Severe Weather and Closed-Cell Spray Foam: A Better Building Technology

The case for closed-cell spray polyurethane foam (ccSPF) in hurricane zones and coastal regions

Homeowners, builders and community developers are more frequently using closed-cell spray polyurethane foam (ccSPF) as an insulation and exterior material, due, in part, to its track record of performance during severe weather events. The material has been shown to increase the ability of homes to withstand the effects of flooding, storm surge and high winds. Longstanding endorsements for closed cell foams by such groups as the Federal Emergency Management Agency (FEMA), coupled with newer research by the University of Florida, highlight the effectiveness of these products in resisting flood and wind forces as well as structural damage.

These benefits, discussed in detail in this residential construction white paper, suggest an increasingly vital role for the use of the closed-cell-type, spray-applied polyurethanes in homes being built or renovated in coastal areas and other regions prone to serious weather events.

Moreover, ccSPF provides excellent performance on other key dimensions such as high insulation R-value, air barrier, vapor retarder and long-term building protection. It is relatively easy to build with, and effective in terms of first and life-cycle costs.

With such a long list of beneficial attributes, the recent reports on the positive performance of ccSPF during storms and flooding should encourage homebuilders, architects, engineers and code officials to examine ccSPF's track record anew.

In this white paper, we provide information on the safety considerations and bottom-line issues that drive the selection and application of ccSPF and other building products today. We conclude with five constructive recommendations – an "Action Plan" – for consideration by builders, developers, designers and homeowners alike – anyone who wants to act on their concerns about severe weather.

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.01 Severe Weather and Residential Construction

Severe weather is the toughest test for residential structures and assemblies. The National Weather Service has estimated that flooding damage annually costs the economy between $6 billion and $25 billion. Insurance claims for hail damage alone average close to $2 billion per year. Worse yet, a single catastrophic event can cause damages of many billions – in the case of Hurricane Andrew in 1992, the tally was $26 billion. Flooding, storm surge and high winds wreak the most violence.

Yet coastal construction remains among the most active nationally. So with higher populations and building densities along coastal cities and communities and the rate at which Mother Nature seems to bombard these areas with weather events of greater intensity and frequency, a growing number of standards organizations, code officials and coastal regions are responding to improve the performance of residential buildings. Armed with new research and data on material performance during extreme weather, local code updates and building practices have begun reflecting lessons learned.

Even in cases where regulators aren't enforcing certain practices, many homeowners are deciding that the risk of damage and destruction, as experienced during recent hurricanes, just isn't worth it. Consequently, many are heeding the advice of experts such as Joseph Lstiburek, Ph.D., principal of Building Science Consulting in Westford, Massachusetts, who says, "You have to assume things are going to get wet and you have to design them to dry." Lstiburek recommends three main common-sense flood-protection practices for home building:

- Elevate structures.
- Build with materials that can become wet.
- Design assemblies to easily dry when they become wet.

Lstiburek also notes that even though the "new" roof designs recently built in Florida's increasingly stringent codes environment are generally surviving, "a good percentage still suffered from leaking rainwater during the last hurricane season."

This being the case, it behooves homebuilders, homeowners and designers to carefully consider higher-quality building products that afford an extra layer of building integrity and protection.

Resisting Wind: The NIST Report and Roofing Materials

Among the information and data gathered in the aftermath of major recent weather events, probably the most extensive report was released by the National Institute of Standards and Technology in June 2006. The study, itself, presents detailed findings of the damage incurred by Hurricanes Katrina and Rita in the late summer of 2005.

In general, the NIST team's analysis of areas most damaged by wind and floodwater discovered that in the realm of residential roofing, laminated shingles fared fairly well. On the other hand, neighborhoods where three-tab shingles were the majority, up to 30% of the shingles sustained damage to as much as 50% or more of the roof area.

Although the number of metal roofs and spray polyurethane foam roofing systems observed in the region was quite small, both types appeared to have suffered little to no damage while SPF was reported to "have sustained Hurricane Katrina extremely well without blow-off of the SPF or damage to flashings."

