Improving Windstorm and Tornado Resilience: Recommendations for One- and Two-Family Residential Structures

Purpose and Intended Audience

The purpose of this fact sheet is to provide a brief overview of building envelope and load path improvements to reduce damage to wood-framed, one- and two-family residential structures when impacted by tornadoes rated on the Enhanced Fujita (EF) Scale as EF2 or less intensity, and indirectly by tornadoes with a greater EF rating. Utilizing higher rated building envelope materials, providing opening protection, and improving the load path and connections can reduce the common types of tornado damage to one- and two-family residential structures, as shown in Figure 1. These mitigation measures will also provide enhanced building performance in other types of windstorms, such as severe thunderstorms and derechos.

Figure 1. Failure of load path, building envelope components (roof shingles, soffits, and siding) and windows observed in Dawson Springs, Kentucky (December 2021)

The information in this fact sheet can be applied to new construction or to the retrofit of existing residential structures in tornado-prone regions of the United States. As seen in Figure 2, the majority of the total number of tornadoes reported annually in the United States (approximately 1,250 tornadoes per year) are EF0 to EF-2.

Tornadoes do not only occur in central and southeast United States but generally occur throughout the region east of the Continental Divide, particularly the lower intensity EF0, EF1, and EF2 tornadoes.

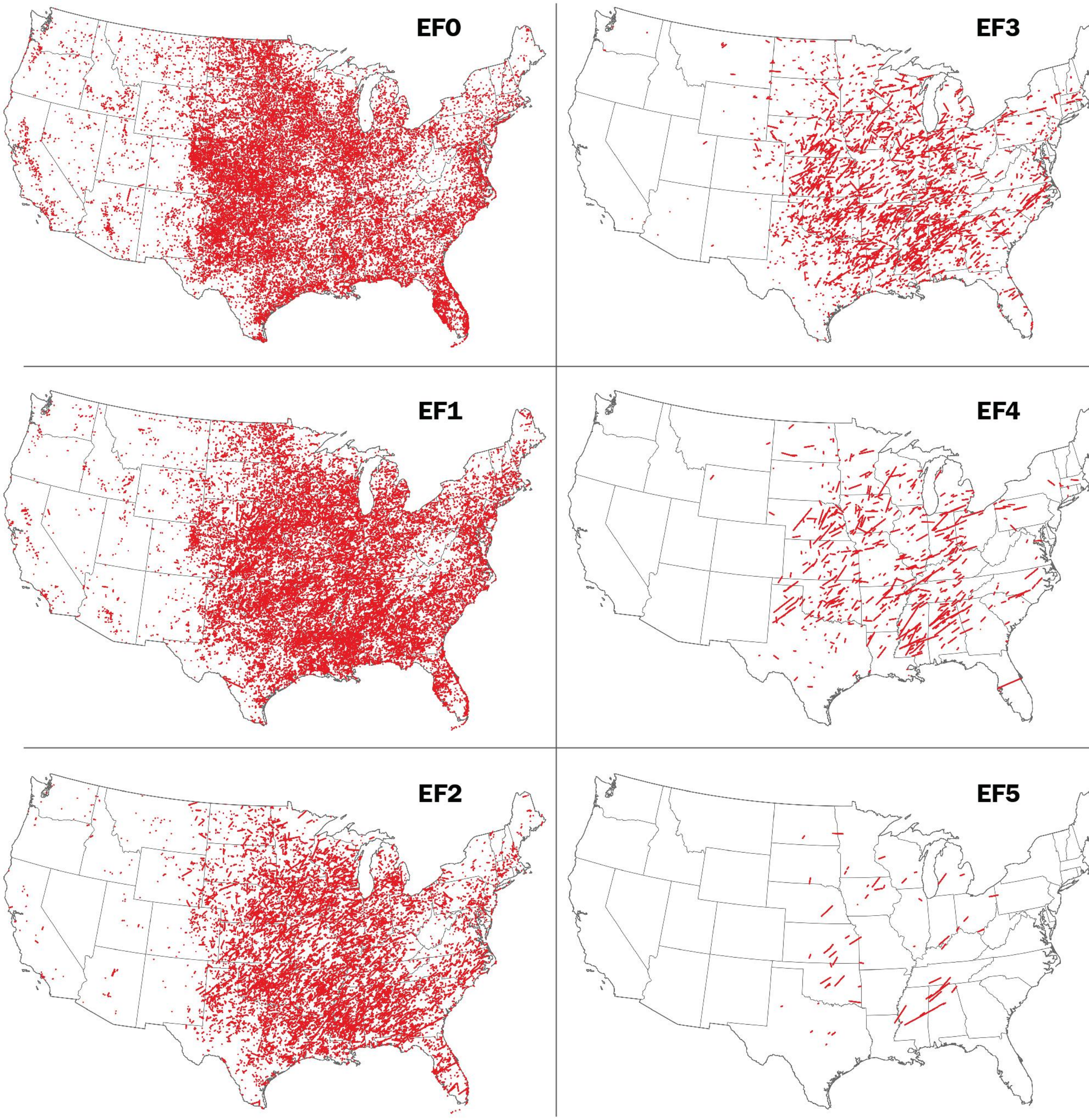


Figure 2. Reported tornadoes in the contiguous United States by EF intensity, from 1950 through 2021. (Data source: NOAA/NWS Storm Prediction Center)

Enhanced Fujita (EF) Scale

The EF Scale is used to classify the intensity of a tornado based on the most intense damage observed along its entire track; the scale ranges from EF0 (weakest) to EF5 (most violent). Windspeed ranges for each of the EF Scale intensity ratings are shown in **Figure 3**, along with information on different levels of residential building damage associated with increasing tornadic wind speeds.

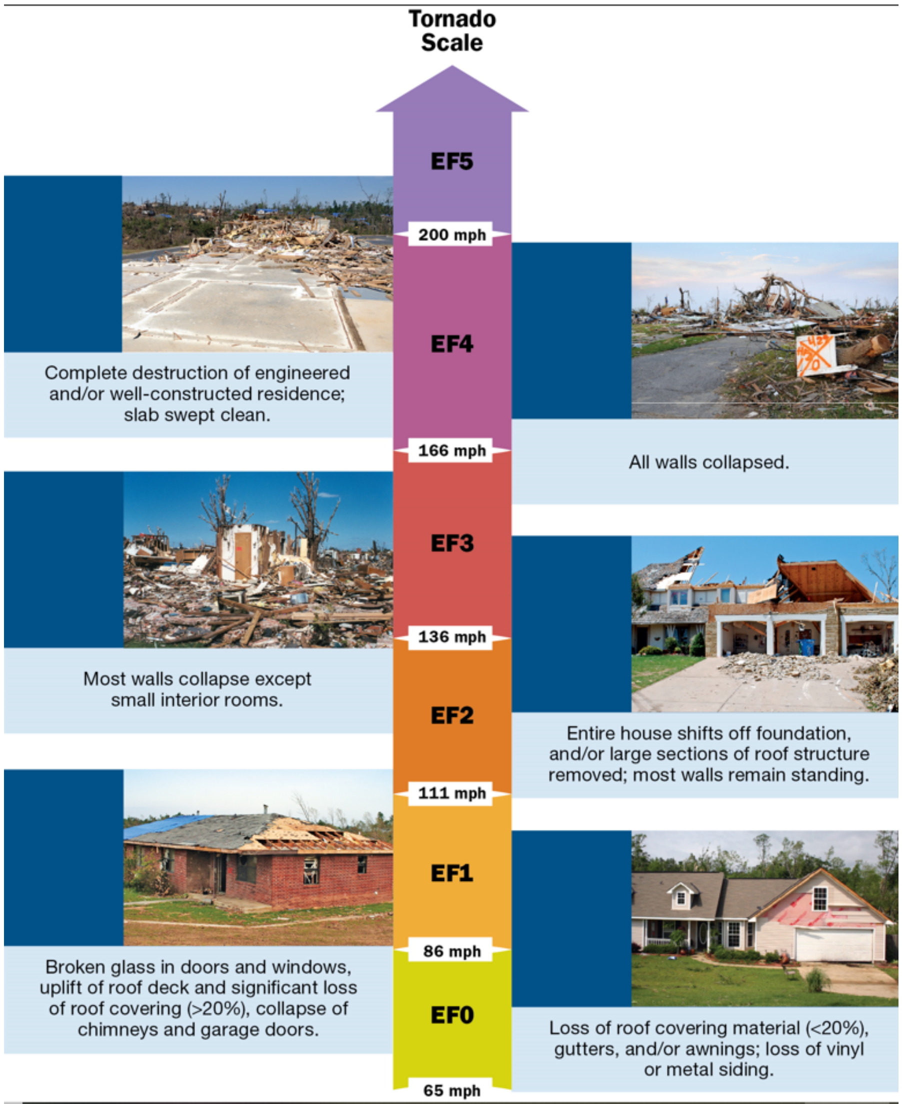


Figure 3. Typical Tornado damage according to the EF Scale (wind speeds are estimated 3-second-gust wind speeds) (Source: FEMA P-320)

This guidance is not applicable to manufactured housing (MH) units or townhouse units. This guidance is intended solely for enhanced building performance to improve resiliency of one- and two-family dwellings from severe windstorms, including tornadoes, thunderstorms and derechos, and does not consider other hazards such as seismic, snow, flood, or any other loads. It should be noted that only storm shelters and safe rooms compliant with the International Code Council (ICC) standard, ICC 500, *Standard for the Design and Construction of Storm Shelters*

(2020a), or FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms* (2021), respectively, provide life safety protection from tornadoes.

