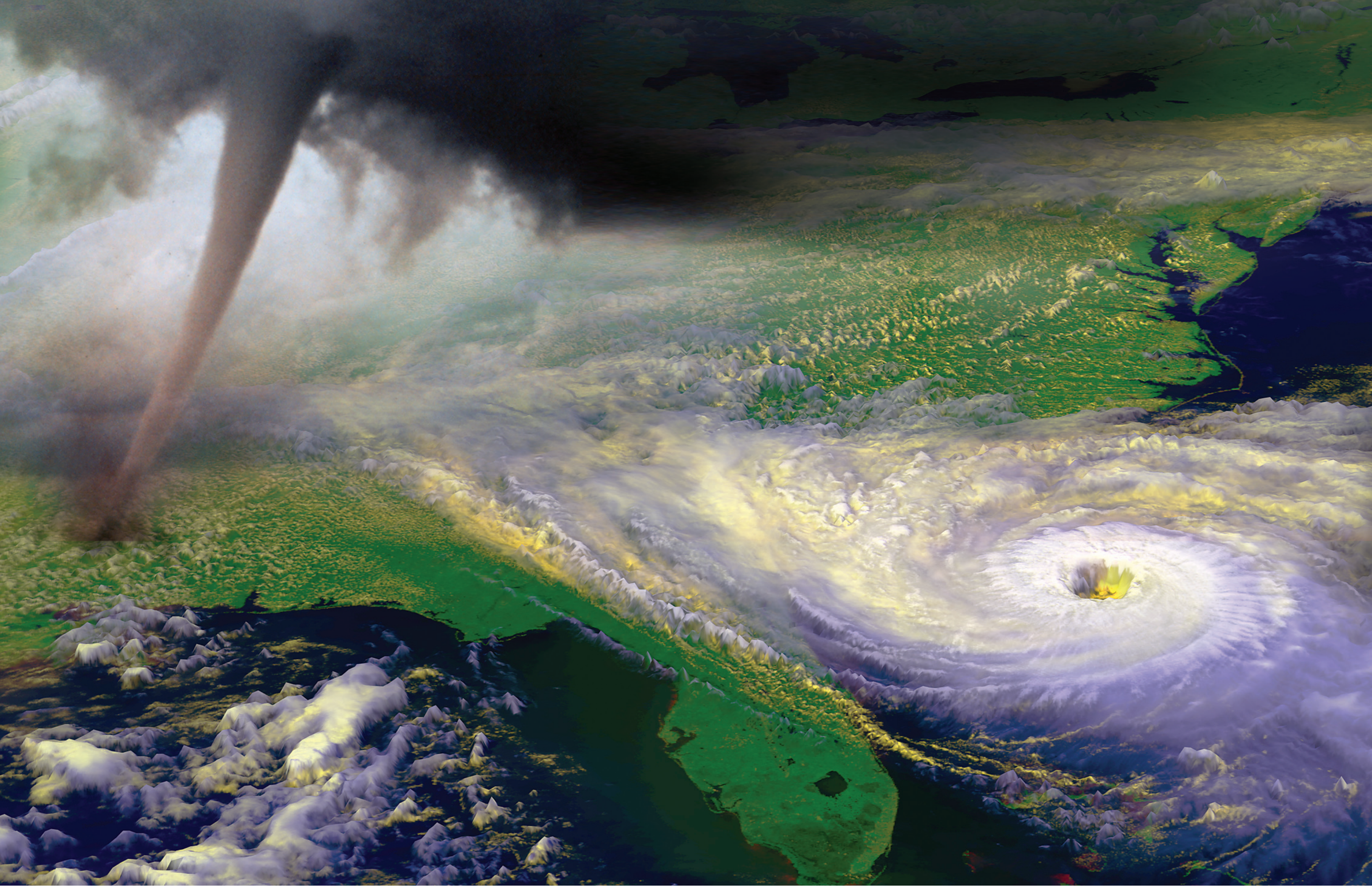


Design and Construction Guidance for Community Safe Rooms

FEMA 361, Second Edition / August 2008

FEMA

1 Introduction

This publication provides guidance for architects, engineers, building officials, local officials and emergency managers, and prospective safe room owners and operators about the design, construction, and operation of safe rooms and storm shelters, and for extreme-wind events. It presents important information about the design and construction of community safe rooms that will provide protection during tornado and hurricane events.

1.1 Purpose

This publication presents the design and construction guidance that the Federal Emergency Management Agency (FEMA) believes is necessary to provide life-safety protection during extreme-wind events. This guidance interprets the new International Code Council® (ICC®) *ICC/NSSA Standard for the Design and Construction of Storm Shelters* [(ICC-500, produced in consensus with the National Storm Shelter Association (NSSA)] design criteria and provides technical design guidance and emergency management considerations to individuals who are looking for "best-practices" that are above minimums in the codes and standards. FEMA continues to advocate the design and construction of safe rooms as evident by its continuing support of safe room initiatives through several grant programs. Since the initiation of its safe room program, FEMA has provided federal funds totaling over $200,000,000 for the design and construction of more than 500 community safe rooms. Through residential safe room initiatives over the same time, FEMA has provided support for the design and construction of nearly 20,000 residential safe rooms with federal funds totaling more than $50,000,000. These projects were completed in both tornado-prone and hurricane-prone regions of the country.[1] Although this publication provides technical information that must be adhered to as part of the funding requirements of the FEMA safe room policy,[2] this is not its primary purpose. Rather, the most important aspect of this publication is that it provides the criteria necessary for any safe room, private or public, to be constructed so that it is capable of providing "near-absolute protection" for its occupants during extreme-wind events.

The first edition of FEMA 361, released in July 2000, set forth design and construction criteria for tornado and hurricane shelters where none had been provided. These criteria were the basis of many community safe rooms that have been designed, constructed, and funded by FEMA since 2000. This second edition of FEMA 361 continues to provide guidance in the design and construction of tornado and hurricane safe rooms, but now references much of the ICC-500

[1] FEMA safe room program statistics are current through March 2008. The dollar figures provided are the estimated federal share obligated towards the design and construction of the safe rooms.

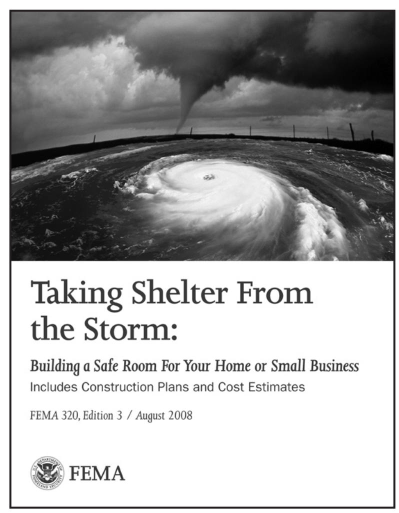
[2] FEMA's policy on the eligibility of the design and construction of safe rooms for federal funding is provided in FEMA Mitigation Interim Policy MRR-2-07-1, *Hazard Mitigation Assistance for Safe Rooms*, dated March 7, 2008.

Storm Shelter Standard. FEMA supports the development of hazard-resistant codes and standards through the monitoring of, and participation in the process of creating these documents, including the ICC-500.

Codes and standards are typically produced by consensus committees through open, public forums and there are always topics and subject areas where compromises are made in the preparation of the design criteria. As such, FEMA has identified specific design criteria in this publication to be more conservative than what is presented in the ICC-500 in large part due to emergency management considerations and maintaining near-absolute protection. FEMA believes the criteria in this updated publication should be incorporated into safe room design and construction projects to best protect individuals from wind and debris during wind storms. This second edition of FEMA 361 relies upon much of the ICC-500, but also identifies the specific technical criteria where the FEMA guidance meets or exceeds the minimum requirements of the ICC-500. This approach is consistent with past publications produced by FEMA. FEMA guidance publications have provided, and will continue to provide, "best-practices" guidance above and beyond the minimum criteria and scope of the consensus codes and standards for design and construction of buildings and structures to resist natural and manmade hazards.

1.2 Safe Rooms vs. Shelters

"Safe room" and "shelter" are two terms that have been used interchangeably in past publications, guidance documents, and other shelter-related materials. However, with the release of the ICC-500 standard, there is a need to identify or describe shelters that meet the FEMA criteria for life-safety protection and those that meet the ICC-500 standard. To help clarify the difference between shelters designed to the ICC-500 standard and the FEMA 320 and 361 guidance, this publication will refer to all shelters constructed to meet the FEMA criteria (whether for individuals, residences, small businesses, schools, or communities) as safe rooms. All safe room criteria in this publication meet or exceed the shelter requirements of the ICC-500.



Safe rooms designed and constructed in accordance with the guidance presented in this publication provide "near-absolute protection" from extreme-wind events. Near-absolute protection means that, based on our current knowledge of tornadoes and hurricanes, the occupants of a safe room built according to this guidance will have a very high probability of being protected from injury or death. Our knowledge of tornadoes and hurricanes is based on substantial meteorological records as well as extensive investigations of damage from extreme winds. However, since extreme-wind events may occur or have hypothetically occurred in the past, to date a wind event exceeding the maximum design criteria in this publication has not been observed. For this reason, the protection provided by these safe rooms is called near-absolute rather than absolute.

TORNADO OCCURRENCE AND RESULTANT LOSSES ARE INCREASING

In 1950, the National Weather Service (NWS) started keeping organized records of tornadoes occurring in the United States (U.S.). Since that time, 1953 was the deadliest year (519 deaths). The average in recent years has been 62 deaths per year. Deaths caused by tornadoes were 38, 67, and 81 for 2005, 2006, and 2007, respectively. As of May of this year, 110 deaths have been caused by tornadoes.

In addition to deaths, tornadoes cause injuries and devastating losses of personal property. Insurance claim losses from a single tornadic event of $1 billion and higher are becoming more frequent. So far in 2008, tornadoes have resulted in insured losses of more than $1 billion (almost $850 million from the mid-South outbreaks on February 5 and 6; in March, Atlanta and its surrounding counties were struck by a tornado that caused $349 million in losses).

This photograph from FEMA's photo library shows the vivid reality of how lives are impacted by tornadoes. (Lafayette, TN – February 5, 2008)

SOURCE: JOCELYN AUGUSTINO/FEMA

Although hurricanes and earthquakes generally generate higher losses per event, since 1953, tornadoes (and related weather events) have caused an average of 57 percent of all U.S. insured catastrophic losses. In 2007, that number increased to 69 percent.

SOURCE: A.M. BEST, CNN

For the purpose of this publication, a community safe room is defined as a shelter that is designed and constructed to protect a large number of people from a natural hazard event. The number of persons taking refuge in the safe room will typically be more than 16 and could be up to several hundred or more. These numbers exceed the maximum occupancy of small, in-residence safe rooms recommended in the second edition of FEMA 320, *Taking Shelter From the Storm: Building a Safe Room Inside Your House*. It should be noted that a third edition of FEMA 320 is being prepared and will be released in conjunction with this update of FEMA 361.

The two types of community safe rooms covered by the guidance in this publication include:

- Stand-alone safe room – a separate building (i.e., not within or attached to any other building) that is designed and constructed or retrofitted to withstand extreme winds and the impact of windborne debris (missiles) during tornadoes, hurricanes, or other extreme-wind events.
- Internal safe room – a specially designed and constructed room or area within or attached to a larger building; the safe room (room or area) that may be designed and constructed or retrofitted to be structurally independent of the larger building, but provides the same wind and missile protection as a stand-alone safe room.

These safe rooms are intended to provide protection during a short-term extreme-wind event (i.e., an event that normally lasts no more than 24 hours) such as a tornado or hurricane. (Minimum safe room occupancy times are 2 and 24 hours for tornadoes and hurricanes, respectively.) They are **not** recovery shelters intended to provide services and housing for people whose homes have been damaged or destroyed by fires, disasters, or catastrophes.

Both stand-alone and internal community safe rooms may be constructed near or within school buildings, hospitals and other critical facilities, nursing homes, commercial buildings, disaster recovery shelters, and other buildings or facilities occupied by large numbers of people. Stand-alone community safe rooms may be constructed in neighborhoods where existing homes lack shelters or where the homes are subject to damage from extreme-wind events. Community safe rooms may be intended for use by the occupants of buildings they are constructed within or near, or they may be intended for use by the residents of surrounding or nearby neighborhoods or designated areas.

This publication provides detailed guidance concerning the design and construction of both stand-alone and internal community safe rooms for extreme-wind events – guidance that is currently not available in other design guides or in building codes or standards. It is a compilation of the best information available at the time of publication. Safe room location, design loads, performance criteria, and human factor criteria that should be considered for the design and construction of such safe rooms are discussed herein. Case studies (one for a stand-alone safe room and one for an internal safe room) are presented in Appendices C and D, respectively, and illustrate how to evaluate existing shelter areas and make safe room selections, and provide construction drawings, emergency operations plans, and cost estimates. Many factors may influence the decision to construct a community safe room. They include the following:

- The likelihood of an area being threatened by an extreme-wind event
- The consequences (deaths and injuries) of an extreme-wind event
- The cost of constructing a safe room

Therefore, this publication also provides decision-making tools that include safe room hazard evaluation checklists and information about economic analysis software. These tools provide an effective means of addressing all or many of the considerations that can affect the decision either to build or to not build a community safe room.

1.3 Background

Tornadoes and hurricanes are among the most destructive forces of nature. Unfortunately, these types of wind storms continue to cause injury and death to people who are unable to safely evacuate or find shelter from these events. This section provides background information about recent tornadoes and hurricanes, post-disaster assessments, research activities, and design criteria development carried out by FEMA and other organizations in an attempt to improve the guidance for safe room design and construction.

1.3.1 Tornado Events

On average, more than 1,275 tornadoes have been reported nationwide each year since 1997. From 1950 through 2006, tornadoes have caused 5,506 deaths and 93,287 injuries,[3] as well as devastating personal and property losses. According to the *Glossary of Meteorology* (AMS 2000), a tornado is “a violently rotating column of air, pendant from a cumuliform cloud or underneath a cumuliform cloud, and often (but not always) visible as a funnel cloud.” The most violent tornadoes are capable of tremendous destruction with wind speeds of up to 250 miles per hour (mph) near ground level. Damage paths over 50 miles long and over 1 mile wide have been reported. During the Great Plains Tornado Outbreak of May 3, 1999, 67 tornadoes struck Oklahoma and Kansas, including numerous EF4 and EF5 tornadoes (EF4 and EF5 are classifications based on the Enhanced Fujita (EF) Tornado Scale – see Table 4-1 in Chapter 4). This tornado outbreak resulted in 49 deaths and leveled neighborhoods. Additional information about the Oklahoma and Kansas tornadoes is available in the FEMA Mitigation Assessment Team (MAT) report *Midwest Tornadoes of May 3, 1999*, FEMA 342. These events had a great influence on FEMA and the decision to develop the first edition of FEMA 361 in June 2000. Figure 1-1 shows Kelley Elementary School in Moore, Oklahoma, and the central corridor of the school, which was the designated tornado refuge area. When the tornado hit, classes were over for the day. However, had this tornado occurred earlier in the day, the effect on individuals taking shelter would have been disastrous.

