Saffir-Simpson Hurricane Scale	
Storm Classification	**Wind Speed (mph)**
Tropical depression	0-38
Tropical storm	39-73
Category 1 hurricane	74-95
Category 2 hurricane	96-110
Category 3 hurricane	111-130
Category 4 hurricane	131-155
Category 5 hurricane	>155

Table 1 – The Saffir-Simpson hurricane scale is used to determine the size and strength of a storm based on sustained wind speeds. Source: NOAA.

While storm surges only impact areas within a few miles of the ocean, wind and rain damage can spread extensively inland. In 2008, Hurricane Ike made landfall in Galveston, Texas, and headed northeast, leaving a swath of destruction across the U.S. and into Canada. Hurricane Ike was so powerful that it left almost one million people without power in Ohio, even after it had been downgraded to a tropical storm.

WIND DAMAGE

According to AccuWeather Inc., of the three primary ways hurricanes can damage homes, wind is the greatest cause of property loss. When Hurricane Andrew struck Florida in 1992, it was the most expensive natural disaster in American history up to that point. Andrew caused over $26 billion in damage, destroyed over 25,000 homes, and severely damaged over 100,000 more. Of those damaged, over half the homes had significant damage to the roof as a result of wind damage. See *Table 2*.

Hurricane winds are unique and pose a specific threat to wooden frame homes and traditional roof systems. First, the sustained winds from a hurricane can last for hours, with occasional gusts up to 50 percent greater than sustained air speed. This means a Category 2 hurricane, with winds at 100 mph, could have gusts that exceed 150 mph, which is equal to Category 4 strength. Also, because hurricanes move slowly, wind direction changes slowly as the storm passes. Consequently, any weakness in the roof system will eventually have to face the brunt of the storm.

Finally, winds from hurricanes can create a challenge for roof systems simply because of the dynamics of wind flow around a home. As air speed increases, the amount of pressure put on the home exponentially rises. A sustained wind speed of 75 mph will deliver about 19 pounds of pressure per square foot (psf), while a 150-mph wind will create almost 80 psf. To put this in context, a standard 4 x 8 sheet of roof sheathing could face over 2,500 pounds of force when set directly in front of a Category 4 hurricane (*Table 3*).

Wind Speed (mph)	75	95	110	130	155	180	200
Velocity Pressure (psf)	19.0	30.6	41.0	57.2	81.3	109.7	135.0

Source: American Society of Civil Engineers, 1990

Table 3 – Velocity pressure as a function of wind speed.

Recent Hurricanes and Their Cost			
Year	**Hurricane**	**Category**	**Cost (US $)**
2012	Sandy (sustained winds near 90 mph)	Category 1	>$52 billion
2008	Ike (sustained winds near 135 mph)	Category 4	$19.3-$21 billion
2006	Wilma (sustained winds of 100 mph)	Category 2	$16.8 billion
2006	Katrina (sustained winds of 174 mph)	Category 5	$75 billion
2006	Dennis (sustained winds of 111 mph)	Category 3	$2.23 billion

Table 2 – Recent hurricanes and their cost. Source: NOAA.

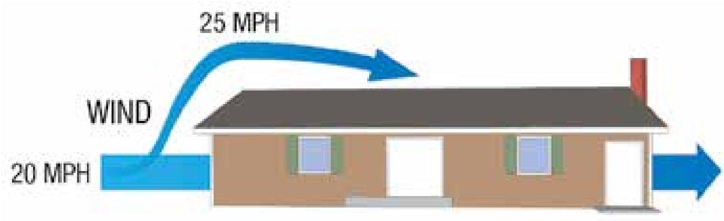

Figure 1 – During strong gusts on relatively flat roof surfaces, air pressure can drop and act as a vacuum, pulling roofing material into the air stream.

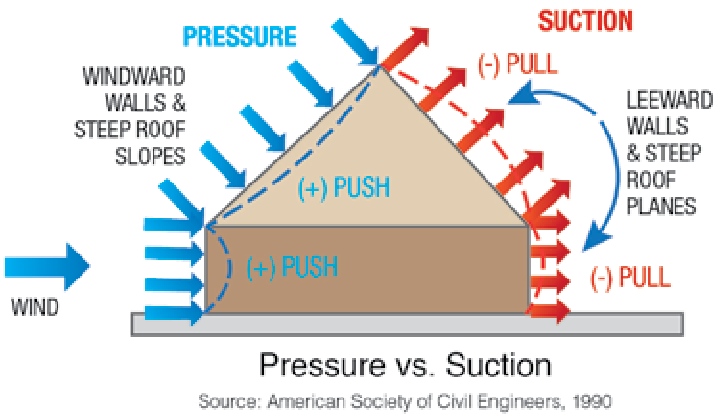

Figure 2 – Wind strikes the leading edge, causing pressure. Then laminar flow on the lee side of the house creates uplift on the downward side.