The intended users of this fact sheet are residential building designers, homebuilders, and homeowners in the tornado-prone region of the United States. The following guidance is not intended to replace the governing residential building codes but to supplement it with the goal of enhancing building performance during high-wind events. For other building types, the American Society of Civil Engineers (ASCE) standard ASCE 7-22, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, and the forthcoming 2024 International Building Code contain procedures specifically addressing design for tornadoes that apply to certain non-residential facilities such as places of assembly, schools, hospitals, and other critical and essential facilities. For more information, please refer to the Federal Emergency Management Agency (FEMA) / National Institute of Standards and Technology (NIST) guide, *Design Guide for New Tornado Load Requirements in ASCE 7-22* (FEMA/NIST 2023).

Background

According to the National Weather Service, approximately 95 percent of recorded tornadoes have EF Scale intensities ranging from EF0 to EF2, corresponding to windspeeds ranging from 65 to 135 miles per hour (mph) (FEMA, 2021). Even within EF3 to EF5 rated tornadoes, a majority of the wind speeds away from the core of the tornado are in the lower EF Scale range. When a tornado is given an EF rating, it is based on the highest observed damage within the tornado path. For example, an estimated 72 percent of the area within the 2011 EF5 Joplin, Missouri, tornado track experienced EF0 to EF2 winds, but the damage at the most intense centerline of the tornado led to the EF5 rating (NIST 2014). Although the EF0 to EF2 wind speeds can cause damage to residential structures, the damage they cause can often be mitigated by good design and construction practices. More damage to residential structures is observed in tornado-prone regions with low building code adoption and enforcement rates.

This guidance is adapted from existing guidance for high-wind regions. The primary sources referenced are FEMA P-804, *Wind Retrofit Guide for Residential Buildings in the Hurricane-Prone Region* (2023),; Insurance Institute for Business and Home Safety (IBHS) *2020 FORTIFIED Home™ Standard* (2020b); FEMA P-499, *Home Builder's Guide to Coastal Construction* (2010); Appendix G of FEMA P-908, *Mitigation Assessment Team Report – Spring 2011 Tornadoes: April 25-28 and May 22* (2012); Hurricane Harvey in Texas Recovery Advisory No. 2*: Asphalt Shingles Roofing for High-Wind Regions Criteria* (FEMA 2018); and Hurricane Michael in Florida Recovery Advisory No. 2*: Best Practices for Minimizing Wind and Water Infiltration Damage* (FEMA 2019). The guidance in these documents for high-wind resistance, when properly implemented with the applicable building code, should significantly enhance performance for wood-framed, one- and two-family residential structures in tornadoes and other severe windstorms. While these guidance publications are not geared towards tornadic winds, which act differently than the wind mechanisms covered by the aforementioned publications, the code requirements of recent building codes and best practices covered within the publications referenced in this fact sheet can mitigate some of the expected wind damages common with EF0 to EF2 tornadoes.

Improving Building Performance

The International Residential Code (IRC) and associated wind loading provisions in ASCE 7 are considered the minimum wind design requirements for one-and two-family dwellings. The design windspeed for one-and two-family structures located in the tornado-prone region and located outside of the hurricane-prone regions of the Gulf of Mexico and Atlantic Coasts, is typically less than 115 mph. The IRC and the wind loading provisions of ASCE 7 provide a reasonable level of safety, and are not focused on property protection, life-safety protection, or preventing all damage during extreme windstorms. The guidance within this document is intended to provide a higher-level performance than typical residential construction. Designing to a higher performance level and using enhanced residential construction methods and materials common in hurricane-prone regions of the United States can reduce damage from tornadoes, particularly those with an EF2 and lesser intensity.

Improvements to building performance in high-wind events can be achieved by strengthening three important areas: roof and wall construction and coverings (building envelope), openings (e.g., windows and doors), and load path connections. In addition to utilizing products with wind ratings higher than IRC requirements, proper installation of building envelope materials, opening protection systems, and load path improvements are necessary to achieve the intended improved level of performance. This guidance should be utilized for improving performance of these components in new and existing one- and two-family residential structures. Further details are provided for existing construction in FEMA P-804, FEMA P-499, and IBHS's *2020 FORTIFIED Home Standard; a*nd for new construction in the *Wood Frame Construction Manual (WFCM)* published by the American Wood Council (2018), and ICC-600, *Standard for Residential Construction in High Wind Regions* (2020b). These documents reference important product standards for high-wind performance, requirements for opening protection, and details for ensuring a continuous load path.

In addition to the use of products rated for greater than the minimum required windspeeds, adjustments to the design of one- and two-family residential structures can result in improved performance. For new one- and two-family residential structures, a design wind speed of 130 mph (which is typically higher than the minimum design wind speed per code) can reduce the risk of damage when subjected to winds associated with up to an EF2 tornado. Additionally, changing the internal pressure coefficient (GC_{pi}) in design from an Enclosed Building (GC_{pi} = +/- 0.18) to a Partially Enclosed Building (GC_{pi} = +/- 0.55) can reduce the potential for pressurization failures if windows, doors, or garage doors fail from wind-borne debris impacts or high wind pressures. If none of the windows or doors fail and the building remains enclosed, the increased internal pressure coefficient then helps account for the greater internal pressures caused by the atmospheric pressure change (because the low static pressure of the tornado outside the building cannot balance with the internal static pressure as rapidly without any large openings, effectively causing additional positive internal pressure).

Building Envelope Improvements

The building envelope consists of the exterior components of the building such as the roof covering and sheathing, siding materials, and openings such as windows and garage doors. The performance of building envelope components during windstorms depends on the wind rating of the product and its proper installation. Using higher than code-minimum, wind-rated products and following correct installation methods can reduce damage during windstorms.

Roof Coverings

Asphalt shingles are the most common type of roof covering in one- and two- family dwellings. Proper installation of asphalt shingle roofing is crucial in areas prone to high windspeeds and can have a lasting effect on the durability and longevity of roofing systems. Damage to asphalt shingle roof coverings in high-wind events is often caused by either improper installation or a poor shingle seal condition. Understanding the wind-resistance ratings and special installation methods for asphalt shingles is important. Addressing these two issues goes a long way in improving the performance of asphalt shingles in high winds. Figure 4 shows the proper location of fasteners for asphalt shingles.

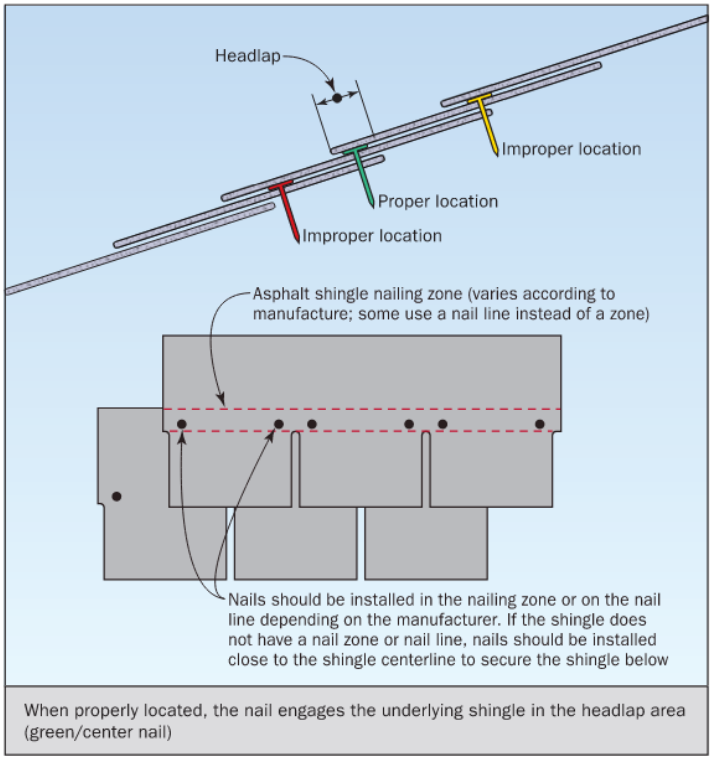


Figure 4. Example of proper installation of asphalt shingles (Source: Hurricane Michael in Florida Recovery Advisory 2)

To reduce wind damage to asphalt shingles, FEMA recommends the use of Class F rated shingles as determined by ASTM International (ASTM) D3161 or Class H rated shingles as determined by ASTM D7158.[1,2] The starter strip should be installed in accordance with the manufacturer's recommendations. The shingles should be installed with six nails.

