MIDWEST ROOFING CONTRACTORS ASSOCIATION

**2024 Conference & Expo**
St. Paul, MN – October 21-23, 2024

# ***NRCA update on low-slope roofing technical issues***

NRCA

**Mark S. Graham**
Vice President, Technical Services
National Roofing Contractors Association
Rosemont, Illinois

1

## New Minnesota Energy Code

- *2024 Minnesota Energy Code with ANSI/ASHRAE/IES Standard 90.1-2019* (link)
- Effective January 5, 2025
- Insulation above roof deck: R-30 minimum
- Insulation at roof curbs: R-10 minimum
- Tapered insulation language removed
  - Being interpreted as R-30 (minimum) at drains/scuppers/gutters

2

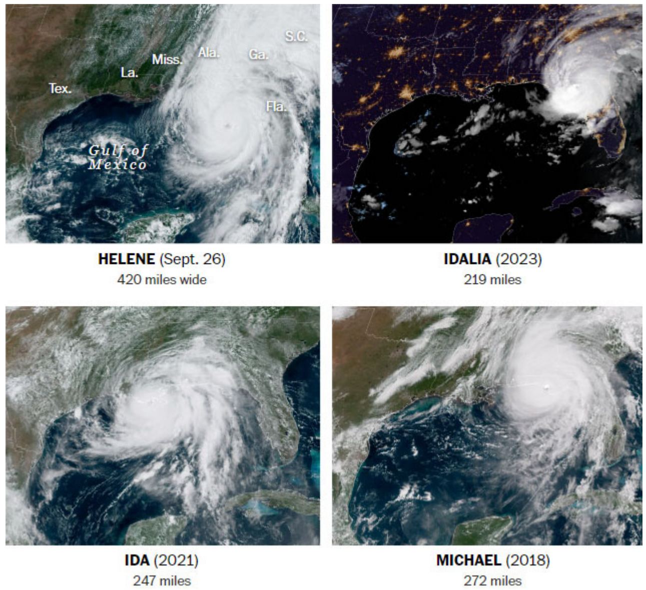
3

# Beaufort wind scale

| Force | Wind Speed (mph) | Description | Characteristics |
|---|---|---|---|
| 0 | 0-1 | Calm | Smoke rises vertically |
| 1 | 1-3 | Light air | Direction of smoke drift |
| 2 | 4-7 | Light breeze | Wind felt of face; leaves rustle |
| 3 | 8-12 | Gentle breeze | Wind extends a light flag |
| 4 | 13-18 | Moderate breeze | Small branches are moved |
| 5 | 19-24 | Fresh breeze | Small trees in leaf begin to sway |
| 6 | 25-31 | Strong breeze | Large branches in motion |
| 7 | 32-38 | Near gale | Whole trees in motion |
| 8 | 39-46 | Gale | Breaks twigs off trees |
| 9 | 47-54 | Severe gale | Slight structural damage occurs |
| 10 | 55-63 | Storm | Trees uprooted; structural damage |
| 11 | 64-72 | Violent storm | Wide-spread damage |
| 12 | 73-83 | Hurricane | See Saffir-Simpson Hurricane Scale |

4

# Hurricanes




5

# Saffir-Simpson Hurricane Wind Scale

| Category | Wind Speed (mph) | Characteristics |
|---|---|---|
| 1 | 74-95 | Very dangerous winds produce some damage |
| 2 | 96-110 | Extremely dangerous winds will cause extensive damage |
| 3 | 111-129 | Devastating damage will occur |
| 4 | 130-156 | Catastrophic damage will occur |
| 5 | 157 and higher | Catastrophic damage will occur |

6

## Tornados

7

## Enhanced Fujita Scale (EF scale)

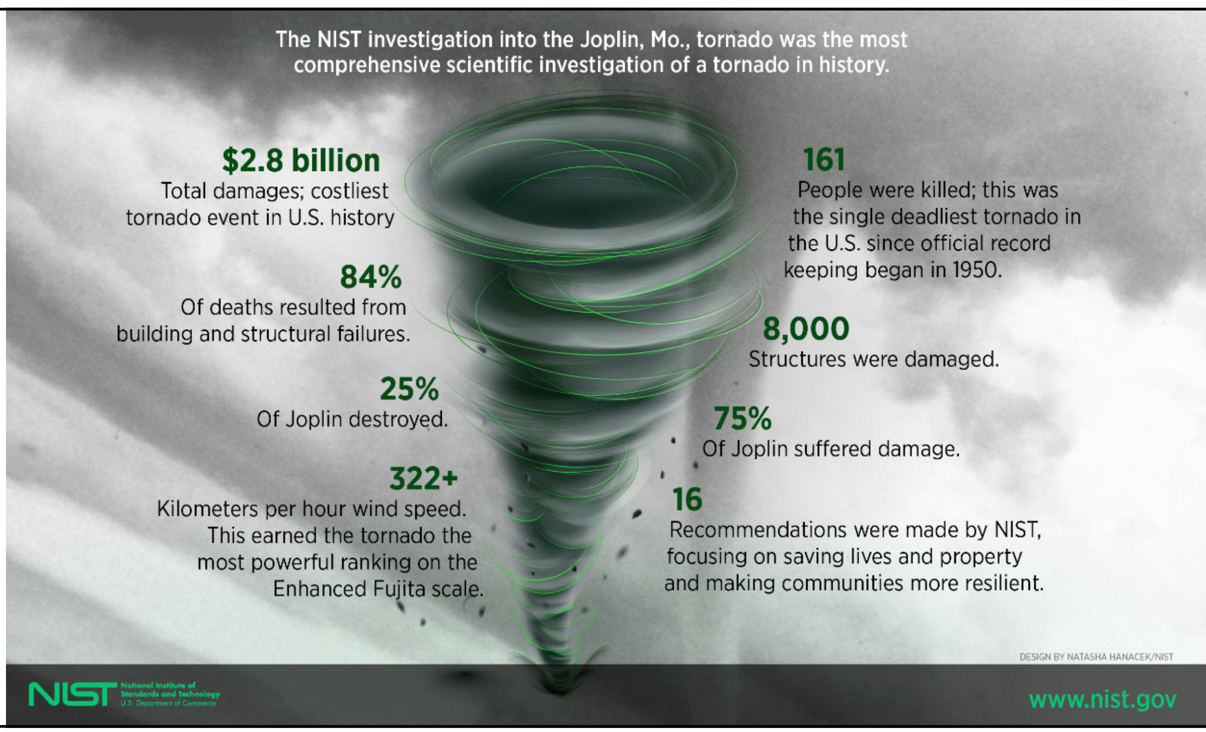
| Category | Wind Speed (mph) |
|---|---|
| 0 | 65-85 |
| 1 | 86-110 |
| 2 | 111-135 |
| 3 | 136-165 |
| 4 | 166-200 |
| 5 | Over 200 |

8

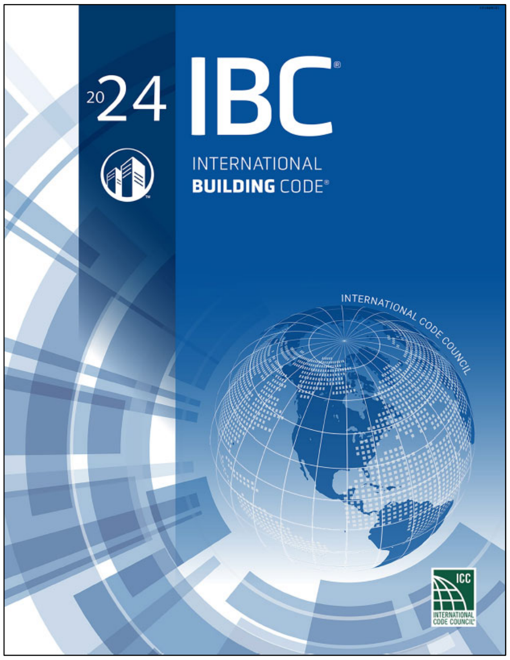
## Joplin, MO

May 22, 2011

9




10




[Link]

***International Building Code, 2024 Edition***

11

11

STRUCTURAL DESIGN

**SECTION 1609—WIND LOADS**

Scan for Changes
ccb96a8

**1609.1 Applications.** *Buildings*, *structures* and parts thereof shall be designed to withstand the minimum wind *loads* prescribed herein. Decreases in wind *loads* shall not be made for the effect of shielding by *other structures*.

**1609.1.1 Determination of wind loads.** Wind *loads* on every *building* or *structure* shall be determined in accordance with Chapters 26 to 30 of ASCE 7. The type of opening protection required, the basic wind speed, *V*, and the exposure category for a *site* is permi... be determined in accordance with Section 1609 or ASCE 7. Wind shall be assumed to come from any hor... ...tion and wind pressures shall be assumed to act normal to the surface considered.

**IBC 2024 Ch. 35-References Standards identifies ASCE 7-22's edition as being applicable**

**Exceptions:**

1. Subject to the limitations ... applicable Group R-2 and ...
2. Subject to the limitations of Section 1609.1.1.1, residential *structures* using the provisions of AWC WFCM.
3. Subject to the limitations of Section 1609.1.1.1, residential *structures* using the provisions of AISI S230.
4. Designs using NAAMM FP 1001.
5. Designs using TIA-222 for antenna-supporting *structures* and antennas, provided that the horizontal extent of Topographic Category 2 escarpments in Section 2.6.6.2 of TIA-222 shall be 16 times the height of the escarpment.
6. Wind tunnel tests in accordance with ASCE 49 and Sections 31.4 and 31.7 of ASCE 7.
7. *Temporary structures* complying with Section 3103.6.1.2.

The wind speeds in Figures 1609.3(1) through 1609.3(4) are basic wind speeds, *V*, and shall be converted in accordance with Section 1609.3.1 to *allowable stress design* wind speeds, $V_{asd}$, when the provisions of the standards referenced in Exceptions 4 and 5 are used.

