ANSI/SPRI RP-14
Wind Design Standard for Vegetative Roofing Systems

This standard was developed in cooperation with Green Roofs for Healthy Cities.

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1.0 Introduction

This standard provides a method of designing wind uplift resistance of vegetative roofing systems. It is intended to provide a minimum design and installation reference for those individuals who design, specify, and install vegetative roofing systems. It shall be used in conjunction with, or enhanced by, the installation specifications and requirements of the manufacturer of the specific products used in the Vegetative Roofing System.

2.0 Definitions

The following definitions shall apply when designing a Vegetative Roofing System.

2.1 Vegetative Roofing System

A Vegetative Roofing System consists of vegetation, growth media, drainage system, and waterproofing over a roof deck.

2.2 Ballast

In Vegetative Roofing Systems ballast is the weight provided by growth media or stones or pavers to provide uplift resistance for roofing systems that are not adhered or mechanically attached to the roof deck. The ballast also provides drainage options when the roofing membrane is mechanically attached or fully adhered. In Vegetative Roofing Systems, when growth media is installed and protected by vegetation that nominally covers the visible surface of the growth media or the growth media is protected by a system to prevent wind erosion the weight of the inorganic portion of the growth media can be considered ballast weight. When modular trays that are filled with growth media are covered by vegetation that nominally covers the visible surface of the growth media or the growth media is protected by a system to prevent wind erosion the weight of the inorganic portion of the growth media can be considered ballast weight. Ballast can also consist of large stones, paver systems, or lightweight interlocking paver systems.

2.3 Vegetation Coverage

2.3.1 Nominal Vegetation Coverage

No area greater than a 5 inches (12 mm) diameter of exposed growth media.

2.3.2 Unprotected Growth Media or Unprotected Modular Vegetative Roof Trays

Systems that do not have nominal vegetation coverage.

2.3.3 Protected Growth Media or Protected Modular Vegetative Roof Trays

Systems that have nominal vegetation coverage or a system to prevent growth media blow off.

2.4 Growth Media

An engineered formulation of inorganic and organic materials including but not limited to heat-expanded clays, slates, shales, aggregate, sand, perlite, vermiculite and organic material including but not limited to compost worm castings, coir, peat, and other organic material.

2.5 Basic Wind Speed

The Basic Wind Speed is the 3-second gust speed at 33 feet (10 m) above the ground in Exposure C and associated with an annual probability of 0.02 of being equaled or exceeded (50 year mean recurrence interval). The Basic Wind Speed value to be used in the design calculations shall be taken from the ANSI/ASCE 7[1] document or the local authority having jurisdiction when local values exceed ASCE 7. The intensifying effects of valleys on wind speed as well as unique topographic features such as hills or escarpments, shall be accounted for in the design. (See Commentary 2.5 and Minimum Design Loads for Buildings and Other Structures Figure 6, in Attachment II) A local authority having jurisdiction shall be contacted for verification of the wind data

1. American Society of Civil Engineers Standard ASCE 7-2005, “Minimum Design Loads For Buildings And Other Structures”.

and shall, if necessary, adjust the values given in Attachment II to account for higher local wind speeds.

2.6 Roof Areas

Different areas of the roof surface are affected by wind in different ways. For design and installation purposes, the roof surface is divided into the following areas:

2.6.1 Corner

The space between intersecting walls forming an angle greater than 45 degrees but less than 135 degrees. (See Figure 1)

2.6.2 Corner Areas

The corner area is defined as the roof section with sides equal to 40% of the building height. The minimum width of a side is 8.5 feet (2.6 m). (See Figure 1)

2.6.3 Perimeter

The perimeter area is defined as the rectangular roof section parallel to the roof edge and connecting the corner areas with a width measurement equal to 40% of the building height, but no less than 8.5 feet (2.6 m). (See Figure 1)

2.6.4 Field

The field of the roof is defined as that portion of the roof surface which is not included in the corner or the perimeter areas as defined above. (See Figure 1)

2.7 Surface Roughness Categories

A ground surface roughness within each 45-degree sector shall be determined for a distance upwind of the site as defined in Section 2.7.1, 2.7.2, or 2.7.3 for the purpose of assigning an exposure category.

2.7.1 Surface Roughness B

Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger. Use of Exposure Category B shall be limited to those areas for which terrain representative of Exposure B prevails in the upwind direction for a distance of at least 2,600 feet (792 m) or 20 times the height of the building, whichever is greater.

2.7.2 Surface Roughness C

Open terrain with scattered obstructions having heights generally less than 30 feet (9.1 m). This category includes flat open country, grasslands and all water surfaces in hurricane-prone regions. Exposure C shall apply for all cases where exposures B or D do not apply.

2.7.3 Surface Roughness D

Flat, unobstructed areas and water surfaces outside hurricane-prone regions. This category includes smooth mud flats, salt flats and unbroken ice. Use of Exposure Category D shall be limited to those areas for which terrain representative of Exposure D prevails in the upwind direction for a distance of at least 5,000 feet (1,524 m) or 20 times the height of the building, whichever is greater. Exposure D shall extend into downwind areas of Surface Roughness B or C for a distance of 600 feet (183 m) or 20 times the height of the building, whichever is greater.

2.8 Impervious Decks

A roof deck that will not allow air to pass through it. Some examples are poured in-place concrete, gypsum, and poured-in-place lightweight concrete. (See Commentary Section 2.8)

2.9 Pervious Decks

A roof deck that allows air to move through it. Some examples are metal, cementitious wood fiber, oriented strand board, plywood and wood plank.

2.10 Importance Factor

Importance factor accounts for the degree of hazard to human life and damage to property. For buildings fitting Category III or IV, the roof shall be designed in accordance with Section 5.6. (See Table 1)

Table 1
Classification of buildings and other structures for wind, snow, and earthquake loads[2]

Nature of Occupancy	Category
Buildings and other structures that represent a low hazard to human life in the event of failure including, but not limited to: ▶ Agricultural facilities ▶ Certain temporary facilities ▶ Minor storage facilities	I
All buildings and other structures except those listed in Categories I, III, IV	II
Buildings and other structures that represent a substantial hazard to human life in the event of failure including, but not limited to: ▶ Buildings and other structures where more than 300 people congregate in one area ▶ Buildings and other structures with elementary school, secondary school, or day care facilities with capacity greater than 150 ▶ Buildings and other structures with a capacity greater than 500 for colleges or adult education facilities ▶ Health care facilities with a capacity of 50 or more resident patients but not having surgery or emergency treatment facilities ▶ Jails and detention facilities ▶ Power generating stations and other public utility facilities not included in Category IV ▶ Buildings and other structures containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released including, but not limited to: A. Petrochemical facilities B. Fuel storage facilities C. Manufacturing or storage facilities for hazardous chemicals D. Manufacturing or storage facilities for explosives	III
Buildings and other structures designated as essential facilities including, but not limited to: ▶ Hospitals and other health care facilities having surgery or emergency treatment facilities ▶ Fire, rescue and police stations and emergency vehicle garages ▶ Designated earthquake, hurricane, or other emergency shelters ▶ Communications centers and other facilities required for emergency response ▶ Power generating stations and other public utility facilities required in an emergency ▶ Ancillary structures (including, but not limited to communications towers, fuel storage tanks, cooling towers, electrical substation structures, fire water storage tanks or other structures housing or supporting water or other fire suppression material or equipment) required for operation of Category IV structures during an emergency ▶ Aviation control towers, air traffic control centers and emergency aircraft hangers ▶ Water storage facilities and pump structures required to maintain water pressure for fire suppression ▶ Buildings and other structures having critical national defense functions	IV

[2] The definitions above are based on those of ANSI/ASCE 7-2005 with modifications to suit the needs of this document.

3.0 General Design Considerations and System Requirements

All Vegetative Roofing Systems shall comply with the following:

3.1 Roof Structure

The building owner shall consult with a licensed design professional such as an architect, architectural engineer, civil engineer, or structural engineer to verify that the structure and deck will support the Vegetative Roofing System loads including the ballast load in combination with all other design loads.

3.2 Building Height

The building height shall be measured from ground level to the roof system surface at the roof edge. When more than one roof level is involved, each shall have its own design per Sections 4.0 and 5.0; or be designed to the criteria required for the most exposed or highest roof level. (See Commentary 3.2) When building height exceeds 150 feet (46 m), the roof design shall be designed by a licensed design professional using current wind engineering practices consistent with ASCE 7 and the design shall be approved by the authority having jurisdiction.

3.3 Slope

The Wind Design Standard for Vegetative Roofing Systems is limited to roof slope designs up to 1.5 in 12 (7 degrees) as measured at the top side of the roof membrane. For slopes greater than 1.5 in 12, a licensed design professional experienced in vegetative roof wind design shall provide design requirements and the design shall be approved by the authority having jurisdiction.

3.4 Large Openings In A Wall

For buildings having openings in a single exterior wall that in total exceed 10% of the exterior wall area, in the story located immediately below the roof, the roof shall be designed to resist the pressure created when the opening(s) are in their full, open, position. Such conditions shall be designed in accordance with Section 5.1. (See Figure 2 and Commentary 3.4)

3.5 Positive Pressure Building Systems

When HVAC equipment generates a positive pressure inside a building greater than 0.5 inches (13mm) of water, the roof system shall be designed to resist the pressure by increasing the wind load requirements in accordance with Section 5.2.

3.6 Rooftop Projections

The roof area at the base of any rooftop projection that extends more than two feet (0.6 m) above the top of the parapet and has one side longer than 4 feet (1.2 m) shall be designed in accordance with Section 5.3.

3.7 Overhangs, Eaves and Canopies

By their design, overhanging eaves and canopies are subject to greater uplift forces than the roof surface because of the impact of the air flow up the wall. Such conditions shall be designed in accordance with Section 5.4. (See Figure 3)

3.8 Membrane Requirements

The membrane specified for use in the vegetative system shall meet the recognized industry minimum material requirements for the generic membrane type, and shall meet the specific requirements of its manufacturer. Membranes not having a consensus Product Standard shall meet the specific requirements of their manufacturer. Where the membrane is not impervious to root penetration, root barriers shall be necessary.

