Webinar
September 16, 2016

Wind design for low-slope roof assemblies

presented by

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

Topics

- Reference documents
- Fundamentals
- Code requirements
- ASCE 7
- Roof Wind Designer
- Additional resources
- Questions

2

Reference documents – "the acronyms"

Wind design

American Society of Civil Engineers (ASCE)

- ASCE 7, "Minimum Design Loads for Buildings and Other Structures"

International Code Council (ICC):

- *International Building Code* (IBC)

FM Global:

- Loss Prevention Data Sheet 1-28, "Design Wind Loads"
- Loss Prevention Data Sheet 1-29, "Roof Deck Securement and Above-deck Roof Components"

3

Reference documents -- continued

Wind design

FM Approvals (a subsidiary of FM Global)

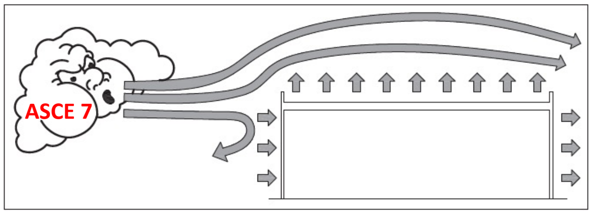
- Approval classifications: 1-60, 1-90, 1-120, etc.
- RoofNav (www.roofnav.com)

Underwriters Laboratories (UL):

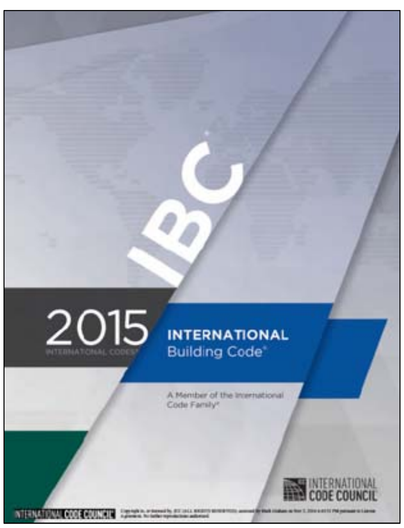
- Fire classifications: Class A, Class B and Class C
- Wind classifications: Class 30, Class 60, Class 90
- Impact (hail) classifications: Class I to IV
- Online certifications directory (www.ul.com)

4

The fundamental concept



Wind creates pressures/forces
on building elements



The Code establishes <u>minimum</u> requirements for building construction (and reroofing)

IBC 2015:
- Ch. 15-Roof Assemblies
  - Sec. 1511-Reroofing
- Ch. 16-Structural Design
  - Sec. 1609-Wind Loads

SECTION 1504
PERFORMANCE REQUIREMENTS

1504.1 Wind resistance of roofs. Roof decks and roof coverings shall be designed for wind loads in accordance with Chapter 16 and Sections 1504.2, 1504.3 and 1504.4.

1504.3 Wind resistance of nonballasted roofs. Roof coverings installed on roofs in accordance with Section 1507 that are mechanically attached or adhered to the roof deck shall be designed to resist the design wind load pressures for components and cladding in accordance with Section 1609.

1504.3.1 Other roof systems. Built-up, modified bitumen, fully adhered or mechanically attached single-ply roof systems, metal panel roof systems applied to a solid or closely fitted deck and other types of membrane roof coverings shall be tested in accordance with FM 4474, UL 580 or UL 1897.

1504.5 Edge securement for low-slope roofs. Low-slope built-up, modified bitumen and single-ply roof system metal edge securement, except gutters, shall be designed and installed for wind loads in accordance with Chapter 16 and tested for resistance in accordance with Test Methods RE-1, RE-2 and RE-3 of ANSI/SPRI ES-1, except V_{ult} wind speed shall be determined from Figure 1609A, 1609B, or 1609C as applicable.

7

1609.5 Roof systems. Roof systems shall be designed and constructed in accordance with Sections 1609.5.1 through 1609.5.3, as applicable.

1609.5.1 Roof deck. The roof deck shall be designed to with~~stand the~~ wind pressures determined in accordance with ASCE 7.

1609.5.2 Roof coverings. Roof coverings shall comply with Section 1609.5.1.

Exception: Rigid tile roof coverings that are air permeable and installed over a roof deck complying with Section 1609.5.1 are permitted to be designed in accordance with Section 1609.5.3.

Asphalt shingles installed over a roof deck complying with Section 1609.5.1 shall comply with the wind-resistance requirements of Section 1504.1.1.

1609.5.3 Rigid tile. Wind loads on rigid tile roof coverings shall be determined in accordance with the following equation:

$$M_a = q_h C_L b L L_a [1.0 - GC_p] \quad \textbf{(Equation 16-34)}$$

8

SECTION 1603
CONSTRUCTION DOCUMENTS

1603.1 General. *Construction documents* shall show the size, section and relative locations of structural members with floor levels, column centers and offsets dimensioned. The design loads and other information pertinent to the structural design required by Sections 1603.1.1 through 1603.1.8 shall be indicated on the *construction documents*.

1603.1.4 Wind design data. The following information related to wind loads shall be shown, regardless of whether wind loads govern the design of the lateral force-resisting system of the structure:

1. Ultimate design wind speed, V_{ult}, (3-second gust), miles per hour (km/hr) and nominal design wind speed, V_{asd}, as determined in accordance with Section 1609.3.1.
2. *Risk category*.
3. Wind exposure. Applicable wind direction if more than one wind exposure is utilized.
4. Applicable internal pressure coefficient.
5. Design wind pressures to be used for exterior component and cladding materials not specifically designed by the *registered design professional* responsible for the design of the structure, psf (kN/m^2).

9

Fundamental premise

Wind resistance ≥ Design wind load

FM or UL rating ≥ ASCE 7

10

ASCE 7-10, "Minimum Design Loads for buildings and Other Structures"

11

Fundamental pressure equation

ASCE 7-10, Equation 30.3-1

$$q_h = 0.00256\ (K_z)\ (K_{zt})\ (K_d)\ (V^2)$$

Where:

K_d = wind directionality factor

K_z = velocity pressure exposure coefficient

K_{zt} = topographic factor

V = wind speed (mph)

q_h = velocity pressure (psf)

12

ASCE 7-10

Wind loads

- Ch. 26: Wind loads: General Requirements
- Ch. 30: Wind loads – Components & Cladding
  - Part 1: Low-rise buildings (h ≤ 60 ft.)
  - Part 2: Low-rise buildings (h ≤ 60 ft.) (Simplified)
  - Part 3: Buildings with h > 60 ft.
  - Part 4: Buildings with h ≤ 160 ft. (Simplified)
  - Part 5: Open buildings
  - Part 6: Building apprutenances and rooftop structures and equipment
- Ch. 31: Wind Tunnel Procedure

13

Design parameters

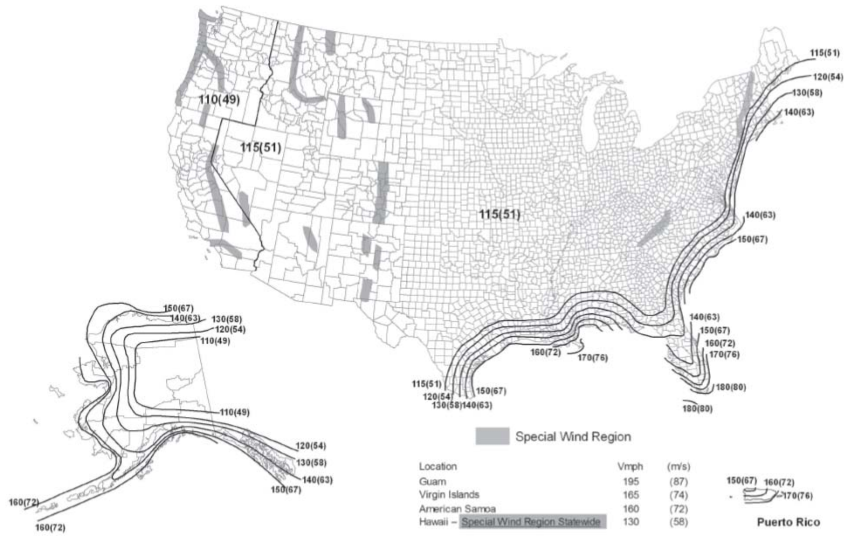
For the "Simplified procedures" (Part 2 and Part 4)

- Mean roof height (h)
- Enclosed building
- Wind-borne debris region (hurricane coastline)
- Regular-shaped building
- Topographical factor (K_{zt})
- Risk Category (Occupancy Category II most common)
- Basic wind speed (map)
- Exposure Category (Exposure C most common)
- Effective wind area (assume 10 ft^2)
- Wind zones (GC_p)

14

Basic wind speed

ASCE 7-10, Occupancy Category II Buildings



15

Pressure coefficients (GC_p)

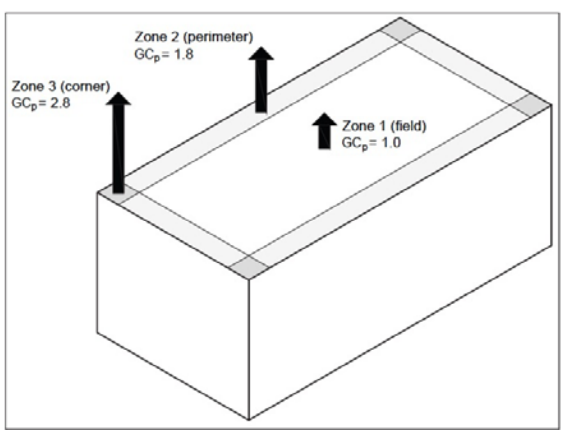


Illustration based upon ASCE 7-10, Fig. 30.4-2A (θ ≤ 7°); Effective wind area = 10 ft^2

16

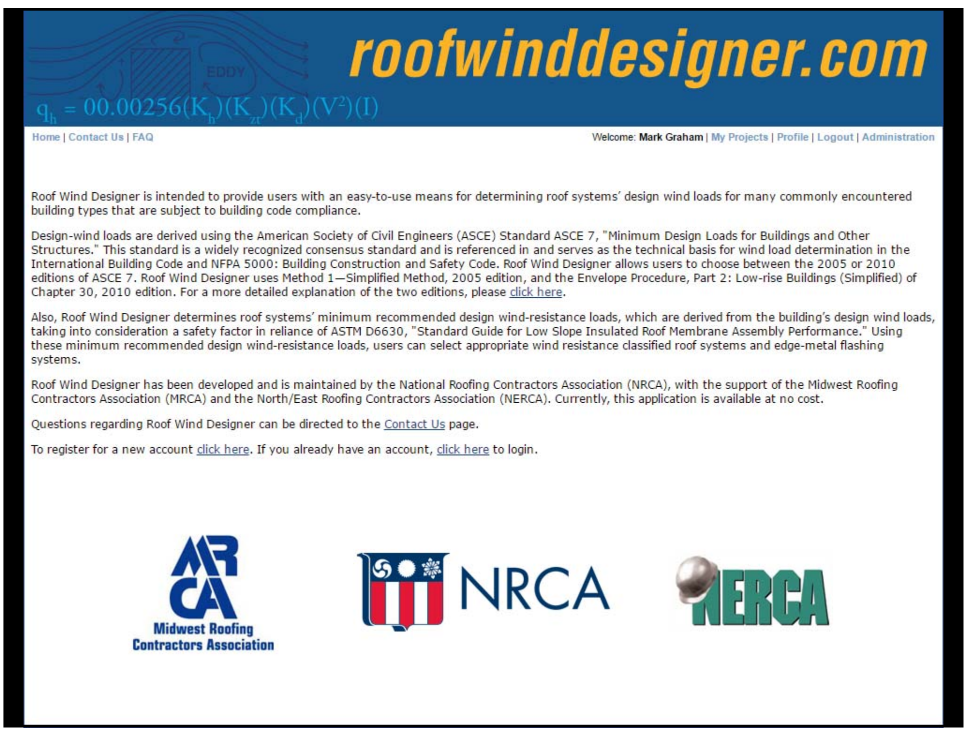
ASCE 7-10

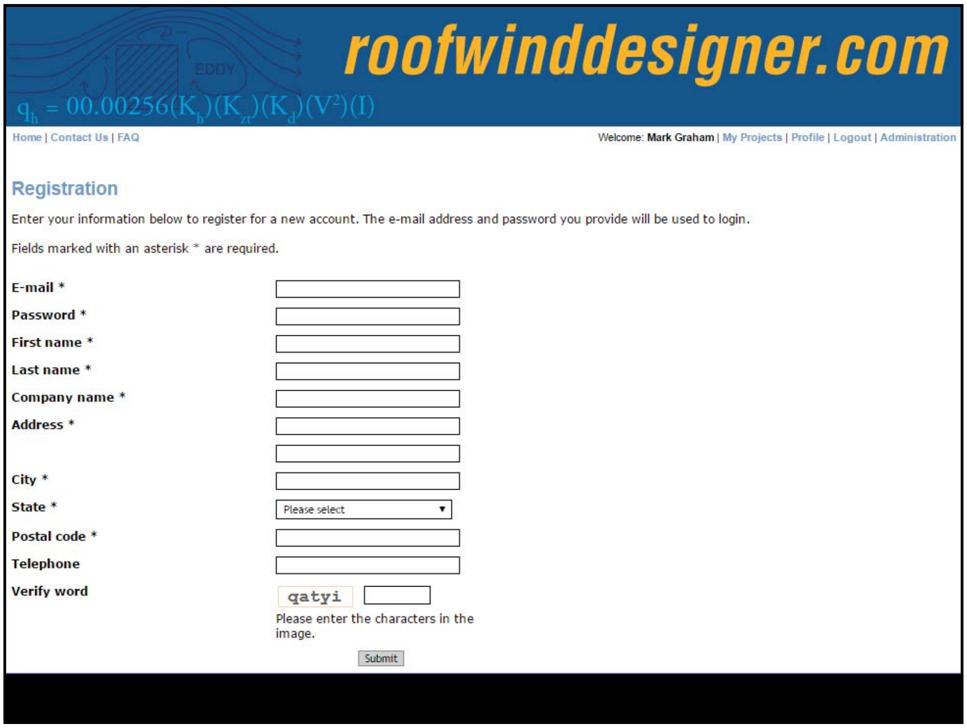
Strength design method vs. Allowable stress method