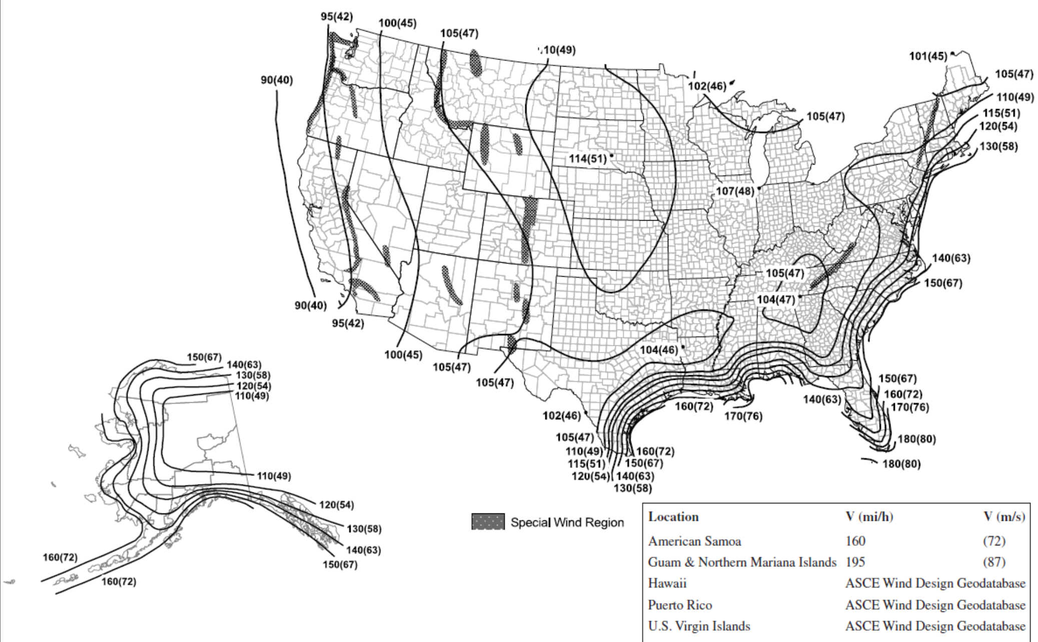
454 2024 INTERNATIONAL BUILDING CODE®

INTERNATIONAL CODE COUNCIL

12

12

**FIGURE 1609.3(2)—BASIC WIND SPEEDS, *V*, FOR RISK CATEGORY II BUILDINGS AND OTHER STRUCTURES**




| Location | V (mi/h) | V (m/s) |
|---|---|---|
| American Samoa | 160 | (72) |
| Guam & Northern Mariana Islands | 195 | (87) |
| Hawaii | ASCE Wind Design Geodatabase | |
| Puerto Rico | ASCE Wind Design Geodatabase | |
| U.S. Virgin Islands | ASCE Wind Design Geodatabase | |



13

13

**TABLE 1604.5—RISK CATEGORY OF BUILDINGS AND OTHER STRUCTURES**

| RISK CATEGORY | NATURE OF OCCUPANCY |
|---|---|
| I | Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to:<br>• Agricultural facilities.<br>• Certain temporary facilities.<br>• Minor storage facilities. |
| II | Buildings and other structures except those listed in Risk Categories I, III and IV. |
| III | Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to:<br>• Buildings and other structures whose primary occupancy is public assembly with an occupant load greater than 300.<br>• Buildings and other structures containing one or more public assembly spaces, each having an occupant load greater than 300 and a cumulative occupant load of these public assembly spaces of greater than 2,500.<br>• Buildings and other structures containing Group E or Group I-4 occupancies or combination thereof, with an occupant load greater than 250.<br>• Buildings and other structures containing educational occupancies for students above the 12th grade with an occupant load greater than 500.<br>• Group I-3, Condition 1 occupancies.<br>• Any other occupancy with an occupant load greater than 5,000.[a]<br>• Power-generating stations with individual power units rated 75 $MW_{AC}$ (megawatts, alternating current) or greater, water treatment facilities for potable water, wastewater treatment facilities and other public utility facilities not included in Risk Category IV.<br>• Buildings and other structures not included in Risk Category IV containing quantities of toxic or explosive materials that:<br>• Exceed maximum allowable quantities per control area as given in Table 307.1(1) or 307.1(2) or per outdoor control area in accordance with the *International Fire Code*; and<br>• Are sufficient to pose a threat to the public if released.[b] |
| IV | Buildings and other structures designated as essential facilities and buildings where loss of function represents a substantial hazard to occupants or users, including but not limited to:<br>• Group I-2, Condition 2 occupancies.<br>• Ambulatory care facilities having emergency surgery or emergency treatment facilities.<br>• Group I-3 occupancies other than Condition 1.<br>• Fire, rescue, ambulance and police stations and emergency vehicle garages<br>• Designated earthquake, hurricane or other emergency shelters.<br>• Designated emergency preparedness, communications and operations centers and other facilities required for emergency response.<br>• Public utility facilities providing power generation, potable water treatment, or wastewater treatment.<br>• Power-generating stations and other public utility facilities required as emergency backup facilities for *Risk Category* IV structures.<br>• Buildings and other structures containing quantities of highly toxic materials that:<br>• Exceed maximum allowable quantities per control area as given in Table 307.1(2) or per outdoor control area in accordance with the *International Fire Code*; and<br>• Are sufficient to pose a threat to the public if released.[b]<br>• Aviation control towers, air traffic control centers and emergency aircraft hangars.<br>• Buildings and other structures having critical national defense functions.<br>• Water storage facilities and pump structures required to maintain water pressure for fire suppression. |

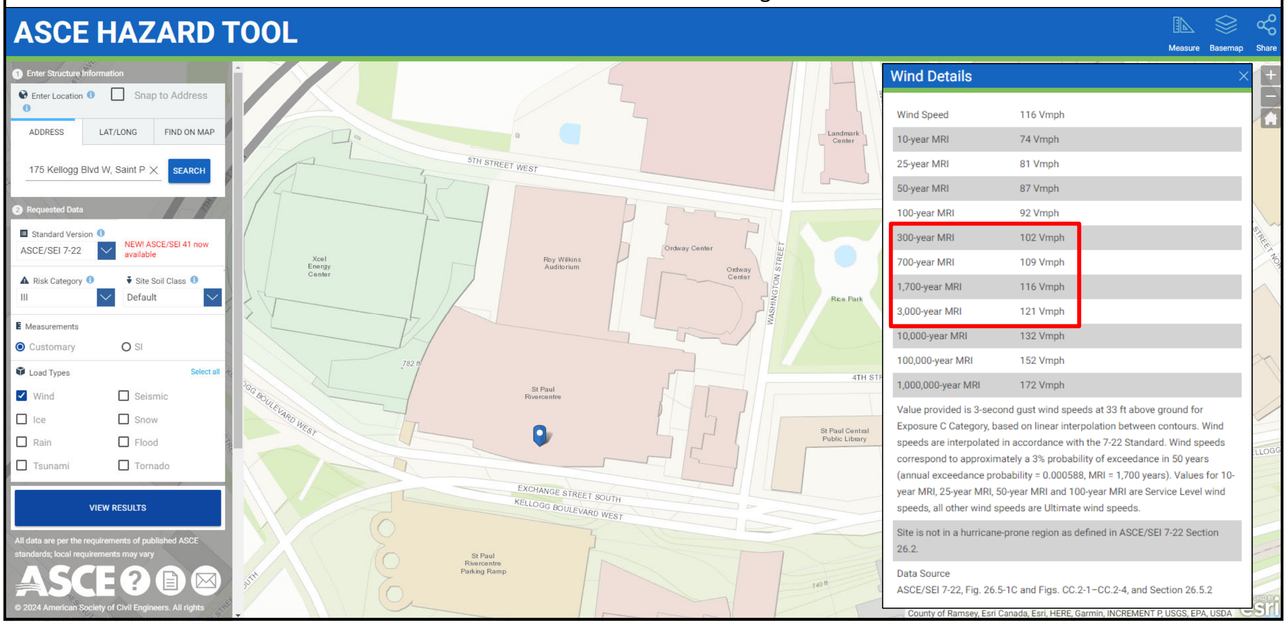
a. For purposes of occupant load calculation, occupancies required by Table 1004.5 to use *gross floor area* calculations shall be permitted to use *net floor areas* to determine the total occupant load. The floor area for vehicular drive aisles shall be permitted to be excluded in the determination of net floor area in parking garages.
b. Where approved by the building official, the classification of buildings and other structures as Risk Category III or IV based on their quantities of toxic, highly toxic or explosive materials is permitted to be reduced to Risk Category II, provided that it can be demonstrated by a hazard assessment in accordance with Section 1.5.3 of ASCE 7 that a release of the toxic, highly toxic or explosive materials is not sufficient to pose a threat to the public.

14

14

# ASCE Hazard Tool

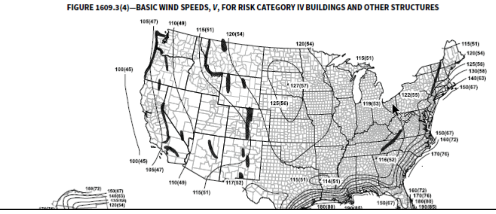
www.ASCEHazardTool.org




15

STRUCTURAL DESIGN

FIGURE 1609.3(4)—BASIC WIND SPEEDS, *V*, FOR RISK CATEGORY IV BUILDINGS AND OTHER STRUCTURES



**1609.3.1 Wind speed conversion.** Where required, the basic wind speeds of Figures 1609.3(1) through 1609.3(4) shall be converted to *allowable stress design* wind speeds, $V_{asd}$, using Table 1609.3.1 or Equation 16-18.

**Equation 16-18** $V_{asd} = V\sqrt{0.6}$ ← i.e., $V_{ASD} = V \times 0.78$

where:

$V_{asd}$ = *Allowable stress design wind speed* applicable to methods specified in Exceptions 4 and 5 of Section 1609.1.1.

$V$ = Basic wind speeds determined from Figures 1609.3(1) through 1609.3(4).

**TABLE 1609.3.1—WIND SPEED CONVERSIONS[a, b, c]**

| $V$ | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{asd}$ | 78 | 85 | 93 | 101 | 108 | 116 | 124 | 132 | 139 | 147 | 155 |

For SI: 1 mile per hour = 0.44 m/s.

a. Linear interpolation is permitted.

b. $V_{asd}$ = allowable stress design wind speed applicable to methods specified in Exceptions 1 through 5 of Section 1609.1.1.

c. $V$ = basic wind speeds determined from Figures 1609.3(1) through 1609.3(4).

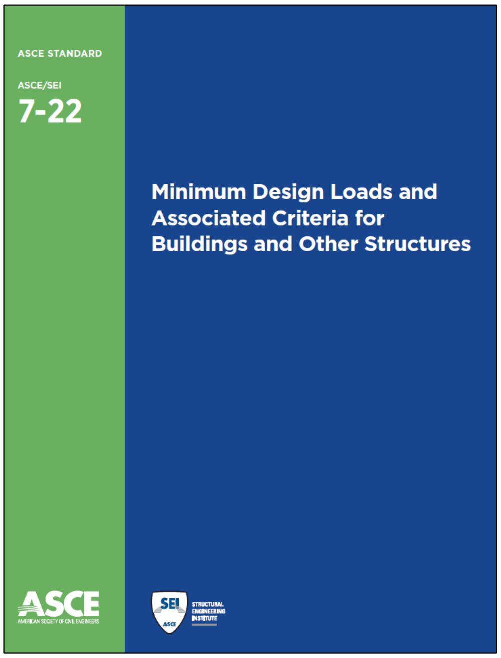
**1609.4 Exposure category.** For each wind direction considered, an exposure category that adequately reflects the characteristics of ground surface irregularities shall be determined for the *site* at which the *building* or *structure* is to be constructed. Account shall be taken of variations in ground surface roughness that arise from natural topography and vegetation as well as from constructed features.