A sealed roof deck provides additional protective measures to the primary roof covering and is designed to stay in place and keep water from entering the house if the primary roof covering is damaged or lost due to high winds. Tests performed by IBHS have consistently demonstrated that a sealed roof deck significantly reduces water intrusion rates when one of these strategies is employed. Hurricane Michael in Florida Recovery Advisory 2 discusses detailed options to create a sealed roof deck and FEMA P-804 provides guidance on sealed roof decks and FORTIFIED Home 2020 sealed roof deck criteria.

[1] ASTM D3161: *Standard Test Method for Wind Resistance of Steep Slope Roofing Products (Fan-Induced Method)*

[2] ASTM D7158: *Standard Test Method for Wind Resistance of Asphalt Shingles (Uplift Force/Uplift Resistance Method)*

Hail-Resistant Shingles

Another common hazard for roof coverings in some of the tornado-prone regions of the United States is hailstorms. To determine your risk to hailstorms, visit https://hazards.fema.gov/nri/hail. To reduce the potential for damage to asphalt singles from hail, consider the installation of impact-rated asphalt shingles. Impact-rated asphalt shingles should have a Class 4 rating as determined by Underwriters Laboratory (UL) 2218, *Impact Resistance of Prepared Roof Covering Materials*, or Class 4 rating per ANSI/FM 4473, *Test Standard of Impact Resistance of Testing of Rigid Roofing Materials by Impacting with Freezer Ice Balls*.

For more in-depth information on improvement of asphalt roof coverings to wind resistance and sealed roof decks, refer to the following:

- IBHS FORTIFIED Home *Roofing Checklist High Wind & Hail* (https://fortifiedhome.org/wp-content/uploads/re-roofing-checklist_high-wind-hail-2020.pdf?v=1666898416992)
- IBHS FORTIFIED Home *Standard Detail Set High Wind* (https://fortifiedhome.org/wp-content/uploads/2020-FORTIFIED-Home-Standard-Detail-Set-HW-ONLY-v2.pdf?v=1666886854360)
- FEMA's Hurricane Harvey in Texas Recovery Advisory 2: *Asphalt Shingles Roofing for High-Wind Regions* (https://www.fema.gov/sites/default/files/2020-07/mat-report_hurricane-harvey-texas.pdf)[3]
- FEMA's Hurricane Michael in Florida Recovery Advisory 2: *Best Practices for Minimizing Wind and Water Infiltration Damage* (https://www.fema.gov/sites/default/files/2020-07/minimizing-wind-water-damage_hurricane-michael_florida.pdf)
- FEMA P-499, Technical Fact Sheet 7.2, *Roof Underlayment for Asphalt Shingle Roofs* (https://www.fema.gov/sites/default/files/2020-08/fema499_2010_edition.pdf)
- Section 4.1 of FEMA P-804, *Wind Retrofit Guide for Residential Buildings in the Hurricane-Prone Region* (to be published in 2023)

Other common roof coverings include tile and metal. For more in-depth information on tile and metal roofs, refer to the following:

- FEMA P-499, Technical Fact Sheet 7.4, *Tile Roofing for High Wind Regions* (https://www.fema.gov/sites/default/files/2020-08/fema499_2010_edition.pdf)
- FEMA P-499, Technical Fact Sheet 7.6, *Metal Roof Systems in High-Wind Regions* (https://www.fema.gov/sites/default/files/2020-08/fema499_2010_edition.pdf)
- IBHS FORTIFIED Home Technical Bulletin FH 2019-01, *Metal Panel Roof Covering: Guidance and Selection, Installation, and Documentation* (https://fortifiedhome.org/wp-content/uploads/2019-01_technical-bulletin_metal-roof-panel-selection_revised.pdf?v=1666886854360).

Roof Sheathing

Adequate sheathing thickness, fastener spacing, and fastener type are vital to the roof sheathing's performance during high-wind events. Inadequate sheathing thickness, nail size, nail spacing, or installation issues can result in roof sheathing failures that lead to structural and non-structural damage. The loss of even one roof sheathing panel

[3] Hurricane Harvey in Texas Recovery Advisory 2 is located in Appendix C of the Mitigation Assessment Team (MAT) Report.

in a high-wind event can lead to total building failure. Existing roof sheathing should be in good condition, have a minimum thickness of 7/16”, be attached with at least 8d common nails or 8d ring shank nails (ASTM F1667 RSRS-01 2 3/8 x 0.113)[4] spaced at 6 inches on center at panel edges and intermediate supports. For more in-depth information on roof sheathing details and installation, refer to the following:

- Section 4.4 of FEMA P-804, *Wind Retrofit Guide for Residential Buildings in the Hurricane-Prone Region* (to be published in 2023)
- IBHS FORTIFIED Home *Roofing Checklist High Wind & Hail* (https://fortifiedhome.org/wp-content/uploads/re-roofing-checklist_high-wind-hail-2020.pdf?v=1666898416992)
- IBHS FORTIFIED Home *Standard Detail Set High Wind* (https://fortifiedhome.org/wp-content/uploads/2020-FORTIFIED-Home-Standard-Detail-Set-HW-ONLY-v2.pdf?v=1666886854360)
- FEMA P-499, Technical Fact Sheet 7.1, *Roof Sheathing Installation* https://www.fema.gov/sites/default/files/2020-08/fema499_2010_edition.pdf)

Solar Panels

Designers should calculate wind loads on solar panels in accordance with the local building code. FEMA recommends using the most current editions of ASCE 7, the *2020 FORTIFIED Home Standard*, and the Structural Engineers Association of California’s publication SEAOC PV2-2017, *Wind Design for Solar Arrays* (2017) for design considerations, including the key elements summarized below.

Verify the solar panels are designed and installed with the following:

- Sufficient uplift resistance to meet the calculated wind loads.
- Panels and rail/rack systems that have UL 1703, *Standard for Flat-Plate Photovoltaic Modules and Panels*, and UL 2703, *Standard for Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels* listing.
- Double-nutting panel clamp bolts.
- All bolted connections made with a calibrated torque wrench.
- Rigid solar panels over metal standing seam roofs using external seam clamps. External seam clamps are required at every roof deck seam.
- Flexible solar panel modules that are FM Approved for hail or meet FM 4476, *Flexible Photovoltaic Modules*, and include a Severe Hail rating.
- Rigid solar panel modules that are FM Approved for hail or meet FM 4478, *Roof Mounted Rigid Photovoltaic Modules*, and include a Class 4 rating.

