ROOF-MOUNTED SOLAR PHOTOVOLTAIC PANELS

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1.0 SCOPE

This data sheet provides property loss prevention guidance related to fire and natural hazards for the design, installation, operation and maintenance of roof-PV systems that generate electrical power.

This document does not address solar towers, roof-mounted solar-powered water heaters, PV carports or ground-mounted solar farms. For guidance on PV carports, ground-mounted solar farms and other elevated PV, see FM Property Loss Prevention Data Sheet 7-106, *Ground-Mounted Solar Photovoltaic Power*. See FM Property Loss Prevention Data Sheet 1-57, *Plastics in Construction*, for wall-mounted, building-integrated photovoltaic (BIPV) façade systems.

1.1 Changes

April 2026. Full revision. Improved clarity and incorporated updated fire and natural hazard mitigation recommendations. A new section on agrivoltaics was added.

1.2 Hazards

1.2.1 Fire Hazards

Exterior fire exposure due to the ignition of combustible PV panel components and the roof assembly below the PV panels will result in damage. Fire exposure can result from electrical components, adjacent buildings, yard storage and wildland fires. PV systems' wiring circuits, combiner boxes, inverter and control equipment are subject to electrical failure and subsequent fire. The panels themselves create heat that can also ignite debris on the roof surface below the panels (e.g., leaves or bird nests).

During a fire event, PV panels installed above the roof cover re-radiate heat back onto the roof surface, leading to accelerated lateral fire spread. All PV panels utilize encapsulants (such as ethylene vinyl acetate or EVA) as part of their construction. These encapsulants provide additional fuel that can worsen a roof-level fire.

Above-deck roof components with a low melting temperature (such as expanded or extruded polystyrene (EPS or XPS) and bitumen roof covers) can melt, burn and flow. A lack of protection at roof expansion joints can allow an exterior roof fire to spread into the building and cause extensive interior damage. Losses involving XPS have damaged the steel deck of the roof, allowing fire and/or smoke to enter the building, leading to larger losses.

Together, these conditions can lead to extensive damage of the roof cover, PV system and building.

1.2.2 Natural Hazards

Natural hazard exposures to PV panel installations include: wind, hail, collapse or earthquake. Proper materials and installation can limit damage.

Wind can be from tropical cyclones, severe thunderstorms, microbursts or winter storms. When PV panels are inadequately designed for the expected winds, varying degrees of damage can occur to the PV solar panels, arrays and racking. PV clamps used to secure the PV panels and frames to the racking or directly to the roof are often the weakest connection point. The panels or frames torsionally bend (i.e., twist) out of the clamps and can crack and affect performance. When inadequately secured, the panels could be dislodged, break or become windborne debris. Windborne debris can damage other panels and the roof cover, allowing water to enter the building, damaging the building interior and contents.

The proper hail rating is crucial to minimizing damage. Many manufacturers can provide information on hail ratings, but careful review of that information is necessary to verify proper testing for kinetic energy. When an improperly rated panel is used, hail can break the glass, damage components, and allow moisture to enter the panel. These types of damage will affect the panel's performance.

Snow can accumulate under and around PV panel installations, resulting in high snow drifts. PV panels with greater slopes and heights will increase snow accumulation and collapse potential, unless the roof can support the extra load. In addition, PV installations can block the path to roof drains and allow excessive ponding on the roof. These situations create additional dead load on the roof structure and can result in roof collapse in extreme cases.

Seismic activity from earthquakes can cause lateral or vertical movement of the panels. This movement can cause broken glass, damage electrical components, and an increase the potential for ignition, leading to a fire following the earthquake.

2.0 RECOMMENDATIONS

Roof assemblies and PV panels interact as a roof-PV system with respect to exterior fire spread and wind design. Additional concerns are related to other natural hazards, such as hail and earthquake. The installation of roof-PV systems creates unintended hazards that can be mitigated through proper planning, installation and maintenance. This data sheet provides guidance on how to mitigate roof-PV system fire hazards and natural hazards.

The roof-PV system acts as one during a fire event, and the components cannot be tested individually or by using small-scale testing.

Testing has shown that unless specifically FM Approved as a roof-PV system, an FM Approved Class 1A roof assembly (without PV) will have the FM Approved Class 1A rating negated once PV panels are placed above it.

Installing all components of the roof-PV system per the FM Approval listing is critical. For a list of roof-PV systems that are FM Approved, see RoofNav, an online resource of FM Approvals. FM Approved roof-PV systems can be found in RoofNav as a “surfacing” layer by selecting “includes photovoltaics” when conducting an assembly search.

Where installations are proposed at FM client locations, submit plans, specifications and calculations to the local FM office for review and comment, prior to ordering materials. For details on what information is needed, see Section 3.9.

2.1 Construction and Location

Use an FM Approved roof-PV system for a new building or when replacing or re-covering the roof. An existing roof more than 10 years old should be replaced or re-covered before installing PV systems that may last 25 to 30 years, exceeding the roof life. PV panels should not be installed over roofs that show signs of deterioration, such as roof leaks, cracks, delamination or blisters.

When installing a new roof cover without PV panels, consider using an FM Approved roof assembly that is part of an FM Approved roof-PV system or that includes a noncombustible cover board. This assembly will allow for future installation of PV panels, while reducing the loss potential.

2.1.1 Fire

The goal of this data sheet is to limit fire spread and prevent fires involving roof-PV systems from entering the building.

2.1.1.1 Follow one of the options below for new roof-PV installations or when the roof system will be replaced in conjunction with the installation of PV panels.

A. Provide an FM Approved roof-PV system.

B. Provide an FM Approved, flexible roof-PV system.

2.1.1.2 Follow one of the options below for existing roof covers that will remain when installing a new PV system above the existing roof cover.

