Essential Facilities Located in Tornado-Prone Regions: Recommendations for Facility Owners

Recovery Advisory 1, February 2023

Purpose and Intended Audience

The December 2021 tornadoes that struck Kentucky and surrounding states highlighted the importance of assessing and mitigating the extreme-wind vulnerability of existing essential facilities and improving the tornado damage resistance of new essential facilities. In addition to widespread property damage, the tornado outbreak resulted in numerous injuries and deaths, demonstrating the importance of providing easily accessible tornado storm shelters or safe rooms to ensure life-safety protection for the occupants of essential facilities.

Essential Facilities

ASCE 7-22, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE/SEI, 2021), and the forthcoming 2024 International Building Code (IBC) define “essential facilities” as “buildings and other structures that are intended to remain operational in the event of extreme environmental loading from flood, wind, tornado, snow, or earthquakes.” Previous editions of ASCE 7 and IBC define “essential facilities” with the same language but don’t include “tornado” because a tornado load determination had not yet been addressed until the publication of ASCE 7-22 and its forthcoming reference by the 2024 IBC (will be first edition to do so).

The purpose of this advisory is to inform essential facility owners, operators, and planners of ways to improve the tornado performance of their existing or new essential facilities and how to reduce loss of functionality of the facility during and after a tornado. With this awareness, they are encouraged to initiate discussions with their design teams to develop options, costs, and recommendations as well as organizational leadership to facilitate requesting and budgeting for the resources needed to implement the recommended or decided upon improvements. The advisory also provides information on providing life-safety protection with an International Code Council (ICC)/National Storm Shelter Association (NSSA) standard ICC 500, *Standard for the Design and Construction of Storm Shelters* (2020)-compliant storm shelter or FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes* (2021)-compliant safe room.

FEMA

This Recovery Advisory Addresses:

- Design Criteria Overview
- Existing Buildings
- New Buildings and Additions to Existing Buildings
- Useful Links and Resources

Design Criteria Overview

Design criteria for all types of buildings are provided in ASCE 7 and the IBC and vary with assigned risk category and geographic location. The IBC references the ASCE 7 standard for loading criteria.

Risk Categories and Location

The risk category of any new building (or other structure) is assigned based on use or occupancy and dictates the minimum environmental loads that it must be designed to resist. The higher the risk category, the greater the design load requirements. All "essential facilities" are the highest designation, Risk Category IV (see definition in page 1 textbox). Designing (and constructing) facilities to resist greater environmental loads results in stronger, more hazard-resistant facilities and provides stakeholders with more confidence that the building will remain operational if subjected to extreme loads.

Minimum environmental design loads are also a function of geographic location, so ASCE 7 (and the IBC through reference to ASCE 7) provides maps for determination of location-specific design criteria needed to develop the minimum loads. For non-tornadic design wind speeds (e.g., straight-line wind, thunderstorms, hurricanes), ASCE 7-16 and ASCE 7-22 include basic wind speed maps for all four risk categories. For example, in Mayfield, KY, the 2018 and 2021 IBC basic wind speeds (based on ASCE 7-16)[1] for Risk Category II, III, and IV are 106 miles per hour (mph), 113 mph, and 117 mph, respectively.

The most recent edition of ASCE 7 includes a different set of maps and procedures that have been developed to address the effects of tornadoes. New tornado load provisions in the 2024 IBC will reference Chapter 32 (Tornado Loads) of ASCE 7-22 and be required to be evaluated for the design of Risk Category III and IV buildings only. Like the basic wind speed maps, the tornado speed maps are based on assigned risk category and geographic location. Because tornadoes impact relatively small geographic areas (e.g., when compared to hurricanes), the new tornado speed maps also consider the facility's effective plan area, as described in the FEMA/National Institute of Standards and Technology (NIST), *Design Guide for New Tornado Load Requirements in ASCE 7-22* (2023).

Although ASCE 7 and the IBC provide consistent definitions for essential facilities and consistent reliability objectives for Risk Categories I–IV, IBC Table 1604.5, *Risk Category of Buildings and Other Structures*, includes a non-exhaustive list of specific facility types or occupancies for each risk category. So, while the IBC lists certain facility types that must be assigned to a risk category (at a minimum), any building that is intended to remain operational during or immediately following extreme environmental loading should be designed to meet or exceed Risk Category

[1] Wind speeds according to ASCE Hazard Tool available at https://asce7hazardtool.online/.

