Introducing the ICC/NSSA Standard for Design and Construction of Storm Shelters

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ABSTRACT

Recent years have witnessed a significant increase in the number and variety of storm shelters being constructed to protect people from hurricanes and tornadoes. Up to now, information and requirements for design of these facilities has been available through a growing mix of guidelines, regulations, industry standards, and research publications. A major advance in the field occurred in late 2008 with the publication of a national consensus standard called ICC 500 - ICC/NSSA Standard for the Design and Construction of Storm Shelters.

This new standard has been several years in the making. The International Code Council (ICC), in conjunction with the National Storm Shelter Association (NSSA) and funded in part by the Federal Emergency Management Agency (FEMA), recently completed a five-year effort to develop a national consensus standard for the design and construction of storm shelters. The consensus committee developing the standard consisted of 18 voting members, supported by a number of 'friends of the committee' (Figure 1). This group represents a wide cross section of interested disciplines, including architects, engineers, building officials, emergency managers, industry representatives, and product manufacturers. These volunteers represent federal, state, and local government agencies, academia, homebuilders, consulting firms, manufacturing firms, and the insurance industry.

The ICC 500 Standard addresses shelters for hurricanes, tornadoes, and combined hazards, ranging in size from small in-residence shelters (safe rooms) to large community shelters. With the intention to provide a holistic approach to storm shelters, the provisions of the standard include structural, architectural, mechanical, electrical, and plumbing requirements for protection of the shelter occupants from extreme winds, windborne debris, rainfall flooding, storm surge flooding, and related hazards.

The ICC 500 Standard is accredited by the American National Standards Institute (ANSI) and is incorporated by reference in the 2009 editions of the International Building Code (IBC) and the International Residential Code (IRC).

The presentation will discuss design criteria and will review key aspects and major provisions of the Standard. The NSSA process for standards compliance verification will be presented. Also covered are lessons learned about performance of storm shelters during recent hurricanes and tornadoes, many of which occurred during the development of ICC 500 and impacted the provisions of the standard.

Figure 1-- ICC 500 Committee and Staff

GENESIS OF STORM SHELTER STANDARDS

Post-storm inspections of wind effects on the built-up and natural environment have been conducted by Texas Tech University personnel and by others since the Lubbock tornado of 1970. It was often observed that a part of a house remained standing even when the house was heavily damaged or destroyed. Often a small room such as a closet or bathroom remained intact. It was reckoned that a small area such as a closet, bathroom, or pantry could economically be hardened and stiffened to provide a high degree of protection from severe winds. Hence the concept of the aboveground storm shelter was born and research and intentional design began to safeguard lives during extreme wind events. Structural integrity was analyzed using familiar structural analysis methods and debris impact testing began to determine resistance to perforation of common wall sections and doors.

The first publication presenting the concept and several preliminary designs of storm shelters came in September 1974 with an article in Civil Engineering, ASCE by Kiesling and Goolsby [1]. During ensuing years, plans and specifications were slowly developed for residential shelters. Limited resources hindered development and very few shelters were built because of the lack of knowledge of the concept and limited marketing and outreach efforts. In 1980 FEMA published *TR-83A Interim Guidelines for Building Occupant Protection From Tornadoes and Extreme Winds*.

The 1997 Jarrell, Texas tornado inflicted a very heavy death toll and total destruction of most homes in a rural subdivision. The severity of the event drew the attention of the National Broadcasting Company (NBC) who produced a documentary of the damage that aired on Dateline NBC. In the same documentary, the concept of the aboveground storm shelter was presented and some footage of debris impacts on the wall sections conducted at Texas Tech University was broadcasted. For the first time the concept of the aboveground storm shelter gained national visibility. Public interest grew as regional television stations did similar filming. Recognizing the public interest and the potential for the concept, the Federal Emergency Management Agency published the first edition of FEMA 320, *Taking Shelter from the Storm: Building a Safe Room Inside Your House*.

