TORNADO OUTBREAK of 2011

IN ALABAMA, GEORGIA, MISSISSIPPI, TENNESSEE, AND MISSOURI

F Recovery Advisories for the Spring 2011 Tornadoes

FEMA has prepared a series of new Recovery Advisories (RAs) that present guidance for safe room and refuge areas, facility operations, and the design and reconstruction of buildings in areas subject to tornadoes. Eight advisories have been prepared and are included in this appendix:

RA1. Tornado Risks and Hazards in the Southeastern United States

RA2. Safe Rooms: Selecting Design Criteria

RA3. Residential Sheltering: In-Residence and Stand-Alone Safe Rooms

RA4. Safe Rooms and Refuge Areas in the Home

RA5. Critical Facilities Located in Tornado-Prone Regions: Recommendations for Facility Owners

RA6. Critical Facilities Located in Tornado-Prone Regions: Recommendations for Architects and Engineers

RA7. Rebuilding and Repairing your Home After a Tornado

RA8. Reconstructing Non-Residential Buildings After a Tornado

These advisories are also available online at http://www.fema.gov/library/viewRecord.do?id=4723

Tornado Risks and Hazards in the Southeastern United States

FEMA

TORNADO RECOVERY ADVISORY *RA1, June 2011*

Purpose and Intended Audience

The purpose of this Tornado Recovery Advisory is to provide background on the tornado hazard in the Southeast. The general population, homeowners and renters, policy makers, local officials, builders, and building departments should understand that tornado occurrence in the Southeast is not a rare event. In fact, of the top 20 States in tornado frequency, 5 are in the Southeast.

This advisory also identifies FEMA resources that can be used to help design and construct portions of almost any building type (including residences) to provide safe refuge from tornadoes, or to help minimize damage caused by these wind events.

This Recovery Advisory Addresses:

- Recent events
- Tornado occurrence outside "Tornado Alley"… how great is the risk?
- Assessing your risk
- Can a building survive a tornado? Yes!
- Weather radios

The National Weather Service uses the Enhanced Fujita Scale (EF Scale) to categorize tornado severity based on observed damage. The scale ranges from EF0 to EF5. See http://www.spc.noaa.gov/efscale for further information on the EF Scale.

EF Scale	3-Second Gust Speed (mph)
EF0	65–85
EF1	86–110
EF2	111–135
EF3	136–165
EF4	166–200
EF5	Over 200

Recent Events

In the late afternoon of April 27, 2011, a large outbreak of tornadoes struck Mississippi, Tennessee, Alabama, and portions of Georgia. The National Oceanic and Atmospheric Administration (NOAA) estimated there were approximately 190 tornadoes that touched down between 8:00 a.m. EDT April 27 and 8:00 a.m. EDT April 28, a record high for a single storm system. Three of the tornadoes were rated by the National Weather Service (NWS) as EF5, 11 were rated at EF4, 21 at EF3, and the remainder at EF2 and below on the Enhanced Fujita Scale. Fatalities for the events in April totaled 361[1] and hundreds more were injured, making April 27th the fourth deadliest day for tornadoes on record.[2] Total damage estimates are still being compiled from this event, but early estimates are that the insured loss for the storms could reach $6 billion, with Alabama accounting for 70 percent of that loss.[3]

On May 22, 2011, Joplin, Missouri, a town of 50,000 people, was devastated by a large tornado. NWS estimated that the tornado was an EF5 (greater than 200 mph) tornado. At the time of publication of this Recovery Advisory, 141 people from Joplin have been confirmed dead and 750 people reported as injured. The Joplin tornado is the deadliest single tornado since modern recordkeeping began in 1950 and is ranked eighth among the deadliest tornadoes in U.S. history.[4] Total damage estimates could reach $3 billion.[5]

1 NOAA, 2011. http://www.spc.noaa.gov/climo/torn/fataltorn.html accessed 5/27/11
2 NOAA, 2011. http://www.noaanews.noaa.gov/april_2011_tornado_information.html accessed 5/17/11
3 Gow, Lauren. May 17, 2011. "US tornado insured losses could reach $6bn" in Global Reinsurance
4 SOURCE: http://www.crh.noaa.gov/sgf/?n=event_2011may22_summary accessed 5/27/11
5 SOURCE: http://money.cnn.com/2011/05/24/news/economy/tornado_joplin/index.htm accessed 5/27/11

Tornado Occurrence Outside "Tornado Alley"… How Great Is the Risk?

"Tornado Alley" is an area of the heartland of the United States known for its tornado activity. Although the exact extent of Tornado Alley can be debated, most scientists agree that Texas, Oklahoma, and Kansas are well known for tornado risk and make up a large portion of Tornado Alley.

What most people may not be aware of is the amount of tornadic activity outside of Tornado Alley. FEMA Region IV has eight States subject to tornadoes and six subject to hurricanes (refer to Figure 1 and Table 1).

Although hurricanes have received most of the attention in recent years in the Southeast, the threat and risk of tornadoes is real. Table 1 below shows the number of tornadoes occurring in each of the States in FEMA Region IV. A total of 11,629 tornadoes were recorded by NOAA's Storm Prediction Center for the 60-year study period from 1950 through 2010. Between 2000 and 2010, Alabama alone experienced 636 tornadoes.

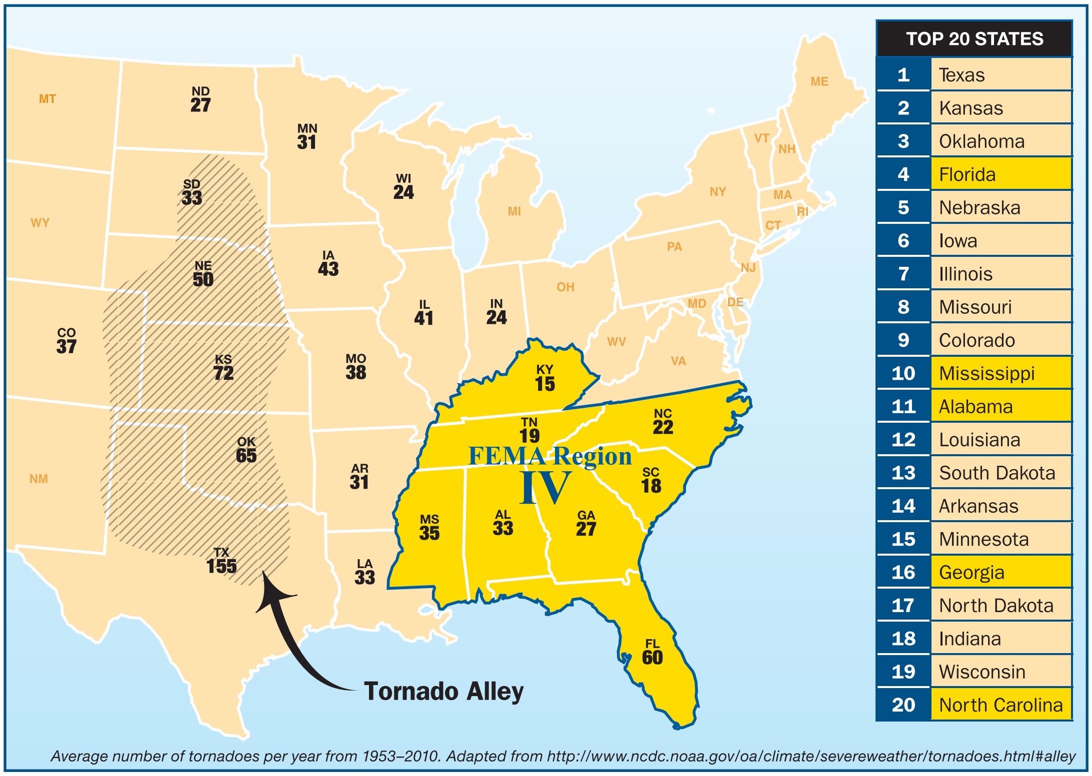


***Figure 1:** Average number of tornadoes per year in FEMA Region IV and Tornado Alley*

Except for in the States of Mississippi and Alabama, tornadoes occurring in the Southeast are typically weak to moderately strong (EF0, EF1, EF2, and EF3 tornadoes). However, these weaker tornadoes can be as deadly as the stronger (EF4 or EF5) tornadoes. For example, more than 50 of the 78 deadliest tornadoes that occurred in Florida between 1882 and 2007 were EF3 or weaker. Further, tornadoes are not always single events; sometimes several tornado outbreaks result from a large storm system.

In addition to the April 27, 2011, outbreak, other notable outbreaks in the Southeast include:

The Super Outbreak of April 3–4, 1974

- 148 tornadoes responsible for 330 fatalities
- Approximately 5,484 injuries
- Approximately $600 million (1975 dollars) in damages
- Tornadoes affected 13 States from Alabama to Michigan

***Table 1:** Tornado occurrences in FEMA Region IV*

States in FEMA Region IV	Total Tornado Occurrences (1950–2010)	Total Fatalities (1950–2010)	Total Injuries (1950–2010)	Fatality Rank
Alabama	1,695	441	6,808	4
Florida	3,052	161	3,307	16
Georgia	1,381	190	4,059	14
Kentucky	741	180	3,310	15
Mississippi	1,790	443	6,223	2
North Carolina	1,116	114	2,536	17
South Carolina	894	60	1,693	23
Tennessee	960	399	5,114	5
TOTAL	11,629	1,988	33,050	

Values do not include Spring 2011 tornadoes.
SOURCE: TornadoHistoryProject.com, which compiles NOAA Storm Prediction Center data found at http://www.spc.noaa.gov/wcm/#data

The Carolinas Outbreak of March 28, 1984

- 22 tornadoes responsible for 57 fatalities
- Approximately 1,250 injuries
- Approximately $200 million (1984 dollars) in damages
- 37 percent of fatalities occurred in manufactured homes

The Palm Sunday Outbreak of March 27, 1994

- 27 tornadoes responsible for 42 fatalities
- Approximately 491 injuries
- Approximately $107 million (1994 dollars) in damages
- Tornadoes hit Alabama, Georgia, South Carolina, and North Carolina

The Enterprise, Alabama Tornado of March 1, 2007

- 8 fatalities and 50 injuries in Enterprise High School
- The fatalities occurred when walls and roof structure collapsed onto a group of students huddled in the hallway in a crouched position
- Tornado estimated at an EF4

In 2010, the Alabama Building Commission passed a bill (Act 2010-746 Safe Space) requiring that all new K-12 school construction projects awarded after July 1, 2010, provide a storm shelter that complies with the ICC-500 storm shelter standard. This was in large part due to the tragic events of March 1, 2007, when a tornado destroyed the Enterprise High School, killing 7 students and 1 teacher.

Assessing Your Risk

To determine if you have a low, moderate, or high tornado risk, use the Frequency map (Figure 2) to determine how many tornadoes were recorded per 2,470 square miles for the area where your building is located. Find the row in Table 2 that matches that number. Next, look at the Wind Speed map (Figure 3) and note the design wind speed (130 mph, 160 mph, 200 mph, 250 mph) for your building location. Find the matching column in Table 2 and find the box that lines up with both the number of tornadoes per 2,470 square miles in your area and your wind speed. The color in that box tells you the level of your risk from extreme winds and helps you decide whether to build a safe room. A safe room is the preferred method of wind protection in high-risk areas.

Example: If your building is located in Birmingham, Alabama, you would see that Birmingham is in an area shaded red on the Frequency map (Figure 2). According to that map, the number of tornadoes per 2,470 square miles in the Birmingham area is >15. On the Wind Speed map (Figure 3), Birmingham is within the dark blue area, identified by the map key with a design wind speed of 250 mph. The box in the Risk Table (Table 2) where the frequency >15 row and the 250 mph wind speed column meet is shaded dark blue, which shows that the building is in an area of high risk.

Note that some areas of low or moderate risk, shown as pale blue or medium blue on Table 2, are within the region of the United States that is also subject to hurricanes (see Figure 3). If you live in this hurricane-prone region, your risk is considered high even if Table 2 shows a moderate or low risk.

Can a Building Survive a Tornado? Yes!

Tornado safe rooms can be designed and constructed to protect occupants from winds and wind-borne debris associated with all tornadoes (EF0–EF5). Buildings designed and constructed above basic code requirements (aka “hardened” buildings) and newer structures designed and constructed to modern, hazard-resistant codes can resist the wind load forces from weak tornadoes (EF1 or weaker). Furthermore, even when stronger tornadoes strike, not all damage is from the rotating vortex of the tornado. Much of the damage is from straight-line winds rushing toward and being pulled into the tornado itself. Many newer homes and commercial buildings designed and constructed to modern codes, such as the *International Residential Code* and *International Building Code* (2009 editions and newer), have load paths that better resist high-wind forces (specified in building codes for hurricane resistance) and may survive without structural failure. The damage to these newer homes and buildings is often to the cladding and exterior systems: roof covering, roof deck, exterior walls, and windows.

For most building uses, it is economically impractical to design the entire building to resist tornadoes. However, portions of buildings can be designed as safe rooms to provide occupant protection from tornadoes. For information on designing safe rooms to resist the strongest tornadoes and hurricane events, see the Tornado Recovery Advisory RA2 titled “Safe Rooms: Selecting Design Criteria” (updated in 2011). For residential safe rooms, see the Tornado Recovery Advisory RA3 titled “Residential Sheltering: In-Residence and Stand-Alone Safe Rooms” (updated in 2011).

Unless a building has a specifically designed safe room, or occupants have access to a community safe room nearby, building owners should work with a qualified architect or engineer to identify the best available refuge areas in the building. For more information on best available refuge areas, see *Tornado Protection: Selecting Refuge Areas in Buildings* (FEMA P-431, 2009) and the Extreme-Wind Refuge Area Evaluation Checklists in *Design and Construction Guidance for Community Safe Rooms* (FEMA P-361, Appendix B1, 2008).

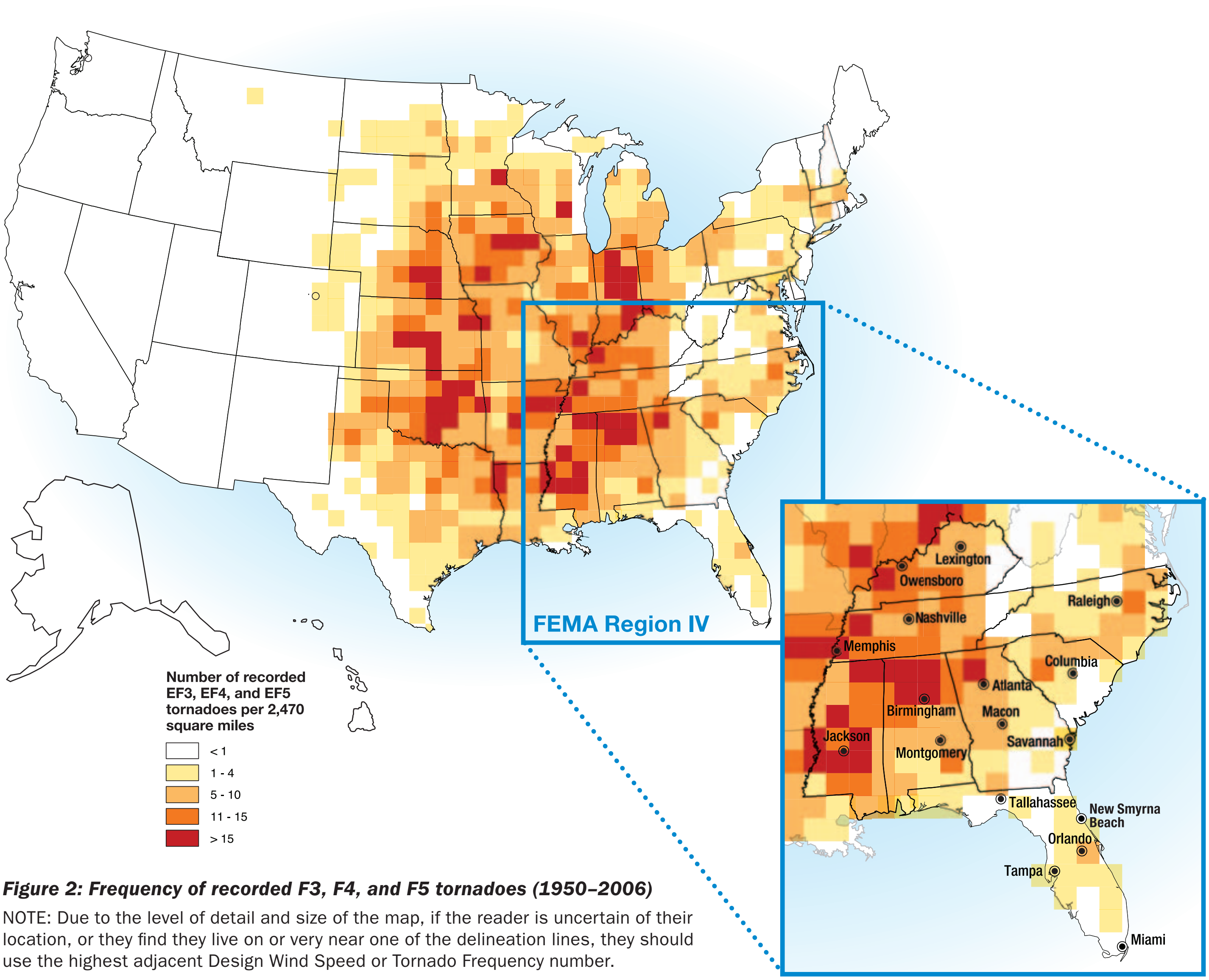


Figure 2: Frequency of recorded F3, F4, and F5 tornadoes (1950–2006)

NOTE: Due to the level of detail and size of the map, if the reader is uncertain of their location, or they find they live on or very near one of the delineation lines, they should use the highest adjacent Design Wind Speed or Tornado Frequency number.

