Severe Weather and Walls/Roofs

The case for using spray polyurethane foam (SPF) in hurricane zones

The track record for spray polyurethane foam (SPF) roof and wall insulation is long and positive. This widely specified and installed roofing and building enclosure system provides good insulating qualities and long-term building protection. It is relatively easy to build with, and effective in terms of first and life-cycle costs.

Recent events, however, including several major U.S. hurricanes, have revealed the real value of SPF as a safe, sturdy and effective product that endures severe weather better than many other commercially available exterior systems.

In fact, a 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 evidence about SPF performance. This report merits new examination of SPF's track record and benefits for buildings subject to severe weather events – a fact that gave impetus to this *Building Design + Construction/RS Means* white paper.

Severe weather is the toughest test for any roof system. Each year, insurance claims for hail damage average close to $2 billion and for wind-related damage more than $160 million. Ten years ago, Hurricane Andrew wrought unprecedented economic devastation, resulting in more than $26 billion in damage in the United States—the most expensive natural disaster in all of U.S. history.

Building owners and managers, as well as design and construction professionals, need to be more vigilant than ever in their specification and detailing of building assemblies that resist the effects of wind and weather events. For their part, manufacturers, consultants, trade associations and other experts are conducting more in-field performance testing as well as materials studies to make roofing and envelope systems that better protect buildings and their occupants during storms and high wind.

In the following pages, we examine the safety considerations and bottom-line issues that drive the selection and specification of SPF and other building products today. We conclude with six constructive recommendations – an "Action Plan" – for consideration by building designers, constructors, developers and owners concerned about severe weather.

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.01 Building Technology and Severe Weather

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.

Contributing to the development of better and more weather-resistant buildings are leading building teams in partnership with specialty consultants, trade groups, and manufacturers. Recent studies and several published papers by these industry leaders address the laboratory and in-field performance of varied roofing and enclosure systems. One of the most remarked upon has been spray polyurethane foam, or SPF. This spray-installed, self-flashing product has been found to demonstrate good durability, high energy efficiency and good maintenance and wear. This sustainable roofing product also stands up to severe weather better than many alternative systems and products.

This white paper examines the performance capabilities of SPF under severe weather, and reviews recent research and field experience behind those general observations.

.02 Background on Storm Events and Effects

No fewer than 800 tropical storms and hurricanes were recorded in the North Atlantic area in just the past 100 years, according to the National Oceanic and Atmospheric Administration (NOAA). And in very recent history, a number of hurricanes have wreaked immense havoc, damage and loss of life. For example, Hurricane Hugo, which hit the Caribbean and continental U.S. in 1989, took 82 lives and caused property damage estimated at $8 billion. And even more devastating, in August of 1992, Hurricane Andrew swept through the Bahamas, Florida and Louisiana, leaving behind damages estimated at $30 billion.

With such far-reaching destruction, Hurricane Andrew was a wake-up call to establish new building requirements for coastal areas. Furthermore, much more investigation and research went into determining which building components are most vulnerable to the high-speed winds and torrential rains characteristic of hurricanes.

The insurance industry has identified roofing as the primary contributor to disaster-related insured losses. Furthermore, it has been found that roofs, followed by windows and doors, are the most susceptible to hurricane damage, as reported by Tony Gibbs, director of CEP International, Barbados.

For roofs, the potential and extent of damage is increased when fastening devices and sheet thicknesses are inadequate, and when there are insufficient frequencies of fasteners in the known areas of greater wind suction, according to Gibbs. As for windows and doors, glass is extremely vulnerable to flying objects, and door hardware, including latches, bolts and hinges, make doors the most vulnerable to failure.

Other areas of vulnerability include:

- Building foundations that aren't large or heavy enough to withstand uplift forces from hurricane winds.
- Connection points in steel frames.
- Walls, both cantilevered parapets and those braced by ring beams and columns.

