Hurricane Warnings

Sifting through the wreckage of Hurricane Andrew to learn why some houses survived and some didn't

by Charles Miller

At 3 a.m., Stan Makowski sat in his living room listening to the wind shriek by. He figured his house could take it. After all, the house started out as a bunker built during the Cuban missile crisis. It had a flat concrete roof and concrete-block walls.

When he converted the bunker into his house, Makowski filled in a 6-ft. opening in the back wall with studs and gypsum board. Now as the wind picked up speed, Makowski gazed at a painting of fish hung on the gypsum-board wall. It was getting noisy outside. Makowski could hear tree limbs, hunks of sheet metal and parts of neighboring houses ricocheting around the yard and off his walls. The wind sucked at the windows and poured through the cracks. The painting seemed to be moving. Makowski pulled it aside and stared in astonishment at the framed wall—it was beating in and out, like a heart. So began the day of Homestead's building inspector..

What greeted Makowski, and his colleagues in the south Florida building community, went beyond comprehension. In about four predawn hours on Aug. 24, 1992, Hurricane Andrew inflicted the most expensive natural disaster in U. S. history. Current estimates are that nearly 80,000 dwellings were destroyed by winds that gusted up to 160 mph and by the 10 in. of rain that fell during the storm. In Homestead, fully 80% of the buildings were beyond repair.

But a fair number of buildings did ride out the hurricane. If 20% of the houses were still standing, what set them apart from the houses that were demolished? And what clues could be found in the rubble that can help us build houses that will stay together when the next hurricane hits? I went to Miami to find out.

Old houses held up—The streets near the coast were lined with tree parts. Limbs, trunks, banyan tendrils and root balls were mounded high into yellowing hedges alongside the roads. Behind the mounds stood the remains of neighborhoods. In the hardest-hit places, homeowners have spray-painted notes to their insurance adjusters on the walls that were left standing. Occasional messages like, "House for sale, half off," or, "Looters will be stoned with roof tile," bespeak a community trying hard to maintain its sense of humor.

In general, houses were destroyed in one of two ways: constant gnawing or sudden collapse. Constant gnawing begins with the hurricane getting a finger into the house—usually at the roof. The roofing material peels away at the gable ends or eaves, exposing the edges of the roof sheathing. If it picks off a piece of sheathing, the wind shoves a torrent of rain down the attic's throat. Saturated, the gypsum-board ceilings collapse. Then the wind is inside the house, and while the structure may survive, the interior and its contents are demolished.

Sudden collapse occurs when the shell of the house is breached instantaneously. For example, a garage door facing the wind blows in, and the full force of the gale hits the interior. The wind has to go somewhere, and it may blow out windows, doors, walls or the roof (top photo, facing page). A smaller breach, like a roof tile bursting through a window, can have the same effect.

Unless they were pelted with an unusual barrage of flying wreckage, the houses built during the 50s and the 60s held up well. These homes have a lot in common with most of the houses built across the country at that time. They're one-story ranch houses but with some touches that make them unmistakably southern. Some go off in a Spanish direction, with terra-cotta tile details and curving archways. Others get modern, with goofy cast-concrete screens that resemble big slices of swiss cheese worked into the walls of the open-air garages.

The walls of these houses are made of concrete blocks set atop a reinforced slab that is thickened at the edges to make a footing. Steel extends from the foundation to the tops of the walls at the corners and on 8-ft. centers, and the cells that contain the steel are filled with concrete. The tops of all the walls are bound together by a contiguous, poured-in-place concrete tie beam. If the house has a gable roof, it has a shallow slope, and the gable-end wall is all masonry. Steel straps cast into the tie beam anchor rafters—typically 4x6s made of Dade County pine, a strong, local rot-resistant conifer that is so hard that you've got to drill holes for nails. The roof decks are T&G planks secured to the rafters with two nails at each intersection.

The roofs on these houses range from inexpensive flat decks covered with tar and gravel to more costly shallow hip roofs (having a pitch of 3-in-12 or less) covered with clay barrel tiles. Both types did well in the hurricane.

