Successfully Retrofitting Buildings for Wind Resistance

FEMA

HURRICANE MICHAEL IN FLORIDA *Recovery Advisory 1, June 2019*

Purpose and Intended Audience

The purpose of this Recovery Advisory is to present key wind retrofit guidelines for buildings located in hurricane-prone regions.[1] The guidelines are applicable not only for buildings that have recently been damaged by wind, but also for buildings that have not experienced wind damage. These retrofit guidelines are intended to help building owners and designers prevent or limit wind damage and water infiltration during high-wind events. The guidelines in this advisory reflect observations and lessons learned by the Federal Emergency Management Agency's (FEMA's) Hurricane Michael Mitigation Assessment Team (MAT), as well as those from past hurricane building performance assessments.

Before repairing wind-damaged buildings or retrofitting a building to be more wind-resistant, all building elements should be assessed for vulnerability to high-wind events, even those that were not damaged. If undamaged elements are determined to have significant vulnerabilities, they should be mitigated as part of the repair work to help prevent future damage. Even when retrofitted elements perform well, if other non-retrofitted elements fail during a high-wind event, the whole retrofit project may be ineffective because the building did not achieve the target performance level intended by the retrofit.

Wind retrofit projects will help reduce or eliminate building and content damage, and also disruption to operations. Well planned and executed wind retrofits can add value to the property and provide greater peace of mind to the owners and occupants. Wind retrofits may also provide better protection for occupants; however, buildings that have wind retrofits do not provide near-absolute protection from wind and wind-borne debris for occupants and should not be used to shelter-in-place unless the retrofits meet the criteria in FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms* (2015b) (see "Safe Room" text box on page 2).

This Recovery Advisory focuses on critical facilities, but is also applicable to other types of buildings, both residential and non-residential. The primary audience is building owners and operators, design professionals, contractors, and entities that fund retrofits.

Key Issues

- Buildings with wind retrofits suffered significant damage—even in cases when the retrofit itself performed well—because other building vulnerabilities were not addressed when the retrofit was implemented.
- Based on MAT observations, many buildings are believed to be very vulnerable to wind and/or wind-driven rain damage, particularly those constructed prior to the first edition of the Florida Building Code (2001).
- Even modest damage to the building envelope or rooftop equipment was observed to lead to costly water damage, which can take months to repair and cause disruption of building operations.

1 As defined in the 2016 edition of the American Society of Civil Engineers Standard 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 7-16).

This Recovery Advisory Addresses

- Examples of ineffective wind retrofit projects
- Five steps to improve wind resistance
- Funding programs for wind retrofit (mitigation) projects
- References

SAFE ROOMS

For buildings that need to provide near-absolute protection for occupants during a high-wind event, refer to FEMA P-361 (FEMA, 2015b) for performance criteria.

For information on selecting best available refuge areas, refer to FEMA P-361 and Hurricanes Irma and Maria in Puerto Rico Recovery Advisory 3, *Safe Rooms and Storm Shelters for Life-Safety Protection from Hurricanes* (FEMA P-2020, 2018b).

DEFINITIONS

Best available refuge area: A BARA is an area in an existing building that has been deemed by a registered design professional as likely to protect building occupants during an extreme-wind event better than other areas in the building when a safe room is not available. The BARA should be regarded as only an interim measure until a safe room can be made available to building occupants.

Building envelope: The building envelope includes exterior doors, glazing, exterior walls, wall coverings, soffits, and roof systems.

Building Risk: A function of the magnitude of the hazard and the building's vulnerabilities. Mitigating existing vulnerabilities can reduce or prevent damage.

Building wind retrofits: Wind retrofits consist of voluntary mitigation actions taken on existing buildings. For a building retrofit to be effective, the building needs to achieve the performance level selected by the building owner or operator (the target performance level) and be commensurate with the magnitude of the wind event for which the retrofit was designed.

Critical facilities: Critical facilities are defined by FEMA as buildings that are essential for the delivery of vital services or protection of a community, and include, but are not limited to, emergency operations centers, healthcare facilities, police and fire stations, schools, and power stations.

Mitigation: FEMA defines mitigation as "the effort to reduce loss of life and property by lessening the impact of disasters" (https://www.fema.gov/what-mitigation). To reduce the impact of disasters on buildings, it is important to identify the hazards (e.g., hurricanes) and building vulnerabilities.

Examples of Ineffective Wind Retrofit Projects

This section provides examples of wind retrofits to building elements that were completed prior to Hurricane Michael but that were ultimately ineffective at limiting significant damage to the building or its contents. Substantial building damage and occupancy disruption occurred because not all significant wind vulnerabilities were addressed by the retrofit. In each case of the examples described below, there was significant interior water damage that resulted in considerable disruption of building operations. The examples demonstrate that even when individual retrofitted elements perform well, for the retrofits as a whole to be effective in avoiding substantial building damage and occupancy disruption, all significant wind vulnerabilities of the building need to be mitigated.

TESTING AND LABELING

The FEMA Michael MAT rarely observed shutter, window, or door assemblies with labels indicating they were tested assemblies.

As a best practice, all installed shutters, window, and door assemblies should have labels showing their wind pressure and/or wind-borne debris resistance. Such labels ensure that the assemblies have been tested and are suitable for their intended purpose.

Refer also to best practices described in Step 4 of this advisory.

Example 1: Fire Station and Community Building (Bay County, FL)

The fire station and community building in Bay County, FL, shown in Figure 1 through Figure 3, were opened in 1978 and retrofitted in about 2001 with roll-down storm shutters and new apparatus bay doors to provide hurricane "hardening" of the building. The community building was designated as a critical facility to be used as a hurricane recovery shelter for displaced community residents. Fourteen people were in the fire station and none in the community building during the hurricane; no one was injured.

FIRE STATION/COMMUNITY BUILDING SITE CONDITIONS

Estimated wind speed = 132 miles per hour (mph)*

Location = Exposure B

ASCE 7-16 basic wind speed for a Risk Category IV building = 146 mph

*Gust, Exposure C, at 33 feet above grade. Wind speed estimate based on ARA (2018).