Figure 2 -- Founding Members of NSSA

The FEMA 320 publication was available when the 1999 Oklahoma City area tornadoes struck, and the first Hazard Mitigation Grant Program (HMGP) was announced. Qualification guidelines for the grant were that site-built shelters as per FEMA 320 designs could be approved by the building inspector. Manufactured shelters, for which no published designs were available, were to be tested at Texas Tech University for debris impact resistance. In addition, the shelter design was required to bear an engineers' seal. A number of issues surfaced concerning performance criteria and the adequacy of designs submitted. To deal with these issues, several shelter manufacturers were invited to Texas Tech University in 2000 (Figure 2) and formed the National Storm Shelter Association (NSSA). No performance standard for storm shelters was available, so the newly formed NSSA group began writing a standard. In that same year the first edition of FEMA 361, *Design and Construction Guidance for Community Shelters* was published. By 2001 the NSSA (industry) *Standard for Design and Construction of (residential)* Storm Shelters was available. It served the industry until it was superseded in 2008 by ICC 500, the International Code Council/National Storm Shelter Association (ICC/NSSA) Standard for Design and Construction of Storm Shelters [2]. The year 2008 also saw publication of the second edition of FEMA 361 and the third edition of FEMA 320, the most-in-demand FEMA publication of all times with almost one million copies printed.

The provisions in ICC 500 are built on existing resources and experience as well as new research. Current shelter design resources that were heavily relied on in developing the new standard include: FEMA guidance for design of in-residence and community shelters (FEMA 320 and 361, respectively); the NSSA standard for shelter design, construction, and performance; the American Red Cross standard for hurricane evacuation shelter selection (ARC 4496); and State of Florida requirements for design of Enhanced Hurricane Protection Areas (EHPA). Recent research was also utilized in developing the standard, particularly in the areas of hurricane wind speeds and the aerodynamics of windborne debris.

ICC 500 DEVELOPMENT - SCOPE

The ICC 500 was developed with the intent of providing a concise standard to regulate the design and construction of storm shelters to better protect shelter occupants in the event of a tornado or hurricane. It was developed by the International Code Council in conjunction with the National Storm Shelter Association, and funded in part by FEMA. The standard covers all types and sizes of storm shelters, including those for tornadoes and hurricanes, residential and community shelters, above-ground and below ground shelters, and standalone shelters or those enclosed or partially enclosed in a host building.

ADMINISTRATION

The ICC 500 Standard includes some prescriptive provisions but generally does not preclude the use of alternative designs, technologies, or products so long as they can be demonstrated to be equivalent and function as well or better, and are approved by the authority having jurisdiction. Dimensions listed in the standard are considered nominal, unless otherwise stated as a "maximum" or "minimum". The standard specifies occupancy of the spaces as either rooms or spaces within other uses, dedicated facilities, or combination storm shelters. Depending upon the type of occupancy, the shelter must comply with specific codes and standards. The *International Building Code* is most widely followed, and must be used when no other construction codes are enforced.

Inspections of construction and installation of storm shelters and accompanying equipment will be done in accordance with the project's adopted building code. Community shelters designed for occupancy of over 300 people (50 in FEMA 361) must undergo a peer review of compliance by a registered design professional not involved with the project. All projects involving fabrication of major components at the premises of the fabricator will be provided with special inspections of the fabricator, with the exception of prefabricated or panelized components that are already inspected, labeled, and approved by an eligible agency. Other special inspections will be done when alternative materials and/or systems are implemented, and/or unusual design and construction applications exist. A registered design professional must conduct visual observations of the construction and completion of the structural system. Any deficiencies must be reported in writing to the owner and authority having jurisdiction. Upon completion of the project, the registered design professional must submit a written statement indicating proper construction observations were conducted, and any unresolved deficiency.

Construction documents must include the following items: key design information (e.g. shelter design wind speed, enclosure classification, etc), clearly indicated enclosure walls and floors, signage types and locations, criteria and schedule of inspections required, special details or installation instructions for systems (i.e. equipment or hardware), special instructions required for specified functional operation, and a quality assurance plan. The quality assurance plan will provide detailed construction and design requirements, quality assurance plan preparation, and contractor responsibilities.