.02 New Research – and Better Materials – For Building Safer Homes

The costs of recent weather events – coupled with the opportunity to reduce damages across U.S. regions and in individual dwellings alike – has led to a proliferation of new research studying the effects of severe weather on homes and other light construction types.

These new investigations have included field studies following major weather events. The report released last year by the National Institute of Standards and Technology (NIST) – detailing the effects of Hurricane Katrina on structures in New Orleans and elsewhere in the Gulf Coast region – provided new and compelling real-world evidence about ccSPF performance. Other similar studies have proven valuable as well. For example, the effects of Hurricane Opal in 1995 were examined in a report commissioned by the Florida State Home Builders Association. Released in January 1996, the study described damage to 200 homes in the Gulf coast areas affected by the Category 3 hurricane. Several types of failures were documented, including:

- Damage to break-away walls.
- Scouring.
- Channeling and shielding.
- Infrastructure damage.
- Wind damage to gable end-walls, building envelopes, and window glazing.
- Racking and overturning.

The results of these studies offer useful comparative data on the performance of specific types of homes and construction features. Slab-on-grade homes, for example, fared poorly during Opal's storm surge, while houses with elevated foundations tended to perform better. The researchers also found that break-away walls functioned as expected. Most important, the surveys showed that newer homes built to current building codes sustained the least amount of damage and failures.

At the same time, laboratory and field research into the performance of specific materials and assemblies has been equally useful. For example, FEMA has ranked and listed materials based on their resistance to water absorption and water damage. The original report, an authoritative technical bulletin issued first in 1993 called *Flood-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas*, listed materials that could withstand prolonged contact with floodwaters and yet require only cosmetic repair. The materials that FEMA lists as Class 4 or "resistant to floodwater damage" include closed-cell spray polyurethane foam insulation. In fact, closed-cell foam is the only cavity insulation approved by FEMA as resistant to floodwater damage.

Other studies have documented the structural strengthening that can be attributed to ccSPF. As early as 1992, and confirmed again in 1996, the national Association of Home Builders (NAHB) showed that ccSPF can add to or even replace structural sheathing to improve the racking strength of residential walls.

Wind uplift, which can lead to major damage by compromising the roof enclosure, has been another key area of study. According to aggregated studies, wind-induced lifting of the roof deck is second only to broken windows as the most prevalent mode of hurricane damage. That led to such investigations as the research by the University of Florida this year, in which test data demonstrated that closed-cell SPF can increase roof deck uplift resistance by more than three times.

Not surprisingly, the NIST report on the effect of Hurricanes Katrina and Rita on structures in New Orleans and elsewhere in the Gulf Coast region provided new and compelling evidence about ccSPF performance. Roofs and walls using ccSPF performed extremely well, often amid considerable devastation to nearby structures due to flooding and wind.

.03 Flood Resistance and Building Materials for Dwellings

While it was an extensive report, the NIST team's analysis of areas most damaged by wind and floodwater from Hurricanes Katrina and Rita observed a limited number of residential and light commercial structures using ccSPF. These building enclosures fared well as compared to neighboring structures and the residential sample overall, yet other reasons have been found to consider using ccSPF.

In particular, with regards to unvented roofs, other studies have shown that wind-blown rain commonly enters into homes through openings in the soffits, gables, and mushroom and ridge vents. This effect is pronounced during severe weather, and the entry of rainwater can cause damage to the ceiling, promote mold growth inside the roof assembly or, worse, lead to premature structural failure.

With such risks at hand, a greater focus is now being placed on "flood-resistant materials," defined as any building material capable of withstanding direct and prolonged contact – 72 hours – with floodwaters, without sustaining significant damage.