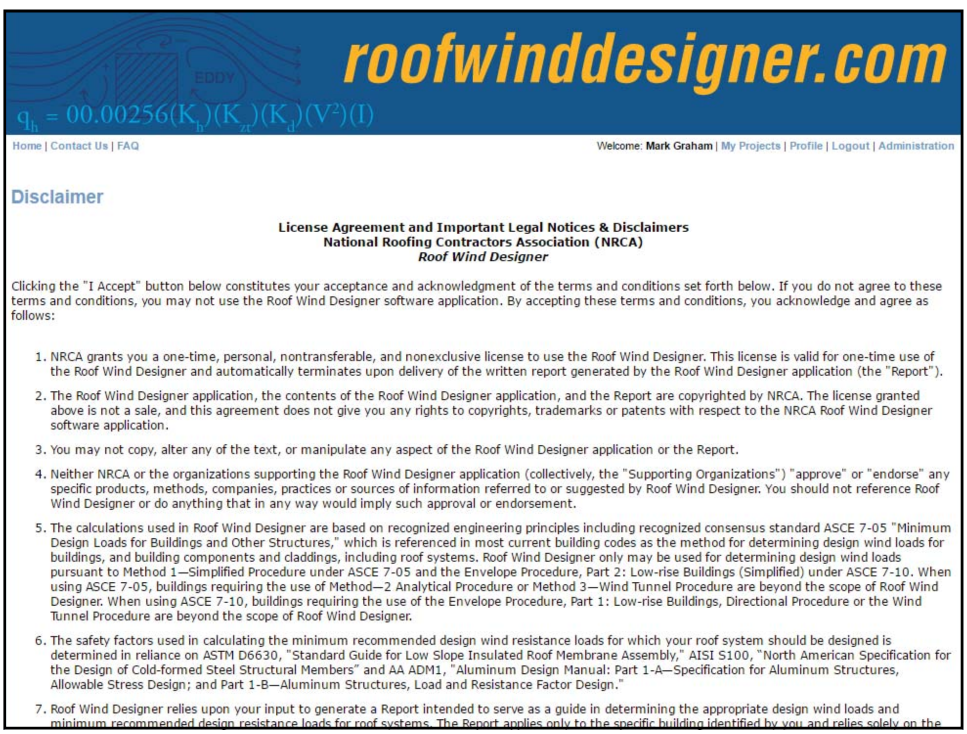
- ASCE 7-10 is based upon the strength design method
  - Increased wind speeds on map
  - Load factor of 1.6
- ASCE 7-10 allows for conversion of allowable stress design (ASD) method:

  ASD value = Strength design value x 0.6
- ASCE 7-05 and previous editions were based upon the ASD method

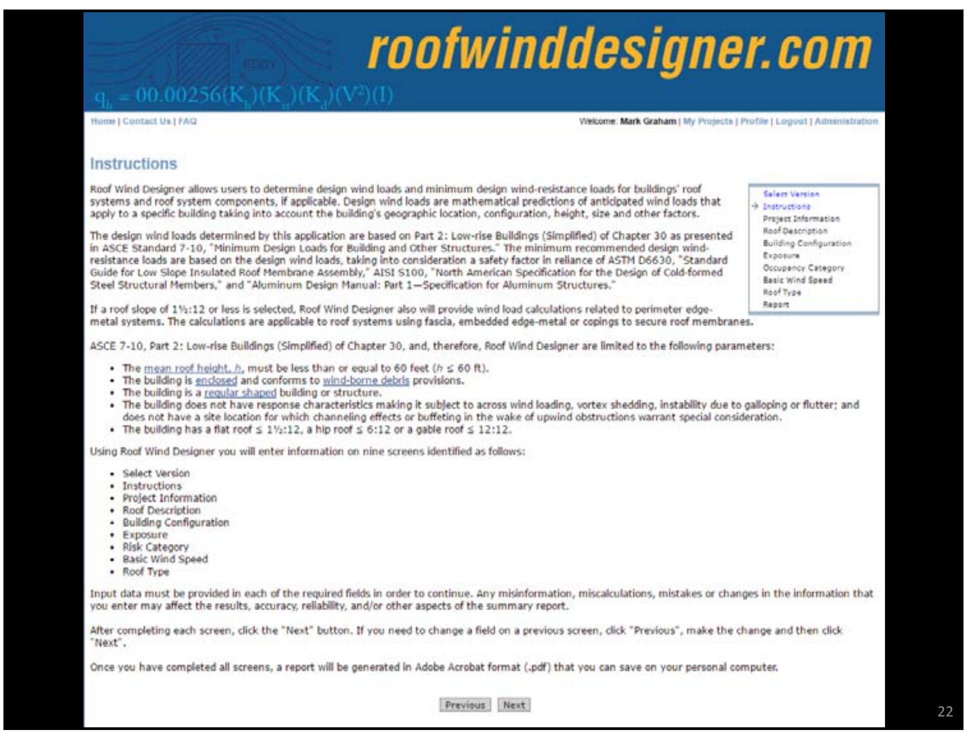
17

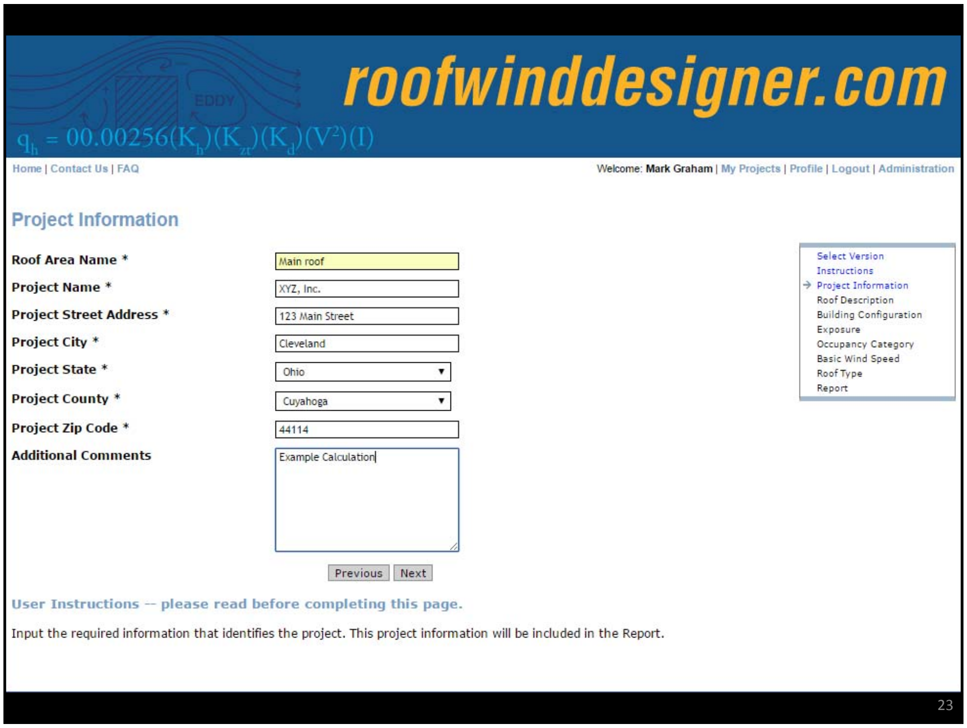


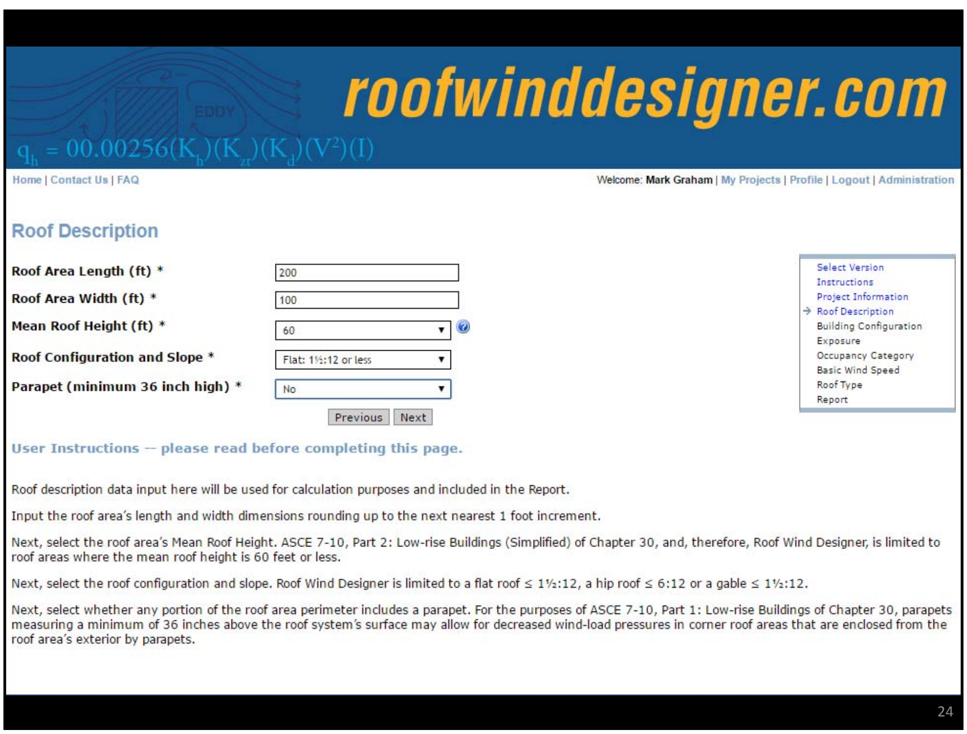

roofwinddesigner.com
$q_h = 00.00256(K_h)(K_{zt})(K_d)(V^2)(I)$
Home | Contact Us | FAQ
Welcome: Mark Graham | My Projects | Profile | Logout | Administration
Registration
Enter your information below to register for a new account. The e-mail address and password you provide will be used to login.
Fields marked with an asterisk * are required.
E-mail *
Password *
First name *
Last name *
Company name *
Address *
City *
State *
Please select
Postal code *
Telephone
Verify word
qatyi
Please enter the characters in the image.
Submit

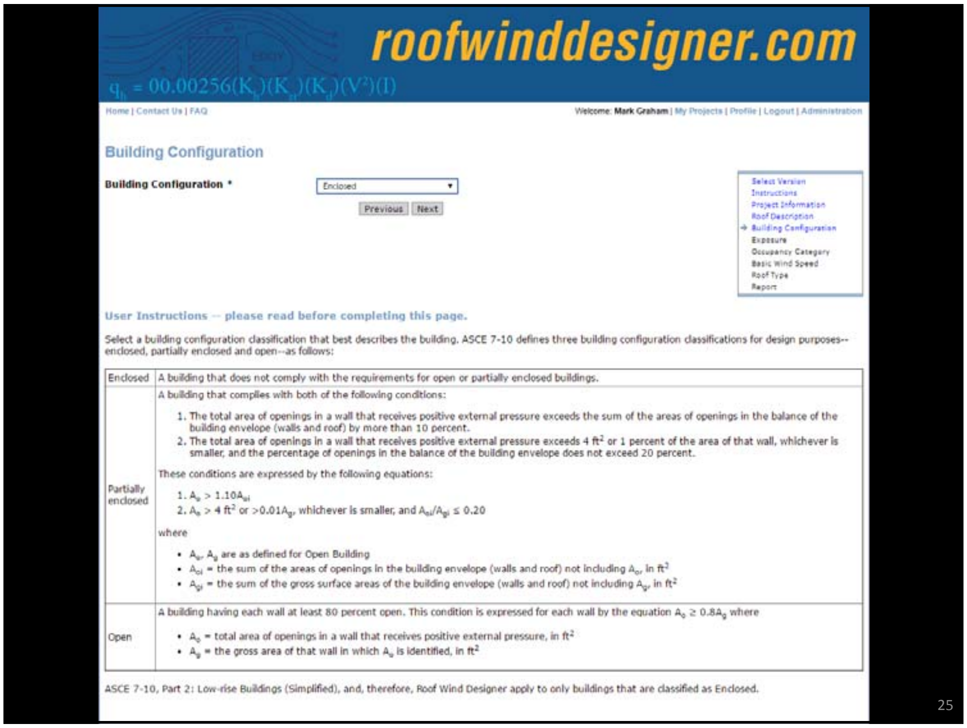

roofwinddesigner.com
$q_h = 00.00256(K_h)(K_{zt})(K_d)(V^2)(I)$
Home | Contact Us | FAQ
Welcome: Mark Graham | My Projects | Profile | Logout | Administration
Disclaimer
License Agreement and Important Legal Notices & Disclaimers
National Roofing Contractors Association (NRCA)
Roof Wind Designer
Clicking the "I Accept" button below constitutes your acceptance and acknowledgment of the terms and conditions set forth below. If you do not agree to these terms and conditions, you may not use the Roof Wind Designer software application. By accepting these terms and conditions, you acknowledge and agree as follows:
1. NRCA grants you a one-time, personal, nontransferable, and nonexclusive license to use the Roof Wind Designer. This license is valid for one-time use of the Roof Wind Designer and automatically terminates upon delivery of the written report generated by the Roof Wind Designer application (the "Report").
2. The Roof Wind Designer application, the contents of the Roof Wind Designer application, and the Report are copyrighted by NRCA. The license granted above is not a sale, and this agreement does not give you any rights to copyrights, trademarks or patents with respect to the NRCA Roof Wind Designer software application.
3. You may not copy, alter any of the text, or manipulate any aspect of the Roof Wind Designer application or the Report.
4. Neither NRCA or the organizations supporting the Roof Wind Designer application (collectively, the "Supporting Organizations") "approve" or "endorse" any specific products, methods, companies, practices or sources of information referred to or suggested by Roof Wind Designer. You should not reference Roof Wind Designer or do anything that in any way would imply such approval or endorsement.
5. The calculations used in Roof Wind Designer are based on recognized engineering principles including recognized consensus standard ASCE 7-05 "Minimum Design Loads for Buildings and Other Structures," which is referenced in most current building codes as the method for determining design wind loads for buildings, and building components and claddings, including roof systems. Roof Wind Designer only may be used for determining design wind loads pursuant to Method 1—Simplified Procedure under ASCE 7-05 and the Envelope Procedure, Part 2: Low-rise Buildings (Simplified) under ASCE 7-10. When using ASCE 7-05, buildings requiring the use of Method—2 Analytical Procedure or Method 3—Wind Tunnel Procedure are beyond the scope of Roof Wind Designer. When using ASCE 7-10, buildings requiring the use of the Envelope Procedure, Part 1: Low-rise Buildings, Directional Procedure or the Wind Tunnel Procedure are beyond the scope of Roof Wind Designer.
6. The safety factors used in calculating the minimum recommended design wind resistance loads for which your roof system should be designed is determined in reliance on ASTM D6630, "Standard Guide for Low Slope Insulated Roof Membrane Assembly," AISI S100, "North American Specification for the Design of Cold-formed Steel Structural Members" and AA ADM1, "Aluminum Design Manual: Part 1-A—Specification for Aluminum Structures, Allowable Stress Design; and Part 1-B—Aluminum Structures, Load and Resistance Factor Design."
7. Roof Wind Designer relies upon your input to generate a Report intended to serve as a guide in determining the appropriate design wind loads and minimum recommended design resistance loads for roof systems. The Report applies only to the specific building identified by you and relies solely on the


roofwinddesigner.com
$q_h = 00.00256(K_h)(K_{zt})(K_d)(V^2)(I)$
Home | Contact Us | FAQ
Welcome: Mark Graham | My Projects | Profile | Logout | Administration
Select Version
Select the design version for this project.
ASCE 7 version *
ASCE 7-10
Previous
Next
Select Version
Instructions
Project Information
Roof Description
Building Configuration
Exposure
Occupancy Category
Basic Wind Speed
Roof Type
Report
21