3.9 Membrane Perimeter and Angle Change Attachment

3.9.1 At Roof Edge and Top of Parapet Wall

When the roofing system is terminated using a metal edge or coping flashing, the metal flashing shall be designed and installed in accordance with ANSI/SPRI/ES-1 except gutters. When the membrane or roof flashing is terminated on a parapet wall below the coping, the perimeter attachment used to terminate a roofing system shall be capable of withstanding the calculated load. The procedure outlined in Attachment I shall be used to measure the pullout strength. For asphaltic and fully adhered single ply membranes, it is permitted to use alternative attachments that comply with manufacturer's drawings and specifications. Roofs terminated at gutters shall meet manufactures requirement for gutter edge securement.

3.9.2 For Angle Changes

All attachments of membranes at angle changes or system type changes in a roofing system shall be capable of withstanding the calculated load. The procedure outlined in Attachment I shall be used to measure pullout strength.

3.9.3 Parapet Height

The parapet height for Vegetative Roofing Systems is the distance from the top of the growth media to the top of the parapet. When the lowest parapet height is outside of the defined corner area of the roof and is less than 70% of the height of the parapet within the defined corner area, then this lower parapet height shall be used for the design. When the lowest parapet is located outside the defined corner area of the roof and is equal to or greater than 70% of the height of the parapet within the defined corner area, then the minimum parapet height within the corner segment shall be used for the design. (See example in Figure 5)

3.9.4 Metal Edge Flashing (Gravel Stop)

When an edge flashing is used at the building perimeter, the top edge of the flashing shall be higher than the top surface of the ballast, but not less than 2 inches (50 mm) above the top surface of the growth media. Metal Edge Flashing shall be designed and installed in accordance with ANSI/SPRI/ES-1.

3.9.5 Transition

At the junction of loose-laid roof membranes with the adhered or mechanically attached membrane areas, a mechanical termination shall be provided. The termination shall resist the forces as calculated using ANSI/SPRI/ES-1.

3.10 Wind Erosion

When the growth media is not nominally covered with vegetation, provision for preventing wind erosion shall be installed in the corner and perimeter to prevent growth media from being wind blown. (See Commentary C3.10)

3.11 High Winds

When the wind speed exceeds 140 miles per hour (63 m/s) 3-second gust wind speed after all adjustments are applied, the roof design shall be designed by a licensed design professional using current wind engineering practices consistent with ASCE 7 and the design shall be approved by the authority having jurisdiction.

3.12 Wind Borne Debris

Roofs installed in regions designated by ASCE 7, or the authority having jurisdiction, as Wind Borne Debris Regions shall be designed by a licensed design professional using current wind engineering practices consistent with ASCE 7 and the design shall be approved by the authority having jurisdiction.

3.13 Ballast Requirements

Ballast shall be in accordance with the manufacturer's specification and not less than the following:

3.13.1 #4 Ballast

Ballast as defined in 2.2. For vegetated roofs when vegetation nominally covers the visible surface of the growth media or provisions have been made to prevent wind erosion from the surface, #4 ballast can consist of any of the following used independently or in combinations:

- Growth media spread at a minimum dry weight of 10 psf (49 kg/m^2) of inorganic material plus organic material;
- Interlocking contoured fit or strapped together trays containing growth media spread at minimum dry weight of 10 psf (49 kg/m^2) of inorganic material plus organic material;
- Independently set modular pre-planted or pre-grown vegetative roof trays containing 18 psf (88 kg/m^2) dry weight inorganic material plus organic material.

  Vegetation coverage or erosion protection is not required when the #4 ballast below is used.
- River bottom or course stone nominal 1-1/2 inch (38 mm) of ballast gradation size #4, or alternatively, #3, #24, #2, or #1 as specified in ASTM D-448, "Standard Sizes of Coarse Aggregate" spread at a minimum weight of 10 psf (49 kg/m^2);
- Concrete pavers independently set (minimum 18 psf (88 kg/m^2)).
- Interlocking, beveled, doweled, or contour-fit lightweight concrete pavers (minimum 10 psf (49 kg/m^2)).

3.13.2 #2 Ballast

Ballast as defined in 2.2. For vegetative roofs when vegetation nominally covers the visible surface of the growth media or provisions have been made to prevent wind erosion form the surface, #2 ballast can consist of any of the following used independently or in combinations:

- Growth media spread at a minimum dry weight of 13 psf (64 kg/m^2) of inorganic material plus organic material;
- Interlocking contoured fit or strapped together trays containing growth media spread at minimum dry weight of 13 psf (64 kg/m^2) of inorganic material plus organic material;
- Independently set modular pre-planted or pre-grown vegetative roof trays containing 22 psf (104 kg/m^2) dry weight inorganic material plus organic material.

  Vegetation coverage or erosion protection is not required when the #2 ballast below is used:
- River bottom or course stone nominal 2-1/2 inch (64 mm) of ballast gradation size #2, or alternatively, #1 as specified in ASTM D-448, "Standard Sizes of Coarse Aggregate" spread at a minimum weight of 13 psf (64 kg/m^2);
- Concrete pavers independently set (minimum 22 psf (104 kg/m^2));
- Interlocking, beveled, doweled, or contour-fit lightweight concrete pavers (minimum 10 psf (49 kg/m^2)).

4.0 Design Options

The vegetative roof wind designs include, but are not limited to, the generic systems shown below. Other systems, when documented or demonstrated as equivalent with the provisions of this standard, shall be used when approved by the authority having jurisdiction. (See Commentary Section 4.0) The designs listed in Sections 4.1 and 4.2 are the minimum specifications.

4.1 Ballasted Vegetative Roofing Systems

See Section 2.2 for definition.

4.1.1 System 1

The installed membrane shall be ballasted with #4 ballast. (See Section 3.13.1)

4.1.2 System 2

The installed membrane shall be ballasted as follows:

4.1.2.1 Corner Area (See Section 2.6.2 for definition of corner area)
The installed membrane in the corner area shall be ballasted with #2 ballast. (See Section 3.13.2 and Figure 1)

4.1.2.2 Perimeter (See Section 2.6.3 for definition of perimeter area)
The installed membrane in the perimeter area shall be ballasted with #2 ballast. (See Section 3.13.2 and Figure 1)

4.1.2.3 Field (See Section 2.6.4 for definition of field)
In the field of the roof, the installed membrane shall be ballasted with #4 ballast. (See Section 3.13.1) For areas designated as wind debris areas, #2 ballast shall be the minimum size-weight ballast used.

4.1.3 System 3: Install the system as follows:

4.1.3.1 Corner Area (See Section 2.6.2 for definition of corner area)
In each corner area, an adhered or mechanically attached roof system designed to withstand the uplift force in accordance with ANSI/ASCE 7 or the local building code, shall be installed in accordance with the provisions for the corner location with no loose stone, unprotected growth media or unprotected modular vegetative roof trays placed on the membrane. (See Figure 1 and Commentary Section 4.0)

When a protective covering is required in the corner area, a fully adhered membrane system shall be used. Over the fully adhered membrane, install minimum 22 psf (104 kg/m^2) pavers, or other material approved by the authority having jurisdiction. Mechanically fastened membrane systems shall not be used when a protective covering is required. (See Commentary 4.1.3.1)

4.1.3.2 Perimeter (See Section 2.6.3 for definition of perimeter area)
In the perimeter area, an adhered or mechanically attached roof system designed to withstand the uplift force in accordance with ASCE 7 or the local building code, shall be installed, in accordance with the provisions for the perimeter location with no loose stone, growth media or modular vegetative roof trays placed on the membrane.

When a protective covering is required in a perimeter area, a fully adhered membrane system shall be used. Over the fully adhered membrane install minimum 22 psf (104 kg/m^2) pavers or other material approved by the authority having jurisdiction. Mechanically fastened membrane systems shall not be used when a protective covering is required. (See Commentary 4.1.3.1)

4.1.3.3 Field (See Section 2.6.4 for definition of field)
In the field of the roof, install #2 ballast. (See Section 3.13.2)

4.1.3.4 Transition

At the junction of loose-laid roof membranes with the adhered or mechanically attached membrane areas, a mechanical termination shall be provided. The termination shall resist the forces as calculated using Attachment I.

4.2 Protected Vegetative Roofing Systems

(Systems where the insulation is installed over the waterproofing membrane see Commentary 4.2 for description)

The protected membrane roof wind designs include, but are not limited to, the generic systems shown below. Other systems, which comply with the provision of this specification, shall be permitted when approved by the authority having jurisdiction.

4.2.1 System 1 and System 2

When the design criteria based on wind speed, building height, and parapet height and exposure, require a System 1 or System 2 design, the ballasting procedures for that respective system shall be according to Sections 4.1.1 and 4.1.2, respectively.

4.2.2 System 3

When the design criteria, based on wind speed and building height, parapet height and exposure require a System 3 design, a minimum 24" (0.6 m) parapet height (See Section 3.9.3 for determining parapet height) is required and the installation procedures for System 3 as defined in Section 4.1.3 above shall be followed. In addition, the insulation that is installed over the fully adhered perimeter and corner areas (mechanically attached systems shall not be used) shall be ballasted with 22 psf (104 kg/m^2) pavers (minimum) or other material approved by the authority having jurisdiction.

4.3 Vegetative Roofing System Using A Fully Adhered Membrane Roofing System: (See Commentary 4.3 for description)

4.3.1. System 1, System 2 and System 3

When the design criteria based on wind speed, building height, and parapet height and exposure, require a System 1 System 2 or System 3 design, the ballasting procedures for that respective system shall be according to Sections 4.1.1, 4.1.2 and 4.1.3 respectively.

4.3.2. Wind Speed Coverage

The wind speed allowed for System 1 and System 2 as defined in Sections 4.1.1 and 4.1.2 shall be increased 10 mph (4.5 m/s) over the stated values in Table 2.

5.0 Design Provisions

5.1 Large Openings in a Wall (See Section 3.4 for description)

When a fully adhered membrane roof system is not used and the total area of all openings in a single exterior wall is between 10 and 50 percent of that wall area in the story located immediately below the roof, the following roof location shall be designed as a corner area of the respective System 2 or System 3 designs. For System 1 designs, the corner area specifications of a System 2 design for the rectangular area shall be used.