IV requirements. In other words, if the building owner's (or stakeholder's) performance objective for their facility is to remain operational during or immediately following extreme environmental events, then they should request and fund the design to meet or exceed the minimum requirements for a Risk Category IV structure, regardless of whether the provisions of IBC Section 1604.5 are triggered or not. Although enhanced design will enable greater resistance to the indicated environmental loads, factors outside the building design (e.g., operations, maintenance, local infrastructure) will also affect its capacity to remain operational.

Windborne Debris Criteria

Aside from increased wind pressures, extreme-wind events can damage buildings when windborne debris impacts a building. When debris penetrates the exterior of a building, it can endanger occupants, allow rainwater to enter the building, and cause further damage by increasing pressures on roofs and walls. Post-event observations and subsequent research have demonstrated that windborne debris hazards are greater for tornadoes than for hurricanes with similar wind speeds. Figure 1 shows an example of a police station, an essential facility in Mayfield, KY, that performed well structurally but suffered extensive damage from windborne debris.

Figure 1: Mayfield, KY Police Station – Concrete building performed well structurally, but glazing failed in many locations; 75 people took shelter in the basement and communications were lost. Top left: Before tornado (Source: Google Earth Pro, www.google.com/earth/ [used with license, accessed January 2023]); Top right: After tornado; note damaged glazing boarded up along front of building. Bottom: After tornado; interior damage.

GLAZED OPENING PROTECTION CRITERIA

ASCE 7 and the IBC have long included requirements to protect glazed openings (e.g., windows and skylights) of buildings in the Windborne Debris Regions (WBDR) along the Atlantic Ocean and Gulf of Mexico coasts, Hawaii, and

U.S. island territories (see ASCE 7-22, Section 26.12.3 for more information). The glazing must either be impact resistant or protected by an impact-protective system that has been demonstrated to comply with standards ASTM E1996 and ASTME1886 (see Resources section for more information). Until the 2022 edition, ASCE 7 requirements only addressed protecting glazing from windborne debris associated with hurricanes.

Where design for tornado loads is required by ASCE 7-22, glazed openings in essential facilities must be protected in accordance with Section 32.12.3 as described in the FEMA Design Guide, *New Tornado Load Requirements in ASCE 7-22.* The tornado missile impact criteria align with requirements for essential facilities located in the WBDR as shown in Table 1, which also shows missile impact criteria for storm shelters and safe rooms.

Table 1: Missile Impact Criteria

Facility Type	Standard Reference	Missile Impact Speed (mph)	Large Missile Specimen	Momentum at Impact ($lb_f s^{-1}$)
Tornado Missile Testing Requirements				
Tornado storm shelters & safe rooms	ICC 500-2020 (Sec.305.1.1)	100 (maximum) 80 (minimum)	15# 2x4 15# 2x4	69 55
Essential Facilities where design for tornado loads is required	ASCE 7-22 (Sec.32.12.3)	55 (maximum) 34 (minimum)	9# 2x4 9# 2x4	23 14
Hurricane Missile Testing Requirements				
Hurricane storm shelters & safe rooms	ICC 500-2020 (Sec.305.1.2)	118 (maximum) 80 (minimum)	9# 2x4 9# 2x4	53 33
Essential Facilities located in the Windborne Debris Region	ASCE 7-22 (Sec.26.12.3)	55 (maximum) 34 (minimum)	9# 2x4 9# 2x4	23 14

Notes:
ICC 500 missile impact speeds shown apply to vertical surfaces.
$lb_f s^{-1}$ = pound (force) per second
mph = miles per hour

Existing Buildings

Existing essential facilities should be assessed for wind vulnerabilities and for best available refuge areas (BARAs) where storm shelters and safe rooms are not provided as described below.

Vulnerability Assessments

FEMA recommends owners, operators, and planners of existing essential facilities in tornado-prone regions engage their design team (or registered design professionals with relevant experience) to conduct wind vulnerability assessments as described in FEMA P-2062, *Guidelines for Wind Vulnerability Assessments of Critical Facilities* (2019).

