonstrated that medium-density ccSPF (installed at 2.0 lbs. per cubic ft.) increases racking strength by 70% to 200% in wall assemblies sheathed with oriented strand board (OSB), plywood, gypsum wallboard, vinyl siding, and polyiso board. The research demonstrated that

Table 8: 1992 SPFA Racking Test Results

SPF Panels			Non-SPF Panels	
Stud Spacing	Vinyl Sheathed	5/8" Plywood	Vinyl	5/8" Plywood
16"	2,800	5,300	913	2890
24"	2,420	6,387	nt	nt
32"	2,588	nt	nt	nt
48"	2,298	nt	nt	nt
16" Braced	nt	nt	3,853	5,262

nt = not tested

NOTE: Average maximum racking load (in pounds) supported by each panel configuration

Table 9: 1996 SPFA Racking Test Results

Specimen	Max Racking Load (pounds)	Max Racking Deflection (inches)	Max Racking Set (inches)
OSB with R-19	4,800	1.045	.516
OSB with SPF	6,000	.767	.142
Drywall with R-19	2,400	.856	.413
Drywall with SPF	5,380	.945	.407

Table 10: 2005 ATI Racking Test Results

Wall Assembly	Maximum Racking Load (pounds)
Test 1 1/2" OSB	2908
Test 2 1/2" Polyiso:	1109
Test 3 1-1/2" SPF/Polyiso:	2259
Test 4 3" SPF/Polyiso	2,152

ccSPF significantly increased rack and shear strength in both wood and metal stud construction. In the 1992 study, ccSPF-filled walls achieved similar racking strength at stud spacings of 16 inches, 24 inches, 36 inches, and 48 inches.

Installed ccSPF also increased the strength of weaker substrates such as gypsum drywall, vinyl siding, and polyiso foam insulation at a much greater percentage than stronger

substrates such as OSB and plywood. In fact, special bracing for wind resistance would not be required for strengthening purposes when using ccSPF in the walls.

As a structural material, medium-density ccSPF can add strength to wall and ceiling assemblies of all sizes and heights, depending on the framing. The 2007 ATI study demonstrates how the racking strength can be enhanced; see **Table 8**, **Table 9**, and **Table 10** on page 11 for the results of these important tests.

While the structural performance testing of ccSPF was not conducted on metal building panels, the historical evidence of ccSPF enhancing the structural strength of existing metal buildings is impressive. The following buildings are examples of the significant structural enhancement that can be expected when using ccSPF to strengthen buildings:

- 1. Pascagoula Shrimp and Ice Co.:** Team members of the Roofing Industries Committee on Weather Issues (RICOWI) Hurricane Katrina Roof Investigation came upon a local business, Pascagoula Shrimp and Ice Co., that had suffered massive damage from high winds during Hurricane Katrina. Two of the roof coverings, consisting of ballasted EPDM and fully adhered

modified bitumen, were ripped off the structure. In one area, pressurization inside the building blew apart a tongue-and-groove wood roof deck. However, three sections of the building consisting of metal panels were insulated with ccSPF from 1975 to 1985. No significant damage occurred to any of the portions insulated with ccSPF. The owner of the building, David Gautier, reported that not only did the ccSPF sections survive Hurricane Katrina in 2005 but also four other hurricanes in the last 30 years.

2. White's Lumber: Mason Knowles Consulting LLC insulated many buildings in the South Padre Island area during the 1970s. White's Lumber was a post-frame construction consisting of corrugated metal panels mechanically fastened to wood trusses. Mason Knowles Consulting LLC installed 2 inches of ccSPF to two walls and a ceiling portion of the building where offices were to be built. After installation of the foam and before construction of the offices, the building took a direct hit from 120 mph sustained winds from Hurricane Allen in 1980. After the storm, all of the corrugated metal panels were missing except those sprayed with ccSPF. The metal panels were replaced, and Mason Knowles Consulting LLC was contracted to install ccSPF to the seams and panel-truss interface in a "picture-frame" technique to enhance the attachment of the panels to the wood trusses. On July 23, 2008, the building was again shaken by a direct hit from Hurricane Dolly with sustained winds over 100 mph. The metal panels that were "picture framed" with ccSPF withstood the winds with no damage while more than a third of new metal panels installed the previous year (without ccSPF) blew off the building.