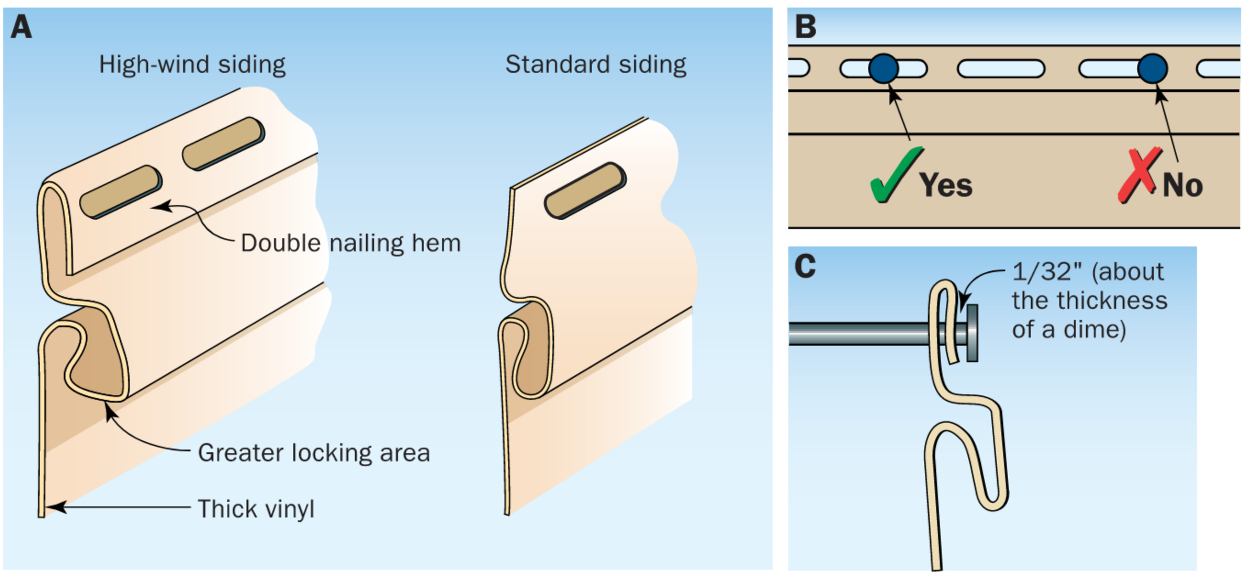
Wind loads on solar panels can be designed per Section 29.4.3 and 29.4.4 of ASCE 7-22.

[4] ASTM F1667: *Standard Specification for Driven Fasteners: Nails, Spikes, and Staples*

Exterior Wall Coverings

Exterior wall coverings are commonly blown off walls or damaged by high winds and can result in water intrusion from wind-driven rain. Providing wall covering systems that are rated for high winds and improving the fastening of the wall covering to the wall sheathing can help to reduce damage and water intrusion during high-wind events.

Vinyl siding can successfully resist high wind speeds when properly specified and installed. **Figure 5** shows (**A**) the difference between high-wind rated vinyl siding and normal vinyl siding, (**B**) the correct location of the nail centered in the nailing slot, and (**C**) the optimum spacing between the nail and the nailing strip to allow for movement. Vinyl siding should meet the requirements of the standard specification for Rigid Poly/Vinyl Chloride (PVC) Siding from the ASTM D3679.[5] Correct attachment of vinyl siding, including the installation of starter strips and utility trim is recommended per IRC Section R703.11.1 and manufacturer installation guidelines.



Sheathing and wall framing are not shown for clarity.

Figure 5. Fastening for high-wind vinyl siding
(Source: FEMA P-499 Technical Fact Sheet 5.3, Siding Installation in High-Wind Regions)

Fiber-cement siding can successfully resist high winds when properly installed. To improve performance of fiber-cement siding and minimize the possibility of wind getting under the unsecured edge of the siding, siding sections should be face nailed through the overlapping board instead of blind nailed (see **Figure 6**). Pieces of siding should end at a stud location, allowing for nails to be installed on each side of the siding butt joint.

[5] ASTM D3679: *Specification for Rigid Poly (Vinyl Chloride) (PVC) Siding*

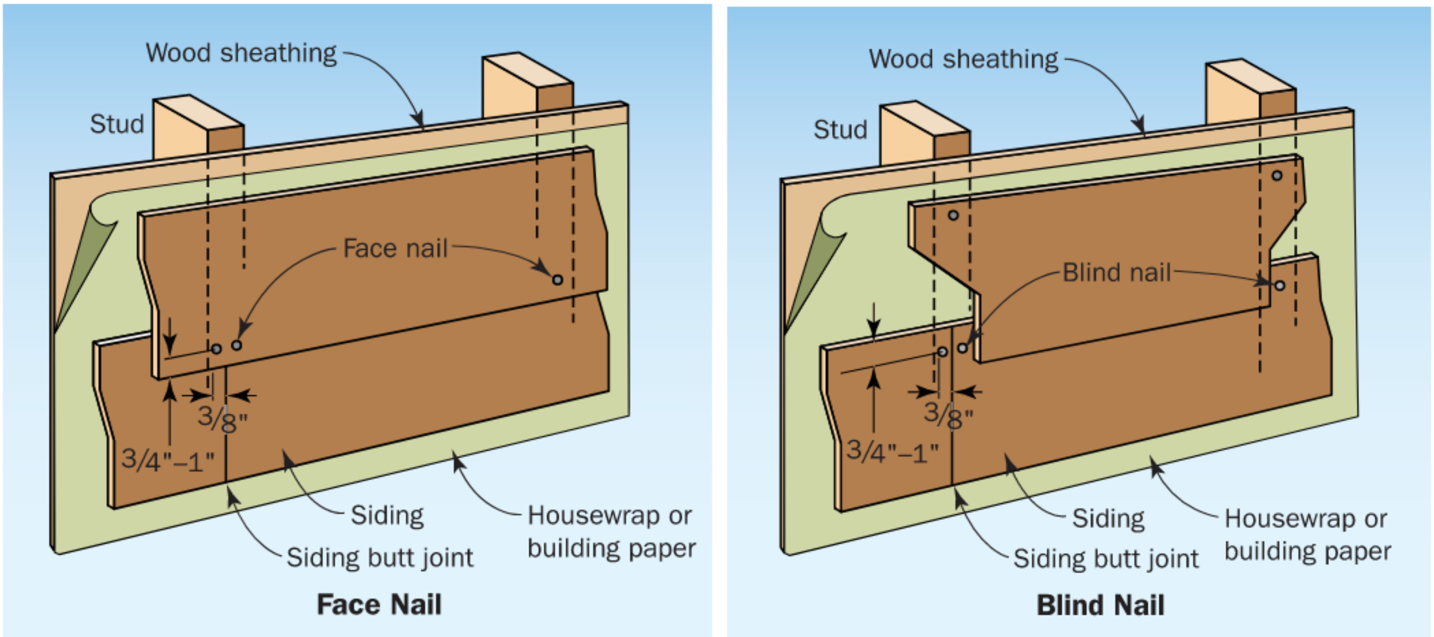


Figure 6. Fastening for fiber cement board (Source: FEMA P-499 Technical Fact Sheet 5.3, Siding Installation in High-Wind Regions)

For more information on vinyl siding and fiber cement siding details and installation, refer to the following:

- FEMA's Hurricane Michael in Florida Recovery Advisory 2: *Best Practices for Minimizing Wind and Water* Infiltration Damage (https://www.fema.gov/sites/default/files/2020-07/minimizing-wind-water-damage_hurricane-michael_florida.pdf)
- FEMA P-499, Technical Fact Sheet 5.3, *Siding Installation in High-Wind Regions* https://www.fema.gov/sites/default/files/2020-08/fema499_2010_edition.pdf)

Brick veneer is another common building envelope finish that is used. Brick veneer can successfully resist high winds when properly installed and is less vulnerable to small wind-borne debris when compared to vinyl or fiber cement siding. For more in-depth information on brick veneer installation, refer to the following:

- FEMA P-499, Technical Fact Sheet 5.4, *Attachment of Brick Veneer in High-Wind Regions* https://www.fema.gov/sites/default/files/2020-08/fema499_2010_edition.pdf)

Openings (Doors and Windows)

The doors and windows of one- and two-family residential structures in tornado-prone regions are vulnerable to high winds and wind-borne debris impacts. The failure of doors and windows can result in increased internal pressures and subsequent failures of the roof and wall elements. For one- and two-family residential structures, opening protection can be achieved by installing impact-resistant coverings, such as shutters or impact-resistant glazing. Shutters are effective for opening protection in hurricane-prone regions due to the comparatively long warning times in advance of a storm. However, tornadoes have a very limited warning time, sometimes less than 5 minutes, leaving insufficient time to install shutters over windows. If a homeowner wants to protect against wind-borne debris from a tornado, impact-resistant glazing offers the best protection. Opening protection will protect against pressurization-induced structural failures and protect the home against water intrusion and debris entry to the interior, both of which can be extremely damaging.

For glazing to be considered impact-resistant it must comply with ASTM E1996[6] and ASTM E1886[7], the Large Missile D. The Florida Building Code Testing Application Standards TAS 201[8] and TAS 203[9] have additional guidelines to provide protection for windows.