SPF and Hurricanes

When it comes to protecting roofs and walls against natural disasters, especially hurricanes, spray (or "sprayed") polyurethane foam (SPF) roof and wall systems have shown remarkable resistance to high wind uplift and blow off, a characteristic attributed to its spray-applied application, strong adhesion, lack of need for fasteners and absence of joints or edges for the wind to grab onto. Closed-cell SPF in wall cavity applications has increased racking strength of 300-400 percent in NAHB tests. Furthermore, SPF roofing 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 SPF systems found that the foam's wind uplift resistance actually exceeded the capacity of both FM (Factory Mutual) and UL (Underwriters Laboratories) test equipment over concrete decks according to Mason Knowles, former technical director of the Spray Polyurethane Foam Alliance (SPFA). In addition, the UL noted that SPF applied over BUR and metal increased the wind-uplift resistance of those roof coverings. Knowles also points out that FM Global's testing showed similar results.

A strong example of such performance was documented at the Paradise Beach Club condominiums in Satellite Beach, Fla., when in 1995 Hurricane Erin nearly ripped off the oceanfront complex's roof. Not only was the roofing contractor able to quickly install a water-resistant, energy-efficient SPF roof, but the roof system went on to survive three subsequent hurricanes impervious to damage and leaks.

In terms of analyzing vulnerability to hail damage, a recent report sponsored by the National Roofing Foundation (NRF) surveying 140 SPF roofs ranging from new to 27 years old, 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." The NRF report also discovered that where roofs had experienced hail damaged, the damage was localized to the upper surface of the foam and most roofs were repaired rather than replaced.

.03 Codes, Standards, Testing – and Roofing

In the aftermath of Hurricanes Katrina and Rita, much discussion has centered around the fact that had a number of major buildings been built to best-practice building codes and standards, a good percentage of property damage may have been averted. Consequently, it's relevant to take a look at which particular building codes were in effect in areas most hit by the hurricanes and to what extent current building codes and standards address hurricanes, or more specifically, windborne debris standards.

As a general rule, the majority of jurisdictions had utilized the Southern Building Code Congress International (SBCCI) Standard Building Code as its basis for buildings codes since the mid-1990s. However, with the formation of the International Code Council, most authorities having jurisdiction (AHJs) had switched over to the 2000 International Building Code (IBC) and Residential Code, or a later edition, by the time the hurricanes hit in 2005.

The IBC includes windborne-debris requirements, in addition to four other building codes, five standards and specifications, and one national wind-load standard. Regarding adoption, Florida, for instance, has established windborne-debris zones in coastal areas where 130-mph winds have the potential to reach inland. Dade County, in particular, also happens to be the first in the U.S. to have adopted such a windborne-debris requirement, in 1993.

Louisiana was a different story. In the aftermath of the 2005 hurricanes, the state changed from a system of allowing cities and counties to establish their own minimum standards for building construction to a statewide code. This came via the adoption the 2003 suite of ICC International Codes, which became immediately applicable to buildings being rebuilt as a result of the hurricanes.

Windborne debris

Regarding which specific building systems need to meet such windborne-debris requirements, windows, doors and skylights are the focal point. The loss of even just a few windows during a hurricane could quickly lead to roof failure as a result of internal and external pressure differentials.

Consequently, typical windborne-debris impact tests involve subjecting these building systems to large, 9-pound missiles and small (2 gram) missiles that simulate roof gravel. Upon surviving multiple impacts without penetration before proceeding to cyclic pressure loading, the window or door being tested is considered approved for meeting windborne-debris requirements.

As for roofing assemblies, windborne-debris code requirements do not directly apply, however, there is a non-profit group, the Performance Based Studies Research Group (PBSRG), based in Arizona State University's School of Construction, that has established the ALPHA Research Project, which analyzes high-performance roofing systems. The results of a recent study showed that urethane-coated SPF had the highest resistance to the simulated hail damage with the minimum-specified system of 30-mil of coating and 40-50-psi compressive strength SPF.