To help choose appropriate materials, FEMA has published a rating system, ranking building products, 1 to 5, from not acceptable to highly acceptable. Taking a look at the rankings, ccSPF, for its outstanding water-resistant qualities, carries a "5" rating. Other top-ranked materials include asbestos-cement board, brick (face or glazed), concrete, metal, structural glazed clay tile, steel (with waterproof applications), stone (natural solid or veneer), and waterproof grout and stone, both artificial non-absorbent solid or veneer types.

.04 Closed-Cell Spray Foam: What It Is, and How It's Used

Closed-cell spray polyurethane foam (ccSPF), also known as medium-density spray foam, can be used as cavity insulation and as an exterior wall and roof material. The material has applications in all climate zones. Blowing agents include Honeywell's Enovate® 245fa, which is approved by the U.S. Environmental Protection Agency under the significant new alternatives policy (SNAP) to replace ozone depleting substances.

The medium-density ccSPF material is contrasted with another product that is used in U.S. residential construction: open-cell SPF, or ocSPF. While the closed-cell type weighs about 2 pounds per cubic foot, the open-cell product weighs only about ½-pound per cubic foot of applied material. The term "open cell" refers to the fact that the tiny bubbles that make up the foam are open pores that fill with air upon installation. The foam feels softer than ccSPF, which has closed cells filled with the blowing agent which acts like the insulating gas in a double pane window.

Both ocSPF and ccSPF expand upon application to fill voids and can create an air seal; both materials also adhere to common construction surfaces. But ccSPF provides higher insulation capabilities (R-values of around 6.2 or greater per inch) than open-cell materials (about 3.5 per inch). The ccSPF can also act as an air barrier at thicknesses of 1 inch or greater, and as a vapor retarder at 2 inches or more. The open-cell products, on the other hand, have a higher vapor permeability. Closed-cell materials also tend to cost more by volume, because they pack more material into the same space.

For exterior roofing applications, an SPF product of up to 3 pounds per cubic foot is typically employed. For unvented roof assemblies, ccSPF insulation has been shown to be highly effective. In addition, some faux-wood trims are made with very dense polyurethane foams weighing up to 40 pounds per cubic foot.

Open-cell spray foams are not advised and often not allowed for below-grade or flood-prone situations because the product will absorb water, defeating its insulating abilities. Where builders face small framing sizes and need the most R-value possible per inch, ccSPF is an effective solution.

.05 Benefits of ccSPF: Water Resistance

Among the numerous benefits offered by ccSPF, the material's water resistance can be an invaluable asset in the face of the severe weather conditions common to coastal regions.

In fact, "Closed-cell spray foam has negligible water permeability, minimal water absorption, and excellent adhesion allowing it to act as a secondary rainwater barrier

Who Gains by Using ccSPF

ccSPF CAPABILITY	HOME DESIGN BENEFIT	HOME BUILDER BENEFIT	CODE BENEFITS	CLIMATE BENEFITS
Impermeable to air	Controls airflow	Combined insulation and air barrier	Improves wall and roof performance	Warm climate: Keeps humid air out
Expands and adheres	Creates an air seal, reduces leakage	Fills voids; ensures contact with studs and walls for better insulation	mproves wall and roof performance	Cold climate: Keeps humid air away from back of roof sheathing
High R-value	Compact roof and wall assemblies	Improves insulation for small stud sizes	Highest R-value per inch	All climates: Reduces HVAC energy required
Resists water vapor	Reduces condensation problems	Vapor retarder not needed	Prevents condensation damage	Cold climate: Provides first condensing plane
Impermeable to water	Flood resistant	Acts as waterproofing and secondary rainwater barrier	Limits flood damage	All climates: Controls rain leakage

Source: Building Science Consulting

to limit damage when primary roof assembly rainwater-control membranes leak," states Christopher J. Schumacher, a principal with Building Science Consulting, Westford, Massachusetts.

"The technology has a very high structural adhesive property," concurs David O. Prevatt, Assistant Professor in the Department of Civil and Coastal Engineering at the University of Florida. "Everywhere there are joints and cracks, the [spray foam] seals and prevents the entry of water." In cases where the primary roof does leak, the ccSPF application can keep water from spreading through to the interior finishes.