Saving Energy, Minimizing Air Movement, Controlling Moisture

There are severe challenges facing designers when trying to provide energy efficiency and control air movement and moisture in metal buildings. Dr. Mark Bomberg, P.E., while a scientist at the National Research Council of Canada, conducted and compiled enough research on how ccSPF performs in buildings to write a book, *SPF in External Envelopes in Buildings*. In this reference, Dr. Bomberg discusses the importance of "controlling interactions of heat, air and moisture collectively" to control the environment within a building.

Dr. Bomberg specifically pointed out the valuable contribution ccSPF could make in climate and moisture control in buildings when installed to the interior of buildings by providing the following building environmental control functions:

- Providing a continuous air barrier.
- Preventing moisture infiltration through air leakage.
- Minimizing dew point problems and condensation within the building.
- Avoiding thermal bridging.
- Resisting heat movement in all directions.
- Providing reliable performance under varying climatic conditions.

Research conducted at ATI and (Oak Ridge National Laboratory) ORNL demonstrated that ccSPF in walls and in attics performs 20% to 50% more efficiently than conventionally insulated assemblies.

As reported earlier in the roofing section, thousands of fasteners and welds intersecting with hundreds of metal beams and metal panels conduct heat into and out of metal buildings, causing insulation to be less effective. Studies by ASHRAE show that thermal bridging in metal buildings can rob up to 40% of the building insulation's energy efficiency. ccSPF can be spray applied in a way to provide a continuous insulation that extends beyond the metal panels to include the beams, girts, purlins, fasteners and other metal connections and junctions on the inside of the building to greatly reduce the potential for thermal bridging. Not only will this save energy usage and costs but building codes allow a reduction in prescriptive R-values when the insulation is continuous.

Air Leakage

Building owners face a serious challenge in trying to air-seal metal buildings. The unusual configurations of the metal panels, beams, and girts can leave large gaps at ceiling-wall joints and wall-floor junctions. Those voids and cracks allow moisture-driven air in and out of the building, making it very difficult to control interior temperature, humidity, and IAQ. Peel-and-stick membranes, as discussed previously, are very hard to install to these areas, while ccSPF can easily fill those gaps.

Building scientists and the design community have determined that in order for air-barrier systems to be effective, they must have the following characteristics:

- Air permeance tested to below 0.02L/sm² at 75 Pa (0.02 liters of air per second per square meter of space at 75 pascals of pressure).
- Provide continuous, structural barrier throughout the building envelope.
- Enough strength to resist air pressure loads.
- Sufficient durability to last the life of the building.

The Air Barrier Association of America (ABAA) uses the following definitions when describing air-barrier technology:

- *Air Barrier* – the primary material that prevents or reduces the passage of air through the building enclosure system.
- *Air Barrier Material* – the principal element installed to provide a continuous barrier to the movement of air through building enclosures.
- *Air Barrier Components* – the transitional element installed to provide a continuous barrier to the movement of air through building enclosures.
- *Air Barrier Assembly* – a collection of air-barrier materials and air-barrier components installed to provide a continuous barrier to the movement of air through building enclosures.
- *Air Barrier System* – a combination of air-barrier assemblies installed to provide a continuous barrier to the movement of air through building enclosures.

Many common individual building materials, such as masonry, wood sheathing, OSB, foam sheathing, metal panels, and the like, are classified as air-barrier materials based on the these ABAA definitions. But many of these installed materials leak enormous amounts of air through gaps, cracks, and crevices around corners, edges, seams, and fasteners that are integral parts of their construction. In order for these materials to become part of an air barrier assembly and system, other materials are required to seal those gaps, cracks, and crevices.

Common products employed to seal the openings include:

- Peel-and-stick membranes.
- Sealants and caulks.
- Closed-cell spray polyurethane foam (ccSPF).
- Spray-applied barrier membranes.
- Building/House wraps Housewraps.