Similar deadly storm outbreaks have occurred since that time. Almost 4 years to the day after the May 3, 1999, tornadoes, 80 tornadoes were reported across eight states, including Kansas, Oklahoma, and Missouri. The tornadoes struck on May 8, 2003, causing 37 deaths and destroying hundreds of homes and businesses. Again in May, but in 2007, a smaller tornado outbreak occurred. On May 4th, 12 tornadoes were spawned by an intense supercell.

[3] Tornado occurrence data obtained from the NOAA Storm Prediction Center records at http://www.spc.noaa.gov/climo/historical.html.

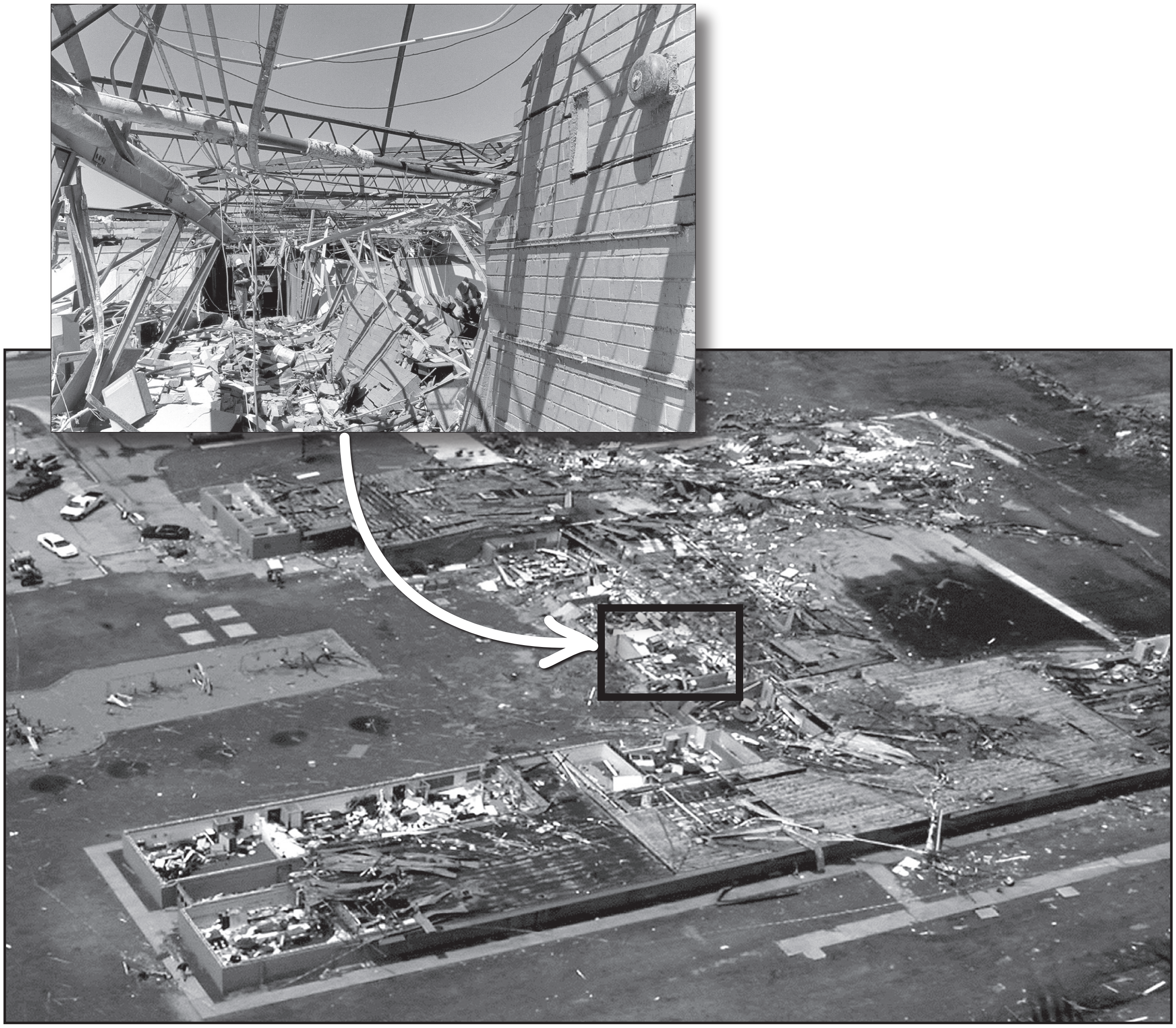


Figure 1-1. Destroyed tornado refuge area at Kelley Elementary School, Moore, Oklahoma (1999)

One of these tornadoes was rated an EF5. Wind speeds from this tornado were estimated to be greater than 205 mph (3-second gust). The tornado had a reported swath of 1.7 miles, and destroyed approximately 95 percent of Greensburg, Kansas, causing 11 deaths in the town.

Prior to the Greensburg tornado, Florida was impacted by a tornado outbreak in February 2007. A small, but deadly outbreak of three tornadoes struck northeast Florida from the Lady Lake area to New Smyrna Beach on the coast. These three tornadoes killed 21 people and injured dozens of others. Of the three tornadoes, two were rated EF3 and one was rated EF1. Because these tornadoes struck in the middle of the night, almost all of the fatalities were to individuals who were in their homes. The unfortunate events of February 2007 remind us that, even in hurricane-prone areas where many homes are considered to be more "hazard-resistant," they are not designed to provide life-safety protection. The two EF3 tornadoes, in the middle of the EF Scale, were not the large EF4 and EF5 tornadoes typically associated with major storm fatalities. These lower intensity, and more common tornadoes, highlight the tornado hazard that exists in hurricane-prone regions and calls attention to the threat posed to homeowners by smaller tornadoes because residential construction is typically not designed to provide near-absolute protection for their occupants.

Also in 2007, a significant tornado developed near Enterprise, Alabama on March 1st, again with deadly results. The tornado was categorized as a lower-end EF4 and produced enough force to damage a significant portion of the town, including directly impacting Enterprise High School (see Figure 1-2). Eight students perished at the high school as they were sheltering-in-place. The school had identified a best-available area for refuge during a tornado, but no portion of the building had been hardened for tornado resistance to provide the level of protection consistent with a FEMA 361 safe room. After the event, the following statement was released by the investigators from the National Oceanic and Atmospheric Administration (*NOAA – Tornadoes in Southern Alabama and Georgia, March 1, 2007*; NOAA tornado assessment):

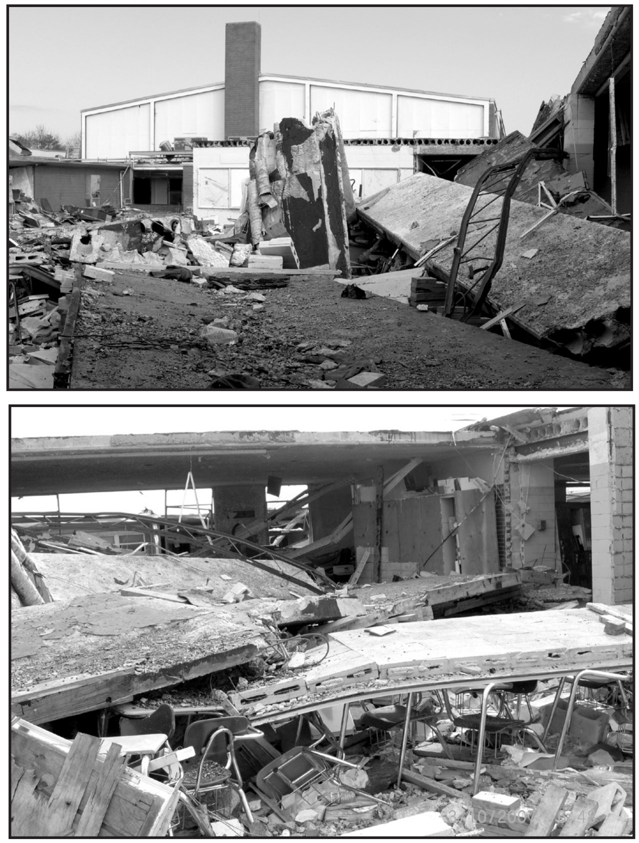


Figure 1-2. Destroyed tornado refuge area at Enterprise High School, Enterprise, Alabama (2007)

> *"The high school in Enterprise followed proper protocol in terms of maximizing student safety. The eight fatalities at the high school appear to have been due to structural failure of the roof and walls, which collapsed on the students. Previous events have shown that hardened safe rooms provide better shelter from tornadoes than other permanent structures, especially during EF3 or greater tornadoes, and may be a critical component of adequate tornado safety plans, especially in mobile home parks, homes with standard grade construction, and non-residential buildings in which many people normally gather (schools, office buildings, etc.)."*

The events in Moore, Oklahoma, Greensburg, Kansas, and Enterprise, Alabama, as well as other events not detailed here, show the deadly and destructive potential of tornadoes. Such events continue to illustrate the compelling need for shelters and safe rooms capable of protecting human lives against the risk of tornadoes. This publication provides design criteria for the design and construction of community safe rooms that should provide the level of protection needed to protect lives from tornadic events.

NOTE

FEMA 320, *Taking Shelter From the Storm: Building a Safe Room For Your Home or Small Business*, is another FEMA publication that provides guidance on safe rooms for tornado and hurricane protection. FEMA 320 presents a summary of storm hazards and prescriptive designs of both above- and in-ground safe rooms that meet the design criteria of FEMA 361 and the ICC-500 for residential and small community shelters.

1.3.2 Hurricane Events

A hurricane, as defined by NOAA, is a tropical cyclone in which the maximum sustained surface wind (using the U.S. 1-minute average) is 74 mph. The term hurricane is used for Northern Hemisphere tropical cyclones east of the International Dateline to the Greenwich Meridian. Around its core, winds can grow with great velocity, generating violent seas. As the storm moves ashore, it can push ocean waters inland (this effect is known as storm surge) while spawning tornadoes and producing torrential rains and floods. In this publication, the term storm surge means an abnormal rise in sea level accompanying a hurricane or other intense storm, whose height is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the cyclone. Storm surge is usually estimated by subtracting the normal or astronomic high tide from the observed storm tide (see Figure 3-3 of Chapter 3).

On average, 10 tropical storms (6 of which become hurricanes) develop each year in the Atlantic Ocean.[4] Approximately five hurricanes strike the United States mainland every 3 years; two of those storms will be major hurricanes (Category 3 or greater on the Saffir-Simpson Hurricane Scale – see Table 4-2 in Chapter 4). The loss of life and property from hurricane-generated winds and floodwaters can be staggering. Although these storms do not make landfall in the U.S. every year, from 1900 through 2006, hurricanes caused 17,832 deaths and substantial numbers of injuries, as well as extensive personal and property losses. Tornadoes of weak to moderate intensity (typically EF0 to EF2) occasionally accompany tropical storms and hurricanes that move over land. These tornadoes are usually to the right and ahead of the path of the storm center as it comes onshore.

CROSS-REFERENCE

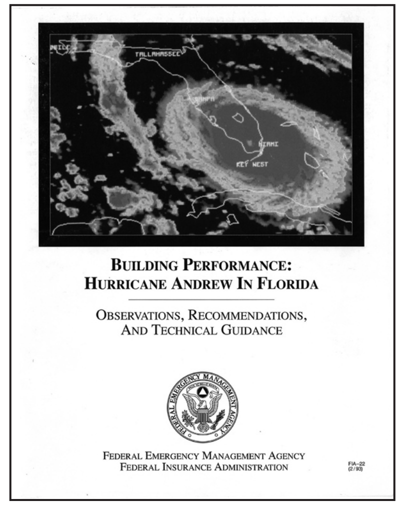
The Saffir-Simpson Hurricane Scale is discussed in Chapter 4.

In the western Pacific, hurricanes are called “typhoons.” The term typhoon is used for Pacific tropical cyclones north of the Equator and west of the International Dateline [(i.e., the Pacific Islands, including Guam and American Samoa)]. In the Indian Ocean, similar storms are called “cyclones.” Like hurricanes and tornadoes, typhoons and cyclones can generate extreme winds, flooding, high-velocity flows, damaging waves, significant erosion, and heavy rainfall. Historically,

[4] Hurricane occurrence data obtained from NOAA historical records. Note: Although the statistical set goes back to 1851, data records older than 1900 may underreport occurrences since many coastal communities had not yet been established.

typhoons have been classified by strength as either typhoons (storms with less than 150 mph winds) or super typhoons (storms with wind speeds of 150 mph or greater), rather than by the Saffir-Simpson Hurricane Scale.

In recent years, multiple hurricanes have caused severe damage to coastal areas in the southern Atlantic and Gulf coast regions of the United States. One hurricane that had significant effects on not only the people and the community impacted, but also on design and construction requirements for all building types (residential, non-residential, and essential facilities) was Hurricane Andrew. The storm made landfall in southeastern Florida on August 24, 1992, generated strong winds and heavy rains over a vast portion of southern Dade County. This Category 4/5 hurricane (which is defined as having sustained wind speeds of approximately 155 mph) produced extreme winds and high storm surge, but the most extensive damage was caused by winds and not the storm surge. The storm caused unprecedented economic devastation; damage in the United States was estimated to be $21 billion dollars in insured losses (adjusted for inflation to 2006 dollars). In Dade County, the storm forces caused 15 deaths and left almost one-quarter million people temporarily homeless. Additional information about Hurricane Andrew was documented in the FEMA report *Building Performance: Hurricane Andrew in Florida*, FIA-22.



Facilities designated as shelters are given the responsibility of protecting the lives of those taking refuge within them. Yet damage to these “shelters” or “hardened areas” continues to be observed, which undermines public confidence. Often, there is a general lack of understanding of effects of exposing buildings not designed to provide life-safety protection from extreme-wind events. A variety of different types of “shelters” that are used before, during, and after storm events, provide different levels of protection. If the building or structure selected for use as a shelter cannot withstand the effects of hurricane winds, the results can be devastating. In 2004, Hurricane Charley moved over Florida as a Category 4 hurricane. In an inland county, a facility had recently been constructed to design wind speeds above the 110 to 120 mph (3-second gust) wind speeds that were actually experienced. The building met minimum requirements established by the state for shelter facilities. The building was sheltering approximately 1,200 people when roof panels began lifting off and one end wall of the facility partially collapsed (see Figure 1-3). Shelter performance such as this prompts scrutiny of the different protection levels that have been developed over the years and again reinforces the need for better shelter design and construction guidance such as FEMA 361 and the ICC-500, which address the entire design and construction life-cycle from planning through design and construction of the facility, and provide a level of protection associated with life-safety of shelter occupants.