2024 INTERNATIONAL BUILDING CODE® 459

INTERNATIONAL CODE COUNCIL®

16

16

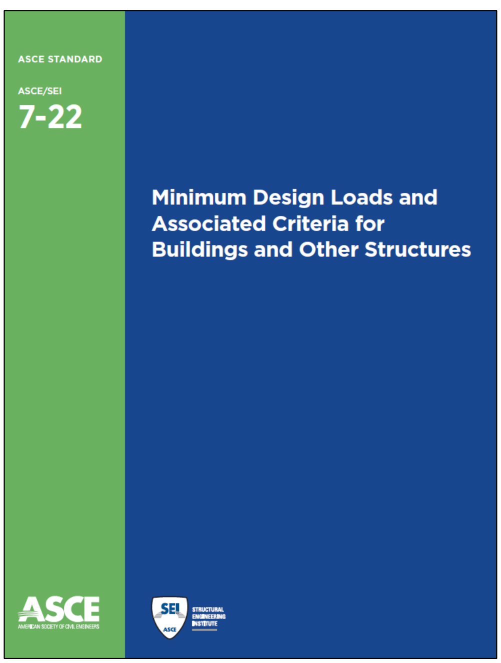



**ASCE 7-22**

- All loads on buildings and structures
- 482 pages + commentary (1046 pages total)
- 32 chapters
- 7 appendixes
- Referenced in IBC 2024 Ch. 16-Wind Design as the basis for wind design

Link

17




**ASCE 7-22 on wind design**

- Ch. 26: Wind loads: General requirements
- Ch. 30: Wind loads: Components and cladding
- Ch. 31: Wind tunnel procedure
- Ch. 32: Tornado loads

*99 pages*

18

CHAPTER 26
WIND LOADS: GENERAL REQUIREMENTS

### 26.1 PROCEDURES

**26.1.1 Scope** Buildings and other structures, including the main wind force resisting system (MWFRS) and all components and cladding (C&C) thereof, shall be designed and constructed to resist the wind loads determined in accordance with Chapters 26 through 31.

Risk Category III and IV buildings and other structures, including the MWFRS and all C&C thereof, shall also be designed and constructed to resist tornado loads determined in accordance with Chapter 32, as applicable.

The provisions of this chapter define basic wind parameters for use with other provisions contained in this standard.

references, is provided in Figure 26.1-1.

Additional outlines and User Notes are provided at the beginning of Chapters 27 through 31 for more detailed step-by-step procedures for determining the wind loads.

***26.1.2.1 Main Wind Force Resisting System*** Wind loads for the MWFRS shall be determined using one of the following procedures:

1. Directional Procedure for buildings of all heights as specified in Chapter 27 for buildings meeting the requirements specified therein;
2. Envelope Procedure for low-rise buildings as specified in Chapter 28 for buildings meeting the requirements specified therein;
3. Directional Procedure for building appurtenances (rooftop structures and rooftop equipment) and other structures (such as solid freestanding walls and solid freestanding signs, chimneys, tanks, open signs, single-plane open frames, and trussed towers) as specified in Chapter 29; or
4. Wind Tunnel Procedure for all buildings and all other structures as specified in Chapter 31.

***26.1.2.2 Components and Cladding*** Wind loads on C&C on all buildings and other structures shall be designed using one of the following procedures:

1. Analytical Procedures provided in Parts 1 through 5, as appropriate, of Chapter 30; or
2. Wind Tunnel Procedure as specified in Chapter 31.

**26.1.3 Performance-Based Procedures** Wind design of buildings and other structures using performance-based procedures shall be permitted subject to the approval of the Authority Having Jurisdiction. The performance-based wind design procedures used shall, at a minimum, conform to Section 1.3.1.3.

#### 26.2 DEFINITIONS

The following definitions apply to the provisions of Chapters 26 through 31.

**APPROVED:** Acceptable to the Authority Having Jurisdiction.

**ASCE WIND DESIGN GEODATABASE:** The ASCE database (version 2022-1.0) of geocoded wind speed design data.

> **User Note:** The ASCE Wind Design Geodatabase of geocoded wind speed design data is available at https://asce7hazardtool.online/.

**ATTACHED CANOPY:** A horizontal (maximum slope of 2%) patio cover attached to the building wall at any height; it is different from an overhang, which is an extension of the roof surface.

**BASIC WIND SPEED, *V*:** Three-second gust speed at 33 ft (10 m) above the ground in Exposure C (see Section 26.7.3) as determined in accordance with Section 26.5.1.

**BUILDING, ELEVATED:** A building supported on structural elements where wind can pass beneath the building.

**BUILDING, ENCLOSED:** A building that has the total area of openings in each wall that receives positive external pressure less than or equal to 4 ft² (0.37 m²) or 1% of the area of that wall, whichever is smaller. This condition is expressed for each wall by the following equation:

$$A_o < 0.01A_g \text{ or } 4\ \text{ft}^2\ (0.37\ \text{m}^2), \text{ whichever is smaller,}$$

where $A_o$ and $A_g$ are as defined for Open Buildings.

**BUILDING, LOW-RISE:** An enclosed, partially enclosed, or partially open building that complies with the following conditions:

Minimum Design Loads and Associated Criteria for Buildings and Other Structures 261

19

### 30.1 SCOPE

**30.1.1 Building Types** This chapter applies to the determination of wind pressures on components and cladding (C&C) on buildings.

1. Part 1 is applicable to an enclosed, partially enclosed, or partially open
   - Low-rise building (see definition in Section 26.2); or
   - Building with $h \leq 60$ ft (18.3 m).

   The building has a flat roof, gable roof, multispan gable roof, hip roof, monoslope roof, stepped roof, or sawtooth roof, and the wind pressures are calculated from a wind pressure equation.
2. Part 2 is applicable to an enclosed, partially enclosed, or partially open
   - Building with $h > 60$ ft (18.3 m).

   The building has a flat roof, pitched roof, gable roof, hip roof, mansard roof, arched roof, or domed roof, and the wind pressures are calculated from a wind pressure equation.
3. Part 3 is applicable to an open building of all heights that has a pitched free roof, monoslope free roof, or troughed free roof.
4. Part 4 is applicable to building appurtenances such as roof overhangs, parapets, and rooftop equipment.
5. Part 5 is applicable to non-building structures – circular bins, silos, and tanks; rooftop solar panels and roof pavers.
   - Circular bins, silos, and tanks with $h \leq 120$ ft (38.6 m);
   - Rooftop solar panels: Buildings of all heights with flat roofs or gable or hip roofs with roof slopes less than or equal to 7 degrees; and
   - Roof pavers: Buildings of all heights with roof slopes less than or equal to 7 degrees.

TER 30
NENTS AND CLADDING

resonance with along-wind vibrations of flexible buildings. The loads on buildings that do not meet the requirements of Section 30.1.2 or that have unusual shapes or response characteristics shall be determined using recognized literature documenting such wind load effects or shall use the wind tunnel procedure specified in Chapter 31.

**30.1.4 Shielding** There shall be no reductions in velocity pressure caused by apparent shielding afforded by buildings and other structures or terrain features.

**30.1.5 Air-Permeable Cladding** Design wind loads determined from Chapter 30 shall be used for air-permeable claddings, including modular vegetative roof assemblies, unless approved test data or recognized literature demonstrates lower loads for the type of air-permeable cladding being considered.

#### 30.2 GENERAL REQUIREMENTS

**30.2.1 Wind Load Parameters Specified in Chapter 26** The following wind load parameters are specified in Chapter 26:

- Basic wind speed, $V$ (Section 26.5),
- Wind directionality factor, $K_d$ (Section 26.6),
- Exposure category (Section 26.7),
- Topographic factor, $K_{zt}$ (Section 26.8),
- Ground elevation factor, $K_e$ (Section 26.9),
- Velocity pressure exposure coefficient, $K_z$ or $K_h$ (Section 26.10.1); Velocity pressure, $q_z$ (Section 26.10.2),
- Gust-effect factor (Section 26.11),
- Enclosure classification (Section 26.12), and
- Internal pressure coefficient, $(GC_{pi})$ (Section 26.13).

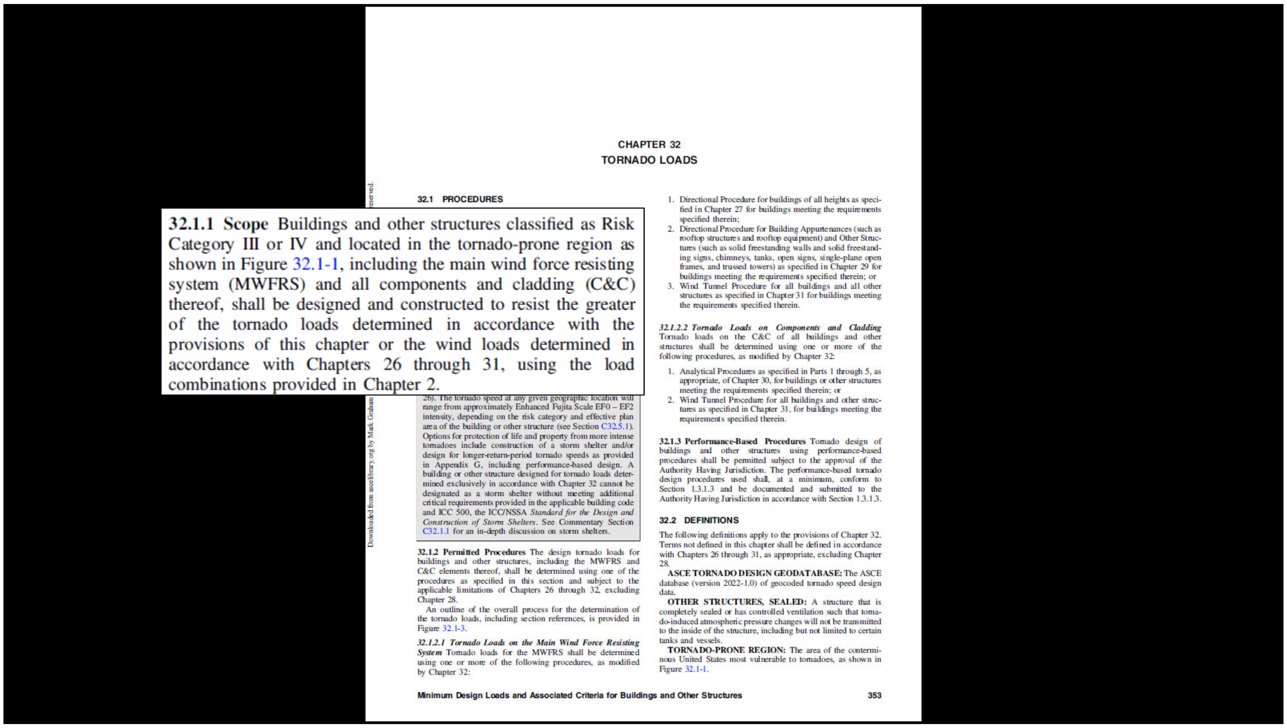
**30.2.2 Minimum Design Wind Pressures** The design wind pressure for C&C of buildings shall not be less than a net pressure of 16 lb/ft² (0.77 kN/m²) acting in either direction normal to the surface.