A. Install the FM Approved PV panel and components from an FM Approved roof-PV assembly that uses the same roof components as the approved roof.

B. Install an FM Approved retrofit roof coating for PV systems, prior to installing glass backed PV panels. The coating must be acceptable for the type of roof on which it will be installed, subject to the manufacturer’s criteria.

C. Install one of the following:

1. An FM Approved Class 1A re-cover for roof-PV systems

2. An FM Approved Class 1A re-cover assembly that utilizes a noncombustible cover board directly below the membrane, and install glass-backed PV panels.

D. Install glass-backed PV panels on FM Approved insulated metal panel, standing seam or lap seam roofs. Use either fiberglass or mineral wool insulation below the roof.

E. Install PV panels at least 3 ft. (0.9 m) off the roof to eliminate the fire hazard. Ensure adherence with Section 2.1.2 due to increased wind loads.

2.1.1.3 An acceptable alternative to an FM Approved roof-PV system or FM Approved retrofit roof coating for PV systems is to install a water spray system designed to protect the space between the PV panel and the roof covering. Design and install the water spray system in accordance with the following:

A. Ensure roof loading and drainage are adequate for the structure to handle the additional system weight (i.e., piping and valves) and water weight (i.e., water discharged by the spray nozzles, including hose streams). (See Data Sheet 1-54, *Roof Loads and Drainage*).

B. Install a water spray system in accordance with National Fire Protection Association (NFPA) 15, *Standard for Water Spray Fixed Systems for Fire Protection*.

C. Use FM Approved and corrosion-resistant components.

D. Provide FM Approved linear heat detection at the edge of the PV panel furthest above the roof deck and installed along the full length of each PV panel row.

- Use detectors that have minimum temperature rating of 220°F (104°C) or 50° above expected ambient temperatures.

E. Arrange nozzles to cover the entire roof area under each PC panel with a minimum 6 in (150 mm) overlap in spray patterns.

F. Design the system to deliver a minimum of 0.07 gpm/ft^2 (3 mm/min) over the nozzle coverage area.

1. Use FM Approved water spray nozzles that will distribute water over the roof area under each panel.
2. Use a minimum discharge pressure of 15 psi (1 bar).
3. Use a maximum discharge pressure of 90 psi (6.2 bar).

G. Provide FM Approved deluge valves for each row of PV panels.

- When a fire is detected, operate the deluge valves for the aisle of origin, plus one aisle on each side.

H. Include 250 gpm (950L/min) for hose streams and the water supply for a duration of 60 minutes.

I. Maintain the system in accordance with FM Property Loss Prevention Data Sheet 2-81, *Fire Protection System Inspection, Testing and Maintenance*.

Figure 2.1.1.3-1 depicts the layout of the spray nozzle under a PV panel in elevation view. Choose a nozzle to ensure adequate coverage of the area under and beyond the panel. Figure 2.1.1.3-2 depicts the layout of the nozzles in a plan view. Both are representative examples of Section 2.1.1.3.