Of these materials, ccSPF offers one clear advantage: ccSPF is installed as a liquid and expands to about 30 times its original volume to effectively seal cracks and crevices that are hard to see and reach. The ccSPF material adheres well to a large variety of substrates, including wood, masonry, metal, foam plastic sheathing and more. The physical properties of the foam do not decline significantly with time, and instead retain their air-sealing, insulating, and strengthening characteristics for the effective life of the building.

Blower door tests and other whole-building analyses consistently demonstrate that ccSPF significantly tightens up the air sealing properties of a building. One example:

CASE STUDY – Energy Solutions of Charleston. The company Energy Solutions of Charleston, LLC, was contracted to perform a case study of the offices of Solar Reflection Inc., located in Charleston, S.C. The baseline testing using the blower door test measured an air leakage flow rate of 1350 cubic feet per minute (cfm). This equates to 0.30 air changes per hour (ACH), or 30% of the air being replaced every hour due to air leakage in the building. During the testing, air leakage was found around doors, windows, and both interior and exterior wall penetrations such as light switches, wall outlets, lighting fixtures, and plumbing penetrations. Following a spray-foam installation in the attic space, the air leakage flow rate was reduced to 700 cfm, or 0.16 ACH. This was a decrease in air leakage of about 47%.

Energy Efficiency

Proof of the air-barrier and insulation benefits of ccSPF has come through documented testing performed at ATI, Architectural Testing Inc., York, PA. ATI is a full-service lab that certifies building products and assemblies for commercial use, such as U-value ratings and the hurricane resistance of doors and windows.

In 2004, the American Plastics Council (APC), as part of the American Chemistry Council, undertook a wall-insulation performance study at the NAHB Research Center. (ATI was contracted to serve as the laboratory for the study.) The purpose of the study was to compare the most common “baseline wall” – in this case, fiberglass batt insulation between 2x4 wood studs, finished with interior drywall – against several walls

Table 11: ATI Wall Performance Data

ATI Test Results: 2 lb density ccSPF installed to OSB:

Assembly	Exterior	Interior	Pressure	U	Ru	C	R	Air Flow	Specimen Heat Flow
	Deg F	Deg F	In WC	BTUH	Ft2-F	BTUH	Ft2-F	SCFM	BTUH
				Ft2-F	BRUH	Ft2-F	BTUH		
Gypsum Board	24.98	70.00	0.00	0.078	12.823	0.090	11.169	0.00	231.771
2lb SPF (1.5 in.)	25.01	70.00	0.101	0.084	11.866	0.092	10.907	0.21	250.302
O.S.B.	-14.99	70.00	0.109	0.087	11.431	0.095	10.547	0.27	490.820
	70.00	115.00	0.082	0.092	10.891	0.100	9.983	0.18	272.760

* U and Ru include the insulative effects of the boundary air film coefficients

*C and R do not include these effects

Table 12: ATI Fiberglass Wall Data

Fiberglass Insulated Wall Assembly:

Exterior	Interior	Wind	Pressure	U	Ru	C	R	Air Flow	Specimen Heat Flow	Specimen Area
Deg F	Deg F	In WC	BTUH	Ft2-F	BTUH	Ft2-F	SCFM	BTUH	Ft2	
				Ft2-F	BTUH	Ft2-F	BTUH			

Unit #1 1/2" gypsum R-13 KFB 7/16" OSB	24.97	70.01	with out	0.013	0.073	13.742	0.081	12.284	0.00	215.548	65.762
	25.01	70.00	with	0.115	0.097	10.316	0.105	9.533	1.71	286.761	65.762
	-14.99	70.00	with	0.126	0.102	9.829	0.110	9.076	1.85	568.621	65.762
	69.99	115.00	with	0.099	0.113	8.850	0.121	8.254	2.10	334.431	65.762

Testing performed on wood frame construction.

containing plastic building products, including foam plastic insulation.

This innovative study evaluated the energy performance of the overall wall systems. The test procedure was designed to characterize the energy consequences of material choices for the wall construction and insulation under simulated wind pressures. The study was funded by APC, and for that reason the results are owned by the American Chemistry Council.

In 2005, the SPFA contracted with ATI to test three wall assemblies insulated with ccSPF in accordance with test protocol and procedures developed by the APC and the NAHB Research Center. The results were then compared to the data for the "baseline fiberglass insulated wall."