SOURCE: FEMA 320, *Taking Shelter From the Storm: Building a Safe Room For Your Home or Small Business,* August 2008, 3rd Edition

Table 2: Levels of risk during high-wind events

Number of Tornadoes per 2,470 Square Miles (see Figure 2)	Design Wind Speed (see Figure 3)			
	130 mph	160 mph	200 mph	250 mph
<1	LOW Risk	LOW Risk ★	LOW Risk ★	MODERATE Risk
1–5	LOW Risk	MODERATE Risk ★	HIGH Risk	HIGH Risk
6–10	LOW Risk	MODERATE Risk ★	HIGH Risk	HIGH Risk
11–15	HIGH Risk	HIGH Risk	HIGH Risk	HIGH Risk
>15	HIGH Risk	HIGH Risk	HIGH Risk	HIGH Risk

LOW Risk – Sheltering from high winds is a matter of preference.

MODERATE Risk – Shelter should be considered for protection from high winds.

HIGH Risk – Shelter is the preferred method of protection from high winds.

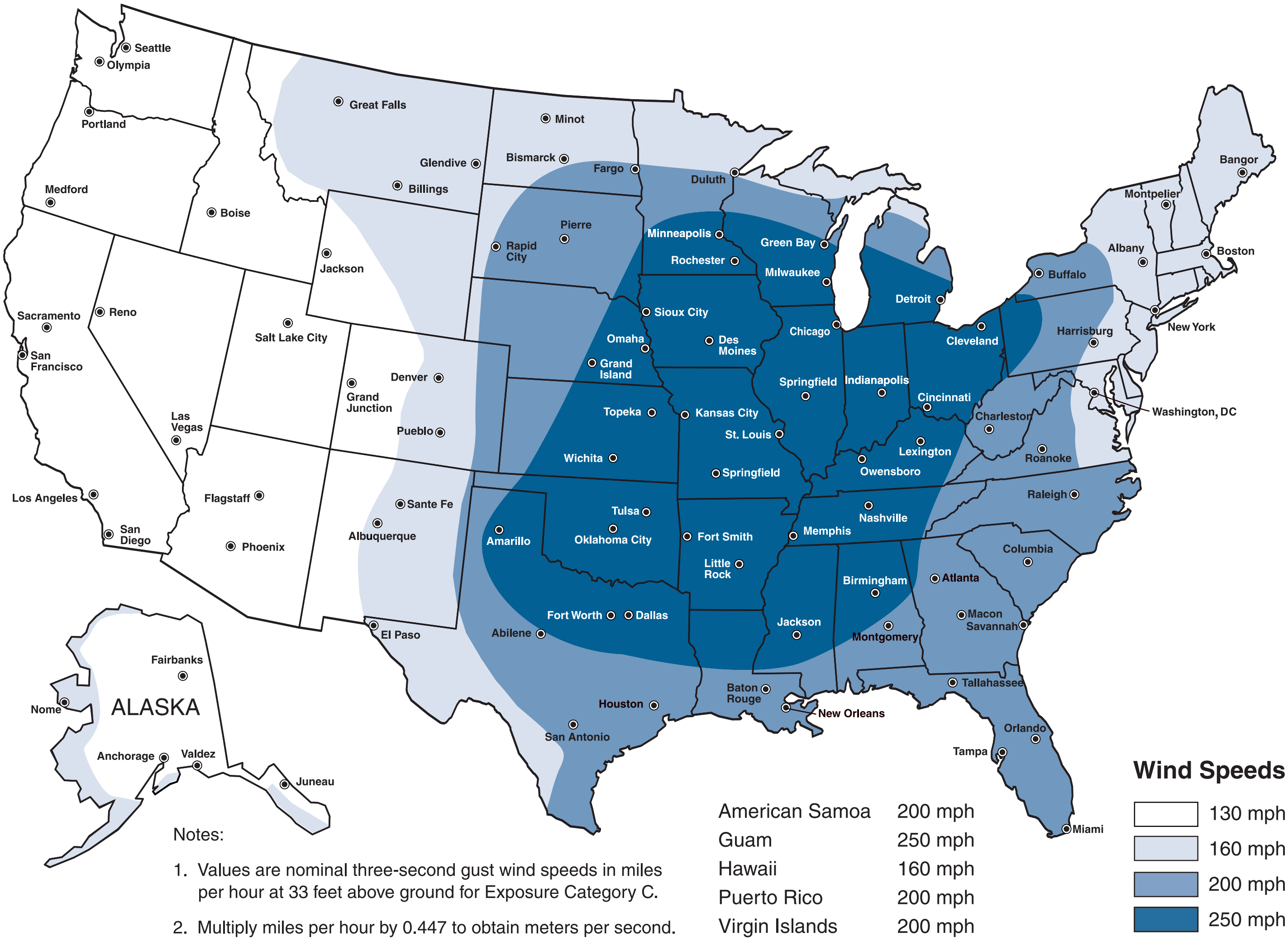


Figure 3: Tornado safe room design wind speeds in the United States

SOURCE: FEMA 361, *Design and Construction Guidance for Community Safe Rooms,* August 2008, 2nd Edition

Weather Radios

Everyone living or working in tornado-prone areas should have a weather radio at their home or place of work. A weather radio is particularly important for those living in areas that do not have storm warning sirens.

The NOAA Weather Radio (NWR) is a nationwide network of radio stations broadcasting continuous weather information directly from a nearby NWS office. NWR broadcasts NWS warnings, watches, forecasts, and other hazard information 24 hours a day, as well as post-event information for all types of hazards, both natural and technological.

NOAA Weather Radios are available at electronics stores across the country and range in cost from $25 up to $100 or more, depending on the quality of the receiver and number of features. The NWS does not endorse any particular make or model of receiver.

Features to look for in a NOAA Weather Radio

- The most desirable feature is an alarm tone. This allows you to have the radio turned on, but silent until a special tone is broadcast before watch and warning messages of an imminent life-threatening situation.
- Specific Area Message Encoding (SAME) technology, a NOAA Weather Radio feature available since the mid-1990s, is capable of providing detailed, area-specific information. Unlike other NOAA Weather Radios, the SAME feature will filter out alerts that do not affect your immediate area.

- The NOAA Weather Radio should be operated on batteries when electrical service may be interrupted. Look for radios with an AC adapter and battery compartment.
- The radio should be tunable to all seven NWR frequencies. For the latest list of frequencies and transmitter locations, check the NOAA Weather Radio Web site http://www.weather.gov/nwr.
- The hearing and visually impaired can receive watches and warnings by connecting weather radio alarms to other kinds of attention-getting devices, like strobe lights, pagers, bed-shakers, personal computers, and text printers.

Automated Spanish translation systems are available for use on transmitters serving a significant Hispanic population to broadcast Spanish translations of all emergency weather and natural hazard messages immediately after the official Emergency Alert System (EAS) warning is issued. For more information in Spanish, please visit the NOAA Web site http://www.weather.gov/nwr/indexsp.htm.

Other Methods to Receive Forecasts, Watches, and Warnings:

- Tune in to your local radio and television stations for the latest weather forecasts, watches, and warnings. In the event of power loss, battery-operated weather radios can be an interim solution to receive forecasts, watches, and warnings.
- NWS products and services are also available on the Internet at http://www.weather.gov/nwr. Delivery of data across the Internet, however, cannot be guaranteed because of potential interruption of service.
- Another low-cost method for receiving the NWS's essential information is available on a wireless data system called the Emergency Managers Weather Information Network (EMWIN). This system presents the information directly on your home or office computer. Users may set various alarms to be alerted to particular information, whether for their local area or adjacent areas. For more information, visit the EMWIN Web site http://www.weather.gov/emwin/index.htm.

FEMA is in the process of introducing the Personal Localized Alerting Network (PLAN), which will allow customers with certain types of mobile devices, such as smartphones, to receive emergency alerts specific to their location. Some cities are planned to be online by the end of 2011, and large portions of the United States should have the service by mid-2012. This service will enable certain national, State, and local agencies to send customers alerts for public safety emergencies like tornado warnings and watches. Customers with PLAN-capable devices will be notified by text message of emergencies relevant to their geographic area.

National Weather Service StormReady Program

In addition to the guidance and outreach offered by FEMA, the National Weather Service has established the StormReady Program to help communities prepare for extreme weather events. The StormReady Program, established in 1999, helps communities establish the communication and safety skills and awareness to reduce impacts from extreme events. This is done by strengthening local safety programs and helping communities with advanced planning, education, and awareness. Through this program, the National Weather Service also provides a number of publications and other forms of information on various types of natural hazards. Visit http://www.stormready.noaa.gov for more information.

Useful Links and Resources

Taking Shelter from the Storm: Building a Safe Room For Your Home or Small Business (FEMA 320), August 2008, 3rd Edition. http://www.fema.gov/library/viewRecord.do?id=1536

Design and Construction Guidance for Community Safe Rooms (FEMA 361) August 2008, 2nd Edition. http://www.fema.gov/library/viewRecord.do?id=1657

Tornado Protection: Selecting Refuge Areas in Buildings (FEMA P-431), FEMA, October 2009, 2nd Edition. http://www.fema.gov/library/viewRecord.do?id=1563

National Storm Shelter Association (NSSA). http://www.NSSA.cc

ICC/NSSA Standard for the Design and Construction of Storm Shelters (ICC-500), June 2008. http://www.iccsafe.org/Store/Pages/Product.aspx?id=8850P08_PD-X-SS-P-2008-000001

Safe Rooms: Selecting Design Criteria

FEMA

TORNADO RECOVERY ADVISORY *RA2, June 2011*

Purpose and Intended Audience

The intended audience for this Tornado Recovery Advisory is anyone involved in the planning, policy-making, design, construction, or approval of safe rooms, including designers, emergency managers, public officials, policy or decision-makers, building code officials, and home or building owners. Homeowners and renters should also refer to the Tornado Recovery Advisory No. 3 titled "Residential Sheltering: In-Residence and Stand-Alone Safe Rooms" (updated in 2011). The purpose of this advisory is to identify the design guidance, code requirements, and other criteria that pertain to the design and construction of safe rooms for tornadoes and hurricanes. Different safe room and storm shelter criteria offer different levels of protection to safe room occupants.

Community safe room being constructed to FEMA 361 criteria in Wichita, KS.

This Recovery Advisory Addresses:

- How safe room construction is different from typical building construction
  - Structural systems
  - Wind-borne debris resistance
- Safe rooms vs. storm shelters
- Selecting refuge areas in buildings

How Safe Room Construction is Different from Typical Building Construction

A safe room is typically an interior room, space within a building, or an entirely separate building, designed and constructed to protect its occupants from tornadoes or hurricanes. Safe rooms are intended to provide near-absolute protection against both wind forces and the impact of wind-borne debris. The level of occupant protection provided by a space specifically designed as a safe room is intended to be much greater than the protection provided by buildings that comply with the minimum requirements of building codes. Until the 2009 International Codes adopted the International Construction Code/National Storm Shelter Association (ICC/NSSA) *Standard for the Design and Construction of Storm Shelters* (ICC-500), the model building codes did not cite design and construction criteria for life safety for sheltering, nor do they provide design criteria for tornado-resistant construction. Information about the ICC shelter criteria and FEMA safe room criteria that provide life-safety protection can be found in other guidance documents referenced in this recovery advisory.

> The term "hardened" refers to specialized design and construction applied to a room or building to allow it to resist wind pressures and wind-borne debris impacts during a high-wind event and serve as a shelter.

Safe rooms typically fall into two categories: residential safe rooms and community (non-residential) safe rooms.

- There are two general types of residential safe rooms: in-residence safe rooms and stand-alone safe rooms, located adjacent to or near a residence. An ***in-residence safe room*** is a small, specially designed ("hardened") room, such as a bathroom or closet, designed as a place of refuge for the people who live in the house. A ***stand-alone residential safe room*** is similar in function and design, but it is a separate structure installed outside the house, either above or below the ground surface. Refer also to Tornado Recovery Advisory No. 3 titled *"Residential Sheltering: In-Residence and Stand-Alone Safe Rooms" (updated in 2011).*
- A ***community safe room*** is intended to protect a larger number of people: anywhere from approximately 16 to several hundred individuals. Community safe rooms include not only public safe rooms but also private safe rooms for businesses and other organizations.
- Guidance on designing and constructing safe rooms can be found in FEMA 320, *Taking Shelter from the Storm: Building a Safe Room For Your Home or Small Business* (2008) and FEMA 361, *Design and Construction Guidance for Community Safe Rooms* (2008).

Structural Systems

The primary difference in a building's structural system when designed for use as a safe room, rather than for conventional use, is the magnitude of the wind forces that it is designed to withstand.

Buildings are designed to withstand a certain wind speed (termed "basic [or design] wind speed") based on historic wind speeds documented for different areas of the country. The highest design wind speed used in conventional construction is near the coastal areas of the Atlantic and Gulf Coasts and is in the range of 140–150 mph, 3-second gust in most locations. By contrast, the design wind speed recommended by FEMA[1] for safe rooms in these same areas is in the range of 200–250 mph, 3-second gust; this design wind speed is intended to provide "near-absolute protection."

Wind pressures are generally calculated as a function of the square of the design wind speed. As a result, the structural systems of a safe room are designed for forces up to almost eight times higher than those used for typical building construction. Consequently, the structural systems of a safe room (and the connections between them) are very robust.

Wind-Borne Debris Resistance

Wind-borne debris, commonly referred to as missiles, causes many of the injuries and much of the damage from tornadoes and hurricanes. Windows and the glazing in exterior doors of conventional buildings are not required to resist wind-borne debris, except for buildings in wind-borne debris regions.[2] Impact-resistant glazing can either be laminated glass, polycarbonate, or shutters. The American Society of Civil Engineers (ASCE) Standard 7 missile criteria were developed to minimize property damage and improve building performance; they were not developed to protect occupants. To provide occupant protection, the criteria used in designing safe rooms include substantially greater wind-borne debris loads and will be detailed later in this recovery advisory.

> If glazing is present in a tornado safe room, it should be protected by an interior-mounted shutter that can be quickly and easily deployed by the safe room occupants, or be designed to resist the wind-borne debris impact and wind pressure tests cited in FEMA 361 and prescribed in ICC-500, Chapter 8.

The roof deck, walls, and doors of conventional construction are also not required by the building code to resist wind-borne debris. However, the roof deck and walls around a safe room space, and the doors leading into it, must resist wind-borne debris if the space inside is to provide occupant protection. Additional information regarding the different levels of wind-borne debris loads is provided below.

1 FEMA 361, *Design and Construction Guidance for Community Safe Rooms,* Second Edition (August 2008)
2 ASCE 7, American Society of Civil Engineers Standard 7, *Minimum Design Loads for Buildings and Other Structures* (2010)

Safe Rooms vs. Storm Shelters

Safe rooms and storm shelters provide different levels of protection depending on the design criteria used. The level of protection provided by a safe room is a function of the design wind speed (and resulting wind pressure) used in designing it, and of the wind-borne debris load criteria. In addition to FEMA 320 and FEMA 361, the International Construction Code/ National Storm Shelter Association (ICC/NSSA) *Standard for the Design and Construction of Storm Shelters* (ICC-500) provides design and construction criteria for storm shelters. FEMA's safe room criteria and ICC-500's storm shelter criteria are similar, with a few differences such as citing with respect to flood hazards and the horizontal missile impact test speed for the hurricane hazard. While the two criteria are similar, FEMA changed the name of its guidance from "shelters" to "safe rooms" when ICC-500 was released to avoid confusion. In addition, FEMA 361, which was updated at the same time ICC-500 was released, references ICC-500 for certain criteria in the design and construction of a safe room, such as testing standards for missile impact and wind pressure resistance.