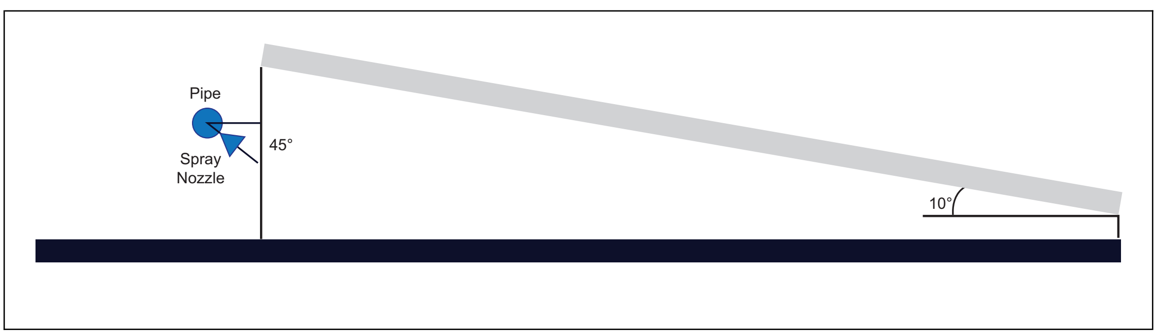

Fig. 2.1.1.3-1. Elevation view of placement of nozzle with PV panel

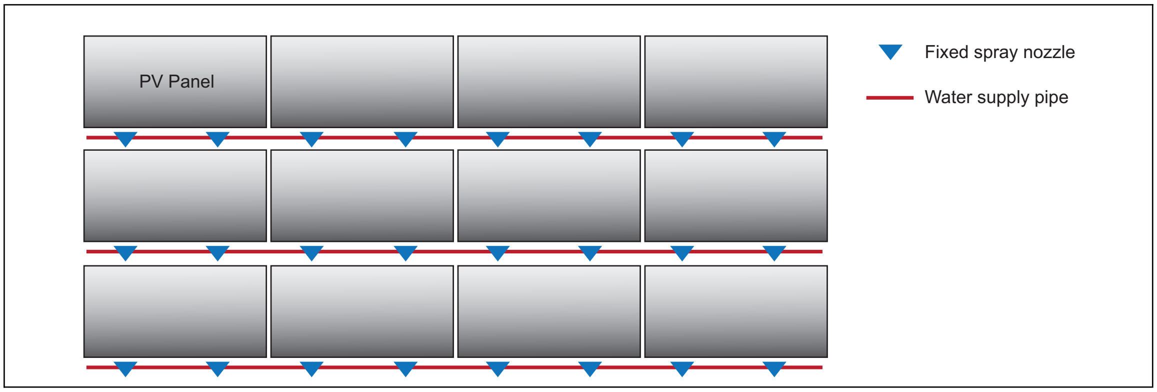

Fig. 2.1.1.3-2. Plan view of nozzle layout and PV panels

2.1.1.4 Provide components and position arrays as follows:

A. Use only noncombustible frames and mounting systems. Use PV panels that are glass backed.

B. Construct arrays with a maximum size of 150 ft (46 m) by 150 ft (46 m).

C. Provide a minimum 4 ft (1.2 m) of space or aisle to the next array.

D. Provide a minimum 4 ft (1.2 m) of space between PV panels and roof expansion joints.

E. Provide a minimum 6 ft (1.8m) of clearance to all skylights.

F. Use scraps of roof cover or roof manufacturer slipsheets placed between the top of the roof cover and PV pedestals to prevent roof cover abrasion. Use only roof cover materials. Do not use rubber or plastic pads below the PV pedestals.

2.1.1.5 Buildings Over 100 ft (30 m) in Height

2.1.1.5.1 Buildings over 100 ft without exterior stair access are considered inaccessible. Consult with the fire service regarding the ability to reach the roof with aerial apparatus.

2.1.1.5.2 If the roof is considered inaccessible, follow one of these options:

A. Install an FM Approved roof-PV system.

B. Install an FM Approved, retrofit roof coating for roof-mounted rigid PV module systems. The coating must be acceptable for the type of roof on which it will be installed and subject to the manufacturer's criteria.

C. Install a fire protection system in accordance with Section 2.1.1.3.

D. Install linear heat detection, exterior access stairs to the roof, and a dry, stand-pipe system (feed at ground and connections at roof level) as required by the local fire service. Connect the heat detection to a monitored fire alarm system.

2.1.1.6 Roof Penetrations

2.1.1.6.1 If the roof cover assembly includes modified bitumen, EPS/XPS insulation, asphalt or other melting or flowing materials, protect roof penetrations greater than 6 in. (152 mm) in diameter by filling all areas around the penetration. Use noncombustible insulation, extending at least 3 in. (75 mm) outward from the penetration (e.g., roof drains, skylights, HVAC, etc.).

2.1.1.6.2 Protect all roof expansion joints with noncombustible, compressible insulation (e.g., mineral wool). See Figure 2.1.1.6-1.

2.1.1.7 Stop the continuity of roof membranes at parapet walls, roof expansion joints or roof area dividers. Use metal cap flashing as recommended in Figure 2.1.1.6-1.

2.1.1.8 Provide adequate space separation between combustible yard storage and exterior walls in accordance with FM Property Loss Prevention Data Sheet 1-20, *Protection Against Exterior Fire Exposure*.

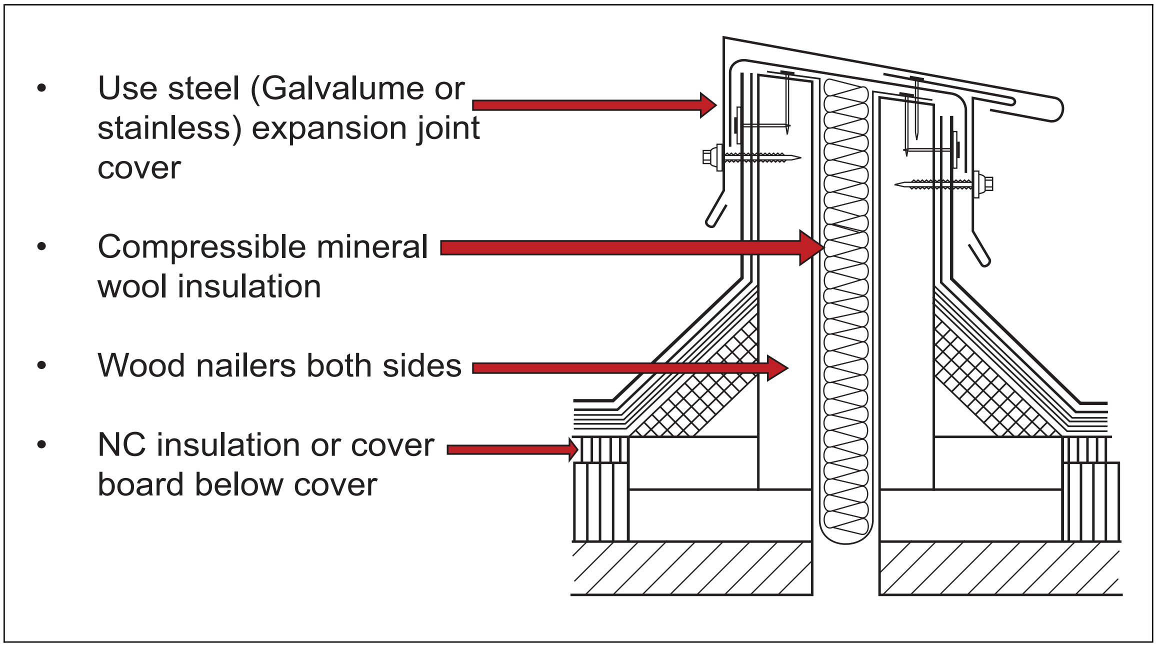

Fig. 2.1.1.6-1. Recommended roof expansion joint

2.1.2 Wind

Design all roof-mounted, rigid PV solar panels and their securement using basic wind pressures in accordance with FM Property Loss Prevention Data Sheet 1-28, *Wind Design* and recommendations A through F below.

