VOLUME 1: **WIND**

DESIGNING FOR NATURAL HAZARDS

A RESILIENCE GUIDE FOR BUILDERS & DEVELOPERS

WIND

ACKNOWLEDGMENTS

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Located in Upper Marlboro, Maryland, Home Innovation Research Labs (Home Innovation) was founded in 1964 as a wholly-owned, independent subsidiary of the National Association of Home Builders (NAHB). Originating as a small product testing laboratory, Home Innovation has since grown to become a full-service market research, building science research, consultant, product testing laboratory, and accredited third-party certification agency dedicated to issues related to the homebuilding industry.

Visit the Disaster Recovery Tool Kit on the U.S. Department of Housing and Urban Development (HUD), Office of Policy Development and Research (PD&R) website—huduser.gov/portal/disaster-recovery.html—to find this report and other relevant resources, reports, guides, and ordinances sponsored by PD&R to aid homeowners and property owners in the disaster recovery process. Many of the reports in the kit are available in print by calling the HUD User Clearinghouse at 1–800–245–2691, option 1. As always, all reports are available as free downloads from HUD User.

FOREWORD

According to the National Oceanic and Atmospheric Administration, the United States spent $145 billion in 2021 recovering from natural disasters, which included wildfires, tropical cyclones, floods, tornados, drought conditions, and extreme winter storm events. To mitigate the impact of natural disasters, the U.S. Department of Housing and Urban Development (HUD) continues to develop technical guidance to improve the resilience of housing.

Resilience is characterized by a community's ability to minimize damage and recover quickly from extreme events and changing conditions.

The *Designing for Natural Hazards: A Resilience Guide for Builders & Developers* series was developed with a technical advisory group that included subject matter experts from a wide range of industry stakeholders. The experts were tasked with identifying above-code construction techniques to improve the resilience of residential buildings. A consensus process was used with the goal of creating a set of practical, actionable guidelines for builders and developers. The guidelines are intended for new construction, improvements before a natural disaster, and major reconstruction efforts after natural disasters, especially where entire communities need to be rebuilt.

The technical advisory group recognized that when natural disasters occur, certain damage is more likely than other types of damage. To address this challenge, the technical advisory group recommended a mitigation strategy that prioritizes high-frequency damage over damage that rarely occurs—based on post-disaster damage assessment reports. This novel approach encourages improving those parts of the building that typically get damaged first. It can also maximize the impact of disaster mitigation grants by preventing future damage to homes.

The resilience guides are an excellent addition to HUD's PD&R Disaster Recovery Took Kit. These guides should be updated periodically based on post-disaster damage assessment data—from future natural disasters. The resilience guides will be valuable resources to builders and developers seeking to incorporate resilience in housing.

Solomon Greene
Principal Deputy Assistant Secretary for Policy Development and Research
U.S. Department of Housing and Urban Development

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INTRODUCTION TO VOLUME 1: WIND

Designing for Natural Hazards is a set of resiliency guides for builders and developers. It is segmented into five short volumes, each focusing on a specific natural hazard type, as illustrated below:

This guide is **Volume 1: Wind,** which highlights the damage caused by windstorms (that is, tornadoes, hurricanes, waterspouts, microbursts, and derechos); in addition, the guide identifies resilient construction practices that can eliminate or minimize wind damage in a meaningful way.

BACKGROUND

HUD tasked Home Innovation Research Labs (Home Innovation) to develop a set of practical, actionable guidelines for builders and developers to design and construct residential buildings, neighborhoods, and accessory structures in a manner that could improve residential resilience and integrate resiliency throughout the entire community. The ***Designing for Natural Hazards*** guides accomplish this task by providing technical content in a very straightforward manner that is easy for a layperson to understand while also providing references for design professionals, builders, developers, and public officials to dive deeper into the necessary details. These resilience guides are not intended to substitute for engineering or architectural project design work; instead, the technical guidance identifies the components that can be enhanced or improved to achieve above-code performance that should make residential buildings and other community assets more resilient.

The ***Designing for Natural Hazards*** guides focus on new construction and major reconstruction after natural disasters, especially reconstruction in areas where entire communities need to be rebuilt after catastrophic events. The guides do not focus on minor repairs or renovations that are common after typical natural disaster events and do not address commercial buildings, although many of the construction practices identified are also applicable to multifamily mixed-use buildings with wood framing.

To make the guides as practical and have as much input and buy-in as possible, Home Innovation employed many of the same approaches used to assemble the Technical Advisory Group (TAG) when helping develop the American National Standards Institute (ANSI) standards. Specifically, Home Innovation recruited a balanced number of stakeholders to reach consensus on the approach to developing content. In addition, all Task Group meetings were open to the public, and input was solicited beyond the members of the TAG and its Task Groups. Although these guides were not developed in accordance with the requirements of an ANSI standard, the approach to these guides mirrored that spirit and intent of creating a voluntary, consensus document.

HOW TO USE THE GUIDES

The ***Designing for Natural Hazards*** guides are intended to be used by a wide range of stakeholders, including design professionals, builders, developers, and even prospective homebuyers. The guides differ from other resiliency programs and resources because they are not a prescriptive program or list of improvements. Instead, the resilience guides are designed to be flexible and allow users to focus on either a single resilient construction practice or multiple resilient construction practices, depending on the user's specific needs.

The technical content is provided on a single, double-sided page for each resilient construction practice. These "one-pagers" are intended to be printed and used as stand-alone documents for a builder or developer to specify an above-code construction practice. The one-pagers can also be given to a prospective homebuyer or building owner as a supplemental marketing document to highlight the resilient construction features that have been included in a new building.

Each one-pager includes key information about the specific natural hazard and resilient construction practice that will minimize or eliminate potential damage. The front of each document identifies (1) the damage expected by the hazard (as shown in the photo); (2) the frequency that a specific type of damage occurs; (3) a description of the resilient construction practice that can minimize damage; (4) a description of the mitigation strategy; and (5) a summary of the cost and benefit of implementing the resilient construction practice. The back of the document provides additional design guidance details, including (1) multiple design variations and supplemental resilient construction practices; (2) the corresponding level of difficulty associated with implementing alternative resilient construction practices; (3) the relative cost of implementing the various options; and (4) technical references that provide more information for each design option.

Because the resilient construction practices summarized in these guides are intended to be implemented in areas where the building code does not specify resilient construction practices, builders cannot rely on a building code official to verify that the practices have been followed. Therefore, builders who undertake these resilient construction practices will need to either incorporate the practices into their internal quality assurance process or hire a third-party organization to confirm that the resilient construction practice(s) was appropriately included in the design and constructed per their specification, which will require some additional detail beyond the one-pagers.

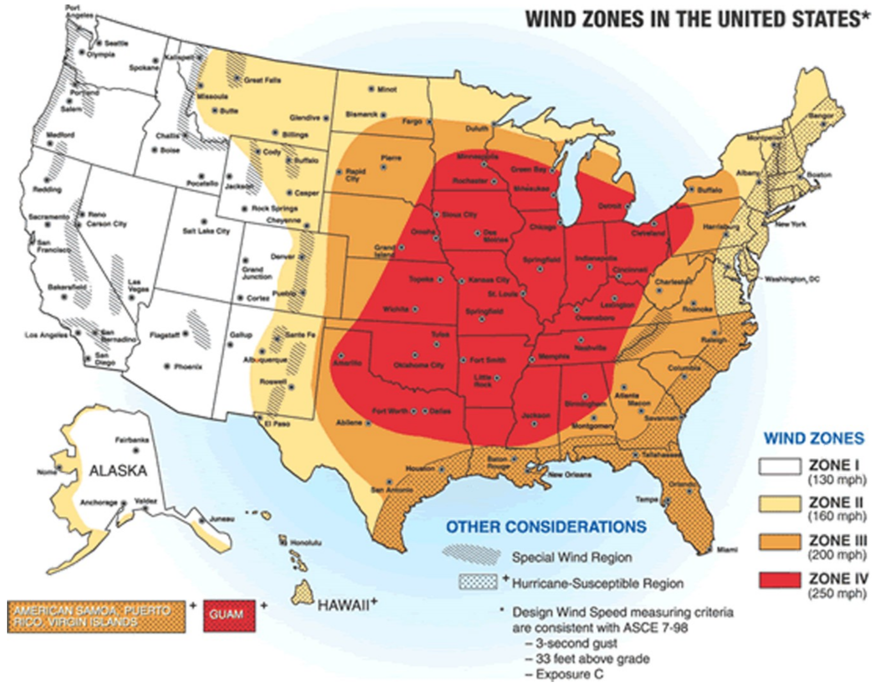


Figure 1. Federal Emergency Management Agency's Composite Wind Zone Map
Source: National Institute of Standards and Technology