HMGP funds were used for this Public Safety Complex constructed so that the entire facility is compliant with FEMA 361 criteria. Robert J. Curry Public Safety Complex, Gulfport, MS.

Design wind speed and wind pressure criteria: Wind pressure criteria are given by different guides, codes, and standards. The wind pressure criteria specify how strong the safe room must be. The design wind speed is the major factor in determining the magnitude of the wind pressure that the building is designed to withstand. In FEMA's safe room publications and ICC-500, the same wind speed hazard maps are used to recommend design wind speeds ranging from 130 to 255 mph. The 2009 *International Residential Code* and the 2009 *International Building Code,* which establish the minimum requirements for residential and other building construction, include design wind speeds ranging from 90 to 150 mph throughout most of the country. Table 1 provides a comparison of safe room/shelter design criteria options.

HMGP-funded community safe room constructed in the basement of a new fire station in Brookside, AL.

Wind-borne debris load criteria: Table 2 presents wind-borne debris criteria given in various guides, codes, and standards. Table 2 shows the different test missiles and the corresponding momentum they carry with them as they strike a safe room. The first entries on the table (Tornado Missile Testing Requirements) are the FEMA missile guidance for residential and community safe rooms that provide near-absolute protection.

Table 1. ***Wind Safe Room/Shelter Design and Construction Codes, Standards, Guidance Comparison***[1] *(page 1 of 2)*

Title or Name of Document	Code, Regulation, Standard, or Statute?	Wind Hazard	Wind Map
FEMA Safe Room Publications: **FEMA 320** Taking Shelter from the Storm: Building a Safe Room For Your Home or Small Business (2008) **FEMA 361** Design and Construction Guidance for Community Safe Rooms (2008)	FEMA guidance document, not a code or standard. "Best Practice" for high-wind safe rooms	Tornado and Hurricane	**FEMA 320:** Hazard map, maximum wind hazard speed of 250 mph used for design **FEMA 361:** Map with four wind speed zones for design (wind mri[2] is 10,000–100,000 years). This map is often referred to as the "FEMA 361 map"
International Code Council/National Storm Shelter Association (ICC/NSSA) High Wind Shelter Standard (ICC-500)	Consensus standard for shelter design and construction. Incorporated by reference into the 2009 IBC and IRC.	Tornado and Hurricane	**Tornado:** Uses FEMA 361 map **Hurricane:** Uses revised ASCE 7 map with contours at 10,000 year mri with minimum shelter design wind speed of 160 mph, maximum approximately 255 mph
Florida State Emergency Shelter Program (SESP) – Florida's interpretation of the American Red Cross (ARC) 4496 Guidance. Note: shelters in this category range from EHPA-recommended design levels, shown in this row, to the code requirement levels (next row), to the ARC 4496 requirements (see below).	Guidance in the Florida Building Code (FBC) "recommending" above-code requirements for EHPAs. See also Appendix G of the Florida SESP report for detailed design guidance.	Hurricane	FBC map, based on ASCE 7-05 (maps basically equivalent); mri is 50–100 years in coastal areas and adjusted with importance factor
ASCE 7-10	2010 edition of ASCE standard on minimum design loads for buildings and other structures.	Hurricane	ASCE 7-10 departs from previous editions and provides multiple wind maps for various "building risk categories" (which are based on occupancy type). The maps have wind speeds based on different mri.
FBC 2000, IBC/IRC 2000 through 2009, ASCE 7-98 through 2005	Building code and design standards for regular (non-shelter) buildings. Some additional guidance is provided in commentary.	Hurricane	ASCE 7 has its own wind speed map based on historical and probabilistic data; mri is 50–100 years in coastal areas and adjusted with importance factor
Institute for Business and Home Safety (IBHS) Fortified Home Program – intended as guidance to improve the performance of residential buildings during natural hazard events, including high-wind events. Not considered adequate for sheltering.	Guidance provided to improve performance of regular (non-shelter) buildings in high winds	Tornado and Hurricane	ASCE 7 or modern State building code map
FBC EHPAs – code requirements for public "shelters" (FBC Section 423.25)	Statewide code requirements for EHPAs	Hurricane	The minimum requirement is based on ASCE 7 (maps basically equivalent); mri is 50–100 years in coastal areas and adjusted with importance factor; the missile impact criteria for openings, walls, and roof as provided in SSTD 12,[3] must also be met
Building Codes: Pre-2000	Building code and design standards for regular (non-shelter) buildings	Hurricane	Each of the older codes used their own published wind contour maps
ARC 4496 Standards for Hurricane Evacuation Shelter Selection	Guidance for identifying buildings to use as hurricane evacuation shelters	Hurricane	ASCE 7-98 or ANSI A58 structural design criteria
Other: Information for selecting areas of refuge/last resort	Guidance from FEMA and others for selecting best-available refuge areas	Tornado and Hurricane	None

NOTES:
1. The wind shelter guidance and requirements shown here are presented from highest to least amount of protection provided
2. Mean recurrence intervals (mri) for wind speeds maps are identified by the code or standard that developed the map. Typically, the mri for non-shelter construction in non-hurricane-prone areas is 50 years and in hurricane-prone regions, approximately 100 years.
3. Standard Building Code/Standard 12 – Test Standards for Determining Resistance from Windborne Debris

Table 1. Wind Safe Room/Shelter Design and Construction Codes, Standards, Guidance Comparison[1] (page 2 of 2)

Wind Design Coefficient Considerations[4,5]	Debris Impact Criteria[6]	Remarks
FEMA 320: N/A – prescriptive design guidance for maximum hazard **FEMA 361:** Use FEMA 361 wind speed map with four zones. Calculate pressures using ASCE 7 methods and use I=1.0, Kd=1.0, Exposure C, no topographic effects, GCpi=+/-0.55 (this will account for atmospheric pressure change [APC])	Test all safe rooms with the representative missile (missile speed dependent on site design wind speed): **FEMA 320:** 15 lb 2x4 at 100 mph (horizontal) and 67 mph (vertical) **FEMA 361 Tornado:** 15 lb 2x4 at 80-100 mph (vertical) and 2/3 of this speed (horizontal) **FEMA 361 Hurricane:** 9 lb 2x4 at 0.1 times the wind speed (horizontal) and 0.5 times the wind speed (vertical)	**FEMA 320:** Intent is to provide "near-absolute protection." No certification is provided. **FEMA 361:** Intent is to provide "near-absolute protection." Safe room operations guidance is provided. Occupancy issues are addressed. Wall section details provided. No certification is provided.
Tornado: Use FEMA 361 wind speed map. Calculate pressures using ASCE 7 methods and use I=1.0, Kd=1.0, Exposure C with some exceptions, Kzt=need not exceed 1.0, GCpi=+/-0.55 or +/-0.18+APC **Hurricane:** Use revised ASCE 7 map and methods and use I=1.0, all other items as per ASCE 7, no APC consideration required.	Test shelters with representative missile (missile speed dependent on site design wind speed): **Tornado:** 15 lb 2x4 at 80–100 mph (vertical) and 2/3 of this speed (horizontal). **Hurricane:** 9 lb 2x4 at 0.1 times the wind speed (horizontal) and 0.4 times the wind speed (vertical)	Intent is to provide a standard for the design and construction of high-wind shelters. Will not use term "near-absolute protection." Occupancy, ventilation, and use issues are also addressed. Shelter operations guidance is provided in the commentary only (commentary is a separate document—not a consensus document).
Recommends that designer add 40 mph to basic wind speed identified on map, Exposure C, I=1.15, Kd=1.00, GCpi as required by design (typically +/-0.18), but recommends +/-0.55 for tornado shelter uses.	In wind-borne debris region (120 mph+): Small – pea gravel; Large – 9 lb 2x4 at 75 mph (horizontal), up to 60 feet above grade, but recommends 15 lb 2x4 at 50 mph (horizontal)	The building, or a portion of a building, is defined as an essential facility and as a shelter. Designer is required to submit signed/sealed statement to building department and State offices stating the structure has been designed as a shelter (EHPA plus added recommended criteria).
Method is basis of most wind pressure calculation methods. All items in design process are site-specific. Unlike ASCE 7-05, ASCE 7-10 does not use importance factor in wind calculation.	Uses the same reference as ASCE 7-05 for debris impact criteria (ASTM E 1996), with wind zones modified to account for higher basic wind speeds (see C26.10 of ASCE 7-10 for more information).	The 2009 model I-codes reference ASCE 7-05. However, ASCE 7-10 will be referenced in the 2012 IBC. The 2010 Florida Building Code references ASCE 7-10.
Method is basis of most wind pressure calculation methods. All items in design process are site-specific. Use I=1.15 for critical and essential facilities.	In wind-borne debris region (120 mph+): Small – pea gravel; Large – 9 lb 2x4 at 34 mph (horizontal) and areas > 130 mph: 9 lb 2x4 at 55 mph (horizontal), up to 60 feet above grade. Note: 2006 IBC requires the 9-lb 2x4 (large) missile to be tested at 55 mph for critical and essential facilities	Code requires increased design parameters only for buildings designated as critical or essential facilities.
Based on regional hazards, recommendations are provided to improve and strengthen the load path and the performance of the building exterior.	Window and glazing protection is recommended for most hurricane-prone areas, not just areas with a basic wind speed of 120 mph and greater.	This program provides design and construction guidance to improve building performance for high-wind events. Compliance will likely improve building performance but does not imply that the building is safe or that it is appropriate to use as a shelter.
Use basic wind speed at site as identified on FBC wind speed map, use exposure at site, use Category III (Essential Buildings), use wind loads in accordance with ASCE 7.	Use the missile impact criteria for the building enclosure, including walls, roofs, glazed openings, louvers, and doors, per SBC/SSTD 12.	The building or a portion of a building is defined as an essential facility and as an EHPA. Designer is required to submit signed/sealed statement to building department and State offices stating the structure has been designed as an EHPA.
Typically these older codes provided a hurricane regional factor for design wind speeds, but little attention was paid to components and cladding	Not required for all buildings. Where required, the Standard Building Code[7] developed and recommended debris impact standards for use in hurricane-prone regions.	These codes specified limited hazard-resistant requirements. Some guidance was provided with SSTD 10 from SBCCI for the design and construction of buildings in high-wind and hurricane-prone regions. Buildings constructed to these early codes were not required to have structural systems capable of resisting wind loads.
None	None	Provides guidance on how to select buildings and areas of a building for use as a high-wind shelter or refuge area. Does not provide or require a technical assessment of the proposed shelter facility.
None	None	Best available refuge areas should be identified in all buildings without shelters. FEMA 431, *Tornado Protection: Selecting Refuge Areas in Buildings,* provides guidance to help identify the best available refuge areas in existing buildings. Because best available refuge areas are not specifically designed as shelters, their occupants may be injured or killed during a tornado or hurricane.

NOTES (continued):

4. ASCE 7-05 Building Design Loads for Buildings and Other Structures (2005) is the load determination standard referenced by the model building codes. The wind design procedures used for any shelter type in this table use one of the wind design methods as specified in ASCE 7-05, but with changes to certain design coefficients that are identified by the different codes, standards, or guidance summarized in this table.
5. From ASCE 7 method: I = importance factor; Kd = wind directionality factor; GCpi = internal pressure coefficient
6. Roof deck, walls, doors, openings, and opening protection systems must all be tested to show resistance to the design missile for the FEMA, ICC, and FL EHPA criteria
7. From the Southern Building Code Congress International, Inc. (SBCCI)

Table 2. Wind-Borne Debris Criteria

Guidance, Code, or Standard Criteria for the Design Missile	Debris Test Speed (mph)	Large Missile Specimen	Momentum at Impact (lbf s)
Tornado Missile Testing Requirements			
FEMA 320/FEMA 361	100 (maximum) 80 (minimum)	15# 2x4 15# 2x4	68 55
International Code Council (ICC) ICC-500 Storm Shelter Standard	100 (maximum) 80 (minimum)	15# 2x4 15# 2x4	68 55
Hurricane Missile Testing Requirements			
FEMA 320/FEMA 361	128 (maximum) 80 (minimum)	9# 2x4 9# 2x4	53 33
ICC 500 Storm Shelter Standard	102 (maximum) 64 (minimum)	9# 2x4 9# 2x4	42 26
Florida State Emergency Shelter Program (SESP) Criteria and Emergency Operations Center (EOC) Design Criteria	50 (EOC recommended) 55 (EHPA recommended) 34 (EHPA minimum)	15# 2x4 9# 2x4 9# 2x4	34 23 14
IBC/IRC 2009, ASCE 7-10, Florida Building Code, ASTM E 1886/E 1996	55 34	9# 2x4 9# 2x4	23 14

NOTES:
IBC/IRC – International Building Code/International Residential Code
lbf-s – Pounds (force) seconds
EHPA – Enhanced Hurricane Protection Area

Using Wind Shelter Design and Construction Codes: An Example

Table 3 shows comparative data for two locations using the design criteria presented in Table 1. Where no guidance is provided for sheltering or basic construction, “N/A” (not applicable) is stated. Where the requirement is not required, “Not required” is stated.

Selecting Refuge Areas in Buildings

Building owners should be aware of any existing public shelters near their building. For instance, new schools in many States are required to include an ICC-500-compliant storm shelter. If no sheltering options are located nearby, building owners should consider whether their building can be retrofitted for a shelter or safe room. While it is recommended that a safe room be installed, this may not solve the immediate problem of needing to identify the best available refuge areas in a building.

During severe weather, building occupants should be moved to a location in the building that is protected from potential wind-borne debris and the least susceptible to collapse. While these areas do not provide near-absolute protection (unless designed as safe rooms), they may limit the number of occupants injured or killed. Appropriate refuge areas should be identified by architects, engineers, or design professionals familiar with FEMA 361 (2008) and FEMA P-431, *Tornado Protection: Selecting Refuge Areas in Buildings* (2009). These refuge areas are usually interior locations with short-span roof systems, reinforced masonry walls, and no glass openings.

Post-disaster assessments following April 2011 Tornado Outbreak demonstrated that administrative officials or others involved in local planning efforts often identified refuge areas without the guidance of an experienced design professional. While it was clear that an effort was made to protect the occupants, many of these refuge areas were located in large spaces—such as gymnasiums or auditoriums—or in areas near exterior windows and doors. Additionally, many of the selected refuge areas were observed to be surrounded by wall systems subject to collapse in high-wind events. In some cases, the refuge areas had insufficient space for all of the building occupants, or were in locations which would be difficult to move the occupants to in a reasonable period of time. While there were no reports of fatalities in the refuge areas studied, it was likely because the areas were not occupied when the storms struck because many of refuge areas had collapsed or filled with broken glass from windows shattered by wind-borne debris.