Performance of retrofitted elements. The fire station's retrofitted shutters successfully protected the windows from wind-borne debris, thus illustrating the importance of protecting glazing (see Figure 2).

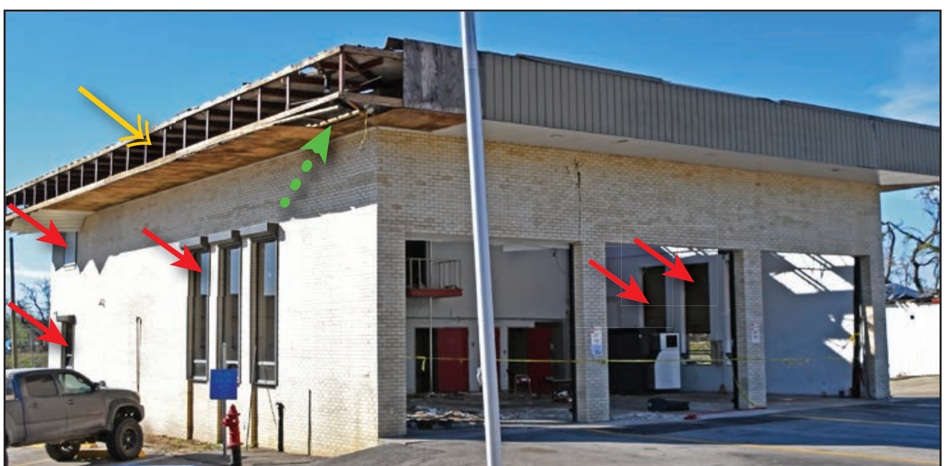
Figure 3 is a view of shutters at the community building, which successfully protected the glazing. The black areas on the brick and both of the shutters are asphalt residue from wind-borne roof membrane debris from the fire station. Note the distorted jamb and sill frame at the right shutter, which was caused by debris impacting the shutter at an angle.

The retrofitted apparatus bay doors did not perform well and were blown inward—the slats pulled out of the track at one door; at another, the door frame's expansion bolts pulled out because the substrate lacked load-path integrity (see Figure 1).

TESTING AND LABELING

It is unclear whether the shutters and doors at the fire station and community building were tested assemblies as those observed did not have a label identifying their wind-borne debris resistance, nor in the case of the doors, their wind pressure resistance.

Overall effectiveness of the retrofit project. At the fire station and community building, the wind retrofit successfully protected windows, but the buildings as a whole were not protected and did not perform well. At both buildings, the roof membrane and several roof deck panels were blown off, as shown in Figure 4: Aerial view of the fire station and community building and Figure 5:. Portions of the fire station's fascia and soffit coverings, and their plywood substrate, were blown away (Figure 1: General view of the damaged fire station and Figure 5:). The damage to the fascia, soffit, and roof allowed wind-driven rain to enter the building. Figure 5: is a view from within the apparatus bay showing where several roof deck panels blew off. A built-up roof was installed over insulation boards attached to cementitious wood-fiber deck panels over steel joists. This type of roof deck on buildings of that era typically possess limited wind uplift resistance. The community building suffered similar damage to the fire station (Figure 4).



The red arrows indicate the retrofitted storm shutters. Wind-driven rain entered the building at the damaged fascia and soffit (yellow and green arrows).

Figure 1: General view of the damaged fire station

Result. The community decided to demolish both the fire station and community center because of the damage that occurred during Hurricane Michael. The cost of repairing the fire station was estimated as more than 80 percent of the cost of a new building. Construction of a new fire station is expected to take 3 to 4 years because of competing budgeting priorities in the county due to hurricane damage.

The red arrow indicates wind-borne plywood debris that was lodged between the shutter slats and frame. The black areas on the brick are asphalt roofing residue from wind-borne debris that struck the building.

Figure 2: This shutter was struck by wind-borne debris but protected the glazing

Figure 3: These shutters were struck by wind-borne roof membrane debris; distorted jamb and sill frame indicated by red rectangle

Only a small portion of the roof membrane remained on both buildings. Several roof deck panels were blown off each building. The yellow double arrow indicates roof deck panels on the ground that became wind-borne debris.

Figure 4: Aerial view of the fire station and community building

The red arrows indicate the retrofitted storm shutters. See Figure 2 for an exterior view of the left shutter.

Figure 5:
View of damaged roof after roof deck panels were blown off

Example 2: Fairground (Bay County, FL)

The main building complex at a fairground in Bay County was designated as a critical facility because it was intended to be used as a post-hurricane staging area for county supplies and a hurricane recovery shelter for displaced community residents. Wind retrofits to the building included rolling doors and roof purlins installed around 2011.

Performance of retrofitted elements. Figure 6: General view of the damaged retrofitted rolling doors and roof panel damage shows the portion of the building that was retrofitted with rolling doors. All of the seven retrofitted rolling doors failed. The door frames appeared to be adequately attached to the original steel rough opening framing members, but the rough opening members failed because they had inadequate wind resistance (Figure 7).

Because earlier wind load code provisions were inadequate, older buildings often have insufficient wind uplift resistance in the roof corner and perimeter edge zones; therefore, it can be appropriate to strengthen wind uplift resistance in those zones. Although an additional roof purlin was installed in the perimeter edge zone in 2011 in an attempt to retrofit the roof framing (Figure 8:), the purlin retrofit was ineffective in preventing roof panel blow-off. A large number of roof panels (R-panels)[2] were blown off. The roof panels typically pulled over their exposed fasteners. Figure 9: shows an aerial view of the main building complex at the fairground in which the roof damage is visible.

Overall effectiveness of retrofit project. Overall, the retrofit of this building was not successful in keeping the rolling doors and roof panels in place during Hurricane Michael.

Result. This portion of the building was not occupiable after the hurricane.

FAIRGROUND SITE CONDITIONS

Estimated wind speed = 128 miles per hour (mph)

Location = Exposure B, with open patches to the northwest, east, south, and west

ASCE 7-16 basic wind speed for a Risk Category III building = 144 mph

TESTING AND LABELING

It is unclear whether the rolling doors on the fairground building were tested assemblies as those observed did not have a label identifying their wind-borne debris and wind pressure resistance.