.04 SPF Products and Applications: An Overview

Spray (or "sprayed") polyurethane foam, commonly referred to as SPF, is a spray-applied insulating foam plastic installed as a liquid that immediately expands to many times its original volume. According to the Spray Polyurethane Foam Alliance (SPFA), Fairfax Virginia, a variety of SPF formulas provide a range of physical properties suitable for various building uses, geographies and climates. SPF roofing foams have a compressive strength of 40-50 lbs./in. compared to other insulations at 20-25 lbs./in. SPF roofing foams typically achieve R-value of 6-7 per inch.

The benefits of SPF building systems include high levels of R-value, as well as the providing of integral air barriers and assistance in moisture control. For roofing, SPF is highly insulating and can eliminate the thermal bridging through fasteners or gaps in decking. Recoating SPF roofs or covering over other roofing types is a proven and cost-effective retrofit method.

Because the physical properties of the SPF change little with age, SPF roofs have been in place for as long as 30 years. The durability of an SPF enclosure depends primarily on the original application and long-term maintenance. SPF roofs, for example, should be inspected twice per year and after any events that could damage the membrane.

SPF adds little weight and can adhere well to a variety of substrates, such as built-up roofing (BUR), modified bitumen, single-ply and other type membrane systems, sheet metal, ceramic tile, concrete, wood and shingles. The highly plastic material can be used to add slope and fill in

Membrane vs. SPF: Comparing Membrane and Sprayed Polyurethane Foam Systems

	SYSTEM DESCRIPTIONS			WEATHER EFFECTS		
	ASSEMBLY	FLASHINGS	ATTACHMENT	PROJECTILES	WIND	WATER
Membrane Roofing	Overhangs, overlaps seams and joints	Attached flashings	Secured to deck with fasteners	Subject to damage and penetration	Can lift off or peel under high wind	Peeling exposes building to water intrusion
SPF Roofing	Continuous surface with no edges, seams or joints	Self-flashing	Self-adhering (adhesion without fasteners)	Resists missile damage and penetration	Grips building wall to resist high wind	Continuous surface protects against water intrusion

depressed areas. SPF is a good specification and installation choice in situations where:

- Additional insulation is desired.
- The roof substrate has many penetrations.
- The roof deck is an unusual shape or configuration.
- Lightweight materials are required.
- Slope must be added to provide positive drainage.
- It is desirable to keep existing roof covering.
- And wherever a roof is in a severe weather environment.

The SPF products are excellent air barriers in buildings. In normal occupancies and moderate climates, SPF insulation typically does not require a vapor retarder. Extremes of climate and building use may require vapor retarders or air barriers.

SPF materials provide great insulation, can assist in the control of condensation within buildings and have several environmental benefits. Both low- and medium-density SPF effectively reduce noise from outside sources by sealing cracks and gaps that allow sound to travel through the walls, floors and ceilings into the building. They are less effective against noise caused by vibration.

According to the life-cycle cost analysis performed by Michelsen Technologies, Lakewood, Colorado, over a 30-year life span SPF roof systems cost between 10 percent and 50 percent less on average than comparably insulated membrane roof systems. The averages were based on SPF roof system recoatings applied every 10 and 15 years, according to the SPFA.

Super SPF Re-Roofing: The Louisiana Superdome

Billed as the nation's largest reroofing project ever for the world's largest domed structure, replacing the 9.7-acre roof of the Hurricane Katrina-ravaged Louisiana Superdome was an impressive display of building team coordination and hard work.

Besides installing what is expected to be a hurricane-resistant, spray-applied polyurethane foam (SPF) roof, the team had the dome's temporary roof up and running in just 18 days, with 45 days allotted for the project, and the permanent roof replacement completed in 4 months, which was two months ahead of schedule.

Playing a significant part in the $32.5 million project was SPF, considered to be the most effective way to eliminate leaks and dry-in the Superdome roof. In fact, the Superdome's original steel-frame-and-panel construction had been covered with SPF, but a 2001 retrofit replaced the foam with an EPDM rubber membrane system adhered to polystyrene insulation, which had been fastened to the panels. Unfortunately, it was this membrane that failed during the hurricane.