**30.2.3 Tributary Areas Greater than 700 ft² (65 m²)** C&C elements with tributary areas greater than 700 ft² (65 m²) shall be permitted to be designed using the provisions for main wind force resisting systems.

**30.2.4 External Pressure Coefficients** Combined gust-effect factor and external pressure coefficients for C&C, $(GC_p)$, are given in the figures associated with this chapter. The pressure coefficient values and gust-effect factor shall not be separated.

ngs and Other Structures 315

20



**CHAPTER 32**
**TORNADO LOADS**



## 32.1 PROCEDURES

**32.1.1 Scope** Buildings and other structures classified as Risk Category III or IV and located in the tornado-prone region as shown in Figure 32.1-1, including the main wind force resisting system (MWFRS) and all components and cladding (C&C) thereof, shall be designed and constructed to resist the greater of the tornado loads determined in accordance with the provisions of this chapter or the wind loads determined in accordance with Chapters 26 through 31, using the load combinations provided in Chapter 2.

26). The tornado speed at any given geographic location will range from approximately Enhanced Fujita Scale EF0 – EF2 intensity, depending on the risk category and effective plan area of the building or other structure (see Section C32.5.1). Options for protection of life and property from more intense tornadoes include construction of a storm shelter and/or design for longer-return-period tornado speeds as provided in Appendix G, including performance-based design. A building or other structure designed for tornado loads determined exclusively in accordance with Chapter 32 cannot be designated as a storm shelter without meeting additional critical requirements provided in the applicable building code and ICC 500, the ICC/NSSA *Standard for the Design and Construction of Storm Shelters*. See Commentary Section C32.1.1 for an in-depth discussion on storm shelters.

**32.1.2 Permitted Procedures** The design tornado loads for buildings and other structures, including the MWFRS and C&C elements thereof, shall be determined using one of the procedures as specified in this section and subject to the applicable limitations of Chapters 26 through 32, excluding Chapter 28.

An outline of the overall process for the determination of the tornado loads, including section references, is provided in Figure 32.1-3.

***32.1.2.1 Tornado Loads on the Main Wind Force Resisting System*** Tornado loads for the MWFRS shall be determined using one or more of the following procedures, as modified by Chapter 32:

1. Directional Procedure for buildings of all heights as specified in Chapter 27 for buildings meeting the requirements specified therein;
2. Directional Procedure for Building Appurtenances (such as rooftop structures and rooftop equipment) and Other Structures (such as solid freestanding walls and solid freestanding signs, chimneys, tanks, open signs, single-plane open frames, and trussed towers) as specified in Chapter 29 for buildings meeting the requirements specified therein; or
3. Wind Tunnel Procedure for all buildings and all other structures as specified in Chapter 31 for buildings meeting the requirements specified therein.

***32.1.2.2 Tornado Loads on Components and Cladding*** Tornado loads on the C&C of all buildings and other structures shall be determined using one or more of the following procedures, as modified by Chapter 32:

1. Analytical Procedures as specified in Parts 1 through 5, as appropriate, of Chapter 30, for buildings or other structures meeting the requirements specified therein; or
2. Wind Tunnel Procedure for all buildings and other structures as specified in Chapter 31, for buildings meeting the requirements specified therein.

**32.1.3 Performance-Based Procedures** Tornado design of buildings and other structures using performance-based procedures shall be permitted subject to the approval of the Authority Having Jurisdiction. The performance-based tornado design procedures used shall, at a minimum, conform to Section 1.3.1.3 and be documented and submitted to the Authority Having Jurisdiction in accordance with Section 1.3.1.3.

## 32.2 DEFINITIONS

The following definitions apply to the provisions of Chapter 32. Terms not defined in this chapter shall be defined in accordance with Chapters 26 through 31, as appropriate, excluding Chapter 28.

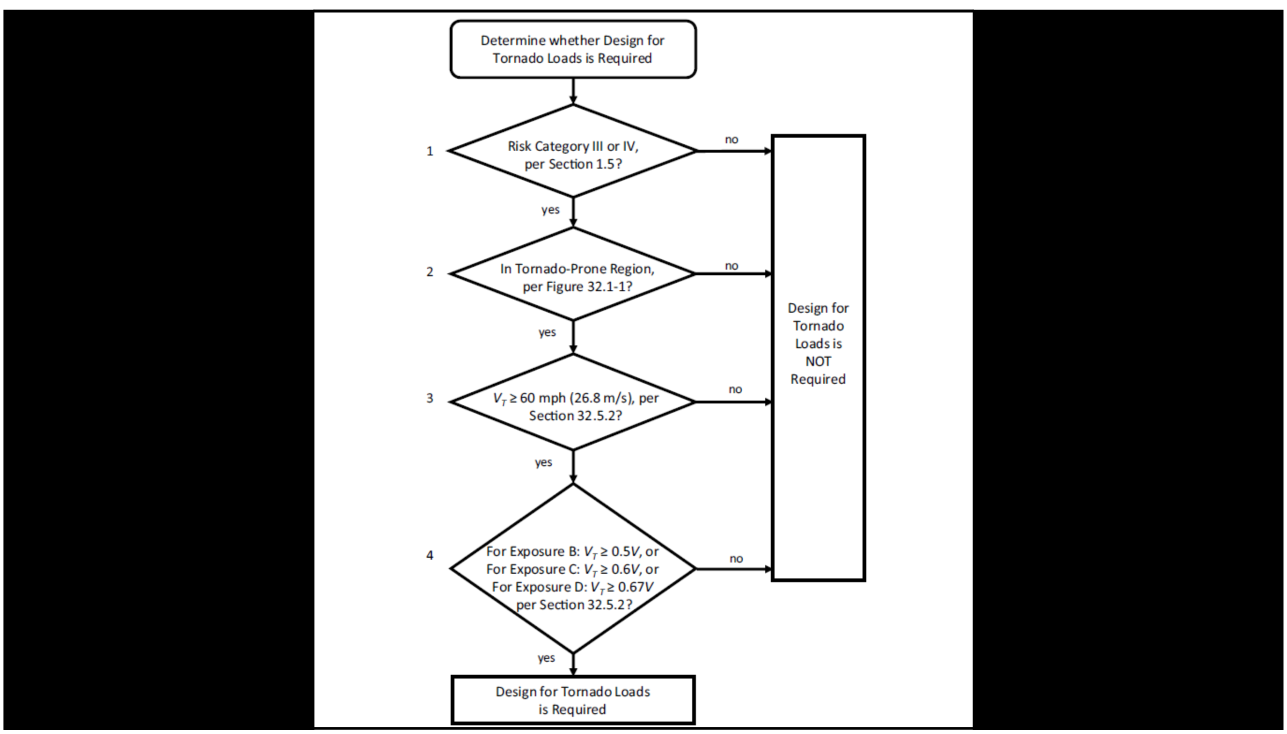
**ASCE TORNADO DESIGN GEODATABASE:** The ASCE database (version 2022-1.0) of geocoded tornado speed design data.

**OTHER STRUCTURES, SEALED:** A structure that is completely sealed or has controlled ventilation such that tornado-induced atmospheric pressure changes will not be transmitted to the inside of the structure, including but not limited to certain tanks and vessels.

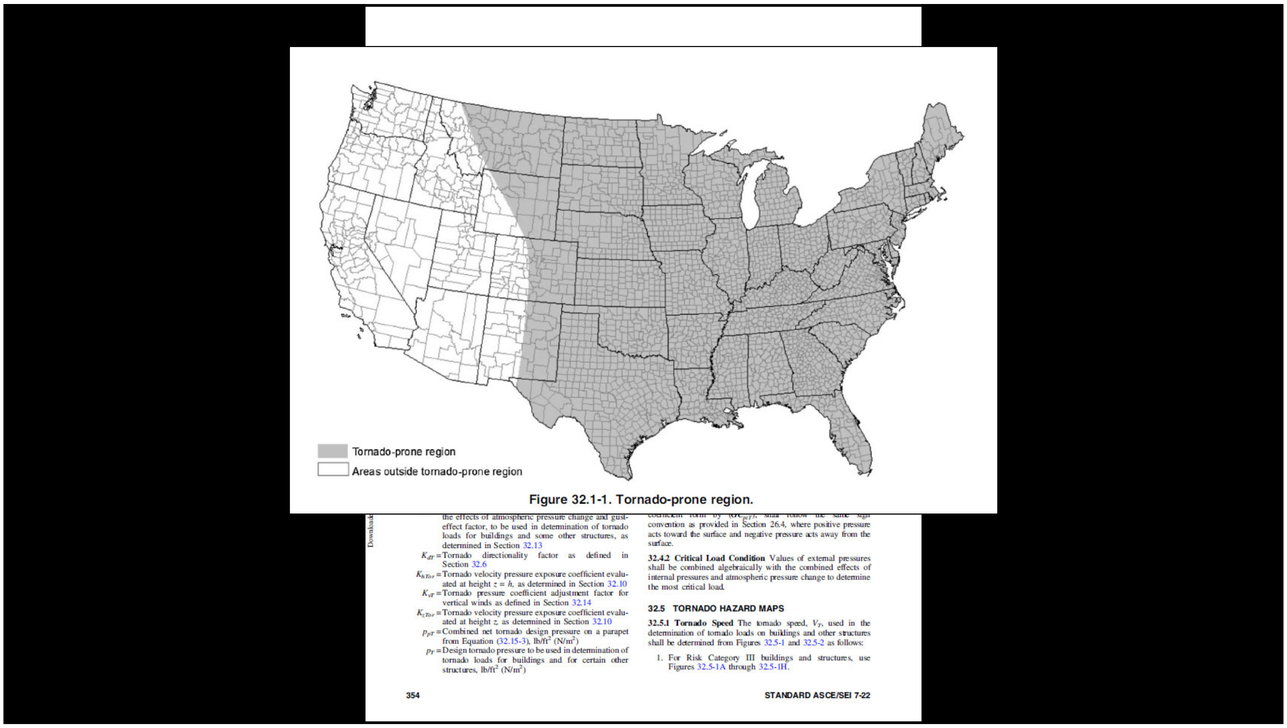
**TORNADO-PRONE REGION:** The area of the conterminous United States most vulnerable to tornadoes, as shown in Figure 32.1-1.