2 An R-panel is generic metal roof panel with a specific profile.

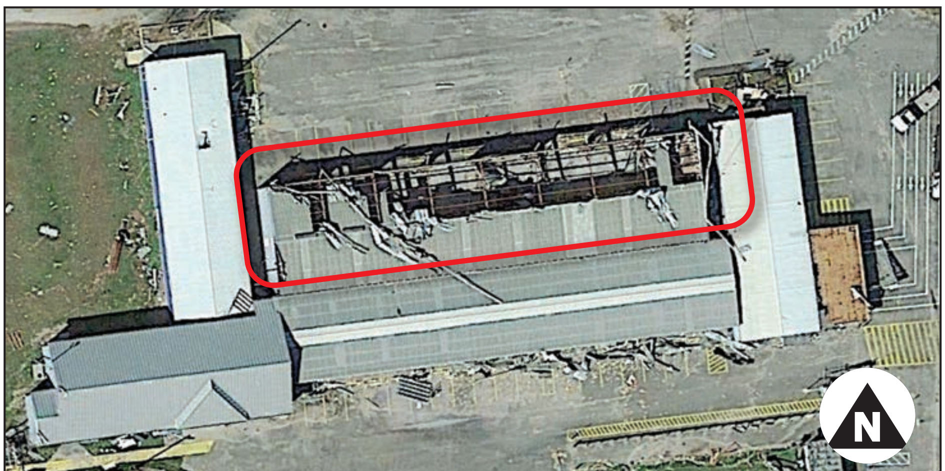
Figure 6: ***General view of the damaged retrofitted rolling doors and roof panel damage***

The yellow arrows indicate the failed rough opening jamb and header framing members. The red arrow indicates a missing rough opening jamb member at an adjacent door.

Figure 7:
View of door failure caused by inadequate wind resistance of rough opening members

The yellow double arrow indicates the added purlin to increase uplift resistance. The red arrow indicates a failed rough opening header.

Figure 8: View of the new purlin



The area shown in Figures 6 through 8 is within the red rectangle. The door and purlin retrofit work was insufficient to prevent significant damage.

Figure 9: Aerial view of the main building complex

Example 3. City Hall and Police Station (Bay County)

The city hall and police station building in Bay County shown in Figure 10 through Figure 12 was constructed in 1942, with subsequent additions. The building was retrofitted around 2001 with roll-down storm shutters to provide hurricane "hardening" of the building. Thirty-three people were in the building during the hurricane; none were injured during the event.

Performance of retrofitted element. There was no apparent damage to the retrofitted storm shutters during the hurricane, but they did not appear to be struck by wind-borne debris (most of them were on the leeward side of the building) (Figure 10).

CITY HALL/POLICE STATION SITE CONDITIONS

Estimated wind speed = 132 miles per hour (mph)

Location = Exposure B, with an open patch adjacent to and northeast of the building

ASCE 7-16 basic wind speed for a Risk Category IV building = 146 mph

TESTING AND LABELING

It is unclear whether the shutters of the city hall and police station building were tested assemblies as those observed did not have labels indicating their wind-borne debris resistance.

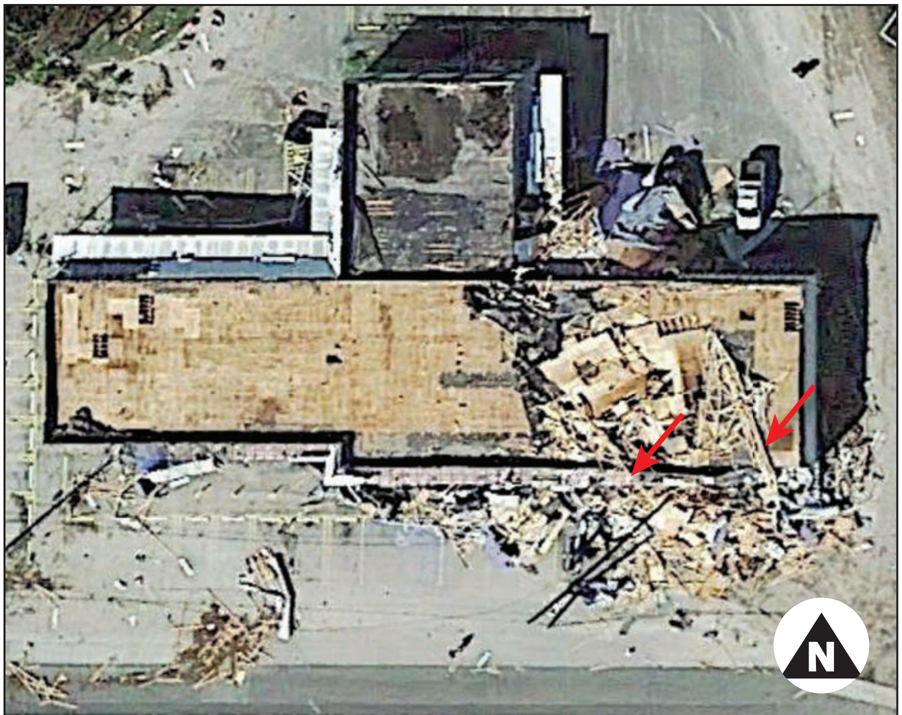
Overall effectiveness of retrofit project. Other portions of the building were not strengthened when the shutters were retrofitted, and the building suffered significant damage during the hurricane as a result. Specifically, the roof trusses were not retrofitted. All of the trusses that supported the sloped roof were blown away (Figure 10: Roll-down shutters were not damaged during Hurricane Michael, but trusses failed). With loss of the entire sloped roof structure, rain was able to enter throughout the building. Also, high-momentum wind-borne debris struck an adjacent wall (Figure 12: Wall penetrated by wind-borne debris).[3] Figure 11: Aerial view of the police station is an aerial view of the building. The wind retrofit performed in 2011 did not achieve its intended purpose because the structural deficiencies were not mitigated at the time the roll-down shutters were installed.