All storm shelters must be equipped with a legible and visible sign indicating the name of the manufacturer or builder of the shelter, the storm type(s) for which it was designed, and design wind speed(s). An approved agency must provide labeling for products, materials, and/or systems as required per building code or jurisdiction.

STRUCTURAL DESIGN CRITERIA

Load and load combination calculations must be in accordance with ASCE 7 unless otherwise indicated in the standard. Strength Design or Load and Resistance Factor Design (LRFD) calculations use load combinations from ASCE 7, Section 2.3.2. However, for ICC 500 load combinations 3, 4, and 6 are changed to the following Equations 1, 2, and 3 respectively:

$$1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W) \quad (1)$$

$$1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R) \quad (2)$$

$$0.9D + 1.0W + 1.6H \quad (3)$$

and Exception 1 shall not apply. Allowable Stress Design (ASD) uses the load combinations in ASCE 7, Section 2.4.1, and load combinations 5, 6, and 7 for ICC 500 are modified as shown in Equations 4, 5, and 6 respectively:

$$D + H + F + (0.6W \text{ or } 0.7E) \quad (4)$$

$$D + H + F + 0.75(0.6W \text{ or } 0.7E) + 0.75L + 0.75(L_r \text{ or } S \text{ or } R) \quad (5)$$

$$0.6D + 0.6W + H \;. \quad (6)$$

Rain loads must be determined using ASCE 7. Rainfall rates are determined using the maps from 2006 International Plumbing Code (which are reproduced in the ICC 500 Standard as Figure 303.2), with the exception that 3 inches per hour must be added to mapped values for storm shelters designed for hurricanes. Roof live loads to be used are those specified in ASCE 7 or the following, whichever is more conservative: 100 pounds per square foot for tornado shelters and 50 pounds per square foot for hurricane shelters. Hydrostatic loads and buoyancy forces must be considered when portions of the storm shelter are underground, assuming that the groundwater level is at ground level, unless justification that a lower groundwater level is provided with proper drainage.

Wind loads must be determined using ASCE 7, Section 6, Analytical Procedure, Method 2 unless otherwise specified in ICC 500. The design wind speeds are determined from Figure 304.2(1) of the Standard for tornado shelters and Figure 304.2(2) for hurricane shelters. The wind directionality factor to be used is K_d = 1.0, the importance factor to be used is I = 1.0, and the topographic factor to be used should not exceed K_{zt} = 1.0. Exposure category C must be used for wind pressures except for hurricane shelters which can use category B if category B exists for all wind directions. Enclosure classifications are determined using ASCE 7, Section 6.2, except for community storm shelters where the largest door or window on the wall receiving positive external pressure is considered an opening.

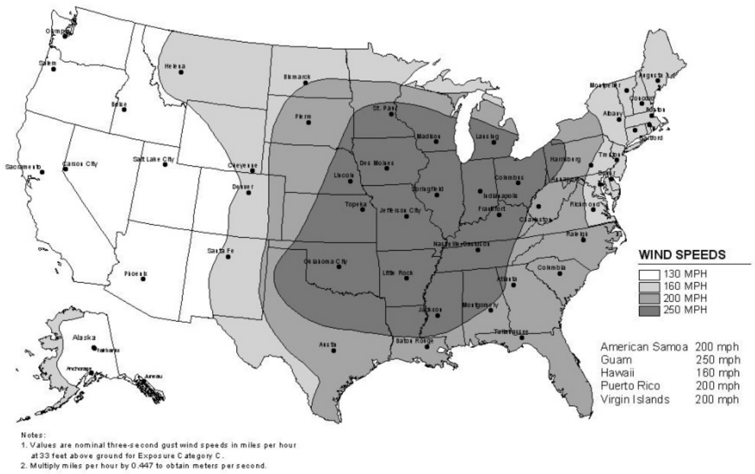

Figure 3 -- Shelter Design Wind Speeds For Tornadoes (Figure 304.2(1) in Standard)

The atmospheric pressure change (APC) for tornado shelters classified as enclosed buildings must be taken into consideration. The internal pressure coefficient to be used is $GC_{pi} = \pm 0.18$ when APC venting area is 1 square foot per 1,000 cubic feet of interior shelter volume. APC venting is defined as an opening in the shelter roof with a slope no more than 10 degrees from the horizontal, or openings divided equally on opposite walls. Shelters classified as partially enclosed buildings require no APC venting area calculations. Tornado shelters that comply with ICC 500, Section 304.8 or that do not require APC venting area calculations use an internal pressure coefficient of $GC_{pi} = \pm 0.55$.