According to a National Institute of Standards and Technology (NIST) study of damage incurred by Hurricanes Katrina and Rita, "Most of the EPDM was observed to have been blown off by Hurricane Katrina. In those areas of the roof where the EPDM membrane was not adequately adhered to the iso-board insulation, the EPDM membrane blew off the structure with the insulation facer undamaged."

The roofing job was completed in two phases as initially a temporary roof had to be erected to enable cleanup and repairs inside the Superdome. Once the temporary roof was up, the crew could methodically replace damaged panels with permanent replacements until the permanent roof was completed.

With regards to SPF for the temporary roof, the specs called for 1 inch of 3-pound spray directly onto the polystyrene "iso-board," except where surface paper had torn loose. Next came the painstaking process of removing roof panels, one section at a time, lowering them 275 feet down to the Superdome's 50-yard line, and sending replacements back up via hydraulic roof hoists, as the largest available crane in Louisiana didn't even make if halfway up the 27-story-high dome.

Finally, to achieve a final uniform thickness of 2.5 inches of 3-pound closed-cell foam, the metal flutes used for application were pre-filled on the Superdome floor prior to installation on the roof. Next, the gaps between the roof panels were filled and trimmed flat before the final coat of SPF was applied. The entire roof was topcoated with 46 mils of spray-applied white elastomeric polyurethane, in four passes. The building owner also was covered by an "Unlimited Wind Warranty" to protect against future roof system blow-offs.

.05 SPF and Severe Weather: Storm Performance Criteria

Roof structures are especially susceptible to high winds and storms. Insurance industry research has identified roofing as one of the greatest contributors to disaster-related insured losses. The problem most often lies in the nature of roof design: Wind can pull edge flashings and copings away from their installed positions, leading to a "peeling away" of the entire surfaces, panels and sections of membrane. This action is much like the movement of the lid of a tin can after it has been cut around the perimeter, resulting in the loss of structural integrity.

Unlike the tin can, however, once the building enclosure is compromised in this way, a chain reaction of events ensues that can lead to catastrophic building failure. After the roof membrane, panels or tiles pull away, the insulation layer is exposed, often with less resistance to the lateral and uplift wind forces. Then the sheathing below and the substructure are subject to movement and wind or water damage, potentially leaving the entire building interior underneath open and vulnerable.

Well-designed and professionally installed spray polyurethane foam (SPF) roofing materials have been found to offer specific benefits and advantages in terms of severe weather-related deterioration and catastrophic failure. SPF roofing performs especially well under the conditions associated with hurricanes and tropical storms, which pose a significant risk to coastal properties and building occupants. In addition some SPF manufacturers now even offer "Unlimited Wind Warranties" as a testament to their performance in severe weather events.

"Off the charts"

The Spray Polyurethane Foam Alliance (SPFA), a trade group representing manufacturers suppliers and installers, reports that SPF's wind-uplift resistance is literally "off the charts." In recent laboratory testing, the SPF assemblies' capacity to resist wind uplift exceeded the ability of Underwriters Laboratories Inc. (UL) equipment.

Testing led UL to make the following public statement: "The application of sprayed foam to steel deck and plywood deck demonstrated uplift load resistance up to the capacity of the test equipment to develop load (160-165 psf) without any sign of delamination or other damage to the foam." UL also observed that SPF roofs applied over built-up roofing (BUR) and metal increased the wind uplift resistance of those roof coverings. Another testing agency, FM Global, has conducted tests showing similarly positive results over a variety of substrates including metal, concrete, and wood.