A. Base the design wind speeds on guidance in Data Sheet 1-28, *Wind Design*. Do not further reduce the design wind speed to that of a lower mean recurrence interval (MRI), based on assumptions regarding the expected lifespan of the panels. Assume Ground Roughness C unless all conditions for Exposure B or D have been successfully met and documented. Apply the topographic factor (K_{ZT}) as determined by following ASCE 7-22 or Data Sheet 1-28, *Wind Design*. For design considerations using Eurocode, see Section 2.1.2.1.

B. Use a safety factor of 2.0 (resistance provided vs. wind loads on each panel) for all new ballasted, mechanically fastened and hybrid systems.

C. Multiply the basic wind pressure (q_h) by the appropriate pressure coefficient for the assembly component in question (panel, clamps, racking, bolts, etc.). Pressure coefficients can be determined by a Boundary Layer Wind Tunnel (BLWT) Test or using prescriptive values based on ASCE 7-22 and SEAOCPV2. The pressure coefficient will, in part, be determined by the chosen effective wind area (EWA). The EWA will be dependent on whether the array is ballasted (EWA determined by the load sharing factor, using a Vertical Load Test [VLT]) or mechanically fastened (EWA determined by the number of panels secured by an anchor). The pressure coefficients should also reflect whether the PV arrays are open or closed (whether they use wind deflectors). See Figure 2.1.2-1.

D.Use an importance factor (IF) of 1.15 for the load determination portion of the wind design.

E. Install rigid PV solar panels and roof components that are FM Approved together as a roof-PV system in accordance with FM 4478, Examination Standard for for Roof-Mounted Rigid Photovoltaic Module Systems. Note that the wind ratings for the roof system and the PV system may be different within the listing.

Fig. 2.1.2-1. Wind deflectors provided on the high sides of panels in each row (closed array)

2.1.2.1 Eurocode

Utilizing Eurocode to determine variables used in the calculation of basic velocity pressures is discussed in FM Data Sheet 1-28, *Wind Design*. The Eurocode concept is similar to ASCE 7-22, except different terminology and some different variables are used. The following guidance should be used for non-tropical cyclone exposed areas when using Eurocode for determining basic velocity pressures:

A. Base the terrain category on site conditions. Use Terrain II if site topography is not known. Whether known or unknown, do not use Terrain IV.

B. Base PV design on Effective Wind Areas (EWAs), not to exceed 108 ft^2 (10 m^2) for array interior panels and 10.8 ft^2 (1 m^2) for array edge and corner panels.

C. Use a 50 yr. MRI windspeed for non-tropical, cyclone-exposed locations and 100 yr. MRI for tropical, cyclone-prone locations.

D. Use a 3 sec. peak wind gust of ≥72 mph (32.2 m/s) or a minimum 10 min. wind speed (used in the Eurocode) of 50 mph (22.5 m/s). A table on windspeed conversions between different durations is provided in Data Sheet 1-28, *Wind Design*, Table AC1.3.

2.1.2.2 Wind Design Documents

Design the system using the key documents described below. The wind loads and resistances determined by these documents for a given PV array should be used in the design. For FM insured clients, submit the following supporting materials to FM to conduct a detailed wind review of a new or (when requested) existing roof-PV system. Refer to Section 3.9 for additional information. Note: not all documents will apply to all installations.

A. A boundary layer wind tunnel (BLWT) test per ASCE 49 (or equivalent international standard) which provides:

- Pressure coefficients
- Roof zones
- Array zones
- Limitations on panel slope
- Limitations on edge factors

- − Parapet factors
- − Limitations on building geometry
  - - Limitations on roof slope
  - - Load sharing factor used

Organizations that are qualified to conduct BLWT tests are noted, and additional information on BLWT testing is provided in Section 3.4.1. These test reports are conducted for all types of PV installations and are needed to properly quantify the loads on the systems.

B. A peer review of the BLWT test report by a qualified third party that validates the BLWT study conforms to ASCE 7-22, SEAOC-PV2 and ASCE 49-12 for the intended use. It should also verify that the racking system structure is adequate for the effective wind area at the specific site.

C. For ballasted PV systems, a valid Vertical Load Test (VLT), which gives the load sharing factor as described in Section 3.4.10 and in FM 4478, *Examination Standard for Roof-Mounted Rigid PV Module Systems*.

D. A manufacturer's summary spreadsheet for the specific proposed system which shows the loads based on the BLWT test, VLT, etc. This spreadsheet should also show the resistance provided for each racking/panel section (amount of ballast or the resistance capacity of mechanical anchors). The loads will vary, depending on the position in the array (interior, edge, corners) and its location on the roof (Zones 1, 2, or 3). The safety factors should then be determined by comparing the resistance to the loads. For ballasted systems, use the combined weight of solar panels, associated hardware and additional concrete paver blocks to determine the resistance.

E. The proposed PV clamp details and a test report showing its resistance when utilized with the selected PV panel. Use FM Approvals data or provided test data (specific to the proposed panel and clamp) to analyze clamp resistance. Compare this resistance with the expected loads, based on the array layout and roof wind zone conditions.

F. Detailed drawings and specifications for racking connections, mechanical anchors and, where applicable, the amount of ballast weight provided throughout the array zones.

G. Drawings of the PV array(s) showing panel layout, setback distances, panel slope, panel orientation (landscape or portrait) and roof-mounted equipment, as well as setback distances of equipment adjacent to and within PV arrays.

H. Specifications for the PV panels showing panel size, wattage, type and thickness of glass, and frame details (including dimensions on thickness, depth and frame height).

I. Details of the roof cover (age of cover, cover type, layers of insulation, including type and thickness), fastening rates and method, and roof deck details (roof deck type, thickness, and the existing deck securement type and spacing).