And for low-slope roofing, ccSPF, by itself, can actually perform as a primary water barrier due to its high adhesion and closed-cell characteristics. It keeps away mold and mildew and is the only FEMA-approved cavity insulation for homes built in flood zones. (As mentioned earlier, closed-cell SPF is also ranked by FEMA as a Class 4 building material, meaning it is acceptable for exposure to floodwaters). With regards to vapor diffusion, analysis of the product's performance has also shown it to act as a "throttle" to control the rate of diffusion, according to Schumacher. "The foam insulation resists the diffusion of water vapor so that the amount of water vapor is reduced as it moves through the thickness of the foam. By the time the water vapor reaches the back of the roof sheathing, there is not enough left to cause condensation problems," he says.

Yet another ccSPF water-related benefit is its rapid drying capability after it is exposed to water. Along these lines, Lstiburek classifies ccSPF as an integral part of flood-resistant home building. "If an insulation system like closed-cell polyurethane spray foam is used, it will not be damaged and will protect the wood [that it is insulating] during a flood," he explains. "Afterwards, just let the building dry with a dehumidifier, then powerwash it, and you're done." In summary, he adds, "It's a powerful technology: It has extremely low water absorption and very low vapor permeability, which is a good attribute for a roof."

.06 Benefits of ccSPF: Racking Strength

The use of spray polyurethane insulation in wood frame construction has been long known to enhance wall structural performance as well.

According to a seminal study by the NAHB Research Center in Upper Marlboro, Maryland, wall panels with SPF, tested according to ASTM standard test methods, were found to have greater resistance to racking than conventional panels with plywood siding. Also, SPF panels with vinyl siding applied directly to the studs had about 70 percent of the racking resistance of conventional wood sheathed vinyl siding panels, regardless of stud spacing.

What was most surprising about those tests, conducted more than ten years ago, was one statement in the report: "Housing built entirely with [cc]SPF-filled wall cavities would likely not require conventionally braced construction." The total resistance of a building could equal or exceed those with conventional bracing, the report stated.

The testing was repeated again several years later by the NAHB Research Center to study the effects of SPF insulation within panels made of 20-gauge structural steel framing. For the light-gauge steel assemblies, "Both of the specimens with SPF-filled cavities sustained higher racking loads than the conventional test specimens filled

Comparing Insulation Products and Features

	INSULATION PRODUCT TYPE				
Feature and benefit	CLOSED-CELL SPF	OPEN-CELL SPF	CELLULOSE	FIBERGLASS BATT	FIBERGLASS LOOSE FILL
R-value per inch Reduces wall thickness and framing costs	6.2	3.6	4.0	3.7	3.2
Air barrier material Increases energy savings, reduces drafts, improves air quality	Yes	No [1]	No	No	No
Expands to fit Provides labeled R-value; eliminates settling	Yes	Yes	No	No	No
Low water-vapor transmission Provides moisture control	Yes	No	No	No [2]	No
Low water absorption Qualifies as FEMA-approved flood-resistant material	Yes	No [3]	No	No	No
High strength and stiffness Improves structural integrity, durability and safety	Yes	No	No	No	No
No measurable formaldehyde Improve indoor air quality	Yes	Yes	Yes	No	Yes

1. Air Barrier Association of America.

2. Qualifies as integral vapor retarder when facings are attached.

3. Open-cell SPF absorbs more than 30% water by volume; closed-cell SPF (ccSPF) absorb between 0 and 4% water by volume.

with R-19 batts," read the report. Besides that, racking deflections and sets for the SPF-filled wall sections were consistently lower than those seen in the batt-insulated wall mock-ups.

These results changed homebuilding methods – and thinking – permanently. The high-performance insulating material, closed-cell SPF, could serve another verifiably useful purpose: strengthening the same walls they insulate. This was a "two-fer" that many builders and architects found irresistible: high insulating performance plus increased safety.