Per Section 2.5 of FEMA P-2062, the assessment process consists of the following six steps (with a modification indicated for Step 3 for the tornado hazard addressed by this RA):

1. Determine the performance expectations (Section 2.4)
2. Perform a Level 1 assessment, which is conducted to address the general condition, remaining service life, and resistance of the various building elements and systems (Section 2.5.1)
3. (Modified) Perform a Level 2 assessment if buildings are in locations where the current basic wind speed is greater than 120 mph for Risk Category IV buildings or $V_t \geq$ 60 mph on the ASCE 7-22 tornado risk maps, and the Level 1 assessment reveals that a given system has several more years of useful service life (Section 2.5.1)
4. Conduct the analysis (Section 2.5.2)
5. Prepare a report (Section 2.5.3)
6. Identify and prioritize any mitigation that is needed based on the assessment results (Section 2.5.4)

A thorough wind vulnerability assessment is intended to identify all significant wind and wind-driven rain vulnerabilities (i.e., those vulnerabilities that could adversely affect building operations). The results of a thorough assessment can be used by building owners, operators, and design professionals; decision makers, entities that award mitigation grants; and state, local, tribal, and territorial government agencies developing mitigation plans.

Many existing essential facilities pre-date current design criteria described in the first section of this Recovery Advisory and, upon assessment, may be determined to be poor candidates for wind retrofitting. In such cases, the permanent relocation of occupants may prove to be the more cost-effective approach for obtaining a facility that provides the desired level of protection and performance.

Best Available Refuge Areas

The term “best available refuge area” or BARA refers to a building area (or areas) that has been determined to be the least vulnerable to the life-threatening effects of extreme-wind events relative to other building areas. FEMA recommends that a storm shelter or safe room be built or installed for occupants of facilities in regions of the United States at high risk for tornadoes. The BARA should be regarded as an interim measure only until a storm shelter or safe room is made available to the building occupants. FEMA also recommends that BARAs be identified by a registered design professional familiar with the methodology and procedures. Findings from investigations of past tornadoes show that many critical facilities contain rooms or areas that may afford some degree of protection from most tornadoes. Because these areas were not specifically designed as tornado storm shelters or safe rooms, their occupants could be injured or killed during a tornado. However, people in BARAs are less likely to be injured or killed than people in other areas of the same building.

FEMA P-431, *Tornado Protection: Selecting Refuge Areas in Buildings* (2009), provides guidance for selecting BARAs for tornadoes and hurricanes. Although an update to the 2009 version of FEMA P-431 is in-progress, an updated “Best Available Refuge Area Checklist” was published in 2017 as an Appendix to the 2009 FEMA P-431. Both documents can be found at https://www.fema.gov/emergency-managers/risk-management/safe-rooms/resources. FEMA developed the BARA checklist to use in assessing a building’s susceptibility to damage from extreme-wind events, such as tornadoes and hurricanes. The checklist evaluation process guides registered design professionals (architects and engineers) in identifying potential refuge areas at a site with one or more buildings. The checklist consists of questions pertaining to structural and non-structural characteristics of a facility and are designed to help identify structural and non-structural vulnerabilities to wind-induced damage based on typical building failures. Depending on the type and degree of deficiency, the BARA evaluation may indicate that no part of the structure is suitable to serve as a refuge area. The BARA checklist is not a substitute for a detailed engineering analysis but can assist in selecting building areas best suited to serve as refuge areas.

Retrofitting or Adding an ICC-500 Storm Shelter or FEMA P-361 Safe Room

ICC 500-compliant storm shelters or FEMA P-361-compliant safe rooms are the only way to ensure life-safety protection for the occupants of essential facilities during tornadoes. The most cost-effective way to design and construct a safe room is to include it in a new building (refer to next section of this Recovery Advisory). The cost of retrofitting an existing building (or a portion thereof) is higher because of the additional design and construction constraints presented or required to overcome by existing conditions. These constraints or conditions can effectively require complete dismantling of an existing building area (tear down walls, dig up foundation) and replace it with new construction to meet the requirements for a storm shelter or safe room design that complies with ICC 500 or FEMA P-361, respectively. Another option is to install a storm shelter or safe room (prefabricated or site-built) outside of the footprint of the existing building (but within the appropriate travel distance[2] for the intended population). For this option, the risk to occupants from windborne debris potentially striking them as they leave the host building during a storm to access the storm shelter or safe room is an important consideration. Land acquisition costs may also be an issue. For additions to existing buildings, refer to the next section of this advisory.