The most devastating hurricane in recent years, however, was Hurricane Katrina, the third strongest hurricane to make landfall in the history of the United States. Though crossing Florida as only a moderate Category 1 hurricane, it moved into the Gulf of Mexico where it rapidly increased to a Category 5 hurricane. After weakening just 24 hours prior to landfall, Katrina came ashore as a Category 3 storm in Louisiana and Mississippi. Hurricane Katrina went on to cause over 1,800 deaths and $81.2 billion in insured losses (making it the largest natural disaster in U.S. history). The storm caused the levees to break in New Orleans, pushing floodwaters throughout much of the city, and caused tremendous damage to many cities and towns all along the Mississippi coast. After the storm, FEMA dispatched a MAT to assess the performance of buildings impacted by the storm (see FEMA 549, *Hurricane Katrina in the Gulf Coast*). Among the many findings and conclusions made by the MAT, it was determined that buildings functioning as critical and essential facilities (which were often used as shelters during the storm) did not perform better than their commercial counterparts. The same construction issues that affected residential and commercial buildings were observed in critical and essential facilities, the very facilities that the public regularly assumes have to been hardened to resist hurricane winds and floodwaters.

Figure 1-3. Severely damaged hurricane shelter at Turner Agri-Civic Center, Arcadia, Florida (2004)

As with the tornado events discussed in the previous section, the events in Florida, Louisiana, and Mississippi represent just a small sampling of the deadly and destructive potential of hurricanes and continue to illustrate the compelling need for shelters and safe rooms capable of protecting human lives. FEMA 361 provides design criteria for the design and construction of community safe rooms for facilities that can resist such wind forces.

1.3.3 Post-Disaster Assessments, Research, and Design Development

When a hurricane, tornado, earthquake, or terrorist attack results in a catastrophic natural or manmade disaster in the United States or one of its territories, FEMA frequently deploys a technical building sciences team to document the performance of the built environment during the event. These teams are referred to as Mitigation Assessment Teams. The objectives of a MAT are to inspect damage to buildings, assess the performance of the buildings, evaluate design and construction practices, and evaluate building code requirements and enforcement. The MAT then makes recommendations for improving building performance in future storm events. The MAT consists of representatives from FEMA Headquarters, the FEMA Regional Offices, state and local governments, and public and private sector experts in design, construction, and building code development and enforcement.

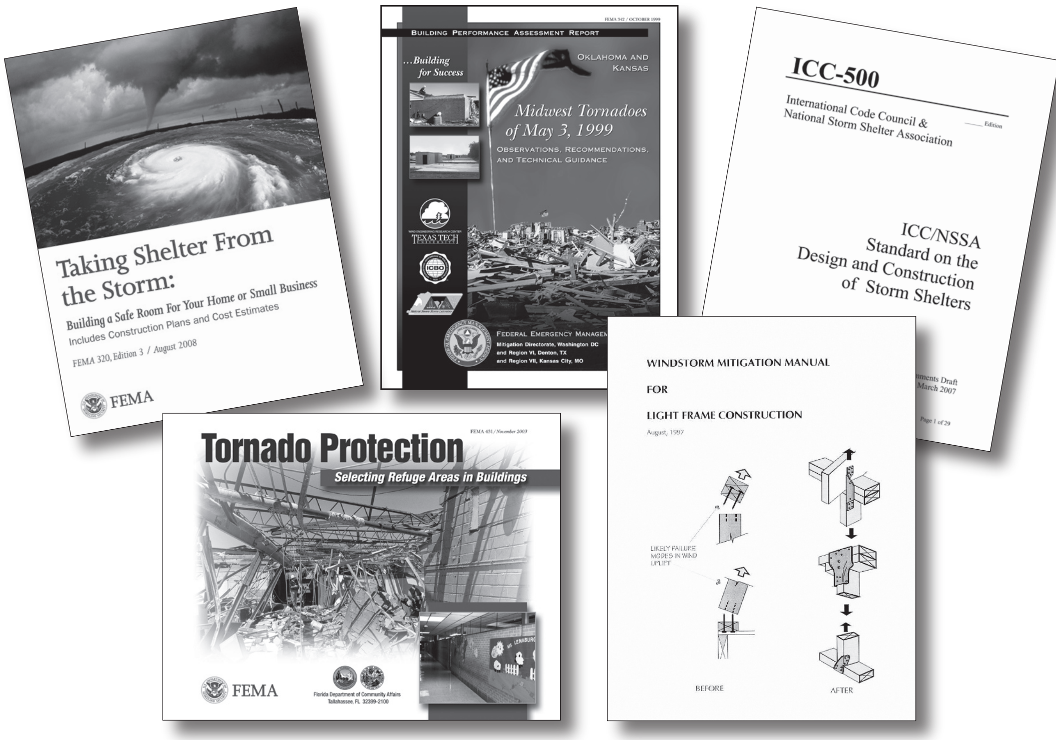
> **The MAT Process:** In response to catastrophic hurricanes, floods, tornadoes, earthquakes, and other disasters, FEMA often deploys Mitigation Assessment Teams (MATs) to conduct field investigations at disaster sites. More information about the MAT program can be found at http://www.fema.gov/rebuild/mat/mat_faqs.shtm.

The findings from MATs outline building science issues of national significance that warrant further study. Since Hurricane Opal in 1989, MATs (and building science teams from preceding programs, such as the Building Performance Assessment Team [BPAT] program) have studied and reported on over 10 major hurricane or tornado events. In addition, FEMA uses smaller technical field assessment teams to support the MAT and other post-disaster activities to further document the performance of buildings and shelters during these events. For example, in 2007, in response to numerous outbreaks of tornadoes, FEMA ordered several teams into the field to assess building performance, damages, and associated issues. These teams produced a series of technical safe room and building improvement documents: the five February 2007 Tornado Recovery Advisories (RAs) (FEMA DR-1679, http://www.fema.gov/library/viewRecord.do?id=2631) and the three May 2007 Tornado RAs (FEMA DR-1699, http://www.fema.gov/library/viewRecord.do?id=2972, 2973, and 2974) prepared for public release to aid in post-disaster reconstruction. The RAs contain informative facts about tornadoes, their effects on various types of construction from manufactured housing to community safe rooms, the risk of tornado events associated with regions of the country, and potential mitigation actions that can be taken to reduce damages to older and new manufactured homes.

Additionally, studies have been conducted since the early 1970s to determine design parameters for safe rooms intended to provide protection from tornadoes, hurricanes, and other extreme-wind events. In 1998, using the results of research conducted by Texas Tech University's (TTU's) Wind Science and Engineering (WISE) Research Center, formerly the Wind Engineering Research Center (WERC), FEMA developed design guidance and construction plans for in-home safe rooms and prepared the booklet *Taking Shelter From the Storm: Building a Safe Room Inside Your House* (FEMA 320). As the title suggests, the guidance presented in FEMA 320 is specific to small safe rooms built inside individual houses.

Since the original guidance was published, several significant tornado and hurricane events have occurred. Considerable engineering and scientific research and investigations have been conducted that have resulted in various important findings. Also, using the original FEMA 361 publication as guidance, the International Code Council in partnership with FEMA and the National Storm Shelter Association (NSSA), formed a national committee that developed and released a new consensus standard to codify the design and construction requirements of extreme-wind storm shelters. This new standard, the *ICC/NSSA Standard for the Design and Construction of Storm Shelters* (ICC-500), was completed in the summer of 2008 and will be incorporated by reference into the 2009 International Building Code® (IBC®) and the International

Residential Code® (IRC®). This second edition of FEMA 361 updates the original guidance and takes into consideration the new ICC-500 standard, along with the additional research and studies that have been conducted since 2000.



This publication builds on the knowledge of field investigations, research, and technical reports and publications prepared by FEMA and other national and state agencies that have studied and researched the performance of the built environment during tornadoes and hurricanes. FEMA remains committed to the development of design and construction criteria and guidance for safe rooms capable of providing the highest quality of life-safety protection from extreme-wind events. Table 1-1 provides a listing of safe room and shelter publications and guidance documents that have been produced by FEMA over the past 32 years.

For questions related to safe room design criteria presented in FEMA 320 or FEMA 361, call the FEMA Building Science helpline at (866) 222-3580 or email saferoom@dhs.gov for technical assistance.

Table 1-1. Past FEMA Safe Room and Shelter Publications and Guidance

Date	Publication
April 1976	FEMA TR-83B, *Tornado Protection: Selecting and Designing Safe Areas in Buildings*
September 1980	FEMA TR-83A, *Interim Guidelines for Building Occupant Protection From Tornadoes and Extreme Winds*
September 1998	FEMA 320, *Taking Shelter From the Storm* (First Edition)
May 1999	FEMA *National Performance Criteria for Tornado Shelters*
August 1999	FEMA 320, *Taking Shelter From the Storm* (Second Edition)
July 2000	FEMA 361, *Design and Construction Guidance for Community Shelters*
October 2001	FEMA 388, *Safe Room and Shelter Resource* – CD
November 2003	FEMA 431, *Tornado Protection – Selecting Refuge Areas in Buildings* (in cooperation with the Florida Department of Community Affairs)
March 2007	2007 *Florida Tornado Outbreak – Tornado Recovery Advisories*
September 2007	*Greensburg, KS Tornado – Tornado Recovery Advisories*

1.4 Organization of the Publication

This publication consists of 10 chapters and 8 appendices. This first chapter is the introduction and provides the purpose and background for the publication. The following is a list of the other chapters herein:

Chapter 2 describes the objectives of designing community safe rooms (the primary objective is the safety of the occupants within the safe rooms), and discusses risk assessment tools and compares FEMA safe room criteria with other shelter criteria.

Chapter 3 presents the FEMA design criteria for both tornado and hurricane safe rooms. Details include applicable ICC-500 design requirements, code compliance, peer review, and design documentation.

Chapter 4 discusses the characteristics of tornadoes and hurricanes, and their effects on structures.

Chapter 5 provides commentary on some of the design criteria given in Chapter 3, safe room location concepts (including safe rooms accessed from the interior or exterior of a building), modifying and upgrading existing interior space, safe room location and accessibility, and types of safe rooms.

Chapter 6 presents commentary on the wind and flood load design criteria for safe room structures (e.g., determination of wind loads, protection against penetration by windborne missiles, and proper anchorage and connection).

Chapter 7 provides commentary on the performance criteria for windborne missile impacts, doors and door frames, windows, and roofs.

Chapter 8 presents the human factors criteria for safe rooms (e.g., proper ventilation, square footage per safe room occupant, accessibility, lighting, occupancy durations, emergency food and water, sanitary management, emergency supplies, and emergency power).

Chapter 9 discusses emergency management considerations, including parameters for developing a plan of action to respond to an extreme-wind event for both community safe rooms and safe rooms in commercial buildings, and preparation of a safe room maintenance plan.

Chapter 10 provides a list of references used in the preparation of this publication.

Appendix A presents a list of the key people involved in preparation of both the first and second editions of the publication. This includes the Project Team, the Review Committee, and a list of individuals and agencies that FEMA would like to acknowledge.

Appendix B contains checklists for use in assessing wind, flood, and seismic hazards at a potential safe room site and for refuge areas. It also contains checklists for designers and planners to use when planning and establishing the design criteria for a new tornado or hurricane community safe room.

Appendices C and D each present a case study in which a community safe room was designed. The case studies include wind load analyses, conceptual safe room design plans, and cost estimates. Appendix C contains conceptual design plans for a community safe room for a community in North Carolina. Appendix D contains conceptual design plans for a safe room for a school building in Wichita, Kansas.

Appendices E and F provide the results of missile impact tests on a variety of different safe room wall sections, and safe room doors and door hardware, respectively.

Appendix G presents design guidance regarding impact protection for wood sheathing.

Appendix H contains the list of acronyms and abbreviations used in this publication.

2 Protection Objectives

As noted in Chapter 1, FEMA has developed prescriptive designs for residential and small community safe rooms (for 16 or fewer occupants) designed to near-absolute protection for the occupants of a home or small business during extreme-wind events. The May 1999 MAT investigation of the tornadoes in Oklahoma and Kansas made it clear that an extreme-wind event can cause a large loss of life or a large number of injuries in high-occupancy buildings (e.g., schools, hospitals and other critical care facilities, nursing homes, day care centers, and commercial buildings). Extreme-wind events can also cause a large loss of life or a large number of injuries in residential neighborhoods where people do not have access to either in-residence or community safe rooms. Based on the concepts for the residential safe rooms, the first edition of FEMA 361 was developed to provide design professionals with guidance on the design of community safe rooms that can accommodate large groups of people for protection from extreme-wind events for larger, at-risk populations.

This publication provides guidance addressing the design and engineering issues for design and construction of "stand-alone" community safe room buildings, constructing safe rooms within or as a part of a new building, and adding a safe room to an existing building. Guidance is also provided by identifying wall and roof sections capable of withstanding impacts from windborne debris (missiles). Although arguably not required for life-safety protection from extreme-wind events, the criteria on reconciling non-structural design criteria with the model building, fire, and life-safety codes are also included, along with a discussion of emergency considerations such as evacuation and operations plans.

This publication provides guidelines for the design and construction of safe rooms with the objective of near-absolute protection. This level of life-safety protection, and the criteria upon which it is based, distinguish this manual from other design standards and model codes, including the ICC-500. To better understand these differences, Table 2-1, presented later in this chapter, gives a detailed review of basic criteria and provisions of all major design standards, codes, and guidelines related to safe room and shelter design and construction.

The design and planning necessary for high-capacity safe rooms that may be required for use in large,

WARNING

A safe room designed according to the guidance presented in this manual provides near-absolute protection from death and injury, even though the building itself may be damaged during a design event. (A design event is determined by design wind speeds for tornadoes and hurricanes from the maps in Figures 3-1 and 3-2, respectively, of Chapter 3.)

public venues such as stadiums or amphitheaters are beyond the scope of this manual. An owner or operator of such a venue may be guided by concepts presented in this publication, but detailed guidance concerning extremely high-capacity safe rooms is not provided. The design of such safe rooms requires attention to behavioral and other non-engineering issues that affect the life safety of a large number of people. Egress timing for thousands of people in a stadium, how to manage a large group of individuals in a safe room or shelter, and security within a shelter or safe room are examples of behavioral and other non-engineering issues that should be addressed when protecting a large group of people. However, these issues are also beyond the scope of this publication.