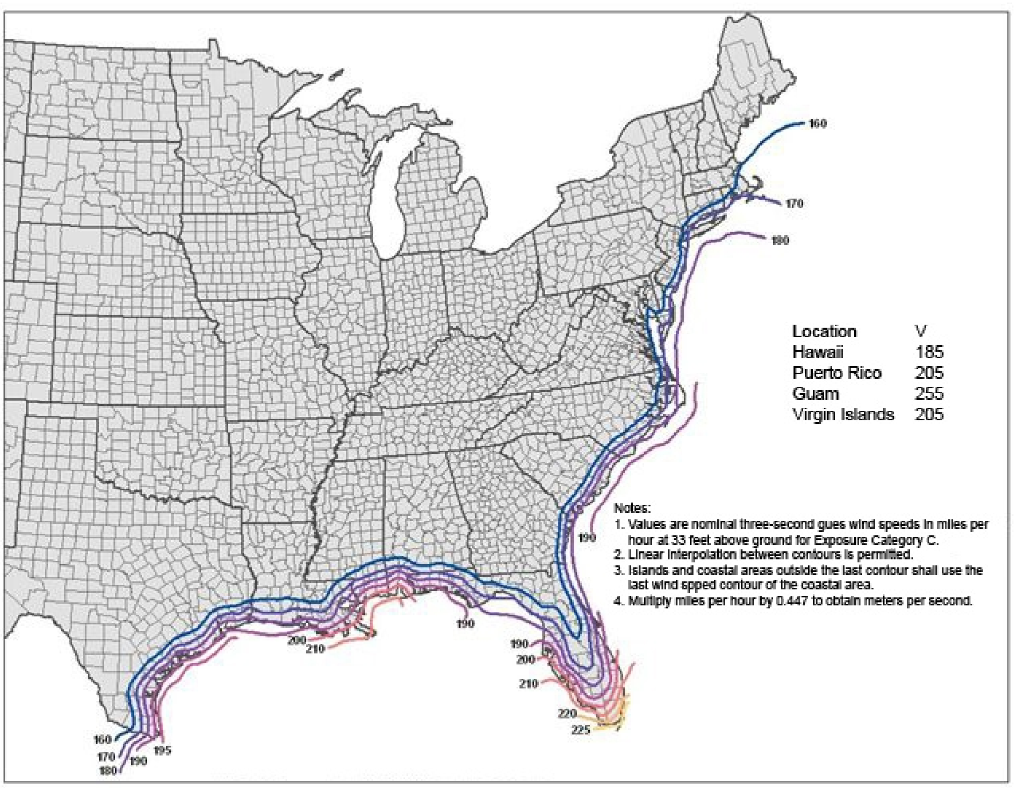

Figure – 4 Shelter design wind speeds for hurricanes. (Figure 304.2(2).of Standard)

DEBRIS IMPACT CRITERIA

All tornado shelters must be designed to withstand impacts of windborne debris as tested with a 15 pound sawn lumber 2 by 4 at speeds corresponding to wind speeds shown in Table 1. Hurricane shelters must be designed to withstand the impact of windborne debris, as tested with a 9 pound sawn lumber 2 by 4. The missile testing speed is equal to at least 0.40 times (0.50 in FEMA 361) the design wind speed for vertical surfaces, and 0.10 times the design wind speed for horizontal surfaces.

Table 1. Speeds for 15-lb sawn lumber 2x4 missile for tornado shelters.