2.1.2.3 New PV Installations Over New and Existing Roofs

Review of a PV assembly design requires an analysis of the vertical loads on the array versus the vertical resistance provided. FM Approved roof-PV assembly RoofNav listings give the ultimate wind resistance provided for these systems.

New PV installations (over new, reroof, or recover construction) should utilize an FM Approved roof-PV assembly as detailed in RoofNav. Select the assembly to meet or exceed the minimum wind ratings needed for both the PV array interior/edge/corner zones and the roof assembly in Zones 1, 2, and 3 when compared to the calculated loads in FM Data Sheet 1-28, *Wind Design*.

2.1.2.3.1 Ballasted, Tilted Panel Systems

Install new ballasted PV systems only over adhered roof membranes. Design for the full wind loads and resistance as follows:

A. Base the wind loads and pressure coefficients on valid BLWT test reports, peer reviews, and VLTs as described in Section 2.1.2.2. Where these reports are not available, design based on the loads, using the prescriptive methods in ASCE 7-22 and SEAOCPV2.

B. Use the recommended safety factors in Data Sheet 1-28 (loads vs. resistance). The safety factors will be listed for each panel in the manufacturer's summary spreadsheet for the specific system, which is described in Section 2.1.2.2.

C. Verify the resistance of the proposed PV panel clamp as described in Section 2.1.2.2.

D. Base the EWAs on a valid VLT report. Alternatively, a Finite Element Analysis can be conducted on the components.

E. Ensure the details of the installation (panel orientation, panel slope, etc.) are consistent with the BLWT test as described in Section 2.1.2.2.

F. Include the specifications for the proposed PV panel (frame dimensions, glass thickness, etc.) as described in Section 2.1.2.2.

G. Install ballasted, rigid PV, roof-mounted solar panels only on roofs with a maximum roof slope of 1/2 in. per ft (2.4°). A higher slope is not recommended for ballasted PV panels, as it will decrease frictional resistance to wind forces and increase sliding forces from gravity loads, weakening wind resistance.

H. Assume a maximum coefficient of static friction (μ) of 0.4 for calculations to ensure resistance to sliding is maximized unless a value greater than 0.4 can be justified. The coefficient of static friction is the lesser of the wet or dry value. Base the coefficient on the materials used and testing in accordance with ASTM D1894 (or equivalent standard outside the United States).

I. Use concrete paver blocks for ballasted PV panels that meet specifications in ASTM C1491 and are tested in accordance with ASTM C1262 (not including pass/fail criteria) for exposure to freeze-thaw cycles. The cumulative weight loss measured in the test should not exceed 5% of the initial weight of the specimen. (Use comparable standards outside the United States.)

J. Do not install PV panels on roofs with aggregate, or where an adjacent higher roof has aggregate, including pea gravel or larger stone ballast.

2.1.2.3.2 Mechanically Attached Tilted Panel Systems

Provide a full FM Approved roof-PV system where a new roof is to be installed. Where a mechanically attached PV system is proposed and a fully FM Approved roof-PV system cannot be installed due to existing construction, design for the full wind loads and resistance as follows:

A. Base the wind loads and pressure coefficients on valid BLWT test reports, peer reviews and VLTs as described in Section 2.1.2.2. Where these reports are not available, design based on the loads using the prescriptive methods in ASCE 7-22 and SEAOCPV2.

B. Use the recommended safety factors in Data Sheet 1-28 (loads vs. resistance). The safety factors will be listed for each panel in the manufacturer's spreadsheet for the specific system, which is described in Section 2.1.2.2.

C. Use an FM Approved mechanical anchor listed in RoofNav.

D. Verify the resistance of the proposed PV panel clamp as described in Section 2.1.2.2.

E. Ensure the details of the installation (panel orientation, panel slope, etc.) are consistent with the BLWT test as described in Section 2.1.2.2.

F. Include the specifications for the proposed PV panel (frame dimensions, glass thickness, etc.) as described in Section 2.1.2.2.

2.1.2.3.3 PV Arrays with Panels Parallel to Roof (Over Higher-Sloped Roofs, including Panel Roof Systems, Clay Tiles or Shingled Roofs)

Install a fully FM Approved roof-PV system where a new roof or re-cover and PV installation is proposed. Where a parallel panel system is proposed, and the existing metal panel is not included in the FM Approved roof-PV RoofNav listing, install the FM Approved PV portion of the system (which includes the PV panel, the panel clamps and any attachment to the roof system). Design per the following:

A. Use the wind pressure loads for PV arrays that are parallel to the roof surface based on the development of wind pressures and ratings determined in FM Data Sheet 1-28, *Wind Design*. These arrays are common with metal panel roofs and higher sloped roofs such as clay tile or shingle roofs.

B. Use an air equalization factor to reduce the wind pressure loads where applicable. This factor γ_A may be applied in accordance with SEAOC PV 2 (2017) or ASCE 7-22, depending on the exact distance between the roof surface and top flat portion of the PV panels. Application of this factor also includes a minimum gap between panels in both directions.

An air equalization factor γ_A will apply in the following instances:

1. Where the distance from the top edge of the PV panel is no more than 10 in. (254 mm) from the flat part of the roof surface, and the horizontal space between panels is at least 1.4 in. (6 mm) in both directions, use a value of 0.8 for γ_A.

2. Where the distance from the top edge of the PV panel is no more than 5 in. (127 mm) from the flat part of the roof surface, and the horizontal space between panels is at least ¾ in. (19 mm) in both directions, use a value of 0.6 for γ_A.