The area where additional ballast is installed is defined as a rectangular roof area located directly above the wall opening; the enhanced rectangular area has as its width 1.5 times the width of the opening and as its depth 2.0 times the width of the opening. (See Figure 2)

When a fully adhered membrane roof system is not used and the total area of all openings in a single exterior wall exceeds 50 percent of that wall area in the story located immediately below the roof, the roof shall be designed as having a pervious deck. Under these conditions, the rooftop, as identified in the Design Tables as a System 1 design (See Table 2), shall be upgraded to the next level of resistance to the wind. That is, a System 1 design shall be

upgraded to a System 2 design, a System 2 design shall be upgraded to a System 3 design, and a System 3 design shall be upgraded to a roof system that is designed to resist the uplift loads in accordance with ASCE 7 or the local building code. The rectangular roof area over the opening shall be designed as a corner section.

5.2 Positive Pressure in Building Interior (See Section 3.5 for description)
For non-adhered membrane systems where positive pressure conditions between 0.5 (125 Pa) and 1.0 inch (250 Pa) of water are present in a building, the applicable roof system design, as identified in the Design Tables (See Table 2), shall be upgraded to a higher level of resistance to wind. Under these conditions, the roof top wind speed shall be increased by 20 mph (9 m/s) from the basic wind speed from the wind map. (See Attachment II) Under these conditions a building roof located in a 90 mph (40 m/s) wind zone would be upgraded to 110 mph (49 m/s), etc. Installation shall follow all of the requirements for the higher design wind. When positive pressures are greater than 1.0 inch (250 Pa) of water, the design of the roof shall be designed by a licensed design professional using current wind engineering practices consistent with ASCE 7, and the design shall be approved by the authority having jurisdiction.

5.3 Rooftop Projections (See Section 3.6 for description)
When rooftop projections rise 2 feet (0.6 m) or more above the parapet height and have at least one side greater than 4 feet (1.2 m) in length, the roof area shall be protected from wind erosion. (See Commentary 3.10)

5.4 Overhangs, Eaves and Canopies

5.4.1 Impervious Decks (See Section 2.8 for description)
When a deck is impervious, overhang, eaves and canopy shall be defined as the following: Eaves and overhangs: The overhang or eave shall be considered the perimeter of the applicable design. (See Figure 3) Canopies: The entire canopy area shall be designed as a corner section of the applicable design.

5.4.2 Pervious Decks (See Section 2.9 for description)
When the deck is pervious and a fully adhered membrane roof system is not used, the design of the entire overhang, eave or canopy area shall be upgraded to the corner design of the next level system for wind resistance over the applicable design. (See Figure 4) For this situation, the entire overhang, eave or canopy of a System 1 Design shall be upgraded to a System 2 Corner Design; the entire overhang, eave or canopy of a System 2 Design shall be upgraded to a System 3 Corner Design; the entire overhang, eave or canopy of a System 3 Design shall be designed to the System 3 Corner Design.

In addition, the main roof area extending in from the overhang or eave shall be ballasted to the applicable system design as though the overhang did not exist. This means the appropriate corner and perimeter areas are to be ballasted in accordance with Section 4.0 in addition to the overhang or eave area treatment as described above. (See Figure 4)

When a fully adhered membrane roof system is used, the design shall follow the impervious deck design. (See Section 5.4.1)

5.5 Exposure D (See Section 2.7.3 for description)
For buildings located in Exposure D, the roof design as identified in the Design Tables (See Table 2) shall be upgraded to a higher level of resistance to wind. Under Exposure C the roof top wind speed shall be increased by 20 mph (9 m/s) from the basic wind speed from the wind map. (See Attachment II) Under these conditions a building roof located in a 90 mph (40 m/s) wind zone would be upgraded to 110 mph (49 m/s.) Installation shall follow all of the requirements for the higher design wind.

5.6 **Importance Factor** (See Section 2.10 for description)
For buildings fitting category III or IV as per Section 2.10, the applicable roof system design as identified in the Design Tables (See Table 2) shall be upgraded to a higher level of resistance to wind. The roof top wind speed shall be increased by 20 mph from the basic wind speed from the wind map. (See Attachment II) Under these conditions a building roof located in a 90 mph wind zone would be upgraded to 110 mph etc. Installation shall follow all of the requirements for the higher design wind.

6.0 Determination of Vegetative System Roof Design

To determine the vegetative design for a given building, the following process shall be followed (See Commentary):

6.1 Based on the building location, the basic wind speed shall be determined following Section 2.5 and exposure from Section 2.7.

6.1.1 The building height shall be determined by following Section 3.2 and the parapet height from Section 3.9.3.

6.1.2 Knowing the wind speed, building height, parapet height, Importance factor and exposure, determine the System Design (1, 2 or 3) using the appropriate Design Table contained in Table 2.

6.1.3 Having determined the System from the Design Tables (Table 2), use Section 4.0, Design Options, to determine the ballasting requirements based on the type of roof system as described in Sections 4.1, 4.2 & 4.3.

6.1.4 Then Section 5.0, Design Provisions shall be reviewed to determine the necessary enhancements to the systems' ballasting requirements. These provisions are the accumulative addition to the base design from the Design Tables.

7.0 Maintenance

Vegetative Roof Systems shall be maintained to provide vegetation that nominally covers the visible surface of the growth media. When wind scour occurs to an existing vegetative roof system and the scour is less than 50 ft^2 (4.6 m^2), the growth media and plants shall be replaced. For scour areas greater than ft^2, the vegetative roof design shall be upgraded a minimum of one system design level per Section 4.0. The requirement for maintenance shall be conveyed by the designer to the building owner, and it shall be the building owner's responsibility to maintain the Vegetative Roofing System.

Table 2
Design Tables[3]

A. From 2 inch high to less than 6.0 inch high parapet

Building height Feet	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	100	105	115	115	130	140
15–30	100	105	110	115	130	140
30–45	90	100	100	115	130	140
45–60	No	No	95	115	120	140
60–75	No	No	90	110	120	120
75–90	No	No	No	No	No	No
90–105	No	No	No	No	No	No
105–120	No	No	No	No	No	No
120–135	No	No	No	No	No	No
135–150	No	No	No	No	No	No

B. For parapet heights from 6.0 to less than 12.0 inches

Building height Feet	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	100	105	115	115	130	140
15–30	100	105	110	115	130	140
30–45	90	100	100	115	130	140
45–60	No	No	95	115	120	140
60–75	No	No	90	110	120	130
75–90	No	No	No	No	No	No
90–105	No	No	No	No	No	No
105–120	No	No	No	No	No	No
120–135	No	No	No	No	No	No
135–150	No	No	No	No	No	No

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

[3] Wind speed reference see Section 2.5. Wind speeds in above tables are “3 second gust” measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

Design Tables[4]

C. For parapet heights from 12.0 to less than 18.0 inches

Building height Feet	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	100	105	115	115	140	140
15–30	100	105	110	115	140	140
30–45	90	105	105	115	140	140
45–60	No	90	95	115	130	140
60–75	No	90	90	110	120	130
75–90	No	No	90	110	110	120
90–105	No	No	90	100	110	110
105–120	No	No	85	100	100	110
120–135	No	No	No	100	100	110
135–150	No	No	No	95	100	110

D. For parapet heights from 18.0 to less than 24.0 inches

Building height Feet	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	110	110	120	120	140	140
15–30	110	110	110	120	140	140
30–45	95	110	110	120	140	140
45–60	85	110	95	120	140	140
60–75	No	90	90	110	140	140
75–90	No	90	90	110	120	130
90–105	No	No	90	100	110	120
105–120	No	No	90	100	110	110
120–135	No	No	90	100	110	110
135–150	No	No	No	100	100	110

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

[4] Wind speed reference see Section 2.5. Wind speeds in above tables are “3 second gust” measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

Design Tables[5]

E. For parapet heights from 24.0 to less than 36.0 inches

Building height Feet	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	110	110	120	120	140	140
15–30	110	110	120	120	140	140
30–45	95	110	110	120	140	140
45–60	85	110	100	120	140	140
60–75	No	90	90	120	130	140
75–90	No	90	90	110	130	140
90–105	No	No	90	100	120	140
105–120	No	No	90	100	120	140
120–135	No	No	90	100	120	140
135–150	No	No	90	100	110	140

F. For parapet heights from 36.0 to less than 72 inches

Building height Feet	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	110	110	120	120	140	140
15–30	110	110	120	120	140	140
30–45	100	110	120	120	140	140
45–60	95	110	105	120	140	140
60–75	90	100	100	120	140	140
75–90	90	100	100	120	140	140
90–105	90	90	100	110	130	140
105–120	85	90	100	110	130	140
120–135	85	90	100	110	130	140
135–150	No	85	100	110	130	140

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

[5] Wind speed reference see Section 2.5. Wind speeds in above tables are “3 second gust” measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

Design Tables[6]

G. For parapet heights from 72 inches and above

Building height Feet	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	110	110	120	120	140	140
15–30	110	110	120	120	140	140
30–45	110	110	120	120	140	140
45–60	100	110	120	120	140	140
60–75	95	110	115	120	140	140
75–90	90	100	110	120	140	140
90–105	90	100	110	120	140	140
105–120	90	100	110	120	130	140
120–135	90	100	110	120	130	140
135–150	85	100	110	110	130	140

Design Tables—Metric

A. From 50 mm height to less than 150 mm parapet height

Building height Feet	Maximum allowable wind speed (m/s)					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	45	47	51	51	58	63
5–9	45	47	49	51	58	63
9–14	40	45	45	51	58	63
14–18	No	No	47	51	54	63
18–23	No	No	40	49	54	63
23–27	No	No	No	No	No	54
27–32	No	No	No	No	No	No
32–37	No	No	No	No	No	No
37–41	No	No	No	No	No	No
41–46	No	No	No	No	No	No

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

[6] Wind speed reference see Section 2.5. Wind speeds in above tables are “3 second gust” measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

Design Tables—Metric[7]

B. For parapet heights from 150 mm to less than 300 mm

Building height Feet	Maximum allowable wind speed (m/s)					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	45	47	51	51	58	63
5–9	45	47	49	51	58	63
9–14	40	45	45	51	58	63
14–18	No	No	47	51	54	63
18–23	No	No	40	49	54	58
23–27	No	No	No	No	No	58
27–32	No	No	No	No	No	No
32–37	No	No	No	No	No	No
37–41	No	No	No	No	No	No
41–46	No	No	No	No	No	No