Result. Repairing the damage caused by Hurricane Michael was determined not to be cost effective, so the building was demolished. The building owner indicated that it is likely to be 3 to 4 years before a new facility is constructed.

The red arrows indicate the retrofitted storm shutters. Two roof trusses are indicated by the yellow double arrows; the other trusses were blown off the roof. The green dashed arrow indicates collapsed brick.

Figure 10: Roll-down shutters were not damaged during Hurricane Michael, but trusses failed

3 If building operations criteria call for no debris entry through walls, walls could be retrofitted to increase debris resistance.



The red arrows indicate the trusses shown in Figure 10.

Figure 11: Aerial view of the police station

The white portion of the wall was stucco over metal lath over plywood over studs. The debris penetrated the interior gypsum board sheathing. The red arrow indicates a dangling light fixture that fell from the soffit.

Figure 12: Wall penetrated by wind-borne debris

Example 4. Residence (Gulf County, FL)

Although the focus of this advisory is non-residential buildings, the types of damage observed and best practices for improving wind performance by appropriate retrofits is similar for residential buildings.

Based on available records, the residence shown in Figure 13: Residence where retrofitted shutters performed well, but significant damage was sustained when rain entered at blown-off roof deck panels (Port St. Joe, FL) was constructed around 1994. It was retrofitted with roll-down storm shutters at an unknown time.

RESIDENCE SITE CONDITIONS

Estimated wind speed = 146 miles per hour (mph)

Location = Exposure D

ASCE 7-16 basic wind speed for a Risk Category II building = 134 mph

Performance of retrofitted elements. There was no apparent damage to the retrofitted roll-down storm shutters during the hurricane, but they may not have been struck by wind-borne debris.

Overall effectiveness of retrofit project. The roof decking was not retrofitted at this residence, and as a result, roof deck panels were blown off during the hurricane. The wind retrofit of the shutters was ultimately ineffective for this residence because a significant amount of rain entered the building when the roof was damaged by wind.

Result. It is likely that this building was not occupiable after the hurricane.

Figure 13: Residence where retrofitted shutters performed well, but significant damage was sustained when rain entered at blown-off roof deck panels (Port St. Joe, FL)

Five Steps to Improve Wind Resistance

As demonstrated by the failures described in the previous section, retrofitting one element of a building without accounting for wind vulnerabilities in the non-retrofitted elements can lead to ineffective mitigation. Simply protecting one element does not necessarily achieve the goal of protecting the building and its contents during a high-wind event, nor does it ensure that the building will be operational after a hurricane. Even when a retrofitted element performs as intended, the building as a whole may not achieve the target performance level intended by the retrofit.

To achieve the intended performance level, all building elements that may be vulnerable to wind damage should be identified, and a comprehensive plan for executing the needed retrofits should be developed. The five-step process outlined in Figure 14 is an approach for consideration.

ASSESS BUILDING USE

Prior to performing the wind vulnerability assessment, the building use should be determined. Any portion of the building intended to allow occupants to shelter-in-place should meet FEMA P-361 criteria (see “Safe Room” text box).

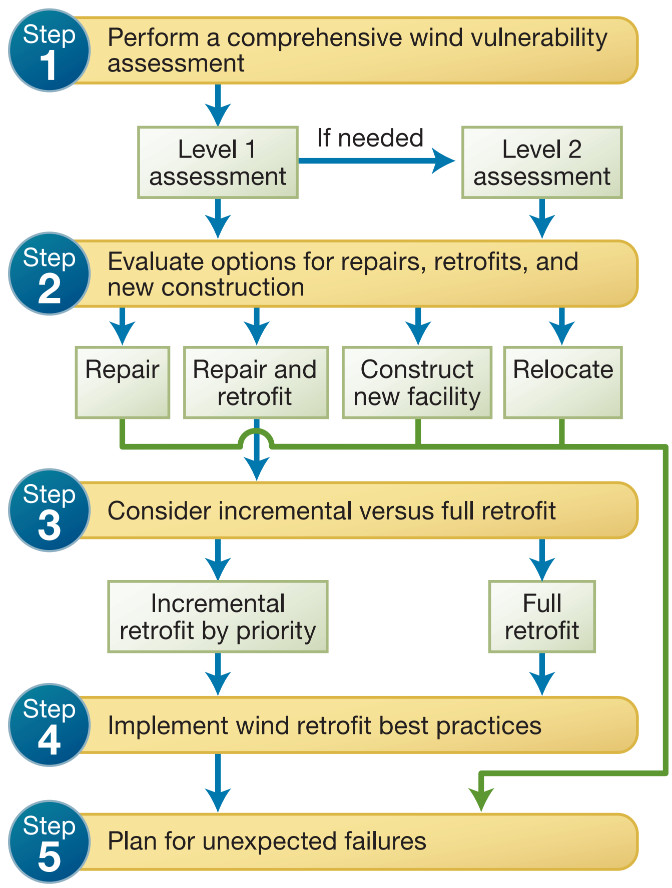


Figure 14: Flowchart showing five-step approach to improving wind resistance

It is recommended that a wind vulnerability assessment (described in Step 1) be performed for the following buildings, and if significant vulnerabilities are identified, additional actions (described in Steps 2–5) should be taken:

- Buildings that need to be operational during or immediately after a hurricane to provide or assist with response and recovery efforts
- Buildings that have been damaged by a hurricane
- Buildings that an owner deems sufficiently important to avoid being damaged by a hurricane

RESIDENTIAL WIND RETROFIT GUIDANCE

Refer to FEMA P-804, *Wind Retrofit Guide for Residential Buildings* (2010a), for information on retrofitting residential buildings:

Evaluating Existing Homes: Explains how to assess homes to determine their vulnerabilities and what type of mitigation measures would be most appropriate and feasible.

Technical Design and Construction Methods: Provides details and specific measures for three Mitigation Package categories: Basic, Intermediate, and Advanced.

Implementing Mitigation Projects: Describes how to move a project forward, important issues and challenges that should be considered, and details about potential sources of assistance.