Design Wind Speed	Missile Speed and Shelter Impact Surface
130 mph	80 mph Vertical Surfaces 53 mph Horizontal Surfaces
160 mph	84 mph Vertical Surfaces 56 mph Horizontal Surfaces
200 mph	90 mph Vertical Surfaces 60 mph Horizontal Surfaces
250 mph	100 mph Vertical Surfaces 67 mph Horizontal Surfaces

Vertical surfaces are defined as walls, doors, and shelter envelope surfaces inclined 30 degrees or more from the horizontal, and horizontal surfaces are define as those inclined less than 30 degrees from the horizontal. Storm shelter components that are covered with 12 inches or less of soil cover protecting horizontal surfaces, or with 36 inches or less protecting vertical surfaces must be tested as if surfaces were exposed. Soil protection may be considered further protection of underground shelters if the soil slopes away from the entrance walls or other near-grade enclosure no more than 2 inches per foot for a horizontal distance of not less than 3 feet from exposed surfaces or unexposed surfaces protected by soil cover. Other considerations of debris hazards include lay down, rollover, and collapse which the design professional must take into account when choosing shelter location on a site.

Any shelter envelope components that withstand missile impact testing requirements for tornado shelters are deemed to also meet hurricane shelter requirements so long as they meet structural design load requirements. All openings of the storm shelters must be protected by devices that withstand testing requirements of ICC 500, Chapter 8. Protective devices for tornado shelters must be permanently affixed and manually operable from inside the shelter. Window and skylight assemblies not protected must withstand testing requirements of ICC 500 for tornado shelters and hurricane shelters.

Exterior cladding and exposed components of hurricane shelters must be able to resist rainwater penetration and meet wind load requirements of ICC 500 Section 304. Exposed metal and electrically grounded electrical fixtures within the shelter must be grounded to the host building external grounding system.

A shelter may be connected to a host building frame if the host building frame is designed for wind forces equaling or exceeding the design wind forces of the storm shelter. Storm shelters that are enclosed within a host building must be comply with the wind load requirements of ICC 500, Section 304. The connection of a storm shelter to the foundation or slab must be designed to resist uplift and lateral forces that occur during a storm, assuming that the host building is totally destroyed. Elevated storm shelter foundation structures must be calculated as if the structure and foundation are fully exposed to shelter design wind and flood forces, including flood-borne debris when applicable in compliance with ASCE 7.

DEBRIS IMPACT TESTING

Testing materials for the impact and pressure testing must be in the same condition as they would be in actual use including size, materials, details, methods of construction, and methods of attachment. Storm shelter components that are to be tested are the wall, roof, and door or window assembly. Wall and roof section debris testing must be done on a 4 feet by 4 feet minimum area, unless the actual component is smaller. Pressure testing on wall and roof sections must be done on a 4 feet by full length span. Doors and windows will be tested for the largest size to be used in the project. A single test specimen may be used for both the impact and pressure testing with consent of the owner, or one for each test. Testing samples must be kept at an ambient temperature for at least 2 hours before testing. The product specifications need to be submitted indicating details of materials and installation.

Missile impact testing requirements must be in compliance with ASTME E 1886, Section 6. However, any equipment equivalent, properly certified, calibrated, and approved by a qualified lab may be used. The missile must be any common softwood lumber that is grade stamped No. 2 or better and free from defects. The size must be a 2 by 4, 13.5 feet ± 6 inches long with a moisture content enough to yield a weight 15 ± 0.25 pounds, or 8 feet ± 4 inches with a moisture content enough to yield a weight of 9 ± 0.25 pounds. If a sabot is required for testing, it must not weigh more than 0.5 pounds and must be included in the weight of the missile. The missile speed measuring device must be able to accurately measure within ± 1 foot per second, and speed tolerance is + 4 miles per hour. Impacts must hit within 5 degrees of the normal of the test plane and must occur at specified points indicated in ICC 500, Chapter 8 depending upon the type of construction and type of specimen. The pass/fail criteria for the missile impact testing include a fail if any perforation of the interior surface of the shelter envelope occurs, dislodgement or disengagement, excessive spall, or permanent deformation.

Pressure testing must be in compliance with ASTM E 330, Section 6 and cyclic testing is in compliance with ASTME E 1886. Pressure testing is done on shelter components such as the wall assemblies, roof assemblies, door assemblies, and opening protective devices.