Boom time—The appetite for housing has grown steadily in south Florida. By the late 70s, builders had largely abandoned the laboriously constructed one-story ranch houses of the prior decades. They started building one-story stick-framed houses with 2x4 roof trusses covered with plywood or OSB (oriented strand board) sheathing. To conserve land, more and more two-story houses popped up. They were framed in the same manner but built atop block walls for the first floor. In addition to the houses getting taller, the roofs started to get steeper, with more of what engineers call gingerbread and what architects call character. Instead of hip roofs, a multitude of gable ends started showing up on houses in Dade County. Gable roofs are cheaper to build than hip roofs, and their profiles make a stylish skyline that is familiar to a lot of folks who have migrated to south Florida from other parts of the country. Unfortunately, gable roofs also present a big target to the wind (bottom photos, facing page). And details like tacked-on rake overhangs give the wind an extra handle to grab.

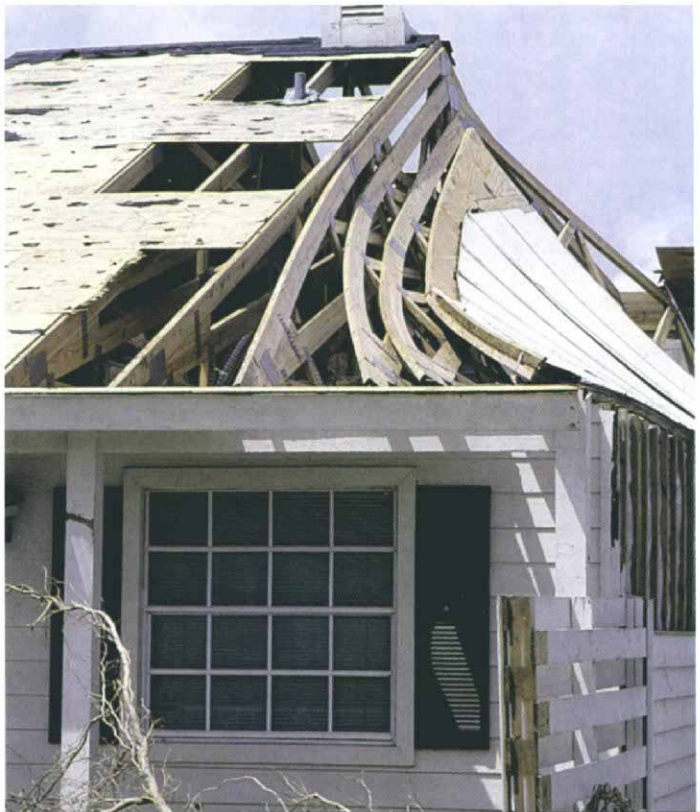
The old-timers knew better than to build steep gable roofs, but it had been since 1967 that Hurricane Betsy had torn up Florida. Memories fade, and the tough South Florida Building Code sets guidelines for assembling stick-built houses that are supposed to stand up to 120-mph winds-even if they have gable roofs. When Hurricane Andrew finally served up such a wind, however, the newer houses fell apart. Can we pin it on something as simple as gable roofs?

While talking to various manufacturers and trade associations, I learned that every special-interest group involved has been pointing fingers at everybody else. For example: "It's not the truss's fault. The sheathing failed." "It's not the sheathing's fault. The shingles failed." "It's not the shingle's fault. The staples were installed wrong." Each one of these statements is true, and they cast a harsh light on an inescapable fact: In an effort to reduce labor and material costs, the newer houses built in Dade County rely on building systems with little room for error. The parts have to be assembled with care by someone who has a feel for what the components are doing. Once exposed to the huffing and puffing of a wolf as fierce as a hurricane, the weak link in the stick-framed house will break, and the house will blow down. Let's look at the links.

Roofing—Two roofing materials predominate in south Florida—asphalt/fiberglass shingles and tiles. Tile is the sentimental favorite. Its mass

Blowout. **Houses that were suddenly pressurized when a door or a window blew in often lost their roofs as the wind sought a way out of the building. With correct nailing and bracing, the roof may have survived.**

Gable roofs are a weak link. **Socked by Andrew, gable roofs facing into the wind were often the first part of a house to fail. Here, a row of unbraced trusses stripped of their sheathing has fallen like dominoes. The steel straps, correctly installed at the top plates, have done their job.**



Don't give the wind a place to grab. **At one subdivision, a popular roof detail was to build a ladder for affixing a soffit and a rakeboard to the end of a gable wall. The roof sheathing then extended beyond the plane of the wall, where winds pushed up on the overhang. This roof was sheathed with OSB, and when it departed, the staples stayed behind in the framing. The horizontal brace atop the webs and the diagonal brace between the first and second trusses helped keep these trusses from collapsing. But the house was still destroyed by water damage.**

