Storm Shelters: Selecting Design Criteria

FEMA

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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 shelters, 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 titled *Residential Sheltering: In-Residence and Stand-Alone Shelter.* The purpose of this advisory is to identify the different types of shelter design guidance, code requirements, and other criteria that pertain to the design and construction of shelters for tornadoes and hurricanes. There are various storm shelter criteria, each of which offers different levels of protection to its shelter occupants.

This Recovery Advisory Addresses:

- How shelter construction is different from typical building construction
  - Structural systems
  - Windborne debris resistance
- Design criteria for different types of shelters
- Shelter considerations
- Useful links and shelter resources

See these 2007 Tornado Recovery Advisories for information about tornado risk, sheltering from tornadoes, and improving manufactured homes against damage from high winds:

- Tornado Risks and Hazards in the Southeastern United States (Tornado Recovery Advisory No. 1)
- Residential Sheltering: In-Residence and Stand-Alone Shelters (Tornado Recovery Advisory No. 3)
- Understanding and Improving Performance of Older Manufactured Homes in High-Wind Events (Tornado Recovery Advisory No. 4)
- Understanding and Improving Performance of New Manufactured Homes in High-Wind Events (Tornado Recovery Advisory No. 5)

How Shelter Construction is Different from Typical Building Construction

A shelter 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. Shelters are intended to provide protection against both wind forces and the impact of windborne debris. The level of occupant protection provided by a space specifically designed as a shelter is intended to be much greater than the protection provided by buildings that comply with the minimum requirements of building codes. The model building codes do not provide design and construction criteria for life safety for sheltering nor do they provide design criteria for tornadoes.

Shelters typically fall into two categories: residential shelters and community (non-residential) shelters.

- There are two general types of residential shelters: in-residence shelters and shelters located adjacent to, or near, a residence. An ***in-residence shelter,*** also called a "safe room," is a small, specially designed ("hardened") room, such as a bathroom or closet that is intended to provide a place of refuge for the people who live in the house. An ***external residential shelter*** is similar in function and design, but it is a separate structure installed outside the house, either above or below ground. Refer also to the Tornado Recovery Advisory titled *Residential Sheltering: In-Residence and Stand-Alone Shelter.*

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

- A ***community shelter*** is intended to provide protection for a large number of people, anywhere from approximately 12 to as many as several hundred individuals. These shelters include not only public shelters but private shelters for businesses and other organizations.

Community storm shelter being constructed to FEMA 361 criteria in Wichita, Kansas.

Structural Systems

The primary difference in a building's structural system when designed for use as a shelter, 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 "design [basic] 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 shelters 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 calculated as a function of the square of the design wind speed. As a result, the structural systems of a shelter are designed for forces up to three times higher than those used for typical building construction. Consequently, the structural systems of a shelter (and the connections between them) are very robust.

Windborne Debris Resistance

Windborne 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 windborne debris, except for buildings in windborne debris regions.[2] Impact-resistant glazing can either be laminated glass, polycarbonate, or shutters. The ASCE 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 shelters include substantially greater windborne debris loads.

> If glazing is present in a tornado shelter, it should be protected by an interior-mounted shutter that can be quickly and easily deployed by the shelter occupants.

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

Design Criteria for Different Types of Shelters

Shelters will provide different levels of protection depending upon the design criteria used. The level of protection provided by a shelter is a function of the design wind speed (and resulting wind pressure) used in designing the shelter, and of the windborne debris load criteria.

Design wind speed and wind pressure criteria: Wind pressure criteria are given by different guides, codes and standards. Wind pressure criteria specify how strong the shelter 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 shelter publications (see Useful Links on page 3), recommended design wind speeds range from 160 to 250 mph. The 2006 *International Residential Code* and the 2006 *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. The table on pages 4–5 provides a comparison of shelter design criteria options. The table on page 6 presents comparative data for two locations using the design criteria presented on pages 4–5.