For more in-depth information on opening protection and installation, refer to the following:

- FEMA P-499, Technical Fact Sheet 6.2, *Protection of Openings- Shutters and Glazing* (https://www.fema.gov/sites/default/files/2020-08/fema499_2010_edition.pdf)

Garage Doors

Failure of garage doors in attached garages can result in rapid pressurization of the house, potentially leading to failure of roof and wall elements (see **Figure 7** for example). Per the 2021 IRC, garage doors are required to be tested in accordance with either ASTM E330[10] or American National Standards Institute (ANSI) / Door & Access Systems Manufacturers' Association (DASMA) 108[11] and meet the pass/fail criteria of ANSI/DASMA 108. Also, garage doors must be listed and labeled to indicate the door manufacturer, model/series number, positive and negative design wind pressure ratings, installation instruction drawing reference number, and applicable testing standard. The performance of garage doors can be improved by installing enhanced pressure-resistant sectional garage doors. Unless local code requirements are more stringent, a single garage door (opening area of 50 square feet [ft^2]) should resist a minimum design pressure of +23 pounds per square foot (psf)/-25 psf (Zone 4) or -29 psf (Zone 5), and a double garage door (opening area of 100 ft^2) should resist a minimum design pressure of +22 psf/-24 psf (Zone 4) or -27 psf (Zone 5).[12] Certification data must be closely examined to ensure the garage door complies with design wind pressures for the building location. Proper fastening of the garage door

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[6] ASTM E1996: *Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes*

[7] ASTM E1886: *Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials*

[8] TAS 201: *Impact Test Procedures*

[9] TAS 203: *Criteria for Testing Products Subject to Cyclic Wind Pressure*

[10] ASTM E330: *Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference*

[11] ANSI/DASMA 108: *Standard Method for Testing Sectional Garage Doors, Rolling Doors and Flexible Doors: Determination of Structural Performance Under Uniform Static Air Pressure Difference*[12] Based on ASCE 7-16, Exposure B and C, and an ultimate wind speed of 130 mph. Plus sign denotes pressures acting towards the garage surface, and minus sign denotes pressures acting away from the garage surface. Refer to ASCE 7 for identification of Zones 4 and 5.

[12] Based on ASCE 7-16, Exposure B and C, and an ultimate wind speed of 130 mph. Plus sign denotes pressures acting towards the garage surface, and minus sign denotes pressures acting away from the garage surface. Refer to ASCE 7 for identification of Zones 4 and 5.

Figure 7. Loss of roof sections and gable end framing initiated from garage door failure Bowling Green, Kentucky (December 2021)

track is provided in DASMA TDS 156 and 161.[13,14] For more in-depth information on garage door design pressure and impact rating requirements, refer to the following:

- IBHS *2020 FORTIFIED Home Standard* (https://fortifiedhome.org/wp-content/uploads/2020-FORTIFIED-Home-Standard.pdf?v=1666886854360)
- IBHS FORTIFIED Technical Bulleting FH 2021-01, *Garage Door Requirements in the 2020 FORTIFIED Home Standard* (https://FORTIFIEDhome.org/wp-content/uploads/2021-01_technical-bulletin_garage-door-requirements.pdf?v=1672845619105)
- FEMA P-499, Technical Fact Sheet 6.2, *Protection of Openings- Shutters and Glazing* (https://www.fema.gov/sites/default/files/2020-08/fema499_2010_edition.pdf)
- Section 4.2 of FEMA P-804, *Wind Retrofit Guide for Residential Buildings in the Hurricane Prone-Region* (to be published in 2023)
- FEMA 488, *Mitigation Assessment Team Report Hurricane Charley in Florida Observations, Recommendations, and Technical Guidance* (https://www.fema.gov/sites/default/files/2020-08/fema488_mat_report_hurricane_charley_fl.pdf)

Soffits

From FEMA observations post-event, soffits have a long history of damage and poor performance during high-wind events. Loss of soffits can result in pressurization of the attic and subsequent water intrusion into the attic, potentially leading to mold growth in the insulation or ceiling collapse. Keeping the soffit material in place to limit the

[13] DASMA TDS 156: DASMA Technical Data Sheet #156, *Wood Horizontal and Vertical Back Jamb Detail Guidelines*

[14] DASMA TDS 161: DASMA Technical Data Sheet #161, *Connecting Garage Door Jambs to Building Framing*

amount of wind and water intrusion during tornadoes and other high-wind events is imperative. Depending on the design and condition of the existing soffits, panels should either be removed, reinforced and reinstalled, or replaced with new materials. Unless local code requirements are more stringent, soffits should have a minimum pressure rating of +22 psf/-30 psf (for a soffit height of 15 feet) to +26 psf/-35psf (for a soffit height of 35 feet).[15] See FEMA P-804 (to be published in 2023) for recommended soffit retrofits. Because of the common failure of soffits, they are now specifically addressed by the IRC.

For more in-depth information on soffits, refer to the following:

- Section 4.2 of FEMA P-804, *Wind Retrofit Guide for Residential Buildings in the Hurricane-Prone Region* (to be published in 2023)
- FEMA's Hurricane Michael in Florida Recovery Advisory 2, *Best Practices for Minimizing Wind and Water Infiltration Damage* (https://www.fema.gov/sites/default/files/2020-07/minimizing-wind-water-damage_hurricane-michael_florida.pdf)
- IBHS *2020 FORTIFIED Home Standard* (https://fortifiedhome.org/wp-content/uploads/2020-FORTIFIED-Home-Standard.pdf?v=1666886854360)
- FEMA P-499, Technical Fact Sheet 7.5, *Minimizing Water Intrusion Through Roof Vents in High-Wind Regions* (https://www.fema.gov/sites/default/files/2020-08/fema499_2010_edition.pdf)

Load Path

The performance of a building's structural system during a high-wind event depends on whether there is an adequate continuous load path that can transfer loads applied anywhere on the building envelope through the structure to the foundation. If there is not an adequate continuous load path in the building, the loads may cause a failure created by inadequate member capacity and/or inadequate point(s) of connection. FEMA P-499, Technical Fact Sheets No. 4.1, *Load Paths*, and 4.3, *Use of Connectors and Brackets*, provide guidance on the concept of a continuous load path through the house (**Figure 8**). A continuous load path for wind events starts at the roof sheathing, goes through the nailed connection into the roof framing members, through the connection of the roof to the wall system and then down to the foundation. **Figure 9** through **Figure 11** highlight the critical components of the load path. For a design standard on the complete load path, see the WFCM published by the American Wood Council and ICC-600. Additionally, the *2020 FORTIFIED Home Standard* by IBHS provides guidance on constructing a continuous load path for new and existing one- and two-family residential structures. Guidance on specific load path components and connection types are provided below.

Roof-to-Wall Connectors

Each roof truss and rafter should be attached to the framed wall's double top plate with a connector designed to resist the loads for the corresponding roof truss or rafter span and spacing. Several types of connections, specifically designed to resist uplift and/or shear forces, are available from manufacturers. To resist the required load for the

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[15] Based on ASCE 7-16, Exposure B and C, and an ultimate wind speed of 130 mph. Plus sign denotes pressures acting towards the soffit, and minus sign denotes pressures acting away from the soffit. Interpolation of soffit heights between 15 feet and 35 feet is permitted.

system, both the adequate number and proper type of fasteners required by the manufacturer and specified by the engineer for the connection, must be used. Additionally, the wall sheathing is to be nailed to both the studs and top plate. Toe-nailing at roof-to-wall uplift connections should never be relied upon in high-wind areas or when intending to resist the forces associated with a high-wind event.

Sill Plate Attachment

Uplift of the wall system and shear failures at the bottom of the wall typically occur because of a failed sill plate connection or lack of hurricane-straps or structural sheathing connections. The sill plate, or bottom plate, should be attached to the masonry or concrete foundation with anchor bolts and minimum 0.229-inch x 3-inch x 3-inch washers. The size and spacing of the anchor bolts will vary based on the foundation type, size of the structure, and aspect ratio. Table 3.2A of the *Wood Framed Construction Manual (WFCM) for One-and Two-Family Dwelling*s (AWC, 2018) may be referenced for prescribed sill plate to foundation connections based on design wind speed.