Hip roofs fared well. **The low profile of hip roofs helped them deflect the storm better than gable roofs did. But tiles didn't always hang on the way they should have. The horizontal lines of mortar under these tiles reveal an incorrect installation.**

helps keep out the relentless heat, and its inorganic composition allows it to survive high humidity. Still, some homeowners prefer the look of wood shakes. But they're a bad idea in south Florida. The houses with shake roofs that I saw had lost most of their shakes. They don't weigh much, and their irregular edges give the wind ample purchase for ripping them off the roof.

When roof tiles go airborne, they can do a lot of damage to neighboring buildings. And as engineer Eric Colville points out, the tiles are ballast for the roof. Engineers routinely consider the weight of the roof in calculating the size of the hardware necessary to keep the roof on the building. When the ballast leaves, the loads change accordingly.

Roof tiles, whether flat, low profile or high profile, are typically laid over a base of 30-lb. felt followed by a layer of 90-lb. roll roofing with a mineral surface. The felt is mechanically fastened to the roof deck with nails 12 in. o. c. driven through thin metal disks called tin caps. The roll roofing is then hot-mopped onto the felt. The roofing's mineral surface provides the tooth that grabs the mortar used to affix roof tiles to the deck. Here's where the trouble usually starts.

In order for a mortar-set concrete tile (flat or low profile) to have a chance in hurricane winds, it has to be fully bedded in a patty of mortar. Once cured, this elliptical patty of mortar should weigh 4 lb. or 5 lb., and it should be about 10 in. long. It should also be placed parallel to the slope of the roof to best grip the tile in line with the tile's longest dimension. I saw roof after roof where the installers had done the opposite (top photo, above), or they had simply skimped on mortar. Cris Starr of Lifetile adds that the mortar must be made with cement that's been approved for roof tiles and must be mixed at the right ratio

Two-piece barrel tiles. **The leading edges of some cap tiles were snapped off by the wind, but the trough tiles remained.**

to ensure a good bond (18 shovels of sand per bag of cement). Though not required by code, it's also a good idea to wet the tiles before installation to keep them from drying out the mortar too quickly. Starr says that Lifetile is experimenting with mortars that have been modified with acrylic/latex admixtures or dolomite lime to increase adhesion and to make it easier for installers to do a good job when the heat is making the mortar set quickly. Starr also points out that starter courses of concrete tiles should be held down by little metal brackets called hurricane clips. They are often left out.

Roofs with a slope of at least 4-in-12 can have tile roofs affixed with nails. Nail-down tiles have a couple of advantages. Bob Ferrante of Monier Tile says that high winds moving over a tile roof create pressure differentials that lift the tiles. If they are nailed down, the tiles can wiggle up and down a little bit to equalize the pressure. Another advantage of nail-down tiles is that they don't rely on a mortar-to-roof bond that can be broken by somebody walking on the roof. To verify that the tiles were installed correctly, you can check the attic to see if there are nails protruding through the roof deck.

Several kinds of high-profile barrel tiles cover roofs in south Florida, and they seem to have fared differently. Instead of being completely blown away, the cap tiles would sometimes depart, leaving behind the trough tiles (photo left). The older tiles are pretty porous, and the evidence I saw suggests they stayed on their roofs better than the newer versions, which have smoother surfaces. John Pistorino, an engineer and consultant to the Dade County Building Department, says the mortar into which the tiles are bedded can get a better grip on the rougher surface of the older tiles. When barrel tiles are loosened by wind or foot traffic, Pistorino says, they can be rebedded with good results by using an adhesive made specifically for that purpose (RT 600, Ohio Sealants, 7405 Production Dr., Mentor, Ohio 44060; 800-321-3578).

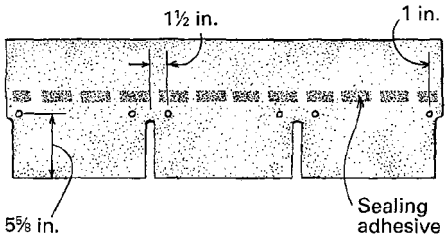
There aren't many metal roofs in Dade County, but the ones I saw were mostly intact. Pistorino, who investigated the damage inflicted by Hurricane Hugo in 1989, says that standing-seam metal roofs do well if they are crimped together using the manufacturer's recommended machines and tools. The peeled-away metal roofs he saw in Hugo's aftermath were largely the result of inadequate installation.