3. For a distance between 10 and 5 in.(25 cm and 12.5 cm), interpolation is acceptable.

Where the above conditions are met, the edge factor, γ_E, that is applied to the outer panels around the entire perimeter of the array may be reduced to 1.25. Per ASCE 7-22. In that situation, γ_E = 1.5 only applies for a distance of $2h_2$ (where h_2 equals the distance between the panels and the flat roof surface) from the panel edge. Since h_2 is ≤ 10 in. (254 mm), $2h_2$ ≤ 20 in. (508 mm); and the panel width is typically ≥ 40 in. (1.0 m); only half of the edge panel has a surcharge load due to the edge effect. For simplicity, use γ_E = 1.25 where γ_A applies.

An example is provided in Appendix C.

C. Use FM Approved external seam clamps (ESC) and FM Approved PV panel clamps as an entire system over existing metal panel (standing seam and lap seam) roofs. Properly fit the specific standing seam rib profile with the appropriate ESC at each seam. Torque clamps and PV studs in accordance with the manufacturer's instructions, and inspect for tightness.

D. Analyze the load transfer from the PV system to the building structure, and show the existing metal panel roof securement is adequate per FM guidelines.

2.1.2.3.4 Insulated Metal Panels

Design PV installations over insulated metal panels (IMP) for the full wind loads and resistance as follows:

A. Use systems that are FM Approved as a complete roof-PV system.

B. Use wind pressures and wind ratings determined in Data Sheet 1-28, *Wind Design*, to calculate the wind pressure loads for new PV systems installed parallel to insulated metal panel roofs.

C. Connect new rigid PV panels over existing insulated metal panel roofs through the IMP, directly into the top flange of the supporting purlins. If the existing IMP roof is FM Approved as part of an FM Approved roof-PV system, utilize the FM Approved system based on the required wind ratings for the proposed system.

2.1.2.4 General Wind Recommendations

2.1.2.4.1 Anchor all related equipment, such as combiner/junction boxes and conduits, to the roof deck or roof structural members (or inverters to concrete foundations) as required to provide proper anchorage against expected loads (see Figure 2.1.2.4.1-1). Use mechanical anchors that can be connected to the equipment and to the roof deck or roof framing. The dead weight and resulting frictional resistance for most equipment is not sufficient to resist wind uplift and lateral wind loads.

2.1.2.4.2 Provide a positive method of securement between concrete paver blocks and pedestals or paver trays. Acceptable methods could include slotted or flanged pedestals or paver trays (see Figures 2.1.2.4.2-1 and 2.1.2.4.2-2).

2.1.3 Hail

2.1.3.1 Use PV panels that have appropriate hail ratings (established in accordance with FM 4478 or FM 4476) recommended for hail-prone regions as defined in FM Property Loss Prevention Data Sheet 1-34, *Hail Damage*. See Table 2.1.3.1-1.

Fig. 2.1.2.4.1-1. Examples of mechanical anchors used to secure equipment to the roof deck or roof framing

Fig. 2.1.2.4.2-1. Slotted pedestal

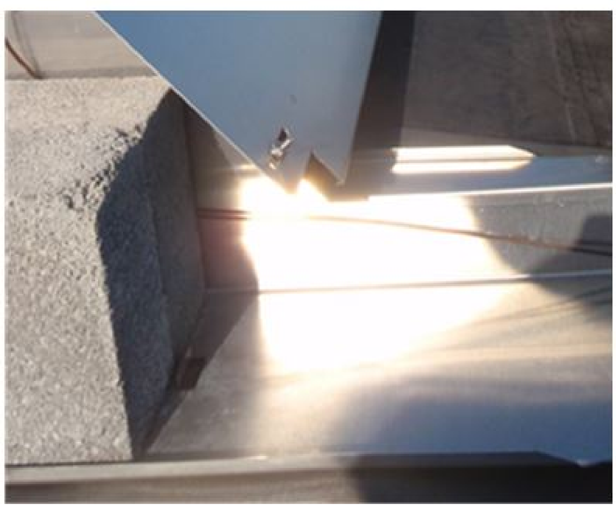

Fig. 2.1.2.4.2-2. Flanged pedestal

Table 2.1.3.1-1. Minimum Hail Ratings for PV Panels

Hail-Prone Region	*Rigid FM 4478*	*Flexible FM 4476*
Moderate Hail	Class 2	MH
Severe Hail	Class 3 or Class 4	SH
Very Severe Hail	Not available	Not available

2.1.4 Earthquake

2.1.4.1 Design rigid PV solar systems located in seismic zones 50 through 500 years to prevent lateral movement during a seismic event. For determination of seismic zones and other details, see FM Property Loss Prevention Data Sheet 1-2, *Earthquakes*. To limit lateral movement, provide anchorage to the roof deck or framing around the entire perimeter of each array. The design of the anchors should consider not only the strength of the anchors, but also the transfer of loads directly to the secondary roof framing or through the deck and deck securement into the secondary roof framing.

2.1.4.2 Provide excess flexible cable (e.g., greater than 2 in. [50 mm]) between panels, combiners, converters and other connected equipment to allow for movement during an earthquake.

2.1.4.3 Use bolted or other positive fastening methods as required by Chapter 13 of ASCE 7-22. Do not consider frictional resistance dependent on gravity.

See Section 3.6 for additional information.

2.1.5 Collapse

2.1.5.1 Design the PV panels and the roof supporting them to resist design snow loads, including potential drifting, in accordance with Data Sheet 1-54. FM Approval of PV panels includes evaluation for gravity load resistance of the PV panels. FM Approvals does not evaluate the gravity load resistance of roof assemblies and building structure, combined with PV installations.