The thermal performance measurements of the fiberglass

insulated assemblies compared to the medium-density ccSPF insulated wall demonstrate that 1.5 inches of ccSPF – with a labeled R-value of 9 – performed equal to or better than 3.5 inches of fiberglass labeled at R-13 at cold and hot temperatures. The ccSPF performed equal to the fiberglass sample even without air infiltration factored into the insulated assembly.

Additionally, the ccSPF insulated wall allowed only 0.18 to 0.27 CFM of air infiltration through the wall, while the fiberglass insulated wall allowed between 1.71 to 2.10 CFM of air infiltration through a similarly constructed wall. Air infiltration can effect energy savings as much as an additional 40% according to NIST studies.

Table 11 and **Table 12** on page 14 present the results of

Table 13: R-Values Required for Climate Zones per IBC and IECC

Climate Zone	1	2	3	4	5 & marine 4	6	7	8
Wall R-value required	R-13	R-13	R-13	R-13	R-13 + R-13	R-13 + R-13	R-13 + R-13	R-13 + R-13
Ceiling or Attic R-value required	R-30	R-30	R-30	R-30	R-30	R-30	R-38	R-38

these valuable tests.

It should be noted that the testing was performed on wood frame construction. The additional R-value reductions of thermal bridging from metal studs and framing members would be expected to increase the energy performance differences between the fiberglass insulated walls and the ccSPF insulated walls. Research performed at ORNL in 1996 concluded that similar R-values of ccSPF installed between metal studs in wall assemblies were 20% to 30% more energy efficient than fiberglass batts installed in similarly constructed wall assemblies. This testing did not include factors such as air infiltration, but rather only heat transfer through conduction. (For more information, the research conducted by Jeff Christian and Jan Kosny of ORNL, from 1993-1995, further details these gains in efficiency: www.ornl.gov/sci/roofs+walls/whole_wall/rvalue.html.)

Indoor Air Quality (IAQ)

When buildings cannot control the transfer of heat, air, or moisture within buildings, condensation – and, consequently, poor indoor air quality (IAQ) – can result.

By air-sealing the building, providing consistently effective insulation, and reducing the potential for condensation, ccSPF reduces the potential for mold growth because ccSPF is an inorganic material and allows HVAC equipment to work more efficiently. This allows the ventilation system to condition the air properly in order to promote better indoor air quality and energy efficiency.

For example, by removing fiberglass insulation and installing ccSPF Mason Knowles Consulting LLC was able to reduce the variation of humidity in the structure from 10% in winter to 65% in summer (without the ccSPF) to a range of 35% in winter to

55% in summer (with ccSPF). This reduced the potential for condensation and provided better IAQ in both summer and winter. Studies conducted by the National Research Council of Canada confirmed that buildings that are air-sealed with ccSPF maintain a much better IAQ than buildings that are not effectively air-sealed.

Building Code Requirements for ccSPF Insulation

The International Building Code (IBC) and the International Energy Conservation Code (IECC) provide building code requirements for commercial metal buildings and the use of ccSPF interior insulation systems. For ccSPF insulation systems, the following rules apply:

1. R-Value. The International Energy Conservation Code Section 502.5 contains R-value tables that prescriptively require minimum insulation values in different climate zones of the United States. See **Table 13** on page 15 to review the R-values for each climate zone.

As an alternate to the prescriptive code requirements, a building code official may at their discretion approve other designs and materials based on performance testing (in accordance with code accepted practices) that could allow R-value totals less than the prescribed value.

2. Fire Resistance. The IBC requires interior applications of ccSPF (and all other foam plastics) be fire-rated Class I or Class II in accordance with ASTM E-84. (Class I is defined as 25 flame spread or less, and 450 smoke developed or less; Class II is defined as 75 flame spread or less, and 450 smoke developed or less.)