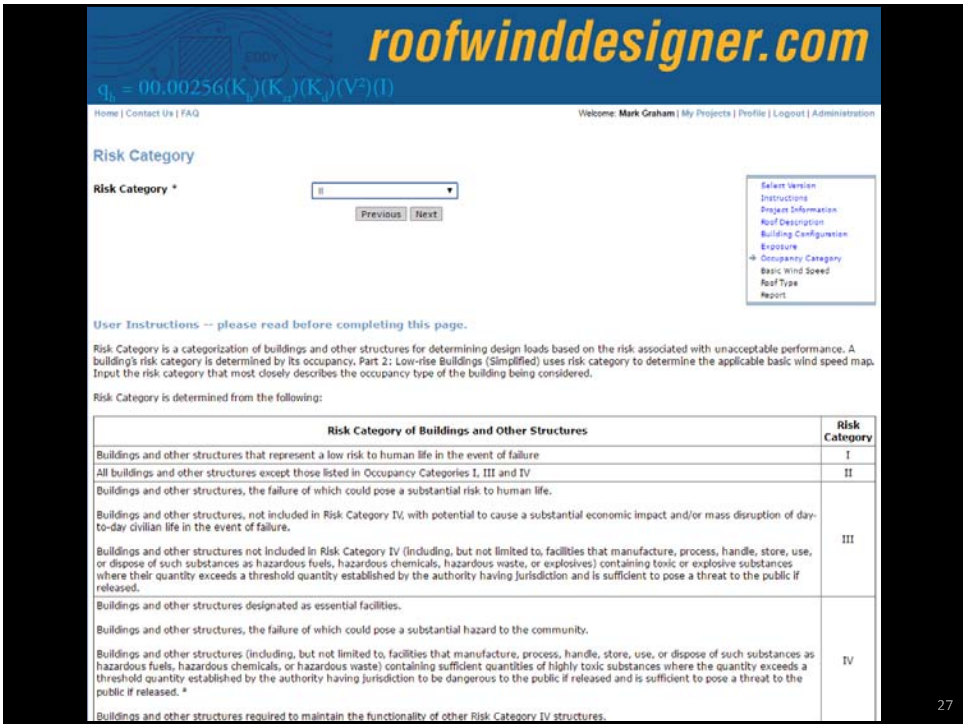

roofwinddesigner.com
$q_h = 00.00256(K_h)(K_{zt})(K_d)(V^2)(I)$
Home | Contact Us | FAQ
Welcome: Mark Graham | My Projects | Profile | Logout | Administration
Instructions
Roof Wind Designer allows users to determine design wind loads and minimum design wind-resistance loads for buildings' roof systems and roof system components, if applicable. Design wind loads are mathematical predictions of anticipated wind loads that apply to a specific building taking into account the building's geographic location, configuration, height, size and other factors.
The design wind loads determined by this application are based on Part 2: Low-rise Buildings (Simplified) of Chapter 30 as presented in ASCE Standard 7-10, "Minimum Design Loads for Building and Other Structures." The minimum recommended design wind-resistance loads are based on the design wind loads, taking into consideration a safety factor in reliance of ASTM D6630, "Standard Guide for Low Slope Insulated Roof Membrane Assembly," AISI S100, "North American Specification for the Design of Cold-formed Steel Structural Members," and "Aluminum Design Manual: Part 1—Specification for Aluminum Structures."
If a roof slope of 1½:12 or less is selected, Roof Wind Designer also will provide wind load calculations related to perimeter edge-metal systems. The calculations are applicable to roof systems using fascia, embedded edge-metal or copings to secure roof membranes.
ASCE 7-10, Part 2: Low-rise Buildings (Simplified) of Chapter 30, and, therefore, Roof Wind Designer are limited to the following parameters:
• The mean roof height, h, must be less than or equal to 60 feet ($h \leq 60$ ft).
• The building is enclosed and conforms to wind-borne debris provisions.
• The building is a regular shaped building or structure.
• The building does not have response characteristics making it subject to across wind loading, vortex shedding, instability due to galloping or flutter; and does not have a site location for which channeling effects or buffeting in the wake of upwind obstructions warrant special consideration.
• The building has a flat roof ≤ 1½:12, a hip roof ≤ 6:12 or a gable roof ≤ 12:12.
Using Roof Wind Designer you will enter information on nine screens identified as follows:
• Select Version
• Instructions
• Project Information
• Roof Description
• Building Configuration
• Exposure
• Risk Category
• Basic Wind Speed
• Roof Type
Input data must be provided in each of the required fields in order to continue. Any misinformation, miscalculations, mistakes or changes in the information that you enter may affect the results, accuracy, reliability, and/or other aspects of the summary report.
After completing each screen, click the "Next" button. If you need to change a field on a previous screen, click "Previous", make the change and then click "Next".
Once you have completed all screens, a report will be generated in Adobe Acrobat format (.pdf) that you can save on your personal computer.
Previous
Next
Select Version
Instructions
Project Information
Roof Description
Building Configuration
Exposure
Occupancy Category
Basic Wind Speed
Roof Type
Report
22


roofwinddesigner.com
$q_h = 00.00256(K_h)(K_{zt})(K_d)(V^2)(I)$
EDDY
Home | Contact Us | FAQ
Welcome: Mark Graham | My Projects | Profile | Logout | Administration
Project Information
Roof Area Name * Main roof
Project Name * XYZ, Inc.
Project Street Address * 123 Main Street
Project City * Cleveland
Project State * Ohio
Project County * Cuyahoga
Project Zip Code * 44114
Additional Comments Example Calculation
Previous Next
User Instructions -- please read before completing this page.
Input the required information that identifies the project. This project information will be included in the Report.
Select Version
Instructions
Project Information
Roof Description
Building Configuration
Exposure
Occupancy Category
Basic Wind Speed
Roof Type
Report
23


roofwinddesigner.com
$q_h = 00.00256(K_h)(K_{zt})(K_d)(V^2)(I)$
EDDY
Home | Contact Us | FAQ
Welcome: Mark Graham | My Projects | Profile | Logout | Administration
Roof Description
Roof Area Length (ft) * 200
Roof Area Width (ft) * 100
Mean Roof Height (ft) * 60
Roof Configuration and Slope * Flat: 1½:12 or less
Parapet (minimum 36 inch high) * No
Previous Next
User Instructions -- please read before completing this page.
Roof description data input here will be used for calculation purposes and included in the Report.
Input the roof area's length and width dimensions rounding up to the next nearest 1 foot increment.
Next, select the roof area's Mean Roof Height. ASCE 7-10, Part 2: Low-rise Buildings (Simplified) of Chapter 30, and, therefore, Roof Wind Designer, is limited to roof areas where the mean roof height is 60 feet or less.
Next, select the roof configuration and slope. Roof Wind Designer is limited to a flat roof ≤ 1½:12, a hip roof ≤ 6:12 or a gable ≤ 1½:12.
Next, select whether any portion of the roof area perimeter includes a parapet. For the purposes of ASCE 7-10, Part 1: Low-rise Buildings of Chapter 30, parapets measuring a minimum of 36 inches above the roof system's surface may allow for decreased wind-load pressures in corner roof areas that are enclosed from the roof area's exterior by parapets.
Select Version
Instructions
Project Information
Roof Description
Building Configuration
Exposure
Occupancy Category
Basic Wind Speed
Roof Type
Report
24


roofwinddesigner.com
q_h = 00.00256(K_h)(K_{zt})(K_d)(V^2)(I)
Home | Contact Us | FAQ
Welcome: Mark Graham | My Projects | Profile | Logout | Administration
Building Configuration
Building Configuration *
Enclosed
Previous Next
Select Version
Instructions
Project Information
Roof Description
Building Configuration
Exposure
Occupancy Category
Basic Wind Speed
Roof Type
Report
User Instructions -- please read before completing this page.
Select a building configuration classification that best describes the building. ASCE 7-10 defines three building configuration classifications for design purposes--enclosed, partially enclosed and open--as follows:
Enclosed
A building that does not comply with the requirements for open or partially enclosed buildings.
Partially enclosed
A building that complies with both of the following conditions:
1. The total area of openings in a wall that receives positive external pressure exceeds the sum of the areas of openings in the balance of the building envelope (walls and roof) by more than 10 percent.
2. The total area of openings in a wall that receives positive external pressure exceeds 4 ft^2 or 1 percent of the area of that wall, whichever is smaller, and the percentage of openings in the balance of the building envelope does not exceed 20 percent.
These conditions are expressed by the following equations:
1. $A_o > 1.10A_{oi}$
2. $A_o > 4\ ft^2$ or $>0.01A_g$, whichever is smaller, and $A_{oi}/A_{gi} \le 0.20$
where
• A_o, A_g are as defined for Open Building
• A_{oi} = the sum of the areas of openings in the building envelope (walls and roof) not including A_o, in ft^2
• A_{gi} = the sum of the gross surface areas of the building envelope (walls and roof) not including A_g, in ft^2
Open
A building having each wall at least 80 percent open. This condition is expressed for each wall by the equation $A_o \ge 0.8A_g$ where
• A_o = total area of openings in a wall that receives positive external pressure, in ft^2
• A_g = the gross area of that wall in which A_o is identified, in ft^2
ASCE 7-10, Part 2: Low-rise Buildings (Simplified), and, therefore, Roof Wind Designer apply to only buildings that are classified as Enclosed.
25


roofwinddesigner.com
q_h = 00.00256(K_h)(K_{zt})(K_d)(V^2)(I)
Home | Contact Us | FAQ
Welcome: Mark Graham | My Projects | Profile | Logout | Administration
Exposure
Exposure *
C
Previous Next
Select Version
Instructions
Project Information
Roof Description
Building Configuration
Exposure
Occupancy Category
Basic Wind Speed
Roof Type
Report
User Instructions -- please read before completing this page.
Exposure is based on surface roughness that is determined by natural topography, vegetation and constructed facilities. ASCE 7-10 has three exposure categories: B, C and D. These are defined as follows:
Exposure B
Exposure B shall apply where the ground surface roughness condition, as defined by Surface Roughness B, prevails in the windward direction for a distance of at least 2,600 feet. For buildings whose mean roof height is less than or equal to 30 feet., the upwind distance may be reduced to 1,500 feet.
Surface Roughness B is defined as urban and suburban areas, wooded areas or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger.
Exposure C
Exposure C shall apply for all cases where Exposures B or D do not apply.
Surface Roughness C applies to open terrain with scattered obstructions having heights generally less than 30 feet. This category includes flat open country and grasslands.
Exposure D
Exposure D shall apply where the ground surface roughness, as defined by Surface Roughness D, prevails in the upwind direction for a distance greater than 5,000 feet. Exposure D shall also apply where the ground surface roughness immediately upward of the site is B or C, and the site is within a distance of 600 feet or 20 times the building height, whichever is greater from an Exposure D condition.
Surface Roughness D is defined as flat, unobstructed areas and water surfaces outside hurricane prone regions. This category includes smooth mud flats, salt flats, and unbroken ice.
Generally, Exposure C applies to most areas of the United States, while Exposure B applies to most urban, suburban and wooded areas, and Exposure D applies to coastline areas.
26



roofwinddesigner.com

$q_h = 00.00256(K_h)(K_{zt})(K_d)(V^2)(I)$

Home | Contact Us | FAQ   Welcome: Mark Graham | My Projects | Profile | Logout | Administration

Risk Category

Risk Category *   II

Previous   Next

Select Version
Instructions
Project Information
Roof Description
Building Configuration
Exposure
→ Occupancy Category
Basic Wind Speed
Roof Type
Report

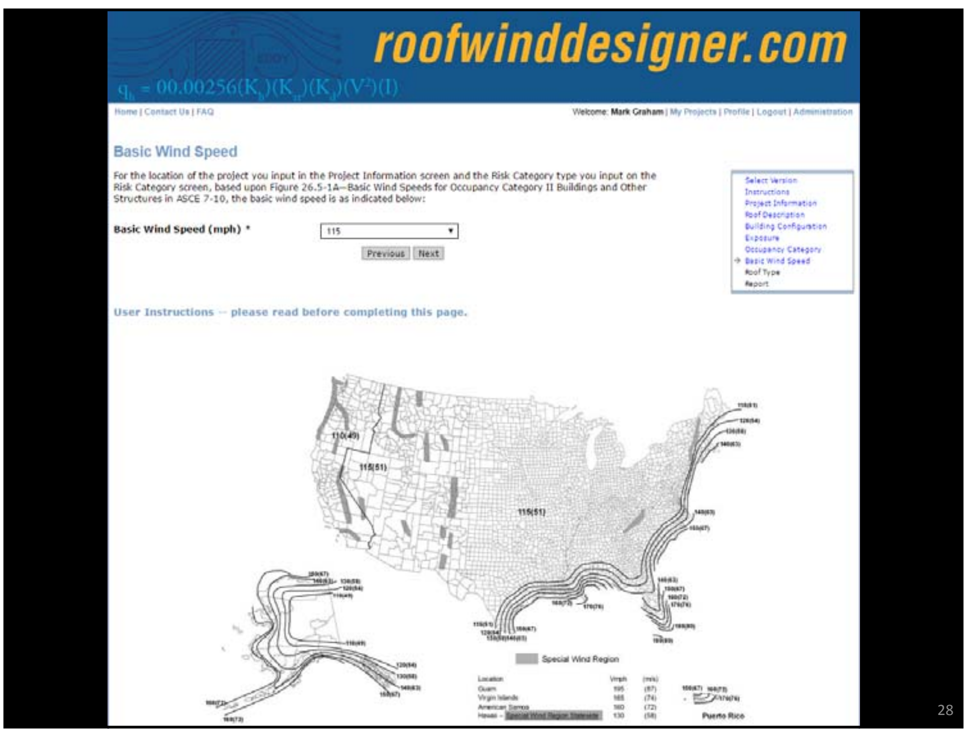
User Instructions -- please read before completing this page.