Defining Wind Damage and Resilient Construction

Wind damage can occur from a variety of windstorms, including the most common types: thunderstorms, microbursts, tornadoes, hurricanes, cyclones, haboobs, and derechos. National Oceanic and Atmospheric Administration (NOAA) defines damaging winds as "those that exceed 50–60 mph. Most thunderstorm winds that cause damage at the ground are a result of outflow generated by a thunderstorm downdraft—[these] damaging winds are often called 'straight-line' winds to differentiate the damage they cause from tornado damage. A tornado is a narrow, violently rotating column of air that extends from a thunderstorm to the ground. Major hurricanes can cause devastating to catastrophic wind damage and significant loss of life simply due to the strength of their winds." For this ***Designing for Natural Hazards*** guide, the Wind Task Group did not distinguish in the cause of wind damage because it can occur from a wide range of weather phenomena and is generally handled the same way by insurance companies.

The first undertaking for the Wind Task Group was to identify typical damage that happens when windstorm events occur. To that end, the group reviewed case studies of major storm events, such as hurricanes and tornadoes, published by the Federal Emergency Management Agency (FEMA) and HUD. The Task Group gathered and discussed the wind damage described in the reports, then reviewed a wide range of technical resources—for example, resources from FEMA, HUD, the American Society of Civil Engineers (ASCE), the International Code Council (ICC), and the Insurance Institute for Business & Home Safety (IBHS)—to identify the most relevant resilient construction content to be included in the Wind one-pagers.

For those building in an area that is already designated as a high-risk wind zone, nearly all of the wind-related resilient construction practices in this guide will apply, in addition to other requirements. However, for those building a more wind-resilient residential building outside a high-risk wind zone area (that is, in a low-risk wind zone area), this guide can help builders implement the practices incrementally by adding one or more wind-resilient features to the building.

FEMA publishes a composite map of wind zones in the United States, as illustrated in Figure 1.

Frequency of Damage Type

After familiarizing themselves with specific damage caused by windstorm events described in various disaster reports, the Wind Task Group was asked to determine the type of damage most likely to occur when considering all possible damage from wind. The authors have identified the damage on the one-pagers, and, to determine the frequency, the Wind Task Group reviewed available damage data from Auburn University's

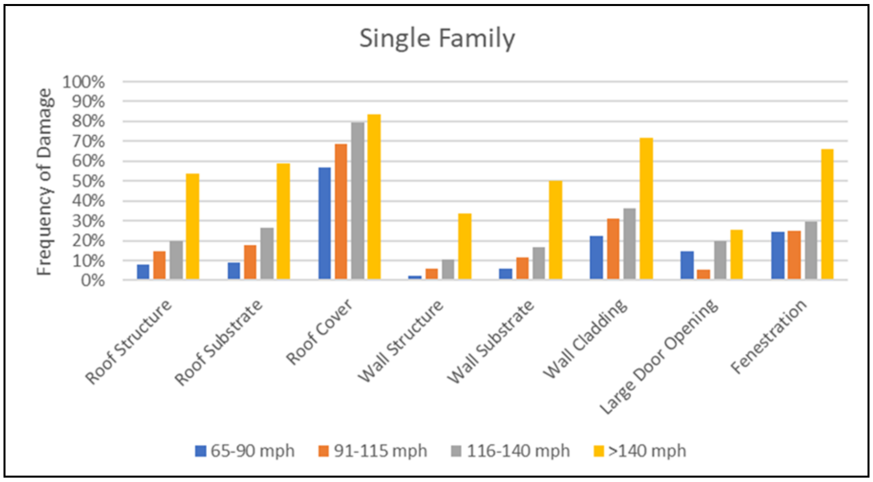


Figure 2. Quantification of Common Wind Damage Patterns in Recent Windstorms
Source: StEER Network

Structural Extreme Events Reconnaissance (StEER) Program.

According to StEER, their mandate is "to investigate structural performance under natural hazards that emphasizes those causing structural damage to the built environment, generally due to dynamic load effects. This would include hurricanes (wind, wave, and storm surge), tornadoes and other wind events, earthquakes, and tsunamis. While wind-driven rain is considered as part of the cascading hazards encountered in wind events like hurricanes, other forms of water damage due to inland flooding are generally not targeted by StEER. Similarly, while cascading hazards such as fire after earthquakes could be investigated as part of an earthquake response, StEER would not respond to a wildfire event in and of itself."

StEER focuses on collecting representative datasets for each hazard event, typically sampling from clusters of similar structure types (for example, single-family residential, commercial) across the hazard gradient and sampling at regularly spaced intervals within the clusters (for example, every other or every third structure).

StEER provided the following damage frequency data in Figure 2, which focuses on the primary building components with visible exterior damage, stratified by hazard intensity and structure occupancy. Please note that damage to large door openings was calculated using only structures that contained large door openings (as a result, it is a smaller sample size).

Prioritizing High-Frequency Damage for Resilience

Because these resilient construction practices are intended for low-risk areas that need additional resilience to wind hazards, several participants on the Technical Advisory Group recommended prioritizing high-frequency-damage areas of the building as the most practical mitigation strategy for resilience. Many were concerned that if funding for above-code practices/strategies were limited, or if a builder wanted to invest in a specific resilient construction practice above all others, knowing what was most important to do would be difficult, if not for some level of prioritization. Data about the frequency of damage type are necessary for builders and developers to prioritize the resilient construction practices that will yield the greatest benefit—or the least damage—to the building. The damage frequency metrics on the one-pagers are intended to provide builders and developers with a general idea of the frequency and severity of possible damage so that cost alone is not driving the mitigation strategy.

The StEER data offer a level of insight for wind-related damage that is not available for other hazard types. The StEER report titled *Quantification of Common Wind Damage Patterns in Recent Windstorm* states, "[Graphs and] plots show that roof damage is more prevalent than wall damage across all classes of buildings [i.e., residential, multifamily, and commercial], with roof cover (e.g., shingles) the most frequently damaged building component. Wall cladding typically is the next most frequently damaged building component. Some variability between occupancy classes in the distribution of damage to the various building components is observed, but the sample sizes for multifamily and commercial structures are notably smaller than that for single-family structures. Care should be taken in any direct comparisons of building performance across the occupancy classes." Because the one-pagers in this document primarily focus on single-family buildings, the authors do not attempt to aggregate single-family data with the multifamily data provided by StEER.

Grouping Resilience Practices

The Wind Task Group believed that licensed design professionals and subject matter experts would be able to prioritize resilient construction practices without much guidance.

The most basic prepackaged system of resilient construction practices could be as simple as selecting the basic practice for each of the one-pagers in the Wind Guide to encourage some baseline level of resilience. The Task Group also explored a "Good, Better, and Best" approach to grouping the one-pagers, in which the basic levels of resilience would be branded as "Good," the more advanced practices could be combined with those basics to offer a "Better" option, and the

Table 1. Example of "Good, Better, and Best" Approach to Resilient Construction Practices for Wind

	USING MULTIPLE 1-PAGERS		
	GOOD	BETTER	BEST
Openings—Shutters	High Frequency	High Frequency	High Frequency
Roof Deck & Underlayment	High Frequency	High Frequency	High Frequency
High-Wind Roof Covering	High Frequency	High Frequency	High Frequency
Continuous Load Path	High Frequency	High Frequency	High Frequency
Garage Doors	High Frequency	High Frequency	High Frequency
Wall System	X	Moderate Frequency	Moderate Frequency
Soffit	X	Moderate Frequency	Moderate Frequency
Pressurization Design	X	Moderate Frequency	Moderate Frequency
Chimney	X	X	Low Frequency
Roof-Mounted Equipment	X	X	Low Frequency

most comprehensively resilient practices could be considered a "Best" level of resilience. Table 1 provides an example of this type of approach for Wind Resilience, in which the one-pagers are grouped on the basis of the frequency of occurrences.