C. For parapet heights from 0.3 m to less than 0.45 m

Building height Feet	Maximum allowable wind speed (m/s)					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	45	47	51	51	63	63
5–9	45	47	49	51	63	63
9–14	40	47	47	51	63	63
14–18	No	No	42	51	58	63
18–23	No	No	40	49	54	58
23–27	No	No	40	49	49	54
27–32	No	No	40	45	49	49
32–37	No	No	38	45	45	49
37–41	No	No	No	45	45	49
41–46	No	No	No	42	45	49

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

[7] Wind speed reference see Section 2.5. Wind speeds in above tables are “3 second gust” measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

Design Tables—Metric[8]

D. For parapet heights from 0.45 m to less than 0.60 m

Building height Feet	Maximum allowable wind speed (m/s)					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	49	49	54	54	63	63
5–9	49	49	49	54	63	63
9–14	42	49	49	54	63	63
14–18	38	49	42	54	58	63
18–23	No	40	40	49	54	58
23–27	No	40	40	49	49	54
27–32	No	No	40	45	49	49
32–37	No	No	40	45	45	49
37–41	No	No	40	45	45	49
41–46	No	No	No	45	45	49

E. For parapet heights from 0.60 m to less than 1 m

Building height Feet	Maximum allowable wind speed (m/s)					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	49	49	54	54	63	63
5–9	49	49	54	54	63	63
9–14	42	49	49	54	63	63
14–18	38	49	45	54	63	63
18–23	No	40	40	54	58	63
23–27	No	40	40	49	58	63
27–32	No	No	40	45	54	63
32–37	No	No	40	45	54	63
37–41	No	No	40	45	54	63
41–46	No	No	40	45	49	58

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

[8] Wind speed reference see Section 2.5. Wind speeds in above tables are “3 second gust” measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

Design Tables—Metric[9]

F. For parapet heights from 1 m to less than 2 m

Building height Feet	Maximum allowable wind speed (m/s)					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	49	49	54	54	63	63
5–9	49	49	54	54	63	63
9–14	45	49	54	54	63	63
14–18	42	49	47	54	63	63
18–23	40	45	45	54	63	63
23–27	40	45	45	54	63	63
27–32	40	40	45	49	58	63
32–37	38	40	45	49	58	63
37–41	38	40	45	49	58	63
41–46	No	38	45	49	58	63

G. For parapet heights from 2 m and above

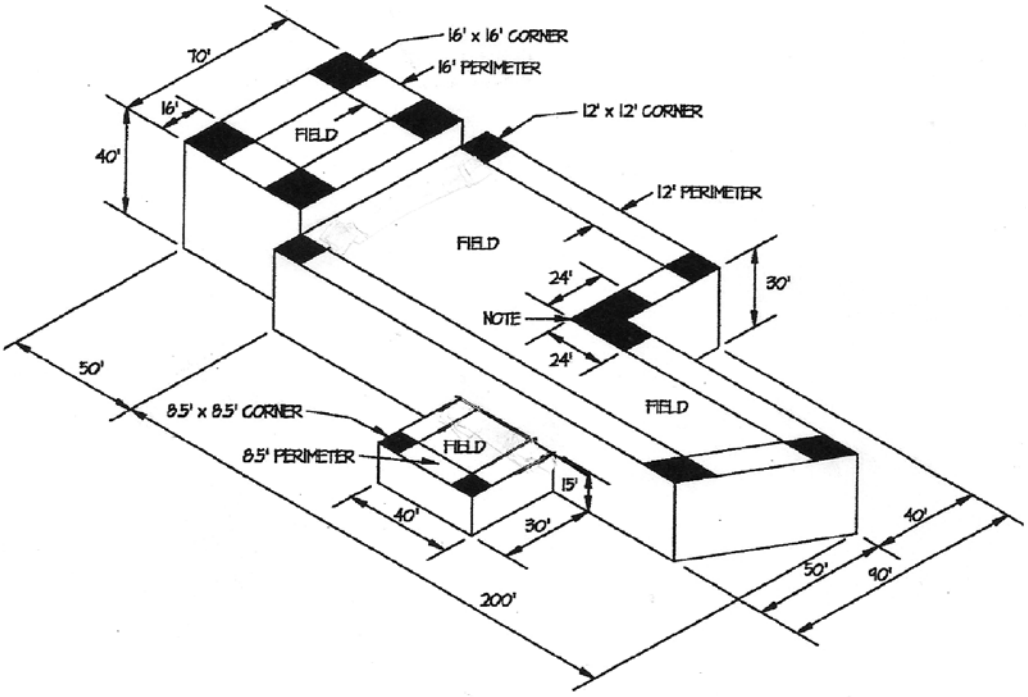
Building height Feet	Maximum allowable wind speed (m/s)					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	49	49	54	54	63	63
5–9	49	49	54	54	63	63
9–14	49	49	54	54	63	63
14–18	45	49	54	54	63	63
18–23	42	49	51	54	63	63
23–27	40	45	49	54	63	63
27–32	40	45	49	54	63	63
32–37	40	45	49	54	58	63
37–41	40	45	49	54	58	63
41–46	38	45	49	49	58	63

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

[9] Wind speed reference see Section 2.5. Wind speeds in above tables are “3 second gust” measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

Figure 1

Roof Layout—Systems 2 & 3



NOTE:
REENTRANT CORNERS ARE LARGER THAN OTHER CORNERS.

	LOW ROOF	MAIN ROOF	HIGH ROOF
ROOF HEIGHT (FT.)	15	30	40
40% OF BUILDING HEIGHT	6.0 FT.	12 FT.	16 FT.
CORNER LENGTH	8.5 FT. (a)	12 FT.	16 FT.
PERIMETER WIDTH	8.5 FT. (a)	12 FT.	16 FT.

(a) 8.5' MINIMUM CONTROLS

Figure 1

Roof Layout System 2 & 3

Metric Dimensions

	Low roof	Main roof	High Roof
Roof height meters	4.6	9	12
40% of building height	2	3.6	5
Corner length	2.6 (a)	3.6	5
Perimeter width	2.6 (a)	3.6	5

(a) 2.6 minimum controls

Other Dimensions

Description	IP	Metric m
High Roof		
Corner	16' x 16'	5m x 5m
Perimeter	16'	5 m
Width	70'	21.3 m
Height	40'	12 m
Main Roof		
Corner	12' x 12'	3.6 m x 3.6 m
Perimeter	12'	3.6 m
Height	30'	9 m
Re-entrant Corner	24' x 24'	7.3 m x 7.3 m
Off set	40'	12 m
Width	90'	27.4 m
Length	200'	61 m
Low Roof		
Corner	8.5' x 8.5'	2.6 m
Perimeter	8.5'	2.6 m
Width	30'	9 m
Height	15'	4.6 m

Figure 2

Large Openings in a Wall

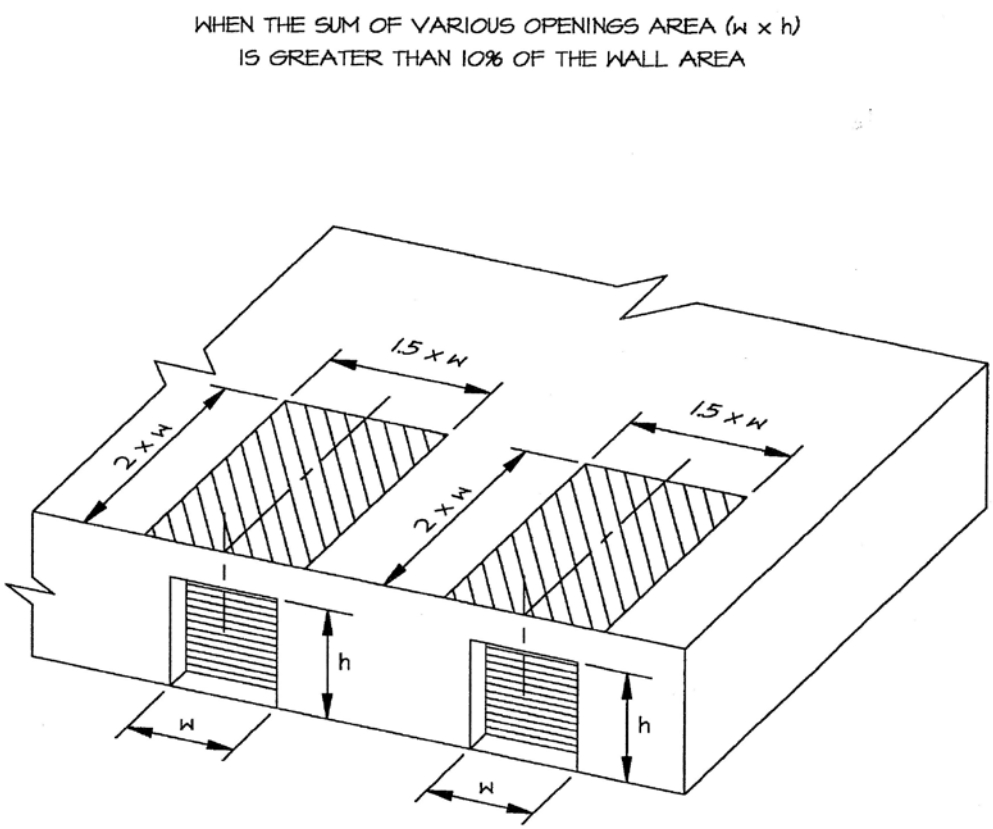
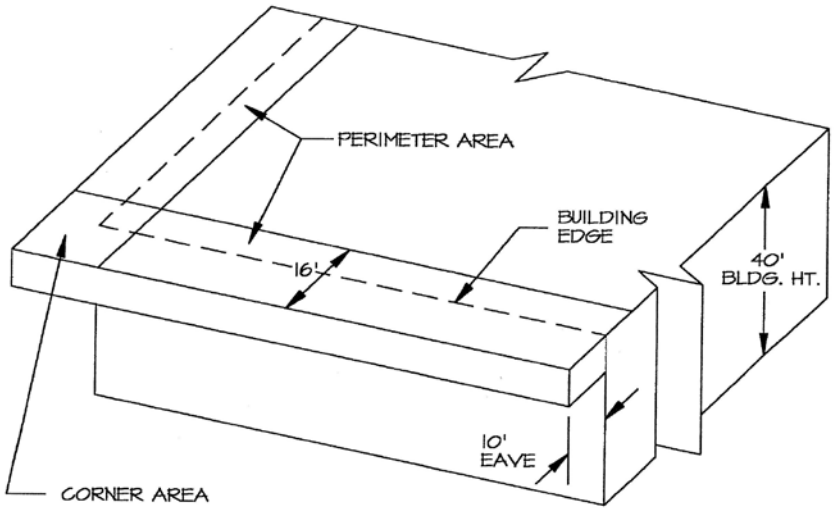


Figure 3

Canopies and Overhang Eaves
Impervious Decks

For Systems 2 & 3



EAVE = 10 FT.