1. FEMA 361, *Design and Construction Guidance for Community Shelters* (July 2000), available online at http://www.fema.gov/fima/fema361.shtm
2. ASCE 7, American Society of Civil Engineers Standard 7, *Minimum Design Loads for Buildings and Other Structures* (2005)

Windborne debris load criteria: The table on page 3 presents windborne debris criteria given in various guides, codes, and standards. The table shows the different test missiles and the corresponding momentum they carry with them as they strike a shelter. The first entries on this table (Tornado Missile Testing Requirements) are the FEMA missile guidance for residential and community shelters that provide near-absolute protection.

Tornado and Hurricane Windborne Debris Criteria

Guidance, Code, or Standard Criteria for the Design Missile	Debris Test Speed (mph)	Large Missile Specimen	Momentum at Impact (lb_f s)
Tornado Missile Testing Requirements			
FEMA 320 / FEMA 361	100	15# 2x4	68
International Code Council (ICC) Shelter Standard	100 (maximum) 80 (minimum)	15# 2x4 15# 2x4	68 55
Hurricane Missile Testing Requirements			
FEMA 320 / FEMA 361	100	15# 2x4	68
ICC Shelter Standard	102 (maximum) 64 (minimum)	9# 2x4 9# 2x4	42 26
Florida State Emergency Shelter Program (SESP) Criteria	50 (recommended) 34 (EHPA minimum)	15# 2x4 9# 2x4	34 14
IBC/IRC 2006, ASCE 7-05, Florida Building Code, ASTM E 1886 / E 1996	55 34	9# 2x4 9# 2x4	21 14

NOTES:

IBC/IRC – International Building Code/International Residential Code

lb_f-s – Pounds (force) seconds

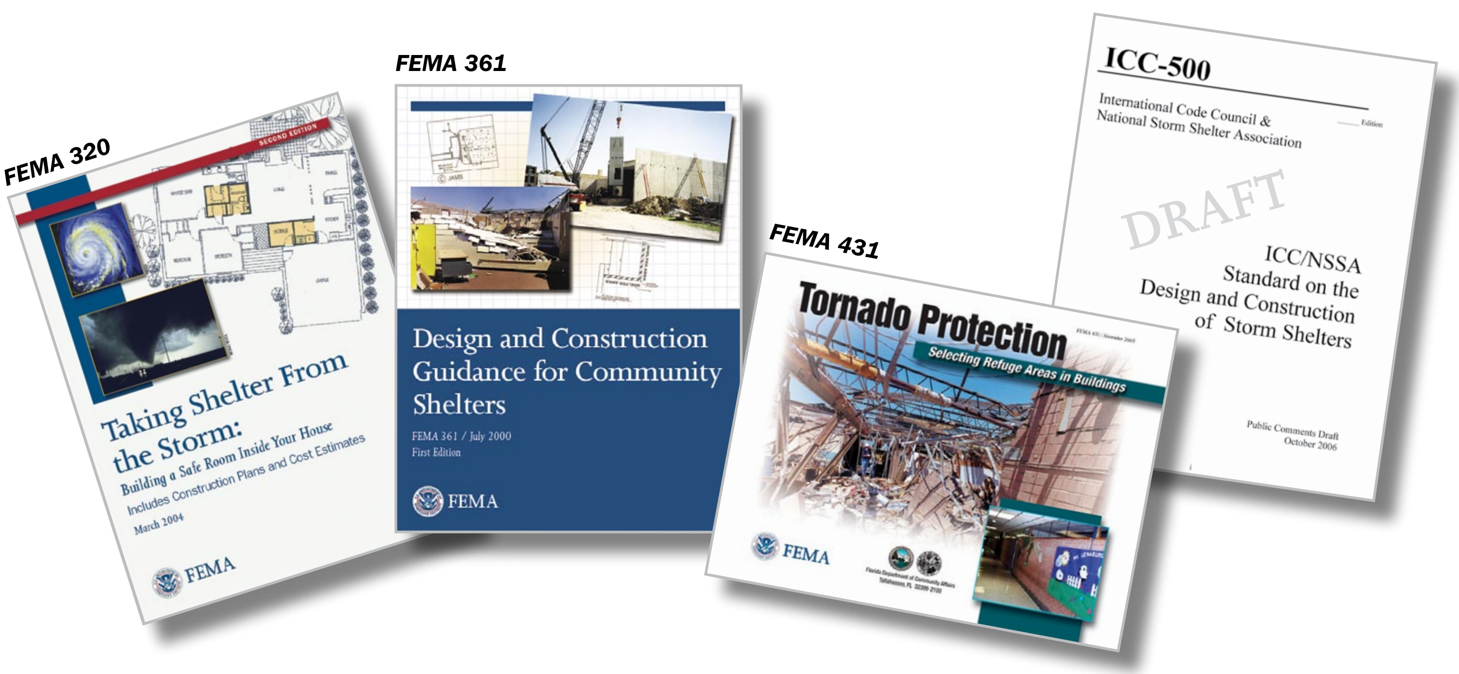
Useful Links and Shelter Resources:

Taking Shelter From the Storm: Building a Safe Room Inside Your House (FEMA 320), FEMA, Washington, DC, Second Edition, March 2004.

Design and Construction Guidance for Community Shelters (FEMA 361), FEMA, Washington, DC, July 2000.

Tornado Protection: Selecting Refuge Areas in Buildings (FEMA 431), FEMA, Washington, DC, November 2003.

Standard on the Design and Construction of Storm Shelters, International Code Council and the National Storm Shelter Association (ICC-500), (Anticipated Release) Late 2007.



Wind Shelter Design and Construction Codes, Standards, Guidance Comparison Table[1]

Title or Name of Document	Code, Reg, Standard, or Statute?	Wind Hazard	Wind Map
FEMA Shelter Publications: **FEMA 320** *Taking Shelter From the Storm: Building a Safe Room Inside Your House* (1999) **FEMA 361** *Design and Construction Guidance for Community Shelters* (2000)	FEMA guidance document, not a code or standard. "Best Practice" for high-wind shelters	Tornado and Hurricane	**FEMA 320:** Hazard map, but wind speeds not 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) – currently in development, tentatively available for adoption in January 2008.	Consensus standard for shelter design and construction, available for adoption in January 2008. To be 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 240 mph
Florida State Emergency Shelter Program (SESP) – Florida Interpretation of the American Red Cross (ARC) 4496 Guidance. Note: shelters in this category will range from Enhanced Hurricane Protection Area (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 FBC "recommending" above-code requirements for EHPAs. See also Appendix G of the State Emergency Shelter Program (SESP) report for the detailed design guidance.	Tornado and Hurricane	Florida Building Code (FBC) map, based on ASCE 7 (maps basically equivalent); mri is 50–100 years in coastal areas and adjusted with importance factor
Florida Building Code (FBC) EHPAs – code requirements for public "shelters" (FBC Section 423.25).	Statewide code requirements for EHPAs	Hurricane	FBC map, based on ASCE 7 (maps basically equivalent); 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 2000 and later, International Building Code (IBC)/International Residential Code (IRC) 2000 and later/ASCE 7-98 and later.	Building code and design standards for regular (non-shelter) buildings. Some additional guidance is provided in commentary.	Hurricane	ASCE 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
American Red Cross (ARC 4496) *Standards for Hurricane Evacuation Shelter Selection.*	Guidance for identifying buildings to use as hurricane evacuation shelters	Hurricane	None
Pre-2000 Building Codes	Building code and design standards for regular (non-shelter) buildings	Hurricane	Each of the older codes used their own published wind contour maps
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.