In this example, the bundling strategy is to prioritize high-frequency occurrences such that a "Good, Better, and Best" program adds more improvements that might be less likely to occur until a builder or developer is doing everything in this guide. Again, this is just one example; other approaches can be developed and deployed.

NEXT STEPS AND FUTURE RESEARCH

As resilient construction practices evolve, the one-pagers within this guide should be updated to reflect improvements or modifications. To improve the damage frequency metric, additional data mining can be done with StEER's damage data.

The Wind Task Group discussed correlating damage data against the age of the house as a way to illustrate if the building code has improved house performance over time. StEER provided the following graph as an example of how their damage data can be evaluated to see if older houses are at greater risk of damage compared with new homes in the same vicinity of a specific windstorm event. See Figure 3, which illustrates the frequency of damage for different building components for homes built before 2002 and those built after that date.

A closer look at the graph indicates that the roof structure and substrate have clearly improved, but roof covering damage is not much different, whether the residential building is newly built or a much older existing residential building. This type of in-depth granular analysis of damage data can improve building products and focus resilience practices where the damage is occurring.

StEER states, "Finally, hazard intensity is clearly correlated with increasing damage overall." Even within the lowest wind speed bin, however (65–90 mph), roof cover damage is still frequently observed. The data show that, considering all hazard intensities and years of construction, 26 to 50 percent of the roof cover on a single-family home is typically damaged in an extreme windstorm.

Considering the damage data available across hazard types, StEER's data should be considered invaluable to understanding how buildings are performing, and more data like this should be gathered for other natural hazards.

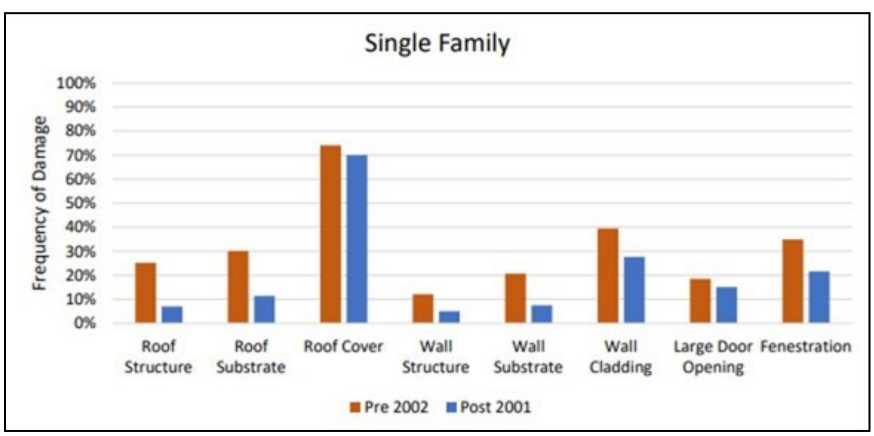


Figure 3. Single-Family Home—Damage Frequency
Source: StEER Network

Broken window from wind-borne debris.

OPENINGS—SHUTTERS

Window shutter styles for hurricane protection include colonial, Bahama, roll-up, and accordion-style shutters.

Adequate window and door protection is vital for keeping your family and your home safe. Exterior doors and windows that have not been designed to withstand severe weather events provide a significant entry point for major wind damage to a home. Openings can be damage amplifiers, in some cases causing structural failures when breached. This product improves the resilience of the structure.

Damage Frequency

HIGH

Construction Practice

Install window shutters to protect from wind-borne debris.

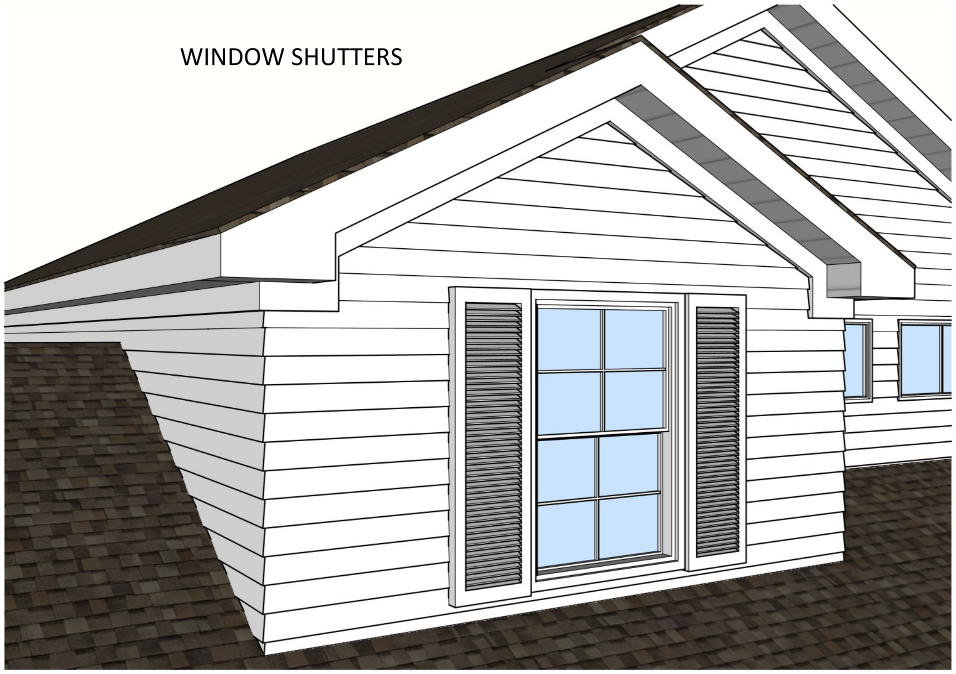
Mitigation Strategy

Storm shutters minimize the risk of windows breaking from wind-borne debris.

Cost & Benefit

Cost range to implement: $–$$$

Benefit: Shutters are built specifically to help guard windows against flying debris, wind, rain, hail, and other extreme forces associated with a tropical storm. Potentially avoids the cost of repairing major damage.



GUIDANCE	DIFFICULTY	COST
Install window shutters to protect from wind-borne debris.	Moderate	$$
Eliminate mulled windows. [1]	Easy	$
Outside swing doors are recommended. [2]	Easy	$
The door and windows, as an assembly, must be rated for the design pressure. [3]	Easy	$
For the door assembly (door and all associated hardware and components), meet the design wind pressure for the site. [3]	Easy	$$
All glazed openings (windows, patio doors, skylights, glass block, etc.) must be able to resist or be protected from wind-borne debris. [3]	Moderate	$$
All exterior door assemblies must be pressure and impact rated or protected by a system that is rated for the exposure category, design wind speed, door size, and door location on the building. Assembly includes door, door frame attachment to wood frame, and lock. [3]	Moderate	$$$

RESOURCES

1. *GM-0501: Rainwater Management Performance of Newly Constructed Residential Building Enclosures During August and September 2004*. Building Science Corporation.
2. 2020 *FORTIFIED Home™ Standard*. Insurance Institute for Business & Home Safety (IBHS).
3. Section R609, Exterior Windows and Doors. 2018 IRC.

Roof deck, cover, & underlayment damage.

Damage Frequency

HIGH

Construction Practice

Proper decking and flashing installation are highlighted in the construction details.

Mitigation Strategy

Strengthen the roof by installing a system built for high-wind events.