In addition, all SPF cavity insulations have at least a Class I fire rating, so they can be used in any wall covered with a thermal barrier, like gypsum board. Research is now underway to determine whether SPF can increase the resistance to sheathing uplift under high wind loads (see Section 7).

This message of increased homeowner safety came through loud and clear: Closed-cell SPF is stiffer and stronger than other insulations. For that reason, ccSPF can strengthen frame walls by a factor of two to three times when applied inside the wall cavities.

.07 Benefits of ccSPF: Wind Uplift

An additional area where ccSPF has well proven its worth include withstanding wind uplift. Considering the fact that uplift of the roof deck is, after window and glazing damage, the most common form of hurricane damage, this can be key.

Looking at the big picture, roof deck failure creates an entry point for the elements to wreak havoc, resulting in total loss of property and contents more than 80 percent of the time. Furthermore, loss of the roof deck often leads to losses exceeding 50 percent of a structure's insured value.

While improved fastening will help, it is far from a solution. And even though adhesives work well, they are expensive and come with their own inherent drawbacks. According to research cited by David O. Prevatt, Assistant Professor, Department of Civil and Coastal Engineering, University of Florida, adhesives only work well when adhered to clean surfaces, which can be hard to come by in retrofit applications. In addition, placement can be difficult within the confined space of a residential attic, sometimes requiring the ceiling or roof sheathing to be removed and replaced in order to properly access and clean the location.

On the other hand, ccSPF works as an adhesive that also insulates – with a typical R-value of 6.2 per inch – and undergoes far less expansion, increasing by 30 times its liquid volume, according to Prevatt.

So how does ccSPF perform with regards to preventing wind uplift? Recent research conducted by Prevatt shows that "by applying a 3-inch layer of ccSPF to the underside of the sheathing as a structural retrofit, a homeowner can increase the ultimate wind uplift capacity of their roof to about 244 psf – that translates to an allowable wind uplift capacity of 122 psf, assuming a factor of safety of 2.0, well above design loads for Miami."

"Overall, our testing shows that wind uplift performance can increase by two to three times," Prevatt concludes.

.08 More Reasons to Build with ccSPF

Beyond water resistance and wind uplift, additional ccSPF properties include thermal insulation and airflow control.

"Closed-cell spray foam acts as an air barrier (at 1 in. or 25 mm minimum thickness) and vapor retarder (at 2 in. or 50 mm minimum thickness) and therefore does not need an additional vapor retarder in cold climates," states Schumacher. And because ccSPF is air impermeable, it adheres well to construction surfaces and expands to fill voids, thereby creating an air seal, adds the building expert.

"In cold climates it prevents warm, humid indoor air from reaching the back (underside) of roof sheathing where it can condense," explains Schumacher. "In warm climates it prevents humid outside air that enters the roof due to natural and/or controlled ventilation from reaching the back of the roof sheathing, which can be cooled below the air temperature by night sky radiation" – in other words, he explains, "the effect that causes dew."

Furthermore, ccSPF can be used to create unvented, conditioned attics, which prevent air leakage – a common problem in many homes. Often holes created by air-conditioning equipment, exhaust fans, ductwork, recessed lighting, and other such penetrations, allow for the movement of air between the attic and living spaces. As Schumacher explains, "Pressures created by the mechanical equipment, as well as wind and temperature differences, cause air to move between these spaces leading to great energy waste and occupant discomfort."

With ccSPF, these problems are eliminated. Industry groups like the Spray Polyurethane Foam Alliance (SPFA) and the Spray Polyurethane Foam Division of the Society of the Plastics Industry (SPI) list a number of additional benefits:

- Energy transfer through ductwork is no longer lost to the exterior.
- Water pipes are better protected from freezing.
- Airtightness requirements for the ceiling plane are reduced or eliminated.
- Renovation and rewiring involve no disturbance to the insulation layer.
- Attic storage space can be increased since insulation is not required on the attic floor.