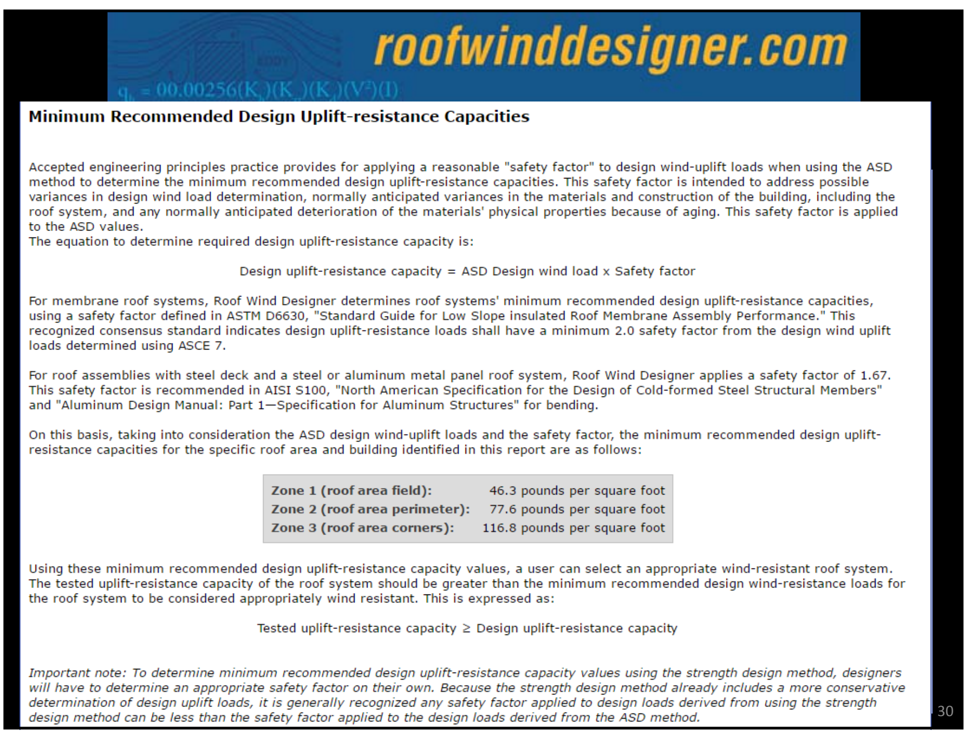
Risk Category is a categorization of buildings and other structures for determining design loads based on the risk associated with unacceptable performance. A building's risk category is determined by its occupancy. Part 2: Low-rise Buildings (Simplified) uses risk category to determine the applicable basic wind speed map. Input the risk category that most closely describes the occupancy type of the building being considered.

Risk Category is determined from the following:

Risk Category of Buildings and Other Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Occupancy Categories I, III and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life. Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure. Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	III
Buildings and other structures designated as essential facilities. Buildings and other structures, the failure of which could pose a substantial hazard to the community. Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released. * Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	IV

27





Minimum Recommended Design Uplift-resistance Capacities

Accepted engineering principles practice provides for applying a reasonable "safety factor" to design wind-uplift loads when using the ASD method to determine the minimum recommended design uplift-resistance capacities. This safety factor is intended to address possible variances in design wind load determination, normally anticipated variances in the materials and construction of the building, including the roof system, and any normally anticipated deterioration of the materials' physical properties because of aging. This safety factor is applied to the ASD values.
The equation to determine required design uplift-resistance capacity is:

Design uplift-resistance capacity = ASD Design wind load x Safety factor

For membrane roof systems, Roof Wind Designer determines roof systems' minimum recommended design uplift-resistance capacities, using a safety factor defined in ASTM D6630, "Standard Guide for Low Slope insulated Roof Membrane Assembly Performance." This recognized consensus standard indicates design uplift-resistance loads shall have a minimum 2.0 safety factor from the design wind uplift loads determined using ASCE 7.

For roof assemblies with steel deck and a steel or aluminum metal panel roof system, Roof Wind Designer applies a safety factor of 1.67. This safety factor is recommended in AISI S100, "North American Specification for the Design of Cold-formed Steel Structural Members" and "Aluminum Design Manual: Part 1—Specification for Aluminum Structures" for bending.

On this basis, taking into consideration the ASD design wind-uplift loads and the safety factor, the minimum recommended design uplift-resistance capacities for the specific roof area and building identified in this report are as follows:

Zone 1 (roof area field):	46.3 pounds per square foot
Zone 2 (roof area perimeter):	77.6 pounds per square foot
Zone 3 (roof area corners):	116.8 pounds per square foot

Using these minimum recommended design uplift-resistance capacity values, a user can select an appropriate wind-resistant roof system. The tested uplift-resistance capacity of the roof system should be greater than the minimum recommended design wind-resistance loads for the roof system to be considered appropriately wind resistant. This is expressed as:

Tested uplift-resistance capacity ≥ Design uplift-resistance capacity

Important note: To determine minimum recommended design uplift-resistance capacity values using the strength design method, designers will have to determine an appropriate safety factor on their own. Because the strength design method already includes a more conservative determination of design uplift loads, it is generally recognized any safety factor applied to design loads derived from using the strength design method can be less than the safety factor applied to the design loads derived from the ASD method.

30

Back to the fundamental premise

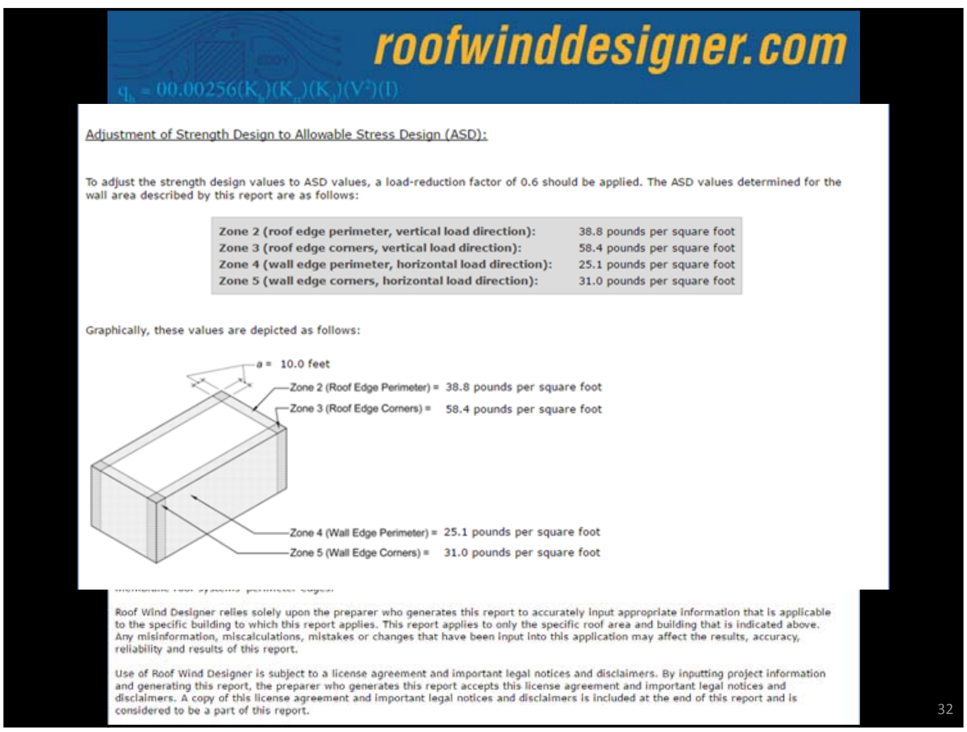
Wind resistance ≥ Design wind load

FM 1-60 ≥ 46.3 psf

or

UL Class 60

31


roofwinddesigner.com

$q_h = 00.00256(K_h)(K_{zt})(K_d)(V^2)(I)$

Adjustment of Strength Design to Allowable Stress Design (ASD):

To adjust the strength design values to ASD values, a load-reduction factor of 0.6 should be applied. The ASD values determined for the wall area described by this report are as follows:

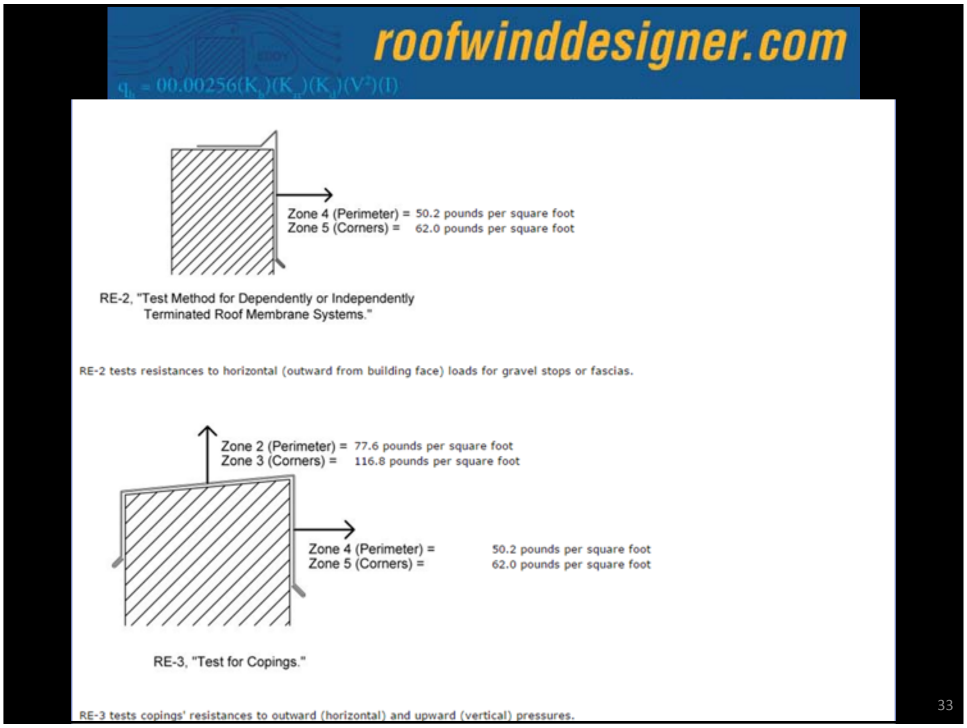
Zone 2 (roof edge perimeter, vertical load direction):	38.8 pounds per square foot
Zone 3 (roof edge corners, vertical load direction):	58.4 pounds per square foot
Zone 4 (wall edge perimeter, horizontal load direction):	25.1 pounds per square foot
Zone 5 (wall edge corners, horizontal load direction):	31.0 pounds per square foot

Graphically, these values are depicted as follows:

Roof Wind Designer relies solely upon the preparer who generates this report to accurately input appropriate information that is applicable to the specific building to which this report applies. This report applies to only the specific roof area and building that is indicated above. Any misinformation, miscalculations, mistakes or changes that have been input into this application may affect the results, accuracy, reliability and results of this report.

Use of Roof Wind Designer is subject to a license agreement and important legal notices and disclaimers. By inputting project information and generating this report, the preparer who generates this report accepts this license agreement and important legal notices and disclaimers. A copy of this license agreement and important legal notices and disclaimers is included at the end of this report and is considered to be a part of this report.