Cost & Benefit

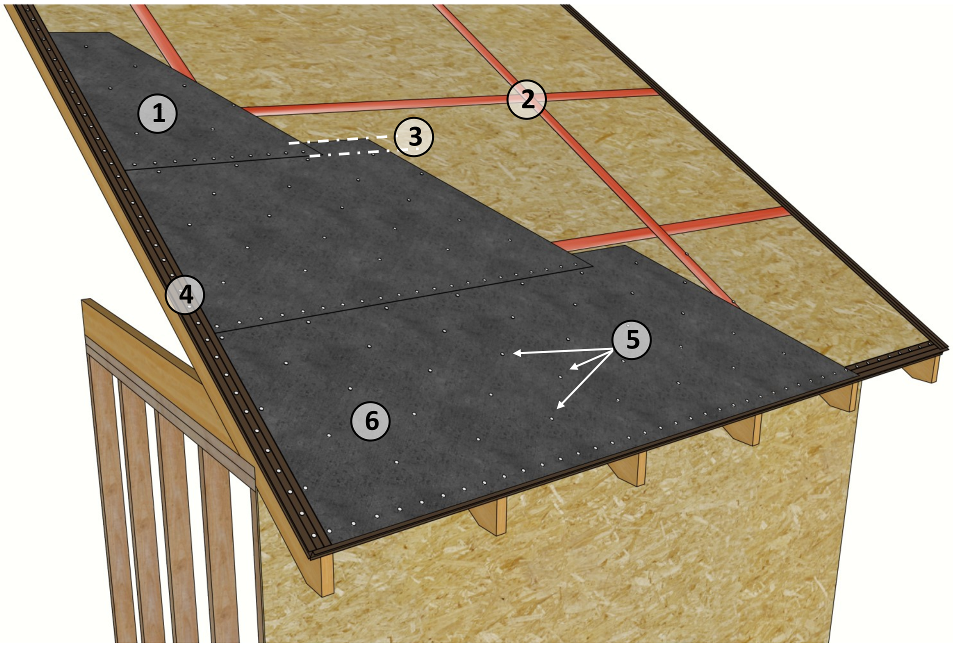
Cost range to implement: $–$$

Benefit: Installing additional layers of protection from water infiltration decreases the chance for potential costly water damage.

ROOF DECK AND UNDERLAYMENT

The roof is the most frequently damaged system of a structure in a severe weather event. Roof damage can be an amplifier, causing additional failures beyond the roof. Wind damage can result in extensive and costly water intrusion damage from water infiltration.

Use a minimum of 7/16 in. plywood or oriented strand board (OSB). For nailing decking—4 in. on center (o.c.) along the edges and 6 in. o.c. in the field, with 8d round head 2-1/2 in., .131 ring shank nails. Follow product installation according to the manufacturer's instructions to maintain warranty and to reduce potential failure.



1. One layer of ASTM D226 Type II, ASTM D4869 Type IV, or ASTM D6757
2. 4 in. wide (minimum) self-adhering modified bitumen tape at sheathing joints
3. 4 in. overlap
4. Metal drip edge
5. Stagger runs
6. Annular ring or deformed shank nails with metal or plastic caps. Cap diameter not less than 1 in. Nail shank diameter not less than 0.083 in. Metal cap thickness not less than 32-gauge sheet metal or 0.01 in. for power-driven fasteners. Plastic cap outside edge thickness not less than 0.035 in.

GUIDANCE	DIFFICULTY	COST
DECKING		
Use a minimum 7/16 in. plywood or OSB. [1]	Easy	$–$$
Nailing decking—4 in. o.c. along the edges and 6 in. o.c. in the field, w/8d round head 2-1/2 in., .131 ring shank nails. [1]	Moderate	$$
SECONDARY WATER BARRIER AND UNDERLAYMENT		
Install a 4-in.-wide (nominal) ASTM D1970 compliant self-adhering polymer-modified bitumen or AAMA 711-13, Level 3 roof deck flashing tape over all roof horizontal and vertical roof deck seams, then cover the deck with a #30 felt or an equivalent synthetic underlayment. Lap up the side walls 4–6 in., and tape with flashing tape. Fasten underlayment with button cap nails at 6 in. o.c. along the laps and 12 in. o.c. spacing, vertically and horizontally, between the laps. [1]	Easy	$
Install a two-layer #30 felt underlayment. To achieve a double layer, cut 17 in. off one side of the roll, and install the remaining 19-in.-wide strip of underlayment. Tack in place. Install a 36-in.-wide roll of underlayment over the 19-in.-wide course of underlayment along the eave. Continue, overlapping the sheets 19 in. (leaving a 17-in. exposure). Attach underlayment with button cap nails at 6 in. o.c. along the laps and 12 in. o.c. spacing, vertically and horizontally, between the laps. Lap up the sidewalls 4–6 in., and tape with flashing tape. [1]	Easy	$
Install a self-adhered (peel-and-stick) membrane meeting ASTM D1970 requirements over the entire roof deck. Lap up the sidewalls 4–6 in. [1]	Moderate	$$
FASTENERS FOR UNDERLAYMENT		
Metal cap nails—32-gauge cap with minimum 1 in. diameter—minimum ring shank 0.083 in. or smooth shank 0.091 in. Length not less than 3/4 in. into roof sheathing. [2]	Moderate	$$
Plastic cap nails—0.035 in. edge cap with minimum 1 in. diameter—minimum ring shank 0.083 in. or smooth shank 0.091 in. Length shall be sufficient to penetrate the roof sheathing or not less than 3/4 in. into roof sheathing. Fasteners shall be corrosion resistant. [2]	Moderate	$$
Fasten underlayment with button cap nails at 6 in. o.c. along the laps and 12 in. o.c. spacing, vertically and horizontally, between the laps. [2]	Moderate	$$

RESOURCES

1. 2020 *FORTIFIED Home™ Standard*. Insurance Institute for Business & Home Safety (IBHS).
2. Chapter 9, Roof Assemblies. 2018 IRC.

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Roof deck, cover, and underlayment damage.

HIGH-WIND ROOF COVERING

During a hurricane, tornado, high winds, or hailstorms, roof shingles can be damaged or blown off the roof, exposing the underlayment and the sheathing as the only protection against rainwater. Exposed sheathing will eventually succumb to water damage. Unsealed joints or holes in the roof sheathing due to storm damage can allow rainwater to enter the building, causing severe damage, including saturation of insulation and ceiling drywall, potentially leading to collapsed ceilings and extensive damage to interior finishes and household contents. Properly select and install asphalt shingles when installing roofing on new construction to minimize the risk of water intrusion due to shingles being damaged or blown off the roof during high winds or hurricanes. Follow product installation according to the manufacturer's instructions to maintain warranty and to reduce potential failure.

Damage Frequency

HIGH

Construction Practice

High-wind roof covering installation details improve the performance in high-wind weather events.

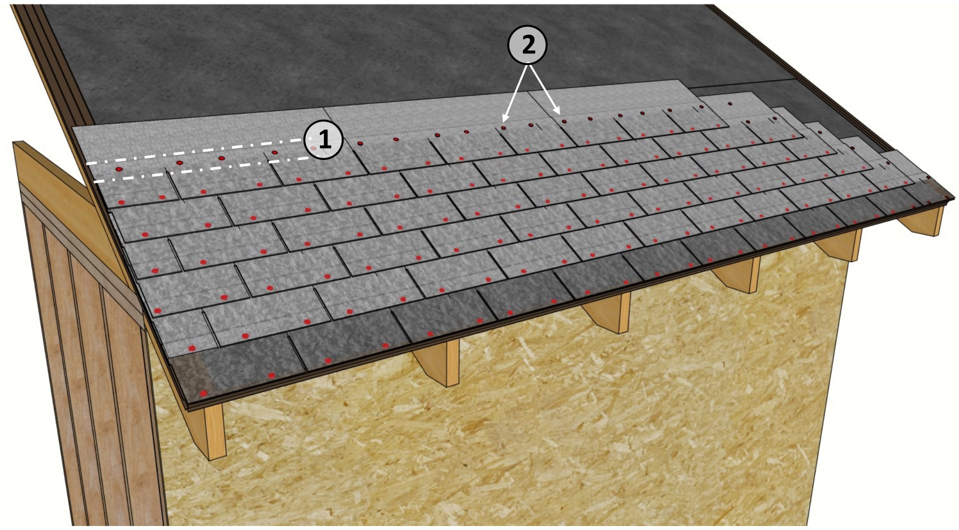
Mitigation Strategy

Install roof coverings specifically designed for high-wind zones.

Cost & Benefit

Cost range to implement: $–$$$

Benefit: Installing additional layers of protection from water infiltration decreases the chance for potential costly water damage.



1. Asphalt shingle nailing zone (varies according to manufacturer; some use nail line instead of a zone).
2. Nails should be installed in the nailing zone or on the nail line, depending on the manufacturer. If the shingle does not have a nail zone or nail line, nails should be installed close to the shingle centerline to secure the shingle below.

