Wind Loads on Rooftop Solar Panels

Addition

29.4.3, 29.4.4

At a Glance

New provisions for determining wind loads on solar panels on buildings have been added to ASCE 7-16. One method applies specifically to low-sloped roofs (less than 7°) and a separate method applies to any roof slope where solar panels are installed parallel to the roof.

2016 Standard

26.2 DEFINITIONS

EFFECTIVE WIND AREA, A: The area used to determine the external pressure coefficient, (GC_p) <u>and (GC_{rn})</u>. For C&C elements, the effective wind area in Figs. 30.3-1 through 30.3-7, 30.4-1, 30.5-1, and 30.7-1 through 30.7-3 is the span length multiplied by an effective width that need not be less than one-third the span length. <u>For rooftop solar arrays, the effective wind area in Fig. 29.4-7 is equal to the tributary area for the structural element being considered, except that the width of the effective wind area need not be less than one-third its length.</u> For cladding fasteners, the effective wind area shall not be greater than the area that is tributary to an individual fastener.

<u>**ROOFTOP SOLAR PANEL:** A device to receive solar radiation and convert it into electricity or heat energy. Typically this is a photovoltaic module or solar thermal panel.</u>

<u>**SOLAR ARRAY:** Any number of rooftop solar panels grouped closely together.</u>

<u>**29.4.3 Rooftop Solar Panels for Buildings of All Heights with Flat Roofs or Gable or Hip Roofs with Slopes Less Than 7°.** The design wind pressure for rooftop solar panels apply to those located on enclosed or partially enclosed buildings of all heights with flat roofs, or with gable or hip roof slopes with θ ≤7°, with panels conforming to:</u>

<u>$L_p \leq$ 6.7 ft (2.04 m),</u>
<u>$\omega \leq 35°$,</u>
<u>$h_1 \leq$ 2 ft (0.61 m),</u>
<u>$h_2 \leq$ 4 ft (1.22 m),</u>

with a minimum gap of 0.25 in. (6.4 mm) provided between all panels, and the spacing of gaps between panels not exceeding 6.7 ft (2.04 m). In addition, the minimum horizontal clear distance between the panels and the edge of the roof shall be the larger of $2(h_2 - h_{pt})$ and 4 ft (1.22 m) for the design pressures in this section to apply. The design wind pressure for rooftop solar panels shall be determined by Eq. (29.4-5):

$$p = q_h(GC_{rn})(\text{lb/ft}^2) \qquad (29.4\text{-}5)$$

$$p = q_h(GC_{rn})(\text{N/m}^2) \qquad (29.4\text{-}5.\text{si})$$

where

$$(GC_{rn}) = (\gamma_p)(\gamma_c)(\gamma_E)(GC_{rn})_{\text{nom}} \qquad (29.4\text{-}6)$$

where

$\gamma_p = \min(1.2; 0.9 + h_{pt}/h)$;
$\gamma_c = \max(0.6 + 0.06L_p, 0.8)$; and
γ_E = 1.5 for uplift loads on panels that are exposed and within a distance $1.5(L_p)$ from the end of a row at an exposed edge of the array; γ_E =1.0 elsewhere for uplift loads and for all downward loads, as illustrated in Fig. 29.4-7. A panel is defined as exposed if d_1 to the roof edge > $0.5h$ and one of the following applies:

1. d_1 to the adjacent array> $\max(4h_2; 4\text{ ft }(1.2))$ and
2. d_2 to the next adjacent panel> $\max((4h_2; 4\text{ ft }(1.2\text{ m}))$.

$(GC_{rn})_{nom}$ = nominal net pressure coefficient for rooftop solar panels as determined from Fig. 29.4-7.

When, $\omega \leq 2°$, $h_2 \leq 0.83$ ft (0.25 m), and a minimum gap of 0.25 inches (6.4 mm) is provided between all panels, and the spacing of gaps between panels does not exceed 6.7 ft (2.04 m), the procedure of Section 29.4.4 shall be permitted.

The roof shall be designed for both of the following:

1. The case where solar collectors are present. Wind loads acting on solar collectors in accordance with this section shall be applied simultaneously with roof wind loads specified in other sections acting on areas of the roof not covered by the plan projection of solar collectors. For this case, roof wind loads specified in other sections need not be applied on areas of the roof covered by the plan projection of solar collectors.
2. Cases where the solar arrays hae been removed.