SITING REQUIREMENTS

ICC 500, Sections 401.1 or 402.2, whichever is applicable to the project, must be used to determine the minimum floor elevation requirements. Community storm shelters must be elevated to the higher of the following requirements: the flood elevation accounting for a 0.2 percent annual chance of being equaled or exceeded in any year (i.e., annual probability of exceedance), two feet above the 1% annual probability flood elevation, two feet above the highest recorded flood elevation, or the maximum inundation elevation associated with a Category 5 hurricane. This requirement is for both tornado and hurricane shelters, except that tornado shelters do not need to adhere with the first condition. Residential shelters must be elevated to the minimum elevation of the floodplain ordinance or one foot above the highest recorded flood elevation. If the shelter will be subjected to flooding, ASCE 7, Section 5 and ASCE 24 must be used for design provisions.

Shelters that are located within a precautionary zone of hazardous materials must be provided with protection from those materials as deemed necessary by the Local Emergency Planning Committee and the authority having jurisdiction. Residential tornado shelters must be within 150 feet of the residences they serve.

OCCUPANCY

Community shelters require a minimum floor area per occupant as shown in Table 2. The usable shelter floor area is determined by reducing the gross floor area of the shelter by 50 percent for areas with concentrated furnishings or fixed seating, 35 percent for areas with unconcentrated furnishings and no fixed seating, or 15 percent for areas with open plan furnishings and no fixed seating. There must be area for one wheelchair for every 200 occupants. The number of doors required for escape purposes is dependent upon the occupancy level of the shelter and the applicable building code. However, if only one door is required by the building code, an emergency escape opening is required. A sign, with minimum dimensions of 8.5 inches by 11 inches that is both tactile and visual, must be placed at every entrance to the storm shelter indicating that it is a shelter in compliance with ICC A117.1.

Table 2. The minimum required area per occupant in a storm shelter.

TYPE OF SHELTER	MINIMUM REQUIRED USABLE SHELTER FLOOR AREA IN SQUARE FEET PER OCCUPANT
Tornado	
Standing or seated	5
Wheelchair	10
Bedridden	30
Hurricane	
Standing or seated	20
Wheelchair	20
Bedridden	40

Residential storm shelters require a minimum floor area per occupant as shown in Table 3. The usable shelter floor area is the gross floor area, not including sanitary facilities. Access to the shelter must include an opening of a minimum of 24 inches by 30 inches, and if required for vertical access, must include stairs, a ladder, or an alternating tread device that comply with ICC 500, Section 502.3.

Locks and latching mechanisms must be permanently mounted and cannot require any tools to be placed in the lock position.

Table 3. Minimum required area per occupant in a storm shelter.

TYPE OF SHELTER	MINIMUM REQUIRED USABLE SHELTER FLOOR AREA IN SQUARE FEET PER OCCUPANT
Tornado	
One- and two-family dwelling	3
Other residential	5
Hurricane	
One- and two-family dwelling	7
Other residential	10

FIRE SAFETY

The storm shelter must be designed to have a minimum fire-resistance rating of 2 hours and comply with the applicable building code. Residential shelters are not required to have fire separation assemblies. All community storm shelters must be equipped with a fire extinguisher that meets the requirements of NFPA 10, and their installation into the storm shelter must not compromise the structural performance of the shelter.

ESSENTIAL FEATURES AND ACCESSORIES

Critical support systems must be protected if located outside of the storm shelter, and must remain functional a minimum of 24 hours for a hurricane shelter, and 2 hours for a tornado shelter. Natural or mechanical ventilation must be incorporated into the shelter design, with minimum requirements shown in Tables 4 and 5 for tornado and hurricane shelters, respectively.

Table 4. Venting area required for tornado shelters.

TORNADO SHELTER TYPE	VENTING AREA
Residential	2 square inches
Community (≤ 50 occupants)	5 square inches
Community (> 50 occupants)	6 square inches

Table 5. Venting area required for hurricane shelters.