Administrative officials interviewed in several communities after the April 2011 Tornado Outbreak indicated that they had been unable to obtain the expertise of a design professional in selecting the appropriate refuge area. The reason cited was liability concerns on the part of the design professional. To ease this concern,

Table 3. Design Criteria Comparison

Shelter Design Standard, Code, or Document	Data[1]	Example Location # 1: Miami, FL	Example Location #2: Joplin, MO
FEMA 361 [2]	Design wind speed	200 mph (tornado) 225 mph (hurricane)	250 mph
	Pressure on windward wall	107 psf[3] (tornado) 135 psf (hurricane)	167 psf
	Pressure on roof section	239 psf (tornado, suction) 303 psf (hurricane, suction)	374 psf (suction)
	Test missile momentum at impact	61 lb_f-s (tornado) 46 lb_f-s (hurricane)	68 lb_f-s
ICC-500	Design wind speed	200 mph (tornado) 225 mph (hurricane)	250 mph
	Pressure on windward wall	107 psf (tornado) 135 psf (hurricane)	167 psf
	Pressure on roof section	239 psf (tornado, suction) 303 psf (hurricane, suction)	374 psf (suction)
	Test missile momentum at impact	61 lb_f-s (tornado) 37 lb_f-s (hurricane)	68 lb_f-s
FBC EHPA/SESP (using + 40 mph recommendation)	Design wind speed	186 mph	N/A
	Pressure on windward wall	106 psf	N/A
	Pressure on roof section	238 psf (suction)	N/A
	Test missile momentum at impact	34 lb_f-s	N/A
ASCE 7-10 (ASTM E 1996)	Design wind speed	170 mph	115 mph
	Pressure on windward wall	77 psf	35 psf
	Pressure on roof section	173 psf (suction)	79 psf (suction)
	Test missile momentum at impact	14 lb_f-s	Not required
ASCE 7-05/IBC 2009 (ASTM E 1996) [4,5]	Design wind speed	150 mph	90 mph
	Pressure on windward wall	69 psf	25 psf
	Pressure on roof section	155 psf (suction)	56 psf (suction)
	Test missile momentum at impact	14 lb_f-s	Not required
IBHS	Design wind speed	150 mph	90 mph
	Pressure on windward wall	69 psf	25 psf
	Pressure on roof section	155 psf (suction)	56 psf (suction)
	Test missile momentum at impact	14 lb_f-s	Not required
FBC EHPA	Design wind speed	146 mph	N/A
	Pressure on windward wall	66 psf	N/A
	Pressure on roof section	147 psf (suction)	N/A
	Test missile momentum at impact	23 lb_f-s	N/A
Pre-2000 Building Codes	Design wind speed	140 mph and less	90 mph and less
	Pressure on windward wall	< 40 psf (varies)	< 15 psf (varies)
	Pressure on roof section	< 120 psf (varies)	< 45 psf (varies)
	Test missile momentum at impact	Not required by all codes	Not required
ARC 4496	Design wind speed	N/A	N/A
	Pressure on windward wall	N/A	N/A
	Pressure on roof section	N/A	N/A
	Test missile momentum at impact	N/A	N/A
Areas of Last Resort	Design wind speed	Unknown	Unknown
	Pressure on windward wall	Unknown	Unknown
	Pressure on roof section	Unknown	Unknown
	Test missile momentum at impact	Not required	Not required

NOTES:
1. Wind pressures were calculated based on a 40-foot x 40-foot square building, with a 10-foot eave height and a 10-degree roof pitch, partially enclosed
2. For a combined tornado/hurricane safe room, the more restrictive criteria apply. FEMA 320 criteria are based on a 250-mph wind speed regardless of location
3. psf – Pounds per square foot; lb_f-s – Pounds (force) seconds
4. Non-storm shelter wind design criteria
5. IBC/IRC 2000, 2003, and 2006 editions and ASCE 7-98 have similar wind design criteria

engineers are encouraged to add the following information and qualifiers to their contract and their findings report:

- The identified area should be considered by building owners as only a “best available area of refuge” and occupants could still be injured or killed
- The findings should include:
  - The level of testing completed during the identification of the area
  - The total number of occupants the area can hold
  - The approximate maximum safe wind speed for the best available refuge area
  - The timeframe before which the area should be re-evaluated
  - An outline of potential modifications that could be made to the structure to improve its performance in high-wind events
- State that changes to the building may make the refuge area no longer the best available refuge area

Agreement between the client and the design professional on these points may ease some of the liability concerns. Administrators and facilities managers for buildings with large occupancies should also review FEMA P-431 (2009) and the refuge area evaluation checklists presented in Appendix B of FEMA 361.

Operating a Safe Room

In addition to the safe room’s structural performance requirements, the following operational, maintenance, and human factors criteria must be considered for a successful safe room:

- Standby power (e.g., generator)
- Protection of critical support systems such as a generator
- Occupancy duration
- Ventilation
- Minimum square footage per occupant
- Egress
- Distance and travel time for occupants traveling to the safe room
- Access for disabled occupants
- Special needs requirements
- Lighting
- Emergency provisions (food, water, sanitation management, emergency supplies, communication equipment)
- Operations and maintenance plans for the safe room

Each of these items is further elaborated in FEMA 361 and ICC-500. Not all items must be considered for a residential safe room, but they are especially important when designing a community safe room.

Useful Links and Shelter Resources

Taking Shelter from the Storm: Building a Safe Room For Your Home or Small Business (FEMA 320), August 2008, 3rd Edition http://www.fema.gov/library/viewRecord.do?id=1536

Design and Construction Guidance for Community Safe Rooms (FEMA 361), August 2008 2nd Edition http://www.fema.gov/library/viewRecord.do?id=1657

Tornado Protection: Selecting Refuge Areas in Buildings (FEMA P-431), October 2009 2nd Edition http://www.fema.gov/library/viewRecord.do?id=1563

ICC/NSSA Standard for the Design and Construction of Storm Shelters, International Code Council and the National Storm Shelter Association (ICC-500), June 2008 http://www.iccsafe.org/Store/Pages/Product.aspx?id=8850P08_PD-X-SS-P-2008-000001#longdesc

National Storm Shelter Association (NSSA); http://www.NSSA.cc

Residential Sheltering: In-Residence and Stand-Alone Safe Rooms

FEMA

TORNADO RECOVERY ADVISORY *RA3, June 2011*

Purpose and Intended Audience

The purpose of this advisory is to inform homeowners, renters, apartment building owners, and manufactured home park owners about in-residence and stand-alone safe rooms.

This Recovery Advisory Addresses:

- Consider a safe room for your home
- In-residence safe room construction and retrofitting options
- Recommendations for sheltering options for when you cannot place a safe room within your home
- Safe room doors
- Refuge areas
- Emergency supply kits and weather radios
- Registering your safe room with local officials

Consider a Safe Room for Your Home

The purpose of having a safe room in or near your home is to protect you and your family from injury or death from extreme winds. Safe rooms are intended to allow occupants to survive tornadoes and hurricanes with little or no injury. To determine your exposure to tornadoes, refer to FEMA 320, *Taking Shelter from the Storm: Building a Safe Room For Your Home or Small Business* (2008). This publication can help you decide whether to construct a safe room to protect you and your family from injury or death during a tornado or hurricane. Additional information is provided in the Tornado Recovery Advisory (RA) No. 1 titled "Tornado Risks and Hazards in the Southeastern United States" (updated in 2011).

After determining that you live in a tornado- or hurricane-prone region, it is important to understand the risks. Most homes, even new ones constructed according to current building codes, do not provide adequate protection for occupants seeking refuge from tornadoes. A tornado or hurricane can cause much greater wind and wind-borne debris loads on your house than those on which building code requirements are based. Only specially designed and constructed safe rooms, which are voluntarily built above the minimum code requirements, offer near-absolute protection during a tornado or hurricane.

> Safe rooms should not be constructed where flood waters have the potential to endanger occupants within the safe room. Safe rooms in areas where flooding may occur during hurricanes should not be occupied during a hurricane. However, occupying such a safe room during a tornado may be acceptable if the safe room will not be flooded by rains associated with other storm and tornado events. Consult your local building official or local National Flood Insurance Program representative to determine whether your home, or a proposed stand-alone safe room site, is susceptible to local, riverine, or coastal flooding.

In-Residence Safe Room Construction and Retrofitting Options

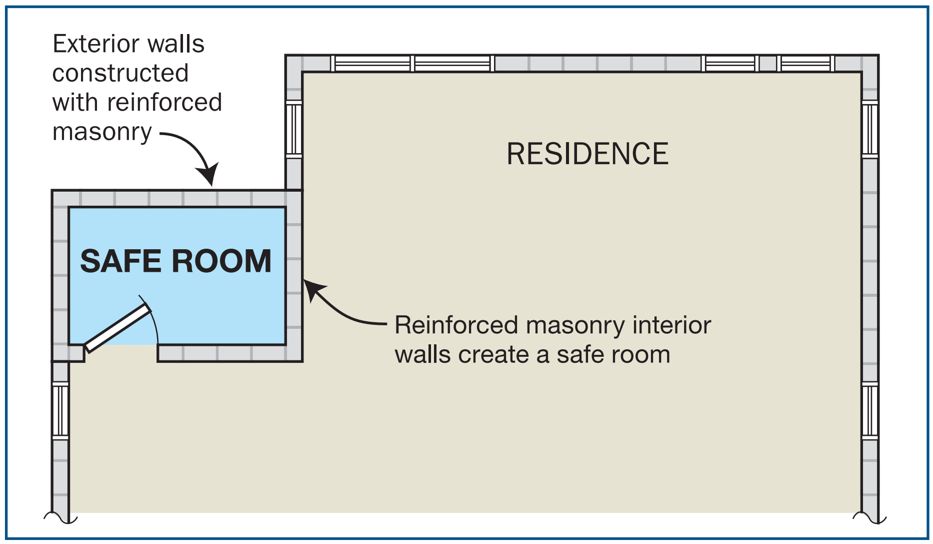
Constructing a safe room within your home puts it as close as possible to your family. While a safe room on the exterior of your home may provide adequate protection, it does require your family to be exposed to the weather elements while traveling to the safe room. A safe room may be either installed during the initial construction of a home or retrofitted afterward. As long as the design and construction requirements and guidance are followed, the same level of protection is provided by either type of safe room.

New Construction

FEMA 320 contains detailed drawings and specifications that can be used by a builder or contractor to construct a safe room in your home. The designs provided are for safe rooms constructed of wood, masonry, or concrete. All of them are designed to resist 250 mph (3-second gust) wind speeds and impacts from wind-borne debris. Pre-fabricated safe rooms are also available for installation when first building your home. The basic cost to design and construct a safe room during the construction of a new house is approximately $6,000; larger, more refined, and more comfortable designs may cost more than $15,000.

It is relatively easy and cost effective to add a safe room when first building your home. For example, when the home is constructed with exterior walls made from concrete masonry units (CMU, also commonly known as "concrete block," see sketch this page), the protection level in FEMA 320 can be achieved by strengthening the safe room area's exterior walls with additional steel reinforcement and grout. The safe room is easily completed by adding interior walls constructed of reinforced CMU, a concrete roof deck over the safe room, and a special safe room door, as shown under construction in the bottom photograph.

CMU was used for the exterior walls at this house under construction (New Smyrna Beach, FL).



Sketch of floor plan showing location of safe room area in house.

View of an in-residence safe room under construction. Steel reinforced and fully grouted CMU surround the safe room space (New Smyrna Beach, FL).

Retrofitting Existing Houses

FEMA 320 contains general guidance for retrofitting a house by adding a safe room. Building a safe room in an existing house will typically cost 20 percent more than building the same safe room in a new house while under construction. Because the safe room will be used for life safety, and because your home might be exposed to wind loads and debris impacts it was not designed to resist, an architect or engineer should be employed to address special structural requirements, even if inclusion of an architect or engineer in such a project is not required by the local building department.

The design drawings provided in FEMA 320 are also appropriate for use in small businesses, fire and police stations, and other public areas where small groups of people may be seeking life-safety protection from extreme winds and wind-borne debris.

Recommendations for Sheltering When You Cannot Place a Safe Room Within Your Home

There are many reasons that homeowners or renters may not be able to install a safe room within their home. These could include lack of permission (the resident does not own the home or does not have rights to modify or change the home), lack of available space, or lack of technical or economic practicality. In those cases, a stand-alone safe room can be designed and constructed outside of a residence. Stand-alone safe rooms can provide the same level of protection against high winds and wind-borne debris as in-residence safe rooms.

For more information about pre-fabricated and stand-alone safe rooms and storm shelters, contact the National Storm Shelter Association (http://www.nssa.cc)

Small Stand-Alone Safe Rooms

Some site-built homes, and most manufactured homes, do not lend themselves to the structural modifications and retrofitting required to install or construct an in-residence safe room. In these instances, a stand-alone safe room may be constructed (either above grade, partially above grade or below grade) near the residence. Small stand-alone safe rooms can be constructed to accommodate the occupants of one house, a few houses, or a small apartment building. The photograph from Tuscaloosa, AL, shows how a stand-alone safe room provides refuge for the residents.

Community Safe Rooms

A community safe room can be constructed to accommodate the occupants of several apartments or homes (site-built or manufactured homes). The small safe room designs in FEMA 320 were revised in 2008 and expanded for applications of up to 16 individuals and are suitable for use by business, public facilities, and others when a small, community safe room is desired. The design criteria for these prescriptive designs are presented in FEMA 361, Design and Construction Guidance for Community Safe Rooms (2008). For additional information about community safe rooms, refer to the Tornado Recovery Advisory No. 2 titled “Safe Rooms: Selecting Design Criteria” (updated in 2011). Many different types of safe rooms can be designed and

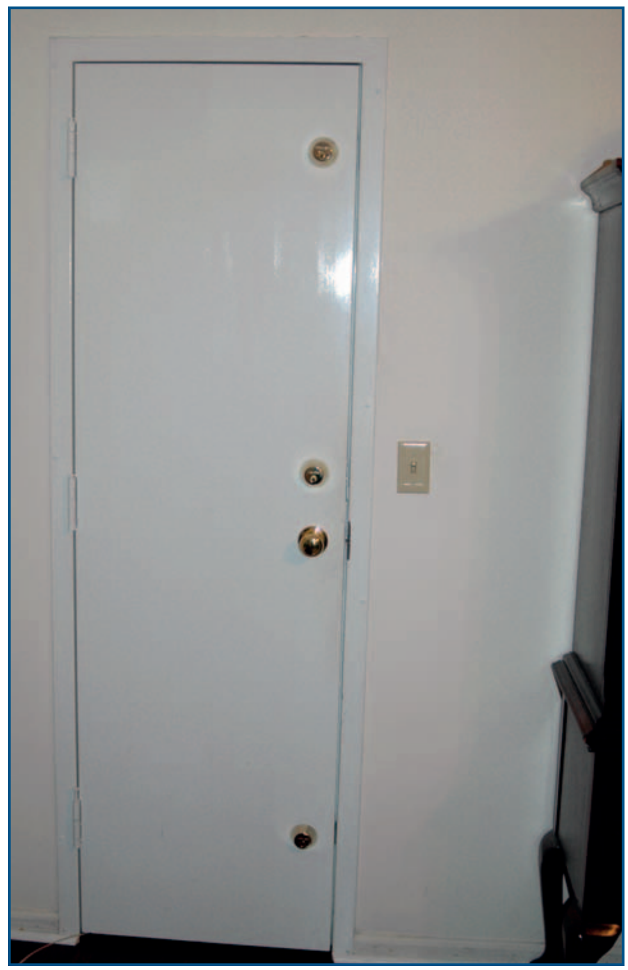
View of a pre-fabricated safe room that serves a residence (Tuscaloosa, AL).

constructed to meet the needs of small or large groups of residents. A safe room may be constructed to be used solely as a shelter or it may be designed as a multi-use building, such as a clubhouse, school, or recreation center. A safe room may also be constructed above-grade, below-grade, or partially below-grade as shown in the photograph from Brookwood, AL. Selecting the right type of safe room will be a collective decision made by the residents, funding agencies, and property owners and managers. For information on community safe rooms for larger populations, including planning and operational issues, see FEMA 361.

View of a partially below-grade community safe room (Brookwood, AL).

Safe Room Doors

When building a safe room, it is very important to pay extra attention to the safe room door. Door construction has been found to be a common weakness in safe rooms' ability to withstand high wind pressures and missile impacts. Door failures are typically due to the type of door construction and door hardware. Standard door construction that meets minimum code requirements is not sufficient to withstand the extreme wind forces and the wind-borne debris impacts often seen in extreme wind events. It is imperative that the walls, ceilings, and doors of a safe room be able to withstand the impacts of missiles carried by extreme winds.



Photograph of safe room door with three deadbolts and three hinges.

Safe room doors are tested by laboratories for their ability to withstand the pressures associated with high-wind events and missile impacts. To meet the criteria set forth in FEMA 320 for residential and small community safe rooms, doors must resist wind pressures and wind-borne debris impacts in tests set forth in the International Construction Code/National Storm Shelter Association (ICC/NSSA) *Standard for the Design and Construction of Storm Shelters* (ICC-500), for a 250 mph safe room design wind speed and impacts from a 15-pound 2x4 sawn lumber member traveling horizontally at 100 mph (additional design restrictions apply).

Research by the NSSA has shown that steel doors with 14-gauge (or heavier) skins are able to withstand the standard missile impact test. Such doors in widths up to 3 feet, typical of what is found in a residential safe room, are capable of withstanding wind loads associated with wind speeds up to 250 mph when they are latched with three hinges and three deadbolts. At the time of this publication, there has not been a wood door that has successfully passed the pressure or missile impact tests using the design criteria for 250 mph winds. Testing has been performed on various sized doors, and guidance on choosing an appropriate safe room door can be found in Appendix F of FEMA 361 (2008).

Refuge Areas

Occupants of dwellings that do not have in-residence safe rooms or access to stand-alone or community safe rooms should identify the best available refuge area in their home before an emergency happens. When people identify and take refuge in the best available space within a building, they are less likely to be injured or killed. However, it is important to remember that "best available refuge areas" are not specifically designed as safe rooms, so occupants can be injured or killed during a tornado or hurricane event if the high winds breach the building.

View of remnants of an interior room of a house that survived a strong tornado (Tuscaloosa, AL).

The lowest floor of a building is usually the safest. Upper floors receive the full strength of the winds. Occasionally, tornado funnels hover near the ground but hit only upper floors. Belowground space is almost always the safest location for a refuge area. The following criteria should be considered when identifying the best available refuge area in your home:

Avoid selecting a refuge area that is near a masonry chimney (Moore, OK).