Asphalt shingles—Three-tab self-sealing asphalt/fiberglass shingles did well if they were attached correctly because they have a nearly nonexistent profile, and their leading edges are glued to the shingles in the lower course.

Like tiles, asphalt shingles are affixed to sheathing that has been covered with 30-lb. felt held down by nails through tin caps (those little metal disks). Metal drip edges, which line the edges of rakes and eaves, must be nailed down with religious dedication. Dade County's new rules say the drip edges should be nailed on 4-in. centers with galvanized nails.

Along the eaves and the gable ends, asphalt shingles should be glued to the drip edges with roofing cement (same for hips and ridges). Kent Blanchard of the Asphalt Roofing Manufacturers Association says the exposure of shingles installed in high-wind areas should be reduced to

Nailing pattern for high winds



4 in., and the shingles should be attached with six nails instead of the usual four (drawing above). As a result of Andrew, staples are no longer allowed in Dade County for attaching asphalt shingles. While proven to perform well in laboratory conditions, there have simply been too many cases of overdriven staples passing right through the shingles.

All flashings should be cemented down and nailed on 4-in. centers. And by the way, you don't have to take the cellophane strip off the back of the shingles. It's there to keep the self-sealing cement along the edges from gluing the shingles together in the bundle.

Sheathing and fasteners—Start up a conversation about plywood vs. OSB roof sheathing, and you're guaranteed to get some divergent opinions. What I saw, and what the engineers I toured the neighborhoods with concluded, was that plywood and OSB fared pretty much the same if they didn't get wet. Add water, and the picture changes: When plywood panels departed, they pulled out their fasteners. When OSB blew away, it sometimes left the fasteners behind (inset p. 83). Engineer Ron Wolfe at the Forest Products Laboratory in Madison, Wisconsin, says this may have to do with a fundamental difference between OSB and plywood.

Unlike plywood, OSB is made of compressed wood chips. When they get wet, the chips swell more than the plywood veneers. Picture an OSB roof deck that has just had its roofing membrane peeled away by a hurricane. Rain pours across the deck, driving water into the panel edges and into the holes made by the fasteners (overdriven staples make the situation worse). As the wood swells, the softened fibers bear against the crown of the staple. The swollen fibers try to lift the staple, but they are no match for the steel edge. Instead, the fibers are cut as the panel swells, exposing more fibers to the rain, and so on. The upward pressure on the roof from the wind lift exacerbates the situation. Finally, the panel pulls away, leaving the staples behind.

I asked Edward Keith, an engineer at the American Plywood Association, why staples would pull through an OSB panel. He told me that a lot of factors come into play, and there weren't any pat answers to the question. Foremost is the installation of the staples. If they're too close to the edge of the panel, they can compromise the integrity of the wood fibers. And if the staples are coated with thermosetting glue, have barbed legs or are embedded in extra-dense wood, their resistance to withdrawal will be greater than the strength of the OSB.

Members of the Dade County Board of Appeals have had long-time reservations about the use of OSB in their climate. On Sept. 4 the board outlawed the use of OSB for roof sheathing.

Staples for all roofing purposes were also banned. Board consultant Pistorino admits that staples can be used successfully to attach roof sheathing to their trusses, but he thinks they should be outlawed because he sees job after job where they aren't accurately placed. "You have to hold the staple gun perpendicular to the truss, and both legs of the staple have to penetrate the chord. A lot of operators hold the gun at an angle, so only one leg of the staple hits the mark." Worse yet, it seems to be easier with staples than with gun-driven nails to miss the mark entirely and not know it (photo above).

Staples missed their marks.

From now on, sheathing must be nailed to the framing. Currently the code says every 6 in. along the edges and 12 in. in the field. Dade County building inspector Jack Delaney thinks it should be reduced to 4 in. and 8 in., respectively.

Roof shapes and bracing—A hurricane applies intense and contradictory forces to a roof. On roofs having a pitch of 7-in-12 or above, the wind will push down on the windward side and lift up on the leeward side. Roofs between 7-in-12 and 2-in-12 act as air foils, and the wind will lift on both windward and leeward sides. Then the hurricane passes, the winds shift, and the whole thing starts again in reverse.