Shear Wall Hold Downs

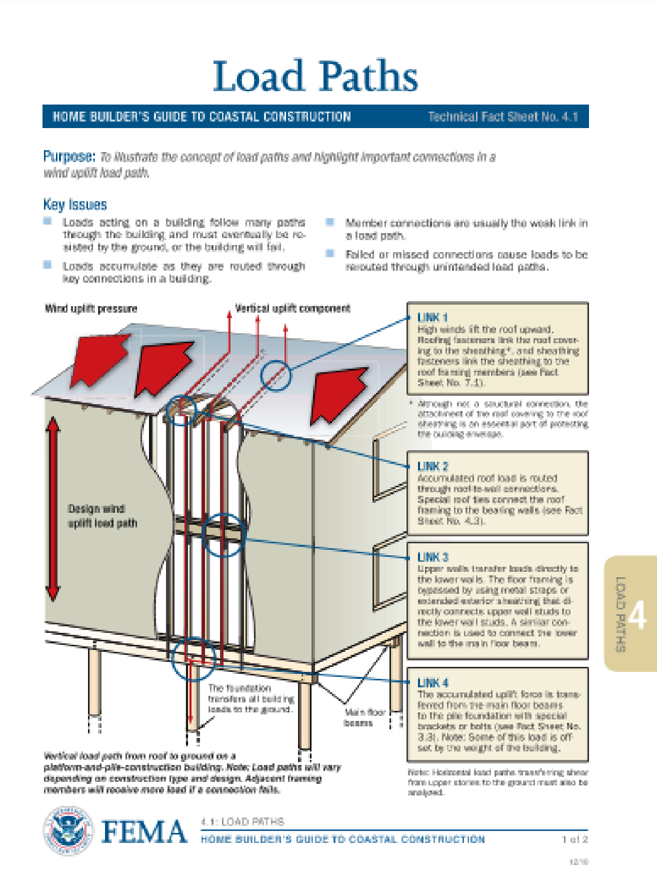
The shear wall hold down anchors will need to transfer the overturning forces from the shear walls to the foundation. Hold down anchors must have sufficient embedment length to adequately transfer the overturning tensile forces. For a complete load path, the loads from the anchor must be taken all the way to the foundation. Reference Table 3.17F of the WFCM for a prescriptive method for sizing shear wall hold downs.

Wall Sheathing

All framed walls should be continuously sheathed with wood structural panels. The primary wood structural panel sheathing options are oriented strand board (OSB) and plywood. When metal connectors are used in the load path, either install connectors on the inside of the framing (opposite face from the wall sheathing) or install the metal connectors on the outside over the wall sheathing in order to prevent the connectors from being perforated by nailing of the sheathing. If the metal connector is installed outside the wall sheathing, a longer nail will be required to provide the same embedment length into the wall framing. To avoid potential rolling of the top plate, if the roof to top plate connector is placed on the inside of the wall, ensure that a top plate to stud connector is also placed on the inside of the wall.

Wall Above to Wall Below Connections

To improve lateral load and uplift load continuity, the wood wall sheathing panels should be extended upward from the first-floor walls and downward from the second-floor walls and nailed to the rim/band joist. In addition, metal connectors should extend from lower floor wall framing, across the floor framing above, and to the upper floor wall framing.



Load Paths

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION — Technical Fact Sheet No. 4.1

Purpose: *To illustrate the concept of load paths and highlight important connections in a wind uplift load path.*

Key Issues

- Loads acting on a building follow many paths through the building and must eventually be resisted by the ground, or the building will fail.
- Loads accumulate as they are routed through key connections in a building.
- Member connections are usually the weak link in a load path.
- Failed or missed connections cause loads to be rerouted through unintended load paths.

Vertical load path from roof to ground on a platform-and-pile-construction building. Note: Load paths will vary depending on construction type and design. Adjacent framing members will receive more load if a connection fails.

Note: Horizontal load paths transferring shear from upper stories to the ground must also be analyzed.

LOAD PATHS 4

FEMA — 4.1: LOAD PATHS — HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION — 1 of 2

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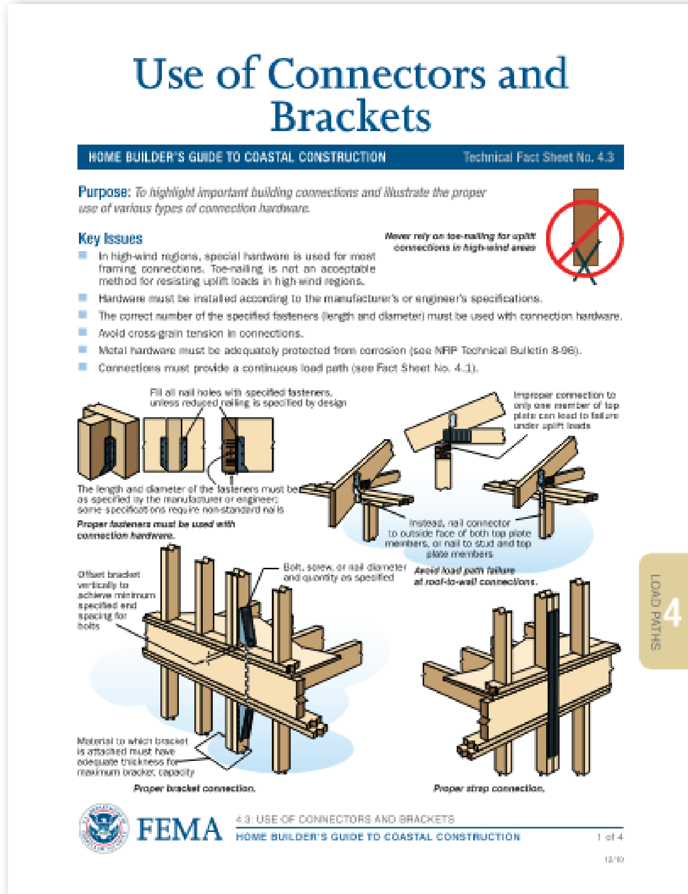

Use of Connectors and Brackets

HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION — Technical Fact Sheet No. 4.3

Purpose: *To highlight important building connections and illustrate the proper use of various types of connection hardware.*

Key Issues

- In high-wind regions, special hardware is used for most framing connections. Toe-nailing is not an acceptable method for resisting uplift loads in high-wind regions.
- Hardware must be installed according to the manufacturer's or engineer's specifications.
- The correct number of the specified fasteners (length and diameter) must be used with connection hardware.
- Avoid cross-grain tension in connections.
- Metal hardware must be adequately protected from corrosion (see NFIP Technical Bulletin 8-96).
- Connections must provide a continuous load path (see Fact Sheet No. 4.1).

LOAD PATHS 4

FEMA — 4.3: USE OF CONNECTORS AND BRACKETS — HOME BUILDER'S GUIDE TO COASTAL CONSTRUCTION — 1 of 4

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Figure 8. FEMA P-499 Technical Fact Sheets No. 4.1, *Load Paths* and No. 4.3, *Use of Connectors and Brackets* (Source: FEMA P-804)