Field-testing has led to even further positive assessments of the capabilities of SPF to endure severe weather conditions. For example, two buildings standing side-by-side in Puerto Rico experienced dramatic wind forces during Hurricane Hugo in 1989. One building's roof panels and membrane roofing were ripped away from the structure, but the building with SPF roofing remained intact, with no peeling, penetration or water leakage. A similar anecdotal case occurred during a tornado strike in Plainfield, Illinois, where a church building had been constructed with a shell completely covered in SPF. Following the tornado, authorities observed "repairable missile damage" to the building enclosure, although the polyurethane foam remained sealed, protecting the envelope and structure from wind-induced uplift.

Even more convincing is the detailed report by the National Institute of Standards and Technology (NIST) released in June 2006, *Performance of Physical Structures in Hurricane Katrina and Hurricane Rita: A Reconnaissance Report*, which comprehensively documents damage from the storms. According to NIST, all buildings with SPF roofs "were found to have sustained Hurricane Katrina extremely well without blow-off of the SPF or damage to flashings." (For more information on this report, see Section 7, "Hurricane Strength," of this White Paper.)

Wind and wind-related effects

Because SPF is highly resistant to wind uplift and blow off, it has garnered attention among contractors and building designers attracted to its high level of adhesion and lack of fasteners. The monolithic quality of the spray-applied product is clean and consistent, but more important it means that there are no joints or edges for the wind to "grab onto." Properly installed, the foam is relatively lightweight yet rigid.

Field verification of the performance of SPF roofs has been widely documented. The effects on 11 SPF roofs in areas of Florida affected by Hurricane Andrew, for example, were reported by the consultant Thomas L. Smith of TLSmith Consulting, who at the time served as research director for the National Roofing Contractors Association (NRCA). Three of the subject buildings were in areas of very high winds, and two of those had roofs comprising SPF retrofitted over existing built-up roofing. (The third was a thin-shell concrete structure.) Minor damage was observed, mainly from wind-borne projectiles. One of the SPF-over-BUR roof structures had minor peeling due to missile impact. Other buildings without SPF roofing in Hurricane Andrew's path did not fare so well. Collapsed trusses, a gable end-wall failure, and blown-off sheathing panels

Hail Damage Susceptibility Factors

HAIL DAMAGE SUSCEPTIBILITY FACTORS FOR EIGHT GENERIC ROOF SYSTEMS.

ROOFING TYPE	GRANULE LOSS	INDENTATION	FRACTURE	SHATTER	PUNCTURE	PLY SEPARATION	SUBSTRATE PROBLEMS
Asphalt shingles	■	■	■				■
Prepared roofing	■	■	■		■	■	■
Bituminous BUR		■			■	■	■
Single-ply membrane		■	■	■	■		■
Wood shingles		■	■		■		■
Inorganic tiles/ slate			■	■			■
Metal		■			■		■
Modified bitumen	■	■			■	■	■
SPF	■	■	■				

SOURCE: Hail Damage to Roofing: Assessment and Classification, presented at the Fourth International Symposium on Roofing Technology by William C. Cullen of the National Roofing Contractors Association (NRCA).

were observed by Smith.

Laboratory testing has been useful in verifying the implied performance attributes of SPF roofing based on storm-area observations. UL and FM Global classify roofing systems based on wind-uplift criteria by the following designations: Class 30; Class 60; Class 90; FM1-60; FM1-90.

Wind resistance is only one measure of a roofing system's potential performance during severe weather. Other key criteria for building owners, designers and contractors to consider include: progressive peeling failure due to missile impact, deck failure, or a lifting and peeling failure at the roof edge, along with the ability to resist water infiltration after being impacted by missiles. In both of these areas, SPF has been found to perform above average as compared to other building systems and products.

Hail impact and effects

Documentation of the effects of hail damage on roofing systems is similarly extensive, and has led to changes in numerous local and regional building codes to protect building occupants and reduce insurance losses. SPF roofing has been found to perform above average as compared to other commercial and residential roofing systems in withstanding hail impacts and hail-related damage and failures. Recent studies of comparative roof performance have included *Hail Damage to Roofing: Assessment and Classification*, a paper presented at the Fourth International Symposium on Roofing Technology by William C. Cullen of the National Roofing Contractors Association (NRCA), which compares eight generic roofing systems (see Chart, page 5).