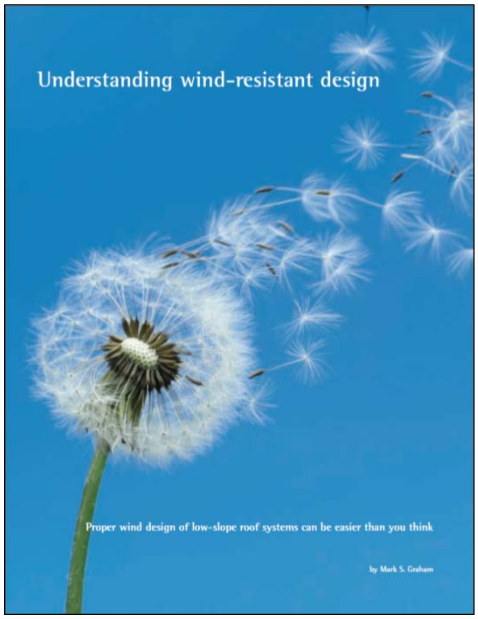
32


roofwinddesigner.com
$q_h = 00.00256(K_h)(K_{zt})(K_d)(V^2)(I)$
Zone 4 (Perimeter) = 50.2 pounds per square foot
Zone 5 (Corners) = 62.0 pounds per square foot
RE-2, "Test Method for Dependently or Independently Terminated Roof Membrane Systems."
RE-2 tests resistances to horizontal (outward from building face) loads for gravel stops or fascias.
Zone 2 (Perimeter) = 77.6 pounds per square foot
Zone 3 (Corners) = 116.8 pounds per square foot
Zone 4 (Perimeter) = 50.2 pounds per square foot
Zone 5 (Corners) = 62.0 pounds per square foot
RE-3, "Test for Copings."
RE-3 tests copings' resistances to outward (horizontal) and upward (vertical) pressures.
33


roofwinddesigner.com
EDDY
$q_h = 00.00256(K_h)(K_{zt})(K_d)(V^2)(I)$
34

Additional references

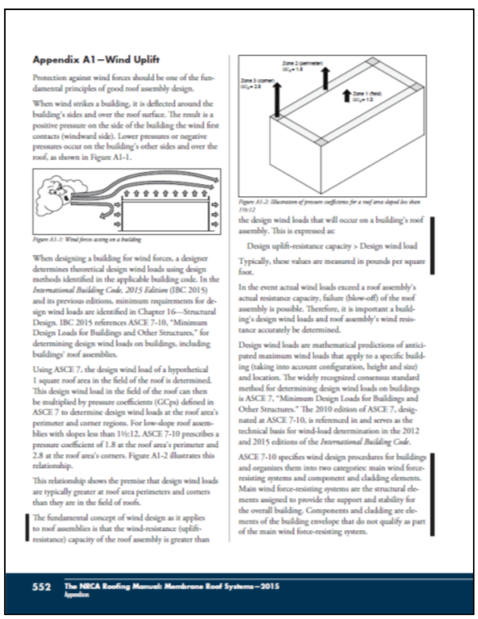
Professional Roofing, March 2007



35

Additional references

The NRCA Roofing Manual: Membrane Roof Systems-2015 (July 2016 Update)



Appendix A1—Wind Uplift

Protection against wind forces should be one of the fundamental principles of good roof assembly design.

When wind strikes a building, it is deflected around the building's sides and over the roof surface. The result is a positive pressure on the side of the building the wind first contacts (windward side). Lower pressures or negative pressures occur on the building's other sides and over the roof, as shown in Figure A1-1.

Figure A1-1: Wind forces acting on a building

When designing a building for wind forces, a designer determines theoretical design wind loads using design methods identified in the applicable building code. In the *International Building Code, 2015 Edition* (IBC 2015) and its previous editions, minimum requirements for design wind loads are identified in Chapter 16—Structural Design. IBC 2015 references ASCE 7-10, "Minimum Design Loads for Buildings and Other Structures," for determining design wind loads on buildings, including buildings' roof assemblies.

Using ASCE 7, the design wind load of a hypothetical 1 square roof area in the field of the roof is determined. This design wind load in the field of the roof can then be multiplied by pressure coefficients (GCps) defined in ASCE 7 to determine design wind loads at the roof area's perimeter and corner regions. For low-slope roof assemblies with slopes less than 1½:12, ASCE 7-10 prescribes a pressure coefficient of 1.8 at the roof area's perimeter and 2.8 at the roof area's corners. Figure A1-2 illustrates this relationship.

This relationship shows the premise that design wind loads are typically greater at roof area perimeters and corners than they are in the field of roofs.

The fundamental concept of wind design as it applies to roof assemblies is that the wind-resistance (uplift-resistance) capacity of the roof assembly is greater than the design wind loads that will occur on a building's roof assembly. This is expressed as:

Design uplift-resistance capacity > Design wind load

Typically, these values are measured in pounds per square foot.

Figure A1-2: Illustration of pressure coefficients for a roof area sloped less than 1½:12

In the event actual wind loads exceed a roof assembly's actual resistance capacity, failure (blow-off) of the roof assembly is possible. Therefore, it is important a building's design wind loads and roof assembly's wind resistance accurately be determined.

Design wind loads are mathematical predictions of anticipated maximum wind loads that apply to a specific building (taking into account configuration, height and size) and location. The widely recognized consensus standard method for determining design wind loads on buildings is ASCE 7, "Minimum Design Loads for Buildings and Other Structures." The 2010 edition of ASCE 7, designated at ASCE 7-10, is referenced in and serves as the technical basis for wind-load determination in the 2012 and 2015 editions of the *International Building Code*.

ASCE 7-10 specifies wind design procedures for buildings and organizes them into two categories: main wind force-resisting systems and component and cladding elements. Main wind force-resisting systems are the structural elements assigned to provide the support and stability for the overall building. Components and cladding are elements of the building envelope that do not qualify as part of the main wind force-resisting system.

552 The NRCA Roofing Manual: Membrane Roof Systems—2015
Appendices

36

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

Twitter: @MarkGrahamNRCA
Personal website: www.MarkGrahamNRCA.com

Understanding wind-resistant design

Proper wind design of low-slope roof systems can be easier than you think

by Mark S. Graham

FM Global's 2006 revisions to its wind-related guidelines have renewed interest and caused considerable discussion within the U.S. roofing industry regarding proper wind-resistant design for low-slope roof systems. For more than 20 years, many in the industry have referred to FM Global's product testing and certifications subsidiary, FM Approvals, for guidance when designing, specifying and installing low-slope roof systems. However, because of FM Global's revisions to its guidelines, some in the industry are rethinking their reliance on FM Global and FM Approvals and taking a different, more fundamental approach to designing roof systems' wind resistances.

The fundamentals

The fundamental concept of wind design as it applies to roof systems is that the design wind-resistance (uplift-resistance) capacity of a building's roof system should be greater than or equal to the design wind loads that will act upon the roof system. This relationship is expressed mathematically as: $w_r \geq w_l$ where w_r = design wind resistance and w_l = design wind load.

In the event actual wind loads exceed a roof system's wind-resistance capacity, the roof system may not be considered wind-resistant and blow-off is possible.

To properly determine appropriate wind-resistant designs for roof systems, roof system designers accurately must determine design wind loads and wind-resistance capacities. Because these values depend on building location, height and configuration, this determination is best conducted on a project-specific basis.

I discourage roof system designers from arbitrarily assuming roof systems' design wind loads or specifying roof systems with what are thought to be excessively high wind-resistance capacity ratings in the hope these ratings adequately will cover the wind loads. The first practice may result in inadequately accounting for necessary design wind loads. And specifying unnecessarily high wind-resistance ratings likely will result in excessive roof system costs with little or no additional benefit to building owners.

Design wind loads

The recognized standard for determining design wind loads on buildings is ASCE 7, "Minimum Design Loads for Buildings and Other Structures." This consensus standard widely is accepted by engineering and design professionals. The 2005 edition of ASCE 7, designated as ASCE 7-05, is referenced in and serves as the

continues on page 46

	Test requirements for UL 580			
	Test phase	Duration (minutes)	Negative pressure (pounds per square foot)	Positive pressure (pounds per square foot)
Class 15	1	5	9.4	0
	2	5	9.4	5.2
	3	60	5.7 to 16.2	5.2
	4	5	14.6	0
	5	5	14.6	8.3
Class 30	1	5	16.2	0
	2	5	16.2	13.8
	3	60	8.1 to 27.7	13.8
	4	5	24.2	0
	5	5	24.2	20.8
Class 60	1	5	32.3	0
	2	5	32.3	27.7
	3	60	16.2 to 55.4	27.7
	4	5	40.4	0
	5	5	40.4	34.6
Class 90	1	5	48.5	0
	2	5	48.5	41.5
	3	60	24.2 to 48.5	41.5
	4	5	56.5	0
	5	5	56.5	48.5

UL 580's, "Tests for Uplift Resistance of Roof Assemblies," negative and positive test-pressure cycling for Classes 15, 30, 60 and 90

continued from page 44

technical basis for wind-load determination in the *International Building Code, 2006 Edition,* (IBC) and *NFPA 5000®: Building Construction and Safety Code* (NFPA 5000). Previous editions of ASCE 7 are referenced in the codes' previous editions and legacy model buildings codes (*The BOCA National Building Code, Standard Building Code* and *Uniform Building Code*).

ASCE 7-05's guidelines applicable to determining wind loads are provided in Chapter 6—Wind Loads, which provides three wind-load determination methods: Method 1—Simplified Procedure, Method 2—Analytical Procedure and Method 3—Wind Tunnel Procedure.

Method 1—Simplified Procedure uses a series of look-up tables to determine design wind loads and is limited to many common building types. The method's limitations include simple diaphragm, regular-shaped, enclosed buildings with mean roof heights of 60 feet or less, making it applicable to most common building types. Use of this simplified method generally is intended for users who do not necessarily have extensive engineering-based knowledge of wind-load determination.

NRCA's online wind-load calculator, www.roofwinddesigner.com, is based on ASCE 7-05's Method 1. (For additional information, see "NRCA's wind-load calculator," February issue, page 26.)

Method 2—Analytical Procedure is a calculation-based wind-load determination method generally used by design professionals who are experienced in wind-load determination. Although this method also contains some limitations (it only is for regularly shaped buildings), it does not contain some of the other limitations, such as mean roof height of 60 feet or less, of Method 1.

Method 3—Wind Tunnel Procedure provides guidelines for determining wind loads by wind-tunnel testing. This complex, costly procedure is intended for situations where Methods 1 and 2 may not be applicable, such as with unusually shaped or tall buildings.

In each of ASCE 7's three methods, three design wind-load values are determined and referred to as being applicable to Zones 1, 2 and 3 of a building's roof area. Zone 1 applies to a roof's field; Zone 2 applies to a roof's perimeter regions; and Zone 3 typically applies to a roof's corner regions.

Another wind-load determination method used by some roofing professionals is FM Global's Loss Prevention Data Sheet 1-28, "Design Wind Loads" (FM 1-28). This document, which includes a series of relatively complex look-up tables and lengthy commentary, provides FM Global's recommended wind-load determination guidelines intended for FM-insured buildings.

FM Global indicates the technical basis of FM 1-28 is the 1998 edition of ASCE

continues on page 49

continued from page 46

7, and FM Global makes several relatively conservative assumptions. For example, FM 1-28 assumes an importance factor of 1.15 for all buildings and structures while ASCE 7 uses importance factors ranging from 0.77 to 1.15, depending on a building's occupancy type.

According to ASCE 7, an importance factor of 1.15 only applies to buildings and structures that represent substantial hazard to human life (ASCE 7 Occupancy Category III) and those designated as essential facilities (ASCE 7 Occupancy Category IV). Examples of essential facilities include hospitals, fire stations and police stations. ASCE 7 uses an importance factor of 1.00 for most building occupancies (ASCE 7 Occupancy Category II) and permits use of an importance factor as low as 0.77 for some buildings and structures that represent a low hazard to human life in the event of failure.

As a result of FM Global's conservative importance factor usage, design wind loads for many buildings determined using FM 1-28 may be from 15 percent to 49 percent greater than the results derived from using ASCE 7.

On this basis, I do not recommend roofing professionals rely on FM 1-28 to determine design wind loads except for FM Global-insured buildings where its use may be required by FM Global. Also, because FM 1-28 is not based specifically on the current edition of ASCE 7-05, results derived using FM 1-28 may not be interpreted as being compliant with IBC and NFPA 5000 requirements.

Safety factor

To provide reasonable assurance that a roof system's wind-resistance capacity is greater than design loads, engineering and wind-design practices call for safety factors to be applied to roof systems' design wind loads.

Safety factors for building materials, components and systems typically vary in magnitude based on a number of factors, including the materials being used and complexity of building system components. For low-slope membrane roof systems, a minimum safety factor of 2.0 typically is considered appropriate.

ASTM D6630, "Standard Guide for Low Slope Insulated Roof Membrane Assembly Performance," which is a recognized consensus standard, prescribes, "Roof system wind uplift resistance shall have a minimum 2.0 factor of safety."

For roof systems, this safety factor accounts for usually anticipated variances in materials and construction and possible deterioration of materials' physical properties as a result of aging.

Once a safety factor is accounted for, the recognized engineering concept is that a roof system's recommended minimum design wind-resistance capacity should be at least two times larger than the design wind load for a low-slope membrane roof system to be

Do wind-resistance capacity test methods yield similar results?

Although the *International Building Code, 2006 Edition*, and *NFPA 5000: Building Construction and Safety Code* allow for testing wind-resistance capacities for low-slope membrane roof systems by any of four test methods, do not assume each of these four test methods will yield identical results. Because the test apparatuses and procedures used in FM 4450, "Approval Standard for Class 1 Insulated Steel Roof Decks"; FM 4470, "Approval Standard for Class 1 Roof Covers"; UL 580, "Tests for Uplift Resistance of Roof Assemblies"; and UL 1897, "Uplift Tests for Roof Covering Systems," differ noticeably, differing wind-resistance capacity results should be anticipated.

In 2001, NRCA conducted wind-resistance capacity testing according to UL 580 and UL 1897 on identical copper architectural metal panel roof system specimens at a recognized testing laboratory. The test conducted according to UL 580 resulted in a wind-resistance capacity of 90 pounds per square foot (UL Class 90). The test conducted according to UL 1897 resulted in a wind-resistance capacity of 165 pounds per square foot, about 80 percent higher than UL 580's result. The tested roof systems' failure mechanisms were similar in both tests.

Although some differences in the tests' results are not unexpected because of differing test durations and pressure cycles, the magnitude of the difference between the results is surprising. NRCA attributes the difference to UL 580's longer test duration and alternating pressure cycling and how this particular roof system type tested responded to the different conditions. (For additional information about this test, see "NRCA analyzes and tests metal," May 2003 issue, page 28.)