And there's more. Sealing soffits with ccSPF to create an unvented attic reinforces them against failure and prevents wind-driven rain from entry. Undesirable internal pressurization of the roof during high winds is also prevented, and the sealant acts as

Suppliers of 2lb closed-cell spray foam

SUPPLIER	PRODUCT	WEBSITE
AirTight Insulation	Airtight Spray Foam	www.airtightinsulation.com/sprayfoam-info.html
Apex Foam	EarthSeal ESCC 1.7®	www.apexfoam.us/desc_escc17.php
BASF Foam Enterprises (BASF-PFE)	ComfortFoam®	www.basf-pfe.com
Bay Systems North America (Bayer)	BaySeal™ 2.0	www.bsna.com/bayseal
Corbond	Corbond®	www.corbond.com
Demilec	HeatLok™ Soya	www.heatloksoy.com
Dow	Styrofoam™	www.dow.com/styrofoam/na/spray_foam/
Gaco Western	PF-173	www.gaco.com/insulation.html
Lapolla	Foam-Lok™	www.lapollacoatings.com/spf.html
NCFI Polyurethanes	InsulStar®	www.insulstar.com
Resin Tech	Permax®	www.henry.com/PERMAX_Insulation.permaxinsulation
SWD Urethane	SWD 225	www.swdurethane.com/SWDpages/wallfoam2.html
UCSC	DuraSeal	www.buyucsc.com

a back-up waterproofing layer to further minimize any potential water leakage.

In a nutshell, Lstiburek emphasizes the fact that ccSPF is one of the few technologies that enables builders to create unvented roofs. "On top of that, you have a huge improvement in thermal performance and structural performance on the assembly, as well as superior wind uplift protection, so you win in multiple ways."

.09 White Paper Action Plan: ccSPF for Better Homes

Based on the reporting and observations made in this white paper, we recommend the following "action plan" for homebuilders, designers and building authorities, as well as for homeowners. These recommendations specifically address growing concerns about home performance during severe weather events:

1. Continue to study ccSPF insulation. It is clear that closed-cell spray polyurethane foam (ccSPF) provides significant advantages in general, but also specifically in performance during and following severe weather events. In addition to improved water resistance, ccSPF increases wall racking strength and protection against wind uplift. The advantages should be studied further to improve homebuilding techniques and built home performance.

2. Expand education on ccSPF. The properties and benefits of construction assemblies using ccSPF are not common knowledge among all builders and designers. Continuing education on the advantages and applications for ccSPF insulation should be expanded.

3. Consolidate and publish studies on ccSPF performance. While this white paper makes an informal attempt to assemble various sources of data on ccSPF insulation, roofing systems and walls/enclosures, it is far from complete. We encourage trade groups, academic think-tanks and professional communities to publish findings on ccSPF in the field and in the lab.

4. Promote the use of ccSPF insulation in wall and roof assemblies. Because of the benefits to sustainability and homeowner safety – and the potential reduction of insurance losses – homebuilders, developers and designers should consider the use of ccSPF where appropriate and suitable.

5. Create awareness among code officials and enclosure experts. The benefits of ccSPF for building occupants, property value and enclosure performance are well documented. In general, it serves as the basis for energy-efficient walls and roofs with good air-quality performance. As these qualities serve the interests of code officials and the jurisdictions they serve, we encourage more awareness among those key policy makers.

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.

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BDCUniversity
Brazos Urethane
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CEP International
Federal Emergency Management Agency
FM Global
Honeywell
Huntsman
International Code Council
Michelsen Technologies
NAHB Research Center
NCFI Polyurethanes
National Association of Home Builders
National Institute of Standards & Technology
National Oceanic and Atmospheric Administration
National Roofing Contractors Association
National Roofing Foundation
Oak Ridge National Laboratory, Buildings Technology Center
Performance Based Studies Research Group
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The Society for the Plastics Industry Inc.
Underwriters Laboratory
University of Florida
Spray Foam Magazine
Spray Polyurethane Foam Alliance