UNDERSTANDING WIND UPLIFT CHARACTERISTICS

However, when hurricane-force winds strike the home, the flow of the air around the building is rarely consistent or direct. Due to the design of a roof, air pressure can vary greatly in different parts of the roof, which can increase the possibility of damage. Roof damage of this nature can result from wind uplift, one of the leading causes of roof failures during a hurricane.

WHAT IS WIND UPLIFT?

Wind uplift is a naturally occurring vacuum created in strong wind events that results in a rapid and sustained loss of air pressure due to high winds or a disruption in the "laminar flow" of air around the building. Laminar flow is a concept stating that air will try to stay in contact with whatever objects it is passing over. If this flow is interrupted because of a sharp rise, curve, or fall in the object, the path of the air stream continues and, under it, a vacuum is created.

Roof damage caused by wind uplift occurs when the air pressure below the roof is greater than the air pressure above the roof. High wind speeds, in general, can cause a reduction in air pressure as they flow over objects.

At the same time, negative pressure is developed on the roof surface by wind flowing over the roof surface, while positive pressure to the underside of the roof deck develops from the wind blowing through open windows and doors of the building. The result is an upward force on the roof. The combination of the negative pressure and positive pressure can double the destructive force of the wind, causing roof assembly failure. (See *Figure 1*.)

During strong gusts on relatively flat roof surfaces where the wind is flowing more than striking, air pressure can quickly drop as air speed increases. This loss of air pressure can act as a vacuum and start to pull roofing materials into the air stream, where the direct force of the wind will potentially sweep them away.

The other force that can create uplift is a disruption in the laminar flow of air around the roof. In the case of a roof, as wind strikes the leading edge, the roof forces the air to flow over the ridge. However, laminar flow is often lost on the lee side of the home, which creates uplift on the downward side. If the wind speed is great enough, this vacuum can pull off shingles, lift eaves, and start to weaken the whole roof structure.

As hurricanes move through an area and wind direction shifts, all parts of the roof can become exposed to both the direct pressure of the wind and the effects of uplift. When the wind is blowing parallel to the eaves and ridge, uplift is created along the rake or inclined edge of a sloped roof over a wall. When the wind is blowing directly towards the roof or at a 90-degree angle from the eaves and ridge, uplift can target the down-wind side of the ridge and corners.

The dynamics of simple air pressure against the exterior of the house can create incredible pressure and uplift on a roof and

Photo 2 – Blown-off roof.

Photo 3 – House is still standing, but the roof has been torn off.

result in extensive damage. Internal pressures during hurricanes also cause roof failures.

PRESSURE VS. SUCTION

When windows or garage doors implode during a hurricane, air pressure within the home increases suddenly and significantly. While exterior surfaces are generally designed and built to withstand extreme air pressure, interior walls and doors are not. The increased air pressure can inflate the home like a balloon. When this happens, roof sheathing can quickly be blown up and away from the home. Not only do the high wind speeds create a vacuum above the roof, but inflation within the home increases air pressure beneath the roof, causing it to be blown off (*Photos 2* and *3*).

In the Federal Emergency Management Agency (FEMA) posthurricane analysis of Hurricane Ivan, which struck the coastal areas of Alabama and Florida in 2004, the mitigation assessment team reported the most common roof damage to homes affected by the storm was the removal of shingles and roofing underlayment. When roofing materials begin to fail during a hurricane, damage to the home can rapidly increase. If roof coverings are damaged or blown away, rainwater can enter the attic space, soak insulation, saturate drywall, and weaken the structure. After Hurricane Andrew, 65 percent of the homeowners who filed insurance claims reported damage from rain. Compounding the problem of water in the structure is mold growth. Once building materials become saturated, mold growth can quickly lead to indoor air quality issues that can persist long after the storm has passed.

Of greater concern, though, is the potential for a building to collapse. Catastrophic failure of roof systems can quickly lead to a complete collapse of the building. Often when homes are completely destroyed, it is the roof system that fails first, allowing wind and rain to enter the home unchecked. Analysis after Hurricane Ivan supported the conclusion that existing approaches to roof fastenings were either insufficient or the fastenings were improperly installed. This is especially true of older buildings that were built before the more stringent building codes were enacted. Among the observations of the mitigation assessment team were:

- Older building code methods did not always result in resistance to high wind pressures on critical building areas such as corners and walls.
- Even if an older building code was in place, the enforcement of the code may have been ineffective.
- Older buildings may have suffered from degradation of strength due to corrosion, termites, dry rot, poor maintenance, or a variety of other factors.
- Construction methods and materials commonly used at the time the older buildings were built may now be considered inappropriate for a high-wind area.