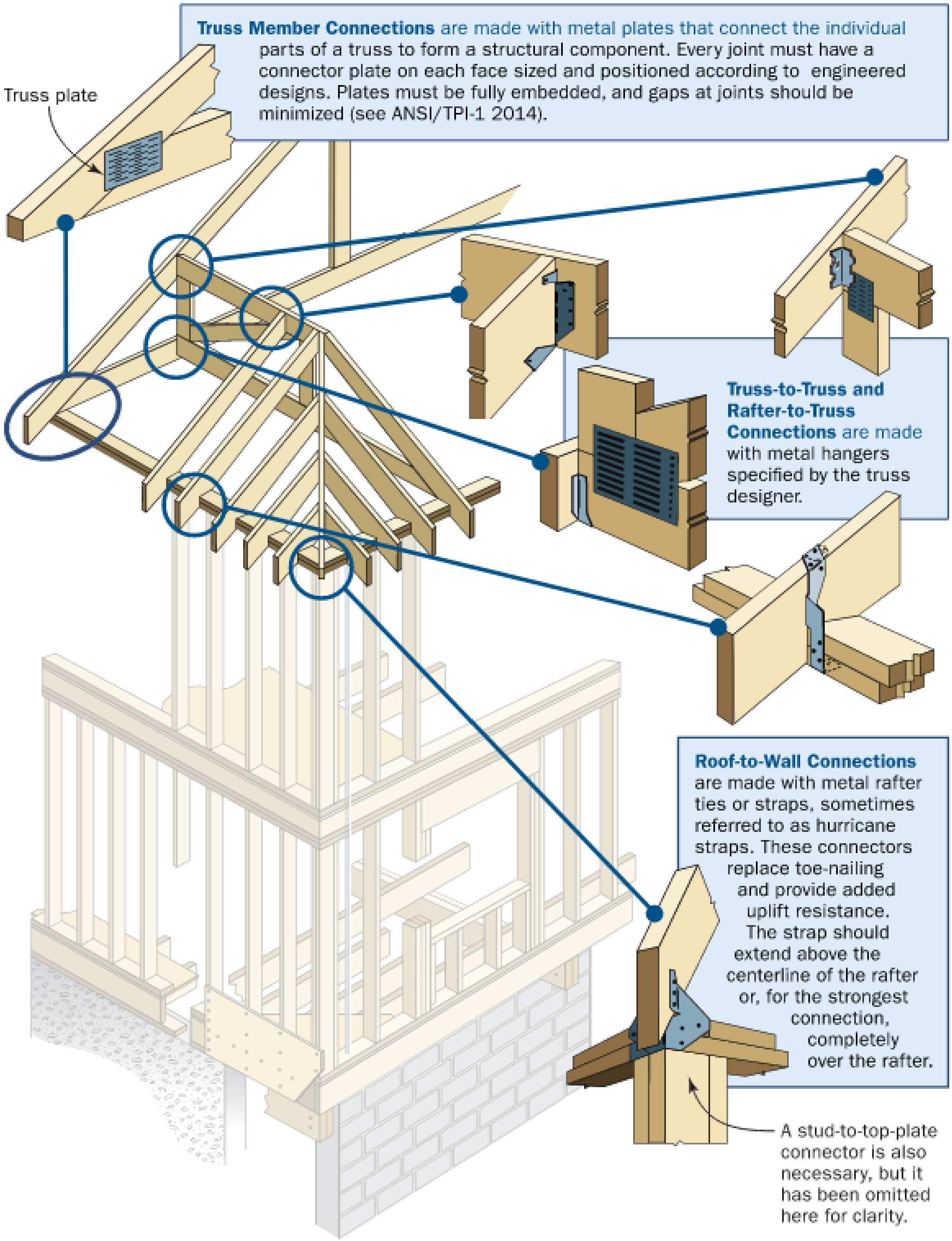

Figure 9. Load path connections of a roof system (Source: Modified from FEMA P-804)

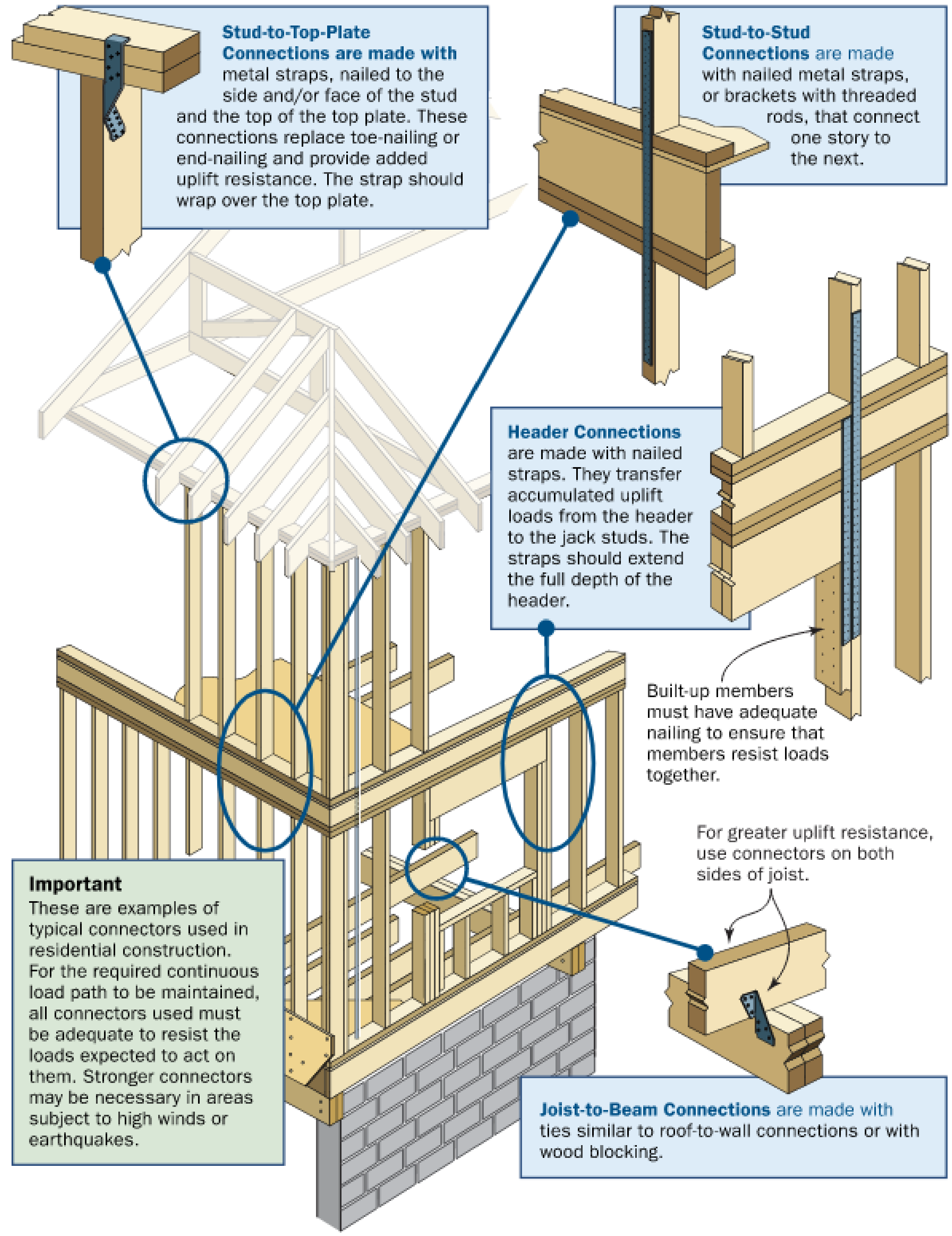

Figure 10. Load path connections of a wall system (Source: Modified from FEMA P-804)

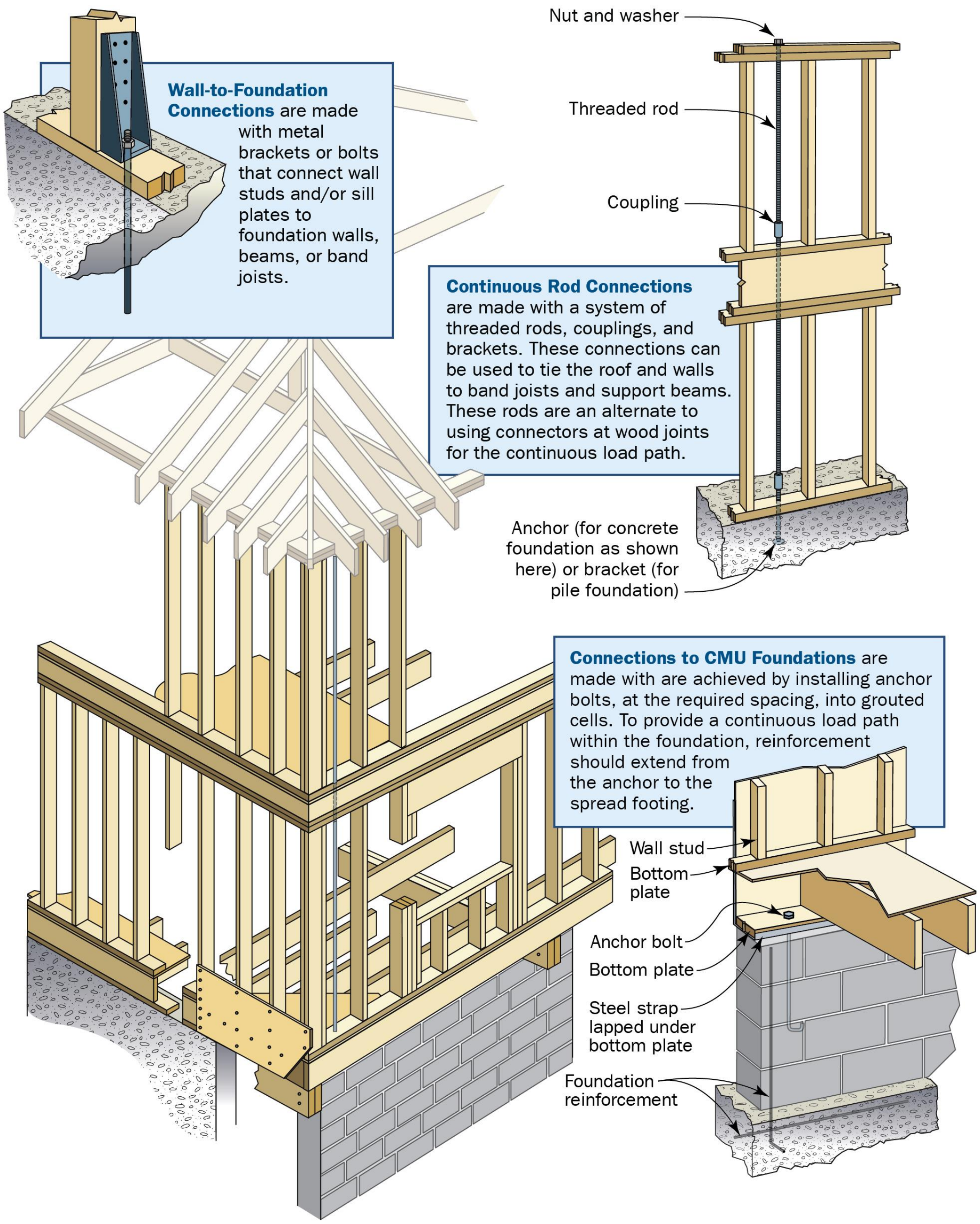

Figure 11. Load path connections of a foundation (Source: Modified from FEMA P-804)