Another recent report sponsored by the National Roofing Foundation, surveyed 140 SPF roofs ranging from new to 27 years old. Among the report's conclusions in terms of hail effects was that SPF roofs help prevent the roof leaking associated with hail storms. "They are not in immediate danger of leaking," reads the report, "provided the penetration does not extend all the way through the foam." Fortunately, the NRF report also concluded that where roofs had experienced hail damage, the impact penetration was limited to the "upper surface" of the foam.

This performance attribute demonstrates the ability of SPF roofing assemblies to protect roofing substrates during hail events – and, for that same reason, building occupants and contents.

Research by the Performance Based Studies Research Group (PBSRG, www.pbsrg.com), spearheaded by Dr. Dean Kashiwagi at Arizona State University's Del E. Webb School of Construction, has helped evaluate the performance and hail resistance of different types of elastomeric coatings for SPF roofing. A published report, *Hail Resistance Test of Sprayed Polyurethane Foam (SPF) Roof Systems*, documents the findings.

Three major coating types of varying thicknesses, SPF foam densities, weathering and granulation were subjected to the FM-SH test for simulating severe hail impact under room temperature, freezing and sub-zero conditions. (Test drops are 0.8-pound steel balls, 1.75 inches in diameter, released from 17 feet, 10 inches overhead.) Urethane-coated SPF displayed the highest resistance to damage, a finding that was independent of variables such as granulation, accelerated weathering procedures and temperature.

These findings were confirmed in field tests conducted in Wyoming and Texas. Severe hail – with missiles about the size of golf balls – produced mechanical penetrations in the SPF roofs, but none experienced ruptures or premature failures.

.06 Hurricane Katrina: The Storm, Damage, and NIST Findings

Arguably the most costly natural catastrophe to hit the United States in the past century, Hurricane Katrina, which first hit land near Buras, Louisiana, on August 29, 2005, caused mind-boggling damage and destruction to communities along the coastline of Louisiana and Mississippi. The hurricane are related breeches of area levees effectively put large sections of New Orleans underwater when the city's flood protection buckled under surge heights of up to 10 feet.

Less than one month later, on September 24, 2005, Hurricane Rita struck the Texas-Louisiana border, and like Hurricane Katrina, Rita reached maximum sustained winds of 180 mph. Together, the two hurricanes caused massive damage to the coastal areas of Alabama, Florida, Louisiana, Mississippi and Texas.

The numbers

According to an extensive report released by the National Institute of Standards and Technology (NIST) in June 2006:

- Fatalities had exceeded 1,300.
- Economic losses were estimated to be in the range of $70 to $130 billion.
- Insured losses were approximated between $45 billion and $65 billion.
- More than 2.6 million applications for disaster assistance were requested.
- More than $88 billion in federal aid was allocated for relief, recovery and rebuilding.

The study itself describes the environmental details of both hurricanes, and also documents the NIST-led team's observation of damage to major buildings, infrastructure and residential buildings caused by wind and wind-borne debris, storm surge, surge-borne debris and surge-induced flooding.

Furthermore, the report concludes with 23 recommendations for: (1) improvements to practice that will have an immediate impact on the rebuilding of structures damaged or destroyed by the hurricanes; (2) improvements to standards, codes, and practice; and (3) further study or research-and-development.

Lack of code compliance

Even though wind speeds during the hurricanes were generally below levels used by codes and standards to define hurricane-force events, the NIST team discovered that a number of shortcomings in code compliance contributed to the region's extensive damage.

For example, NIST found that many masonry wall failures could have been prevented had they been properly anchored and reinforced, as required by the current model codes. Applying SPF closed-cell wall foam actually increases racking strength 3 to 4 times according to NAHB (National Home Builders Association) conducted May 25, 1992 and November 18, 1996. Also, wind-borne gravel from building rooftops caused much damage to nearby structures, whereas adherence to model building codes, which do not permit aggregate surface roofs in high wind zones, may have significantly reduced such damage.