CORNER AREA = .4 x THE BUILDING HEIGHT
(OR 8.5 FT. MINIMUM)
16 FT. FOR THIS EXAMPLE.

PERIMETER AREA = .4 x THE BUILDING HEIGHT
(OR 8.5 FT. MINIMUM)
16 FT. FOR THIS EXAMPLE.

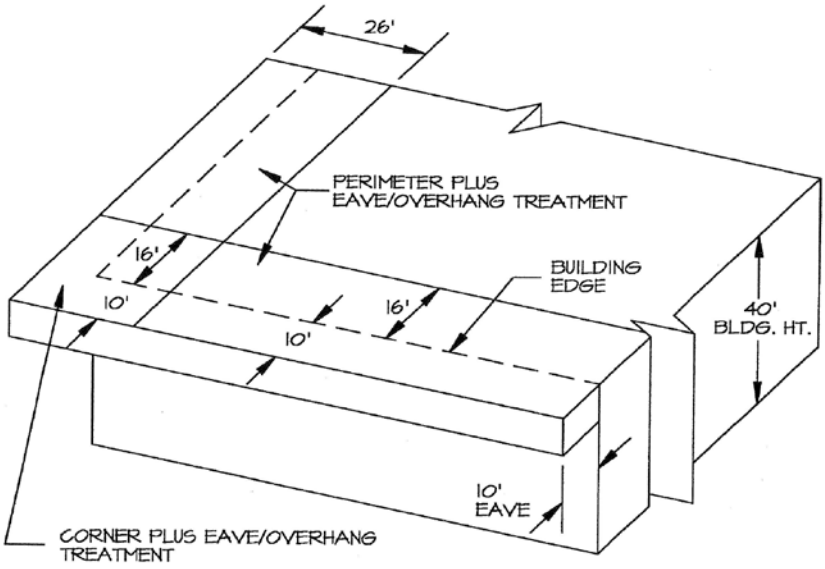
Metric Dimensions

Description	IP	Metric m
Building height	40'	12
Eave	10'	3
Corner and perimeter area	8.5' minimum	2.6
Corner and perimeter area	16' for this example	5

Figure 4

Canopies and Overhang Eaves
Pervious Decks

For Systems 1, 2 & 3



EAVE = 10 FT.

CORNER AREA = .4 x THE BUILDING HEIGHT PLUS
THE OVERHANG AREA
(OR 8.5 FT. MINIMUM)
26 FT. FOR THIS EXAMPLE.

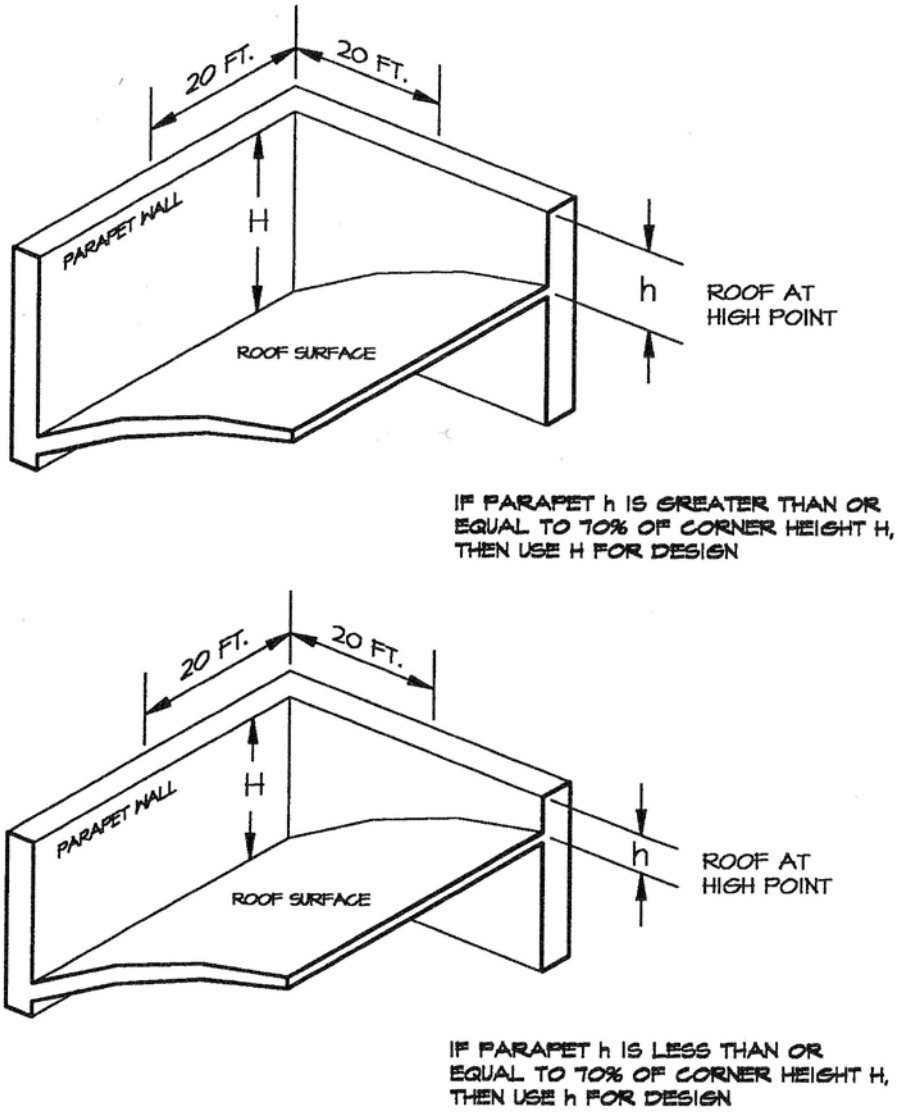
PERIMETER AREA = .4 x THE BUILDING HEIGHT PLUS
THE OVERHANG AREA
(OR 8.5 FT. MINIMUM)
26 FT. FOR THIS EXAMPLE.

Metric Conversion

Description	IP	Metric m
Building height	40'	12
Eave	10'	3
Perimeter	16’	5
Corner and perimeter area	8.5' minimum	2.6
Corner and perimeter area	66' for this example	8

Figure 5

Parapet Height Design Consideration



Metric Conversion

Description	IP	Metric m
Corner	20'	6

Attachment I

SPRI Test RE-1
Test for Roof Edge Termination of Ballasted or Mechanically attached Roofing Membrane Systems

- Fully adhered systems or systems using an alternative method of terminating the roof at the edge shall not require this test.
- For ballasted roofs, the edge device assembly shall provide a minimum load resistance **(F)** of 100 lbs/ft (134 kg/m).

  F=100 for ballasted roofs
- For mechanically attached systems the distance (**D**) of the first row of fasteners parallel to the edge away from corner regions, and distance ($\mathbf{D}_{corner}$) of the first row of fasteners parallel to the edge in the building corner regions shall be used in the following equations to determine the load resistance which shall be the greater of:
  - **F=** (**D**) (**P**) ÷2 and
  - $\mathbf{F}_{corner}$ = 1.5($\mathbf{D}_{corner}$)(**P**) ÷2
  - The edge device assembly shall provide a minimum load resistance which is the maximum of **F** or $\mathbf{F}_{corner}$

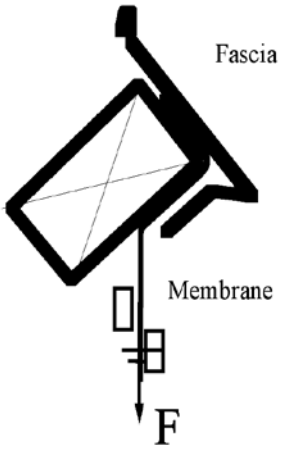
Testing
Load resistance shall be tested using the following method.

Method
A minimum 12-inch (300 mm) wide mock up of the edge device system shall be constructed and mounted on the base of a tensile testing device so the membrane is pulled at a 45° angle to the roof deck to simulate a billowing membrane. For devices in which fasteners are part of the membrane securement, at least two such fasteners shall be included in a balanced sample. However, no more fasteners shall be installed than would be typically installed in field conditions.

The jaws of the tester shall be connected to two bars that clamp the membrane securely between them so that the load is distributed uniformly along the width of the membrane. The tester is loaded until failure occurs. Failure is defined as any event that allows the membrane to come free of the edge termination or the termination to come free of its mount. The roof edge termination strength is deemed satisfactory if the test force at failure on a 12-inch (300 mm) wide sample meets or exceeds the force, **F**, as specified above.

For further information see **ANSI/SPRI/ES-1**.