NRCA has not performed correlative testing between UL 580 and UL 1897 and FM 4450 or FM 4470. However, for many roof system types, NRCA anticipates FM 4450's and FM 4470's results to be equal or relatively close to the results from UL 1897. This is because FM 4450 and UL 1897 have similar test durations and relatively similar test pressure conditions.

considered adequately wind-resistant. This is mathematically expressed as: $w_{r\ min.} \geq 2.0 \times w_l$ where $w_{r\ min.}$ = minimum recommended design wind resistance and w_l = design wind load. 2.0 represents the assigned safety factor.

Wind-resistance capacity

Roof systems' abilities to resist wind loads often are referred to as their wind-resistance capacities. For most low-slope membrane roof systems, wind-resistance capacities are determined by laboratory testing.

IBC and NFPA 5000 prescribe four laboratory test methods for determining low-slope membrane roof systems' wind-resistance capacities: FM 4450, FM 4470, UL 580 and UL 1897. Roof systems need only satisfy one of these four test methods to be considered adequately wind-resistant.

FM 4450, "Approval Standard for

continues on page 52

continued from page 50

Class 1 Insulated Steel Roof Decks," and FM 4470, "Approval Standard for Class 1 Roof Covers," provide a series of laboratory test methods to determine roof systems' combustibility (fire resistance), wind resistance, corrosion resistance, impact resistance and susceptibility to heat damage. The wind-uplift resistance portions of these test methods are similar and based on another test method, FM 4474, "Evaluating the Simulated Wind Uplift Resistance of Roof Assemblies Using Static Positive and/or Negative Differential Pressures."

FM 4450 and FM 4470 are FM Approvals' internally developed guidelines and not considered to be recognized consensus standards. FM 4474 has been developed and is maintained using an American National Standards Institute- (ANSI-) accredited process and is considered a recognized consensus standard.

With FM 4474, either a small-scale (2- by 2-foot) bench test, 5- by 9-foot test apparatus or 12- by 24-foot test apparatus is used depending on the roof system type and roof deck substrate being analyzed. Testing is conducted at graduated, increasing pressure increments held at 15-pounds-per-square-foot increments for a minimum of 60 seconds. Then, the pressure is increased to the next increment until failure or the test is suspended. Results typically are reported as the highest pressure level maintained for a 60-second period.

FM 4474's classification designations 60, 75, 90 and so forth indicate roof systems having tested wind-resistance capacities of 60 pounds per square foot, 75 pounds per square foot and 90 pounds per square foot, respectively. These designations are similar to the 1-60, 1-75 and 1-90 classifications derived from FM 4450 and FM 4470; the "1-" portion of the designation applies to the tested system's combustibility classification.

UL 580, "Tests for Uplift Resistance of Roof Assemblies," consists of a 10- by 10-foot test apparatus that creates uniform positive pressures on the bottom side of a roof deck and oscillating negative pressures on the top side of a roof membrane specimen. Test cycling and duration are indicated in the figure.

UL 580 has been developed and is maintained using Underwriters Laboratories Inc.'s standards technical panel, which is considered a consensus process and recognized by the model codes as meeting the requirements for reference standards.

Based on UL 580, a Class 30 rating is assigned to tested roof systems that successfully complete the 80-minute Class 30 cycle. A Class 60 rating is assigned to tested roof systems that successfully complete the 160-minute Class 30 and Class 60 cycles . A Class 90 rating is assigned to tested roof systems that

continues on page 55

continued from page 52

successfully complete the 240-minute Class 30, Class 60 and Class 90 cycles.

UL 1897, "Uplift Tests for Roof Covering Systems," consists of a 10- by 10-foot apparatus that creates a steady negative static pressure on the top side of a roof membrane specimen. A test pressure differential of 15 pounds per square foot is applied to the specimen and held for one minute. Thereafter, the pressure is raised in 15-pounds-per-square-foot increments and held for one minute each. These incremental increases are continued until failure or the test is suspended. UL 1897 has been developed and is maintained using an ANSI-accredited process and is considered a recognized consensus standard.

Based on UL 1897, a Class 30 rating is assigned to roof system specimens that successfully complete the 15-pounds-per-square-foot and 30-pounds-per-square-foot increments. A Class 60 rating is assigned to roof system specimens that successfully complete Class 30 testing and additional 45-pounds-per-square-foot and 60-pounds-per-square-foot increments of testing. Roof system specimens that successfully complete Class 60 testing and additional 75-pounds-per-square-foot and 90-pounds-per-square-foot increments of testing receive Class 90 ratings.

For loose-laid, ballasted single-ply membrane roof systems, FM 4450, FM 4470, FM 4474, UL 580 and UL 1897 do not apply. Instead, IBC and NFPA 5000 prescribe wind resistances be designed according to ANSI/SPRI RP 4, "Wind Design Standard for Ballasted Single-Ply Roofing Systems."

Roof system selection

Once design wind loads and minimum recommended design wind resistances (including a safety factor) for a building's roof system are determined, roof system designers can select appropriate wind-resistant roof systems that have tested capacities equal to or greater than the minimum recommended design wind resistances.

Roof systems' wind-resistance capacities that have been tested and currently are approved by FM Approvals in accordance with FM 4474, FM 4450 or FM 4470 are described and listed in FM Approvals' online approval directory, RoofNav.

Roof systems' wind-resistance capacities that have been tested and currently are classified by UL in accordance with UL 580 or UL 1897 are listed in UL's *Roofing Materials & Systems Directory* and online certifications directory.

Also, roof system designers should consult roof system manufacturers for roof system design, specification and installation information that may not be described by FM Approvals or UL.

When evaluating and comparing wind-resistance capacities among different roof systems, I encourage roofing professionals to make comparisons using similar wind-resistance capacity determination test methods. For some identical roof systems, wind-resistance capacity results sometimes vary significantly between test methods (see "Do wind-resistance capacity test methods yield similar results?" page 50).

Also, for hurricane-prone regions, I encourage designers to consider specifying roof systems that have been tested and are classified based on long-duration test methods, such as UL 580. Long-duration test methods provide for test conditions that are more representative of the duration of high winds during actual hurricane conditions than short-duration test methods (such as UL 1897, FM 4450, FM 4470 and FM 4474). ASCE 7-05 defines hurricane-prone regions as areas in the U.S. and its territories along the Atlantic Ocean and Gulf of Mexico where the basic wind speed is greater than 90 mph and Hawaii, Puerto Rico, Guam, Virgin Islands and American Samoa.

The fundamental approach

Roof system designers should use ASCE 7-05 to determine design wind loads on roof systems on a project-specific basis. By applying an appropriate safety factor to design wind loads, designers can determine roof systems' minimum recommended design wind resistances. For many common building types, NRCA's online wind-load application, www.roofwinddesigner.com, can be used to help determine these values.

From these values, roof system designers should select and specify roof systems with wind-resistance capacities equal to or greater than minimum recommended design wind resistances. UL's *Roofing Materials & Systems Directory* and online certifications directory and FM Approval's RoofNav application can be used to help identify such systems.

In most instances, roof system designers should be able to perform the calculations and analyses necessary to provide wind-resistant and code-complaint low-slope membrane roof systems. In situations where this determination is more complex, a roofing professional experienced in wind-resistant design or licensed design professional should be consulted.

Mark S. Graham is NRCA's associate executive director of technical services.

WEB EXCLUSIVE WWW

For more information related to this article and links to NRCA's online wind-load calculator, FM Approvals' RoofNav and Underwriters Laboratories Inc.'s online certifications directory, log on to www.professionalroofing.net.

Appendix A1—Wind Uplift

Protection against wind forces should be one of the fundamental principles of good roof assembly design.

When wind strikes a building, it is deflected around the building's sides and over the roof surface. The result is a positive pressure on the side of the building the wind first contacts (windward side). Lower pressures or negative pressures occur on the building's other sides and over the roof, as shown in Figure A1-1.

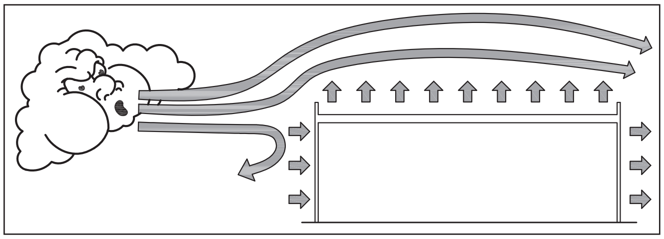


Figure A1-1: Wind forces acting on a building

When designing a building for wind forces, a designer determines theoretical design wind loads using design methods identified in the applicable building code. In the *International Building Code, 2015 Edition* (IBC 2015) and its previous editions, minimum requirements for design wind loads are identified in Chapter 16—Structural Design. IBC 2015 references ASCE 7-10, "Minimum Design Loads for Buildings and Other Structures," for determining design wind loads on buildings, including buildings' roof assemblies.

Using ASCE 7, the design wind load of a hypothetical 1 square roof area in the field of the roof is determined. This design wind load in the field of the roof can then be multiplied by pressure coefficients (GCps) defined in ASCE 7 to determine design wind loads at the roof area's perimeter and corner regions. For low-slope roof assemblies with slopes less than 1½:12, ASCE 7-10 prescribes a pressure coefficient of 1.8 at the roof area's perimeter and 2.8 at the roof area's corners. Figure A1-2 illustrates this relationship.

This relationship shows the premise that design wind loads are typically greater at roof area perimeters and corners than they are in the field of roofs.

The fundamental concept of wind design as it applies to roof assemblies is that the wind-resistance (uplift-resistance) capacity of the roof assembly is greater than

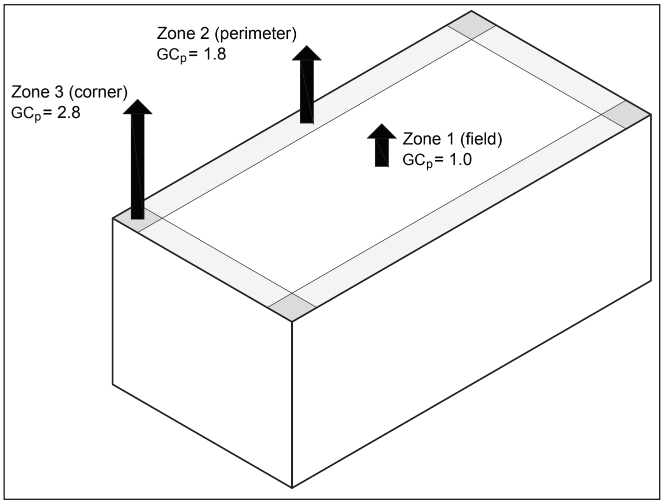


Figure A1-2: Illustration of pressure coefficients for a roof area sloped less than 1½:12

the design wind loads that will occur on a building's roof assembly. This is expressed as:

Design uplift-resistance capacity > Design wind load

Typically, these values are measured in pounds per square foot.

In the event actual wind loads exceed a roof assembly's actual resistance capacity, failure (blow-off) of the roof assembly is possible. Therefore, it is important a building's design wind loads and roof assembly's wind resistance accurately be determined.

Design wind loads are mathematical predictions of anticipated maximum wind loads that apply to a specific building (taking into account configuration, height and size) and location. The widely recognized consensus standard method for determining design wind loads on buildings is ASCE 7, "Minimum Design Loads for Buildings and Other Structures." The 2010 edition of ASCE 7, designated at ASCE 7-10, is referenced in and serves as the technical basis for wind-load determination in the 2012 and 2015 editions of the *International Building Code*.

ASCE 7-10 specifies wind design procedures for buildings and organizes them into two categories: main wind force-resisting systems and component and cladding elements. Main wind force-resisting systems are the structural elements assigned to provide the support and stability for the overall building. Components and cladding are elements of the building envelope that do not qualify as part of the main wind force-resisting system.

ASCE 7-10 also provides two methods to determine minimum design load requirements for buildings: allowable stress design (ASD) method and strength design method. The wind design procedures in ASCE 7-10 result in strength design values; however, roof systems typically are designed using ASD.

ASD and strength design methods take into account applicable load types, such as dead, live, wind, seismic, etc., to ensure the structure's safety under anticipated loading conditions. The individual loads are then combined using load combination equations which include "load factors." Load factors allow for deviations and uncertainties in the analysis and the probability of simultaneously occurring loads. Load factors are applied as coefficients to the individual loads in the load combination equations. The load factor for wind loads is 1.0 when using the ASD method and 1.6 when using the strength design method. Because roof systems typically are designed using ASD, a designer may want to adjust strength design values to ASD values. In doing so, applying a load reduction factor of 0.6 to ASD values may be appropriate.

Design Wind Loads: Requirements for wind loads are found in Chapters 26 to 30 in ASCE 7-10. Chapter 30 specifically addresses components and cladding. This chapter offers the following six methods, referred to as parts, to determine design wind loads:

- Part 1: Low-rise Buildings. This method is applicable to enclosed or partially enclosed buildings less than or equal to 60 feet in height. The building has a flat, gable, multispan gable, hip, monoslope, stepped or sawtooth roof. Wind pressures are calculated from a wind pressure equation.
- Part 2: Low-rise Buildings (Simplified): This method is applicable to enclosed buildings less than or equal to 60 feet in height. The building has a flat, gable or hip roof. This is a simplified method and wind pressures are determined directly from a table.
- Part 3: Buildings with h>60 ft. This method is applicable to enclosed or partially enclosed buildings greater than 60 feet in height. The building has a flat, pitched, gable, hip, mansard, arched or domed roof. Wind pressures are calculated from a wind pressure equation.
- Part 4: Buildings with h≤160 ft. (Simplified). This method is applicable to enclosed buildings less than or equal to 160 feet in height. The building has a flat, gable, monoslope or mansard roof. This is a simplified method and wind pressures are determined directly from a table.
- Part 5: Open Buildings. This method is applicable to open buildings of all heights. The building has a pitched, monoslope or trough roof. Wind pressures are calculated from a wind pressure equation.
- Part 6: Building Appurtenances and Rooftop Structures and Equipment. This method is for determining design wind pressures for component and cladding elements of parapets, roof overhangs or rooftop structures of enclosed and partially enclosed buildings less than or equal to 160 feet in height. Wind pressures are calculated from a wind pressure equation.