In addition, the IBC requires that a code-approved thermal barrier – the equivalent of ½ inch gypsum wallboard – cover

Table 14: IBC Fire Performance Requirements for ccSPF

Area of Building	Max Flame & Smoke Rating	Covering	Fire Tests
Wall or ceiling	75 flame 450 smoke	Thermal Barrier	FM 4880, UL 1715, UBC 26.3, NFPA 286 required for exception to thermal barrier
Attic or crawl space	75 flame 450 smoke	Ignition Barrier	FM 4880, UL 1715, UBC 26-3, NFPA 286, SWRI-99-02
Sill Plate/header	25 flame 450 smoke	None	None required
Fire resistive walls or ceilings	25 flame 450 smoke	Thermal Barrier	ASTM E 119 for assemblies E 84 for foam plastics (not considered part of the assembly)

foam plastics in all inhabited areas, except where approved by a code official based on diversified large-scale fire tests that are specific to the application. Other exceptions are included such as:

- Ignition barriers in attics and crawl spaces.
- Small coolers or freezers (400 sq. ft. or smaller).
- Roofing systems (requires roof covering test rating of class a, b, or c).
- Sill plates and headers (2 pcf, closed-cell SPF only).

Table 14 on page 16 lists the general fire performance rules when using ccSPF.

3. Air Leakage. The IBC section 1102.4.1 requires that the commercial building thermal envelope “shall be durably sealed to limit infiltration,” and the code lists specific areas that should be caulked, sealed, weather-stripped, and gasketed with an air barrier material or solid material.

However, the codes do not provide a pass-fail criterion to determine whether a material meets the minimum requirements of an air-barrier.

4. Moisture Control. Section 502.5 of the 2006 IECC requires the use of a vapor retarder in commercial buildings with a permeance of 1 or less on the warm side of the insulation in climate zones 5, 6, 7, 8 and marine 4. When ccSPF is installed at 2 inches or greater, the material typically provides a permeance of 1 or less.

The 2007 IECC Supplement section 502.5 introduced three classes of vapor retarders as follows:

- Class I vapor retarder: > 0.1 perms
- Class II vapor retarder 0.1 - 1.0 perms
- Class III vapor retarder < 1.0 - > 10.0 perms

The 2007 IECC Supplement allows Class I and Class II vapor

retarders in all climate zones and allows Class III vapor retarders in Climate zones 1 through 4 without additional vapor retarders, but with specific restrictions in climate zones Marine 4, 5, 6, 7, and 8.

Regardless of the code prescribed, ccSPF can be used in all climate zones of the US without an additional vapor retarder – if the vapor drive is not consistently in one direction.

Sustainable Construction Using ccSPF

The terms “green building” and “sustainable design” building have been around for many years and yet may be interpreted different ways by many diverse groups, including the U.S. Green Building Council (USGBC), the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE), the NAHB, and the American Institute of Architects (AIA). But after more than a dozen years of debate, all of these groups agree buildings that are “sustainable” when they use resources more efficiently, conserving energy, water, and materials while reducing the building’s impact on human health and the environment.

As emphasis on the environmental impact of buildings increases, building owners are beginning to recognize the unique features and physical characteristics of ccSPF that assist in the development of sustainable building design. For example, designers and builders can use ccSPF to:

- Reduce energy usage.
- Reduce construction waste.
- Performing multiple design functions to eliminate additional materials.

- Increase durability of buildings.
- Provide environments to better control IAQ.
- Extend life of assemblies (such as roofing systems).
- Decrease urban heat-island effect.
- Enable other sustainable or green features of a building to perform more efficiently, such as photovoltaic panels for solar energy systems.
- On-site manufacturing.

Whether ccSPF is used inside the building or on the outside, it can reduce the total amount of construction materials used in the building. Reducing the amount of construction materials eliminates all of the environmental life-cycle drawbacks of those materials including extraction of natural resources, the energy it takes to manufacture those items and the maintenance and eventual disposal of the items.

Durability: Beginning in 1983, Dr. Dean Kashiwagi, a teaching professor at the Del E. Webb School of Construction at the University of Arizona, has surveyed and documented the performance of thousands of ccSPF roofing systems. In addition, in 1998 and in 2003, Dr. Rene Dupuis, working on a grant from the NRF, published results of his inspection and evaluation of more than 350 ccSPF roofing systems in six different U.S. climate zones.