2.1 What is a Safe Room?

A safe room is typically an interior room, a space within a building, or an entirely separate building, designed and constructed to provide life-safety protection for its occupants from tornadoes or hurricanes. Safe rooms constructed to the criteria in this publication will 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 safe room is intended to be much greater than the protection provided by buildings that comply with the minimum requirements of most model building codes. Model building codes usually are developed not for life-safety protection, but rather for property loss protection. The model building codes currently do not provide design and construction criteria for life safety for sheltering nor do they provide design criteria for tornadoes, but this will change in 2009. In 2008, the ICC will release for adoption the ICC-500 Storm Shelter Standard. This document will provide the basis for the design and construction of shelters that was produced through the consensus standard process. The ICC-500 will be incorporated by reference into the 2009 IBC and IRC codes to regulate the design and construction of buildings, or portions thereof, that have been designed as safe rooms to provide life-safety protection from extreme-wind events. The purpose and scope of the ICC-500 are presented below:

NOTE

Neither FEMA 361 nor the ICC-500 mandates the design and construction of residential or community safe rooms or shelters within a jurisdiction. Rather, these documents provide criteria or requirements for regulating and enforcing the proper design and construction of safe rooms and shelters.

> ***ICC-500, Section 101.1 Purpose.*** *The purpose of this standard is to establish minimum requirements to safeguard the public health, safety, and general welfare relative to the design, construction, and installation of storm shelters constructed for protection from high winds associated with tornadoes and hurricanes. This standard is intended for adoption by government agencies and organizations for use in conjunction with model codes to achieve uniformity in the technical design and construction of storm shelters.*

> ***ICC-500, Section 101.2 Scope.*** *This standard applies to design, construction, installation, and inspection of storm shelters constructed as separate detached buildings or constructed as safe rooms within buildings for the purpose of providing safe refuge from storms that produce high winds, such as tornadoes and hurricanes. Shelters designed and constructed to this standard shall be designated to be hurricane shelters, tornado shelters, or combined hurricane and tornado shelters.*

These statements are very similar to the purpose and scope identified in FEMA 361, but important differences between the two documents do exist. From a technical standpoint, the ICC-500 has successfully standardized and codified a good deal of the original design guidance provided in the first edition of FEMA 361. However, some of the criteria originally proposed in FEMA 361 were modified during the consensus process that produced the ICC-500. FEMA acknowledged the rationale behind some of the changes and has accepted the new criteria. This second edition of FEMA 361 incorporates these changes by referring to sections of the ICC-500 for the design and construction requirements of a community safe room.

FEMA continually reviews its safe room design criteria and has interpreted the available research differently from the consensus standard committee. In FEMA's view, many wind design, windborne debris hazards, flood hazards, and operational issues should be addressed from a more conservative standpoint than the one agreed upon in the consensus standard process. From a procedural standpoint, FEMA's criteria have been, and will remain, guidance; they are not code or standard enforceable in a jurisdiction unless they have been adopted to act as a standard for extreme-wind protection. The same applies to the ICC-500 from its release in late 2008 until the release of the 2009 Editions of the IBC and IRC. Upon the release of the 2009 codes, the ICC-500 will not only be a stand-alone consensus standard document, it will be a part of the building code (incorporated by reference) as a readily enforceable design standard. This will be the case for any jurisdiction that adopts the 2009 IBC and IRC and that does not eliminate or delete the reference language in the code that invokes the use of the ICC-500 to govern how shelters should be constructed.

FEMA safe rooms may be classified into two categories: residential and community (non-residential) safe rooms.

- **A residential safe room** is intended to provide protection for a small number of people (16 or less). There are two general types of residential safe rooms: in-residence safe rooms and 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, which is intended to provide a place of refuge for the people who live in the home. An external residential safe room is similar in function and design, but it is a separate structure installed outside the home, either above or below ground. The residential safe room criteria presented by FEMA are for the combined tornado and hurricane hazards and are capable of proving life-safety protection as defined in Section 3.5 of this publication.

- **A community safe room** is intended to provide protection for a large number of people, anywhere from approximately 16 to as many as several hundred individuals. These safe rooms include not only public but also private safe rooms for business and other types of organizations. Tornado and hurricane community safe rooms are buildings or portions thereof that have been designed and constructed to the criteria set forth in Sections 3.3 and 3.4, respectively.

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 an extreme-wind event and are capable of providing life-safety protection as defined in Sections 3.3, 3.4, and 3.5 of this publication.

2.1.1 Structural and Building Envelope Characteristics of Safe Rooms

The primary difference in a building’s structural system 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. Conventional (normal) buildings are designed to withstand forces associated with a certain wind speed (termed “design [basic] wind speed”) based on historic wind speeds and probabilistic wind events documented for different areas of the country and presented in design standards such as the American Society of Civil Engineers (ASCE) 7-05, *Minimum Design Loads for Buildings and Other Structures*. 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 to 150 mph for a 3-second gust. By contrast, the design wind speed recommended by FEMA for safe rooms in these same areas is in the range of 200 to 225 mph for a 3-second gust and is intended to build safe rooms that can provide “near-absolute protection” for occupants.

For envelope or cladding systems, the governing design criterion is windborne debris, commonly referred to as missiles, which 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 when the buildings are located within windborne debris regions. Buildings located in windborne debris regions must have impact-resistant glazing systems or protection systems to protect the glazing. These systems can be laminated glass, polycarbonate glazing, or shutters. The ASCE 7-05 missile criteria were developed to minimize property damage and improve building performance; they were not developed to protect occupants and notably do not require walls and roof surfaces to be debris impact-resistant. To provide occupant protection for a life-safety level of protection, the criteria used in designing safe rooms include substantially greater resistance to penetration from windborne debris. Sections 3.3.2, 3.4.2, and 3.5.2 present the debris impact-resistance performance criteria for the tornado, hurricane, and residential safe rooms, respectively.

DEFINITION

ASCE 7-05 defines hurricane prone regions and windborne debris regions as follows:

Hurricane Prone Regions: Areas vulnerable to hurricanes; in the United States and its territories defined as:

1. The U.S. Atlantic Ocean and Gulf of Mexico coasts where the basic wind speed is greater than 90 mi/h, and
2. Hawaii, Puerto Rico, Guam, Virgin Islands, and American Samoa.

Windborne Debris Regions: Areas within hurricane prone regions located:

1. Within 1 mile of the coastal mean high water line where the basic wind speed is equal to or greater than 110 mi/h and in Hawaii, or
2. In areas where the basic wind speed is equal to or greater than 120 mi/h.

* ASCE 7-05 uses mi/h, which equates to mph.

The roof deck, walls, and doors in conventional construction systems are not required by the model building codes to resist windborne debris.[1] However, if the space defined as a safe room is to provide adequate life-safety occupant protection, the roof deck and walls that define the protected area and the doors leading into it all must resist windborne debris impacts. Additional information regarding criteria for the different levels of windborne debris resistance is provided in Sections 3.3.2, 3.4.2, and 3.5.2.

2.1.2 Design Criteria for Different Types of Safe Rooms and Shelters

Safe rooms, shelters, and refuge areas all provide different levels of protection depending on the design criteria used. The level of protection provided by a safe room or shelter is a function of the design wind speed (and resulting wind pressures) and of the windborne debris load criteria used in designing the facility.

The required design strength of the safe room, shelter, or refuge area, is dictated by wind pressure criteria given by different guides, codes, and standards. FEMA recommends design wind speeds for safe rooms that range from 130 to 250 mph for tornado hazards and from 160 to 255 mph for hurricane hazards.

[1] The last several editions of the Florida Building Code (FBC) have a requirement for protecting the walls, roofs, doors, and non-opening portions of certain buildings. Critical and essential facilities designed in special regions as High Velocity Hurricane Zones (HVHZs) are required by Chapter 16 of the FBC to provide debris impact-resistance per the windborne debris requirements of the American Society for Testing and Materials (ASTM) E 1996.

By contrast, the 2006 IRC and the 2006 IBC, which establish the minimum requirements for residential and other building construction, define a design wind speed as 90 mph in the Midwest (where a corresponding safe room design wind speed is 250 mph). Table 2-1 compares shelter design criteria and levels of protection with different guidance manuals, codes, regulations, standards, and shelter programs. The last row is provided to address the issue of selection of the area within existing buildings to be used as a refuge of last resort. Several publications related to identifying refuge areas from hurricane and other storm events exist. A good example is FEMA 431, *Tornado Protection: Selecting Refuge Areas in Buildings*. This publication, as well as others, does not set minimum criteria for improving buildings to resist wind loads and debris. Rather, FEMA 431 provides information about how buildings are damaged by wind and windborne debris so individuals who do not have access to a safe room or shelter, but are exposed to extreme-wind hazards, may identify the best available spaces within a building or structure in which to take refuge. This guidance in the publication is based on lessons learned and field observations of buildings and structures that have experienced extreme-wind events. However, individuals seeking protection in “refuges or areas of last resort” should understand that these portions of buildings have not been designed to resist extreme-wind loads or debris impacts and may not protect the individuals inside from being killed or injured during an extreme-wind event.

Table 2-2 presents comparative data for three locations using these design criteria for the different safe room and shelter documents. “N/A” (not applicable) is used to indicate that no guidance is provided for sheltering or basic construction., “Not required” indicates that there are no requirements.

2.1.3 Occupant Safety

This publication presents guidance for the design of engineered safe rooms that will protect large numbers of people during an extreme-wind event. Safe rooms designed by a professional according to the criteria outlined in this publication (including the safe room design wind speed selected in Chapter 3) are intended to minimize the probability of death and injury during an extreme-wind event by providing their occupants with near-absolute protection.

The risk of death or injury from tornadoes or hurricanes is not evenly distributed throughout the United States. This publication guides the reader through the process of identifying the risk of extreme winds in a particular location and mitigating that risk. The intent is not to mandate the construction requirements for safe rooms for extreme-wind events, but rather to provide design guidance for persons who wish to design and build such facilities. Levels of risk, and tools for determining the levels of risk, are presented in this chapter.

The intent of this publication is not to override or replace current codes and standards, but rather to continue to provide important guidance where none has been available before. Until the development of the ICC-500 Storm Shelter Standard, no building, fire, or life-safety code or engineering standard had provided detailed design criteria for the design of tornado or other extreme-wind shelters. FEMA 361 remains unique in that its goal is not just to help provide a safe space for individuals to take shelter from extreme-wind events, but it also presents guidance on how to achieve near-absolute protection. The information provided in this document is the best available at the time of publication. This information will support the design of a safe room that provides near-absolute protection during an event with a specified design wind speed that has been determined to define the wind threat for a given geographic area. Designing and constructing a safe room according to the criteria in this publication does not mean that the shelter will be capable of withstanding every possible extreme-wind event. The design professional who ultimately designs a safe room should state what the design parameters are and describe them in detail in the project documents as required by Sections 3.8 and 3.9. Examples of actual safe rooms that have been designed to the criteria presented in this publication are contained in Appendices C and D.

2.2 Safe Room Design Process

The decision to design and construct a safe room can be based on a single factor or on a collection of factors. Single factors are often related to the potential for loss of life or injury (e.g., officials at a hospital that cannot move patients housed in an intensive care unit, officials at a school that takes care of a large number of small children, etc.). Other factors that are considered in the risk assessment process should include the type of hazard event, probability of event occurrence and severity, vulnerability of buildings in the community, size of the population at risk, and probable single and aggregate annual event casualties.

The flowchart in Figure 2-1 presents the decision-making process that should take place when the construction of a community safe room is being considered. The major steps of this process are discussed in Sections 2.2.1 through 2.2.5.

2.2.1 The Threat From Extreme-Wind Events

The assessment of the level of threat from extreme winds is a first step in quantifying the risk to which a community is exposed. The exposure to extreme-wind hazards differs greatly in various parts of the country. Although the level of exposure to wind hazards is not easy to quantify accurately, areas exposed to stronger or more frequent tornadoes or hurricanes have been identified and mapped.

The assessment of the level of threat, or the exposure to wind hazards, is determined on the basis of probability of occurrence of a hazard event of specific magnitude at a specific location. The probabilities of occurrence are statistical estimates drawn from historical records of previous hazard events that describe not only the time and place, but also the details related to the intensity, size, duration, general circumstances, and effects of the event. Much of this information has been compiled into a number of risk assessment tools such as wind speed maps and frequency maps and tables.

Table 2-1. Wind Safe Room and Shelter Design Codes, Standards, and Guidance Comparison

Title or Name of Document[1]	Code, Regulation, Standard, or Publication	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 extreme-wind safe rooms.	Tornado and Hurricane	**FEMA 320:** Hazard map, maximum wind hazard speed of 250 mph used for design. **FEMA 361, Tornado:** 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." **FEMA 361, Hurricane:** Uses ICC-500 hurricane map.
International Code Council/National Storm Shelter Association (ICC/NSSA) *Standard for the Design and Construction of Storm Shelters* (ICC-500, August 2008)	Consensus standard for shelter design and construction, tentatively available for adoption in 2008. To be incorporated by reference into the 2009 IBC and IRC.	Tornado and Hurricane	**Tornado:** Uses FEMA 361 map. **Hurricane:** Uses revised ASCE 7-05 map with contours at 10,000-year MRI[2] with minimum shelter design wind speed of 160 mph, maximum approximately 255 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 SESP report for the detailed design guidance.	Tornado and Hurricane	**Florida Building Code (FBC)** map +40 mph recommended, based on ASCE 7-05 (maps basically equivalent); MRI is 50–100 years in coastal areas and adjusted with importance factor.
Florida Building Code EHPAs – code requirements for public "shelters" (FBC Section 423.25)	Statewide code requirements for EHPAs	Hurricane	**FBC map**, based on ASCE 7-05 (maps basically equivalent); MRI is 50–100 years in coastal areas and adjusted with importance factor.
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 the 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.
Refuge Areas of Last Resort	Guidance from FEMA and others for selecting best-available refuge areas	Tornado and Hurricane	None

Table 2-1. Wind Safe Room and Shelter Design Codes, Standards, and Guidance Comparison (continued)