Part 1, Part 3, Part 5 and Part 6 involve calculations and concepts that are fairly complex and beyond the scope and intent of this manual. Part 2 and Part 4 are considered simplified methods and apply to many commonly encountered building types. For these reasons, roof system designers are most likely to use Part 2 and Part 4 methods.

Part 2: Low-rise Buildings (Simplified): This method is limited to the following parameters:

- The mean roof height, h, must be less than or equal to 60 feet.
- The building is enclosed and conforms to wind-borne debris provisions.
- The building is a regular-shaped building or structure.
- The building does not have response characteristics making it subject to across wind loading, vortex shedding, and instability because of galloping or flutter, and does not have a site location for which channeling effects or buffeting in the wake of upwind obstructions warrant special consideration.
- The building has a flat roof, a hip roof ≤ 6:12 or a gable roof ≤ 12:12.

For design wind load pressures, the basic equation is:

$p_{net} = \lambda \times K_{zt} \times p_{net30}$

Where:

p_{net}	=	net design wind pressure (a sum of internal and external pressures) for the field of the roof, in pounds per square foot
λ	=	adjustment factor from ASCE 7-10's Figure 30.5-1 (determined by mean building height and exposure category)
K_{zt}	=	topographic factor as defined in ASCE 7-10's Section 26.8
p_{net30}	=	net design wind pressure for exposure B at building height = 30 ft. Taken from ASCE 7-10's Figure 30.5-1 (determined by the basic wind speed, roof slope, effective roof area and zone)

It is important to note that "p_{net}" determines design wind load pressures for the field of the roof.

Part 4: Buildings With h ≤ 160 ft (Simplified): This method is limited to the following parameters:

- The mean roof height, h, must be less than or equal to 160 feet.
- The building is enclosed or partially enclosed.
- The building is a regular-shaped building or structure.
- The building has a flat roof, gable roof, hip roof, monoslope roof or mansard roof.

For design wind load pressures, the basic equation is:

$p = p_{table} \times EAF \times RF \times K_{zt}$

Where:

p	=	design wind pressure for the field of the roof, in pounds per square foot
p_{table}	=	wind pressure from ASCE 7-10's Table 30.7-2 (determined by basic wind speed, roof type, load case and zone)
EAF	=	exposure adjustment factor from ASCE 7-10's Table 30.7-2 (determined by building height and exposure category)
RF	=	reduction factor from ASCE 7-10's Table 30.7-2 (determined by effective wind area, roof type and zone)
K_{zt}	=	topographic factor as defined in ASCE 7-10's Section 26.8

It is important to note that "p" determines design wind load pressures for the field of the roof.

Design parameters and definitions: Part 2 and Part 4 refer to the following design parameters and definitions:

- Mean roof height
- Enclosed building
- Wind-borne debris region
- Regular-shaped building
- Topographic factor
- Risk category
- Basic wind speed
- Exposure category
- Effective wind area
- Wind zones

Mean roof height (h). ASCE 7 uses a building's mean roof height in the calculations. It is defined as the average of the roof eave height and the height to the highest point on the roof surface, except that, for roof angles less than 10 degrees, the mean roof height is permitted to be the eave height.

Enclosed buildings. For design purposes, ASCE 7-10 has three building configuration classifications: open, partially enclosed and enclosed. Part 2: Low-rise Buildings (Simplified) only can be used with enclosed buildings and Part 4: Buildings With h ≤ 160 ft (Simplified) can be used with enclosed and partially enclosed buildings. ASCE 7-10 defines them as follows:

> Open: A building having each wall at least 80 percent open.
>
> Partially Enclosed: A building that complies with both of the following:
>
> 1. The total area of openings in a wall that receives positive external pressure exceeds the

sum of the areas of openings in the balance of the building envelope (walls and roof) by more than 10 percent.

2. The total area of openings in a wall that receives positive external pressure exceeds 4 square feet or 1 percent of the area of that wall, whichever is smaller, and the percentage of openings in the balance of the building envelope does not exceed 20 percent.

Enclosed: A building that does not comply with the requirements for open or partially enclosed buildings.

Wind-borne debris regions. These are areas within hurricane-prone regions where impact protection is required for glazed openings.

Regular-shaped building. A regular-shaped building (or other structure) is a building that does not have an unusual geometrical irregularity in spatial form.

Topographic factor (K_{zt}). The topographic factor takes into account wind speed-up effects that occur at isolated hills, ridges or escarpments that constitute an abrupt change in the general topography. This applies for any exposure category. It is determined by an equation and involves wind design concepts that are particularly complex. Therefore, a structural engineer should be consulted to determine K_{zt}. For buildings that are not located by any abrupt changes in the general topography, using a K_{zt} value of 1.0 is appropriate.

Risk Category. Risk Category is a categorization of buildings and other structures for determining design loads based on the risk associated with unacceptable performance. A building's risk category is determined by its use and occupancy. See Figure A1-3. Risk Category II applies to most common buildings.

Basic wind speed. Basic wind speed is a three-second gust at 33 feet above the ground in Exposure C. ASCE 7-10 has the following three basic wind speed maps based on the risk category of a building (Figures A1-4, A1-5 and A1-6 on pages 556 and 557):

- Figure 26.5-1A—Basic Wind Speeds for Occupancy Category II Buildings and Other Structures

Risk Category of Buildings and Other Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life. Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure. Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	III
Buildings and other structures designated as essential facilities. Buildings and other structures, the failure of which could pose a substantial hazard to the community. Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use or dispose of such substances as hazardous fuels, hazardous chemicals or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released.[a] Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	IV
[a] Buildings and other structures containing toxic, highly toxic or explosive substances shall be eligible for classification to a lower Risk Category if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 that a release of the substances is commensurate with the risk associated with that Risk Category.	

Figure A1-3: Risk Category of Buildings and Structures

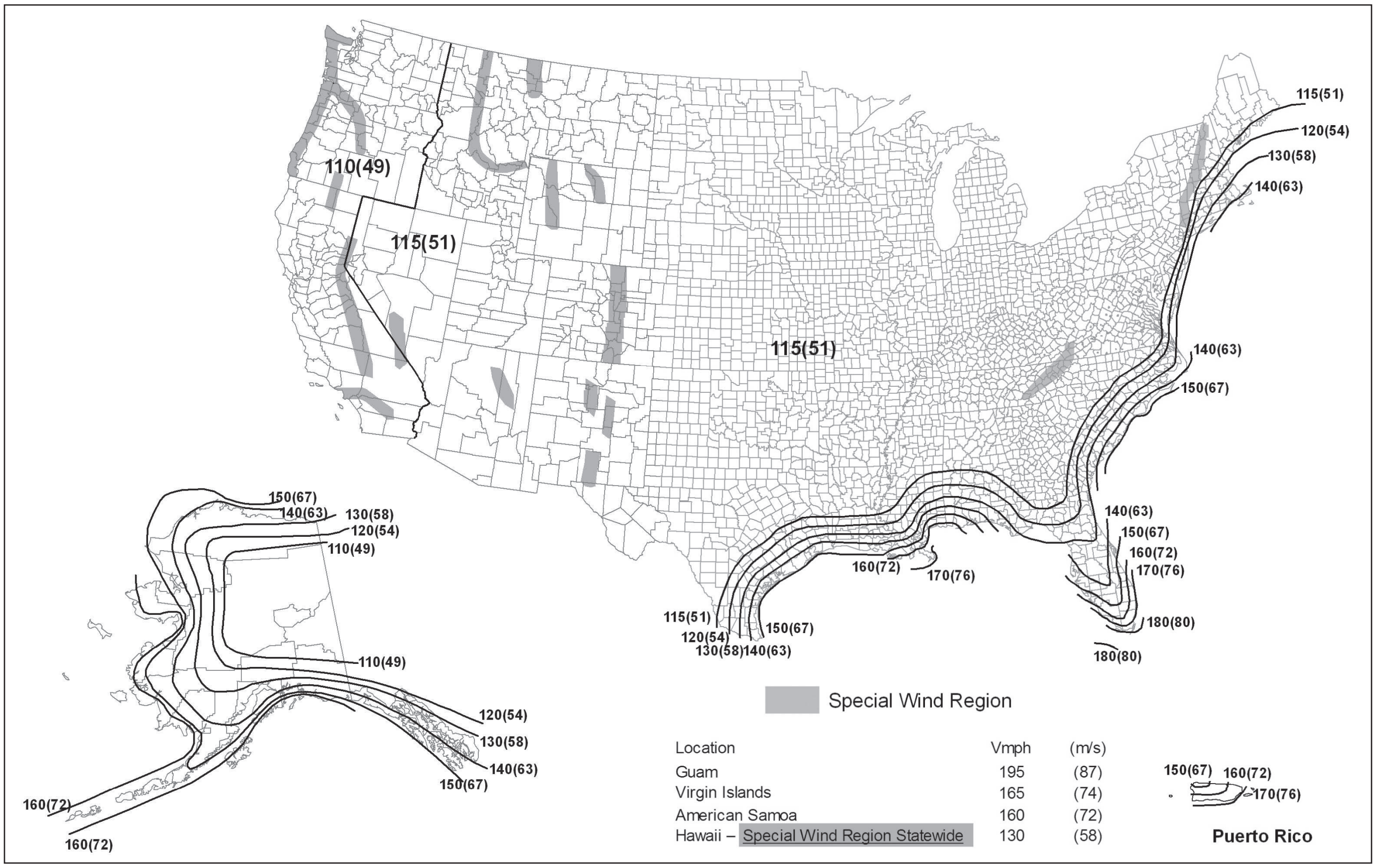


Figure A1-4: Figure 26.5-1A—Basic Wind Speeds for Occupancy Category II Buildings and Other Structures

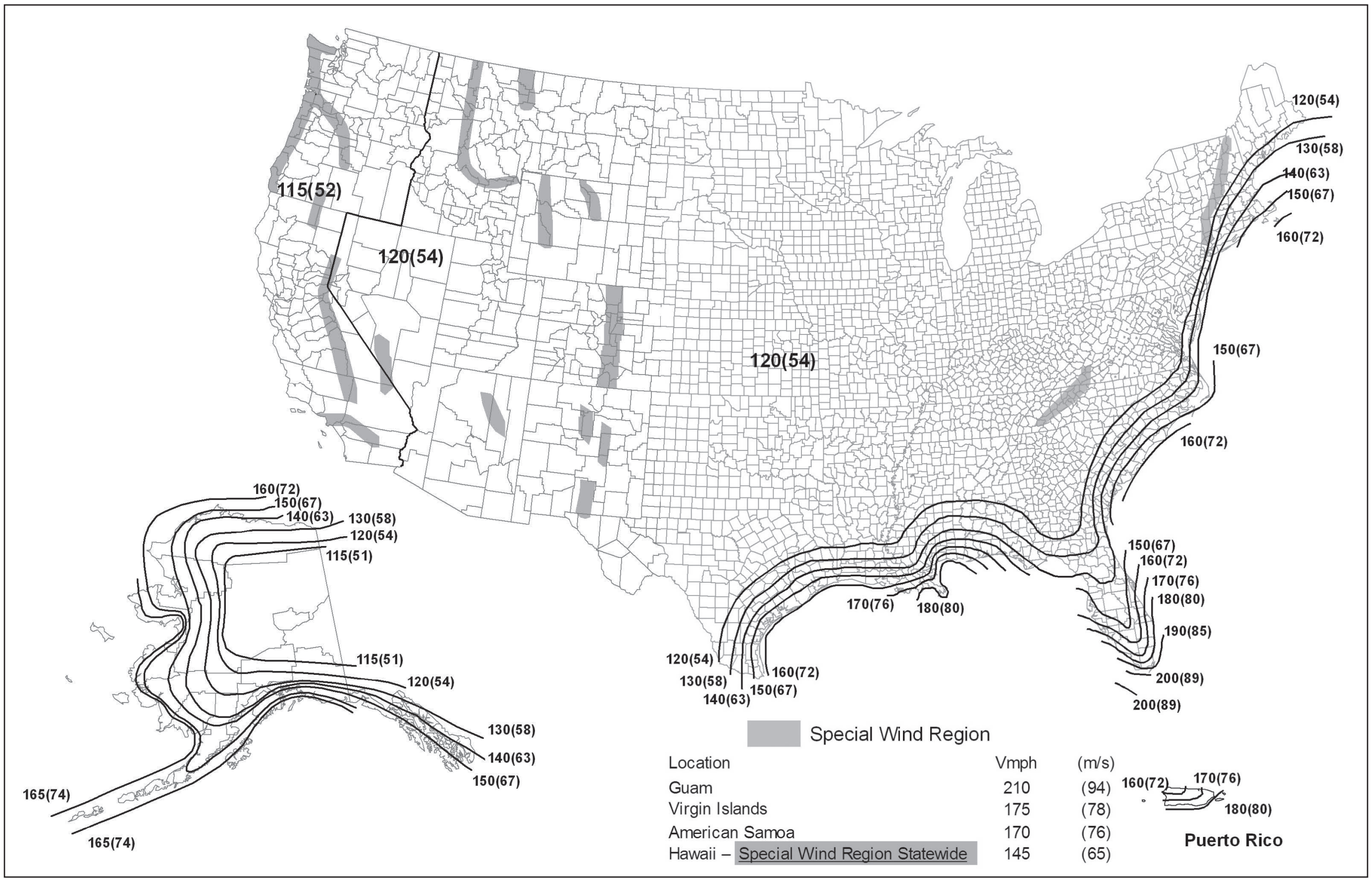


Figure A1-5: Figure 26.5-1B—Basic Wind Speeds for Occupancy Category III and IV Buildings and Other Structures