29.4.4 Rooftop Solar Panels Parallel to the Roof Surface on Buildings of All Heights and Roof Slopes. The design wind pressures for rooftop solar panels located on enclosed or partially enclosed buildings of all heights, with panels parallel to the roof surface, with a tolerance of 2° and with a maximum height above the roof surface, h_2, not exceeding 10 in. (0.25 m) shall be determined in accordance with this section. A minimum gap of 0.25 in. (6.4 mm) shall be provided between all panels, with the spacing of gaps between panels not exceeding 6.7 ft (2.04 m). In addition, the array shall be located at least $2h_2$ from the roof edge, a gable ridge, or a hip ridge. The design wind pressure for rooftop solar collectors shall be determined by Eq. (29.4-7):

$$p = q_h(GC_p)(\gamma_E)(\gamma_a)(\text{lb/ft}^2) \qquad (29.4\text{-}7)$$

$$p = q_h(GC_p)(\gamma_E)(\gamma_a)(\text{N/m}^2) \qquad (29.4\text{-}7.\text{si})$$

where

(GC_p) = external pressure coefficient for components and cladding of roofs with respective roof zoning, determined from Figs. 30.3-2A-I through 30.3-7 or 30.5-1, and

γ_E = array edge factor = 1.5 for uplift loads on panels that are exposed and those within a distance $1.5(L_p)$ from the end of a row at an exposed edge of the array; γ_E =1.0 elsewhere for uplift loads and for all downward loads, as illustrated in Fig. 29.4-7. A panel is defined as exposed if d_1 to the roof edge > 0.5h and one of the following applies:

1. d_1 to the adjacent array > 4 ft (1.22 m) or
2. d_2 to the next adjacent panel > 4 ft. (1.22 m), and

γ_a = solar panel pressure equalization factor, defined in Fig. 29.4-8.

The roof shall be designed for both of the following:

1. The case where solar panels are present. Wind loads acting on solar collectors in accordance with this section shall be applied simultaneously with roof wind loads specified in other sections acting on areas of the roof not covered by the plan projection of solar collectors. For this case, roof wind loads specified in other sections need not be applied on areas of the roof covered by the plan projection of solar collectors.
2. Cases where the solar panels have been removed.

30.13 ROOFTOP SOLAR PANELS FOR BUILDINGS OF ALL HEIGHTS WITH FLAT ROOFS OR GABLE OR HIP ROOFS WITH SLOPES LESS THAN 7°

The design wind pressures for rooftop solar modules and panels shall be determined in accordance with Section 29.4.3 for rooftop solar arrays that conform to the geometric requirements specified in Section 29.4.3.

Analysis and Significance

Design wind loads for solar panels mounted on roofs of buildings have not previously been specifically addressed by ASCE 7. With this lack of guidance in ASCE 7, designers have often attempted to use a combination of the components and cladding tables for enclosed buildings and main force resisting system tables for open structures. This approach can lead to unconservative