Also, refer to Hurricane Michael in Florida Recovery Advisory 2, *Best Practices for Minimizing Wind and Water Infiltration Damage* (2019), for recommendations on reducing wind and water infiltration damage to new and existing residential buildings.

Step 1: Perform a Comprehensive Wind Vulnerability Assessment

Many building owners overestimate the wind and wind-driven rain resistance of their buildings and underestimate the amount of time it will take to make repairs to a damaged building or construct a new one. They also tend to underestimate the impact of wind and water damage on the continuity of building operations. This lack of awareness may preclude building owners from mitigating their building's vulnerabilities. To understand a building's wind resistance, it is important to have a vulnerability assessment performed. A thorough wind vulnerability assessment is intended to identify all significant wind and wind-driven rain vulnerabilities (i.e., those vulnerabilities that could adversely affect building operations). The building elements most commonly damaged in high-wind events are shown in the table (see text box titled, "Step 1: Common Wind Vulnerabilities").

A new FEMA publication, *Guidelines for Wind Vulnerability Assessments of Existing Critical Facilities*, is expected to be available in 2019. It will provide detailed guidelines to assist architects and engineers in performing Level 1 and 2 building assessments, including assessing a facility's ability to cope with prolonged loss of municipal utilities. Until this new guideline becomes available, refer to FEMA P-424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds* (2010b), which includes a checklist in Section 6.[6] to use as a guide for performing a vulnerability assessment, as well as examples of mitigation measures that are often applicable.

ACCEPTABLE RISK

The maximum level of damage from a realistic risk event scenario or probability that can be tolerated.

Assessment team. A qualified team of architects and engineers should perform the assessment. Additionally, the design professionals performing the assessment should be experienced with the type of building element that is being evaluated. This experience is critical because accurately assessing the wind resistance of existing buildings is very difficult, in part because of a severe lack of field test methods and the difficulty in performing evaluations/inspections after construction. Good professional judgment is vital for a quality assessment.

Assessment process. Before the assessment, the assessment team should meet with the facility owner to determine the desired building performance. The discussion should establish the acceptable risk, and hence the target building performance level. Performance levels are inversely related to four levels of anticipated damage to a building, its contents, and its occupants: mild, moderate, high, and severe.

After the performance expectations (and associated acceptable damage levels) are established, the assessment team should perform a Level 1 assessment, followed by a Level 2 assessment if appropriate.

- **Level 1 assessment:** (1) Review historical information files (i.e., as-built drawings and specifications, submittals, previous leakage and repair reports); (2) discuss with personnel familiar with the building to determine whether it has leaks or has other known issues and obtain historical information that is not in the file; (3) conduct a field investigation; and (4) report findings.

  The assessment includes site issues (e.g., egress [i.e., roads], collapse hazards [e.g., trees, communications towers, poles], and rolling debris), the main wind force resisting system (i.e., structural elements), the building envelope, and exterior-mounted equipment.

  For buildings that need to be operational during or soon after a hurricane or other high-wind event, the assessment should include an evaluation of the facility's ability to maintain operations if municipal or other utility services (power, water, sewer, communications, or other) are lost. For instance, the assessment should determine whether the facility has a water storage tank or well for backup water.

- **Level 2 assessment:** For buildings in locations where the current basic wind speed is greater than 120 mph[4] and the Level 1 assessment reveals that a given system has several more years of useful service life, the assessment team should recommend performing a Level 2 assessment. A Level 2 assessment consists of destructive and/or nondestructive testing.[5]

STEP 1: COMMON HIGH-WIND VULNERABILITIES

Numerous wind damage assessments have revealed that the building elements most commonly damaged by high winds are as shown below.

ELEMENT	DESCRIPTION	FIGURES IN THIS RECOVERY ADVISORY THAT ILLUSTRATE VULNERABILITY
Glazing	Glazing is commonly broken when wind-borne debris strikes it.	
Roof coverings	Roof coverings are the most commonly damaged building element in high-wind events.	Figures 1, 4–10, 11, and 13 and Step 2 and 5 text boxes
Roof structure	Roof structure blow-off or collapse typically occurs in buildings constructed before approximately 1990.	Figures 1, 4, 5, 10, 11, and 13 and Step 5 text box
Rooftop equipment		Step 2 text box
Sectional (garage) and rolling doors	Collapse of sectional and rolling doors typically occur in those installed before approximately 2000.	Figures 1, 5, and 6–8
Soffits		Figure 1
Wall coverings		Figure 12

4 The 120 mph basic wind speed is based on ASCE 7-16, Risk Category III buildings. This wind speed trigger is based on peer-reviewed subject matter expert judgement

5 Additional guidance will be included in FEMA's *Wind Vulnerability Assessments for Existing Critical Facilities*, anticipated for publication in 2019.

Step 2: Evaluate Options for Repairs, Retrofits, and New Construction

After completing Step 1, the assessment results are analyzed to determine if there are significant vulnerabilities that may inhibit achieving the desired target performance level. If there are, then the design professionals, in consultation with the building owner, should determine whether it is best to retrofit the building or plan for new construction to replace it.

In the case of damaged buildings, there are four options to achieving acceptable risk levels:

1. Repair the damage and perform the minimum amount of work necessary to comply with the building code. The extent of the repairs may necessitate replacing undamaged items such as fire alarm or communication systems, or adding fire sprinklers. This option accepts the risk associated with future wind damage of vulnerable building elements that are not addressed by the repair work.
2. Repair the damage and perform additional wind retrofit work that is beyond that required by the building code to address identified wind vulnerabilities.
3. Design and construct a new facility.
4. Move operations to another facility capable of meeting the given needs.