The surveys conducted by Dupuis and Kashiwagi are very similar in their conclusions: ccSPF roofing systems are highly sustainable. In Kashiwagi's 1996 report, the oldest performing ccSPF roofs are more than 26 years old, and 97.6% did not leak, 93% had less than 1% deterioration, and 55% were never maintained. Kashiwagi and Dupuis also noted that the physical properties of the ccSPF materials did not diminish over time, and that more than 70% of the ccSPF roofs were applied over existing roofing systems.

Life Cycle: When used in a building, ccSPF does not require replacement after a certain period of time. Its main physical properties of compressive strength, dimensional stability, adhesion, water absorption, permeability, and the like, do not change significantly over time. So the ccSPF can continue to provide these climate-control functions over the life of the buildings.

In roofing applications, ccSPF is typically installed over existing roof coverings. Commercial roof coverings are replaced

on average every 10 to 15 years, depending on the system. A properly installed and maintained ccSPF roofing system does not require tear-off but can be renewed by recoating the surface once every 15 years, on average.

During the course of a metal building roof deck's life cycle, the use of ccSPF would not only prevent the existing roof covering from being deposited into a landfill. This is not an insignificant amount, since the Department of Energy's ORNL reported that more than 20% of the nation's landfill consists of construction debris, and the majority of that debris is from tear-off of roof coverings. (In addition, many ccSPF roofing contractors recycle loose aggregate and ballast stones that cover many roofing systems, thereby eliminating an additional amount of construction debris going into landfills.)

According to the building life-cycle cost analysis performed by Michelsen Technologies, Lakewood, Colorado, over a 30-year life span ccSPF roof systems cost between 10% and 50% less, on average, than comparably insulated membrane roof systems.

There are many examples of ccSPF roofing systems that go significantly beyond these estimates. In fact, many companies in the ccSPF roofing industry consider a 20-year recoating schedule to be easily achieved with proper maintenance.

Reduction of waste during construction: The on-site application of ccSPF generates very little debris and waste. A typical 10,000-square-foot roofing or insulation project produces less than 1/2 of a cubic yard of scrap ccSPF, tape, and plastic (used for masking), and only between one pint to three gallons of waste solvent, depending on the type of protective covering used. Compare this to the typical reroofing project that produces more than 10 yards of construction debris from tear-off and application waste.

More information on the green building characteristics and renewability of spray polyurethane roofing systems is available at www.ccfam.com/video/beyond_video.php, and at www.masonknowles.com/docs/sustainable_characteristics.pdf.

Reduced energy during manufacture: A key element that is often disregarded in the environmental analysis of a product is how much energy it takes to extract, process and eventually use materials. In 1992, Franklin and Associates published a study called "The Comparative Energy Evaluation

Credits and Sources

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

Architectural Testing Inc.
Arizona State University, ASTM
BaySystems North America
BASF
FM Global
Honeywell
International Code Council
International Building Code (IBC)
International Energy Conservation Code (IECC)
Metal Building Manufacturers Association (MBMA)
Michelsen Technologies
National Institute of Standards & Technology
NAHB
National Roofing Contractors Association
National Research Council of Canada
National Roofing Foundation
Oak Ridge National Laboratory, Buildings Technology Center
Roofing Industry Committee on Weather Issues, Inc.
Spray Foam Magazine
Spray Polyurethane Foam Alliance
Syracuse university
TLSmith Consulting
Underwriters Laboratory

of Plastic Products and Their Alternatives for the Building and Construction Industry.” The study was unique at the time because it compared the total energy requirements for the manufacture of plastic products to the total energy requirements for the manufacture of alternatives. The life-cycle analysis (LCA) focused on all major steps in the manufacture of a product, from raw material extraction from the earth, to fabrication and even to transport, rather than a single manufacturing step.

The study concluded that plastic products in the building and construction industry use less energy from all sources than 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. In other words, the amount of energy saved in one year was equal to 578,000 barrels of oil or 3.4 billion cubic feet of natural gas.

More information on this study can be obtained

at www.greenbuildingsolutions.com/s_greenbuilding/doc.asp?TRACKID=&CID=552&DID=1794 and at www.envirofoaminsulation.com/PDF%20Docs/plastic%20construction.pdf. The whole study is available at www.vinylbydesign.com/docs/franklin.pdf.