GUIDANCE	DIFFICULTY	COST
ROOF COVER		
Asphalt shingles should be high-wind rated and be installed with six nails, per high-wind installation instructions. [1]	Easy	$
For shingle roof installations, seal the drip edge at eaves using a self-adhering starter strip or applying an 8-in.-wide layer of flashing cement, maximum 1/8 in. thick. [1]	Moderate	$
Use asphalt roof cement to glue and ensure bonding to enhance the attachment of hip and ridge shingles. [2]	Moderate	$
All other roof coverings (metal, concrete and clay tile, low-sloped roofs, wood shakes, or shingles) should be rated and installed per the manufacturer for the site-specific wind speed and design pressures. *Use the ASCE 7-16 FORTIFIED™ Wind Uplift Design Pressure Calculator on fortifiedhome.org* [1]	Moderate to Complex	$$–$$$
DRIP EDGE and FLASHING		
Install drip edge on top of the underlayment (except where instructions or the building code stipulate a different method), extend a minimum of 1/4 in. below roof sheathing, and extend onto the roof deck 2 in. [1]	Easy	$
Drip edges must be mechanically fastened to the roof deck at a maximum of 4 in. o.c. [1]	Easy	$
Install flashing at wall and roof intersections at each change in roof slope or direction and around roof openings. A flashing shall be installed to divert the water away from where a roof intersects a vertical sidewall. [3] Base flashing against a vertical sidewall shall be continuous or step flashing and shall be not less than 4 in. in height and 4 in. in width and shall direct water away from the vertical sidewall onto the roof or into the gutter. [3]	Moderate	$

RESOURCES

1. *2020 FORTIFIED Home™ Standard*. Insurance Institute for Business & Home Safety (IBHS).
2. *Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas, 4th ed. Volume I.* FEMA P-55. 2011.
3. Chapter 9, Roof Assemblies. 2018 IRC.

DESIGNING FOR NATURAL HAZARDS
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Failure due to lack of load path. Source: FEMA

Damage Frequency

HIGH

Construction Practice

Using connectors, attach adjacent wood structural sheathing over common framing to provide lateral and uplift load continuity.

Mitigation Strategy

Use continuous load path connections.

Cost & Benefit

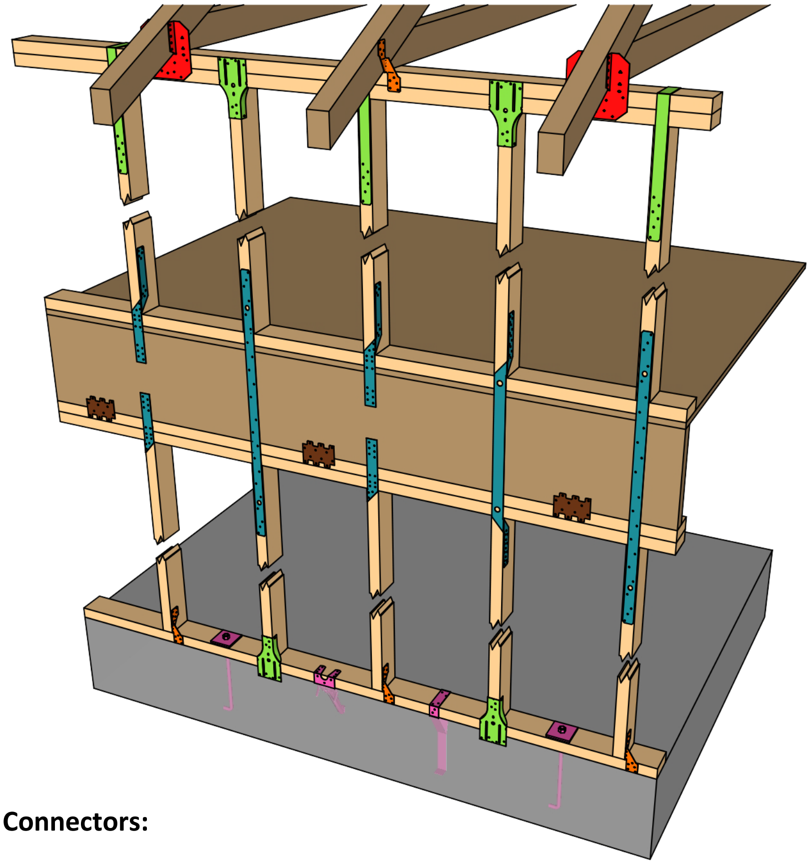
Cost range to implement: $–$$

Benefit: Good connections that tie the floor, walls, and roof together provide continuity in the load path and more reliable building performance. Potentially avoids the cost of repairing major damage.

CONTINUOUS LOAD PATH

Designing a structure to withstand the forces of wind is one of the greatest challenges a builder can face. Much like breaking the weakest link in a chain, high wind at the weakest point in the load path may cause a home structure to fail.

A complete load path ensures that all of the parts and systems of a home work together—a properly designed roof should be tied to a properly designed wall system, which is tied to a properly designed foundation. Each home and site will have a unique load path and conditions and need to be considered individually. This general image illustrates connecting the different structural systems together.



Connectors:

- Roof Member to Top Plate
- Top Plate to Stud
- Floor to Floor
- Stud to Sill Plate
- Sill Plate to Foundation
- Shear Load Transfer

FOR WIND LOADING ONLY

GUIDANCE	DIFFICULTY	COST
Attach adjacent wood structural panel wall sheathing over common framing to provide lateral and uplift load continuity. [1]	Easy	$
Have a licensed engineer design the load path to consider site-specific conditions.	Easy	$$
Roof Sheathing Attachment: Increase the nailing to 4 in. at panel edges and 6 in. along intermediate supports (from a 6/12-in. pattern), and use ring/screw shank nails to increase withdrawal strength. [2]	Easy	$
Gable End Walls: Brace gable end walls at both the top and bottom, and ensure that they are properly attached to the roof and wall, respectively. [3]	Easy	$
Gable End Walls: Sheathe all gable ends with wood structural panels that have the same performance category as the walls. [4]	Easy	$
Roof Truss/Rafter Attachment: Attach roof framing member to the wall top plates with a fastener that resists loads in all three directions. [5]	Easy	$
Bracing of Roof Framing: Ensure that trusses and rafters, especially those with taller heels, are properly braced with solid blocking between the top plates and roof sheathing to transfer the loads from the roof to the walls. [6]	Easy	$
Floor-to-Floor Connections: Ensure that upper and lower floors are properly attached to resist uplift loads and create a solid lateral connection. [7]	Easy	$
Wall System Design: Ensure that walls are properly designed to resist all loads. [8]	Easy	$
Wall-to-Foundation Connection: Attach sill plates to the foundation with 1/2 in. anchor bolts at 32-48 in. o.c. Provide a 3x3-in.-square plate washer at each anchor bolt. Ensure that the wall sheathing is attached to the properly anchored sill plate with the nailing pattern of the edge of the sheathing, as required by the wall design. [9]	Easy	$

RESOURCES

1. *Building for High-Wind Resistance in Light-Frame Wood Construction.* Form No. M310E. APA – The Engineered Wood Association. August 2018.
2. *Building for High-Wind Resistance,* Figure A.
3. *Building for High-Wind Resistance,* Figure B.
4. *Building for High-Wind Resistance,* Figure C.
5. *Building for High-Wind Resistance,* Figure D.
6. Section R602.10.8 Braced Wall Panel Connections. 2018 IRC.
7. *Building for High-Wind Resistance in Light-Frame Wood Construction,* Figure E.
8. *Building for High-Wind Resistance,* Figures F and G.
9. *Building for High-Wind Resistance,* Figures H and I.

Broken garage door from wind-borne debris.

GARAGE DOORS

Adequate garage door protection is vital for keeping your family and your home safe. The garage door, the largest and weakest opening in your house, is the area of your home most likely to fail first. Garage doors can be damage amplifiers, in some cases causing structural failures of the roof when breached. The garage door must be rated for high winds with reinforced components.

Damage Frequency

HIGH

Construction Practice

Install additional brackets and rails in the garage door. Brackets reinforce the frame, and the rails reinforce the garage door.