STEP 2: EXAMPLE OF A DAMAGED BUILDING THAT COULD BE EVALUATED PER THE FOUR OPTIONS OF STEP 2

SCHOOL SITE CONDITIONS

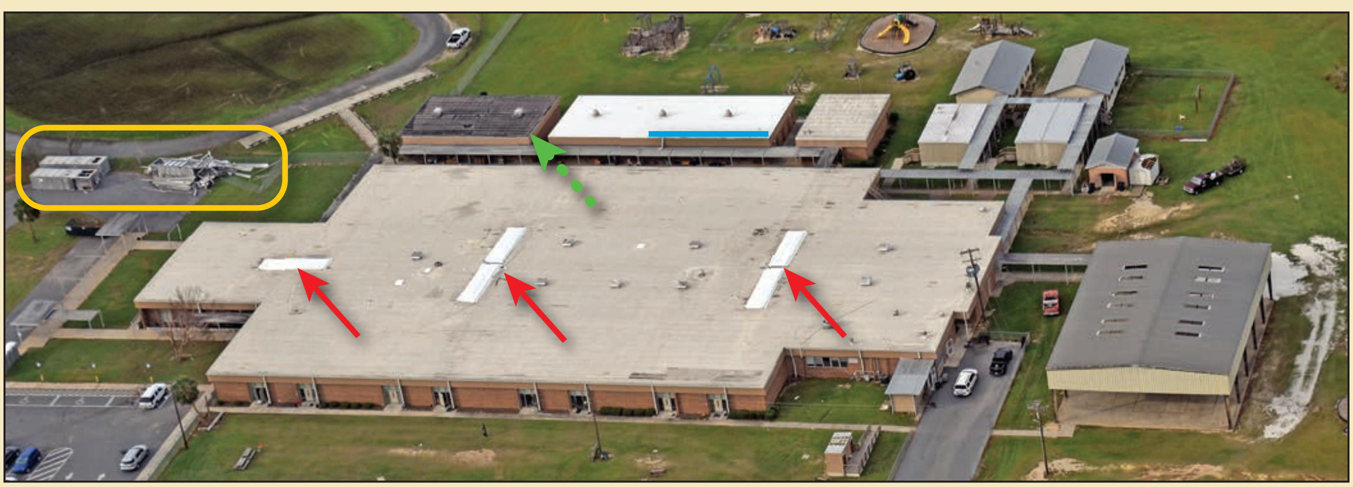
Estimated wind speed = 136 mph

Location = Exposure B, with an open patch surrounding the school

ASCE 7-16 basic wind speed for this site for a Risk Category III building = 133 mph

This Blountstown, FL, school opened in 1970 and was damaged during Hurricane Michael. This building offers an example of a damaged building that could be evaluated using the four options of Step 2.

The building had cementitious wood-fiber roof deck panels over steel joists (the same type of deck/structure shown in Figure 5:). The three large HVAC units that blew off their curbs were moved to the area within the yellow rectangle; one unit blew off the roof and damaged the wall of another building, indicated by the green arrow. Water entered the school at the open curbs (shown as white areas [red arrows] where there are temporary patches over the curbs on which the three units sat before the storm) and at several locations where the wind-borne equipment tore the roof membrane. At least one window was broken by wind-borne debris. The blue line indicates where metal edge flashing blew off. Some of the smaller pieces of rooftop equipment were also damaged. There were numerous roof punctures in the main roof area.



Step 3: Consider Incremental versus Full Retrofit

If the Step 2 evaluation results in the decision to perform a wind retrofit, but funds are insufficient to mitigate all significant vulnerabilities, the best approach is to prioritize mitigation actions per the recommendations of the assessment team. The following priorities, listed in descending order, are often appropriate, but should be tailored as needed:

1. Structural elements and exterior walls (including glass curtainwalls) that have the potential to fail or collapse during wind speeds of 90 mph[6] peak gust (Exposure C) or less
2. Building envelopes and exterior-mounted equipment that have the potential to blow off or collapse during wind speeds of 90 mph peak gust (Exposure C) or less

Weak hurricanes and other weak storms are statistically more likely to occur at any given facility than strong hurricanes or other strong storms. Therefore, at some facilities (depending on their function), it may be appropriate to complete inexpensive remedial work first and more comprehensive/expensive work later. For example, if the roof deck, gutter, and rooftop equipment attachments on a school building are weak, but the roof system has another 5 years of useful service life, the gutter and equipment attachments could be strengthened immediately, and the roof deck attachment deficiency could be more economically addressed when the roof system is replaced. However, if a roof over a hospital intensive care unit (ICU) has the same vulnerabilities, forgoing the roof system's remaining service life and proceeding immediately with reroofing and deck attachment strengthening is usually prudent.

PRIORITIZATION CONSIDERATIONS

Scheduling mitigation retrofits can be prioritized based on a variety of factors including availability of funding, building function, and the likelihood of occupancy during a hurricane or other high-wind event.

For instance, a school is not typically occupied during a hurricane (unless it is used as a shelter), and damage during a hurricane would typically not pose a risk of occupant injury or death. In contrast, a hospital ICU is likely to be occupied during a hurricane, so building damage could present a risk to occupants.

If an incremental retrofit is executed because there are insufficient funds for a full retrofit, it is important to select retrofit work that results in the desired performance and acceptable risk level (as discussed in Step 1), commensurate with available funds. As shown in several figures in this advisory, it is highly unlikely that a single retrofit measure alone will improve protection and reduce risk from a hurricane or other high-wind event. Consider the analogy of a chain that has a few links that are extremely weak, others that are very weak, others that are somewhat weak, and some that are strong. A tailored incremental retrofit of the chain would start with strengthening or replacing all of the extremely weak links. Then, when more funding is available, strengthen or replace the very weak and somewhat weak links until the desired target performance level is achieved. It is recommended that this process be used when planning and budgeting for the building's continued use over its anticipated useful life.

STEP 3: EXAMPLE FACILITY

Assume a public facility is in a hurricane-prone region. After performing a vulnerability assessment of the building, the assessment team found the following:

1. The large storefront windows are susceptible to failure when wind speeds reach about 95 mph, which based on ASCE 7 have a 25-year mean recurrence interval (MRI).
2. The roof system has not been replaced since the building was constructed many years ago and is susceptible to blow-off when wind speeds reach about 105 mph (approximately a 50-year MRI based on ASCE 7).
3. The attachment of the roof trusses to the bearing walls is insufficient when wind speeds reach about 130 mph (approximately a 300-year MRI based on ASCE 7).