These observations led to a common theme that hurricane clips or straps were ineffective if corroded or not installed correctly. Installing closed-cell SPF to the underside of the roof deck glues the whole structure together, reducing or eliminating the "weak spots" that a corroded or poorly attached hurricane clip might have.

Photo 4 – Close-up of spray foam applied to walls.

In hurricane-prone areas like Florida, building codes for new construction now mandate protection for up to 120-mph winds or Category 3 hurricanes. Other improvements to buildings include more aggressive nail patterns in roof assemblies and taping of the seams in roof sheathing to reduce water intrusion. While more stringent building codes help reduce the amount of damage to new homes, what actually happens during hurricanes does not always match expectations.

In the case of Hurricane Ivan, building codes had prescribed a design wind speed of between 140 and 150 mph, meaning that new residential construction was meant to withstand a Category 4 hurricane. However, reports after Hurricane Ivan indicate that even though actual sustained wind speeds were recorded at around 109 mph (Category 2 strength), damage to building exteriors was significant and widespread. Specifically, roof decking, windows, doors, and wall claddings all appeared to have been exposed to much greater wind speeds and suffered considerable damage. The observations concluded that even when hurricane wind pressures are 25 to 40 percent less than code-prescribed measures, roof systems can still be vulnerable to hurricane destruction.

CLOSED-CELL SPF RECOGNIZED BY FEMA

One technology gaining traction among architects, builders, and federal agencies for use in improving roof integrity during hurricanes is closed-cell SPF. In its "Home Builder's Guide to Coastal Construction," FEMA highlights the benefits of closed-cell SPF. In Fact Sheet 1.8, "Non-Traditional Building Materials and Systems," FEMA incorporates an entire section on sprayed closed-cell foam insulation and the inherent advantages of its use in coastal building practices. Major points include the speed of installation versus batt insulation, foam expanding to fit wall cavities (*Photo 4*), formation of a rigid barrier to keep moisture out, and "offers acceptable flood resistance" (citing a National Flood Insurance Program technical bulletin). The fact sheet goes on to explain that a complete system of flood resistance would also include corrosion-resistant metal or pressure-treated wood framing for maximum effectiveness in a severe flood situation.

Closed-cell SPF is an insulation that also functions as an air and bulkwater barrier and as a moisture vapor retarder. SPF is made by reacting methylene diphenyl diisocyanate (MDI) on the "A" or polyisocyanurate (polyiso) side with a polyol blend ("B" or resin side). The two liquid components are joined under pressure in a spray nozzle where they are applied directly onto the wall, roof, or building assembly. Once the reacting liquid hits a surface, it expands and solidifies into a foam matrix. SPF is typically applied by certified professionals.

Closed-cell SPF (2-3 lb. per cubic ft.) has a high R-value of over 6 per inch, provides structural enhancements to buildings, and is effective in all climates. It is typically installed in wall cavities, attics, basements, crawl spaces, or on a building's exterior walls.

In 2007, Dr. David O. Prevatt conducted a study at the University of Florida's Department of Civil and Coastal Engineering to determine how closed-cell SPF could be used to increase the structural integrity of roof assemblies during severe weather events like hurricanes.

Specifically, the research evaluated how SPF could protect the roof from uplift and reduce the chances of water intrusion during storm events. To test the material, two approaches were taken. First, a continuous 3-in.-thick blanket of closed-cell SPF was applied between the 2 x 4 roof rafters to evaluate the effectiveness of a full, monolithic covering of closed-cell SPF in the roof assembly. The next approach was to apply closed-cell SPF as a three-inch fillet to the junction of the roof plywood deck and the roof rafter/truss top chords.

The study concluded that using closed-cell SPF—either in a continuous 3-in. blanket or in fillets—increased the roof panel wind uplift capacity by 2.6 times that of roof panels fastened using conventional mechanical fasteners and nailing patterns.

In fact, roofing sections with closed-cell SPF applied as an adhesive were able to withstand air pressures in excess of 153 psf, or roughly the wind speed found in a Category 4 hurricane.

SPF ADDS RACKING STRENGTH

Three separate studies in 1992,[1] 1996,[2] and 2006,[3] conducted by the National Association of Home Builders' (NAHB) Research Center and Architectural Testing Inc., compared relative structural strength of common baseline wall assemblies to similarly constructed wall assemblies insulated with closed-cell SPF. The studies found (closed-cell) SPF could add from 75 to 300 percent increase in racking strength to walls of oriented strand board (OSB), plywood, gypsum wallboard, vinyl siding, and polyiso board.