Most Dade County gable roofs are made of prefabricated trusses, and Pistorino's investigation convinced him that they held up very well. But he also points out that roof trusses were rarely braced adequately. By code, any truss roof is supposed to be braced along the top and bottom chords and at the webs. Gable ends in high-wind areas should be braced diagonally with 2x4s affixed to the sides of the vertical webs in the gable-end trusses. Every set of working drawings is supposed to have a plan that details such

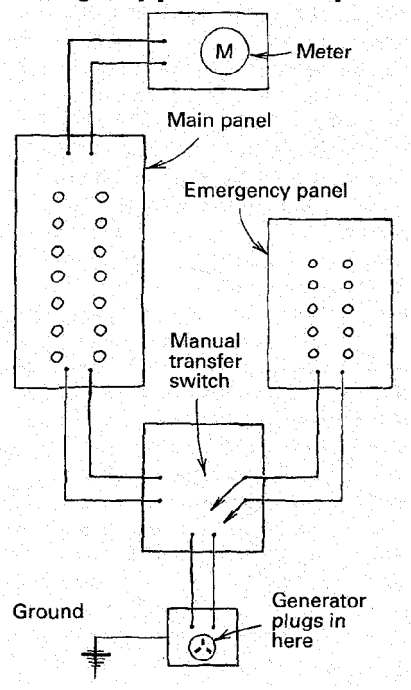
Emergency power

In the blackout that followed Andrew, people died in fires caused by candles lit to illuminate darkened houses. That's just one reason that Miami architect Brad Schiffer thinks an alternate power supply is at the top of the hurricane preparedness list. The brisk black-market sales of portable generators right after the hurricane bears him out.

When people fire up portable generators to power their household circuitry, a lot of things can go wrong. The primary problem is back-feeding into the grid. A generator hooked up to the public utility can send a deadly jolt into someone working on downed power lines. Multiple extension cords and poorly vented operating locations are other problems with generators.

The drawing below shows the schematic that Schiffer has his electrician follow in setting up an emergency panel. The panel feeds all the circuits deemed first-priority during an emergency. They typically include power for refrigeration, water pump, ceiling fan, alarm systems, a few lights and a couple of duplex outlets. During normal operation, the emergency panel is powered by two 110v legs coming off the main panel. Those legs pass through a manual transfer switch that can be flipped to a wall-mounted socket for hooking up the generator. Flipping the switch decouples the generator from the public utility. The generator should be located in a place where its fumes don't present a health hazard and where refueling can be done away from any open flames. —*C. M.*

Emergency-power circuitry



Drawings: Christopher Clapp

bracing, and the bracing plan is usually supplied by the company that makes the trusses. But the working drawings can be signed off by the architect and the engineer without the bracing plan affixed to the drawings. A note reminds whomever reads it that the bracing plans are still to come. A lot of times they just get overlooked.

In nearby Collier County, directly east of Dade County, the building department makes truss bracing a separate inspection. Pat Cornelison, chairman of Collier County's Code Revision Committee, says the county adopted gable bracing as a requirement after Hurricane Hugo revealed the weakness of gable ends in truss roofs. He says the county lost gable ends on older buildings during Hurricane Andrew, but none failed on houses built since the new code went into effect. Cornelison says bracing the roof of a three-gable, 1,700-sq. ft. house adds between $80 and $ 100 to the price of the building.

Hip roofs are likely to survive hurricane winds because they present a lower profile to the wind. What's more, their hips are diagonals, which by virtue of their shapes make hip roofs self-bracing. Kishor Mehta, director of the Wind Engineering Research Center, says the localized uplifts that peel away tiles and shingles on gable roofs are far less of a problem on hip roofs.

Walls and strap ties—During a hurricane, walls have to do more than keep out the weather. They must keep out debris that's flying down the street. Not surprisingly, the best suit of armor is concrete block finished with stucco. Wood-frame houses can provide decent protection if they have ¾-in. thick plywood sheathing under their siding or stucco finish. The framed wall that offers the least protection is the one sheathed with moisture-resistant ⅝-in. drywall and covered with hardboard siding (top photo, facing page).