2.1.5.2 When PV systems are proposed for existing roofs, ensure the dead weight of the proposed PV system does not reduce the roof resistance for snow, rain and other live loads below acceptable levels recommended in Data Sheet 1-54. Consider 2 to 3 psf (0.10 to 0.14 kPa) for the PV panels and hardware, plus additional recommended ballast weight.

2.1.5.3 Ensure the path for rainwater flowing to roof drains, through wall scuppers, or edge drainage is unobstructed by the PV array installation. Analyze in accordance with Data Sheet 1-54, *Roof Loads and Drainage*.

2.1.6 Vegetative and Agrivoltaic Photovoltaic Systems

Vegetative roof systems and agrivoltaics create an exposure. The vegetative roof design brings grass, decorative shrubs and trees to the roof top. These vegetative roof systems are then integrated with PV systems. Many rooftop agrivoltaic systems have PV panels installed perpendicular to the roof top. This design allows for extra space between the panels for planting, access, and harvesting, while allowing energy production, but creates wind design issues (see Section 2.1.2).

2.1.6.1 Use an FM Approved vegetative roof system. See FM Property Loss Prevention Data Sheet 1-35, *Vegetative Roof Systems, Occupied Roof Areas and Decks*. Use this data sheet, as applicable, for agrivoltaics.

2.1.6.2 Install photovoltaics or agrivoltaics in combination with vegetative roof systems that are composed of low-growing ground cover and succulent plants. Choose plants based on moisture retention and those which require little-to-no maintenance. Do not install in areas susceptible to wildland fires. (See FM Property Loss Prevention Data Sheet 9-19, *Wildland Fire*.)

2.1.6.3 Install vegetative or agrivoltaics over a minimum of 3 in. (50–76 mm) of compacted, engineered growth media beneath the plantings. (See Data Sheet 1-35, for additional guidance on growth media or engineered soil.)

2.1.6.4 Do not use plastics trays or plastic mix in the growth media or engineered soils.

2.1.6.5 Design agrivoltaic panels installed perpendicular to the roof system for horizontal wind loading and wind uplift. (Some designs will raise the panels to allow growing beneath.)

2.1.6.6 Inspect and maintain agrivoltaics in accordance with FM Property Loss Prevention Data Sheet 1-35, *Vegetative Roof Systems, Occupied Roof Areas and Decks*.

2.1.6.7 Do not use vegetative and agrivoltaic photovoltaic systems in tropical cyclone-prone areas. (See Data Sheet 1-28, *Wind Design* and Data Sheet 1-35 for additional guidance.)

2.1.6.8 Secure vegetative roof components and photovoltaic panels so that the installation does not produce windborne debris. (See Data Sheet 1-35 for guidance.)

2.2 Electrical

2.2.1 Install new PV electrical energy systems, including the array circuit(s), inverter(s) and controller(s) for these systems, in accordance with NFPA 70, *National Electrical Code* (or equivalent international standard) and as required by the local fire service.

2.2.2 Consult with the local fire service for approved locations of inverters and rapid shutdown equipment.

2.2.3 Provide inverters with safety functions that meet both of the following:

A. DC ground fault protection that meets UL 1741, *Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources*, or IEC 62109, *Safety of Power Converters for Use in Photovoltaic Power Systems*; and

B. Arc fault protection that meets UL 1699B, *Photovoltaic (PV) DC Arc-Fault Circuit Protection* or IEC 63027, *Photovoltaic Power Systems – DC Arc Detection and Interruption*.

For more information, see Section 3.8.

2.2.4 Do not install electrical wiring within the rib opening of steel decking or otherwise within the plane of the above-deck components, as wiring can serve as a possible ignition source. It would also inhibit access for maintenance and repair and be subject to damage from mechanical fasteners used to secure above-deck roof components.

2.2.5 Provide a service loop of flexible cable (e.g., greater than 2 in. [50 mm]) for movement between panels, combiners, converters and other connected equipment, to ensure adequate expansion and contraction from extreme temperature fluctuations during the year. This recommendation includes wiring, as well as the interface between the PV panels and the roof cover.

2.2.6 Design and install interior cables and bus bars in accordance with FM Property Loss Prevention Data Sheet 5-31, *Cables and Bus Bars*.

2.2.7 Use rigid PV panels that meet electrical performance criteria per IEC/EN 61215-1, 61215-1-1 and 61215-2.

2.2.8 Use rigid PV panels that comply with criteria for electrical safety per IEC/EN 61730-2, *Photovoltaic (PV) Module Safety Qualifications, Part 2: Requirements for Testing*, or ANSI/UL 1703, *Flat Plate Photovoltaic Modules and Panels*.

2.3 Commissioning, Operation and Maintenance

2.3.1 Implement a commissioning program for all photovoltaic systems larger than 0.5 MW. For systems less than 0.5 MW, the installer should provide a written verification, indicating they have complied with these commissioning requirements. Maintenance is applicable to all photovoltaic systems regardless of size.

2.3.1.1 Mechanical Equipment

Commissioning: With oversight of an owner representative (either in house or third party hired), ensure all fasteners are inspected during commissioning and installation to ensure they are properly tightened and secured. Use a calibrated torque wrench to ensure that fasteners are tightened to the manufacturer's specified torque values, avoiding both under- and over-tightening. Ensure that any identified deficiencies are corrected prior to commercial operation.

2.3.1.1.1 Mechanical Maintenance

Conduct the following mechanical maintenance:

- One year after commercial operation date (COD) or pre-warranty end date, perform a visual inspection of all mechanical connections, including fasteners.
- Repair or modify any findings after the one-year COD inspection or pre-warranty end date.
- Conduct annual visual inspections of the mechanical components to ensure original installation condition.