Inside or Out, Where Should ccSPF Be Installed?

For many building owners and specifiers, the question will arise: “Inside or out, where do I install ccSPF?” This question sometimes is very obvious and other times difficult to determine.

The application of ccSPF to the inside of a building controls structural movement better by gluing the trusses, joists, beams, and other elements together. On the other hand, installing the insulation on the outside of the building provides better energy efficiency and can serve a dual function as the actual roof waterproofing covering too.

In some cases in an existing occupied building, there is so much going on inside a building – such as ongoing operations, equipment, racks, storage, furnishings, and occupied areas – that the only way to use ccSPF is to apply to the outside of the building envelope. In other cases, overspray prep or poor potential weather conditions would dictate interior applications. So, to make an informed decision, it is important to weigh the potential benefits to each system.

To determine the type of ccSPF application to be used, some basic information about the building is required, such as the location and climate, the intended use and occupancy, and the like. Questions need to be answered first, such as what are the major concerns or challenges. For example:

- Are there leak, moisture or condensation issues?
- Is energy efficiency a major concern?
- Will there be considerable work disruption from an interior application?
- Will there need to be overspray prep before the application?
- Is additional structural strength desired, and if so, of what type? For example, if the building is in a hurricane-prone zone and the owner would like to reinforce the whole building

against wind damage, what are the options?

- What type of substrate preparation is required?
- Are there surface or assembly preparation challenges? For example, is rust treatment or replacement of fasteners or welds required?

After considering the building requirements and desired changes, the building owner should then review the characteristics and benefits for each type of ccSPF system.

1. ccSPF Roofing and Exterior Insulation Systems. ccSPF roofing and exterior insulation systems have many benefits for metal buildings including (but not limited to):

- Providing a seamless, continuous, fully adhered waterproofing, insulative membrane.
- Insulating from the outside of the envelope, stopping thermal bridging, and preventing the metal from being affected by exterior temperature.
- Conforming to the configuration of the structure and substrate.
- Reducing the potential for moisture condensation on the metal surface.
- Reducing movement caused by thermal shock.
- Increasing wind uplift resistance of the roof covering.
- Providing a cool roof coating system that reduces urban heat-island effect.
- Reducing air infiltration to the interior.
- Reducing potential for pressurization.
- Minimizing damage to substrate from wind-driven debris and hail.

- Containing leaks even when foam is damaged.
- Providing self-flashing around roof top penetrations and parapet walls.
- Allowing installation in various thicknesses, thereby promoting positive drainage.
- Providing better indoor climate control and noise reduction, saving energy and promoting better indoor air quality.
- Improving IAQ by allowing mechanical HVAC systems to work efficiently.

2. ccSPF interior insulation systems benefits and considerations. The ccSPF insulation systems have many benefits for metal buildings including (but not limited to):

- Providing a seamless, continuous, fully adhered insulation to beams, girts, purlins, metal panels, and the like, which reduces thermal bridging.
- Conforming to irregular surfaces and sealing hard-to-reach areas.
- Stopping air infiltration.
- Adding structural strength.
- Increasing wind uplift resistance of roof decking system (up to 300%).
- Reducing the potential for condensation on metal surfaces.
- Providing a secondary barrier against water leaks.
- Reducing the potential for pressurization.
- Providing better indoor climate control, saving energy and promoting better IAQ, again, by allowing HVAC systems to work efficiently.

Regardless of the building owner's ultimate decision to

Additional Sources

For additional information on the use of ccSPF to enhance and rehabilitate metal buildings, refer to the following white papers and articles:

<http://www.ccf foam.com>

<http://www.honeywell.com/enovate>

<http://sc.leadix.com/honeywell/files/Insulation%20Energy%20Savings%20Final.pdf>

http://sc.leadix.com/honeywell/files/HW_Severe_Commercial_WP.pdfhttp://sc.leadix.com/24/70/live/files/BD+C_WP_AirBarriers.pdf

http://masonknowles.com/docs/modern_materials_hurricane.pdf

http://www.sprayfoam.org/index.php?page_id=242

Table 5: 2006 IECC R-Value Requirements of Roof Insulation on Metal Decks

Climate Zone	1	2	3	4	5 & marine 4	6	7	8
Roof Insulation R-value required (with continuous insulation)	R-15	R-15	R-15	R-20	R-20	R-25	R-25	R 25

install a ccSPF roofing system outside a metal building – or to install a ccSPF insulation system inside a metal building or a combination of the two – research and historical evidence suggests the application will provide greater energy savings, moisture control, and durability to the structure, while enhancing mechanical systems operations, indoor IAQ, and occupant comfort. The sustainable characteristics of ccSPF also make it a very attractive choice when considering the environmental impact of ccSPF when compared to many available alternative materials.