Wind Design Coefficient Considerations[3,4]	Debris Impact Criteria[5]	Remarks
FEMA 320: Use 250 mph and calculate pressures using ASCE 7-05 methods and use I=1.0, K_d=1.0, Exposure C, no topographic effects, GC_{pi}=+/-0.55 (this will account for atmospheric pressure change [APC]). FEMA 361, Tornado: Use FEMA 361 wind speed map with four zones. Calculate pressures using ASCE 7-05 methods and use I=1.0, K_d=1.0, Exposure C, no topographic effects, GC_{pi}=+/-0.55 (this will account for APC). FEMA 361, Hurricane: Use ICC-500 process, but also must use Exposure C and design building using GC_{pi}=+/-0.55.	FEMA 320: Test all safe rooms with the representative missile: a 15-lb 2x4 at 100 mph (horizontal) and 67 mph (vertical). FEMA 361: Test safe rooms with representative missile (missile speed dependent on site design wind speed). Tornado: 15-lb 2x4 at 80–100 mph (horizontal) and 2/3 of this speed (vertical). Hurricane: 9-lb 2x4 at 80-128 mph (horizontal) and 16-26 mph (vertical).	FEMA 320: Intent is to provide “near-absolute protection” with prescriptive designs that meet the highest hazard design criteria for both tornadoes and hurricanes. FEMA 361: Intent is to provide “near-absolute protection” through appropriate design and construction guidance. Design criteria for features such as debris impact-resistance, flood hazard-resistance, and operational criteria are more conservative than criteria in the ICC-500. Safe room operations guidance is provided. Occupancy issues addressed. Wall section details provided. Building evaluation checklist provided. Notes: (1) Does not require the design and construction of safe rooms, but provides criteria for doing so. (2) FEMA does not provide safe room certification or product approvals.
Tornado: Use FEMA 361 wind speed map. Calculate pressures using ASCE 7-05 methods and use I=1.0, K_d=1.0, Exposure as appropriate, no topographic effects, GC_{pi}=+/-0.55 or +/-0.18+APC. Hurricane: Use revised ASCE 7-05 map and methods and use I=1.0, special definitions for enclosure classification, all other items as per ASCE 7-05, no APC consideration required.	Test safe rooms with representative missile (missile speed dependent on site design wind speed): Tornado: 15-lb 2x4 at 80–100 mph (horizontal) and 2/3 of this speed (vertical). Hurricane: 9-lb 2x4 at 64–102 mph (horizontal) and 16-26 mph (vertical)	Intent is to provide a standard for the design and construction of extreme-wind shelters. Will not use term “near-absolute protection.” Occupancy, ventilation, and use issues are also addressed. Notes: (1) The standard does not require the design and construction of shelters, but provides criteria for doing so. (2) The ICC-500 does not provide shelter or shelter component certifications, but rather defines the procedure by which testing must be performed to be certified and define what type of laboratory certification is required.
Recommends that designer add 40 mph to basic wind speed from map, Exposure C, I=1.15, K_d=0.85, GC_{pi} 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 a 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, GC_{pi} as required by design (typically +/-0.18).	In windborne debris region: 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 a signed/sealed statement to building department and state offices stating the structure has been designed as an EHPA.
Method is the 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: Small – pea gravel; Large – 9-lb 2x4 at 34 mph (horizontal), up to 60 feet above grade. Note: FBC, IBC, and ASCE 7-05 require 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. For improved performance of residential buildings (but not life-safety protection), design criteria and prescriptive solutions can be found in ICC-6, *Standard for Residential Construction in High Wind Regions* (Fall 2008)
None	None	Provides guidance on how to select buildings and areas of a building for use as a wind shelter or refuge area during wind events. 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 (SBC)[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 extreme-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:

1. The wind shelter guidance and requirements shown here are presented from highest to least amount of protection provided.
2. Mean recurrence intervals (MRIs) 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. ASCE 7-05 *Minimum 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 7-05 method: I = importance factor; K_d = wind directionality factor; GC_{pi} = internal pressure coefficient.
5. Roof deck, walls, doors, openings, and opening protectives 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).

Table 2-2. Wind Safe Room and Shelter Design Values Comparison

Shelter Design Standard, Code, or Document	Data[1]	Example Location #1: Miami, Florida Tornado and Hurricane Hazards	Example Location #2: Galveston, Texas Tornado and Hurricane Hazards	Example Location #3: Greenburg, Kansas Tornado Hazards
FEMA 361	Design wind speed	200 mph (tornado) 225 mph (hurricane)	200 mph (tornado) 160 mph (hurricane)	250 mph (tornado)
	Pressure on windward wall[2]	107 psf (tornado) 136 psf (hurricane)	107 psf (tornado) 69 psf (hurricane)	167 psf (tornado)
	Pressure on roof section[2]	257 psf (tornado, suction) 325 psf (hurricane, suction)	257 psf (tornado, suction) 202 psf (hurricane, suction)	401 psf (tornado, suction)
	Test missile momentum at impact[2]	62 lb_f-s (tornado) 46 lb_f-s (hurricane)	62 lb_f-s (tornado) 33 lb_f-s (hurricane)	68 lb_f-s (tornado)
ICC-500[3]	Design wind speed	200 mph (tornado) 225 mph (hurricane)	200 mph (tornado) 160 mph (hurricane)	250 mph (tornado)
	Pressure on windward wall[2]	107 psf (tornado) 136 psf (hurricane)	107 psf (tornado) 69 psf (hurricane)	167 psf (tornado)
	Pressure on roof section[2]	257 psf (tornado, suction) 325 psf (hurricane, suction)	257 psf (tornado, suction) 202 psf (hurricane, suction)	401 psf (tornado, suction)
	Test missile momentum at impact[2]	62 lb_f-s (tornado) 36 lb_f-s (hurricane)	62 lb_f-s (tornado) 26 lb_f-s (hurricane)	68 lb_f-s (tornado)
FBC EHPA/ SESP Recommend Criteria (using basic wind speed + 40 mph)	Design wind speed	186 mph	130 mph	N/A
	Pressure on windward wall[2]	91 psf	44 psf	N/A
	Pressure on roof section[2]	217 psf (suction)	106 psf (suction)	N/A
	Test missile momentum at impact[2]	34 lb_f-s	14 lb_f-s	N/A

Table 2-2. Wind Safe Room and Shelter Design Values Comparison (continued)

Shelter Design Standard, Code, or Document	Data[1]	Example Location #1: Miami, Florida Tornado and Hurricane Hazards	Example Location #2: Galveston, Texas Tornado and Hurricane Hazards	Example Location #3: Greensburg, Kansas Tornado Hazards
FBC EHPA (Required per FBC Section 423.25)	Design wind speed	146 mph	N/A	N/A
	Pressure on windward wall[2]	39 psf	N/A	N/A
	Pressure on roof section[2]	117 psf (suction)	N/A	N/A
	Test missile momentum at impact[2]	14 lb_f-s	N/A	N/A
ASCE 7-05/IBC 2006 (ASTM E 1996)	Design wind speed	150 mph	105 mph	90 mph
	Pressure on windward wall[2]	41 psf	18 psf	15 psf
	Pressure on roof section[2]	124 psf (suction)	52 psf (suction)	44 psf (suction)
	Test missile momentum at impact[2]	14 lb_f-s	Not required	Not required
ARC 4496	Design wind speed	Not specified	Not specified	Not specified
	Pressure on windward wall[2]	Not specified	Not specified	Not specified
	Pressure on roof section[2]	Not specified	Not specified	Not specified
	Test missile momentum at impact[2]	Not specified	Not specified	Not specified
Pre-2000 Building Codes	Design wind speed	140 mph and less	90 mph and less	90 mph and less
	Pressure on windward wall[2]	< 40 psf (varies)	< 15 psf (varies)	< 15 psf (varies)
	Pressure on roof section[2]	< 120 psf (varies)	< 45 psf (varies)	< 45 psf (varies)
	Test missile momentum at impact[2]	Not required by all codes	Not required	Not required
Refuge Areas of Last Resort	Design wind speed	Unknown	Unknown	Unknown
	Pressure on windward wall[2]	Unknown	Unknown	Unknown
	Pressure on roof section[2]	Unknown	Unknown	Unknown
	Test missile momentum at impact[2]	Not required	Not required	Not required

Notes:

1. Wind pressures were calculated based on a 40-foot x 40-foot 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.
3. ICC-500 Hurricane design criteria used the most restrictive case that may be appropriate, which results in the use of GC_{pi}=+/-0.55 and Exposure Category C at the site.

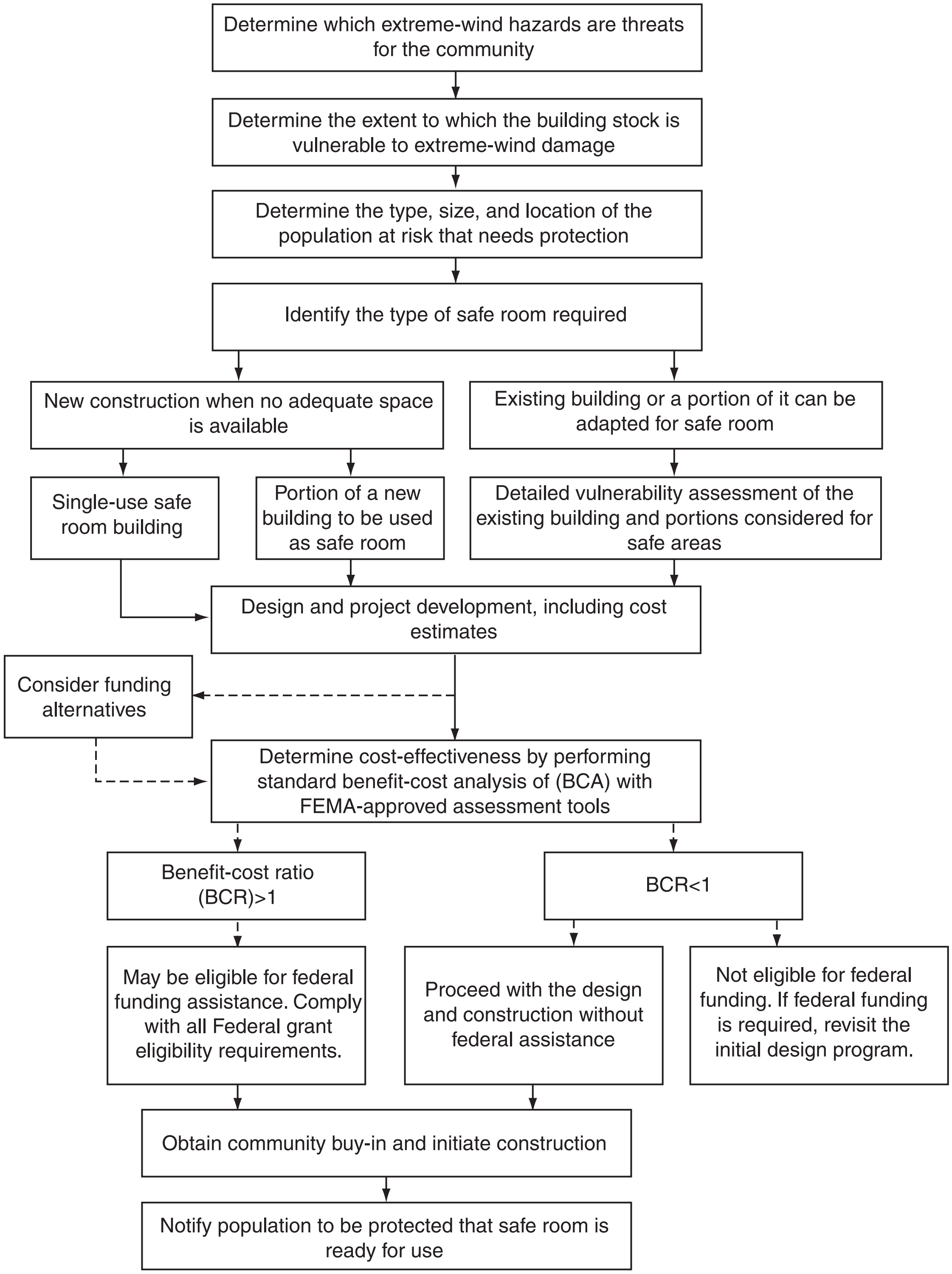


Figure 2-1. Process for risk and needs assessments for safe rooms

Frequency or Probability of Occurrence Maps

Researchers have complied data that illustrate the frequency of extreme-wind events. These frequency maps show the number of extreme-wind hazard events, such as tornadoes, that occurred in various parts of the country. Although tornadoes were recorded as far back as 1700s, the systematic gathering of data related to tornado events did not start until the early 1950s. Therefore, the historical records used for statistical analysis of frequencies span only slightly more than 50 years. Figure 2-2 shows the areas of the United States with the greatest incidence of strong tornadoes, those that were designated as EF3, EF4, or EF5. The historical information on past windstorms is used to calculate their statistical frequency or the probability of occurrence of a wind event of certain magnitude. The probability of occurrence therefore describes a wind event of specific intensity irrespective of the place of occurrence. This wind event characteristic is known as the mean recurrence interval (MRI). The mean recurrence interval represents the frequency with which large or small hazard events take place. For example, most buildings are designed and constructed to resist wind pressures resulting from a wind event with a 50-year MRI or 2 percent annual probability of exceedence.

Most wind speed maps in use today reflect a specific MRI that was adopted as a risk indicator for that design standard. ASCE 7-05 wind maps, for example, use a 50-year MRI to determine the basic wind speeds for non-hurricane-prone areas. Some occupancies categorized by ASCE 7-05 as Category III and IV buildings are required to be designed for 100-year wind events, which necessarily involves higher wind speeds. This adjustment in the MRI is accomplished through the use of an importance factor (I) in the wind load calculations. The FEMA 361 map for tornado hazards, which is identical to the ICC-500 tornado map, uses 10,000 to 100,000 MRI wind events to determine the wind speed zones for tornado safe rooms. The low probability of occurrence or the mean recurrence interval of 10,000 to 100,000 years is used in order to make sure that safe rooms are protected even against the rarest of wind storms with extreme-wind speeds of 250 mph (3-second gust).

For the hurricane hazard, NOAA and other meteorological groups have more readily available tracking maps to illustrate the occurrence of hurricanes. Furthermore, the ASCE 7-05 basic wind speed map was developed from a combination of historical and probabilistic storm events (which include hurricanes, but not tornadoes). As a result, for the hurricane-prone regions the mapped speeds reflect the hurricane influence and hazard and should be considered to be 100-year MRI basic wind speeds.[2] The FEMA 361 map uses the ICC-500 Shelter Design Wind Speeds for Hurricanes Map (ICC-500, Figure 304.2.2), which has been developed using the same modeling approach and inputs as the ASCE 7-05 basic wind speed map. However, it has been developed for an ultimate wind event of 10,000 MRI (based on both historical and probabilistic storm data). As a result, appropriate maximum hazard wind speeds associated with the hurricane event alone (tornadoes are not included in this model) are 225 mph for the mainland U.S. and 255 mph for certain U.S. island territories (3-second gust).

[2] For a complete discussion on the MRI use for hurricane and non-hurricane wind speeds depicted in the ASCE 7-05 Basic Wind Speed Map, see the commentary for Chapter 6 of ASCE 7-05.