[2] Please refer to FEMA P-361, Section B4.2.2.6 for guidance on occupant travel times to tornado safe rooms.

New Buildings and Additions to Existing Buildings

For new essential facilities or additions to essential facilities in areas prone to tornadoes, facility owners, operators, and planners should work with their design team to minimize facility vulnerabilities to tornado damage, improve operational resilience, and consider options for including safe rooms or storm shelters to protect building occupants. Performance improvements can be accomplished by leveraging new tornado design criteria available in ASCE 7-22 and/or applying best practices described in this advisory.

Storm Shelters and Safe Rooms

Tornado storm shelters and safe rooms are specifically designed for life-safety protection during strong and violent tornadoes. Although some may use the terms “safe room” and “storm shelter” interchangeably, they are different. To distinguish between the two, “storm shelters” meet the requirements in the ICC 500 standard while “safe rooms” meet the requirements in the ICC 500 standard and the more stringent FEMA Funding Criteria of FEMA P-361. Based on field investigation and research, FEMA believes these Funding Criteria are necessary to provide near-absolute life safety protection during extreme-wind events.

Multi-Use of Safe Rooms

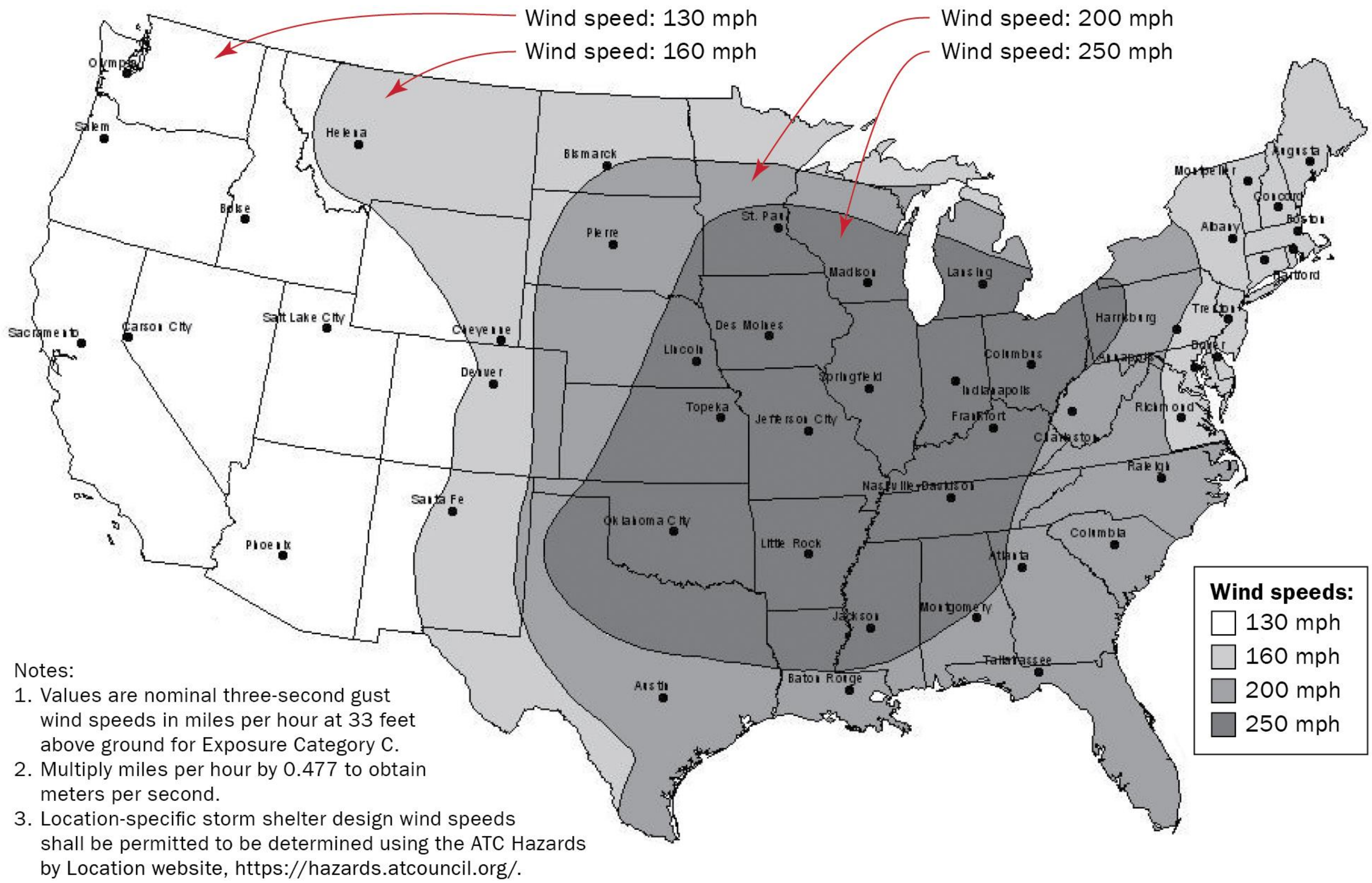
Essential facility storm shelters and safe rooms are typically multi-use, meaning that during normal times, the space may function as a training room, restroom, locker room, or other such purpose. They may also be sited in areas of essential facilities that must remain operational during tornadoes, such as an Emergency Operations Center.