Yet another example was the failure of facilities to place backup electrical generators, electrical equipment, chillers and other critical equipment above expected flood levels, as mandated by model code provisions.

.07 Hurricane Strength: NIST Report on Materials and Systems Performance During Hurricanes Katrina and Rita

Delving into the details of the NIST report on Hurricanes Katrina and Rita, the areas of building damage studied included roofing, window systems, cladding and water damage to building contents and equipment. The hurricanes winds not only caused damage to roofing and rooftop equipment, but provided paths for water ingress into buildings. In addition, wind-driven rain through walls and around intact windows led to water damage in building interiors as well.

In the coastal areas and in New Orleans, storm surge was determined to be the main cause of damage, while wind and wind-borne debris was the main culprit inland. Furthermore, window glass in major buildings fell victim to high winds blowing debris from aggregate surface roofs and/or the damaged façade/structure on adjacent buildings, as well as damaged equipment screens on top of nearby buildings.

NIST's investigation of residential structures discovered that those exposed to impact forces of the storm surge generally did not remain intact, while buildings somewhat protected from the force of moving water did survive, but typically sustained major damage. The study also found that conventional reinforced-concrete construction made of columns and beams, slabs, and load-bearing walls fared much better than other types of structures, even when not elevated.

Roofing report

Of the hundreds of structures examined by the NIST-led team, the extent to which major commercial and industrial building roofs were damaged was wide ranging, with some experiencing little to no damage, even along the coast, while others suffered extensive damage. But overall, researchers estimated that 20 percent to 30 percent of the roofs investigated had sustained some level of damage. For individual buildings or wings of large buildings, damage ranged from less than 5 percent of the roof area to greater than 50 percent or more.

While conventional bituminous membranes and polymer-modified bituminous membranes were found to be the predominant roofing systems on major buildings in the area, other roofing types studied included metal roofing, synthetic single-ply roofing and spray polyurethane foam (SPF) roofing. In general, examples of typical damage to all roofing types included:

- Failure of metal flashings.
- Puncturing of roof coverings or the total roof system.
- Blow-off of the roof coverings, often accompanied by loss of insulation.
- Blow-off of the insulation and covering, accompanied by loss of deck, loss of metal roof.
- Panels with and without damage to structural members.
- Combinations of these types of damage.

Honing in on bituminous membrane roofing, researchers found these systems to be most vulnerable to blow-off of some section of the membrane. In addition, damage generally came on the heels of three modes of failure including: (1) poor performance of perimeter metal flashing; (2) inadequate interlaminar strength of insulation and inadequate adhesion between membranes and insulation; and (3) poor attachment of bituminous base sheets to decks and other substrates.

Numerous case studies from the affected areas were cited in the report. In one such case, two wings of a hospital in Pascagoula, Mississippi, that had a built-up bituminous membrane roofing systems – estimated to be 5 years to 10 years old – were damaged at a windward corner, apparently due to lack of adequate interlaminar adhesion strength of the membrane and insulation components to resist the wind-imposed uplift forces. In another case, a small commercial building in New Orleans totally lost its bituminous roofing membrane, most likely caused by the uplift and tearing of the membrane base sheet from around the fasteners that secured the membrane to the wood-fiber cementitious panels.

Roofing recommendations

Due to the fact that roofing damage created a major point of entry for the elements to wreak even more damage to structures left vulnerable – for example, interior flooding, personal property damage, collapsed ceilings, mold growth, and damage to building materials and structural components – the NIST report identified roofing as a major area to proactively address.

Consequently, the following recommendations were put forth to mitigate such future damage from weather events:

- Selecting a covering, designed and tested for use in the wind zones where the structure is located.
- Proper installation and attention to correctly attaching the covering and flashings, per the manufacturer's instructions.
- Applying an underlayment below the primary waterproof covering to serve as secondary protection against water penetration.