If steel strap ties are nailed according to specs, they work. A correctly detailed wood-frame house in Dade County has strap ties everywhere. The straps are used for tying each stud to its bottom plate, tying first- and second-floor walls together at each stud and tying studs to trusses. In concrete-block houses, straps anchor concrete tie beams to framed walls and trusses.

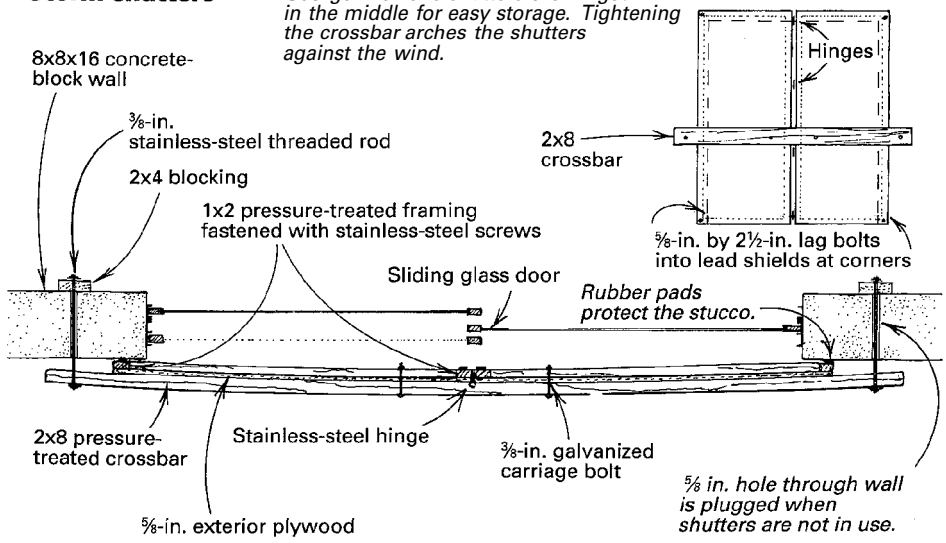
Here are the typical failure points: If the bottom plates aren't pressure-treated or set atop roofing felt, the plates will rot, and the connections will be useless. If the joint between a concrete first story and a framed second story isn't correctly trimmed and flashed, the studs will decay, and the straps will fail. The straps that anchor roof trusses to a concrete tie beam must be positioned at the edge of the truss and wrap over and down the top chord.

Shutters—Modern weather forecasting gave Florida residents some time to get ready for Andrew. Many of them bought plywood, cut it up and tacked it over their windows and doors. Then the winds ripped the plywood off and sent it down the street. Roll-down shutters and louvered aluminum shutters were equally ineffective (bottom right photo, facing page).

Shutters should be bolted to the building. Builder Steven Suddarth's house, made of concrete block, has ⅜-in. machine bolts embedded in the blocks at each window corner and around the doors. He used them to anchor ¾-in. plywood shutters. They took plenty of hits—mostly from tree limbs—but nothing came through.

Storm shutters

George Brewer's shutters are hinged in the middle for easy storage. Tightening the crossbar arches the shutters against the wind.



Lacking bolts, you can make serviceable shutters out of 2x2 frames covered with ¾-in. plywood for windows inset in masonry walls. Make the shutters a little smaller than the opening, and use wooden wedges to keep them in place. When the wedges get wet, they swell up and hold tenaciously.

George Brewer's house on Eleuthera in the Bahamas *(FHB* #67, pp. 59-63) has four pairs of sliding glass doors on its third floor. Andrew's eye passed directly over Brewer's house but couldn't get through the folding shutters he made out of plywood (drawing above).

Venting—The wind will go around a building, or it will go through it. In Haiti, most houses don't have glazed windows. The winds sail in and out, and the rain soaks the houses. But they are built to get wet, and in presenting less obstacle against the wind, they usually remain standing.

There are two schools of thought in Florida. The old school says it's a good idea to keep the windows on the leeward side of a house open a crack during a hurricane to equalize the air pressure. According to engineer Herbert Saffir, that was a good idea in theory, but he says, "When it's pitch black at 4 a.m. in the middle of a hurricane, you can't always tell where the lee side is." The risk is letting the wolf in by accident.

Nowadays, people are advised to button up their houses as tight as a drum during a hurricane and hope the envelope stays intact. But some events that took place during Andrew suggest that some kind of controlled air flow through a building might increase its chances of survival.