- Choose a location that is large enough for all the residents of the home. It is recommended that each person be provided with a minimum of 5 square feet of space in the refuge area. Additional space will need to be accounted for if the residents of the home are wheelchair users or bedridden. Guidance is provided in FEMA P-431, *Tornado Protection: Selecting Refuge Areas in Buildings* (2009).
- Avoid locations with high ceilings. These spaces often have long-span roofs that can collapse under the forces imposed by tornado winds.
- Choose the lowest floor of the residence. A basement is preferable, or first floor if there is no basement).
- Avoid taking refuge in basements with exterior doors or large windows (i.e., walk-out basement). If no other viable option exists, take shelter in a basement area that is away from windows and exterior doors.
- Choose a small interior room without windows (i.e., none of the room's walls is an exterior wall), such as a bathroom or closet, preferably with only one door.

- Choose a room located away from masonry chimneys, trees, or power poles.
- Keep the room relatively free of clutter so you and the other residents can enter and remain in the room for up to several hours.

Homeowners and renters should also refer to the Tornado Recovery Advisory No. 2 titled "Safe Rooms: Selecting Design Criteria" (updated in 2011).

Emergency Supply Kits and Weather Radios

FEMA 320 includes information on preparing a family emergency plan and an emergency supply kit for a shelter. Further, all individuals living or working in tornado-prone areas should have a battery-powered weather radio in their home or place of work. For more information about weather radios, see Tornado Recovery Advisory No. 1 titled "Tornado Risks and Hazards in the Southeastern United States" (updated 2011).

Registering Your Safe Room with Local Officials

FEMA recommends that the local fire department, local emergency management agency (EMA), and other relevant local officials be given the location of the safe room. Providing the latitude and longitude coordinates of the entrance to the safe room to local officials can be vital in post-disaster recovery efforts. In the event that debris is surrounding or on top of the safe room, this will allow them to check on the safe room to make sure the occupants are not trapped inside.

Useful Links and Resources

Taking Shelter from the Storm: Building a Safe Room For Your Home or Small Business (FEMA 320), August 2008, 3rd Edition http://www.fema.gov/library/viewRecord.do?id=1536

Design and Construction Guidance for Community Safe Rooms (FEMA 361), August 2008, 2nd Edition http://www.fema.gov/library/viewRecord.do?id=1657

Tornado Protection: Selecting Refuge Areas in Buildings (FEMA P-431), FEMA, October 2009, 2nd Edition http://www.fema.gov/library/viewRecord.do?id=1563

National Storm Shelter Association (NSSA); http://www.NSSA.cc

Safe Rooms and Refuge Areas in the Home

FEMA

TORNADO RECOVERY ADVISORY *RA4, June 2011*

Purpose and Intended Audience

The intended audience for this Tornado Recovery Advisory is homeowners or home builders. Homeowners and renters should also refer to the Tornado Recovery Advisory No. 3 titled "Residential Sheltering: In-Residence and Stand-Alone Safe Rooms" (updated in 2011). The purpose of this advisory is to identify the different types of safe rooms and provide a brief overview of areas of refuge.

This Recovery Advisory Addresses:

- How safe room construction is different from typical home construction
    - Which guidance should be followed
    - What constitutes a safe room
- Refuge areas in the home

An example of an above-ground, in-residence safe room that successfully protected two people (Joplin, MO).

How Safe Room Construction is Different from Typical Home Construction

A residential safe room is a space, either within a home or an entirely separate structure, designed and constructed to protect its occupants from tornadoes or hurricanes. The safe room may be located above or below ground. Safe rooms are intended to provide protection against both wind forces and the impact of wind-borne debris. Near-absolute life-safety protection is the level of occupant protection provided by a space specifically designed as a safe room and constructed to meet criteria set forth by FEMA; this is much greater than the protection provided by buildings that comply with the minimum requirements of building codes. Although the FEMA guidance on safe rooms has been available since 1998, building codes did not begin to provide design and construction criteria for life-safety protection from wind events until 2009. When constructed to meet the criteria set forth in the building codes, hardened areas are called storm shelters. Design criteria for storm shelters are similar to criteria for safe rooms, but differences do exist. Information about safe room criteria and storm shelter criteria can be found in other guidance documents referenced in this recovery advisory. A slightly higher level of protection is provided when safe rooms are constructed to meet the FEMA criteria, and owners may be eligible for FEMA grant programs to fund the design and construction of the safe room.

> A safe room is a room or structure specifically designed and constructed to resist wind pressures and wind-borne debris impacts during an extreme-wind event for the purpose of providing life-safety protection.

Safe rooms typically fall into two categories: residential safe rooms and community (non-residential) safe rooms.

- **Residential Safe Rooms:** There are two general types of residential safe rooms: in-residence safe rooms and stand-alone safe rooms (located adjacent to, or near, a residence). An ***in-residence safe room*** is a small, specially designed ("hardened") room, such as a bathroom or closet that is intended to provide a protected area for the people who live in the house. A ***stand-alone safe room*** is similar in function and design, but it is a separate structure installed outside the house, either above or below the ground surface. FEMA guidance is available in FEMA 320, *Taking Shelter from the Storm: Building a Safe Room For Your Home or Small Business* (2008).
- **Community Safe Rooms:** Some areas construct community safe rooms that provide protection for a large number of people—from 16 to as many as several hundred individuals. Criteria for designing and constructing a safe room can be found in FEMA 361, *Design and Construction Guidance for Community Safe Rooms* (2008).

A small area located inside a detached garage used as a refuge area during a tornado (Athens, AL).

The following should be considered when identifying the best available refuge area in your home:

- Choose a location that is large enough for all the residents of the home to be seated. Account for additional space if the residents of the home are wheelchair users or bedridden.
- Choose the **lowest** floor of the residence. A basement is preferable, or first floor if there is no basement. Below-ground space is almost always the safest location for a refuge area.
- Choose a small interior room without windows (i.e., none of the room's walls is an exterior wall), such as a bathroom or closet, preferably with only one door.
- Choose a room located away from masonry chimneys, trees, or power poles.
- Avoid locations with high ceilings. These spaces often have long-span roofs that can collapse under the forces imposed by tornado winds.
- Avoid taking refuge in basements with exterior doors or large windows (i.e., walk-out basement). If no other viable option exists, choose an area that is away from windows and exterior doors.
- Keep the room relatively free of clutter so you can remain in the space for up to several hours.

Selecting Refuge Areas in the Home

If there are no hardened areas within or near a home to use during high wind events, homeowners should consider whether their house can be retrofitted for a safe room. If this is not a viable option, homeowners should identify the best available refuge areas in their home. People in manufactured homes should seek shelter in a community safe room.

Useful Links and Safe Room Resources

Taking Shelter from the Storm: Building a Safe Room For Your Home or Small Business (FEMA 320), August 2008, 3rd Edition http://www.fema.gov/library/viewRecord.do?id=1536

Design and Construction Guidance for Community Safe Rooms (FEMA 361), August 2008, 2nd Edition
http://www.fema.gov/library/viewRecord.do?id=1657

ICC/NSSA Standard for the Design and Construction of Storm Shelters, International Code Council and the National Storm Shelter Association (ICC-500), June 2008
http://www.iccsafe.org/Store/Pages/Product.aspx?id=8850P08_PD-X-SS-P-2008-000001#longdesc

Additional information from FEMA Building Science can be found at http://www.fema.gov/rebuild/buildingscience and http://www.fema.gov/plan/prevent/saferoom

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

FEMA

TORNADO RECOVERY ADVISORY RA5, July 2011

Purpose and Intended Audience

Critical facilities are emergency operations centers (EOCs), fire and police stations, hospitals, nursing homes, schools, and other buildings that are essential for the delivery of vital services or protection of a community. Tornado damage investigations and other research have shown us techniques for protecting occupants of critical facilities struck by tornadoes, as well as maintaining continuity of operations for those facilities. The 2011 tornadoes that struck the southeast United States specifically highlighted the importance of properly selecting the best available refuge area in existing facilities as well as the importance of minimizing collapse hazards, such as tree fall and other nearby objects. The purpose of this advisory is to inform critical facility owners of enhancements that can be made both to existing facilities and those still in the planning stage. With this awareness, facility owners can budget for desired enhancements and request that these enhancements be incorporated into the construction documents.

This Recovery Advisory Addresses:

- Best available refuge areas
- Tree fall and other collapse hazards
- Safe rooms
- Strengthening new facilities to minimize damage from tornadoes
- Enhancements to avoid interrupted operations

Existing Buildings

Critical facility owners should hire the services of a qualified architect or engineer to evaluate their existing building. The evaluation should determine whether the facility adequately protects occupants, operations, and the facility itself from tornadoes and other appropriate hazards. The evaluation should identify the best available refuge areas in the existing facility. Any needed enhancements can be incorporated into capital improvement planning and budgeting. Lack of adequate planning can result in loss of operation and possible loss of life when buildings are inadequately hardened or lack a best available refuge area for occupants (Figure 1).

Figure 1: An EOC in Tuscaloosa, AL, that saw a loss of operations but remained intact even though the story above it collapsed (Tornado 2011)
PHOTO COURTESY OF THE TUSCALOOSA COUNTY SHERIFF'S OFFICE.

Best Available Refuge Areas

In regions of the United States subject to tornadoes, identifying the best available refuge areas within buildings is essential for the safety of building occupants. ***Safe rooms*** specifically designed and constructed to resist wind-induced forces and the impact of wind-borne debris provide the best protection. However, findings from investigations of past tornadoes show that many critical facilities contain rooms or areas that may afford some degree of protection from all but the most extreme tornadoes (i.e., an EF4 and EF5 tornado). The ***best available refuge areas*** should be identified in buildings that do not have areas designed and constructed to serve as safe rooms. Giving building occupants a best available refuge area in a building greatly reduces the risk of injury or death. Best available refuge areas do not guarantee safety; they are, however, the safest areas available for building occupants.

Interior areas with short-span roof systems, such as corridors and small rooms (e.g., restrooms), are often the best available refuge areas. However, as shown in Figure 2, this is not always the case. It is therefore recommended that owners of critical facilities hire a qualified architect or structural engineer familiar with tornado risk analysis to assess existing buildings and identify the best available refuge areas.

The architect's or engineer's systematic review of a building may reveal some problems (such as doors with glass vision panels) within the best available refuge area that can be economically mitigated to improve the refuge area. Areas that include such doors or other problems could still be considered the best available refuge areas despite the vulnerability of the glass. However, known problems should be addressed to the extent possible. Examples of corrective actions include replacing any doors that contain windows or replacing the existing glazing with impact-resistant glazing.

Collapse Hazards

Collapse hazards can include parts of the building, communication towers and equipment, chimneys, poles, and trees. Collapses can break windows and rupture roof coverings of critical facilities, damage components such as emergency generators and HVAC equipment needed for the operation of a critical facility, and cause structural damage to buildings (Figure 3). Collapse hazards must be addressed in design and sheltering decisions to avoid injuries or death and to ensure operational requirements of a critical facility are met. Potential collapse hazards can be evaluated using the checklists in Appendix B of FEMA 361, *Design and Construction Guidance for Community Safe Rooms* (2008) and the results can be used to evaluate the best available refuge areas.

Guidance documents for identifying best available refuge areas are referenced in FEMA Recovery Advisory No. 6, *Critical Facilities in Tornado-Prone Regions: Recommendations for Architects and Engineers*.

Enhanced Fujita Scale	
EF0	65–85 mph winds
EF1	86–110 mph
EF2	111–135 mph
EF3	136–165 mph
EF4	166–200 mph
EF5	>200 mph

Figure 2: Debris in an elementary school restroom in Tuscaloosa, AL (Tornado 2011)

Figure 3: Collapse of a large communications tower onto a building in Joplin, MO (Tornado 2011)

Proper maintenance and placement of trees will minimize damage to critical facilities and surrounding buildings. Trees should be placed such that the distance between the critical facility and the tree is greater than the height the tree will reach when it is fully grown. Trees with wounds, decay, structural defects, known internal trunk voids, severed roots, and soil compaction are prime targets for storm damage. These defects are often a result of damage from a lawnmower or weed trimmer and can be avoided with proper, careful lawn maintenance.

Vulnerability assessment of existing facilities: Most existing critical facilities are vulnerable to damage if struck by tornadoes. The damage may result in minor inconvenience or it may necessitate shutting down the facility. Facilities struck by an EF4 or EF5 tornado will normally not be operational unless the facility was designed to remain operational if struck.

A vulnerability assessment can be conducted by a team of architects and engineers. Findings from such an assessment can lay the groundwork for planning and budgeting capital improvements or developing contingency plans that address facility disruption.

New trees should be planted at the correct depth. Trees planted too deep can develop stem girdling, where the tree roots encircle the stem and weaken it just below the ground, making it more likely to snap off at the stem-girdled point in the event of a forceful wind. In addition, mature trees should be pruned to correct defects, such as multiple leaders and weak branch attachments. Prune trees as soon as the defect is detected because younger trees will heal faster from the pruning.

New Buildings and Additions to Existing Buildings

During planning and budgeting for a new facility or making additions to existing facilities, a designer or space planner normally helps the facility owner develop a program for types of spaces, size of space, equipment needed, parking, and many other elements. For critical facilities in areas prone to tornadoes, owners should consider building safe rooms, strengthening their facility to minimize damage, and enhancing their facility to avoid interruption of operations (see also Recovery Advisory No. 6 for the associated design and construction guidance).

Safe Rooms

All new critical facilities should include one or more safe rooms (depending on facility size) to provide occupant protection. When adding on to an existing facility that does not have a safe room, facility owners should budget for a safe room within the addition (see Figure 4). If possible, the safe room should be sized to accommodate the number of occupants in the existing building and the addition.

Safe rooms are typically dual-function rooms. During normal times, the safe room may function as a training room, restroom, hallway, or other such purpose. When tornadoes threaten, the specially designed and constructed safe room serves to protect the building occupants. The additional cost of making a room serve a dual function as a safe room varies. Excluding interior finishes and furnishings in the safe room area, a cost of $200 per square foot for budgeting is usually sufficient to cover design fees and construction.[1]

Safe rooms afford building occupants near absolute protection. However, facility operations that are housed outside of a safe room 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 recommended below.

Figure 4: The addition to this school was designed to serve as a safe room (Wichita, KS)

If Federal funding for the design and construction of a safe room is sought, the technical information in FEMA 361 (2008) must be adhered to as part of the funding requirements of the FEMA safe room policy. FEMA policy on the eligibility of the design and construction of safe rooms for Federal funding is provided in FEMA Mitigation Interim Policy MRR-2-09-1, *Hazard Mitigation Assistance for Safe Rooms*, dated April 30, 2009.

Strengthening New Facilities to Minimize Damage from Tornadoes

By using design strategies and building materials that are used in hurricane-prone regions[2], facilities can be built to be more resistant to tornadoes. Therefore, facility owners should consider budgeting for strengthening new buildings or additions to minimize damage and disruption from nearby weak and strong tornadoes and from violent tornadoes that are on the periphery of the facility. With appropriate strengthening and selection of building materials and systems, the cost of tornado repairs and the potential for disruption of operations (see Figure 5) will likely be reduced. Even when constructing a facility using stronger systems, a safe room should be included in the facility to protect occupants during an EF4 or EF5 tornado that strikes the facility.

Enhancement to Avoid Interrupted Operations

Designing a facility to ensure it will remain operational if struck by a violent tornado is expensive. Therefore, when considering the costs and benefits of designing for continuity of operations, it may be more cost effective to design to minimize building damage and/or provide safe rooms. If, because of the additional expense, the owner determines that a critical facility does not need to be operational if struck by a violent tornado, then this reduced building performance should be clearly considered and addressed in emergency operations plans. Other critical facilities should be identified (that are not expected to be impacted by the same tornado) from which to continue critical operations. Appropriate planning, emergency plans, and agreements should be put in place. For facilities such as Emergency Operations Centers that are determined to be critical in providing effective emergency response, owners should budget facility enhancements to avoid interrupted operations even if struck by violent tornadoes.

Specific design recommendations pertaining to continuity of operations are provided in FEMA Recovery Advisory No. 6, *Critical Facilities in Tornado-Prone Regions: Recommendations for Architects and Engineers*.

1 Section 2.3 and Table 2-4 in FEMA 361 (2008), provides additional information on safe room costs.

2 For more information on constructing buildings hurricane-prone regions, refer to FEMA P-424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds* (2010); FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds* (2007); and FEMA 577, *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds* (2007).

Specific design recommendations for minimizing building damage are provided in FEMA Recovery Advisory No. 6, *Critical Facilities in Tornado-Prone Regions: Recommendations for Architects and Engineers.*

Figure 5: Most of the exterior glass in this Joplin, MO, hospital was broken (Tornado 2011)

Vulnerability assessment of new facilities: As part of the planning process for new facilities, other natural hazards (flood, seismic, and wildfire) should be considered in addition to the tornado hazard. FEMA P-424 (2010), 543 (2007), and 577 (2007) provide guidance on conducting vulnerability assessments. If the building design does not ensure continuity of operations, contingency plans should be developed that address facility disruption.