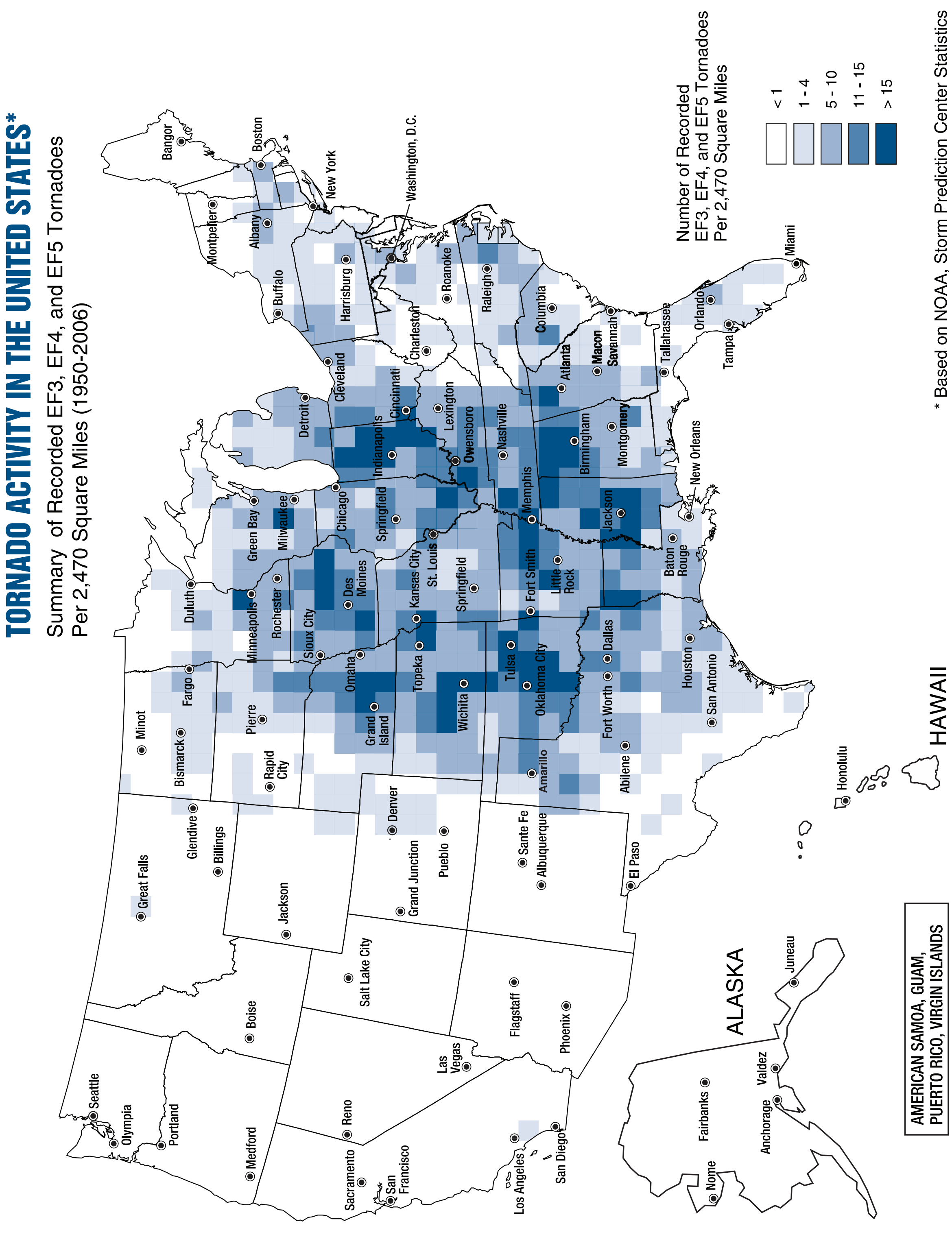


Figure 2-2. Tornado occurrence map

Wind Speed Maps

Safe rooms are designed to protect the occupants from windstorms such as tornadoes, hurricanes, or thunderstorms. The prevailing wind hazard along the Gulf of Mexico and Atlantic coasts and in the Caribbean and some Pacific Islands is a hurricane, although some regions of the Pacific and Alaska refer to the extra-tropical cyclones as typhoons. Interior areas in the United States are mainly threatened by tornadoes or thunderstorms.

The wind speed maps in Figures 3-1 and 3-2 consider tornado and hurricane hazards separately and present safe room design wind speed maps for each hazard. For the tornado hazard, this map is primarily based on historical data. Since 1997, almost 1,300 tornadoes, on average, have been reported nationwide each year. Most tornadoes are short-lived, average less than 500 feet wide, and traverse less than 2,000 feet. Some large tornadoes have been known to cause damage along paths that are 1-mile wide and many miles long; however, tornadoes such as these occur only a few times each year. The land area directly impacted by all tornadoes in a year is relatively small. At present, it is not possible to directly measure wind speeds in a tornado because of its short life. Thus, the data available for tornadoes, intensity, and area of damage are relatively sparse and require special consideration in the probability assessment of wind speeds.

For hurricane wind speeds along the Gulf of Mexico and Atlantic coasts, ASCE 7-05 uses the Monte Carlo numerical simulation procedure to establish design wind speeds. The numerical simulation procedure provides reasonable wind speeds for an annual probability of exceedance of 0.02 (50-year MRI). For wind speeds with an extremely low probability of occurrence, the current numerical procedure, according to some critics, gives unusual answers (e.g., wind speed estimates in Maine are higher than those in Florida). The ICC-500 Review Committee, which prepared the new map for the hurricane hazard, considered these issues in its work with the ASCE modelers who developed a set of maps that the committee believed appropriately represented the hurricane wind hazards along the coastal U.S.

The measure (or units) used to identify tornadic and hurricane safe room design wind speeds are unified to one averaging time: a 3-second gust wind speed. The resulting 3-second gust speeds are consistent with the reference wind speeds used in ASCE 7-05. Consequently, they can be used in the wind pressure calculation formulas from ASCE 7-05 to determine wind loads as discussed in Chapters 3 and 6. Further, unless otherwise noted, all wind speeds presented in this publication are 3-second gust wind speeds, for Exposure C, over land, at 33 feet (height) above the ground.

The safe room design wind speeds shown in Figures 3-1 and 3-2 are valid for most regions of the country. However, the Special Wind Regions (e.g., mountainous terrain, river gorges, ocean promontories) shown on the ASCE 7-05 basic wind speed map are susceptible to local effects that may cause substantially higher wind speeds at safe room sites. Mountainous areas often experience localized winds of considerable magnitude. For instance, mountain-induced windstorms in the lee of the Colorado Front Range (generally the eastern side of the range) have been documented at speeds approaching 120 mph. In Boulder, Colorado, straight-line winds in excess of 60 mph are observed about once a year. The frequency and maximum intensity of such extreme-wind events at higher elevations within Special Wind Regions are likely to be more frequent and even stronger. When the desired shelter location is within one of these regions, or there is reason to believe that the wind speeds on the map do not reflect the local wind climate, the design professional should seek expert advice from a wind engineer or meteorologist.

Based on this information as well as a community's own historical records, it is possible to determine to what extent the area is susceptible to extreme-wind hazards. The information within this section was provided to help better understand the risk associated with the jurisdiction in which a safe room may be designed or constructed.

2.2.2 Vulnerability Assessment

When a community is exposed to extreme-wind hazards, the level of threat is determined using the historical information described in the previous section. This represents a first step in determining the actual risks to the community from extreme-wind events. Community safe rooms are built to provide safe areas for a local, at-risk population that may be exposed to extreme-wind hazards. Life safety depends on the ability of people to reach a hardened, safe location in a timely manner and remain inside unharmed during the wind storm. Since not all buildings and structures can be considered a safe room in a wind storm, it is necessary to evaluate the building stock in the community in order to identify their potential vulnerability to wind damage that could cause casualties. This is a critical step for all high-occupancy buildings or buildings that house highly vulnerable populations. (See Appendix B for a checklist to assist in the performance of the assessments discussed below.)

1. **Vulnerability of buildings**
   An inventory of vulnerable buildings based on architectural/engineering (A/E) review of building-specific factors such as structural integrity, age, condition, building materials, design, quality of construction, etc., should be conducted. It is recommended that a building vulnerability assessment be performed in two stages. The first stage should comprise a general survey of the building stock in the community to identify the buildings that could potentially pose the greatest risk of serious damage or collapse in an extreme-wind event. The buildings that would need to be identified in advance comprise older manufactured housing units, old wood-frame and unreinforced masonry (URM) buildings, and especially any potentially hazardous high-occupancy structures that might require a more detailed inspection. The second stage would need to be performed by a well-qualified and experienced professional. It is recommended that the second stage should identify all high-occupancy buildings that are prone to wind damage and rank them according to the level of potentially harmful wind effects. This stage is an especially important component of the risk analysis that will assist communities in prioritizing their safe room needs. It is also recommended that the second stage of the vulnerability assessment identify the interior areas of high-occupancy buildings that may serve as the safest refuge areas in the event of an extreme-wind event. These areas should not be confused with safe rooms or other types of wind shelters because they would not be

able to offer the near-absolute level of life-safety protection. The occupants of buildings, however, should be aware of the best places in the building in which to seek refuge in an emergency.

2. **Identify buildings or structures that could be used as safe rooms**
During the second stage of the vulnerability assessment, special attention should be made to identify stand-alone buildings, portions of existing buildings, or the interior areas of high-occupancy buildings that could be used as safe rooms after the structural hardening and other recommended improvements are completed. The main criteria for selection of structures as potential safe rooms are related to their suitability for a retrofit according to the design and construction recommendations described in Chapter 3. Other criteria that outline how the space should be used and how the occupants should be provided for are no less important and should also be considered. The accessibility of such places should be evaluated along with their size or their everyday functions with respect to their availability for safe room usage in an emergency.

3. **Potential losses as a result of identified weaknesses of buildings**
Physical vulnerability of the built environment to wind damage represents only one component of the vulnerability assessment. It must be combined with the level of exposure of building occupants to potential wind damage in order to calculate the potential losses in the event of an extreme-wind event. Potential losses should therefore be estimated on the basis of identified weaknesses in the buildings and their occupancy type (see Section 2.2.3). Occupancy types such as hospitals, long-term care centers (nursing homes), or elementary schools and day care centers are likely to suffer greater losses than other types of occupancies with the same level of a building's physical vulnerability to wind damage.

4. **Identify areas with high concentration of vulnerable structures**
The above-mentioned first stage of the vulnerability assessment of the community's building inventory serves another important purpose. By identifying the areas of high concentrations of vulnerable structures and occupancies based on area-specific factors such as the presence of manufactured housing parks, old residential neighborhoods, blighted areas, topography, and others, local communities can easily map and plan their safe room needs. This can be an invaluable tool in selecting the most appropriate and most effective sites for new and retrofitted safe rooms.

2.2.3 Population at Risk

Community safe rooms have a single purpose - to protect the life safety of the population at risk during the storm event. The population at risk is understood to encompass only those people who are unable to evacuate ahead of the storm for any reason. The community safe rooms are different from other types of shelters in that they are designed to safeguard people only during a relatively short period of time when the extreme winds are the strongest and able to cause the greatest damage. FEMA considers this period to be a minimum of approximately 2 hours for tornadoes and a minimum of approximately 24 hours for hurricanes.

Since the warning times for approaching hurricanes are considerably longer than for tornadoes, the at-risk population for hurricane safe rooms might include those who must remain in the area (like emergency response personnel) and those who are unable to evacuate on time either because of their frailty, lack of transport, a suitable place to go, or other reasons. In the case of approaching tornadoes, the definition of special population that cannot evacuate on time is extended to include practically all the people in buildings deemed vulnerable to damage and failure from extreme-wind events.

Identifying the population at risk is required not only for risk assessment (determining potential losses as a result of possible building damage), but also for effective mitigation, by determining the location and optimal size/capacity of a community safe room. The intent of the guidance in this section on the at-risk population is to start the thought process necessary to determine the size of the safe room that may be needed. The design criteria in this document have been defined using a minimum floor area per occupant approach, in order to ensure that adequate hardened space is provided for the safe room population, irrespective of who comprises that population. However, state and local agencies responsible for emergency management and developing and executing evacuation plans should be consulted when identifying a population in need of protection. FEMA safe room guidance should also be reviewed for detailed recommendations for determining the population at risk.

2.2.4 Risk Analysis

Risk analysis is the final step in the risk assessment process in which all components are brought together to estimate the risk and help prioritize the mitigation activities. In the case of the safe room risk assessment process, risk analysis should be performed for each proposed safe room project to make sure that the safe room will serve those most at risk. The potential losses determined on the basis of the vulnerability of a building and its occupants to damage and resultant death and injury from an extreme- wind event of a certain magnitude are compared with the probability of occurrence of such an event at that location. Table 2-3 below proposes a basic matrix for categorizing or quantifying the risk into three general risk levels: low (L), moderate (M), and high (H). Once a moderate level of risk can be identified, a safe room should be considered for the community. Communities are, however, encouraged to devise their own methods and risk levels that are best suited to local conditions.

Table 2-3. Risk Analysis Matrix

	Probability of Occurrence of an Extreme-Wind Event			
Potential Losses	Low	Moderate	High	Very High
Minor	L	L	L	M
Moderate	L	M	M	H
Severe	M	M	H	H
Catastrophic	M	H	H	H

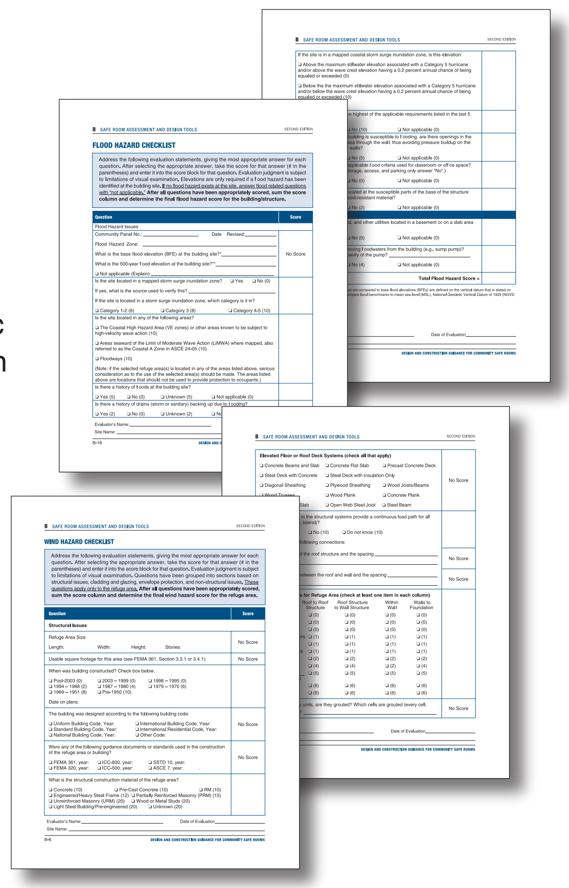
2.2.5 Types of Safe Rooms

In inspecting areas of existing buildings that are used as safe room areas, FEMA has found that owners may overlook the safest area of a building. In addition, the safety of a hallway or other potential safe room area may be overestimated. Evaluating safe room areas in an existing building helps the owner:

- Determine whether the safest part of the building is being used as a safe room
- Identify possible ways to make existing areas safer
- Decide whether to design and build a safe room according to the guidance in this publication

> **CROSS-REFERENCE**
>
> For improved flood hazard assessment checklists and criteria, see FEMA 543. For improved seismic hazard assessment checklists and criteria, see ASCE 31-03.

A preliminary evaluation may be performed by a design professional or by a potential safe room owner, property owner, emergency manager, building maintenance person, or other interested party. This person must have a basic knowledge of building sciences and be able to read and understand building design plans and specifications.