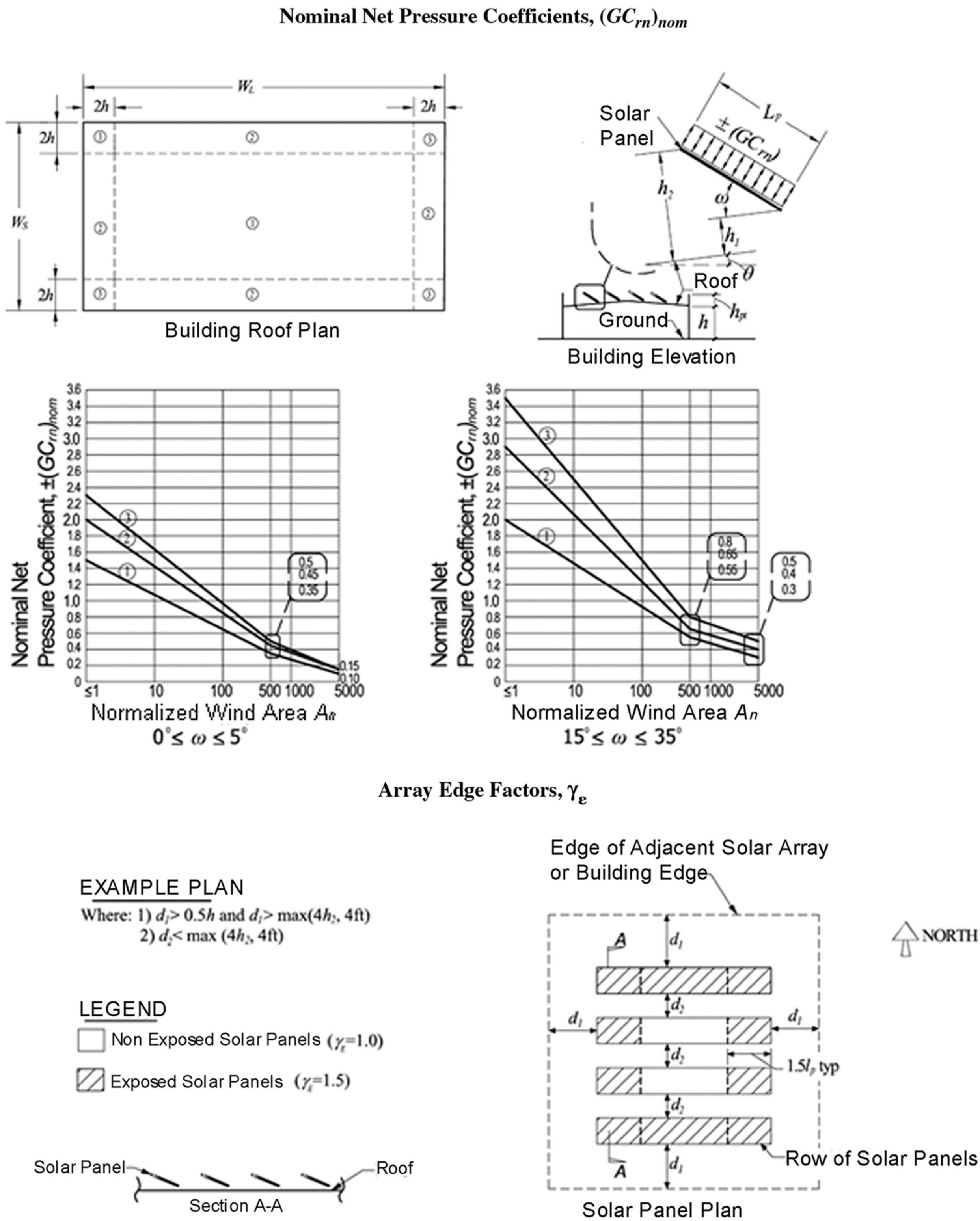


Figure 29.4-7 Design wind loads (All Heights): Rooftop solar panels for enclosed and partially enclosed buildings, roof θ≤7º

Notation

A = Effective wind area, in ft^2 (m^2).
A_n = Normalized wind area, in ft^2 (m^2).
d_1 = For rooftop solar array, horizontal distance orthogonal to the panel edge to an adjacent panel or the building edge, ignoring any rooftop equipment in Fig. 29.4-7, in ft (m).
d_2 = For rooftop solar arrays, horizontal distance from the edge of one panel to the nearest edge in the next row in Fig. 29.4-7, in ft (m).
h = Mean roof height of a building or height of other structure, except that eave height shall be used for roof angle θ less than or equal to 10°, in ft (m).
h_1 = Height of the gap between the panels and the roof surface, in ft (m).
h_2 = Height of a solar panel above the roof at the upper edge of the panel, in ft (m).
h_{pt} = Mean parapet height above the adjacent roof surface for use with Eq. (29.4-5), in ft (m).
L_p = Panel chord length.
W_L = Width of a building on its longest side in Fig. 29.4-7, in ft (m).
W_S = Width of a building on its shortest side in Fig. 29.4-7, in ft (m).
γ_ε = array edge factor as defined in Section 29.4.4.
θ = Angle of plane of roof from horizontal, in degrees.
ω = Angle that the solar panel makes with the roof surface in Fig. 29.4-7, in degrees.

Notes

1. GC_{rn} acts toward (+) and away (-) from the top surface of the panels.
2. Linear interpolation is allowed for ω between 5° and 15°.
3. $A_n = (1,000/[\max(L_p, 15)^2]$ A, where A is the effective wind area of the structural element of the solar panel being considered, and L_b is the minimum of $0.4(hW_L)^{0.5}$ or h or W_s in ft (m).