**Minimum Design Loads and Associated Criteria for Buildings and Other Structures** 353

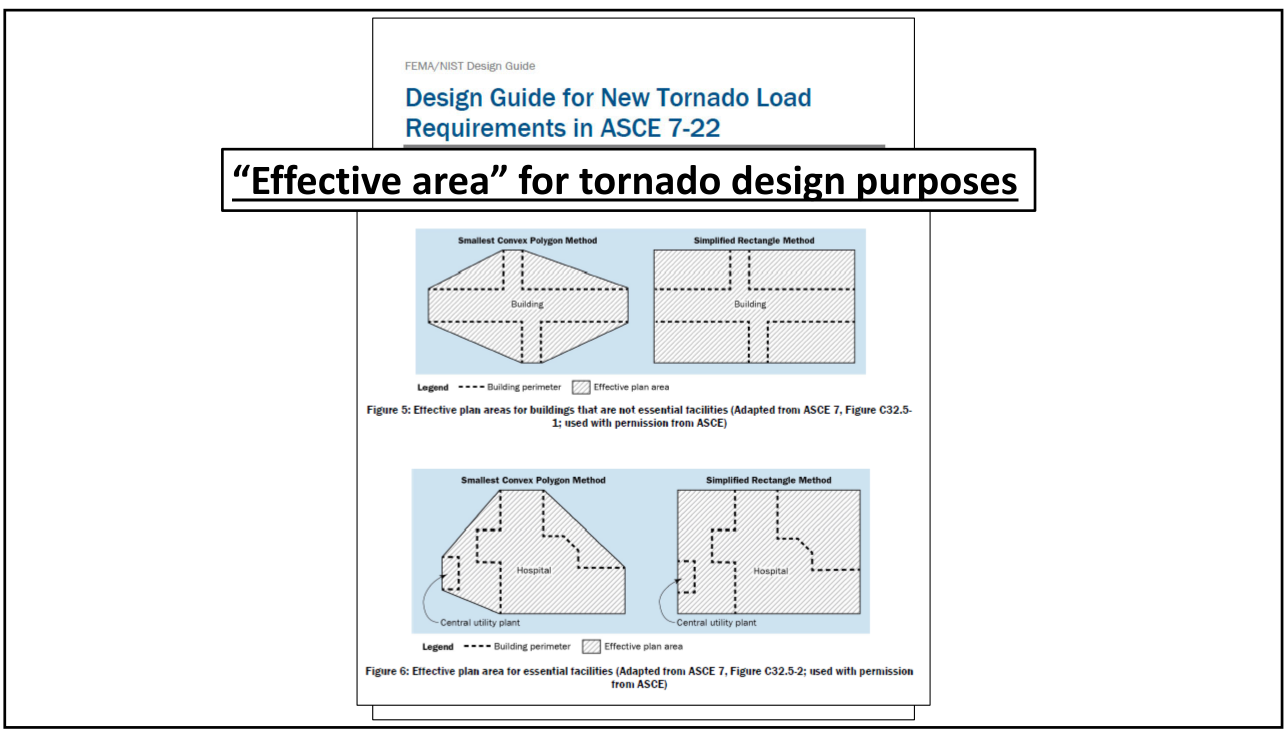
21



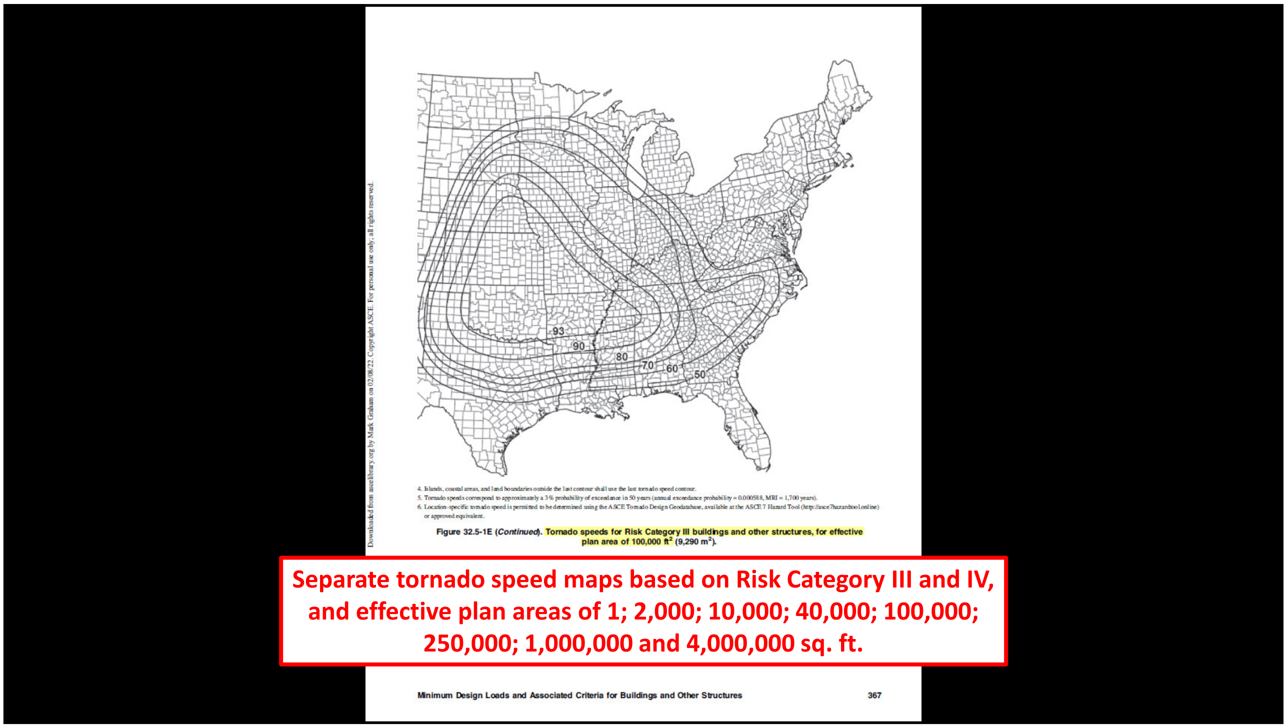

22


Tornado-prone region
Areas outside tornado-prone region
Figure 32.1-1. Tornado-prone region.
32.4.2 Critical Load Condition Values of external pressures shall be combined algebraically with the combined effects of internal pressures and atmospheric pressure change to determine the most critical load.
32.5 TORNADO HAZARD MAPS
32.5.1 Tornado Speed The tornado speed, $V_T$, used in the determination of tornado loads on buildings and other structures shall be determined from Figures 32.5-1 and 32.5-2 as follows:
1. For Risk Category III buildings and structures, use Figures 32.5-1A through 32.5-1H.
354
STANDARD ASCE/SEI 7-22

23


FEMA/NIST Design Guide
Design Guide for New Tornado Load Requirements in ASCE 7-22
"Effective area" for tornado design purposes
Smallest Convex Polygon Method
Simplified Rectangle Method
Building
Legend
Building perimeter
Effective plan area
Figure 5: Effective plan areas for buildings that are not essential facilities (Adapted from ASCE 7, Figure C32.5-1; used with permission from ASCE)
Smallest Convex Polygon Method
Simplified Rectangle Method
Hospital
Central utility plant
Legend
Building perimeter
Effective plan area
Figure 6: Effective plan area for essential facilities (Adapted from ASCE 7, Figure C32.5-2; used with permission from ASCE)

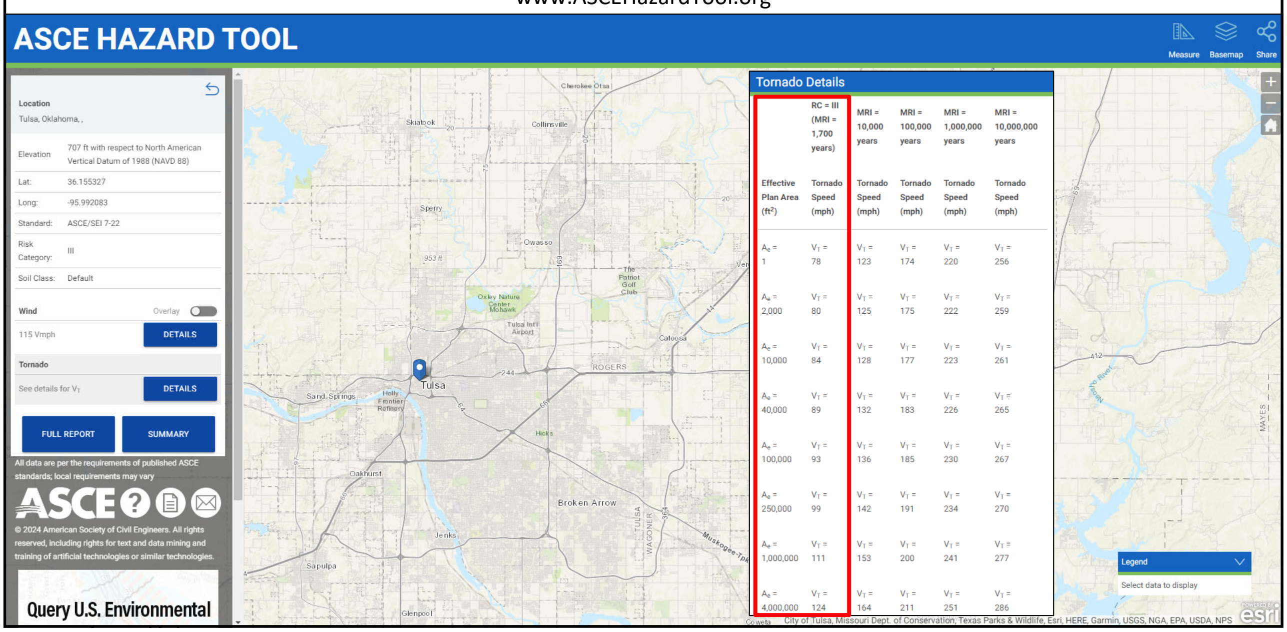
24




25

# ASCE Hazard Tool

www.ASCEHazardTool.org




| Effective Plan Area (ft²) | RC = III (MRI = 1,700 years) Tornado Speed (mph) | MRI = 10,000 years Tornado Speed (mph) | MRI = 100,000 years Tornado Speed (mph) | MRI = 1,000,000 years Tornado Speed (mph) | MRI = 10,000,000 years Tornado Speed (mph) |
|---|---|---|---|---|---|
| $A_e$ = 1 | $V_T$ = 78 | $V_T$ = 123 | $V_T$ = 174 | $V_T$ = 220 | $V_T$ = 256 |
| $A_e$ = 2,000 | $V_T$ = 80 | $V_T$ = 125 | $V_T$ = 175 | $V_T$ = 222 | $V_T$ = 259 |
| $A_e$ = 10,000 | $V_T$ = 84 | $V_T$ = 128 | $V_T$ = 177 | $V_T$ = 223 | $V_T$ = 261 |
| $A_e$ = 40,000 | $V_T$ = 89 | $V_T$ = 132 | $V_T$ = 183 | $V_T$ = 226 | $V_T$ = 265 |
| $A_e$ = 100,000 | $V_T$ = 93 | $V_T$ = 136 | $V_T$ = 185 | $V_T$ = 230 | $V_T$ = 267 |
| $A_e$ = 250,000 | $V_T$ = 99 | $V_T$ = 142 | $V_T$ = 191 | $V_T$ = 234 | $V_T$ = 270 |
| $A_e$ = 1,000,000 | $V_T$ = 111 | $V_T$ = 153 | $V_T$ = 200 | $V_T$ = 241 | $V_T$ = 277 |
| $A_e$ = 4,000,000 | $V_T$ = 124 | $V_T$ = 164 | $V_T$ = 211 | $V_T$ = 251 | $V_T$ = 286 |

26

panel systems shall be equal to the effective plan area of the largest structurally independent photovoltaic support structure that does not share structural components with other adjacent structures.