The wind hazard evaluation checklists in Appendix B will help the user assess a building's susceptibility to damage from extreme-wind events such as tornadoes and severe hurricanes. Although the threat of damage from extreme-wind events is the predominant focus of the evaluation, additional threats may exist from flood and seismic events. Therefore, flood and seismic hazard evaluations should be performed in conjunction with the wind hazard evaluation to assess the multi-hazard threats at the site. Checklists for flood and seismic hazard evaluations are also provided in Appendix B. However, the checklists are designed to support only a generalized evaluation (the wind hazard section includes detailed screening processes for the building structure).

The wind, flood, and seismic hazard evaluation checklists in Appendix B may be used for the preliminary assessment. Prior to the design and construction of a safe room, a design professional should perform a more thorough assessment in order to confirm or, as necessary, modify the findings of a preliminary assessment. The checklists in Appendix B can provide a starting point for the more thorough assessment.

An entire building or a section of a building may be designated a potential safe room area. If an existing building is selected for use as a community safe room, the hazard evaluation checklists will help the user identify potential safe room areas within the building and evaluate their vulnerability to natural hazards. The intent of the checklist evaluation process is to guide the user through the selection of the best safe room areas within the building and focus the evaluation on the critical sections of the building. For example, an evaluator who inspects a portion of a building being considered for use as a safe room should determine whether that portion is structurally independent of the rest of the building, easily accessible, and of sufficient size.

CROSS-REFERENCE

Guidance concerning the siting of safe rooms is presented in Chapter 5 of this publication.

The checklists consist of questions pertaining to structural and non-structural characteristics of the area being considered. The questions are designed to identify structural and non-structural vulnerabilities to wind hazards based on typical failure modes. Structural or non-structural deficiencies may be remedied with retrofit designs (structural and non-structural mitigation); however, depending on the type and degree of deficiency, the evaluation may indicate that the existing structure is unsuitable for use as a safe room area. The checklists are not a substitute for a detailed engineering analysis, but they can assist the decision-makers involved with hazard mitigation and emergency management to determine whether a building or section of a building has the potential to serve as a safe room.

The checklists are also used to comparatively rank multiple facilities within a given geographic region that are considered potential safe room sites. A scoring system is included to enable the user to compare performance characteristics at various potential safe room sites and to highlight vulnerabilities. For each question on the checklist, deficiencies and vulnerabilities are assessed penalty points. Therefore, a high score reflects higher hazard vulnerability and a low score reflects lower hazard vulnerability, but only relative to the other buildings considered in the scoring system. There is a minimum possible score for the checklists, but this minimum score will vary, depending on the design wind speed selected from Figures 3-1 and 3-2. Therefore, although a low score is desired, there is no “passing score” or “minimum acceptable score for protection.” Again, these checklists help a user determine which area of a building is likely to perform best during an extreme-wind event and which areas require engineering and retrofit design if they are to provide protection from a tornado, a hurricane, or both.

2.3 Safe Room Costs

Costs for the design, construction, and maintenance of community safe rooms will vary by location and construction type. This section presents information related to safe room costs and the relative impact of different aspects of the design and construction on the cost of a safe room.

2.3.1 Design Parameters Affecting Safe Room Costs

As part of the risk assessment plan discussed earlier in this chapter, budgetary cost estimates (estimates that will be ± 30 percent accurate) should be prepared by the design professional for each proposed safe room alternative. Key design parameters that drive the cost of community safe rooms are:

- Safe room use. Single or dual-use of the safe room (multi-purpose space within a building) will affect the cost of many building components, finishes, furnishings, and other occupancy-driven design parameters.
- Simplicity of design. The simpler the safe room construction system (short walls, short roof spans, and minimal interior finishes), the lower the cost. Safe rooms with large, open spaces that require more elaborate construction systems will undoubtedly cost more than an ordinary building. The choices made during the initial planning and design stage will have a direct impact on cost.
- Safe room design wind speed. The safe room design wind speed will affect the strength criteria, which both the structural system and exterior components and cladding of the safe room need to satisfy in order to resist the design wind loads.
- Safe room debris impact-resistance criteria. These design criteria arguably have the most significant influence over cost. Common building materials are readily available to harden wall and roof systems to be debris impact-resistant. However, opening protection systems and devices for doors, windows, vents, and other elements that may protrude through the safe room are much less common. Costs for these systems range from $50 (basic code compliance for building protection) to $400 per square foot of opening (for life-safety protection that meets FEMA 361 safe room criteria). Thus, the more openings desired by the safe room owner/operator/designer, the greater the cost of the safe room. The decision to include more windows or openings in a safe room, because it has uses other than sheltering, will have a significant impact on the safe room cost.
- Exterior walls and roof materials. The materials selected by designers may be readily available common building materials or newer technologies that may improve the safe room performance, but at a premium cost.
- Location of the safe room – impact on foundation type. The foundation of a safe room may be a simple, slab-on-grade with minimal footings and a relatively low cost. A basement safe room will cost more to excavate, but these increased costs are offset by higher levels of debris impact protection afforded by the surrounding soils in addition to debris impact-resistant walls. A safe room needed to protect at risk population located

in an area subject to flooding may require elevated foundations that are more expensive than other options, but are inevitable for this type of a safe room.

- Location of the safe room – other hazards. A safe room constructed in an open field may not be exposed to any additional hazards such as falling objects and building debris. However, safe rooms located on the lower floors of small buildings that have not been designed to resist high winds, or those located near trees or large power, telephone, light, or cellular towers and poles, are usually exposed to falling debris hazards. The safe rooms that cannot avoid these additional risks can be designed to resist them, but often at a premium cost. Additionally, the location of a safe room with respect to local seismic risk must also be considered. When constructing safe rooms in areas subject to seismic activity, these loads may govern some aspects of the design, resulting in an increase to the cost of the safe room.

2.3.2 Recent Safe Room Cost Data

Community shelters and safe rooms have been designed long before the first edition of FEMA 361 was released in July 2000. However, since that time there have been hundreds of extreme-wind hazard community safe rooms designed and constructed across the country. Since 2000, over 500 community safe rooms have been constructed around the country with some federal funding being provided through FEMA grant programs. For the update to this publication, FEMA reviewed a more recent series of cost estimates from 2005 to 2008 (including the 2008 Pre-Disaster Mitigation [PDM] Grant Program cycle, which included 36 safe room grant applications from 12 states). Table 2-4 presents cost metrics that have been developed to assist groups planning to design and construct safe rooms. These data were compiled from extreme-wind-hazard safe room projects.

Table 2-4. Cost Data From Recent Community Safe Room Projects

Description	Cost Metric	Comments
General Safe Room and Shelter Data		
Safe room average cost per square foot	\$150 – \$240 per square foot (sf)	Single use community safe rooms consistently had the lowest associated (estimated or actual) per square foot cost. Safe rooms in the lower range of this cost had low walls and short roof spans. Average costs at the higher end were typically for larger safe rooms (by square footage and occupancy) with much of the protected areas designed as large, open spaces with long roof spans.
Percent increase in building cost to harden a portion of a new building to resist 250-mph winds from a 140-mph basic wind speed	5% – 7%	Percent increase in cost per square foot associated with the structural and envelope hardening to meet 250-mph safe room design wind speed versus 140-mph basic wind speed from the building code. This is a cost increase per square foot of the safe room area being hardened.
Percent increase in building cost to harden a portion of a new building to resist 250-mph winds from a 90-mph basic wind speed	15% – 20%	Percent increase in cost per square foot associated with the structural and envelope hardening to meet 250-mph safe room design wind speed versus 90-mph basic wind speed from the building code. This is a cost increase per square foot of the safe room area being hardened.

Table 2-4. Cost Data From Recent Community Safe Room Projects (continued)

Description	Cost Metric	Comments
General Safe Room and Shelter Data (continued)		
Percent increase in building cost to harden a portion of a new building to resist debris impact from a 15-lb 2x4 board missile traveling horizontally at 100 mph and impacting vertical surfaces and the same missile traveling vertically at 67 mph and impacting horizontal surfaces	5% – 27%	Percent increase in cost per square foot associated with the hardening of all portions of the safe room exterior walls, roofs, and opening protective devices versus providing no debris impact protection at all (debris impact resistance only, wind pressure resistance not considered). This is an increase to the cost per square foot of the safe room area being hardened. The percent increase for hardening the safe room exterior components to resist debris impact is highly dependent on a number of factors including, but not limited to: size of the safe room, materials used, strength in wall and roof systems already provided by designing to resist wind loads from the safe room design wind speed, the percentage of openings in the safe room exterior, the number of egress points to be protected, and several others. For the purposes of this comparison, the safe room projects considered had minimal doors and building exteriors requiring protection for openings (windows) that ranged from 0% to 10% of the total building exterior.
Percent increase in building cost to harden a portion of a new building to resist 250-mph winds and associated debris impacts from a 90-mph basic wind speed	20% – 32%	Percent increase in cost per square foot associated with the structural and envelope hardening to meet 250-mph safe room design wind speed versus 100-mph basic wind speed and provide debris impact protection from a 15-lb missile traveling at 90 mph. This is a cost increase per square foot of the safe room area being hardened.
2008 PDM Grant Application Sample Cost Data (36 safe room projects)		
Safe room sizes proposed	Max = 32,000 sf Min = 700 sf Avg = 6,500 sf	Most projects associated with the submittals for this cycle proposed an entire building as the safe room (78% of projects). In most instances, 85% of the usable space within the proposed protected area was considered available for occupants; see Chapter 3 for appropriate occupant loads per square foot of available space.
Range of safe room average cost per square foot for projects considered technically feasible and effective for providing protection	Max = $480/sf Min = $90/sf Avg = $188/sf	These cost figures are as proposed. Their incorporation here is for informational purposes only. These numbers were separately evaluated on a project by project basis for cost-effectiveness.

Notes:

1. Costs were based on safe room and shelter projects meeting the criteria of FEMA 361 (July 2000).
2. Safe room sizes for the General Safe Room and Shelter Data sections of the table varied from 5,000 square feet to 32,000 square feet.
3. Data in this table are from several sources including, but not limited to: cost estimates prepared by designers/architects/engineers on behalf of prospective and actual safe room owners, FEMA analyses, FEMA grant applications, and state and local emergency management agencies.

2.3.3 Other Factors Impacting Cost

The most cost-effective means of constructing a safe room at a site is to incorporate the safe room into a new building design in the initial planning stage. The cost to design and construct hardened safe room areas within new buildings is much lower than the cost of retrofit (i.e., when the existing buildings or portions of existing buildings need to be hardened). For example, in recent FEMA-funded mitigation projects in many midwestern and southeastern states, the construction costs (per square foot) for retrofitting safe rooms have been (at a minimum) approximately 10 to 15 percent higher than construction costs for safe rooms in new buildings. It is important to remember, however, that this increase in cost applies only to a small area of the building (i.e., the area being hardened and not the entire building).

Also, Table 2-4 shows how the relative cost per square foot for safe rooms included as a part of a building project increases when life-safety protection is provided. For large new building projects, however, the percent increase in the overall project cost is quite small. For example, many safe rooms protecting 200 to 300 occupants being constructed as part of a new school have added only 1 to 2 percent to the total project cost when the safe room was included in the design process at the beginning of the project.

The level of protection afforded by a safe room also impacts the cost of the safe room; however, that does not always mean that a safe room constructed for a higher level of protection will cost more than one that has been constructed for a lower level of protection. Table 2-1 provides a comparison of different levels of protection offered by FEMA safe rooms and shelters designed and constructed to other criteria or code requirements. For example, a simplified design for a single-use, tornado community safe room may cost less than a large, multi-use hurricane community safe room that has multiple uses and a long-span roof system. Similarly, constructing a shelter or safe room to comply with ICC-500 flood criteria in a V zone may cost upwards of 10 percent more (per square foot of the entire project cost) than the same safe room constructed to meet the FEMA 361 community safe room flood design criteria that does not permit safe room construction in V zones. Although a higher level of protection is provided by the FEMA compliant safe room because it has been removed from the velocity zone, the elevation of the shelter to the ICC criteria (which allows placement in the V zone) results in a more expensive solution because of the elevated foundation required even though the hazard is still present.

Table 2-4 shows relative incremental cost increases for constructing safe rooms to FEMA 361 criteria in comparison to building code required construction, even in hurricane-prone regions where the design of buildings is more robust. In these cases, buildings such as critical or essential facilities constructed in coastal areas called “wind-borne debris regions” are required to be designed and constructed to resist wind speeds up to 145 to 150 mph (3-second gust) and also have debris impact-resistance for a 9-lb missile traveling at 55 mph. This improved level of protection is required for these areas by the building code to reduce damage to these facilities by known hazards; however, they do not provide a level of protection that can be considered near-absolute for life-safety of occupants within the building. Further, Table 2-4 presents data from recent projects indicating that safe rooms constructed to the FEMA 361 criteria for 250 mph (to resist both wind pressures and debris impacts) where the protected areas provide near-absolute protection for its occupants have been constructed for as little as 5 percent more (on a cost per square foot basis) than critical and essential facilities designed to a 140-mph basic wind speed.

Intuitively, it may be stated that when two safe rooms are constructed of the same materials, but one is designed to the level of protection being offered by a FEMA 361 tornado community safe room while the second is designed to the level of protection offered by a FEMA 361 hurricane community safe room (where the safe room design wind speed and the design missile impact is based on a smaller and slower missile), the cost of the hurricane community safe room may be even closer to that of the critical facility designed to resist 140 mph (and associated debris impacts) per ASCE 7-05. This is based on the assumption that smaller quantities of the building materials are required and thus the safe room will cost less. The same may be said when comparing differences in costs associated with the level of protection offered by a FEMA 361 safe room and an ICC-500 shelter (for either hazard or for the combined tornado and hurricane hazards) constructed of the same materials. But such a comparison needs to be completed carefully. Factors such as single-use versus multi-use shelters or safe rooms and optional features that result from the selection of a multi-use safe room (such as taller walls, more windows, more doors/egress points, etc.) must be identified when comparing the cost estimates for two protected areas designed to different criteria. No two safe rooms or shelters were able to be identified with matching building materials and design assumptions, thus specific cost comparisons could not be made at the time this publication was prepared.

Both the new FEMA 361 hurricane community safe room design criteria presented in Chapter 3 and the new ICC-500 hurricane community shelter criteria specify new wind speed ranges and new debris impact-resistance criteria. Because these criteria are new, no products other than those that satisfy the existing FEMA 361 life-safety criteria (250 mph and a 15-lb 2x4 board missile traveling at 100 mph) are available in the market for a number of the components. Thus, specific wall systems, opening protection devices and systems, and glazing or glazing protection systems that satisfy the new criteria do not yet exist. Since no products have been developed at this time, no cost comparisons can be made.