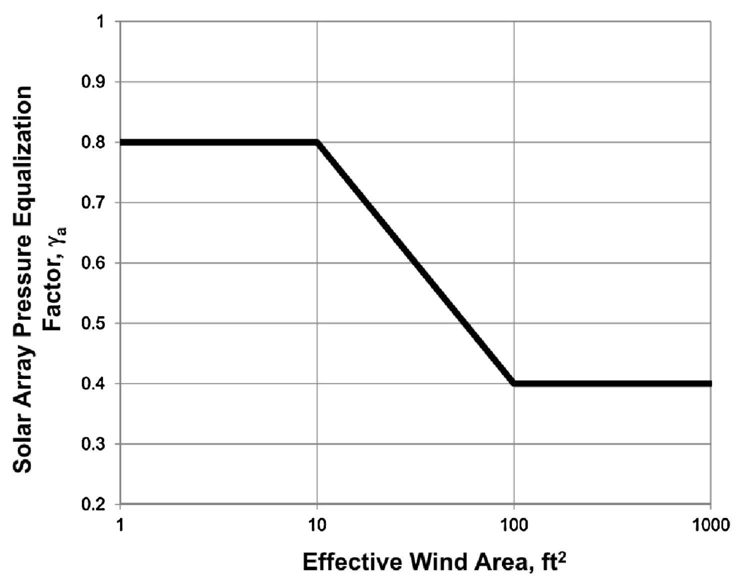


Figure 29.4-8 Solar panel pressure equalization Factor γ_a, for enclosed and partially enclosed buildings of all heights

results, particularly when considering the size of the edge and corner roof zones. The wind tunnel procedure is another approach but can be costly and time consuming, particularly for small or single-use projects.

ASCE 7-16 now includes provisions for determining design wind loads on rooftop solar panels. Two methods are provided. One method (Section 29.4.4) is specific to buildings with roof slopes less than 7^o with limitations on the panel length, tilt, and height above the roof. The other method (Section 29.4.4)applies to all roof slopes but the panels are required to be installed parallel (+/- 2^o) to the roof with specific other limitations including the height above the roof and location on the roof.

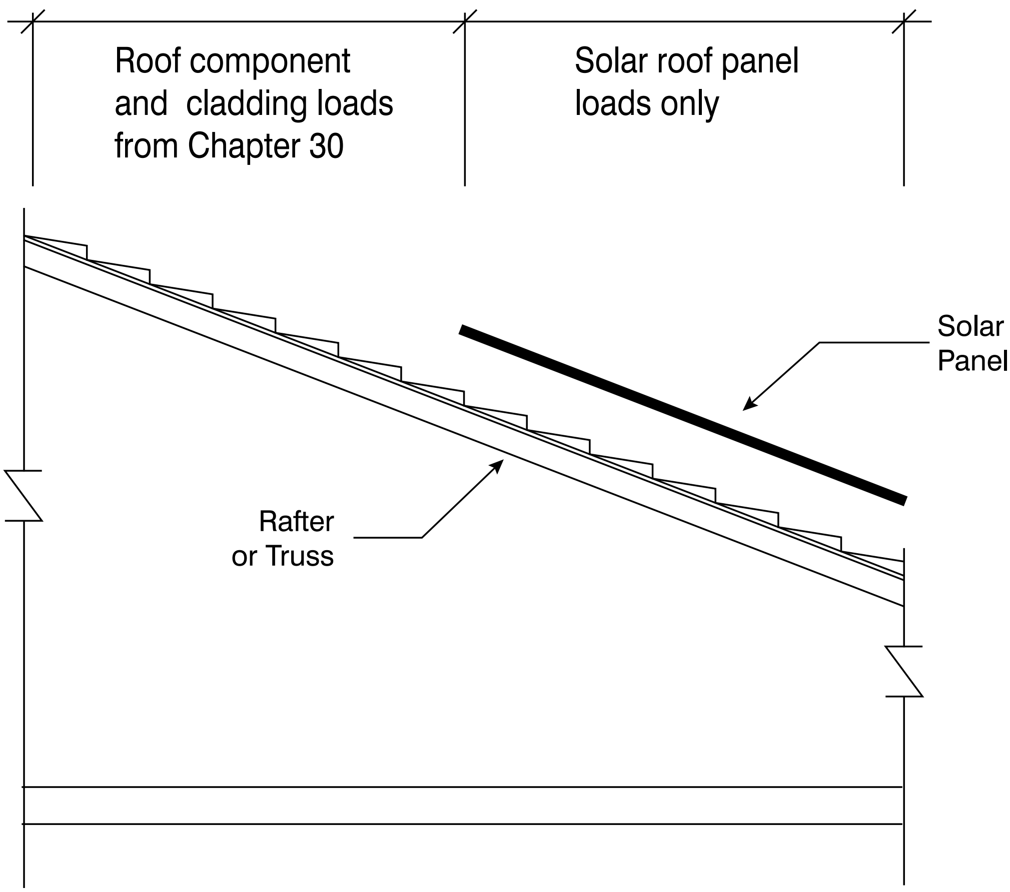
Section 29.4.3 addresses low-profile solar panels installed on roofs with slopes less than 7^o. Specific criteria for this type of solar array is provided because such systems are in widespread use and have been subject to wind-tunnel testing. Section 29.4.3 and Figure 29.4-7 intentionally have a limited range of application, with the panel tilt angle limited to a maximum of 35^o, the maximum height above the roof surface, h_2, for the solar panels limited to 4 feet and the panel chord length, L_p, limited to 6.7 feet (for tilted panels, the shorter height above the roof, h_1, is limited to maximum of 2 ft). Wind tunnel testing indicates that increasing the overall height above the roof or panel chord length increases the wind loads on the solar panels. Additionally, increasing the height above the roof surface can result in uplift exceeding that covered by this criterion. The requirements are not applicable to open structures because the applicable test data are from enclosed structures, which exhibit different aerodynamics for flow over the roof than open structures.