Pistorino recalls the story of one homeowner who heeded the advice of a local weatherman and closed his doors and windows, and even sealed up a pair of turbine vents in the attic. The house was standing well against the storm when a tile smashed a window, and the wind immediately started to inflate the house like a balloon. The owner reported an instantaneous pressure in his ears, like that felt by divers as they descend in the water. Swallowing hard to relieve the pressure, the homeowner heard a couple of pops in the attic as the plugs in the turbine vents blew out. The pressure dropped immediately, and the roof stayed put.

The next-door neighbor had exactly the same experience, but he didn't have any turbine vents to relieve the pressure. His roof blew away.

At the Lakes by the Bay development, blocks of houses with ridge vents, gable-end vents and no rake overhangs (bottom left photo, facing page) remained largely intact. On other streets in the development, houses with rake overhangs and no ridge vents lost major portions of their roofs. I asked Richard Marshall, leader of the structural evaluation group at the National Institute of Standards and Technology, about the benefits of ridge vents. He says a ridge vent can help the roof in a hurricane because the ridge is the "flow separation point"—the point of lowest pressure and hence greatest uplift. Chances are, the net uplift applied to the roofs was diminished by the airflow from the gable vents to the ridge vents.

Weak spots—Garage doors need to be rated for hurricane-force winds, and their tracks have to be correctly anchored to the framing. If you've got a trellis, it should be engineered to the same standards as the house, or it might become a hazard. For example, a trellis tied to the roof framing proved to be the weak link of a house in Homestead. When the wind tore it away, the resulting gap in the eaves let the wind into the attic, blowing off a hunk of the roof and ruining the interior.

Make sure door and window frames are securely fastened to their rough framing. Several installations revealed sliding glass door frames that were affixed to the adjacent studs with six short screws that barely penetrated the studs. The doors blew in.

Engineer Roger Jeffrey says remember the headers. He saw one set of doors that failed because the header above them was held in the wall with just a couple of toenails instead of

Hardboard was no protection. **Wood-framed walls covered with 5/8-in. exterior-grade gypsum board and hardboard siding were easily penetrated by flying debris.**

Vents might help. **In a development of severely damaged houses, these homes escaped relatively unscathed. The gable-end vents and ridge vents may have helped equalize the air pressure on this roof, helping it stay intact. It's also possible that the overhang on the gable to the left contributed to the shingle damage while the lack of overhangs on the right-hand gable helped the shingles survive.**

Useless shutters. **Plywood now covers the window smashed by the roof tiles that went through this aluminum louvered shutter.**

the required steel strapping. The doors took the header with them during the storm.

As their houses eroded around them, many homeowners found refuge in a bathroom or a closet in the middle of the house. Such tiny spaces provide little more than emotional cover in an environment where flying 2x4s have been known to go through reinforced concrete walls. Cornelison says Collier County is considering adopting a code that will require new houses to have one room that's projectile-proof. They will likely be 8 ft. square, with stud walls covered with 4 in. of plywood.

Cornelison also notes that interior walls framed with steel studs were typically destroyed when a window blew out, allowing the wind access to the rest of the house. Partition walls made of wood studs did far better, sometimes localizing wind and water damage to a single room.

Wind blows, work shows—Much of Dade County's inquiry into the widespread destruction of new homes focuses on how the panels were attached to their roofs. Longtime Miami builder Suddarth recalls remodeling a house in the Country Walk subdivision 15 years ago. He was stunned to find roof-sheathing panels that were attached with only four nails.

Suddarth saw repeated, purposeful code violations at Country Walk. In their rush to finish the job, subcontractors didn't completely nail off roof decks, left out hurricane clips and installed truss straps incorrectly. The inspectors would fail the job, then the builders would fix the most visible errors and get the job passed.

Now that thousands of houses have been blown open for inspection, we're learning that what Suddarth saw wasn't an isolated incident. Sleazy builders watched over by indifferent or overworked inspectors sabotaged the spirit of a tough code designed to safeguard the community. Hurricane Andrew has made it clear that the most important links that hold together the houses on our landscape don't come to the job site on a delivery truck. There's no substitute for an understanding of how the pieces should fit together and the pride and the vigilance that it takes to make sure the job is done right. □

Charles Miller is senior editor of Fine Homebuilding. *Photos by the author.*