Depending upon the “features” included in the design of a safe room or shelter, arguments may be made that a combined hazard safe room can likely be constructed for nearly the same cost as a hurricane-specific hazard safe room (depending upon size, number of openings, building materials selected, etc.), but it is difficult to quantify for many of the reasons discussed above. As such, it is also difficult to state or prove that a hurricane-specific safe room will cost significantly less to construct than a combined-hazard safe room with minimal doors and openings. At this time, the percent cost difference between a FEMA 361 hurricane community safe room and a FEMA 361 combined tornado and hurricane community safe room cannot be specifically provided, but is assumed to be less than 5 percent. This statement is based on the project data in Table 2-4 that showed cost per square foot increases as small as 5 to 7 percent to improve building wind resistance from the level of a critical facility constructed to the building code in a hurricane-prone region with 140-mph design wind speed criteria and the 250-mph safe room design wind speed criteria presented in Chapter 3. It would follow that, to reduce the design parameters to a slightly lower wind speed (250 to 200 mph) and to reduce the debris impact resistance requirements for the lighter missile of the FEMA 361 hurricane safe room criteria, because the magnitude of the design criteria is not as significant as to drop back to code-level requirements, the cost impact would also not be as dramatic.

Similarly, the cost differences between a FEMA 361 safe room and an ICC-500 shelter cannot be quantified at this time. Even though the differences in design criteria exist, FEMA criteria are mostly equivalent to or slightly more restrictive than the ICC-500 requirements. The wind speeds are the same and the missiles are the same. The small differences in design parameters and missile impact speeds (for FEMA hurricane safe rooms versus the ICC-500 shelters) are less in magnitude than the design parameters for essential facilities that are constructed at protection levels based on 140 mph 3-second gust at costs of 5 to 7 percent less than the costs associated with a FEMA 361 safe room. As such, the cost differential to construct an ICC-500 shelter should be between these two costs since the design criteria required for compliance are between the FEMA 361 and the essential facility criteria of the building code.

2.3.4 Additional Factors to Consider When Constructing a Safe Room

A number of factors can influence the decision-making process in addition to cost considerations. The potential for death or injury may be a sufficient reason to build a safe room at a given building site. The benefit-cost ratio of constructing a safe room discussed in Section 2.4 may be a contributing factor or a requirement of the safe room design process, depending upon the funding source. However, additional factors may be involved in the decision-making process:

- Do the residents feel safe without a safe room?
- Does a business want to provide the protection for its workers?
- Does a safe room allow for faster business recovery after an extreme-wind event?
- Is the building in question a government-owned building that is required to have a safe room?
- Do zoning ordinances require it?
- Are there insurance benefits?

2.4 Benefit-Cost Analysis

Benefit-cost analysis (BCA) is a method used to determine the cost-effectiveness of proposed projects. FEMA regulations require mitigation projects funded under Hazard Mitigation Assistance (HMA) programs to have benefits (avoided losses) that exceed costs, usually expressed as a benefit-cost ratio (BCR) greater than 1.0.

The July 2000 Edition of FEMA 361, Design and Construction Guidance for Community Shelters, included BCA software for tornado and hurricane shelters, which will be referred to below as the "existing shelter BCA software." This software focused exclusively on the reduction of injuries and deaths (life-safety benefits) from shelters as the basis for benefits. Beginning in 2007, in parallel with revisions to FEMA 361, FEMA undertook to redesign all BCA software associated with their mitigation grant programs for flood, earthquake, hurricane, and tornado hazards. As the new Tornado Safe Room BCA and Hurricane Safe Room BCA software are finalized, they will be used in place of the existing shelter BCA software. The new Tornado Safe Room BCA software will be included in release 4.0 of the new Benefit-Cost Analysis software, with an anticipated release date of fall 2008. The Hurricane Safe Room BCA software requires more extensive revisions and is planned to be included in release 5.0 of the Benefit-Cost Analysis software, with an anticipated release in 2009. Copies of the existing and new BCA software and information on the final releases of the new software can be found at the FEMA BCA website, http://www.fema.gov/government/grant/bca.shtm.

2.4.1 Existing Shelter BCA Software

The existing shelter BCA software was designed based on the presumed need to provide community safe rooms that were either retrofits of existing structures, such as schools, or retrofits of designs for new structures (e.g., adding a hardened hallway to the design of a new town hall). Figure 2-3 is a flowchart of the existing benefit-cost model. The project costs to be inputted should be based on the costs of building construction and any additional maintenance costs incurred by the project. Benefits, or avoided damages, are based on the reduction of casualties (injuries and deaths) resulting from the construction of the proposed shelter. The four main factors used to calculate these benefits are:

- Losses associated with injury or death
- Safe room occupancy
- Probability of injury and death due to tornado or hurricane winds
- Probability of tornado or hurricane wind events

Original default loss values are based on values from the 1990s used by the Federal Aviation Administration (FAA) for insurance purposes. These defaults include a single injury level estimated to cost $12,500 per person and a death is estimated as $2,200,000 per person. Safe room occupancy is based on average hourly occupancy counts throughout a 24-hour period. The software was developed with the assumption that these occupants would only include the people who would have already been in the structure, which eliminates the consideration of issues such as warning response time and travel time to the safe room. These values are entered by the user.

The probability of an injury or death is represented by casualty rate tables giving estimated death and injury percentages for five building types (with two window covering categories) over nine wind speed ranges. Building types represent before-mitigation (pre-safe room) conditions. To represent the safe room, the before-mitigation death and injury values are reduced by a certain percentage based on safe room design. These tables were developed by FEMA tornado experts and consultants on the basis of professional experience and judgment.

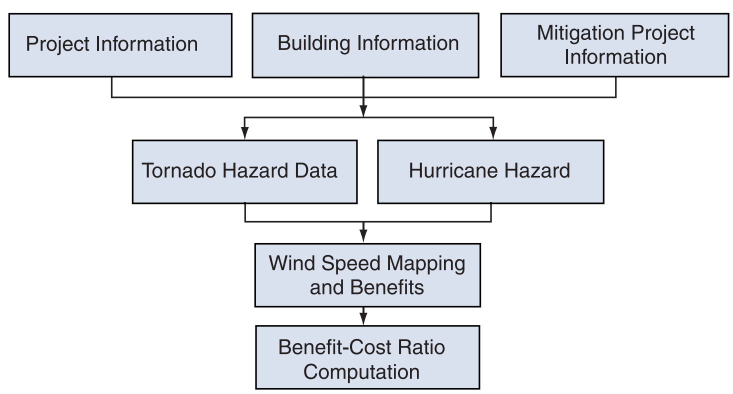


Figure 2-3. Flowchart for the existing benefit-cost model

The probability of a tornado hitting a safe room is based on the NOAA Storm Prediction Center's Historical Tornado Data Archive from 1950-2006. County-based tornado statistics were calculated directly from this archive for Fujita (F) and now Enhanced Fujita (EF) class, time of day, and tornado length and width. Because tornado occurrence is infrequent for certain Fujita classes, especially F3 (and EF3) and greater, the current software used a geographic information system (GIS)-based approach that has the user select a region of counties surrounding the county of the safe room until a significant number of tornadoes has been reached. Probability of tornado occurrence is then calculated for this region of counties based on NOAA data and the shelter footprint area. The probability of hurricane events is based on the ASCE 7-98 map of 50-year MRI wind speeds and adjustment equations for other recurrence intervals compared against maximum anticipated wind speeds from storms.

The final benefit calculation compares the before- and after-mitigation expected deaths and injuries. This calculation is performed separately for tornadoes and hurricanes and then added for the total benefits.

2.4.2 New Tornado Safe Room BCA Software

The use of the existing shelter BCA software for grant programs like PDM has highlighted a number of issues. The New Tornado Safe Room BCA software addresses many of these issues and allows users to choose between the following safe room projects:

- New vs. retrofit safe room
- Stand-alone vs. internal safe room
- Community vs. residential safe room

The benefits (losses avoided) are calculated as a difference between losses that would occur before the safe room is built and the losses that would occur after the safe room is fully operational. The losses before mitigation (safe room construction) are determined on the basis of potential damage to different types of buildings where potential safe room occupants would be taking shelter during the storm.

In many cases, a new safe room, especially a stand-alone one, will serve a population that would not necessarily be on site. The potential safe room occupants would need to travel to the safe room from the surrounding area within the minimum allowed time period. This approach now requires the new methodology to take into account warning response times and travel times to the safe room.

The four main factors used to calculate the benefits remain the same:

- Costs associated with injury and death
- Shelter occupancy

- Probability of injury and death due to tornado winds
- Probability of tornado wind events

However, the way that each of these factors is calculated has changed. In 2007, FEMA convened an outside panel of building performance experts (with significant knowledge in tornado and hurricane building damage assessments) and life-safety experts from consulting firms, research organizations, and academia. This expert panel evaluated the existing methods for calculating benefits and provided guidance on updated methods. The costs associated with casualties are now divided between three injury levels (self-treat, treat and release, hospitalized) and death, based on updated tables from the FAA (2007 dollars).

The occupancy load is counted for three intervals during a 24-hour period: day, evening, and night. Since the majority of the potential occupants of the community safe room will come from the surrounding areas, the new methodology allows the user to select up to two before-mitigation structure types to represent the level of risk to which the potential occupants would be exposed in conditions without a safe room. These two types can be selected from eight pre-defined structure types provided in the model, based on the categories used in the development of the Enhanced Fujita Scale. The casualty rates for each damage state were defined on the basis of damage indicators and degree of damage tables published in the Enhanced Fujita Scale report (TTU 2006).[3]

The probability of a tornado striking a safe room is still based on NOAA tornado historical records, but employs a regional analysis method to eliminate the need for user-selected regions. Tornado records with recorded paths or start points were expanded and updated to cover the period from 1950 to 2006. This information was used as part of a geospatial analysis method, based on tornado probability research, to produce tornado occurrence maps for each Enhanced Fujita class. Tornado probability is then calculated using published average national tornado length and width values. When the user selects the county where the safe room will be located, the pre-calculated tornado probabilities are accessed from the software database.

The basis for project costs (initial project costs and maintenance) has remained the same as in the existing model; however, new cost estimation tools have been developed. As a result of all of these changes and overall changes to the BCA software platform, the new Tornado Safe Room BCA provides an updated, defensible, and more user-friendly tool to calculate life-safety benefits for tornado safe rooms, for both the community and residential units.

[3] *A Recommendation for an Enhanced Fujita Scale (EF-Scale)*, Revision 2, October 2006, prepared by the Wind Science and Engineering Research Center, Texas Tech University.

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Updated on: 8/19/2012

1. There has not been a ingle reported failure of a safe room constructed to FEMA criteria.

    a) True
    b) False

2. FEMA continues to advocate the design and construction of safe rooms as evident by its continuing support of safe room initiatives through _________.

    a) guidance of safe room design, such as FEMA 361
    b) several grant programs
    c) both a) and b)
    d) none of the above

3. _________ means that, based on our current knowledge of tornados and hurricanes, the occupants of a safe room built according to this guidance will have a very high probability of being protected from injury or death.

    a) Near-absolute protection
    b) Maintainable protection
    c) Absolute protection
    d) Probable protection

4. In _________, the National Weather Service (NWS) started keeping organized records of tornados occurring in the United States.

    a) 1950
    b) 1910
    c) 1850
    d) 1980

5. _________ is a specially designed and constructed room or area within or attached to a larger building; the safe room (room or area) that may be designed and constructed or retrofitted to be structurally independent of the larger building, but provides the same wind and missile protection as a stand-alone safe room.

    a) Internal safe room
    b) External safe room
    c) Adjacent safe room
    d) Intra-building safe room

6. The term storm surge means an abnormal rise in sea level accompanying a hurricane or other intense storm, whose height is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the hurricane.

    a) True
    b) False

7. When a hurricane, tornado, earthquake, or terrorist attack results in a catastrophic natural or manmade disaster in the United States or one of its territories, the objectives of a FEMA Mitigation Assessment Team is to _________.

    a) inspect damage to buildings
    b) assess the performance of the buildings
    c) evaluate design and construction practices
    d) all of the above

8. FEMA has developed prescriptive designs for residential and small community safe rooms (for 6 or fewer occupants) designed to near-absolute protection for the occupants of a home or small business during extreme-win events.

    a) True
    b) False

9. The term _________ 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 an extreme-wind event and are capable or providing life-safety protection.

    a) softened
    b) hardened
    c) strengthened
    d) weakened

10. The primary difference in a building's structural system 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.

    a) True
    b) False

11. Areas within hurricane prone regions located within 1 mile of the coastal mean high water line where the basic wind speed is equal to or greater than 110 mph and in areas where the basic wind speed is equal to or greater than 120 mph are called _________.

    a) wind borne debris regions
    b) category 5 zones
    c) high velocity regions
    d) all of the above

12. The required design strength of the safe room, shelter, or refuge area, is dictated by wind pressure criteria given by different guides, codes, and standards. FEMA recommends design wind speeds for safe rooms that range from 130 to 250 mph for tornado hazards and from 160 to 255 mph for hurricane hazards.

    a) True
    b) False

13. During the second stage of the vulnerability assessment, special attention should be made to identify _________ that could be used as safe rooms after the structural hardening and other recommended improvements are completed.

    a) stand-alone buildings
    b) portions of existing buildings
    c) the interior areas of high-occupancy buildings
    d) all of the above

14. Community safe rooms have a single purpose - to protect the life safety of the population at risk during the storm event. The population at risk is understood to encompass only those people who are unable to evacuate ahead of the storm for any reason.

    a) True
    b) False

15. When evaluating risk analysis ,the potential losses determined on the basis of the vulnerability of a building and its occupants to damage and resultant death and injury from an extreme-wind event of a certain magnitude are compared with the _________.

    a) cost of constructing the safe room
    b) the probability of occurrence of such an event at that location
    c) maintenance cost of structure
    d) damage to structure and building are the only two considerations

16. Evaluating safe room areas in an existing building helps the owner _________.

    a) determine whether the safest part of the building is being used as a safe room
    b) identify possible ways to make existing areas safer
    c) decide whether to design and build a safe room according to the guidance in this publication
    d) all of the above

17. The simpler the safe room construction system (short walls, short roof spans, and minimal interior finishes), the lower the cost. Safe rooms with large, open spaces that require more elaborate construction systems will undoubtedly cost more than an ordinary building.

    a) True
    b) False

18. The cost for constructing a community safe room is approximately $150-$240 per square foot.

    a) True
    b) False

19. The most cost-effective means of constructing a safe room at a site is to _________.

   a) use local materials
   b) incorporate the safe room into a new building design in the initial planning stage
   c) reduce the design wind speed
   d) use a lighter foundation

20. Benefits or avoided damages are based on the reduction of casualties (injuries and deaths) resulting from the construction of the proposed shelter. The main factor(s) used to calculate these benefits is _________.

   a) losses associated with injury or death
   b) safe room occupancy
   c) probability of injury and death due to tornado or hurricane winds
   d) all of the above