Useful Links and Resources

2007 Tornado Recovery Advisories. FEMA. 2007. http://www.fema.gov/library/viewRecord.do?id=2631

Hazard Mitigation Assistance for Safe Rooms FEMA. April 2009. Mitigation Interim Policy, MRR-2-09-1. http://www.fema.gov/library/viewRecord.do?id=3634

HMA Unified Guidance FY 10. FEMA. 2009. http://www.fema.gov/library/viewRecord.do?id=3649

HMA Unified Guidance FY 11. FEMA. 2010. http://www.fema.gov/library/viewRecord.do?id=4225

Recovery Advisory No. 6, *Critical Facilities in Tornado-Prone Regions: Recommendations for Architects and Engineers.* FEMA. 2011.

Taking Shelter from the Storm: Building a Safe Room For Your Home or Small Business (FEMA 320). August 2008, 3rd Edition. http://www.fema.gov/library/viewRecord.do?id=1536

Design and Construction Guidance for Community Safe Rooms (FEMA 361). August 2008, 2nd Edition. http://www.fema.gov/library/viewRecord.do?id=1657

Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds (FEMA P-424). December 2010, Second Edition. http://www.fema.gov/library/viewRecord.do?id=1986

Tornado Protection: Selecting Refuge Areas in Buildings (FEMA P-431). October 2009, Second Edition. http://www.fema.gov/library/viewRecord.do?id=1563

Design Guide for Improving Critical Facility Safety from Flooding and High Winds (FEMA 543). January 2007. http://www.fema.gov/library/viewRecord.do?id=2441

Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds (FEMA 577). June 2007. http://www.fema.gov/library/viewRecord.do?id=2739

ICC/NSSA Standard for the Design and Construction of Storm Shelters (ICC-500), June 2008. http://www.iccsafe.org/Store/Pages/Product.aspx?id=8850P08_PD-X-SS-P-2008-000001

Critical Facilities Located in Tornado-Prone Regions: Recommendations for Architects and Engineers

FEMA

TORNADO RECOVERY ADVISORY *RA6, August 2011*

Purpose and Intended Audience

Critical facilities are emergency operations centers (EOCs), fire and police stations, hospitals, nursing homes, schools, and other buildings that are essential for the delivery of vital services or protection of a community. Tornado damage investigations and other research have helped to identify techniques for protecting occupants of critical facilities struck by tornadoes, as well as maintaining continuity of operations for those facilities. The 2011 tornadoes that struck the southeast United States specifically highlighted the importance of properly selecting the best available refuge areas in existing facilities as well as the importance of minimizing collapse hazards, such as tall trees and other nearby objects.

The purpose of this advisory is to inform architects and engineers of design enhancements that can be made to both existing facilities and facilities in the planning stage. With this awareness, desired enhancements can be incorporated into construction documents.

The interim information in this Recovery Advisory is intended to assist during the recovery and redevelopment of tornado-damaged areas and to minimize future tornado damage and interruption of operations. This information was developed because of the lack of design guidance on this topic.

This Recovery Advisory Addresses:

- Existing Buildings
  - Best available refuge areas
  - Tree fall and other collapse hazards
- New Buildings and Additions to Existing Buildings
  - Safe rooms
  - Strengthening new facilities to minimize damage from tornadoes
  - Enhancements to avoid interrupted operations

Standard of Care

Critical facilities have facility and operational requirements that should be met in addition to building code requirements. Building codes do not stipulate expected building performance for tornadoes. The designer should discuss expectations for acceptable building damage, operational requirements, and occupant safety with the facility owner to ensure the full range of solutions for any special requirements is considered.

Multi-hazard Design

This Recovery Advisory addresses the tornado hazard. However, critical facilities may be damaged—and continuity of operations may be impaired—by other natural hazards such as flooding, seismic events, and wildfire. When performing vulnerability assessments and design work on critical facilities, all natural hazards that can affect the facility should be considered and accounted for.

Terminology: Safe Rooms and Shelters

"Safe rooms" are defined as buildings or portions thereof that comply with FEMA 361, *Design and Construction Guidance for Community Safe Rooms* (2008).

"Shelters" are defined as buildings or portions thereof that comply with International Code Council (ICC), ICC 500, *ICC/NSSA Standard on the Design and Construction of Storm Shelters* (2008).

FEMA 361 and the ICC 500 criteria are quite similar. All safe room criteria in FEMA 361 meet the shelter requirements of the ICC 500. However, a few design and performance criteria in FEMA 361 are more restrictive than those in the ICC 500.

A summary of the primary differences between FEMA 361 and ICC 500 is presented in Recovery Advisory No. 2, *Safe Rooms: Selecting Design Criteria* (June 2011). The 2009 edition of the International Building Code (IBC) references ICC 500 for the design and construction of hurricane and tornado shelters. However, although ICC 500 specifies shelter criteria, it does not require shelters.

FEMA's MRR-2-09-1, *Hazard Mitigation Assistance for Safe Rooms*, dated April 30, 2009, sets forth eligibility requirements for Pre-Disaster Mitigation Program and Hazard Mitigation Grant Program safe room projects and requires adherence to FEMA 361. Also refer to the appropriate State Hazard Mitigation Officer for additional information (http://www.fema.gov/about/contact/shmo.shtm).

Existing Buildings

Although safe rooms specifically designed and constructed to resist wind-induced forces and the impact of wind-borne debris provide the best protection, buildings can have rooms or areas that afford some degree of protection from all but the most extreme tornadoes (i.e., an EF4 or EF5 tornado on the Enhanced Fujita scale). In buildings that do not have areas designed and constructed to serve as safe rooms, the goal of the architect or engineer should be to select the ***best available refuge areas***. Giving building occupants a best available refuge area in a building greatly reduces the risk of injury or death. Best available refuge areas do not *guarantee* safety; they are, however, the safest areas available for building occupants. Interior areas with short-span roof systems, such as corridors and small rooms (e.g., restrooms), are often best available refuge areas. However, as shown in Figures 1 and 2, this is not always the case. It is therefore recommended that qualified architects or engineers familiar with tornado risk analysis follow the guidance in FEMA P-431, *Tornado Protection: Selecting Refuge Areas in Buildings* (2009), and the checklists in Appendix B of FEMA 361, to identify best available refuge areas. It is recommended that the best available refuge area(s) have a permanent sign installed that states "Tornado Refuge Area."

An architect's or engineer's systematic review of a building may reveal some problems (such as doors with glass vision panels as shown in Figure 3) within the best available refuge area that can be economically mitigated to improve the refuge area.

Vulnerability Assessment of Existing Facilities

Most existing critical facilities are vulnerable to damage if struck by tornadoes. The damage may result in minor inconvenience or it may necessitate shutting down the facility. Facilities struck by a violent (EF4 and EF5) tornado will normally not be operational unless the facility was designed to remain operational if struck.

A vulnerability assessment can be conducted by a team of architects and engineers. Findings from such an assessment can lay the groundwork for planning and budgeting capital improvements or developing contingency plans that address facility disruption.

Figure 1: Debris in a school corridor in Joplin, MO (2011 Tornado)

Figure 2: Collapsed concrete masonry unit (CMU) walls at a Joplin, MO, school restroom (2011 Tornado)

Figure 3: Broken vision panel at an elementary school corridor in Tuscaloosa, AL (2011 Tornado)

Areas that include such doors or other problems could still be considered the best available refuge areas despite the vulnerability of the glass. However, known problems should be addressed to the extent possible. An example of a corrective action would be to replace doors that have vision panels with new door/vision panel assemblies that resist the test Missile E load specified in ASTM E 1996, when tested in accordance with ASTM E 1886. For more information on the test Missile E, see Section 6.3.3.3 of FEMA P-424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds* (2010).

Collapse Hazards

Position poles, towers, and trees with trunks larger than 6 inches in diameter away from new buildings, additions to existing buildings, and primary site access roads so that they do not hit or block access to the facility if they topple.

When evaluating critical facilities to determine the best available refuge areas, architects and engineers should identify ***potential collapse hazards*** using the checklists in Appendix B of FEMA 361. Collapse hazards can include parts of the building, communication towers and equipment, chimneys, poles, and trees that can damage buildings with light-frame construction, break windows, and rupture roof coverings (Figures 4 and 5). Refer also to Recovery Advisory No. 5, *Critical Facilities in Tornado-Prone Regions: Recommendations for Facility Owners* (2011).

Figure 4: Collapse of a large communications tower onto a building in Joplin, MO (2011 Tornado)

Figure 5: Tree-fall damage at a critical facility in Tuscaloosa, AL (2011 Tornado)

New Buildings and Additions to Existing Buildings

Architects and engineers designing new critical facilities or additions to existing facilities should consider including a safe room to protect occupants, making enhancements that will minimize building damage, and designing the facility to remain operational even if it is struck by a violent tornado.

Safe Rooms

For all new critical facilities, the facility design should incorporate one or more safe rooms (depending on facility size) to provide occupant protection. When adding on to an existing facility that does not have a safe room, incorporate safe rooms within the addition. Size the safe room to accommodate the number of occupants in the existing building and the addition. Note that if temporary buildings will be used to accommodate increases in occupancy (for example, schools with portable classrooms), space should be designed in the safe room to account for these potential changes in safe room occupancy.

FEMA 361 provides comprehensive guidance for the design of safe rooms, as well as for quality assurance and quality control for their design and construction. FEMA 320, *Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business* (2008), provides prescriptive solutions for safe rooms that will shelter 16 or fewer occupants. If a safe room is not incorporated, it is recommended that the architect or engineer identify the best available refuge area(s) and that a permanent sign be installed that states "Tornado Refuge Area."

Flood Hazards

See FEMA 361 Sections 3.2.1, 3.6, and 4.4.3 for information regarding flood hazards.

Minimizing Building Damage by Enhancing Building Resistance

By using design strategies and building materials that are used in hurricane-prone regions, critical facilities can be built to be more resistant to most tornadoes (i.e., EF0–EF3). FEMA's design guide series (see textbox) provides recommendations for facilities located outside of hurricane-prone regions; these recommendations should be considered minimum baseline recommendations for all critical facilities. The design guides also provide above-baseline recommendations for facilities located within hurricane- and tornado-prone regions.

New buildings and building additions can be strengthened to minimize building damage and disruption from weak (EF0–EF1) and strong (EF2–EF3) tornadoes that pass directly over the facility, and from violent (EF4–EF5) tornadoes on the periphery of the facility. With appropriate strengthening and selection of building materials and systems, the cost of tornado repairs and the potential for disruption of operations will likely be reduced. When strengthening buildings, it is recommended that a safe room(s) also be included in the critical facility to protect occupants in case a violent tornado (i.e., EF4 or EF5) passes over or near the facility.

FEMA Design Guides

Wind design recommendations for critical facilities located both inside and outside of hurricane- and tornado-prone regions can be found in the following FEMA publications:

- FEMA P-424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds* (2010)
- FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds* (2007)
- FEMA 577, *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds* (2007)

Enhancement Levels

FEMA recommends three enhancement levels. As the enhancement level increases, so does the level of protection from damage, disruption, and cost. Note that none of the enhancement levels ensure continuity of services such as electrical power or communications (see *Continuity of Operations* below). Table 1 provides a summary of the provisions to minimize building damage by enhancement level.

Level 1 Enhancements

Weak tornadoes (EF0 and EF1) have wind speeds that are below or somewhat above the 90-mph basic wind speed,[1] which is the design wind speed throughout most of the continental United States. Hence, buildings that comply with the International Building Code should exhibit good structural, door, and wall performance when struck by weak tornadoes. However, weak tornadoes can generate wind-borne debris that can break unprotected glazing and puncture many types of door, wall, and roof assemblies, which can result in significant interior damage and disruption. When the Level 1 enhancement recommendations are followed, the potential for debris and water to enter the building, if struck by weak tornadoes, is low.

Level 1 Enhancement Recommendations: In addition to the baseline recommendations in the FEMA P-424, 543, and 577 chapters that discuss high winds, design the roof deck, exterior doors, exterior glazing, and exterior walls to resist complete penetration by the test Missile E specified in ASTM E 1996. In addition, follow the roof system recommendations in P-424 (Section 6.3.3.7), 543 (Section 3.4.3.4), or 577 (Section 4.3.3.8) for hurricane-prone regions to reduce the potential for wind-borne debris-induced roof leakage. Figure 6 shows one of the recommended roof systems: sprayed polyurethane foam (SPF) over structural concrete. The strong tornado that struck this building did not debond the SPF from the concrete. Although wind-borne debris caused numerous gouges in the foam, the building did not leak because gouged SPF is not susceptible to leakage unless the foam is completely penetrated.

For fire stations, it is additionally recommended that apparatus bay doors and their connections to the structure be designed for a basic wind speed of 150 mph (plus an importance factor of 1.15).[2]

Brick veneer, aggregate roof surfacing, roof pavers, slate, and tile cannot be effectively anchored to prevent them from becoming missiles if a strong or violent tornado passes near a building with these components. To reduce the potential number of missiles, and hence reduce the potential for building damage and injury to people, it is recommended that these materials not be specified for critical facilities in tornado-prone regions.

Table 1: Summary of Provisions to Minimize Building Damage by Enhancement Level

Enhancement Levels	Recommendations
Level 1	• Resist test Missile E • Special roof system • Avoid listed roof and wall coverings • Design fire station apparatus bay doors for a basic wind speed of 150 mph
Level 2	• Level 1 enhancement recommendations • Design for basic wind speed of 150 mph
Level 3	• Level 2 enhancement recommendations • Special roof deck and exterior walls

Figure 6: Although struck by a strong tornado, the SPF roof system of this Plainfield, IL, building did not blow off (1990 Tornado)

Brick Veneer

If brick veneer is selected, the veneer should not be depended on to resist debris because of the high potential for collapse of the veneer.

Level 2 Enhancements

Strong tornadoes (EF2 and EF3) have wind speeds that are below or near the Level 2 enhancements design wind speed. Hence, when Level 2 recommendations are followed, buildings should not experience structural failure or door or wall collapse when struck by strong tornadoes. However, debris from an EF3 tornado may penetrate the building and result in extensive interior water and perhaps wind damage.

1 The 90-mph basic wind speed is based on the 2005 edition of American Society of Civil Engineers ASCE 7, *Minimum Design Loads for Buildings and Other Structures*. If ASCE 7-10 is used, the equivalent basic wind speed for Risk Category III and IV buildings is 120 mph.

2 The 150-mph basic wind speed is based on ASCE 7-05. If ASCE 7-10 is used, the equivalent basic wind speed for Risk Category III and IV buildings is 200 mph. (Note: The importance factor is built into the ASCE 7-10 maps; hence, the 1.15 importance factor is not used in the ASCE 7-10 pressure calculation equation.)

Level 2 Enhancement Recommendations: The facility should be designed to incorporate Level 1 enhancements and to a basic wind speed of 150 mph (plus an importance factor of 1.15) for the main wind-force resisting system (MWFRS), the building envelope, and rooftop equipment.

Note: The basic wind speed in south Florida is nearly 150 mph, and as a result, numerous products and systems are available that have been tested for pressures associated with this wind speed.

Level 3 Enhancements

With incorporation of Level 3 enhancements, penetration of the roof deck or walls by EF3 debris is unlikely, but debris may penetrate doors or glazing. Designing with Level 3 enhancements also minimizes the potential for interior water and wind damage from strong tornadoes. However, significant interior damage could occur (though not within the safe room) if the core of a violent tornado (EF4 or EF5) passes over or near the building.

Level 3 Enhancement Recommendations: Facility design should incorporate Levels 1 and 2 enhancements as well as the following:

- Roof deck – A minimum 4-inch-thick, cast-in-place, reinforced concrete deck is the preferred deck. Other recommended decks include minimum 4-inch-thick structural concrete topping over steel decking and precast concrete with an additional minimum 4-inch-thick structural concrete topping.
- Exterior walls – A minimum 6-inch-thick, cast-in-place concrete wall reinforced with #4 rebar at 12 inches on center each way is the preferred wall. Other recommended walls are a minimum 8-inch-thick, fully grouted CMU reinforced vertically with #5 rebar at 40 inches on center and minimum 6-inch-thick precast concrete that is reinforced equivalent to the recommendations for cast-in-place walls.

  Note that the above reinforcing recommendations are based on wind-borne debris resistance. More reinforcing steel may be required in the wall to carry wind loads, depending on the design and geometry of the wall.

The benefit of the Level 3 enhancement deck recommendation is illustrated by the fire station shown in Figure 7, which was struck by a strong tornado. The apparatus bay doors collapsed (red arrow), and all of the unprotected glazing was broken. However, the walls and cast-in-place concrete roof deck remained in place. Interior damage was substantial as a result of the glazing failures. If the Level 3 enhancement door, glazing, and rooftop equipment recommendations had been followed, this station would likely have had little, if any, interior damage. The adjacent unreinforced CMU apartment building (red circle) experienced blow off of the wood roof structure and collapse of some exterior CMU walls.