**32.6 TORNADO DIRECTIONALITY FACTOR**

The tornado directionality factor, $K_{dT}$, shall be determined from Table 32.6-1 and shall be used to determine the tornado loads in accordance with Sections 32.15 through 32.17.

**32.7 TORNADO EXPOSURE**

Tornado velocity pressure exposure coefficients $K_{zTor}$ and $K_{hTor}$ are determined in Section 32.10.1. Exposure requirements in Section 26.7 shall not apply to the determination of $K_{zTor}$ and $K_{hTor}$.



**32.10 TORNADO VELOCITY PRESSURE**

**32.10.1 Tornado Velocity Pressure Exposure Coefficient** A tornado velocity pressure exposure coefficient, $K_{zTor}$ or $K_{hTor}$, as applicable, shall be determined from Table 32.10-1.

**32.10.2 Tornado Velocity Pressure** Tornado velocity pressure, $q_{zT}$, evaluated at height $z$ above ground, shall be determined in accordance with the following equation:

$$q_{zT} = 0.00256 K_{zTor} K_e V_T^2 \text{ (lb/ft}^2\text{)}; V_T \text{ in mi/h} \quad (32.10\text{-}1)$$

$$q_{zT} = 0.613 K_{zTor} K_e V_T^2 \text{ (N/m}^2\text{)}; V_T \text{ in m/s} \quad (32.10\text{-}1.\text{SI})$$

where

$K_{zTor}$ = Tornado velocity pressure exposure coefficient, see Section 32.10.1;
$K_e$ = Ground elevation factor, see Section 32.9;
$V_T$ = Tornado speed, see Section 32.5; and
$q_{zT}$ = Tornado velocity pressure at height $z$.

The velocity pressure at mean roof height shall be computed as $q_{hT} = q_{zT}$ evaluated from Equation (32.10-1) using $K_{zTor}$ at mean roof height $h$.

**32.12 TORNADO ENCLOSURE CLASSIFICATION**

**32.12.1 General** For the purpose of determining internal pressure coefficients for tornadoes, buildings and other structures for which tornado internal pressure coefficients, $(GC_{piT})$, apply shall have an enclosure classification assigned in accordance with this section. If a building or other structure satisfies both the "open" and "partially enclosed" tornado enclosure classification definitions, it shall be classified as a "partially open" building or other structure.

**32.12.2 Openings** To assign the tornado enclosure classification, the amount of openings in the building envelope shall be determined by taking each wall of the building or other structure, assuming it functions as the windward wall, and summing the total area of openings present with respect to the area of the remaining building envelope. Buildings shall be classified as enclosed, partially enclosed, partially open, or open as defined in Section 26.2. Other structures shall be classified as sealed, as defined in Section 32.2, or enclosed, partially enclosed, partially open, or open as defined in Section 26.2.

Where not required by Section 32.12.3 to protect glazed openings, enclosed buildings and other structures shall either (1) be reevaluated for classification as partially enclosed, with all unprotected glazed openings on each assumed windward wall considered as openings; or (2) be protected in accordance with Section 32.12.3.1.

**32.12.3 Protection of Glazed Openings** Glazed openings shall be protected as specified in this section for Essential Facilities and for buildings and other structures required to maintain the functionality of Essential Facilities.

***32.12.3.1 Protection Requirements for Glazed Openings*** Glazing in buildings requiring protection shall be protected with an impact-protective system or shall be impact-resistant glazing. Impact-protective systems shall be either (a) permanently affixed non-operable systems or (b) permanently affixed operable systems capable of being fully deployed from inside the building within five minutes and used in buildings that are staffed 24 hours per day.

Impact-protective systems and impact-resistant glazing shall be subjected to missile tests in accordance with ASTM E1996 using missile level D or E as described in Table 2 of ASTM E1996. Testing to demonstrate compliance with ASTM E1996 shall be in accordance with ASTM E1886. Impact-resistant glazing and impact-protective systems shall comply with the pass/fail criteria of Section 7 of ASTM E1996. Glazing in sectional doors, rolling doors, and flexible doors shall be subjected to missile tests in accordance with ANSI/DASMA 115 as applicable. Glazing and impact-protective systems shall comply with the "Enhanced Protection" requirements of Table 3 of ASTM E1996, with tornado speed used in place of basic wind speed for determination of wind zone.

**EXCEPTION:** Other testing methods and/or performance criteria are permitted to be used where approved.

**32.13 TORNADO INTERNAL PRESSURE COEFFICIENTS**

Tornado internal pressure coefficients, $(GC_{piT})$, shall be determined from Table 32.13-1 based on building and other structure enclosure classifications determined in accordance with Section 32.12.1.

**Minimum Design Loads and Associated Criteria for Buildings and Other Structures** 357

27

$$F_{vT} = q_{hT} K_{dT} K_{vT} (GC_r) A_r \text{ (lb)} \quad (32.16\text{-}4)$$

$$F_{vT} = q_{hT} K_{dT} K_{vT} (GC_r) A_r \text{ (N)} \quad (32.16\text{-}4.\text{SI})$$

where

$q_{hT}$ = Tornado velocity pressure from Section 32.10.2 evaluated at mean roof height $h$, lb/ft² (N/m²),
$K_{dT}$ = Tornado directionality factor from Section 32.6,
$K_{vT}$ = Tornado pressure coefficient adjustment factor from Section 32.14,
$(GC_r)$ = Product of external pressure coefficient and gust-effect factor from Section 29.4.1, and
$A_r$ = Horizontal projected area of rooftop structure or equipment, ft² (m²).

***32.16.3.3 Roofs of Isolated Circular Bins, Silos, and Tanks*** Section 29.4.2.2 shall apply for determination of MWFRS loads on the roofs of isolated circular bins, silos, and tanks, as modified in this section. The net design tornado pressures shall be determined in accordance with the following equation, which replaces Equation (29.4-4):

$$p_T = q_{hT}[G_T K_{dT} K_{vT} C_p - (GC_{piT})] \text{ (lb/ft}^2\text{)} \quad (32.16\text{-}5)$$

$$p_T = q_{hT}[G_T K_{dT} K_{vT} C_p - (GC_{piT})] \text{ (N/m}^2\text{)} \quad (32.16\text{-}5.\text{SI})$$

where

$q_{hT}$ = Tornado velocity pressure from Section 32.10.2 evaluated at mean roof height $h$, lb/ft² (N/m²),
$G_T$ = Tornado gust-effect factor from Section 32.11,
$K_{dT}$ = Tornado directionality factor from Section 32.6,
$K_{vT}$ = Tornado pressure coefficient adjustment factor from Section 32.14,
$C_p$ = External pressure coefficient from Section 29.4.2.2, and
$(GC_{piT})$ = Tornado internal pressure coefficient from Section 32.13.

***32.16.3.4 Rooftop Solar Panels for Buildings of All Heights with Flat Roofs or Gable or Hip Roofs with Slopes Less Than 7 Degrees*** Section 29.4.3 shall apply for determination of MWFRS loads on rooftop photovoltaic panels for buildings of all heights with flat roofs or gable or hip roofs with slopes less than 7 degrees, as modified in this section. The design tornado pressure, $p_T$, for rooftop photovoltaic panels shall be determined by the following equation, which replaces Equation (29.4-5):

$$p_T = q_{hT} K_{dT} (GC_m) \text{ (lb/ft}^2\text{)} \quad (32.16\text{-}6)$$

$$p_T = q_{hT} K_{dT} (GC_m) \text{ (N/m}^2\text{)} \quad (32.16\text{-}6.\text{SI})$$

where

$q_{hT}$ = Tornado velocity pressure from Section 32.10.2 evaluated at mean roof height $h$, lb/ft² (N/m²),
$K_{dT}$ = Tornado directionality factor from Section 32.6, and
$(GC_{rn})$ = Net pressure coefficient from Section 29.4.3.

***32.16.3.5 Rooftop Solar Panels Parallel to the Roof Surface on Buildings of All Heights and Roof Slopes*** Section 29.4.4 shall apply for determination of MWFRS loads on rooftop photovoltaic panels parallel to the roof surface on buildings of all heights and roof slopes as modified in this section. The design tornado pressure, $p_T$, for rooftop photovoltaic panels shall be

**Minimum Design Loads and Associated Criteria for Buildi**



**32.17.1 Low-Rise Buildings** Section 30.3 shall apply for determination of component and cladding tornado loads on low-rise buildings, as modified in this section. The design tornado pressures, $p_T$, on C&C elements in low-rise buildings and buildings with $h \leq 60$ ft ($h \leq 18.3$ m) shall be determined in accordance with the following equation, which replaces Equation (30.3-1):

$$p_T = q_{hT}[K_{dT} K_{vT}(GC_p) - (GC_{piT})] \text{ (lb/ft}^2\text{)} \quad (32.17\text{-}1)$$

$$p_T = q_{hT}[K_{dT} K_{vT}(GC_p) - (GC_{piT})] \text{ (N/m}^2\text{)} \quad (32.17\text{-}1.\text{SI})$$

where

$q_{hT}$ = Tornado velocity pressure from Section 32.10.2 evaluated at mean roof height $h$, lb/ft² (N/m²);
$K_{dT}$ = Tornado directionality factor from Section 32.6;
$K_{vT}$ = Tornado pressure coefficient adjustment factor from Section 32.14;
$(GC_p)$ = External pressure coefficient from Section 30.3; and
$(GC_{piT})$ = Tornado internal pressure coefficient from Section 32.13.

***32.17.1.1 Bottom Horizontal Surfaces of Elevated Buildings*** Section 30.3.2.1 shall apply for determination of C&C loads on bottom horizontal surfaces of elevated buildings, as modified in this section. The design tornado pressure, $p_T$, for the effects of tornado pressure on C&C shall be determined in accordance with Equation (32.17-1), where $K_{vT}$ = 1.0.