HURRICANE SHELTER TYPE	VENTING AREA
Residential	4 square inches
Community (≤ 50 occupants)	8 square inches
Community (> 50 occupants)	12 square inches

Natural ventilation openings for tornado and hurricane shelters must be configured so that 25 percent of the required area is the least of 46 inches or less from the floor or in the lower half of the height of the shelter (this must be balanced in hurricane shelters with the greater of not less than 50 percent of openings located a minimum of 72 inches from the floor or in the upper one-fourth of the height of the shelter). Exceptions for tornado shelters may occur when 4 square inches of venting area per shelter occupant is added. The mechanical ventilation for both tornado and hurricane shelter intake openings must be a minimum of 10 feet horizontally, and cannot be near any hazardous or noxious contaminant. The exhaust and intake openings must also be protected and comply with ICC 500, Section 306.3.

Some shelters require sanitation facilities to be located within the storm shelter area, including a toilet and hand-washing facility. The requirements are shown in Tables 6 and 7 for tornado and hurricane shelters, respectively.

Table 6. Required sanitation facilities for tornado shelters.

TORNADO STORM SHELTER TYPE	TOILET FACILITIES	HAND-WASHING FACILITIES
Residential, one- and two-family dwellings	Not Required	Not Required
Residential, other	1	Not Required
Community (≤ 50 occupants)	1	Not Required
Community (> 50 occupants)	2 minimum and 1 per 500 occupants or portions thereof	1 per 1000 occupants

Table 7. Required Sanitation facilities for hurricane shelters.

HURRICANE STORM SHELTER TYPE	TOILET FACILITIES	HAND-WASHING FACILITIES
Residential, one- and two-family dwellings	Not Required	Not Required
Residential, other	1	Not Required
Community (≤ 50 occupants)	1	Not Required
Community (> 50 occupants)	1 per 50 occupants	1 per 100 occupants

Emergency lighting is required for community storm shelters with an average of 1 foot-candle of illumination in shelter areas, support areas, required corridors, passageways, and means of egress. Exceptions for shelters with occupant loads of 50 or less dictate that lighting can be provided through personal flashlights when at least 1 per 10 occupants is provided. Tornado shelter emergency power systems must be able to provide continuous power for a minimum of 2 hours, and hurricane shelter emergency power systems must provide continuous power for a minimum of 24 hours. Hurricane shelters require standby power for shelters with 50 occupants or more, and the system must be accessible within a protected access route. First aid kits are required in all hurricane shelters and tornado shelters with 50 or more occupants.

NSSA

The National Storm Shelter Association is a not-for-profit, self-policing, trade association for the benefit of the public and a strong, credible industry. Functions of the organization include quality verification, educating the public, and monitoring applicable research. The ICC 500 is the reference standard by which quality of shelters is measured and as the standard that must be met for admission to NSSA Producer Membership. The storm shelter quality verification process includes:

- A pledge from producer members to produce only shelters that meet or exceed the NSSA Industry Standard
- Abide by NSSA bylaws and code of ethics
- Obtain third-party compliance verification of design or variations from FEMA 320
- Test shelter or FEMA 320 variations for debris impact resistance
- Affix the NSSA seal and file the Certificate of Installation with NSSA for each shelter installed

NSSA membership benefits for shelter producers are increased credibility, distinction, enhanced reputation, compliance verification by an independent third-party engineering company, decreased liability, professional listings, a head-start on inspections, and qualifications for grants in some areas. Consumer benefits include guidance to quality-verified products and producers, information on important elements of shelter quality, guidance on shelter selection and location, and increased value with a NSSA seal.

ACKNOWLEDGEMENTS

Tribute is paid, to the founders and members of NSSA who spent countless hours in writing bylaws, formulating policies, writing standards and in many ways tending the business of NSSA. In addition, the members of the ICC committee and friends of the committee who labored diligently over a period of five years to develop the ICC 500 Standard and those who contributed to the development of FEMA guidelines are heroes of the shelter industry.

Pataya Boontheekul , a graduate student in Wind Science and Engineering at Texas Tech University performed noteworthy work in extracting information from various sources to form this publication.

REFERENCES

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[2] ICC/NSSA Standard for the Design and Construction of Storm Shelters—2008 (ICC 500). International Code Council.