Hospitals and Nursing Homes

Designing to at least the Level 1 enhancement recommendations is particularly important for hospitals and nursing homes. Designing these facilities to the Level 3 enhancement recommendations is preferable. Sometimes tornado warning time is ample for occupants to reach a safe room; however, at times an approaching tornado is not noticed until a few minutes before it strikes. In those instances with little or no warning of an impending tornado strike, maintaining building envelope integrity is crucial to providing protection to patients, residents, and staff, and to minimizing disruption of services.

Figure 7: Fire station with a cast-in-place concrete roof deck in Tuscaloosa, AL. The apparatus bay doors (red arrow) collapsed and the adjacent building (red circle) was damaged (2011 Tornado).

Figure 8: Collapse of the second-floor roof structure, interior walls, and exterior walls of a school in Tuscaloosa, AL (2011 Tornado)

The performance of the fire station in Figure 7 is in stark contrast to the school shown in Figure 8, which did not have any of the Level 1, 2, or 3 enhancements. The school was struck by the same strong tornado as the fire station, but the school's steel deck/steel joist roof structure blew away, and the exterior CMU/brick veneer walls and interior walls on the second floor collapsed.

Continuity of Operations

Designing a facility to ensure it will remain operational if struck by a violent tornado is expensive. Therefore, when considering the costs and benefits of designing for continuity of operations, designing to minimize building damage and/or provide safe rooms may be more cost effective. Facilities such as EOCs that are determined to be critical in providing effective emergency response should be designed to avoid interrupted operations even if struck by violent tornadoes. The following practices will reduce the chances of interrupted operations related to building damage or loss of municipal utilities (i.e., water, sewer, and electrical power).

Vulnerability Assessments

As part of the planning process for new facilities, other natural hazards (flood, seismic, and wildfire) should be considered in addition to the tornado hazard. FEMA P-424, 543, and 577 provide guidance on conducting vulnerability assessments. If the building design does not ensure continuity of operations, contingency plans should be developed that address facility disruption.

Follow Recommendations in FEMA 361

If the entire facility must remain operational, FEMA 361 recommendations should be applied to the entire building. However, if only a portion of the building must remain operational, the recommendations can be applied only to that portion.

Figure 9 shows an example of an EOC (red oval) located in a portion of the first floor of a large building.[3] The collapsed second floor of this facility did not need to remain operational; hence, if a similar facility were being constructed, designing the second floor in accordance with FEMA 361 would not be necessary.

Figure 9: An EOC in Tuscaloosa, AL, that remained intact even though the story above it collapsed (Tornado 2011)

Avoid Water Leakage

Critical facilities can be housed either on a top floor, with a roof overhead, or a bottom or intermediate floor with another story overhead. Avoiding water leakage is important for both scenarios. For critical facilities with a roof overhead, either of the following options is recommended:

- A modified bitumen roof membrane that is torch-applied to a primed concrete roof deck. Over this membrane, apply roof insulation, gypsum roof board, and another roof membrane as recommended in FEMA P-424 (Section 6.3.3.7), 543 (Section 3.4.3.4), or 577 (Section 4.3.3.8).
- A minimum 4-inch-thick SPF roof system over a concrete roof deck. The SPF should be coated rather than protected with an aggregate surfacing.

  For critical facilities with a floor slab overhead, as shown in Figure 9, collapse of an upper level could allow water to leak into the critical facility. If water-sensitive equipment or operations are within the critical facility, the following is recommended.

- Design a false ceiling between the equipment or operations and the floor slab above. Design a waterproof membrane over the top of the false ceiling to prevent leakage into the water-sensitive area below.

3 The building shown in Figure 9 was not FEMA 361 compliant.

Design to Protect the Heating, Ventilation, and Air Conditioning

FEMA 361 provides recommendations pertaining to protecting heating, ventilation, and air conditioning (HVAC) equipment for safe rooms. Safe rooms, however, are normally occupied for relatively short durations, whereas critical facilities are normally needed for continuous long-term operation after a tornado. Therefore, additional provisions for ventilation and/or cooling may be required depending on facility operational requirements.

Maintaining functioning HVAC equipment in facilities that must either remain operational during an event or be able to be made operational shortly after an event can be challenging. Portions of commercial HVAC systems are typically inside the building, but portions that transfer heat to the environment are located outside and are, therefore, vulnerable to damage from wind and wind-borne debris (Figures 10 and 11).

Figure 10: ACC units vulnerable to wind and wind-borne debris

Figure 11: Cooling tower vulnerable to wind and wind-borne debris

To protect HVAC components outside buildings from horizontal wind-borne debris, wind- and debris-resistant walls can be designed around the equipment. Vertical debris protection is more difficult to achieve. Baffling, as shown in FEMA 361 (Section 3.3.2.e and Figure 7-12) to protect doors from direct debris impact, can be used to prevent damage to exterior equipment. However, baffling can restrict air flow and thereby reduce the cooling capacity of HVAC equipment. The effects of baffling should be considered in the system design.

Geothermal loops transfer heat to the earth and are, therefore, protected from wind and wind-borne debris. Although retrofitting existing systems to use geothermal loops is often not practical, installing geothermal systems during original construction can produce HVAC systems that meet the wind pressure and wind-borne debris criteria in FEMA 361.

An alternative to protecting equipment from debris is to rely on a temporary system, especially in situations when cooling is not needed immediately after an event. In this scenario, portable chiller units, cooling towers, or DX units could be brought to the site if a tornado damages the equipment. If temporary systems will be used, facility owners should source the equipment in advance, and design professionals should specify preinstallation for the power and control connections, as well as the associated piping and duct connections.

Ensure Water Supply

Depending on facility operational requirements, drinking water or other water needs (such as for hand washing and fire protection) may be satisfied by stored water bottles, a water storage tank within the facility, or a well that is protected by an enclosure that meets the wind pressure and wind-borne debris criteria in FEMA 361.

Ensure Sewer Service

FEMA 361 recommends self-contained, chemical-type receptacles/toilets to provide sewer service for safe rooms. However, the recommendations in FEMA 361 may be inadequate for critical facilities that do not have to access to functional municipal sewer service for days or weeks after a tornado. For these facilities, a temporary storage tank that can be pumped out by a local contractor should be designed.

FEMA has observed critical facilities that were flooded by backflow from surcharged sewer systems as a result of loss of electrical power to sewage lift stations or storm-damaged sewage treatment plants. Sewer backflow valves can be installed in the sewage discharge line to avoid this problem. However, because sewage will also not be able to leave the building from the primary discharge line, provisions should be made for diversion to a temporary storage tank.

Make Provisions for Emergency Power

FEMA 361 provides recommendations pertaining to emergency power. However, because critical facilities may have to rely on emergency generators for several days or weeks after a tornado, designers of critical facilities should also refer to the electrical power recommendations in FEMA P-424 (Section 6.3.5.1). Following these recommendations will minimize the loss of needed emergency power (see Figures 12 and 13). These recommendations also pertain to dual fuel generators.[4]

Figure 12: This Joplin, MO, building housing the switchgear (red arrow) and emergency generator (Figure 13) collapsed (2011 Tornado)

Figure 13: The steel deck/steel joist roof structure and unreinforced CMU walls of this Joplin, MO, building collapsed onto the emergency generator (2011 Tornado)

Minimizing Operational Disruption in Hospitals

Hospitals present special challenges because of the need for glazing in patient rooms. The following options should be considered to minimize disruption of operations in hospitals.

Adhere to FEMA 361: To ensure continuity of operations, designers could follow the recommendations provided in Continuity of Operations above, including specifying that the entire building, including all exterior glazing, meet the tornado wind-borne debris and wind pressure criteria in FEMA 361.

Note: The test missile used for safe room design has much greater momentum than test Missile E (68 versus 22 pounds force per second). Glazing assemblies that have passed the Missile E testing are readily available, and a few assemblies are available that meet the tornado test missile. Known assemblies that have passed the tornado test missile requirement employ polycarbonate glazing. In some assemblies, a pane of glass is on the exterior side of the polycarbonate. The glass protects the outer surface of the polycarbonate from scratches, but the inner surface is susceptible to scratching.

Note: Safe rooms that have a few small windows protected by a shutter on the inside of the room have been designed. However, expecting a shutter within each patient room to always be closed before a tornado event is impractical.

Implement Level 3 enhancement recommendations: To minimize operational disruption, the Level 3 enhancement recommendations could be implemented in patient rooms, lobbies, and other areas where exterior glazing is necessary. In other areas of the facility (such as the emergency room, lab, radiology department, surgery department, and the physical plant), the recommendations provided in Continuity of Operations above could be implemented. By taking this approach, some exterior glazing might be breached if a violent tornado passed over or near the hospital, but much of the facility would have a high potential of remaining operational.

4 After a tornado, main natural gas lines may need to be turned off to prevent fires. If a critical facility has a gas-fired generator, it may not be operational unless it has a secondary diesel fuel source.

Useful Links and Resources

Recovery Advisories from the Tornado MATs for Alabama, Mississippi, Tennessee, and Georgia. FEMA. 2011. Available from: http://www.fema.gov/library/viewRecord.do?id=4723.

- Tornado Recovery Advisory No. 1 – *Tornado Risks and Hazards in the Southeastern United States*
- Tornado Recovery Advisory No. 2 – *Safe Rooms: Selecting Design Criteria*
- Tornado Recovery Advisory No. 3 – *Residential Sheltering: In-Residence and Stand-Alone Safe Rooms*
- Tornado Recovery Advisory No. 4 – *Safe Rooms and Refuge Areas in the Home*
- Tornado Recovery Advisory No. 5 – C*ritical Facilities Located in Tornado-Prone Regions: Recommendations for Facility Owners*.

Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business (FEMA 320), August 2008, Third Edition. http://www.fema.gov/library/viewRecord.do?id=1536.

Design and Construction Guidance for Community Safe Rooms (FEMA 361), August 2008, Second Edition. http://www.fema.gov/library/viewRecord.do?id=1657.

Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds (FEMA P-424), December 2010, Second Edition. http://www.fema.gov/library/viewRecord.do?id=1986.

Tornado Protection: Selecting Refuge Areas in Buildings (FEMA P-431), October 2009, Second Edition. http://www.fema.gov/library/viewRecord.do?id=1563.

Design Guide for Improving Critical Facility Safety from Flooding and High Winds (FEMA 543), January 2007. http://www.fema.gov/library/viewRecord.do?id=2441.

Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds (FEMA 577), June 2007. http://www.fema.gov/library/viewRecord.do?id=2739.

ICC/NSSA Standard on the Design and Construction of Storm Shelters, International Code Council (ICC) and National Storm Shelter Association (NSSA) (ICC 500), June 2008, Country Club Hills, IL. http://www.iccsafe.org/Store/Pages/Product.aspx?id=8850P08_PD-X-SS-P-2008-000001#longdesc.

Rebuilding and Repairing Your Home After a Tornado

TORNADO RECOVERY ADVISORY *RA7, August 2011*

Purpose and Intended Audience

The purpose of this advisory is to identify which standard of construction should be used when repairing houses damaged in high-wind events (see Figure 1). The intended audience for this Tornado Recovery Advisory is homeowners or home builders. The advisory explains how to determine which building code is appropriate, describes how to incorporate best practices into construction, and lists resources for installing residential safe rooms. Homeowners and renters should also refer to Tornado Recovery Advisory No. 3, *Residential Sheltering: In-Residence and Stand-Alone Shelters* (updated in 2011).

This Recovery Advisory Addresses:

- Determining the Appropriate Building Code
- Incorporating Best Practices
- Protecting Building Occupants by Installing Residential Safe Rooms

Figure 1: A house that lost large sections of the roof and the garage due to internal pressurization.

Determining the Appropriate Building Code

Building codes are used in many jurisdictions as a minimum standard of construction practice to provide occupants with an improved level of safety from natural hazards, fire, and poor air quality. Building codes are instituted when either the State or a local jurisdiction adopts them. Most building codes are based on one of the current prevailing model building codes published by the International Code Council (ICC).

Houses constructed in hurricane-prone regions may be constructed to the ICC 600, *Standard for Residential Construction in High-Wind Regions*, in addition to the International Residential Code. ICC 600 provides a prescriptive approach for building and repairing houses in regions where the design wind speed is above 90 mph (3-second gust) and, for some construction methods, up to 150 mph. Even if the design wind speed for your location is 90 mph or less, designing to the ICC 600 standard may improve the performance of your house in a high-wind event such as a weak tornado. Although constructing to a higher standard may not eliminate all damage to the building, it may reduce damage from high-wind storm events.

While building codes can be adopted at the State, county, or local jurisdiction (city) level, in some areas of the United States, no building codes are adopted or enforced. Where building codes are not adopted and enforced, residential construction quality may not be ensured by plan reviewers or a building inspector. In these areas, the building owner should hire a qualified professional to conduct inspections and verify that the work is being done properly.

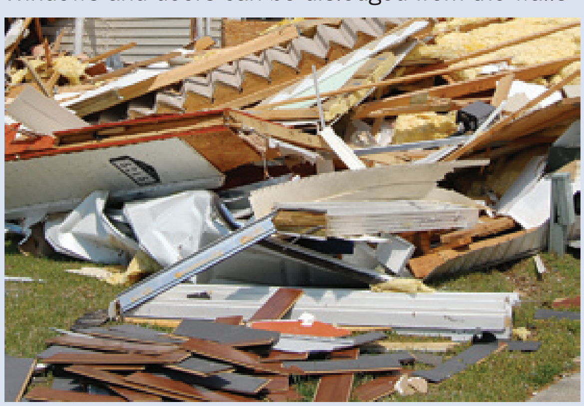
Incorporating Best Practices

Best practices are design or construction practices that go beyond the minimum code requirements of the latest model codes to improve building performance. An example of a best practice is adding metal connectors to a structure to improve the transfer of loads through the house from the roof system to the foundation. Construction details and material selection can result in a house with improved resistance to wind pressures and wind-borne debris. Resources for best practices include the ICC 600 standard and FEMA P-499, *Home Builder's Guide to Coastal Construction* (FEMA 2010), which is a technical fact sheet series for improving house performance in high-wind regions. The FEMA P-499 fact sheets are appropriate for use throughout the country, and they provide best practice recommendations for a variety of building systems.

Best practices can be incorporated not only into new construction, but also into existing homes. Houses can be retrofitted either as part of the repair process, such as when replacing the roof covering, or as part of an independent retrofit project. FEMA P-804, *Wind Retrofit Guide for Residential Buildings* (FEMA 2010), describes how to improve a house's performance during high-wind events. The guide outlines three levels of building performance and describes groups of retrofits that can reduce damage to a house. In addition, proper application of the retrofit packages described in FEMA P-804 may result in insurance premium rate reductions in certain areas of the country.

When constructing a new home or repairing a damaged house, certain practices should be considered. Table 1 lists building components that are commonly observed to fail during high-wind events and provides recommended practices to avoid these failures. The failure of these components often results in damage from wind-blown rain and, in some cases, pressurization of the house, which may lead to the loss of walls or the entire structure. While this list is not all-inclusive, it addresses some of the most common and inexpensive preventive measures.

Table 1. Upgrades to Prevent Common Building Component Failures

Building Component	Typical Failure	Recommended Practice
Asphalt Shingles	Shingles blown off in high-wind events, exposing the roof to wind-blown rain 	Use shingles rated for 90+ mph wind and use a minimum of four nails per shingle; preferred use is six nails per shingle (Source: FEMA P-499, Fact Sheet 7.3)
Windows and Doors	Windows and doors can be dislodged from the walls 	Make sure windows and doors are properly shimmed and nailed into the framed opening using nails of sufficient length to tie the window and door frames into the adjacent studs (Source: FEMA P-499, Fact Sheet 6.1)

Building Component	Typical Failure	Recommended Practice
Baseplate or Sillplates	Uplift of the wall systems and shear failures 	Make sure there are anchor bolt connections between the plate and the foundation at least every 4 feet (Source: FEMA P-499, Fact Sheet 4.3)
Roof-to-Wall Connections	Uplift of the roof systems and either significant damage or loss of the entire roof 	Ensure there is a continuous load path from the roof to the foundation using metal connectors that are approved for use with the applicable basic wind speed (Source: FEMA P-499, Fact Sheets 4.1, 4.2, and 4.3)
Sheathing	Penetration of fiberboard sheathing and rigid insulation board by wind-borne debris in even weak tornadoes 	Use oriented-strand board (OSB) or plywood to prevent penetration from wind-borne debris and racking (Source: FEMA 342, Chapter 8)
Garage Doors	Buckling of doors either outward or inward 	Select doors designed for higher wind speeds (Source: FEMA P-804, Chapter 4)

Building Component	Typical Failure	Recommended Practice
Brick Veneer	Brick veneers pull away from the wall systems 	Attach veneers with brick ties to the wall framing at adequate spacing as shown in FEMA P-499 (Source: FEMA P-499, Fact Sheet 5.4)
Vinyl Siding	Vinyl siding pulls off wall sheathing 	Use vinyl siding rated for high wind applications and attach it to the wall framing as noted in FEMA P-499 (Source: FEMA P-499, Fact Sheet 5.3)
Gable End Walls	Gable end walls collapse or rotate, causing loss of the roof system, causing failure of hinges and possibly large sections of the building, and causing walls to buckle 	Improve the gable end wall bracing details with additional connections and by improving the load path with additional framing and metal connectors (Source: FEMA P-804, Chapter 4)

Protecting Building Occupants by Installing Residential Safe Rooms

When reconstructing after a tornado event, homeowners may want to consider installing a residential safe room to protect building occupants in the event of a future tornado. A safe room can be an interior room, a space within a building, or an entirely separate building designed and constructed to protect its occupants from tornadoes and hurricanes. Safe rooms are intended to provide protection against both wind forces and the impact of wind-borne debris.