**32.17.2 Buildings with $h$ > 60 ft** ($h$ > 18.3 m) Section 30.4 shall apply for the determination of component and cladding tornado loads on buildings with $h > 60$ ft ($h$ > 18.3 m), as modified in this section. The design tornado pressures, $p_T$, on C&C elements for all buildings with $h$ > 60 ft ($h$ > 18.3 m) shall be determined in accordance with the following equation, which replaces Equation (30.4-1):

$$p_T = q K_{dT} K_{vT}(GC_p) - q_i(GC_{piT}) \text{ (lb/ft}^2\text{)} \quad (32.17\text{-}2)$$

$$p_T = q K_{dT} K_{vT}(GC_p) - q_i(GC_{piT}) \text{ (N/m}^2\text{)} \quad (32.17\text{-}2.\text{SI})$$

where

$q = q_{zT}$ For external pressure on all walls evaluated at height $z$ above the ground, lb/ft² (N/m²);

28

***If the tornado loads are greater than the conventional wind loads, use the tornado loads as the basis for wind design***

29

## A wind and tornado design example…

**Hypothetical situation:** A hospital (Risk Category IV) building with a 70 ft. mean roof height 343 square low-slope roof area is located in an urban (Exposure B) Tulsa, OK

30

30

## Solution:

**Wind design:**

| | Wind Speed | $Z_1$ (Field) | $Z_2$ (Perimeter) | $Z_3$ (Corner) |
|---|---|---|---|---|
| **Ult. method** | 120 mph | 53 psf | 77 psf | 101 psf |
| **ASD method** | 93 mph | FM Class 75 | | |

**Tornado design:**

$A_e$=40,000 sq. ft.

| | Wind Speed | $Z_1$ (Field) | $Z_2$ (Perimeter) | $Z_3$ (Corner) |
|---|---|---|---|---|
| **Ult. method** | 107 mph | 61 psf | 81 psf | 107 psf |
| **ASD method** | -- | FM Class 75 | | |

31

31

## Impact of effective area ($A_e$)

$A_e$=40,000 sq. ft.

| | Wind Speed | $Z_1$ (Field) | $Z_2$ (Perimeter) | $Z_3$ (Corner) |
|---|---|---|---|---|
| **Ult. method** | 103 mph | 61 psf | 81 psf | 107 psf |
| **ASD method** | -- | FM Class 75 | | |

$A_e$=100,000 sq. ft.

| | Wind Speed | $Z_1$ (Field) | $Z_2$ (Perimeter) | $Z_3$ (Corner) |
|---|---|---|---|---|
| **Ult. method** | 107 mph | 65 psf | 87 psf | 115 psf |
| **ASD method** | -- | FM Class 90 | | |

$A_e$=250,000 sq. ft.

| | Wind Speed | $Z_1$ (Field) | $Z_2$ (Perimeter) | $Z_3$ (Corner) |
|---|---|---|---|---|
| **Ult. method** | 113 mph | 73 psf | 97 psf | 128 psf |
| **ASD method** | -- | FM Class 90 | | |

32

32

## Impact of effective area ($A_e$) - continued

$A_e$=1,000,000 sq. ft.

| | Wind Speed | $Z_1$ (Field) | $Z_2$ (Perimeter) | $Z_3$ (Corner) |
|---|---|---|---|---|
| **Ult. method** | 125 mph | 89 psf | 119 psf | 156 psf |
| **ASD method** | -- | **FM Class 120** | | |

$A_e$=4,000,000 sq. ft.

| | Wind Speed | $Z_1$ (Field) | $Z_2$ (Perimeter) | $Z_3$ (Corner) |
|---|---|---|---|---|
| **Ult. method** | 138 mph | 109 psf | 145 psf | 191 psf |
| **ASD method** | -- | **FM Class 135** | | |

33

33

*While ASCE 7-22's wind load provisions are relatively manageable, the tornado provisions, where applicable, can get rather complex.*

34

# Roof Wind Designer

www.roofwinddesigner.com


***Tornado design is being added to Roof Wind Designer***

35

35

***What about FM Global-insured buildings?***

36

**FM Global**
**Property Loss Prevention Data Sheets** **1-28**

October 2015
Interim Revision January 2024
Page 1 of 94

**WIND DESIGN**

**INSUREDS OF FM GLOBAL SHOULD CONTACT THEIR LOCAL FM GLOBAL OFFICE BEFORE BEGINNING ANY ROOFING WORK.**

**Table of Contents**





37

## FM 1-28, "Wind design"

- Intended to apply to FM Global-insured buildings
- ASD basic wind speed maps and design method
- Some ultimate design concepts (e.g., zones)
- Importance Factor = 1.15
- Tornado provisions added

Link

37

**FM Global**
**Property Loss Prevention Data Sheets** **1-28**

October 2015
Interim Revision January 2024
Page 1 of 94

**WIND DESIGN**

**INSUREDS OF FM GLOBAL SHOULD CONTACT THEIR LOCAL FM GLOBAL OFFICE BEFORE BEGINNING ANY ROOFING WORK.**

**Table of Contents**

Page
1.0 SCOPE ..... 5
1.1 Changes ..... 5
1.2 Hazard ..... 5
2.0 LOSS PREVENTION RECOMMENDATIONS ..... 6
2.1 Design Wind Pressures ..... 6
2.2 Exterior Walls ..... 8
2.3 Section Reserved for Future Use ..... 8
2.4 Opening Protectives in Exterior Walls ..... 8
2.4.1 Exterior Doors ..... 8
2.4.2 Windows in Exterior Walls ..... 9

**1.1 Changes**

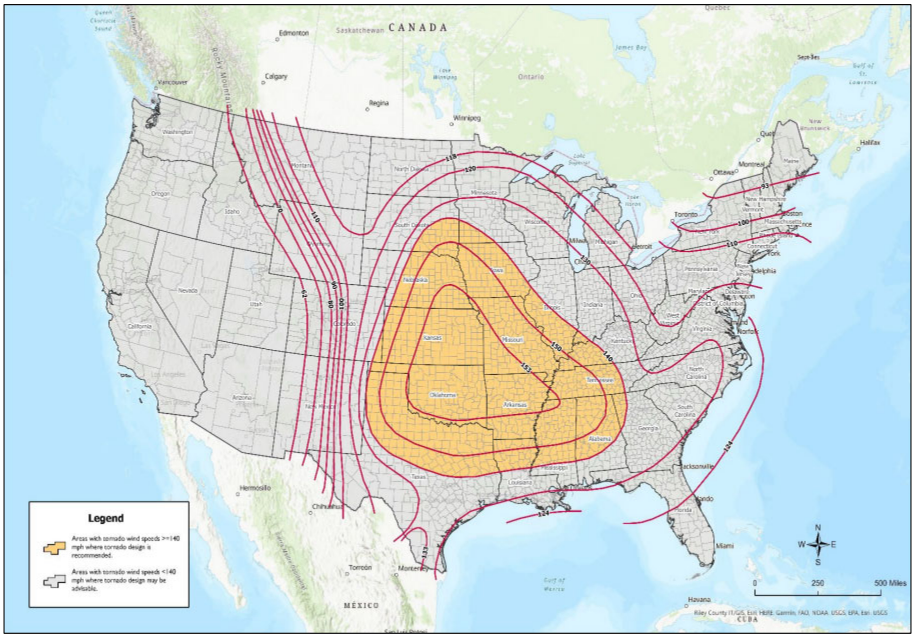
**January 2024.** Interim revision. The following changes were made:

A. The tornado guidance formerly in Appendix D has been transferred to new Sections 2.11 and 3.12, and to existing Section 4.2. All tables, figures and equations have been re-numbered to the new sections. Appendix D has been deleted in its entirety.

Typhoons and Cyclones ..... 17
3.2 Wind Pressure Determination ..... 18
3.2.1 Calculating Basic Wind Pressure ..... 18
3.2.2 Wind Zones of Buildings ..... 19
3.2.3 Determining Surface Roughness Exposure ..... 26
3.2.4 Building Enclosure Classification ..... 26
3.2.5 Topographic Factor ($K_{ZT}$) ..... 28
3.2.6 Velocity Pressure Coefficient ($K_Z$) ..... 28
3.2.7 Importance Factor ..... 29
3.3 Section Reserved for Future Use ..... 29
3.4 Wind Design Pressures for Less-Common Roof Shapes ..... 29
3.4.1 Steep-Slope, Mono-Slope, and Shed Roofs ..... 29
3.4.2 Steep-Slope Saw-Tooth Roofs ..... 29
3.4.3 Arched Roofs ..... 30
3.4.4 Domed Roofs ..... 35
3.4.5 Steep-Slope Multi-Span Gabled Roofs ..... 36
3.4.6 Gabled Roofs with Slopes Greater than 45° ..... 36
3.5 Wind Ratings for FM Approved Roof and Wall Assemblies ..... 37
3.5.1 FM Approved Roof Assemblies ..... 37
3.5.2 FM Approved Exterior Wall Assemblies ..... 38
3.5.3 Windborne Debris Ratings ..... 39

©2015-2024 Factory Mutual Insurance Company. All rights reserved. No part of this document may be reproduced, stored in a retrieval system, or transmitted, in whole or in part, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without written permission of Factory Mutual Insurance Company.

38



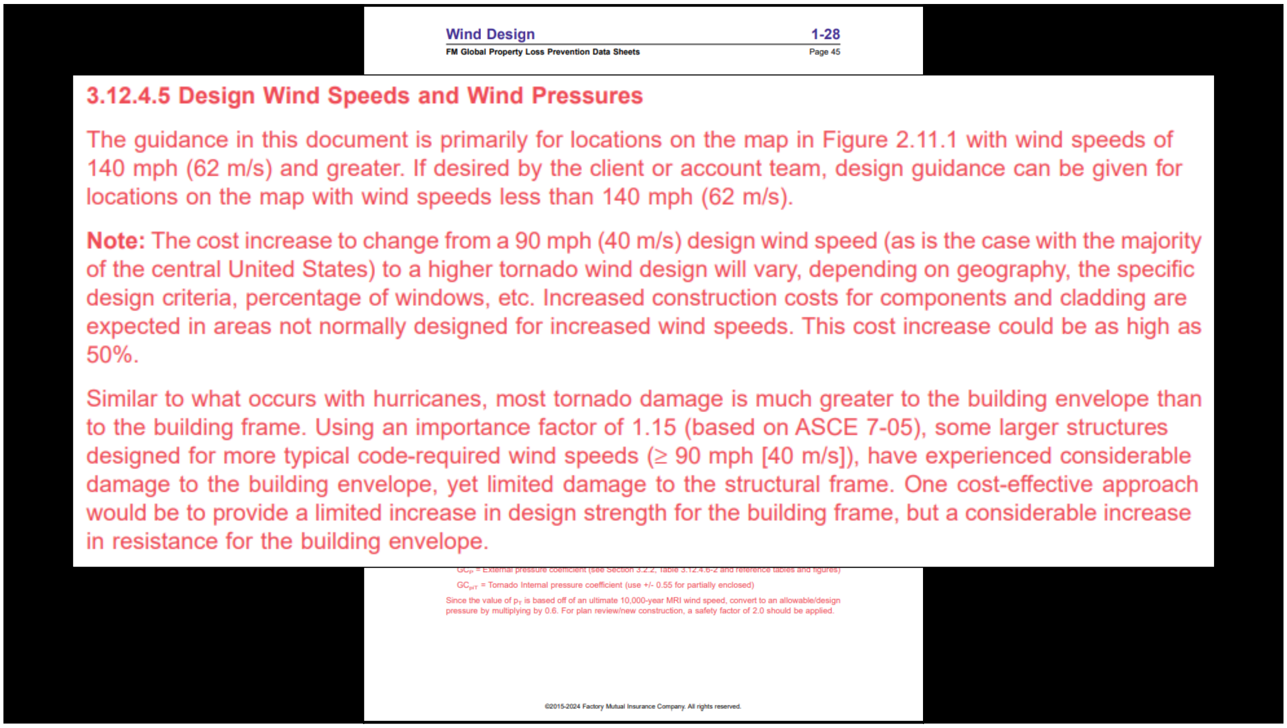

39

## Tornado design recommendations

FM 1-28, Sec. 2.11-Tornados

- Assume "partially enclosed" and Exposure C
- Avoid the use of windows
  - When windows are provided, use FM 4350 Level D or E impact-resistant glazing
- Limit other exterior wall openings (e.g., doors)
  - Doors should open outward and have positive latching
- Do not use aggregate on roofs
- Consider full-time QAO during exterior wall and roof application