Addendum:

Building Code Requirements for Metal Buildings and ccSPF

The International Building Code (IBC) and the International Energy Conservation Code (IECC) provide building code requirements for commercial metal buildings and the use of ccSPF roofing and exterior insulation systems. For ccSPF roofing systems, the following rules apply:

1. Roof Covering Tests. The IBC requires that all roof coverings be approved as a Class A, Class B, or Class C in accordance with UL 790 (ASTM E 108) or by FM as a Class I Roof Covering. The UL 790 standard procedure tests a roof covering for its resistance to fire and burning brand from exterior flame sources. UL 790 test also lists the maximum slope and thickness of ccSPF that may be installed to achieve its ratings. For example, a ccSPF roofing system may have a Class A rating with a 2:12 slope, but only a Class B with a 3:12 slope.

Of the two, the FM Class I Roof Covering approval is arguably more rigorous, because it includes not just fire testing of the roof covering from external flame sources as does UL 790, but

also a room-corner test for fire resistance from flames inside the building, wind uplift, and hail resistance.

2. Physical Properties. The 2006 IBC requires that ccSPF used in roofing applications comply with the physical properties of ASTM C 1029 (*Standard Specification for Spray Applied Cellular Polyurethane Foam*).

3. Protective Coatings. The IBC requires that protective coatings used with ccSPF roofing systems comply with ASTM standards for acrylic, moisture cured polyurethane, and silicone coatings. Those standards are ASTM D 6083, D 6947, and D 6694, respectively.

4. Exterior Insulation Systems Code Compliance. Exterior insulation systems may require testing in accordance with ASTM E 119 to determine their overall fire resistance ratings. As with interior insulation applications, it is up to the code official or code consultant to determine whether the ccSPF system is part of the fire-resistive wall assembly or insulation installed to a fire-resistive assembly.

(In the case of a Quonset-style building, it's not easy to distinguish where the roof stops and the wall starts. In such cases, local building code officials may vary in their interpretation of the building as a roof or an exterior wall. As mentioned, it is important to know before installing the ccSPF what testing and approvals are required to comply with the building codes in the project area.)

5. R-Value Requirements. The IECC contains prescriptive tables that determine R-values for different climate zones. **Table 5** on page 20 lists the R-values required by the 2006 IECC for insulation installed in a continuous manner to the roof of metal deck assemblies. As an alternate to the prescriptive code requirements, a building code official may at their discretion approve other designs and materials based on performance

testing (in accordance with code accepted practices) that could allow R-value totals less than the prescribed values.

6. Vapor Retarder. Section 502.5 from the 2006 IECC requires the use of a vapor retarder in commercial buildings with a permeance of 1 or less on the warm side of the insulation in climate zones 5, 6, 7, 8 and marine 4. A ccSPF installation of 2 inches or greater typically provides the required permeance of 1 or less.

The 2007 IECC Supplement section 502.5 introduced three Classes of vapor retarders as follows:

- Class I vapor retarder: > 0.1 perms
- Class II vapor retarder 0.1 - 1.0 perms
- Class III vapor retarder < 1.0 - > 10.0 perms

The 2007 IECC Supplement allows Class I and Class II vapor retarders in all climate zones and allows Class III vapor retarders in climate zones 1 through 4 without additional vapor retarders, but with specific restrictions in the climate zones marine 4, 5, 6, 7, & 8.

So regardless of the code prescribed, ccSPF can be used in all climate zones found in the United States without an additional vapor retarder – if a vapor drive is not consistently in one direction. Additional Information at: <http://www.ccfoam.com>

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