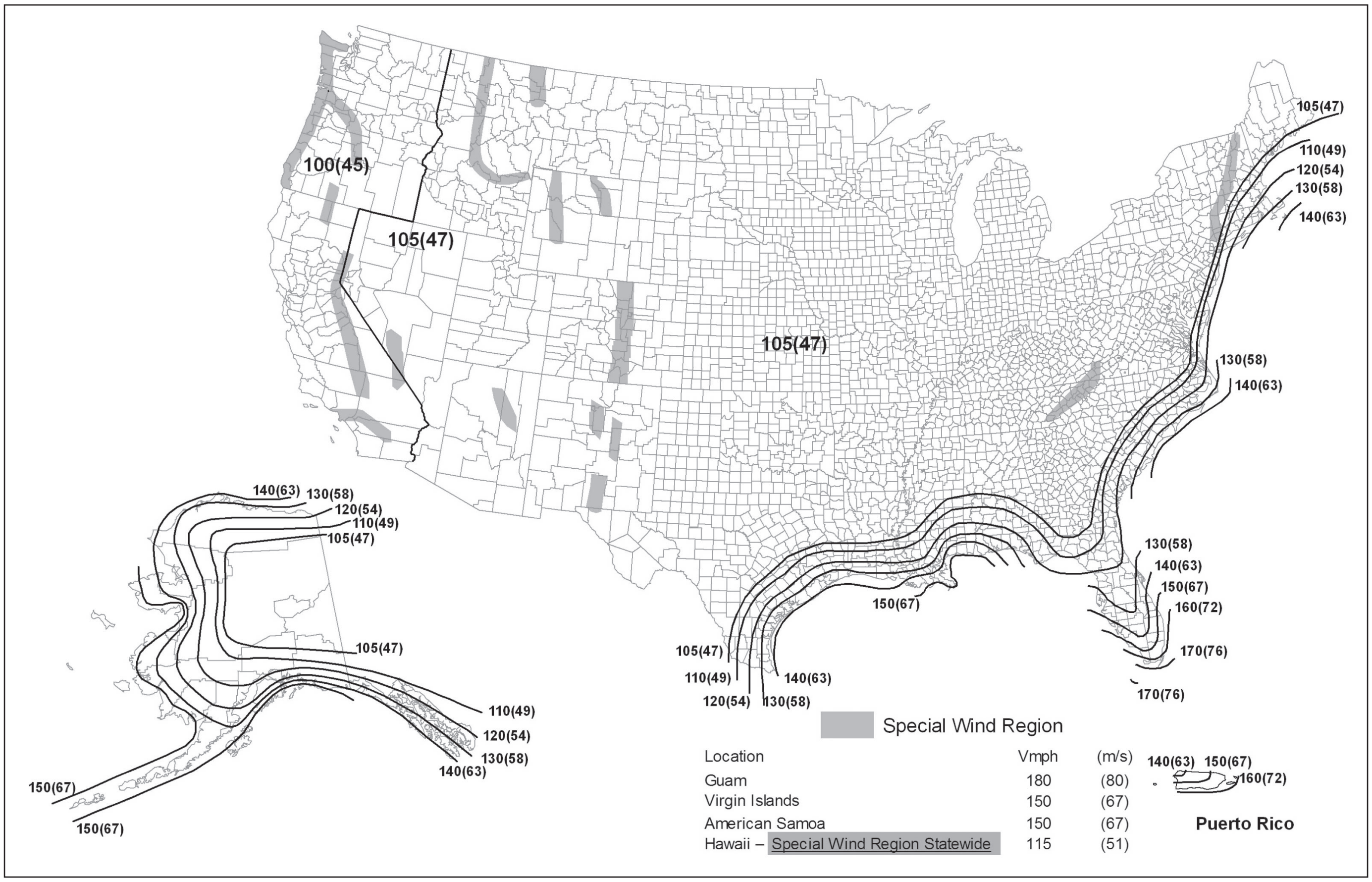


Figure A1-6: Figure 26.5-1C—Basic Wind Speeds for Occupancy Category I Buildings and Other Structures

- Figure 26.5-1B—Basic Wind Speeds for Occupancy Category III and IV Buildings and Other Structures
- Figure 26.5-1C—Basic Wind Speeds for Occupancy Category I Buildings and Other Structures

These basic wind speed maps are based on strength design. The previous edition of ASCE 7 (2005 edition) had a single map based on allowable stress design. Since the maps in ASCE 7-10 are based on strength design, a load reduction factor needs to be applied to convert them to allowable stress design. Since roof systems generally are designed using allowable stress design, applying a load reduction factor of 0.6 to design wind loads may be appropriate.

Exposure category. Exposure is based on surface roughness that is determined by natural topography, vegetation and constructed facilities. ASCE 7-10 has three exposure categories: B, C and D. See Figure A1-7 (on page 558). Generally, Exposure C applies to most areas of the U.S., while Exposure B applies to most urban, suburban and wooded areas, and Exposure D applies to coastline areas.

Effective wind area. Effective wind area is defined as the area secured by a single fastener. ASCE 7-10's Table 30.7-2 includes four effective wind areas, 10, 20, 50 and 100 square feet. For membrane roof systems, 10 square feet is appropriate.

Wind Zones. In ASCE 7-10, three design wind-load values are determined and referred to as being applicable to Zones 1, 2 and 3. Zone 1 refers to a roof's field as determined by Part 2: Low-rise Buildings (Simplified) and Part 4: Buildings with h≤160 ft. (Simplified); Zone 2 applies to a roof's perimeter region; and Zone 3 applies to a roof's corner region. See Figure A1-8 (on page 558).

Design wind load values for perimeter areas (Zone 2) and corners (Zone 3) are higher than the field of a roof (Zone 1). The parameters that affect the determination of the higher design wind load pressures for Zones 2 and 3 are internal and external pressure coefficients (referred to as GC_{pi} and GC_p, respectively). Pressure coefficients are ratios of between actual wind pressures and a computed velocity pressure. Internal pressure coefficient values (GC_{pi}) are based on a building's enclosure classification (enclosed, partially enclosed or open). External pressure

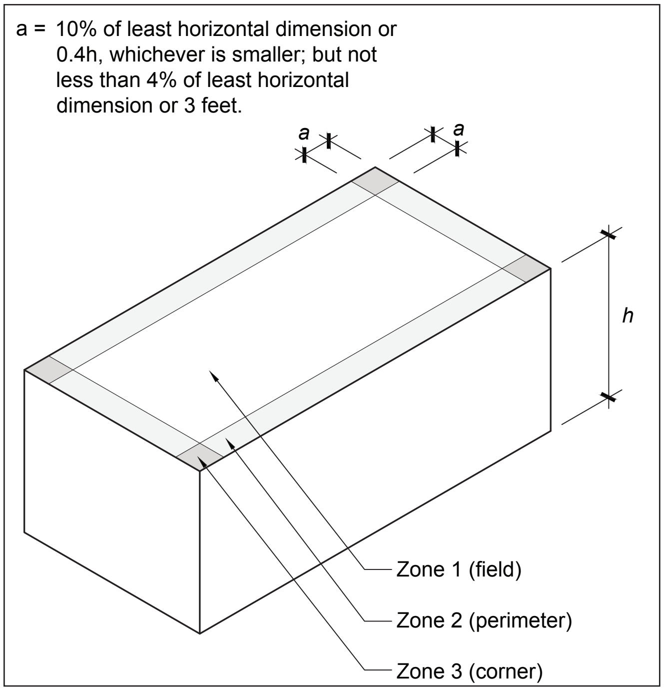


Figure A1-8: Wind zone areas

coefficient values (GC_p) are based on building height, the surface relative to the wind direction, roof slope and roof shape (e.g., flat, gable, hip, shed).

Dimension "*a*". ASCE 7-10 identifies a dimension determined by calculation, referred to as "*a*," that defines the depth of the perimeter and corner zones from the roof area's edges. See Figure A1-8. Dimension "*a*" is 10 percent of the least horizontal dimension of the building or 0.4 times the mean building height, whichever is smaller; but not less than either 4 percent of the least horizontal dimension or 3 feet.

Roof edge parapets may assist in reducing design wind loads acting in the corner regions of the roof area. ASCE 7-10, Part 3: Buildings with h > 60 ft., allows for this reduction only when a minimum 36-inch high parapet occurs at the two outside edges of the specific corner area where the design wind load is being reduced. See Figure A1-9.

Adjustment of Strength Design to Allowable Stress Design (ASD): As previously mentioned, the design wind loads determined by ASCE 7-10 are strength design values. Because roof systems and roof system components generally are designed using the ASD method, a designer can adjust the strength design method's values to ASD method's values. A load-reduction factor is applied as a multiplier to the strength design values to determine the ASD values. ASCE 7-10 provides a load-reduction factor of 0.6 for this purpose, and the calculation is expressed as follows:

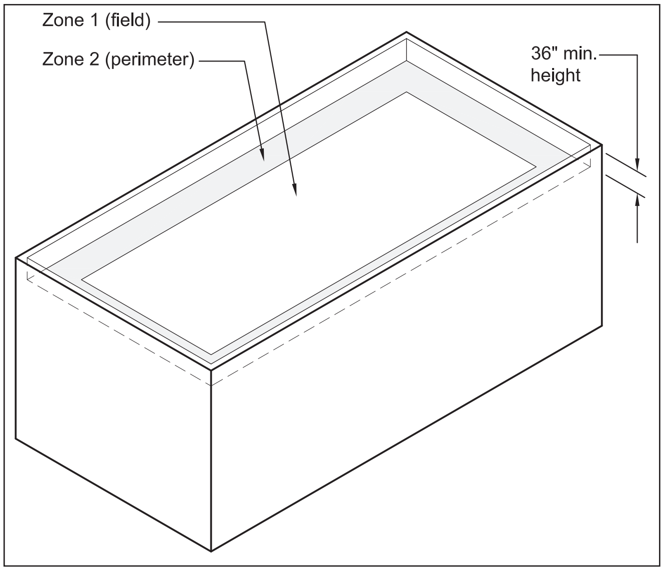


Figure A1-9: Roof edge parapet

ASD value = Strength design value x 0.6

Determining Minimum Recommended Design Uplift-resistance Capacity: To determine the appropriate minimum recommended design uplift-resistance capacity, multiply the ASD design wind loads by an appropriate safety factor. It would be expressed as follows:

Design Uplift-resistance Capacity = [ASD Design Wind Load] x [Safety Factor]

To reasonably ensure a roof system's wind-resistance capacity is greater than design loads, engineering and wind-design practices call for safety factors to be applied to roof systems' design wind loads. For roof systems, this safety factor accounts for usually anticipated variances in materials and construction and possible deterioration of materials' physical properties as a result of aging. Safety factors for building materials, components and systems typically vary in magnitude based on a number of factors, including materials used and complexity of building system components.

For low-slope membrane roof systems, a minimum safety factor of 2.0 typically is considered appropriate and based on ASTM D6630, "Standard Guide for Low Slope Insulated Roof Membrane Assembly Performance."

However, for a roof assembly with a steel deck and a steel or aluminum metal panel roof system, a safety factor of 1.67 is considered appropriate. This safety factor is recommended in AISI S100, "North American Specification for the Design of Cold-Formed Steel Structural Members" and The Aluminum Association's *Aluminum Design Manual*, Specification for Aluminum Structures section.

Tested Uplift-resistance Capacities: Using these minimum recommended design uplift-resistance capacity values, a user can select an appropriate wind-resistant roof system. Roof systems' tested uplift-resistance load capacities typically are determined by laboratory testing or engineering analysis. The tested uplift-resistance capacity of a roof system should be greater than the minimum recommended design wind-resistance loads for the roof system to be considered appropriately wind-resistant. This is expressed as:

Tested uplift-resistance capacity ≥ Design uplift-resistance capacity

Roof System Design: How a roof system is designed and installed to resist wind uplift depends on the roof assembly. Following are some examples.

- For built-up or polymer-modified bitumen roof systems installed on a nailable deck, the base sheet has to be designed and installed to resist wind uplift.
- For built-up, polymer-modified bitumen or adhered single-ply roof systems installed over an insulated deck, the rigid board insulation has to be designed and installed to resist wind uplift.
- For conventional mechanically attached single-ply membrane roof systems installed over an insulated deck, the rigid board insulation and roof membrane have to be designed and installed to resist wind uplift.
- For induction welded roof systems installed over an insulated deck, the fasteners that secure board insulation to a structural deck are the same fasteners that secure the roof membrane.

In all cases, the corners and perimeters are designed to resist greater wind-uplift loads. The designer is responsible for determining the required fastening patterns at corner and perimeter regions and clearly indicating this information in the project's drawings and specifications. NRCA recommends that designers determine the required attachment patterns based on manufacturer's test data.

For additional information on the attachment of base sheets, rigid board insulation and roof membranes, refer to Chapter 6—Fasteners.

Building Code Requirements: Requirements for structural design are indicated in Chapter 16—Structural Design of *The International Building Code, 2015 Edition*. This chapter necessitates that design loads and other information pertinent to the structural design be shown on the construction documents. Design information should include live, flood, seismic, snow, wind and any other special loads that are applicable to a building. For wind design, the following information should be provided, regardless whether the wind loads govern the design of the lateral force-resisting system of the structure:

- Ultimate wind design
- Risk category
- Wind exposure
- Applicable internal pressure coefficient
- For components and cladding: the design wind pressures in terms of pounds per square foot (psf) to be used for the design of exterior component and cladding materials not specifically designed by the registered design professional.

Designer Responsibility: Designers should not place the responsibility for determining roof system or individual component design wind loads on manufacturers, component suppliers or installers, or roofing contractors. Also, designers' sole reliance on specifying wind speed warranties is not a substitute for code-required wind design data. Such warranties typically do not address consideration of ultimate and nominal design wind speeds, building height, risk category, wind exposure, and external and internal pressure coefficients applicable to the specific building necessary for properly determining roof systems' design wind loads.

Responsibility for properly determining and clearly identifying wind design data, including design wind loads for roof systems, is required by the building code and is that of roof system designers. Roof system designers may retain a structural engineer or qualified consultant to help them fulfill their design responsibilities.

To help designers determine wind loads for commonly encountered low-slope roof systems, NRCA, the Midwest Roofing Contractors Association and North/East Roofing Contractors Association have developed and offer a free online application, Roof Wind Designer.

Roof Wind Designer is a web application that allows users to determine design wind loads using ASCE 7, "Minimum Design Loads for Buildings and Other Structures," 2005 or 2010 editions. Roof Wind Designer is accessible at www.roofwinddesigner.com.