Of the roofing damage studied, it was discovered that the majority of failure came as a result of failing to comply with the currently accepted practice as detailed in manufacturers' literature and trade association

Miami Airport Chooses SPF

According to sources at the Miami International Airport, a major re-roofing project for the airport facilities will rely on spray polyurethane foam (SPF) roofing backed by an "Unlimited Wind Warranty."

The airport is located in an area of frequent high winds and airborne projectiles due to hurricanes and tropical storms. It is also subject to the stringent Miami-Dade County building codes.

SPF has been shown to perform better than other roofing systems in resisting wind uplift, tearing and breakage, and compromises due to missiles such as hail and wind-borne debris. These characteristics were considered in the award of the roofing project.

guidelines. For example, failed roofs, by in large, were found to have an inadequate number of fasteners, mislocated fasteners and/or inadequate heating of modified bituminous membranes.

.08 The NIST report: Findings on SPF systems

When it came to revealing how SPF roofing systems weathered the storm, the NIST study of Hurricanes Katrina and Rita reported exceptional performance, despite the fact that a limited number of systems were observed in the storm damage zones. Basically, with one minor exception, SPF handled the winds "extremely well" without suffering from SPF blow-off or damage to the flashings.

A good deal of NIST's findings came from analyzing a number of SPF roofing systems found in the Pascagoula, Mississippi, area, generally estimated to be around 20 years old. Describing the one "minor exception," NIST reported: "The SPF had been applied to a wood-fiber insulation that had been mechanically fastened to the metal deck with an inadequate number of fasteners. Failure likely occurred when the insulation board delaminated from the deck. The area of the failure was less than 1 percent of the total roof area."

NIST did not elaborate on the successful performance of the SPF systems. However, there are numerous documented reasons for SPF's superior record under severe weather conditions like those experienced during Hurricanes Katrina and Rita. For example, compared to other roofing systems, SPF uniquely provides smooth, continuous surfaces that have no edges, seams or joints for the wind to grab onto. In addition, SPF is self-flashing and offers 100 percent adhesion without fasteners, which has been found to be a common point of failure in other systems. Yet another SPF benefit is the fact that it grips the building walls, thereby holding tight in the face of high winds.

.09 White Paper Action Plan: Six Constructive Recommendations

Based on the reporting and observations made in this White Paper, we recommend the following "action plan" for building owners, designers and constructors, as well as for the building materials industry at large. These recommendations are specifically oriented toward those members of these professional communities who are concerned about severe weather events:

1. Continue to study the efficacy of SPF roofing in severe weather conditions. It is clear that SPF provides significant advantages in performance during severe weather events. The advantages deserve to be studied by industry groups, academy, and private-sector experts for the betterment of building performance.

2. Propagate the NIST findings. Specifiers and designers of buildings in hurricane zones can incorporate the observations by NIST in consideration of future building projects. Similarly, building owners and construction professionals should be aware of the NIST report.

3. Expand professional education on SPF. The properties and benefits of construction assemblies using spray polyurethane foam are not well understood across large segments of the professional community. Building designers, contractors and owner-managers should encourage further continuing education on the advantages and opportunities of presented by SPF.

4. Aggregate current findings on SPF performance. While this White Paper makes an informal attempt to consolidate various sources of data on SPF roofing and enclosure systems, it is far from complete. We encourage trade groups, academic think-tanks and professional communities to spearhead the aggregation of all current findings on the in situ and laboratory performance of SPF.

5. Promote the use of SPF roofing and walls to enhance the building enclosure. Where appropriate and suitable, building teams should consider the use of SPF. The SPFA and other industry groups should continue their promotion of the building systems and underlying materials.

6. Create awareness among codes officials and enclosure experts. The benefits of SPF for building occupants, property value and enclosure performance are well documented. In general, it is a highly sustainable building system with good energy and air-quality performance. As these qualities serve the interests of codes officials and roofing/façade/enclosure experts, we encourage more awareness of SPF's characteristics and common applications among those "thought leader" groups.