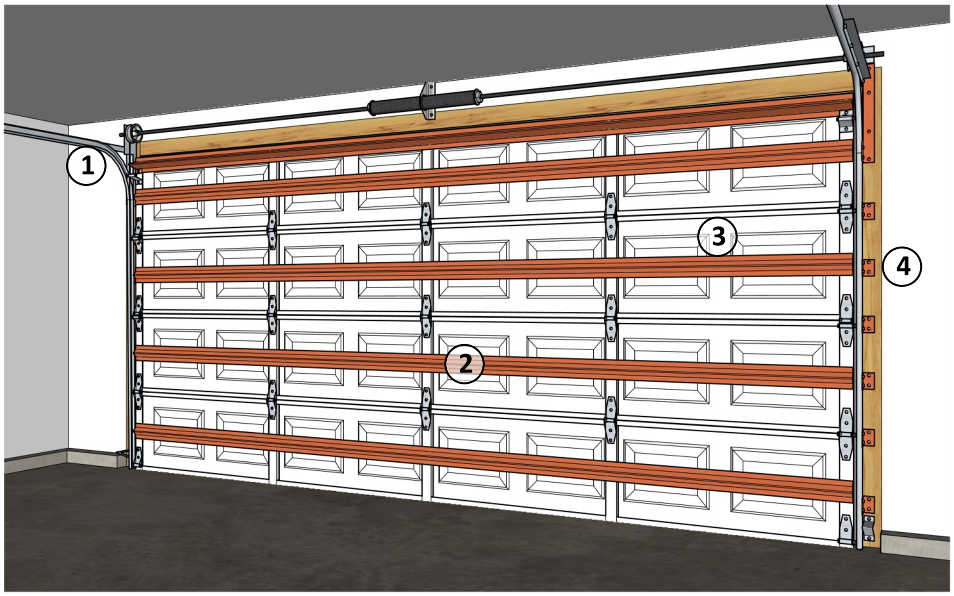
Mitigation Strategy

Additional structural support for garage door.

Cost & Benefit

Cost range to implement: \$–\$\$\$

Benefit: A wind-rated garage door can minimize damage to the home.



1. Heavy gauge metal track
2. Horizontal structural reinforcement
3. Heavy-duty panel section
4. Heavy-duty brackets and hinges

GUIDANCE	DIFFICULTY	COST
Install additional brackets and rails in the garage door. Brackets reinforce the frame, and the rails reinforce the garage door.	Moderate	$$–$$$
For garage doors **without** glazed openings (windows), the door assembly (door and all associated hardware and components) must meet the design wind pressure for the site or protect the garage door with an impact-rated shutter/screen product that meets the design wind pressure for the site. [1,2]	Moderate	$$
For garage doors **with** glazed openings (windows), the door assembly must be rated for the design pressure and impact, or the garage door shall be protected with an impact-rated shutter/screen product that meets the design wind pressure for the site. [1,2]	Moderate	$$–$$$

RESOURCES

1. 2020 *FORTIFIED Home™ Standard*. Insurance Institute for Business & Home Safety (IBHS).
2. Section R609, Exterior Windows and Doors. 2018 IRC.

Exterior wall damage from high winds.

Damage Frequency

MODERATE

Construction Practice

Use a full wrap of oriented strand board (OSB) or plywood around the exterior of the home, running from roof to foundation. Nail per IRC 6 in. o.c. on all four edges and 12 in. o.c. in field.

Mitigation Strategy

Continuous load path connections, sheathing, a weather-resistant barrier, and wind-rated windows and doors can improve the wall system performance.

Cost & Benefit

Cost range to implement: $–$$$

Benefit: A continuously sheathed, well-designed wall system minimizes structural and water penetration damage.

WALL SYSTEM

Designing a structure to withstand the forces of wind is one of the greatest challenges a builder can face. A continuously sheathed, well-designed wall system resists racking. This guidance provides information on constructing and installing the wall system components, which include framing, sheathing, water-resistive barriers (WRBs), windows, and doors.

1. House framing
2. OSB or plywood sheathing
3. High-wind-rated windows
4. Weather-resistant barrier
5. High-wind-rated entry door
6. High-wind-rated garage door

GUIDANCE	DIFFICULTY	COST
Use a full wrap of OSB or plywood around the exterior of the home, running from roof to foundation. Nail per IRC 6 in. o.c. on all four edges and 12 in. o.c. in field. [1,2]	Moderate	$$–$$$
Increase interior and exterior shear walls nailing pattern to 4 in. o.c. on edges and 6 in. o.c. in field. [3]	Easy	$
Inspect nailing patterns for exterior structural panels and shear walls.	Easy	$
Corrugated Brick Ties: Anchor into studs, not sheathing. [1] --OR-- For anchoring into sheathing, refer to IRC 2018 Section Table 703.8.4(2). [1]	Easy	$
Use reinforced CMU/ICF for exterior walls of the home, running from roof to foundation. These concrete wall systems are also applicable to foundation/basement walls. [4]	Moderate	$$–$$$
Use vinyl siding that complies with the 2017 edition of ASTM D3679 (2017), and verify that selected siding has a design wind pressure rating that equals or exceeds the required design wind pressure. [5,6]	Moderate	$
Use high-wind-rated fiber cement products for exterior cladding (no blind nailing) and trim in lieu of vinyl siding. [7]	Moderate	$–$$
Verify that selected fiber cement products and attachment schedules are designed or tested to meet the design wind pressures in the 2018 IRC or ASCE-10. [5]	NA	NA

NA = not applicable.

RESOURCES

1. Section R703, Exterior Covering. 2018 IRC.
2. *Full-Scale 3D Wall Bracing Tests.* APA Report T2007-73. APA—The Engineered Wood Association. November 2007.
3. APA Engineered Wood Construction Guide. Table 23. APA E30. APA—The Engineered Wood Association. 2019.
4. PCA100-2017 *Prescriptive Design of Exterior Concrete Walls for One and Two-Family Dwellings.* Portland Cement Association.
5. *Best Practices for Minimizing Wind and Water Infiltration Damage, Hurricane Michael in Florida.* FEMA. 2019.
6. *Mitigation Assessment Team Report: Hurricane Irma in Florida: Building Performance Observations, Recommendations, and Technical Guidance.* FEMA P-2023. 2018.
7. BSD 111: Flood and Hurricane Resistant Buildings. *Building Science Digests*. Building Science Corporation. 2006.

Damaged soffit.

Damage Frequency

MODERATE

Construction Practice

Install additional nailing strips for all types of soffit materials.

Mitigation Strategy

Soffits should be fastened securely to the eave structure; they should not be loose in the channels.

Cost & Benefit

Cost range to implement: $–$$

Benefit: Prevents further damage, as wind-driven rain can push into the building, causing damage to attic insulation and interior walls.

SOFFIT

Attics are vented (cooled) three ways: (1) **vents on the roof**, (2) **gable end vents**, and (3) **vents under eaves or overhangs** (soffit vents). Hurricane winds can drive large amounts of water through attic ventilation openings. During major storm events, if gable end vents are present, they should be covered or closed (similar to other building envelope openings). The following information is intended to help minimize water intrusion through attic ventilation systems, not to change from a ventilated to an unvented system.

1. Vent on the roof
2. Gable end vents
3. Soffit vents under eaves or overhangs

GUIDANCE	DIFFICULTY	COST
Additional nailing strips for all types of soffit materials. [1]	Easy	$
With vinyl and metal soffit, follow manufacturer-recommended high-wind application. [1]	Easy	$
Use fiber cement or wood soffit material (confirm nailing patterns). [2]	Moderate	$$
Use fiber cement soffit material applied over additional nailing strips. [1]	Moderate	$$