FEMA Hazard Mitigation Assistance (HMA) Funds

The FEMA *Hazard Mitigation Assistance Guidance* is updated periodically. For information on FEMA grant programs and safe room eligibility, as well as how this guidance handles safe rooms also intended to be used after an event as recovery shelters, download the most current HMA policy and HMA Guidance and Addendum from https://www.fema.gov/grants/mitigation/hazard-mitigation-assistance-guidance.

Since the 2015 edition, Section 423 of the IBC, requires ICC 500-compliant storm shelters for the following new essential facility buildings constructed in the 250-mph tornado shelter design wind speed zone (see Figure 2 for wind speed zone details):

- 911 call stations
- Fire, rescue, ambulance, and police stations
- Emergency operation centers



Source: ICC 500 (2020) Figure 304.2(1) Used with Permission
Notes:
Values are nominal Three-second gust wind speeds in miles per hour at 33 feet above ground for Exposure Category C.
Multiply miles per hour by 0.477 to obtain meters per second.
Location-specific storm shelter design wind speeds shall be permitted to be determined using the ATC Hazards by Location website, https://hazards.atcouncil.org/.

Figure 2: Safe room design wind speed zones for tornadoes

Although K-12 school buildings are not required to be designated as essential facilities (i.e., Risk Category IV per IBC Section 1604.5), Section 423 also requires storm shelters for K-12 school buildings with an occupant load of 50 or more where they are constructed in the 250-mph tornado shelter wind speed zone (some exceptions apply). Furthermore, since the 2018 edition, the International Existing Building Code (IEBC) has required storm shelters for additions to K-12 school buildings when that addition has an occupant load of 50 or more and is located in the 250-mph tornado shelter design wind speed zone. The provisions are intended to supplement IBC storm shelter requirements for new Group E buildings and are similar in scope. When facility stakeholders add on to an existing facility that does not have a safe room or storm shelter, FEMA recommends they strongly consider including one within the addition to accommodate the number of occupants for both the existing building and the addition.

In addition to saving students and school staff from tornado-caused injuries and death, school storm shelters or safe rooms that are opened to a surrounding neighborhood(s) have the potential of protecting the wider community.

FEMA recommends that owners of all types of buildings in the 160-mph, 200-mph, and 250-mph tornado storm shelter design wind speed zone consider having a storm shelter or safe room. See Section A1.4 of FEMA P-361 for information pertaining to making a decision to install a safe room.

Essential Facility Requirements, Recommendations, and Best Practices

For essential facility occupants, many of whom must stay onsite during tornado emergencies, storm shelters and safe rooms provide life-safety protection. However, facility operations that are housed outside of a safe room or storm shelter are normally susceptible to tornado damage and disruption. To minimize damage or to ensure continuity of operations, additional design and construction measures are needed as described below.