Test Schematic for Test RE-1



Attachment II
Basic Wind Speed Map
ASCE 7
Minimum Design Loads for Buildings and Other Structures, Figure 6

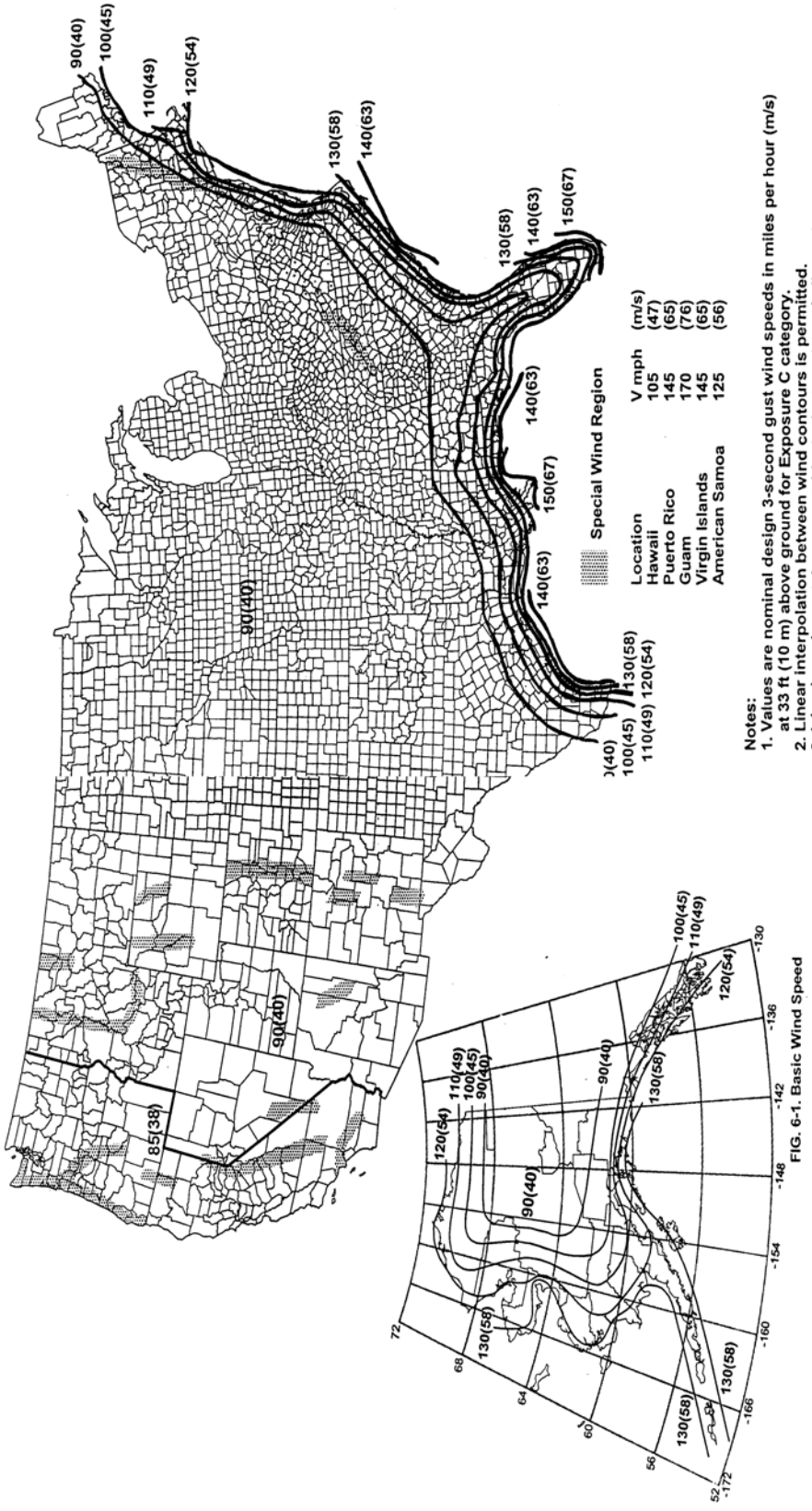


FIG. 6-1. Basic Wind Speed

Commentary to SPRI RP-14

This Commentary consists of explanatory and supplementary material designed to assist designers and local building code committees and regulatory authorities in applying the requirements of the preceding standard.

The Commentary is intended to create an understanding of the requirements through brief explanations of the reasoning employed in arriving at them.

The sections of this Commentary are numbered to correspond to the sections of the RP-14 standard to which they refer. Since it is not necessary to have supplementary material for every section in the standard, there are gaps in the numbering of the Commentary.

All metric conversions within the standard are “soft metric” within the tolerances of the inch pounds dimensions.

Metric engineering lengths: mm = millimeter, m = meter

Wind speed = m/s meters per second

Weight = kg/m^2

Pressure = Pa = Pascal

All conversions are based upon the 2009 ASHRAE Book of Fundamentals.

C1.0 Introduction

Green roofs, also known as vegetative roofs, eco-roofs, and rooftop gardens fall into two main categories -intensive, primarily defined as having more than 6 inches (0.15 m) of growing medium, greater loading capacity requirements, and greater plant diversity, and extensive, defined as having less than 6 inches (0.15 m) of growing media, less loading capacity requirements and fewer options for plants.

These systems are considered to be roof gardens or landscaped roofs or part of a roof garden or landscaped roof. Vegetative roofs are complex systems consisting of many parts critical to the functioning of the system. A few of the components generally found in these systems include, but are not limited to: insulation, waterproofing membrane, protection mats/boards, root barrier, drainage layer, filter fabric, growth media, and vegetations. A vegetative roof may consist of more than just growth media and vegetation with such things as walkways, water features, stone decoration, and benches included. Requirements between manufacturers vary, and some items may be optional.

RP-14 is a minimum standard and may be enhanced by designer or manufacture requirements.

A Vegetative Roofing System may cover the whole roof or share a portion of the surface with a conventional roofing system. They are versatile systems with many strong attributes including storm water management, reduced heat island effect, and aesthetics to name a few.

When large shrubs and trees are used attention should be given to ensure adequate anchorage and structural support.

While the standard is intended as a reference for designers and installers, the design responsibility rests with the “designer of record.”

C.2.0 Definitions

C2.1 Vegetative Roofing Systems

A Vegetative Roofing System consists of vegetation, growth media, drainage system, and waterproofing over a roof deck. Where the membrane is not impervious to root penetration, root barriers shall be necessary. The system can be considered to be a roof garden or landscaped roof. Systems that do not have live vegetation do not fit this definition. Membranes are permitted to be loose laid, mechanically attached or partially adhered to the roof.

The design tables are based on the premise that the ballast will not blow off the roof at the design wind speed. The weight of growth media or other ballast may not always be adequate to resist uplift loads that result from some internal or other under membrane pressures. There shall be no direct path from exterior of walls or interior of building to the space directly beneath

the membrane. This standard is based on having no deliberately installed air retarders for all systems with 10-lbs./sq. ft or more of ballast weight. For lighter weight systems, air retarders are required, but this standard assumes the air retarder is imperfect. Reference # 7, can provide guidance on elimination of direct paths for air pressurization of membranes. This standard recognizes that a fully adhered roofing membrane will eliminate direct paths for air pressurization to the underside of the growth media. The growth media holding capability of the root systems and the wind blocking effects of the plants are also taken into account.

Several wind performance tests on Vegetative Roofing Systems have been conducted. They have shown that the systems are very stable when vegetation is present or when a soil tackifier or erosion mat is included in non-vegetated areas. See References #24, 29 and 30.

There are several types of vegetative roofs that are generically described in Section 4.

C2.2 Ballast

The ballast used in roofing systems is made up of a number of types. For the growth media, the designs that follow in the document consider the exposed media is the worse case scenario therefore the wind erosion mats and soil tackifiers are used to cover the exposed media to prevent wind scour. However, when the plants cover the media, the media gets the benefit of the windbreak provided by the plants and the holding power of the root system in the zone around the plants. Combinations of large aggregate or stones and growth media can also be considered as part of the ballast weight when they are protected by vegetation.

Ballast is any object having weight that is used to hold or steady an object. In ballasted roofing systems, the most common ballast used is stone. However, materials such as concrete pavers, lightweight concrete pavers, rubber pavers, and weighted insulation panels are often used to ballast loose laid roofing systems. With the advent of vegetative roofs, growth media and pre-constructed vegetative modular trays also act as ballast. These ballast systems have been organized into categories based on their ability to resist the forces of the wind.

C2.5 Basic Wind Speed

The wind speed used in this document is from ASCE 7. When the current code in the area of the building being constructed is not ASCE 7, but an older ASCE wind map, the commonly used conversion is; fastest mile plus 20 mph (8.9 m/s) is approximately equal to the 3-second gust speed. When more detail is needed, consult ASCE 7.

Ballasted roofs are not recommended where the basic wind speed is greater than 140 mph (63 m/s). However they can be designed using Reference 1, consultation with a wind design engineer, or wind tunnel studies of the specific building and system.

- Special Wind Regions (mountains or valleys): Refer to Section C6.5.4.1 of the ANSI/ASCE 7 Commentary.
- The intensifying effects of topography (hills or escarpments) are to be accounted for. Information on speed up over hills and escarpments can be found in ASCE 7 Minimum Design Loads for Buildings and Other Structures; section 6.5.7. ASCE 7 provides data for wind pressure increase, but does not give specific advice for wind speed tables as are used in this document. Consult a wind engineer to determine the roof top wind speed. The increase in wind speed due to hills is the K_{zt} factor from the above ASCE reference. (i.e. multiply the wind speed by K_{zt} and use this new wind speed as the design wind speed.) A conservative approach is to add the height of the hill to the height of the building. Hills less than 60 ft (18 m) above the surrounding terrain in Ground Roughness A & B and 15 ft (4.6 m) above the surrounding terrain in Ground Roughness C & D, need not be considered.

C2.6 Wind Borne Debris Regions

ASCE 7 defines these regions as areas within hurricane regions located:

1. within one mile of the coastal high water line where the basic wind speed is equal or greater than 110 mph (49 m/s) and in Hawaii; or
2. in areas where the basic wind speed is equal to or greater than 120 mph (54 m/s). This document requires the use of #2 Ballast only, in these areas. For vegetative roofs used in this area, consideration shall be taken to minimize woody vegetation that could become wind borne debris. Trees, palms, woody bushes could have limbs break off in the wind leading to building damage.

The "authority having jurisdiction" is the only source for approval of designs not covered in this document. ASCE 7 gives guidance on how non-standard conditions should be evaluated. (See Reference 1, or conduct wind tunnel studies in accordance with ASCE 7 for information to determine requirements for designs or systems not covered.)

C2.6.1 Corners are not always square. They are formed by the intersection of two walls. This document is using the definition of the angle formed by the two walls as being between 45 and 135 degrees to signify a corner. The designer may choose to include angles outside this range as a corner.

C2.6.2 The corners and perimeters used in this document are 0.4 times the
C2.6.3 building height, which is greater than the 0.1 times the building height in ASCE 7. This 0.4 factor adds a significant conservative factor for taller buildings. This is particularly true for tall narrow buildings where a 90 ft. (27 m) high roof designed to this standard would require a 36 ft. (11 m) wide perimeter.