For more in-depth information on continuous load paths, refer to the following:

- Section 4.3.4 of FEMA P-804, *Wind Retrofit Guide for Residential Buildings in the Hurricane-Prone Region* (to be published in 2023)
- IBHS *2020 FORTIFIED Home Standard* (https://fortifiedhome.org/wp-content/uploads/2020-FORTIFIED-Home-Standard.pdf?v=1666886854360)
- FEMA P-499, Technical Fact Sheet 4.1, *Load Paths* (https://www.fema.gov/sites/default/files/2020-08/fema499_2010_edition.pdf)

- FEMA P-499, Technical Fact Sheet 4.3, *Use of Connectors and Brackets* (https://www.fema.gov/sites/default/files/2020-08/fema499_2010_edition.pdf)
- *Wood Frame Construction Manual (WFCM)* (https://awc.org/publications/2018-wfcm/)
- ICC-600, *Standard for Residential Construction in High-Wind Regions* (https://codes.iccsafe.org/content/ICC6002020P1)

Gable Wall Bracing

One of the weakest locations in a residential structure is a platform gable end wall section that is more than 3 feet tall. The weakness is caused by one or more of the following conditions: 1) non-structural sheathing is used; 2) the gable end wall framing is subjected to weak axis bending; or 3) there is an insufficient connection of the gable end to the wall framing below, resulting in a weak horizontal joint at the ceiling level. FEMA P-804 (to be published in 2023) Section 4.2.3 provides best practices for gable end wall bracing.

For more in-depth information on strengthening gable ends, refer to the following:

- Section 4.2.3 of FEMA P-804, *Wind Retrofit Guide for Residential Buildings in the Hurricane-Prone Region* (to be published in 2023)
- IBHS *2020 Fortified Home Standard* (https://fortifiedhome.org/wp-content/uploads/2020-FORTIFIED-Home-Standard.pdf?v=1666886854360)

References

American Wood Council (AWC). 2018 *Wood Framed Construction Manual (WFCM) for One-and Two-Family Dwellings*, ANSI/AWC NDS. Leesburg, VA. https://awc.org/publications/2018-wfcm/.

ASCE (American Society of Civil Engineers). 2016. *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-16).ASCE Standard ASCE/SEI 7-16.

ASCE. 2022. *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-22). ASCE Standard ASCE/SEI 7-22.

FEMA (Federal Emergency Management Agency). 2005. *Mitigation Assessment Team Report Hurricane Charley in Florida Observations, Recommendations, and Technical Guidance*. (FEMA 488). https://www.fema.gov/sites/default/files/2020-08/fema488_mat_report_hurricane_charley_fl.pdf.

FEMA. 2010. *Home Builder's Guide to Coastal Construction*. (FEMA P-499). https://www.fema.gov/sites/default/files/2020-08/fema499_2010_edition.pdf.

FEMA. 2012. *Mitigation Assessment Team Report Spring 2011 Tornadoes: April 25-28 and May 22 Building Performance Observations, Recommendations, and Technical Guidance*. (FEMA P-908). https://www.fema.gov/sites/default/files/documents/fema_p_908_tornado_mat_combined_0.pdf.

FEMA. 2019. *Mitigation Assessment Team Report Hurricane Harvey in Texas Building Performance Observations, Recommendations, and Technical Guidance*. (FEMA P-2022). https://www.fema.gov/sites/default/files/2020-07/mat-report_hurricane-harvey-texas.pdf.

- Hurricane Harvey in Texas Recovery Advisory No. 2: *Asphalt Shingles Roofing for High-Wind Regions Criteria*

FEMA. 2020. *Mitigation Assessment Team Report Hurricane Michael in Florida Building Performance Observations, Recommendations, and Technical Guidance*. (FEMA P-2077). https://www.fema.gov/sites/default/files/2020-07/mat-report_hurricane-michael_florida.pdf.

- Hurricane Michael in Florida Recovery Advisory No. 2: *Best Practices for Minimizing Wind and Water Infiltration Damage*

FEMA. 2021. *Design and Construction Guidance for Community Safe Rooms*. (FEMA P-361). April 2021, 4th Edition. https://www.fema.gov/sites/default/files/documents/fema_safe-rooms-for-tornadoes-and-hurricanes_p-361.pdf.

FEMA. 2023. *Wind Retrofit Guide for Residential Buildings in the Hurricane-Prone Region*. (FEMA P-804).

FEMA/NIST (Federal Emergency Management Agency / National Institute of Standards and Technology). To be published 2023. *Design Guide for New Tornado Load Requirements in ASCE 7-22*.

IBHS. 2020a. 2020 FORTIFIED Home *Roofing Checklist High Wind & Hail*. https://fortifiedhome.org/wp-content/uploads/re-roofing-checklist_high-wind-hail-2020.pdf?v=1666898416992

IBHS. 2020b. *2020 FORTIFIED Home Standard*. https://fortifiedhome.org/wp-content/uploads/2020-FORTIFIED-Home-Standard.pdf.

IBHS. 2020c. 2020 FORTIFIED Home *Standard Detail Set High Wind.* https://fortifiedhome.org/wp-content/uploads/2020-FORTIFIED-Home-Standard-Detail-Set-HW-ONLY-v2.pdf?v=1666886854360.

IBHS. 2020d. 2020 FORTIFIED Technical Bulletin FH 2019-01, *Metal Panel Roof Covering: Guidance and Selection, Installation, and Documentation*. https://fortifiedhome.org/wp-content/uploads/2019-01_technical-bulletin_metal-roof-panel-selection_revised.pdf?v=1666886854360.

IBHS. 2021. FORTIFIED Technical Bulletin FH 2021-01, *Garage Door Requirements in the 2020 FORTIFIED Home Standard*. https://FORTIFIEDhome.org/wp-content/uploads/2021-01_technical-bulletin_garage-door-requirements.pdf?v=1672845619105.

ICC. 2020a. *ICC/NSSA Standard for the Design and Construction of Storm Shelters*. (ICC 500), 2020. https://codes.iccsafe.org/content/ICC5002020P1.

ICC. 2020b. *Standard for Residential Construction in High-Wind Regions*. (ICC 600), ICC. 2009–2024. Country Club Hills, IL. Public access available at https://codes.iccsafe.org/content/ICC6002020P1.

ICC. 2024. *International Building Code (IBC)*, ICC. 2009–2024. Country Club Hills, IL. Public access available at https://codes.iccsafe.org/codes/standards/icc-standards.

ICC. 2024. *International Residential Code (IRC) for One-and Two-Family Dwellings*, ICC. 2009–2024. Country Club Hills, IL. Public access available at https://codes.iccsafe.org/codes/standards/icc-standards.

NIST (National Institute of Standards and Technology). 2014."Final report: NIST technical investigation of the May 22, 2011, tornado in Joplin Missouri." https://doi.org/10.6028/NIST.NCSTAR.3.

Structural Engineers Association of California. 2017. *Wind Design for Solar Arrays*. (SEAOC PV2-2017).

DISCLAIMER– The policy of NIST is to use the International System of Units in all publications. However, in this document, units are presented in the system prevalent in the relevant discipline. Unit conversions are provided below.

Unit Conversions

1 mph = 0.447 m/s, 1 in = 2.54 cm, 1 ft = 0.3048 m, 1 ft^2 = 0.0929 m^2, 1 psf = 47.88 N/m^2

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