Part 2 of table (continued from page 4)

Wind Design Coefficient Considerations[3,4]	Debris Impact Criteria[5]	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, K_d=1.0, Exposure C, no topographic effects, GCpi=+/-0.55 (this will account for atmospheric pressure change [APC])	Test all shelters with the representative missile: a 15-lb 2x4 at 100 mph (horizontal) and 67 mph (vertical)	**FEMA 320:** Intent is to provide "near-absolute protection." No certification is provided. **FEMA 361:** Intent is to provide "near-absolute protection." Shelter operations guidance is provided. Occupancy issues 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, K_d=1.0, Exposure as appropriate, no topographic effects, 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 85–100 mph (horizontal) and 2/3 of this speed (vertical). **Hurricane:** 9-lb 2x4 at 68–105 mph (horizontal) and a lower 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, K_d=0.85, GCpi as required by design (typically +/-0.18), but recommends +/-0.55 for tornado shelter uses	In windborne debris region (120 mph+): Small – pea gravel; Large – 9-lb 2x4 at 34 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).
Use basic wind speed at site as identified on FBC wind speed map, use exposure at site, use I=1.15, K_d=0.85, GCpi as required by design (typically +/-0.18)	In windborne debris region (120 mph+): Small – pea gravel; Large – 9-lb 2x4 at 34 mph (horizontal), up to 60 feet above grade	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.
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.
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 windborne debris region (120 mph+): Small – pea gravel; Large – 9-lb 2x4 at 34 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.
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.
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[6] 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	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):

3. 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.
4. From ASCE 7 method: I = importance factor; K_d = wind directionality factor; GCpi = internal pressure cofficient
5. 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.
6. From the Southern Building Code Congress International, Inc. (SBCCI).

The table below shows comparative data for two locations for the design criteria presented in the previous table. 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.

Design Criteria Comparison

Shelter Design Standard, Code, or Document	Data[1]	Example Location #1: Miami, FL	Example Location #2: Atlanta, GA
FEMA 320/361	Design wind speed	200 mph	200 mph
	Pressure on windward wall	107 psf[2]	107 psf
	Pressure on roof section	257 psf (suction)	257 psf (suction)
	Test missile momentum at impact	68 lb_f-s[2]	68 lb_f-s
ICC-500 (pending 1/08)	Design wind speed	200 mph (tornado) 225 mph (hurricane)	200 mph (tornado) 160 mph (hurricane)
	Pressure on windward wall	107 psf (tornado) 136 psf (hurricane)	107 psf (tornado) 69 psf (hurricane)
	Pressure on roof section	257 psf (tornado, suction) 325 psf (hurricane, suction)	257 psf (tornado, suction) 202 psf (hurricane, suction)
	Test missile momentum at impact	68 lb_f-s (tornado) 42-26 lb_f-s (hurricane)	68 lb_f-s (tornado) 42-26 lb_f-s (hurricane)
FBC EHPA/SESP (using + 40 mph recommendation)	Design wind speed	186 mph	130 mph
	Pressure on windward wall	91 psf	44 psf
	Pressure on roof section	217 psf (suction)	106 psf (suction)
	Test missile momentum at impact	34 lb_f-s	34 lb_f-s
FBC EHPA	Design wind speed	146 mph	N/A
	Pressure on windward wall	39 psf	N/A
	Pressure on roof section	117 psf (suction)	N/A
	Test missile momentum at impact	14 lb_f-s	N/A
IBHS	Design wind speed	150 mph	90 mph
	Pressure on windward wall	41 psf	15 psf
	Pressure on roof section	124 psf (suction)	44 psf (suction)
	Test missile momentum at impact	14 lb_f-s	14 lb_f-s
ASCE 7-05/IBC 2006 (ASTM E 1996)	Design wind speed	150 mph	90 mph
	Pressure on windward wall	41 psf	15 psf
	Pressure on roof section	124 psf (suction)	44 psf (suction)
	Test missile momentum at impact	14 lb_f-s	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
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
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.
2. psf – Pounds per square foot; lb_f-s – Pounds (force) seconds