Additional information on safe rooms can be found in Recovery Advisory No. 3, *Residential Safe Rooms: In-Residence and Stand-Alone Safe Rooms* (updated in 2011).

Useful Links and Resources

2011 Tornado Recovery Advisories. FEMA. 2011. http://www.fema.gov/library/viewRecord.do?id=4723

Recovery Advisory No. 3, *Residential Safe Rooms: In-Residence and Stand-Alone Safe Rooms*. FEMA. 2011. http://www.fema.gov/library/viewRecord.do?id=4723

Recovery Advisory No. 5, *Critical Facilities Located in Tornado-Prone Regions: Recommendations for Facility Owners*. FEMA. 2011. http://www.fema.gov/library/viewRecord.do?id=4723

Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business (FEMA 320). August 2008, Third Edition. http://www.fema.gov/library/viewRecord.do?id=1536

Midwest Tornadoes of May 3, 1999: Observations, Recommendations, and Technical Guidance (FEMA 342). October 1999. http://www.fema.gov/library/viewRecord.do?id=1423

Home Builder's Guide for Coastal Construction (FEMA P-499). December 2010, Second Edition. http://www.fema.gov/rebuild/mat/mat_fema499.shtm

Wind Retrofit Guide for Residential Buildings (FEMA P-804). December 2010. http://www.fema.gov/library/viewRecord.do?id=4569

Standard for Residential Construction in High-Wind Regions. ICC 600, International Code Council (ICC). 2008. Country Club Hills, IL.

International Residential Code for One- and Two-Family Residences (IRC) ICC. 2009. Country Club Hills, IL.

ICC/NSSA Standard for the Design and Construction of Storm Shelters (ICC-500), June 2008. http://www.iccsafe.org/Store/Pages/Product.aspx?id=8850P08_PD-X-SS-P-2008-000001

Reconstructing Non-Residential Buildings After a Tornado

FEMA

TORNADO RECOVERY ADVISORY *RA8, August 2011*

Purpose and Intended Audience

The purpose of this advisory is to identify which standard of construction should be considered for repairing buildings damaged in high-wind events (see Figure 1). The intended audience for this Tornado Recovery Advisory is architects, engineers, builders, and building owners. This advisory explains how to determine which building code is appropriate, incorporating best practices into construction, common building failures and how to avoid them, and resources for installing shelters and safe rooms.

This Recovery Advisory Addresses:

- Determining the appropriate building code
- Incorporating best practices
- Common building failures and recommendations to mitigate them
- Protecting building occupants by installing shelters and safe rooms

Figure 1: A business damaged by roof damage and water intrusion from a weak tornado

Determining the Appropriate Building Code

Building codes are used in many jurisdictions as a minimum standard of construction practice to provide occupants with an improved level of safety for natural hazards, fire, and air quality. Building codes are instituted when either the State or a local jurisdiction adopts them. Most building codes are based on a model building code.

The current prevailing model building code is the family of International Building Codes produced by the International Code Council (ICC). Codes are typically updated on a predetermined cycle of reviews. Codes from the ICC are updated on a 3-year cycle, and most governmental bodies are using a code based on the 2003, 2006, or 2009 ICC building codes. At the time of this publication, the 2012 ICC building codes have been published, but few local jurisdictions have adopted this version of the code yet. Building codes typically use a performance approach, which means that construction practices are based on a specific building's design and location. In addition to construction methods, building codes also usually dictate administrative practices such as permitting, reviews, and inspections.

Design loads are calculated using design standards or other design guidance referenced by the codes. With only a few exceptions, the International Building Code (IBC) requires the use of American Society

Standard of Care

Critical facilities have facility and operational requirements that should be met in addition to building code requirements. Building codes do not stipulate expected building performance for tornadoes. The designer should discuss expectations regarding acceptable building damage, operational requirements, and occupant safety with the facility owner to ensure the full range of requirements is considered.

of Civil Engineers (ASCE) 7, *Minimum Design Loads for Buildings and Other Structure*, to calculate wind and other loads on buildings.

Even if there is no building code enforced in the jurisdiction where you are building, it is still important to construct to a building code to provide a minimum standard of care. While building permits in these areas may be required, building inspections may not be conducted, and it may be necessary to hire a qualified professional to conduct inspections to verify that the work is being done properly. The latest version of the International Codes (2012) is recommended as a minimum code.

Incorporating Best Practices

Best practices are design or construction practices that go beyond minimum code requirements to improve building performance. Four options should be considered for increasing the design loads on buildings: increasing the occupancy category, increasing the design wind speed, designing as a partially enclosed building, or designing as if in a hurricane-prone region. Each of these methods will effectively result in a building that can withstand higher wind pressures and/or improve debris impact resistance. Increasing the building occupancy category typically only results in minimal increases in wind resistance; the other methods will improve building performance more substantially.

Increasing Design Wind Speed: ASCE 7 promulgates the minimum loading requirements for building design. To improve wind resistance, higher wind loads can be calculated using the calculations in ASCE 7. For an Occupancy Category II building in a non-hurricane-prone area, the standard design wind speed is 90 mph, but increasing the design wind speed to 115 mph will result in a 63 percent increase in velocity pressures and be consistent with similar buildings using the ASCE 7-10 wind speeds. In addition to using a higher design standard for loads, improved construction methods and materials can also improve building performance. Even small practices—such as slightly increasing reinforcing steel sizes and increasing development and lap splice lengths—can greatly improve building performance.

Designing as a Partially Enclosed Building: In most cases, buildings are designed to function as an enclosed structure, meaning that it is designed to only allow minimal air into the building even during a high wind event. Once windows or doors are broken by windborne debris, wind pressures can greatly increase and cause significant structural damage to the building. Designing exterior and load-bearing walls, roof systems, and the foundation to resist the increased wind pressures will result in significant improvements to the building structure performance. The recent edition of the International Building Code has tables and charts for these wind speeds and wind pressures that can aid in building detailing.

Designing as if in a Hurricane-Prone Region: The design strategies and building materials used in hurricane-prone areas result in buildings that are more resistant to most tornadoes (i.e., Enhanced Fujita [EF] 0–EF3). With appropriate strengthening and selection of building materials and systems, both the potential for disruption of operations and the cost of repairs after a tornado event can be reduced. If the costs associated with loss of function or business interruption are significant, then a higher standard of construction may be appropriate. Building performance can also be improved with engineering techniques introduced through some of the observations noted for critical facilities (see Recovery Advisory No. 6, *Critical Facilities Located in Tornado-Prone Regions: Recommendations for Architects and Engineers* [FEMA 2011] for additional information).

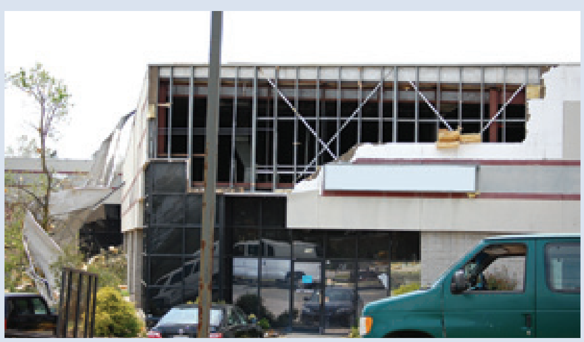
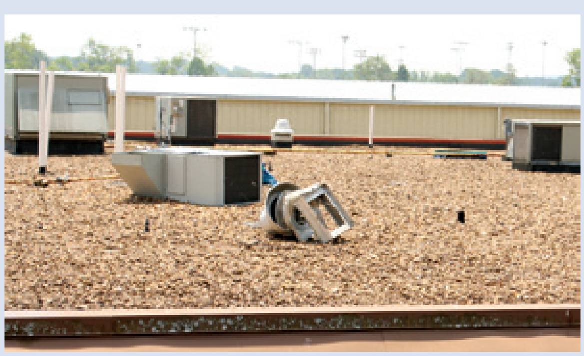
Common Building Failures and Recommendations to Mitigate Them

Table 1 describes the typical failures observed after the 2011 tornadoes. The table also provides recommended practices to reduce these failures in buildings subjected to weak tornadoes and minimize them for buildings on the periphery of stronger tornadoes.

Table 1. Building Failures and Recommendations

Building Component	Typical Failure	Recommended Practice
Superstructure		
Pre-Engineered Buildings	Failure of endwall trusses and endwall truss bracing. 	Size the endwall trusses to resist wall loads and verify that anchor bolts are sized to resist lateral loading. (Source: FEMA 489)
Masonry Buildings	Collapse of unreinforced masonry walls. 	Fully grout walls and increase reinforcement to resist lateral loads and uplift loads on the roof system. (Source: FEMA P-424)
Roof Coverings and Roof Systems		
Ballasted Roofs	Ballasted roof systems can become wind-borne debris and damage surrounding objects. 	Select an alternative ballasting system or fully adhere ballast to the roof system. (Source: FEMA P-424)

Building Component	Typical Failure	Recommended Practice
Roof Truss Connections	Loss of roof trusses from uplift loads. Trusses typically fail at the connection with the wall system, either through poor grouting of anchor bolts or insufficient embedment. 	Improve connection of roof trusses to prevent failure from uplift loads. Verify that the load path is continued through the wall system into the foundation. (Source: FEMA P-424)
Double Tee Connections	Double tees shift due to uplift loads and failures at angle iron welds or insufficient anchor bolts, allowing the double tee to slip off the corbel. 	Ensure that anchor bolts provide sufficient strength to prevent uplift. (Source: FEMA P-424)
Gable End Walls	Insufficient attachment of gable end walls results in building pressurization, loss of the roof system, and possibly large sections of the building. 	Improve the gable end wall bracing details with additional connections and strengthen the load path. (Source: FEMA P-804)

Building Component	Typical Failure	Recommended Practice
Building Envelope		
Metal Sheeting	Loss of wall coverings due to insufficient girts. 	Increase framing between trusses to reduce loads on metal sheeting. Increase metal sheeting thickness to resist the potential for pulling off connectors. (Source: FEMA 489)
Brick Veneer	Wall failures resulting from insufficient brick ties. 	Increase number of brick ties, properly attach ties to the wall system, and sufficiently embed ties into the brick veneer. (FEMA P-499, Fact Sheet 5.1)
Exterior Insulation and Finishing System (EIFS)	Loss of large sections of EIFS due to impact of wind-borne debris. 	Reduce vulnerability of EIFS by using it in locations that are high enough to prevent damage from wind-borne debris. (Source: FEMA 424)
Rooftop Equipment	Damage to rooftop equipment, typically by wind-borne debris or as a result of insufficient anchorage. 	Protect exterior equipment from wind-borne debris. Evaluate connections to rooftop or slab. (Source: FEMA 424)

Building Component	Typical Failure	Recommended Practice
Roll-up Door Systems	Buckling of roll-up door systems, typically due to either positive or negative pressures. Door tracks and rollers can fail in high winds. 	Specify a door system for a higher wind speed than the minimum required by code. (Source: FEMA 489)

Two common building types that failed in the recent tornadoes were masonry buildings and pre-engineered buildings. Both of these building types are common and have aspects that put them at risk of significant damage in high-wind events.

Masonry Buildings: Masonry buildings can be constructed as either reinforced or unreinforced masonry. The most common failure noted is with unreinforced masonry walls. The lack of reinforcement makes them particularly susceptible to collapse. Unreinforced walls are commonly observed in older construction, but numerous examples of more recently constructed buildings that contained little or no reinforcement were observed after the 2011 tornadoes. Due to the lack of rigidity, unreinforced masonry walls tend to bow and collapse in high-wind events. The lack of reinforcement also makes the roof system particularly susceptible to uplift.

Failure of reinforced masonry walls is also not uncommon. The failures noted after the 2011 tornadoes were because the wall systems either contained too little reinforcement or insufficient splices or development lengths in the bars. The walls failed in large sections and pulled away from the foundation or slab due to insufficient splice designs. Poor connections between roof systems and wall systems were also noted to cause failure of reinforced masonry walls.

Pre-Engineered Buildings: Pre-engineered buildings can sustain significant loss of exterior sheeting, and in some cases, failure of the frame. Exterior sheeting should be sufficiently supported to resist deflection from high winds; additional girts and purlins may be required. Increasing the thickness of the exterior sheeting can reduce the potential for sheeting pulling off connectors. Endwall trusses of pre-engineered buildings should be designed to resist wall loads, and anchor bolts should be sized to resist uplift from high wind loads.

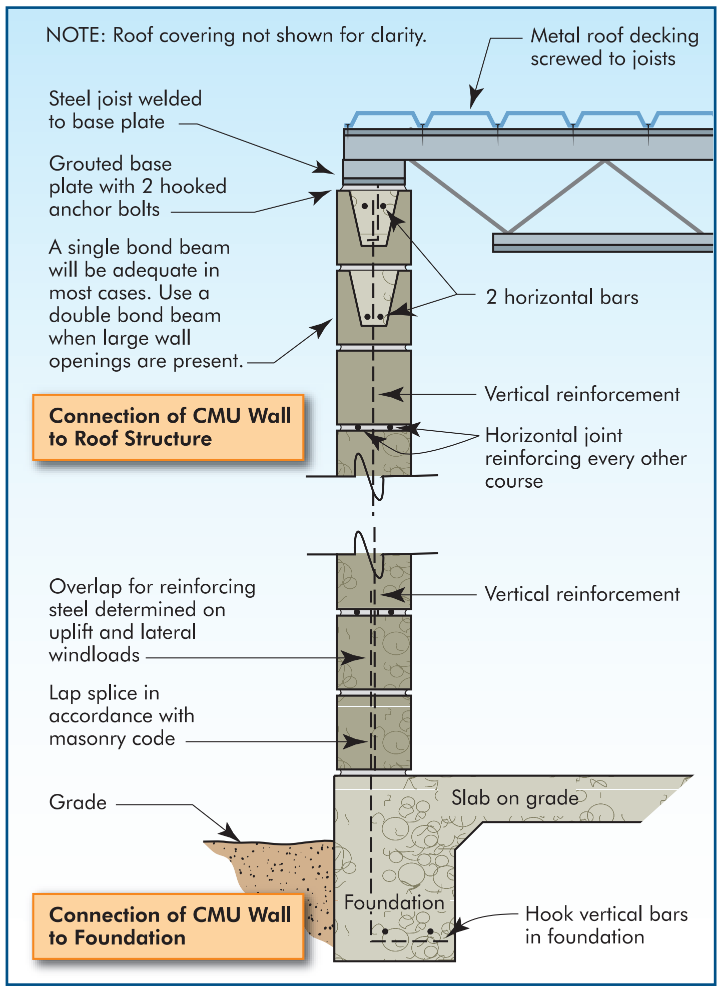


Figure 2: Example of a masonry wall detail, incorporating many construction best practices. Source: FEMA P-424, Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds (FEMA 2010)

Protecting Building Occupants by Installing Shelters and Safe Rooms

When reconstructing after a tornado event, building owners may want to consider installing a safe room or shelter to protect occupants in the event of a future tornado. The distinction between a safe room and a shelter is described in the following text box.

More information on the construction of safe rooms can be found in the FEMA 2011 Recovery Advisory No. 2, *Safe Rooms: Selecting Design Criteria*.

A ***shelter*** (including safe rooms) is typically an interior room, space within a building, or an entirely separate building, designed and constructed to protect occupants from tornadoes or hurricanes. Shelters are intended to provide protection against both wind forces and the impact of wind-borne debris.

Useful Links and Resources:

Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers (ASCE), 2005. ASCE Standard ASCE/SEI 7-05.

Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers (ASCE), 2010. ASCE Standard ASCE/SEI 7-10.

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