The research demonstrated SPF significantly increased rack and shear strength in both wood and metal stud construction. Additionally, it was learned that SPF increased 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.

Special bracing for wind resistance would not be required for strength purposes when using SPF in the walls. As a structural material, closed SPF can add strength to wall and ceiling assemblies of all sizes and heights, depending on the framing.

The most recent study, conducted in 2006, demonstrated that even 1.5 inches of closed-cell SPF provides equivalent racking strength enhancement to polyiso sheathing as 3.5 inches of closed-cell SPF (*Photo 5.*)

The results of the tests are outlined below:

SPF installed between metal studs (3.5 inches):

- Increased racking strength of drywall sheathed walls: 2,400 to 5,380 lbs.
- Increased racking strength of OSB: sheathed walls 4,800 to 6,000 lbs.

SPF installed between wood studs (3.5 inches):

- Increased racking strength of vinyl sheathed walls: 913 to 2,800 lbs.
- Increased racking strength of plywood sheathed walls: 2,890 to 5,300 lbs.
- Increased racking strength of polyiso sheathed walls: 1,109 to 2,159 lbs.

SPF installed between wood studs (1.5 inches):

- Increased racking strength of polyiso sheathed walls: 1,109 to 2,257 lbs.

According to Applied Research Associates, Inc., in "Development of Loss Relativities for Wind-Resistive Features of Residential Structures," for the Florida Department of Community Affairs, "Roof deck attachment during a hurricane is critical to the survival of the building. Once a building loses one or more pieces of roof deck, the losses increase exponentially

Photo 5 – Closed-cell SPF applied to the underside of a roof increases the racking strength.

due to the vast amount of water that enters the building. Field observations and insurance claim folders indicate that the house quickly becomes a major loss once the roof deck begins to fail in a hurricane. In other words, even if the walls are intact and the roof trusses do not fail, loss of roof deck and a few windows typically leads to losses greater than 50 percent of the insured value."

STRONG AND SAFE

When applied properly to the underside of the roof sheathing, closed-cell SPF does not impact the fire rating of the roof assembly.

SPF doesn't affect the rating of the roof assembly as long as the roof decking material is wood structural panel sheathing a minimum of 0.47-in. thick. According to the International Code Council (ICC), Section 2603.4.1.5,[4] "Foam plastic insulation under a roof assembly or covering that is installed in accordance with the code and the manufacturer's instructions shall be separated from the interior of the building by wood structural panel sheathing not less than 0.47 inch in thickness. A thermal barrier is not required for foam plastic insulation that is part of a Class A, B, or C roof-covering assembly, providing the assembly with the foam plastic insulation satisfactorily passes FM 4450 or UL 1256."

Any foam plastic must be protected by a thermal barrier when installed to the interior of a building, regardless of area. There are exceptions—for example, in attics and crawl spaces used only for service of utilities, an ignition barrier may be used; or the foam can be tested in accordance with appendix X of AC 377, and the ICC Evaluation Report must be followed.

The insulation is part of the interior, not the roof system, so all that is needed is the thermal or ignition barrier, depending on whether the underside of the roof deck is interior space or an attic.[5]

CONCLUSION

It is estimated that over 60 percent of existing residential homes in hurricane-prone regions currently do not have adequate wind resistance when faced with even a lesser hurricane. Retrofitting homes along the Gulf Coast and Eastern Seaboard continues to be a challenge for states trying to proactively reduce the risk of property loss from hurricanes.

To date, several manufacturers of closed-cell SPF have met the Florida Building Commission's 2007 Florida Building Code Performance Standards for wind uplift resistance. Other organizations, such as the Insurance Institute for Business and Home Safety, specifically suggest installing closed-cell SPF along the joint between the roof sheathing and the rafters or trusses (fillet method) as an approach to keep wind and water out of the home during severe weather events.

If you live in an area with a history of hurricanes, the odds of having to ride out a Category 5 storm are low. However, history has shown that even tropical depressions and wind speeds in the double digits are significant enough to cause considerable damage to homes and, especially, roofs. Making sure that a structure is prepared for a strong storm and that the roof can weather the wind and rain of a hurricane can provide peace of mind and protection of property.

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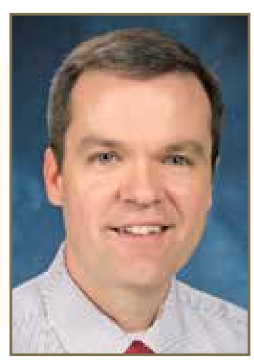

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