6 The 90 mph trigger is based on peer-reviewed subject matter expert judgement.

STEP 3: EXAMPLE FACILITY (CONCLUDED)

The building owner may decide to use limited funds to address the vulnerabilities to events that are most likely to occur in the short term and would, therefore, install new window assemblies and replace the roof system (including incorporation of a secondary roof membrane). Because not all of the building vulnerabilities were addressed, the owner should consider planning and funding future retrofits to accomplish the desired target performance level. Again, while wind retrofits may provide better protection for occupants; buildings that have wind retrofits do not provide near-absolute protection from wind and wind-borne debris for occupants and should not be used to shelter-in-place unless the retrofits meet the criteria in FEMA P-361 (FEMA, 2015b).

Step 4: Implement Wind Retrofit Best Practices

After determining the scope of the planned retrofit (Step 3), the next step is to perform the retrofit design work and prepare contract drawings and specifications. FEMA P-424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds* (2010b), provides several best practices that are more conservative than, or are in addition to, the requirements in the Florida Building Code and International Building Code.

As part of the retrofit design process, it is important to understand limitations of potential retrofit options. Although some options may be less expensive, they may not provide the level of desired protection. For example, if a building has windows that are susceptible to being broken by wind-borne debris, one option would be to replace them with new tested window assemblies that have protected glazing (e.g., laminated glass or polycarbonate). Another option would be to protect the existing windows with tested shutter assemblies, an option that is typically more economical. However, if the second option of shutters is selected, building owners should understand that shutters do not protect against over-pressurization of existing doors or windows, nor do they typically reduce the potential for the entrance of wind-driven rain. An example of this over pressurization is shown in the “Step 4: School Example” text box.

SPECIFY LABELS

A “labeled” door or window assembly indicates that it has been tested for wind-borne debris impacts and/or tested to resist a given wind pressure. Without a label, whether an assembly has adequate resistance to wind-borne debris and/or wind pressure is unclear.

It is important to specify that windows and doors have a permanently mounted label that indicates they were tested. The label should indicate the test method and tested pressure. Shutters, windows, skylights, and glazed doors intended to resist wind-borne debris should also have a label that indicates the test method and test missile level.

As a best practice, it is recommended that existing windows be replaced with new tested window assemblies rather than installing shutters if the existing windows do not possess sufficient wind pressure resistance. For facilities that cannot tolerate entrance of wind-driven rain, existing windows can be field tested to evaluate leakage potential (part of a Level 2 evaluation) or can be replaced with windows that comply with American Architectural Manufacturers Association (AAMA) 520, *Voluntary Specification for Rating the Severe Wind-Driven Rain Resistance of Windows, Doors and Unit Skylights* (2012).[7]

As part of the retrofit implementation, it is important to specify that adequate inspection and field testing be conducted to help ensure that the retrofit work was performed correctly.

7 AAMA 520 has 10 Performance Levels. A Performance Level should be specified that is commensurate with the building owner’s tolerance to water infiltration.

STEP 4: SCHOOL EXAMPLE

This school in Panama City, FL, was retrofitted with permanently mounted screen shutters. At one of the windows protected by a screen, positive pressure caused the failure of the window frame, and glass was blown into the room, injuring two occupants.

View of a window that failed under positive wind pressure

The left photo is a view of windows protected by permanently mounted screen shutters. The red arrow indicates the primary wind direction during the hurricane. The right photo is a view of the window that failed due to positive pressure exceeding the resistance of the window frame.

Step 5: Plan for Unexpected Failures

The true vulnerability of a building may not be known until tested by an actual wind event. Field testing and the various field checks conducted during a vulnerability assessment are performed at discrete locations, so data on conditions and wind and water resistance are only obtained for the areas that are tested or checked. There is always the potential for an undetected anomaly that could allow wind damage or wind-driven rain infiltration.

A best practice is to develop contingency plans for interruption of facility operations in case wind damage or leakage occurs. For example, a contingency plan should be available to the staff of a hospital that indicates where the staff and patients should be relocated within the facility if the roof begins to leak. Similarly, a contingency plan should include procedures for evacuating the entire facility before, during, or immediately after a hurricane or other high-wind event requiring its activation. The plan should account for the potential risks of evacuating a facility during a hurricane (though those risks may be lower than staying in a severely damaged facility). All contingency plans should clearly define activation trigger points that have been coordinated, prepared, and approved by leadership, as well as clear instructions of actions that should be taken by which staff and when.

PROTECT BUILDING CONTENTS

For buildings that will not be occupied during a hurricane but have significant wind vulnerabilities, have a contingency plan for protecting building contents to the extent possible prior to landfall. This can include, for example, backing up electronic files and moving fire trucks from weak buildings to safer locations.

NEAR ABSOLUTE PROTECTION

For buildings or portions of buildings that need to provide near-absolute protection for occupants during a high-wind event, refer to FEMA P-361 (FEMA, 2015b) for performance criteria.

wind retrofit projects. The State of Florida also offers grant funding for wind retrofit projects through different programs and organizations.

All retrofits, whether funded through Federal or State grant programs, must comply with applicable local, State, and/or national building codes, standards, and regulations. Additionally, wind retrofit projects of one- and two-family residential buildings undertaken with FEMA grant funds must be designed in conformance with the design criteria found in FEMA P-804, *Wind Retrofit Guide for Residential Buildings* (2010a) to be eligible for funding. FEMA's and Florida's wind retrofit grant programs are summarized below.

FEMA Wind Retrofit Grant Programs

FEMA Pre-Disaster Mitigation Program. FEMA's PDM program provides nationally competitive grants for implementing pre-disaster natural hazard mitigation projects. The goal is to reduce overall risks to the population and buildings from future hazard events and also reduce reliance on Federal funding in the event of future disasters. Additional information is available online at https://www.fema.gov/pre-disaster-mitigation-grant-program.