C2.7 Exposure Categories/Surface Roughness

A roof being designed in a city center may be either too tall to benefit from the protection of adjacent buildings, or is low enough to be affected by wind channeling between them. Wind profiles are much more complex in city centers, and therefore not necessarily subject to the more rational directionality as studied in the wind tunnels. Choosing Exposure Category C reduces the wind speeds at which the system is safely installed. Because of the effects on ballasted roof systems performance if ballast disruption were to occur, city centers and individual tall buildings should be evaluated to determine if a more stringent wind exposure category should be used in the design. ASCE 7 has photo's that show the various categories in the Commentary C6.5.6.

C2.8 Impervious Deck

The first thing that comes to mind when thinking about materials such as poured concrete and gypsum is that they are impervious to the flow of air. However, in deck constructions there are from time to time penetrations that are cut through these decks that air can pass through. There are also constructions where the expansion joint is located at the deck-wall junction or the wall construction itself (stud or cavity wall construction) can let air in under the roof system. The designer should investigate to assure the "impervious construction" is truly that. All penetrations (new or existing) are to be sealed to prevent the system from pressurization. Unless proper detailing is considered the system is to be treated as pervious. (See Reference 7 for detailing)

C2.9 Pervious Decks can result in significant uplift loads on ballasted systems. This can be particularly true if the building is pressurized, or the building is designed as a partially enclosed structure. Partially enclosed areas directly beneath a roof area which allow wind pressure to develop through open soffits, windows of pervious structures, should be considered for enhanced design as described in paragraph 5.4.2 or incorporate an air retarding system as described in Reference 7.

C3.0 General Design Considerations and System Requirements

C3.2 Building Height

Vegetative roofs with heights greater than 150 feet (46 m) can be designed using Reference 1, consultation with a wind design engineer, or wind tunnel studies of the specific building and system.

C3.4 Large Openings In A Wall

As an example, because of the great amount of air leakage that often occurs at large hanger doors and roll-up doors (e.g., a warehouse with multiple truck docks), the designer should utilize the provisions of Section 5.1 for design enhancements.

Glazed openings that are sited in hurricane-prone regions with a basic wind speed of 110 mph (49 m/s) or greater, or in Hawaii, are either required to be designed for missile impact or the building should be designed for higher internal pressure. Glazing below 60 ft (18 m) is very vulnerable to breakage from missiles unless the glazing can withstand reasonable missile loads and subsequent wind loading, or the glazing is protected by suitable shutters. Glazing above 60 ft (18 m) is also somewhat vulnerable to missile damage. The designer should take this into consideration and follow the design provision of Section 5.1. See ASCE-7 for further discussion.

C3.5 Positive Building Pressure

Although a rarely used at the action level and is likely only found on hospitals, research facilities and computer centers, pressure in a building can become pressure beneath the membrane. When the pressure under the membrane increases it can reduce the effect of the ballast weight. Determining the system design with a 20 mph (8.9 m/s) increase in wind speed provides a simplified way to increase the resistance of the system to this potential increased pressure beneath the membrane. An alternate method is to add approximately 3 lbs (1.4 kg) of ballast for every 0.5 inches (125 Pa) of water interior pressure increase. The Building owner and/or a licensed design professional should consult with the mechanical design engineer for design and/or operating conditions of HVAC equipment, which may lead to positive pressure beneath the membrane.

C3.8 Membrane Requirements

The membrane specified for use in the vegetative system shall meet the recognized industry minimum material requirement listed below for the generic membrane type, and shall meet the specific requirements of its manufacturer. Membranes not having a consensus Product Standard shall meet the specific requirements of their manufacturers.

EPDM	*ASTM D-4637*
PVC	*ASTM D-4434*
TPO	*ASTM D-6878*
Hypalon/CPE/PIB	*ASTM D-5019*
KEE	*ASTM D-6754*
SBS MB	*ASTM D-6164, 6163, 6162*
APP	*ASTM D-6222, 6223, 6509*
BUR	*As defined by the standards referenced in the International Building code*
	Fully Adhered Hot-Applied Reinforced Waterproofing System ASTM D 6622

Certain membranes contain plasticizers that may be extracted from the membrane. They may require a slip-sheet between the membrane and some insulations and growth media.

C3.9 Membrane Termination

This standard addresses the basic requirements for membrane termination. For more details on the design of edging and attachment of nailers, see Attachment I, and SPRI's document "ANSI/SPRI ES-1 Wind Design Standard for Edge Systems Used with Low Slope Roofing Systems".

Perimeter Attachment

Some wall constructions allow pressure from the interior of the building to flow up wall cavities, bypassing the deck and entering the space between the roof covering and roof deck. This can be mitigated by following Reference 7 or consulting the manufacturer for expert design.

Exterior through wall scuppers, if not sealed on the exterior, can allow air on the windward side of the parapet wall to pressurize the space under the roof covering.

C3.9.3 Parapets

The use of parapets will improve the wind performance of the roofing system. The designer, whenever possible, should use a parapet design that will improve the roof system's ability to resist the wind. When parapets are less than 1 feet (0.3 m), vegetative systems are limited to 75 feet (23 m). The improvement in wind resistance is a function of parapet height. See tables for response.

C3.10 Wind Erosion

There are several ways to prevent wind erosion of growth media. The most common approach is to use a wind erosion mat. When the vegetation does not nominally cover the growth media a wind erosion mat or erosion soil conditioner or tackifier is to be installed over the roof to prevent growth media from being wind blown. The mat shall be anchored in place using techniques that provide pull out resistance capable of withstanding the calculated load as tested according to Attachment I with consideration for the porosity of the mat. Wind erosion mats can be attached to, or held by a paver, attached to the deck at the perimeter of the vegetation. Mats can use soil staples or other devices to hold them in place. Wind erosion can also be prevented by the installation of pavers in place of growth media or wind screens. Pre-cultivated mats have also been shown to hold the growth media in place.

The requirements for soil stabilizers or tackifiers will vary with the soil used and the wind loads. Products should be tested for the soil conditions on the roof being installed. Most are not designed for prolonged exposure.

C3.12 In wind borne debris areas consideration shall be taken to minimize woody vegetation that could become wind borne debris.

C3.13 Ballast is any object having weight that is used to hold or steady an object. In ballasted roofing systems, the most common ballast used is stone. However, materials such as concrete pavers, lightweight concrete pavers, rubber pavers, and weighted insulation panels are often used to ballast loose laid roofing systems. With the advent of vegetative roofs, growth media and pre-constructed vegetative modular tray also act as ballast. These ballast systems have been organized into categories based on their ability to resist the forces of the wind.

Ballast Weight

The minimum ballast weight is based on the wind design requirements of the system. Structural design should consider that the installed system will have variation of weight across the surface and with the amount of water retention in the system. Additional structural capacity should always be considered.

The dry weight of the growth media can be determined using ASTM E2399.

Combinations

Combinations of any of the types of ballast can be used on any roof, and combinations of stone and growth media etc. can be used to achieve the ballast weight required.

All stone ballast comes with some **fines** mixed in. ASTM standard D-448 allows up to 5 percent fines. This may lead to problems at drains, scuppers, etc. due to build-up of these fines. If the source of stone is including too many fines, it may be advisable to have it “double washed”. The research basis for the stone ballast was model stone that approximated the gradations of ASTM D-448. This included fines and the largest sizes in the simulated gradation. The average size of the stone was deemed to be the controlling factor in wind performance.

Vegetative Roofing Systems also bring the problem of root growth that may work their way into the drain leading to clogging problems. On Vegetative Roofing Systems using less than 4 inches (100 mm) of growth media depth, stone ballast should be placed around the drain extending out a minimum of 1 foot (0.3 m) (a clear space around drains is required but stones are optional for modular tray systems). For systems with greater than 4 inches (100 mm) depth of growth media, a perforated drain box wrapped with a filter fabric is to be installed over the drain to keep the growth media and as an aide to keep the plant roots out of the drain. The drain box should have a cover. Drains should be inspected twice a year to make sure they are clean.

Air/Drainage layers are often incorporated. When these layers contain inorganic matter, such as stone the weight of the inorganic matter can be considered part of the ballast weight.

C4.0 Design Options

The Design Options of Section 4, which also references the Design Tables in Table 2, are built on the wind tunnel work done by Kind and Wardlaw and supported by extensive field investigations. (See references) The base used as the design criteria from the wind tunnel work was Critical Wind Speed VC2, the gust wind speed above which scouring of stones would continue more or less indefinitely but not blow off the roof if the wind speed were maintained.

The corners and perimeter areas are where the greatest effects of the disrupted airflow over the building will occur. The worse case scenario is the wind coming onto a corner at a 45% angle. These situations generate wind vortices along the roof edges causing low-pressure areas over the roof system as well as wind turbulence that can scour ballast and balloon the membrane. Typically, scour occurs first. To prevent ballast movement, enhanced design provisions are required in some cases for these areas.

The terminology “documented as demonstrated as equivalent with the provisions of the standard” means that a proprietary system has been evaluated through one or all of the following methods:

- Wind Tunnel Testing Conducted in accordance with ASCE 7;
- In a Full Scale Test conducted by a licensed design professional; and/or
- Field Documented Studies.

The results would show performance levels that meet the locations design requirements.

Test methods typically used to evaluate roof systems for their ability to resist uplift forces are ANSI/FM4474 and Underwriters Laboratories ANSI/UL1897. Both testing facilities publish the results for the specific roof systems tested. Contact them for additional information.

C4.1 Ballasted Vegetative Roofing Systems

Ballasted Vegetative Roofing Systems may be installed over both loose-laid and mechanically fastened roof systems. However, when mechanically attached roof systems are used special precautions need to be taken to prevent damage to the membrane due to the fastener and plates below the membrane and impact damage and wear that can occur at these locations. Mechanically attached systems can be used with approval from the membrane manufacturer whose membrane is used for the purpose of water proofing under the vegetative systems. All precautions from the membrane manufacture must be followed.

C4.1.3.1 ANSI/SPRI Wind Design Standard Practice for Roofing Assemblies (ANSI/SPRI WD-1) provides pre-calculated loads based on ASCE 7. This tool can provide shortcut data when the building meets the criteria in the guide.

Caution should be used when installing **pavers** to not damage the membrane. Some manufacturers require a separation material between the membrane and the paver.