RESOURCES

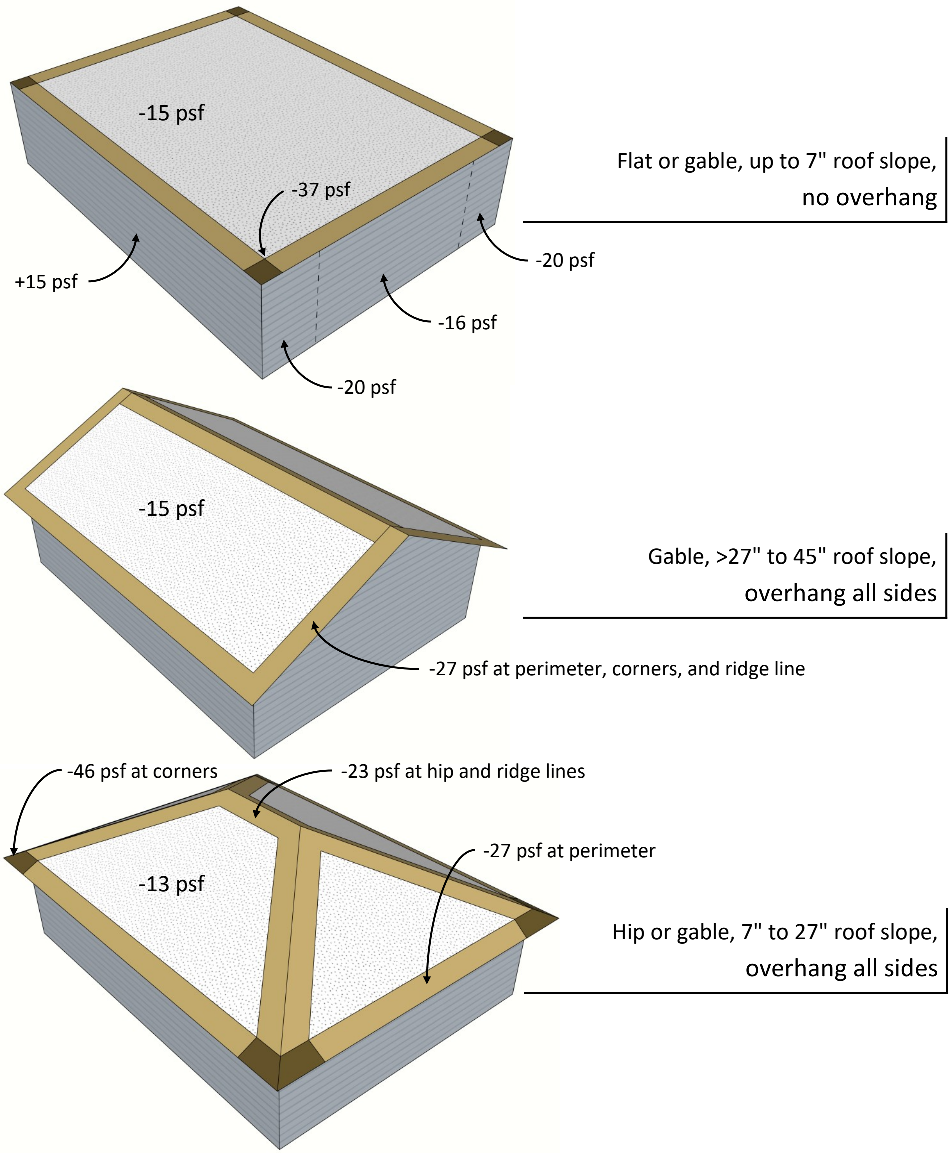
1. Technical Fact Sheet No. 7.5, Minimizing Water Intrusion Through Roof Vents in High-Wind Regions. *Home Builder's Guide to Coastal Construction.* FEMA P-499. 2010.
2. BSD 111: Flood and Hurricane Resistant Buildings. *Building Science Digests*. Building Science Corporation. 2006.

DESIGNING FOR NATURAL HAZARDS
A RESILIENCE GUIDE FOR BUILDERS & DEVELOPERS

Structure failure due to wind pressurization.

PRESSURIZATION DESIGN

Designing a structure to withstand the high forces of wind is one of the greatest challenges a builder can face. Proper design is critical to resist high wind. This guidance provides designers and builders with information and resources such that they will consider wind- and water-resistant building envelopes.



Damage Frequency

MODERATE

Construction Practice

Attachment to roof should not compromise roof system and should be engineered on the basis of site location.

Mitigation Strategy

Encourage the use of wind-resistant roof shapes (for example, hip over gable design).

Cost & Benefit

Cost range to implement: $–$$$

Benefit: Proper roof design can minimize damage to roofs from high winds.

GUIDANCE	DIFFICULTY	COST
Do not distribute concentrated loads in walls around openings.	Easy	$
Stack openings of each level. [1]	Easy	$
Shear walls should have low aspect ratios (height-to-width ratio). [2,4]	Easy	$
Shear walls/protections should be at corners. [3,4]	Easy	$
Ask engineer to optimize shear wall lengths.	Complex	$$
Larger openings should be parallel to main roof joists (in non-load-bearing walls).	Easy to Complex	$–$$$

RESOURCES

1. *Advanced Framing Construction Guide.* APA M400. APA—The Engineered Wood Association. April 2016.
2. ANSI/AWC 2015 *Special Design Provisions for Wind and Seismic* (SDPWS). American Wood Council.
3. *2018 Wood Frame Construction Manual* (WFCM). American Wood Council.
4. Wind Safety of the Building Envelope. *Whole Building Design Guide.* National Institute of Building Sciences. June 15, 2017.

Chimney and wall damage due to high winds.

Damage Frequency

LOW

Construction Practice

Proper reinforcement of chimney.

Mitigation Strategy

Chimney structure should be anchored correctly to the roof system.

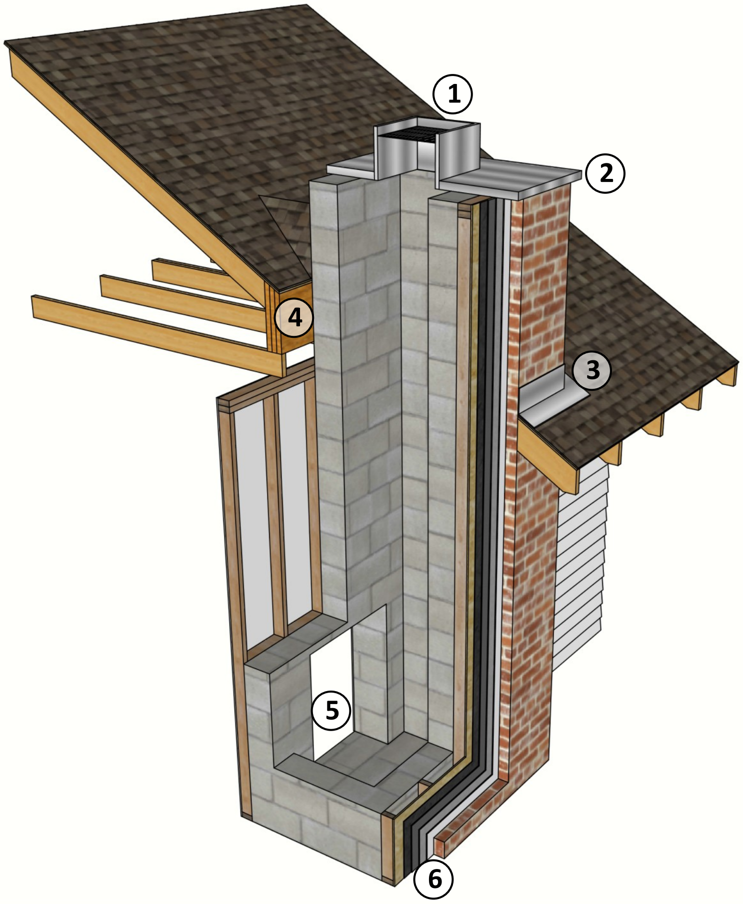
Cost & Benefit

Cost range to implement: $–$$

Benefit: A properly anchored chimney can prevent costly damage to the roof structure.

CHIMNEY

The chimney is an integral part of the overall structural performance and considered part of the load path requirements. Proper anchoring of a masonry chimney structure within the framing of the roof system is critical to resist high wind, prevent damage to roof cover, and prevent chimney from overturning or becoming flying debris.