FEMA Hazard Mitigation Grant Program. FEMA's HMGP provides grants following a Presidential major disaster declaration. The goal of the program is to support the critical mitigation measures during reconstruction that reduce the risk of loss of life and property from future disasters. Additional information is available online at https://www.fema.gov/hazard-mitigation-grant-program.

FEMA Public Assistance Program. FEMA's PA program provides supplemental grants so that communities can quickly respond to and recover after a disaster declaration. The PA program also has discretionary authority to provide assistance for hazard mitigation measures in conjunction with the repair of disaster-damaged facilities. More detailed information and a list of example eligible retrofit activities (in Appendix J) is available in FEMA's *Public Assistance Program and Policy Guide* (2018b) at https://www.fema.gov/public-assistance-local-state-tribal-and-non-profit.

FEMA HAZARD MITIGATION ASSISTANCE (HMA)

For questions related to FEMA's administration of grant funding for wind retrofit projects, please contact the HMA Helpline by calling 1.866.222.3580. Additional resources are available online at https://www.fema.gov/hazard-mitigation-assistance.

Also refer to FEMA's *Hazard Mitigation Assistance Guidance: Hazard Mitigation Grant Program, Pre-Disaster Mitigation Program, and Flood Mitigation Assistance Program* (2015a).

Florida Wind Retrofit Grant Funding

Two examples of Florida programs and organizations that offer funding for wind retrofit projects are described below. Information on additional funding sources may be obtained from the Florida State Hazard Mitigation Grant Program (see text box).

Rebuild Northwest Florida is a public/private partnership established after Hurricane Ivan (2004). The program applies for mitigation grants through FEMA to help homeowners and nonprofit organizations implement mitigation projects against hurricane damage. For more information, visit http://www.rebuildnwf.org.

The **Hurricane Mitigation Loss Program** was created by the Florida Division of Emergency Management after Hurricane Andrew (1992). The program receives $7 million annually from the Florida Hurricane Catastrophe Trust Fund to provide grants for wind and flood mitigation projects, as well as public education and outreach, and hurricane research. As a part of this overall program, up to $3.4 million is to be used on improving community resiliency through the Hurricane Loss Mitigation Program Retrofit Grant. This grant funds residential and non-residential retrofit projects, including inspection costs, to increase a building's ability to withstand flood and winds from hurricanes. Retrofits done under this program must meet the requirements of the Florida Building Code. For more information, visit https://www.floridadisaster.org/dem/mitigation/hurricane-loss-mitigation-program/.

FLORIDA WIND RETROFIT GRANT FUNDING

For more information on wind retrofit grant funding in Florida, contact the Florida State Hazard Mitigation Grant Program:

Web page: https://www.floridadisaster.org/dem/mitigation/hazard-mitigation-grant-program/

Contingency plans are critical when buildings are occupied during a hurricane. In 2004, Hurricane Charley severely damaged the Turner Agri-Civic Center in Arcadia, FL, which had been designed to serve as a hurricane shelter. A partial collapse resulted in the need to relocate approximately 1,400 occupants to a nearby high school during passage of the hurricane eye. The text box titled "Step 5: School Complex Example" shows another example where a contingency plan would be advantageous.

STEP 5: SCHOOL COMPLEX EXAMPLE

The first story of this school building in Panama City, FL, was constructed in 1995 and retrofitted with permanently mounted screen shutters. During the hurricane, portions of several of the buildings at the school complex were used as a shelter, including this one where the occupants took refuge on the first floor.

While the occupants remained safe on the first floor during the hurricane, the steel roof deck blew off the second floor (Photo A). Floor assemblies generally provide greater overhead protection than roof assemblies, so using the first floor for sheltering benefitted the occupants. However, once the roof deck was lost, occupants were evacuated and relocated to a nearby building.

Because building occupants were in the building during the hurricane, it can be assumed the roof failure was unexpected. The failure of the roof offers an example of an unexpected failure that highlights the need for contingency planning. A contingency plan for a building that is occupied during a hurricane such as this one could be used to specify a plan of action should the building become damaged, including relocating occupants to an undamaged portion of the building or evacuation under certain damage conditions.

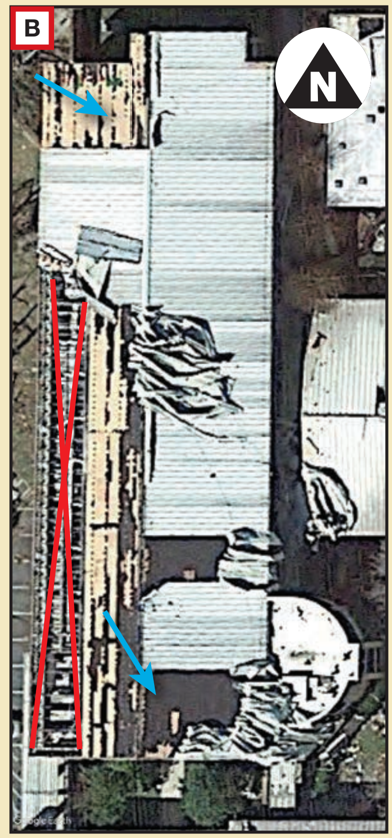


Photo A.
Shows the inside of the second story of the school building; the first floor of this building was used as a shelter

(Photo Courtesy of Bay County Public Schools)

Photo B.
Aerial view of the school building. The red lines indicate the area where the steel roof deck blew off. The blue arrows indicate where the structural standing seam trapezoidal metal roof panels blew off

Funding Programs for Wind Retrofit (Mitigation) Projects

Both Federal and State grant programs provide funding for wind retrofit projects. FEMA administers several Federal programs that provide grant funding for both structural and non-structural retrofits to reduce the risk of future wind damage and protect occupants. The Pre-Disaster Mitigation (PDM) program, the Hazard Mitigation Grant Program (HMGP), and the Public Assistance (PA) program all provide funding opportunities for

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For more information, see the FEMA Building Science Frequently Asked Questions website at http://www.fema.gov/frequently-asked-questions-building-science.

If you have any additional questions on FEMA Building Science Publications, contact the helpline at FEMA-Buildingsciencehelp@fema.dhs.gov or 866-927-2104.

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