C4.2 Protected Vegetative Roofing System

A protected vegetative roof system consists of vegetation, ballast as defined in 2.2, a fabric that is pervious to air and water, insulation, membrane or membrane and substrate materials installed over a structural deck capable of supporting the system. Membranes are permitted to be loose laid, mechanically attached or partially or fully adhered to the roof deck or supporting insulation.

In Protected Vegetative Roof designs, the insulation is placed above the roofing membrane. When working with this design, the designer needs to account for the potential rafting of the insulation as it might float. A diffusion open fabric or similar material should be used to keep the insulation in place. The roofing membrane may be loose laid, attached or adhered. Attached membrane covers all of the potential methods of attachment, such as mechanical fasteners, adhesives, foam bonding agents and hot asphalt etc.

The water-and-air pervious fabric is used for two purposes: one, to prevent gravel fines from working down between the insulation joints to the membrane (which can lead to membrane damage) or clogging the drainage layer; and two, to control insulation board rafting. Rafting is when an insulation board, which may be floating due to a heavy rainfall or a slow draining roof, moves out of place when an uneven load, such as foot traffic on the roof, is applied to the insulation board.

For information on air retarders, see References 7 and 10. Although all systems may benefit from well-installed air retarders, this standard is based on having no deliberately installed air retarders for all systems with 10-lbs./sq. ft or more of ballast weight. For systems less than10-lbs/sq ft, air retarders are required, but this standard assumes the air retarder is imperfect.

Several options exist for increased interconnectivity and securement of the perimeters. Heavy weight ballast is a non-proprietary way of achieving this requirement.

System 3 design can be achieved by consulting References 6, 7, 8, and 9 or manufacturer's proprietary designs.

C4.3 Vegetative Roofing Systems Using A Fully Adhered Roof Membrane System

A Vegetative Roofing System using a fully adhered membrane system consists of vegetation, ballast as defined in 2.2, a membrane that is fully adhered to attached insulation, or adhered directly to a roof deck.

The fully adhered roof systems increase the wind performance of the ballasted systems by eliminating any concern of membrane ballooning causing subsequent growth media upheaval due to air infiltration from below. Attached insulation covers all of the potential methods of attachment, such as mechanical fasteners, adhesives, foam bonding agents and hot asphalt etc

C4.1.2.4 Wind erosion requirements apply to all areas of the roof. Additional protection may be needed around glass walls, penetrations and other features that disrupt the plane of the roof.

C5.0 Design Provisions

C5.1 Large Openings in a Wall

The design provision for large openings considers glass as a solid wall. However, if the wall just under the roof system is largely glass, the designer, working on a project in an area where there is the potential for severe weather, may want to consider the glass as an opening because of the potential for glass breakage due to flying debris. Glass breakage is primarily an issue in wind borne debris zones and other hurricane prone areas. See ASCE 7 for further discussion.

C6.0 Determination of Ballasted System Roof Design

When a building does not fit the criteria of this document, the designer should refer to Reference 1 and ASCE 7.

C7.0 Maintenance

Vegetative Roofing Systems shall be maintained to provide vegetation that nominally covers the visible surface of the growth media. When wind scour occurs to an existing Vegetative Roof System and the scour is less than 50 ft^2 (4.6 m^2), the growth media and plants shall be replaced. For scour areas greater than 50 ft^2 (4.6 m^2), the vegetative roof design shall be upgraded a minimum of one system design level per Section 4.0. Maintenance shall be the responsibility of the building owner.

Vegetative Roofs should always be inspected after a wind event and at least 2 times per year to make sure the vegetation and growth media are in place, drains are open, and do any weeding necessary to maintain the performance and desired look of the system. The system needs to be maintained to promote the growth of the vegetation for the loss of the vegetation will have major impact on the wind and water retention performance and fire properties of the system, let alone the aesthetics of the system. Items like watering and fertilizing are important functions to support the vegetation. For more information on the care and maintenance of vegetative roof systems, see Reference 22, Guideline for the Planning, Execution and Upkeep of Green-Roof Sites. The requirements for maintenance must be clearly spelled out to the owner of the roof, and the maintenance is a responsibility of the building owner.

Wind Scour

The basic design requirements are that wind scour does not occur. A wind speed significantly greater than the wind speed in the tables is required to initiate scour. Scour can occur without anything being blown off the roof and becoming wind borne debris.

References

1. Kind, R.J. and Wardlaw, R.L., Design of Rooftops Against Gravel Blow-Off, National Research Council of Canada, Report No. 15544, September 1976.
2. Kind, R.J. and Wardlaw, R.L., "The Development of a Procedure for the Design of Rooftops Against Gravel Blow-off and Scour in High Winds," Proceedings of the Symposium on Roofing Technology, 1977, pp. 112.
3. Gillenwater, R.J., "Wind Design Guide For Ballasted Roofing Systems", Proceedings of the Second International Symposium on Roofing Technology, 1985, pp. 219.
4. Kind, R.J. and Wardlaw, R.L., "Wind Tunnel Tests on Loose-Laid Roofing Systems for Flat Roofs," Proceedings of the Second International Symposium on Roofing Technology, 1985, pp. 230.
5. Schneider, K.G. Jr., "A Study of the Behavior of Loose-Laid, Ballasted Single-Ply Roofing Systems Subjected to Violent Winds," Proceedings of the Second International Symposium on Roofing Technology, 1985, pp. 243.
6. Kind, R.J., Savage, M.G., and Wardlaw, R.L., "Further Model Studies of the Wind Resistance of Two Loose-Laid Roof Systems (High-Rise Buildings), National Research Council of Canada, Report LTR-LA-269, April 1984.
7. "A Guide To Achieve the Secure Single-Ply", Technical Note No. 20, The Dow Chemical Company, 1986.
8. Kind, R.J., Savage, M.G., and Wardlaw, R.L., "Further Wind Tunnel Tests of Loose-Laid Roofing Systems", National Research Council of Canada, Report LTR-LA-294, April 1987.
9. Kind, R.J., Savage, M.G., and Wardlaw, R.L., "Pressure Distribution Data Measured During the September 1986 Wind Tunnel Tests on Loose-Laid Roofing Systems", September 1987.
10. Dregger, P.D., "Role of Air Retarders Deserve Closer Scrutiny," Professional Roofing, October 1991, pp. 46.
11. Smith, T.L., Kind, R.J., McDonald, J.R., "Hurricane Hugo: Evaluation of Wind Performance and Wind Design Guidelines for Aggregate Ballasted Single-Ply Membrane Roof Systems," Proceedings of the VIII International Roofing and Waterproofing Congress, 1992, pp. 598.
12. Proceedings of the Ballasted Single-Ply System Wind Design Conference, held in Carlisle, PA, 1984.
13. American Society of Civil Engineers Standard ASCE 7-2005, "Minimum Design Loads For Buildings And Other Structures".
14. Bienkiewicz, B and R. N. Maroney, Wind Effects on Roof Ballast Pavers, J. of Structural Mechanics, Proc. ASCE, Vol. 114, No. 6 June 1988, pp 1250–1267.
15. Bienkiewicz, B. and Y. Sun, Wind-Tunnel Study of Wind Loading on Loose-Laid Roofing Systems, Journal of Wind Engineering and Industrial Aerodynamics, Vol 41–44, 1992, pp. 1817–1828
16. Bienkiewicz, B. and Y. Sun, Numerical and Experimental Studies of Wind Loading on Loose-laid Roofing Systems. U.S. National Conference on Wind Engineering, UCLA 1993
17. SPRI/FM 4435/ES-1 Wind Design Standard for Edge Systems Used with Low Slope Roofing Systems, SPRI, Waltham, MA.
18. ANSI/SPRI Wind Design Standard Practice for Roofing Assemblies, SPRI, Waltham, MA 2008
19. Manual of Roof Inspection, Maintenance, and Emergency Repair for Existing Single Ply Roofing Systems. SPRI/NRCA Waltham, MA/Rosemont, IL.
20. Bienkiewicz, B. and Y. Sun; Wind loading and resistance of loose-laid roof paver systems, Journal of Wind Engineering and Industrial Aerodynamics, Vol. 72,1997, pp. 401–410
21. Hurricanes Charley and Ivan Wind Investigation Report, RICOWI Inc. Powder Springs, GA 30127, 2006

22. FLL Standard “Guideline for the Planning, Execution and Upkeep of Green-Roof Sites”, Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. – FLL, Colmantstr, Bonn, Germany
23. Gerhardt, H.J., “The Effect of Wind on Roofing Systems” Shaker Verlag (publishers) Aachen, Germany, 1999
24. Gomez, J. Gerhardt, H. J. “Assessment of Positional Security Against Wind Uplift for a Roof Planting System that is Permeable to Wind,1999
25. ENV 1991-2-4. “European Wind Loading Standard for Structures”.
26. DIN “1055 - Part 4. “Design Loads for Structures”. Wind Effect Standards
27. Minnesota Department of Transportation, “Standards for Construction” 2000
28. “Soil Erosion Control, Mulches Blankets and Mats” Metropolitan Council. St. Paul, MN 55101 ·
29. Bofah, K.K., Gerhardt, H.J., Kramer, C. “Calculations of Pressure Equilibrium Underneath Loose Laid flow Permeable Roof insulation Boards” Journal of Wind Engineering and Industrial Aerodynamics, Volume 59, Issue 1, January 1996, Pages 23–37
30. Retzlaff, B., Celik, S., Morgan, S., Luckett, K. ”Wind Uplift of Pre-Vegetated Mats” Southern Illinois University, Edwardsville. January 2010.
31. Crowley,J., Bell,D., Kopp-Holtwiesche,B., *“ENVIRONMENTALLY-FAVORABLE EROSION CONTROL WITH A POLYVINYL ACETATE-BASED FORMULATION”* Cognis Corporation, Cincinnati, Ohio

1. The wind speed map shown as Attachment II is an element of the ANSI/ASCE 7 document, “Minimum Design Loads for Buildings and Other Structures”, an American National Standards Institute Standard, copyrighted in 2005 by the American Society of Civil Engineers. Copies of this standard may be purchased from the American Society of Civil Engineers at 1801 Alexander Bell Drive, Reston, VA 20191. All other references to ANSI/ASCE 7 are for the 2005 standard.