40



**Wind Design** 1-28

FM Global Property Loss Prevention Data Sheets Page 45

**3.12.4.5 Design Wind Speeds and Wind Pressures**

The guidance in this document is primarily for locations on the map in Figure 2.11.1 with wind speeds of 140 mph (62 m/s) and greater. If desired by the client or account team, design guidance can be given for locations on the map with wind speeds less than 140 mph (62 m/s).

**Note:** The cost increase to change from a 90 mph (40 m/s) design wind speed (as is the case with the majority of the central United States) to a higher tornado wind design will vary, depending on geography, the specific design criteria, percentage of windows, etc. Increased construction costs for components and cladding are expected in areas not normally designed for increased wind speeds. This cost increase could be as high as 50%.

Similar to what occurs with hurricanes, most tornado damage is much greater to the building envelope than to the building frame. Using an importance factor of 1.15 (based on ASCE 7-05), some larger structures designed for more typical code-required wind speeds (≥ 90 mph [40 m/s]), have experienced considerable damage to the building envelope, yet limited damage to the structural frame. One cost-effective approach would be to provide a limited increase in design strength for the building frame, but a considerable increase in resistance for the building envelope.

$GC_{p}$ = External pressure coefficient (see Section 3.2.2, Table 3.12.4.6-2 and reference tables and figures)

$GC_{piT}$ = Tornado Internal pressure coefficient (use +/- 0.55 for partially enclosed)

Since the value of $p_T$ is based off of an ultimate 10,000-year MRI wind speed, convert to an allowable/design pressure by multiplying by 0.6. For plan review/new construction, a safety factor of 2.0 should be applied.



41

***FM Global's tornado design provisions are more stringent than IBC 2024's and ASCE 7-22's***

42

# Some useful references

Tornado design

43

FEMA/NIST Design Guide

## Design Guide for New Tornado Load Requirements in ASCE 7-22

This instructional guidance is for design professionals and building officials to help them determine when a building or other structure is required to be designed to minimum tornado loads and how to calculate design tornado forces. This guide is in accordance with the updated requirements of the American Society of Civil Engineers (ASCE) / Structural Engineering Institute (SEI) standard ASCE 7-22, ***Minimum Design Loads and Associated Criteria for Buildings and Other Structures.***[1]

This Design Guide is intended for users with a basic understanding of ASCE 7 and who know how to determine wind loads using ASCE 7 methodology, as presented in Chapters 26 through 31.

### Introduction and Background

Tornadoes have historically killed more people in the United States than hurricanes and earthquakes combined (NWS, 2020; USGS, 2015). According to the Insurance Information Institute, Inc. (2020), the average annual insured catastrophe losses for events involving tornadoes exceeded those for both hurricanes and tropical storms combined, for the period of 1997–2016. The 2011 Joplin tornado disaster was the deadliest and costliest tornado in the U.S. since 1950 and was one of the primary drivers for the addition of tornado load provisions in ASCE 7 (NIST, 2022). With the publication of ASCE 7-22 (ASCE; 2021), tornado load requirements are now considered as a minimum design load in conventional building design when buildings are located in tornado-prone areas. The new ASCE 7 tornado load provisions do not apply to storm shelters or safe rooms. The ASCE 7 tornado load requirements will be included in the 2024 International Building Code (IBC), the 2024 National Fire Protection Association (NFPA) 5000 Building Construction and Safety Code, and the 2023 Florida Building Code. The adoption of the ASCE 7 tornado load provisions by the State of Florida is an example of local Authorities Having Jurisdiction incorporating the most current design guidance prior to their inclusion in the model building codes.

**Storm shelters and safe rooms** are specifically designed for life safety protection during the most extreme wind events and require more extreme design hazard intensities than conventional buildings. Buildings and other structures designed per Chapter 32 of ASCE 7 do not meet the requirements for storm shelters or safe rooms.

[1] The references to ASCE 7 within the design guide represent references to ASCE 7-22.

FEMA NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY U.S. DEPARTMENT OF COMMERCE

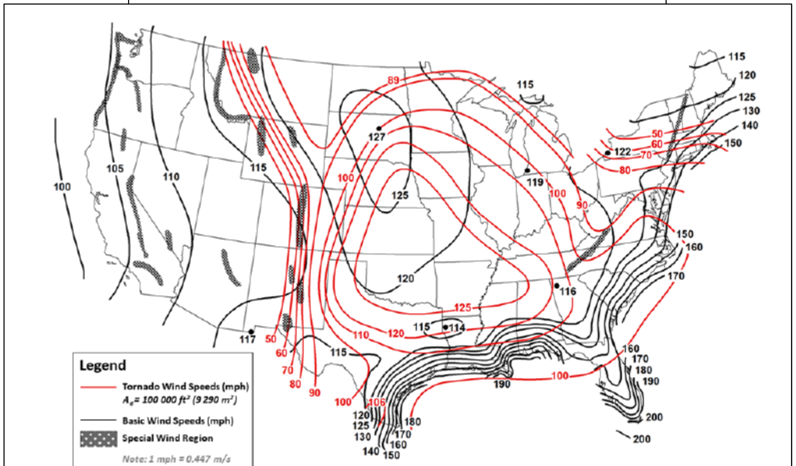
January 2023 - 1

Link

44

NIST Technical Note 2214

**Economic Analysis of ASCE 7-22 Tornado Load Requirements**




Basic wind speeds shown are based on Risk Category IV

[Link]

45



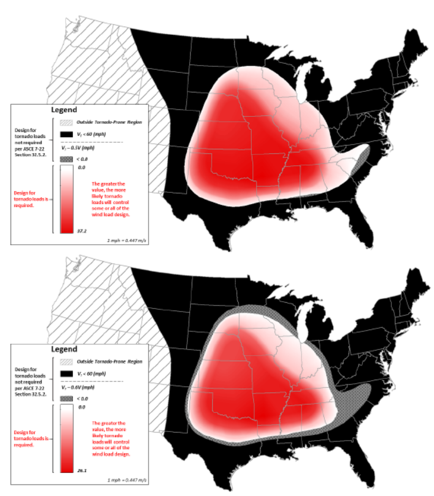



**Fig. 8.** Map of likelihood that design for tornado loads is required for a Risk Category III $A_e$ = 100 000 ft² (9290 m²) building or other structure in Exposure B (top) and Exposure C (bottom)

18

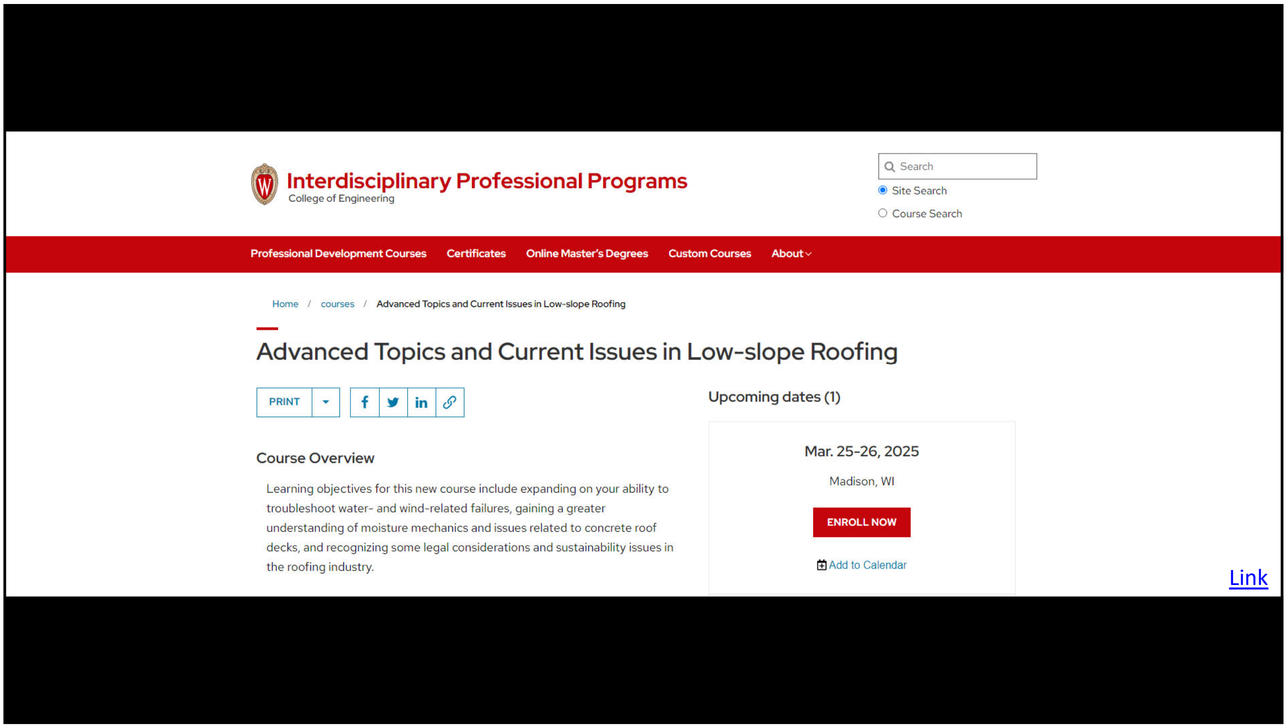
46

***Other topics and questions…***

47


Link

48




49

**Mark S. Graham**
Vice President, Technical Services
National Roofing Contractors Association
10255 West Higgins Road, 600
Rosemont, Illinois 60018-5607

(847) 299-9070
mgraham@nrca.net
www.nrca.net

Personal website: www.MarkGrahamNRCA.com
LinkedIn: linkedin.com/in/MarkGrahamNRCA

50