1. Chimney cap
2. Drip edge
3. Chimney flashing
4. Roof/wall system
5. Interior fireplace area
6. Exterior wall of chimney

GUIDANCE	DIFFICULTY	COST
Masonry chimney adjacent to the building envelope should be properly reinforced and anchored back to the wood framing. [1]	Easy	$
Chimney must be less than 5 ft. unless engineered.	Easy	$
Masonry chimney sitting on top of a deck and that penetrates the balloon frame should be properly reinforced and engineered.	Easy	$$
Framed chimneys that penetrate roof structure around metal flue on top of roof should be properly anchored, balloon framed, and engineered.	Easy	$$
Framed chimneys adjacent to the building envelope around metal flue should be properly anchored and attached to the structure.	Easy	$$

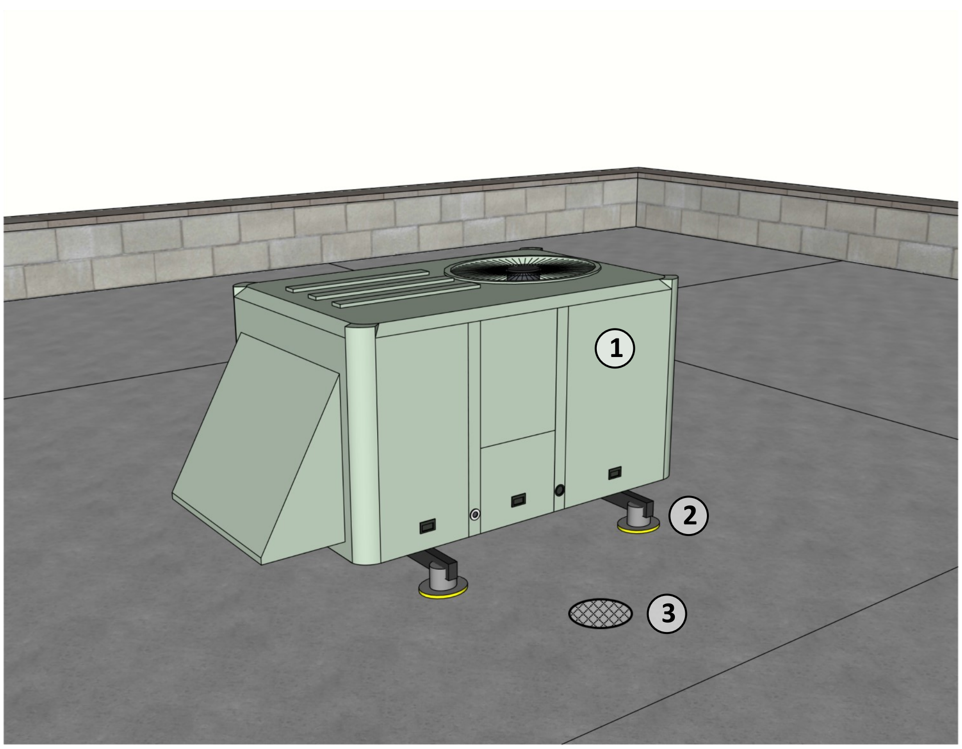
RESOURCES

1. 2020 *FORTIFIED Home™ Standard*. Insurance Institute for Business & Home Safety (IBHS).

Damaged HVAC unit.

ROOF-MOUNTED EQUIPMENT

Proper fastening of equipment is critical to resist high wind, prevent damage to roof cover, and prevent equipment from becoming flying debris. Damaged equipment can impair the operation of the facility, and the equipment can detach and become damaging wind-borne debris. In addition, water can enter the building where equipment has been displaced or damaged. The most common problems typically relate to inadequate equipment anchorage, inadequate strength of the roof structure to support the equipment, and corrosion of equipment and connectors.



1. Corrosion-resistant material
2. Anti-vibration mounts and supports
3. Roof drainage features

Damage Frequency

LOW

Construction Practice

Attachment to roof should not compromise roof system and should be engineered on the basis of the roof truss system.

Mitigation Strategy

Proper fastening and anchoring of equipment.

Cost & Benefit

Cost range to implement: $–$$

Benefit: Minimizes damage to the roof system.

GUIDANCE	DIFFICULTY	COST
HVAC attachments to roof should not compromise roof system and should be engineered per site location. Proper flashing is critical. [1,2]	Easy	$
Ground mounting of solar panels is optimal wherever possible. [3]	Easy	$$
Solar (photovoltaic [PV]) should be installed at “zero tilt.” Panels should be rated for wind zone and designed for building location design wind speed. Panels should be rated for snow/hail as appropriate for location. Attachment to roof should not compromise roof system and should be engineered per site location. Proper flashing is critical. [3]	Easy	$
Ground mounting of HVAC is optimal wherever possible. [1,2]	Easy	$
Ground mounting of deck is optimal wherever possible. [1,2]	Easy	$
Deck attachments to roof should not compromise roof system and should be engineered per site location. Proper flashing is critical. [1,2]	Easy	$$

RESOURCES

1. *Attachment of Rooftop Equipment in High-Wind Regions.* USVI-RA-2. FEMA. March 2018.
2. Section 5.1.3.4, Rooftop Equipment. *Mitigation Assessment Team Report: Hurricanes Irma and Maria in Puerto Rico.* FEMA P-2020. October 2018.
3. *Wind Design for Solar Arrays.* PV2-2017. Structural Engineers Association of California.

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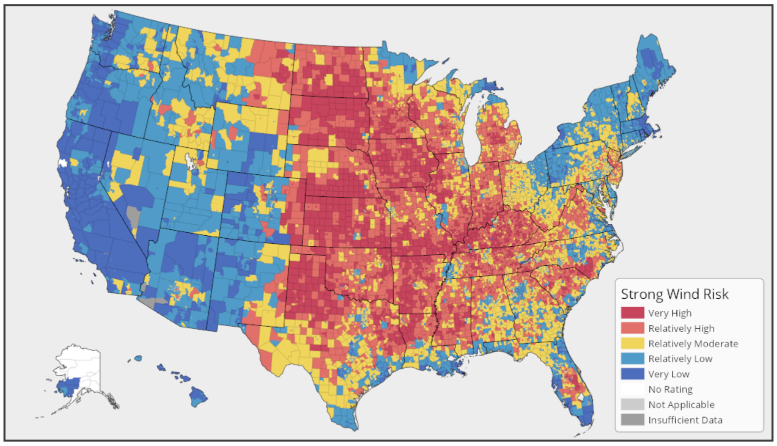
FEMA's Interactive Strong Wind Risk Map illustrates the risk by county: https://hazards.fema.gov/nri/strong-wind.



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https://www.fema.gov/sites/default/files/2020-07/mat-report_hurricane-michael_florida.pdf.

Mitigation Assessment Team Report: Hurricane Harvey in Texas. FEMA P-2022. 2019.
https://www.fema.gov/sites/default/files/2020-07/mat-report_hurricane-harvey-texas.pdf.

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https://www.fema.gov/sites/default/files/2020-07/mat-report_hurricane-irma-maria-puerto-rico_2.pdf.

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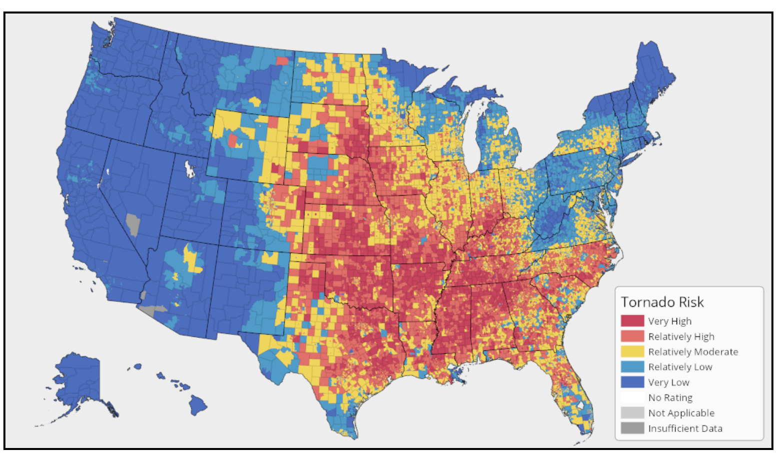
Wind Damage vs. Water Damage: What You Need to Know When Filing a Claim.
https://www.fema.gov/fact-sheet/wind-damage-vs-water-damage-what-you-need-know-when-filing-claim.

FEMA's interactive Tornado Risk Map illustrates the risk by county:
https://hazards.fema.gov/nri/tornado.



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Review of HUD's Report of the Impact of Hurricane Charley on Manufactured Homes. MHI. 2006. http://www.manufacturedhousing.org.php56-9.dfw3-2.websitetestlink.com/wp-content/uploads/2016/09/513temp.pdf.

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Technical Investigation on the May 22, 2011, Tornado in Joplin, Missouri. NIST. 2011. https://nvlpubs.nist.gov/nistpubs/NCSTAR/NIST.NCSTAR.3.pdf.

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