There are several other factors that adjust the design wind loads based on the presence of parapets, the length of the panel, and the proximity to the edge of the roof. The parapet height factor, γ_p, accounts for the fact that the presence of a parapet typically increases the wind loads on solar panels. Parapets lift the vortices higher above the roof surface and reduce the interaction with the roof surface. The parapet height factor, γ_p, accounts for this effect. The panel chord factor, γ_E, is a reduction factor for shorter panel lengths. It essentially scales from a factor of 1.0 to 0.8 for lengths between 6.7 ft and 3.3 ft respectively. The array edge factor, γ_E, takes into account the fact that end rows and edge panels experience larger wind pressures than interior panels, which are sheltered by adjacent panels. The array edge factor, γ_E, is 1.5 for uplift loads on exposed panels and 1.0 elsewhere and for downward loads. A solar panel is defined as exposed based on its proximity to the building edge and adjacent panels.

The nominal net pressure coefficient, $(GC_{rn})_{nom}$, for solar panels are based on normalized wind area and presented in a form that is similar to that used for component and cladding pressure coefficients using a logarithmic curve in Figure 29.4-7. These curves were derived from wind tunnel test data. The net pressure coefficient (GC_{rn}) is determined multiplying the nominal net pressure coefficient, $(GC_{rn})_{nom}$, by the parapet, panel length, and array edge factors. The $(GC_{rn})_{nom}$ values are not linearly related to the panel tilt angle over the full tilt angle range. As a result, Figure 29.4-7 contains two $(GC_{rn})_{nom}$ curves: a $(GC_{rn})_{nom}$ curve for low tilt panels in the 0- to 5^o range and another for high tilt panels in the 15- to 35^o range. For panel tilt angles in the 5- to 15^o range, linear interpolation is permitted.

The method addressed in Section 29.4.4 applies to solar panels that are installed close to and parallel to the roof. Wind loads on panels installed as prescribed by this section tend to be lower than the design loads for the roof. This reduction in loads for the solar panels is due to pressure equalization. The solar panel pressure equalization factor, γ_a, of Figure 29.4-8 accounts for this effect. Panels have to be installed within 2° of parallel to the roof surface and a maximum height above the roof surface of 10 inches, in addition to other limitations on panel gap spacing and proximity to the roof edge. The array edge factor, γ_E, applies the same as prescribed in Section 29.4.3.

The wind loads for solar panels do not have to be applied simultaneously with the component and cladding wind loads for the roof in areas where the roof is covered by a solar panel. However, the roof still has to be designed assuming that the solar panels are removed or are not present. When a span of the roof member is partially covered by a solar panel, it has to be designed for the roof component and cladding loads from Chapter 30 for the uncovered portion and the roof solar panel wind loads on the portion covered by solar panels. It must also then be designed for the roof component and cladding loads from Chapter 30 assuming that the solar panels are removed.



Note: The span also has to be designed for roof component and cladding loads assuming the solar panels are removed.

Solar Panel Partially Covering a Roof Member