TORNADO LOAD REQUIREMENTS AND RECOMMENDATIONS

With the publication of ASCE 7-22, tornado load requirements are now considered as a minimum design load for conventional building design. The new ASCE 7 tornado load provisions do not apply to storm shelters or safe rooms. Buildings and other structures that are classified as Risk Category III or IV and are located in the tornado-prone region per Figure 32.1-1 of ASCE 7-22 may be required to be designed and constructed with consideration for tornado loads determined in accordance with Chapter 32 of ASCE 7. Structures are to be designed using the greater of the wind loads in accordance with Chapters 26 through 31 of ASCE 7 and the tornado loads in accordance with Chapter 32 of ASCE 7 using the load combinations in Chapter 2 of ASCE 7. The ASCE 7 tornado load requirements will be included in the 2024 IBC, the 2024 National Fire Protection Association (NFPA) 5000 Building Construction and Safety Code, and the 2023 Florida Building Code. The adoption of the ASCE 7 tornado load provisions by the State of Florida is an example of local authorities having jurisdiction (AHJs) incorporating the most current design guidance prior to their inclusion in the model building codes. For more information, please refer to FEMA/NIST, *Design Guide for New Tornado Load Requirements in ASCE 7-22* (2023). Additionally, NIST Technical Note 2214, *Economic Analysis of ASCE 7-22 Tornado Load Requirements* (2022), compares basic wind speed to tornado wind speed requirements across the country to help designers understand where tornado loads will govern design and gives cost comparisons when designing for basic vs. tornado wind loads. NIST Technical Note 2214 can be accessed at https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=934540.

Although the 2024 IBC is expected to be published and available for AHJ adoption sometime in late 2023 (most states and jurisdictions require time to review, modify, and legislate in accordance with applicable laws/ordinances prior to their adoption and enforcement), building owners can request and registered design professionals can incorporate the ASCE 7-22 tornado load design procedures into new designs while adhering to the requirements of their currently adopted code. This is because the applicable basic wind loading requirements in the edition of ASCE 7 (2016, 2010, etc.) that is referenced in the locally adopted edition of the IBC establish the required minimum load for every portion of the building’s roof and walls.

Please note that the AHJ may have requirements that are more stringent than FEMA’s guidance and recommendations. As with all design and construction matters, please work with the local building department and all other AHJs to ensure that ALL AHJ requirements are being met, even when using FEMA publication and guidance recommendations.

BEST PRACTICES FOR ENHANCED TORNADO RESILIENCE

As briefly described in the Design Criteria section, the new tornado speed maps are primarily different from basic wind speed maps because tornado speeds depend on the effective plan area of the building or other structure under design (i.e., facilities with smaller effective plan areas are assigned lower tornado speeds than larger facilities with the same risk category and in the same location). As a result, the minimum tornado loads required by ASCE 7-22 for small facilities may not significantly affect their design. Other factors that affect the design tornado speed are Risk Category and geographic location.

In cases where building owners and planners would like to amplify tornado loads to enhance the essential facility's tornado resilience, FEMA recommends either increasing the tornado speeds to at least 120 mph (where lower tornado speeds are the required minimum) or using the higher mean recurrence interval maps provided in ASCE 7-22 Appendix G.

Other best practices for enhancing the tornado resilience of essential facilities where ASCE 7-22 is not referenced in the adopted building code include protecting glazed openings from impact and increasing basic wind load parameters as described in December 2021 Kentucky Tornadoes Recovery Advisory 2, *Reconstructing a Non-Residential Building After a Tornado* (2023).

Resources

ASCE/SEI (American Society of Civil Engineers / Structural Engineering Institute). 2021. *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, ASCE 7-22. www.asce.org/bookstore.

ASTM (ASTM International). 2019. *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*. ASTM E1886.

ASTM. 2020. *Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes*. ASTM E1996.

FEMA (Federal Emergency Management Agency). 2009. *Tornado Protection: Selecting Refuge Areas in Buildings* (FEMA P-431).

FEMA. 2015. *Hazard Mitigation Assistance Guidance* and *Hazard Mitigation Guidance Addendum*. https://www.fema.gov/grants/mitigation/hazard-mitigation-assistance-guidance.

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FEMA. 2019. *Guidelines for Wind Vulnerability Assessments of Existing Critical Facilities,* (FEMA P-2062). https://www.fema.gov/sites/default/files/2020-07/guidelines-wind-vulnerability.pdf

FEMA. 2021. *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms*, (FEMA P-361). https://www.fema.gov/emergency-managers/risk-management/safe-rooms/resources.

FEMA. 2023. *Reconstructing a Non-Residential Building After a Tornado.* December 2021 Kentucky Tornadoes Recovery Advisory 2.

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

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

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For More Information

For more information, see the FEMA Building Science Frequently Asked Questions website at https://www.fema.gov/emergency-managers/risk-management/building-science/faq.

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