- Perform tightness checks of accessible mechanical fasteners once every three years or following severe weather events.

2.3.1.2 Electrical Equipment

- Commissioning: With oversight of an owner representative (either in house or third party), conduct thermographic inspections of the top side of PV panels and electrical systems in accordance with ASTM E1934 immediately after, and again 14 days after energizing the system. Include connectors, cabling, combiner boxes, inverters, optimizers and any underside connections where accessible.
- Correct all electrical deficiencies prior to commercial operation.
- Track PV output

2.3.1.2.1 Electrical Maintenance

Conduct the following electrical maintenance.

- Visually inspect all equipment for damage every six months or after seismic or severe weather events.
- Visually inspect for signs of loose equipment, corrosion, poor connections and water or moisture within combiner or inverter boxes.
- Conduct thermographic inspections of the top side of PV panels and accessible electrical systems (including connectors, cabling, combiner boxes, inverters, optimizers, etc.) every three years in accordance with ASTM E1934. Include any underside connections where accessible.
- Correct all electrical deficiencies.

2.3.2 Inspect the sealing of roof penetrations for watertightness annually, and repair as needed.

2.3.3 Refer to FM Property Loss Prevention Data Sheet 9-0, *Asset Integrity*, for general recommendations on establishing an asset integrity program, including maintenance and inspection programs for equipment and systems.

2.4 Human Element

2.4.1 Arrange pre-fire planning with the fire service. (See FM Property Loss Prevention Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*.) Ensure the fire service is familiar with ground access, stairs to the roof, PV array aisles, the location of combiner boxes and inverters, and all related fuses and disconnects. Ensure they understand that the roof cover system significantly contributes to the spread of fire.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Basic Operation of PV Systems

PV solar panels are made of semiconductors in the form of individual silicon cells wired in series and are usually protected above by tempered glass, polymeric encapsulant or composite material. Panels are linked together in series to form strings, and then individual strings are connected within a combiner box to form an array. The panels within the array convert energy from sunlight into direct current (DC) electrical power. This power can be stored as DC. More commonly, DC power is converted to alternating current (AC) using an inverter and then fed into a large electrical grid or used directly on-site. Usually, one or more arrays/combiner boxes are connected to an inverter when the electric power is converted from DC to AC.

Common sites for PV panels are roofs of warehouses and other facilities that do not require extensive rooftop equipment that would shadow the PV panels. Aisles are often provided within or between arrays to allow access for maintenance of rooftop equipment and manual firefighting. Aisles are also provided to prevent the panels from being shadowed by equipment, higher roofs or other obstructions to sunlight. For additional information on ground-mounted PV panels, see Data Sheet 7-106.

3.2 Exterior Fire Spread in Roof-Mounted PV Arrays

Roof mounted PV arrays increase the risk of exterior fire spread compared to roof assemblies alone. Even when panels contain minimal or no combustible materials, electrical wiring associated with the PV system can ignite the roof surface. Fire growth of this system depends largely on the roof covering and insulation beneath the array. Additionally, panels may alter airflow to the fire. They can also redirect flames back toward the roof system, intensifying re-radiation and damage.

New products continue to emerge to meet market demand, including lightweight photovoltaic panels that reduce structural loads and enable installations on roofs with limited capacity for added dead weight. While these lighter panels decrease weight and expand installation options, they often incorporate additional plastic polymer components, thereby increasing the fuel load.

Thin film photovoltaic panels are increasingly used due to their low weight and very thin profile, and many are installed by adhering them directly to the roof covering. This installation method can reduce heat flux into the roof. However, fires involving thin film products are expected to perform to the lower of the roof or PV fire classifications—meaning a Class C panel applied over a Class A roof will behave as a Class C system. Additionally, the method of adhesion can influence wind exposure and overall fire behavior.

Components of common rigid PV panels—such as plastic frames, backsheets and adhesives—can ignite and radiate heat back onto the roof covering and insulation, significantly increasing exterior fire spread beyond what the roof assembly alone would produce. To manage this elevated fire spread risk, only certain roof assemblies are considered suitable for use with roof mounted PV panels.

The ASTM E108 test evaluates roof coverings for their potential surface flame spread and their ability to resist exterior fire penetration to the underside of the roof deck. It also determines whether the roof system will ignite from burning airborne debris, known as “flying brands.” Roof coverings tested under ASTM E108 receive a fire classification of Class A, B or C.

The FM Approval 4478 test evaluates the fire performance of roof PV systems using a modified ASTM E108 method that tests the roof covering and PV panel together. By placing both components at the leading edge of the test apparatus, the procedure exposes them simultaneously to wind driven fire conditions. FM also uses the ASTM E108 method to assess flexible photovoltaic modules under FM 4476, Examination Standard for *Flexible Photovoltaic Modules*.

3.3 Flexible PV Installations

Adhered, flexible solar modules and their roof systems are not currently FM Approved; as modules secured only at the edges cannot distribute wind loads uniformly to the roof cover beneath them.

3.4 Wind Resistance

3.4.1 Boundary Layer Wind Tunnel (BLWT) Testing and Ballasted PV Systems

Testing in a boundary layer wind tunnel (BLWT) is conducted to determine wind loads and resistance for roof-mounted PV panels. The scaled models used to replicate the proposed roof-mounted panels should be as representative as possible, particularly with ballasted arrays. Include the sizes of individual panels, the weights of the panels and ballast, the PV panel slope, the coefficient of friction (μ) between the roof surface and the underside of the panel pedestals or paver trays, and the size of the array. Tests should replicate the minimum array size to be used, the number of interconnected panels within a given array and the minimum number of panels within a row or column.

To allow the test data to be used for various combinations of roof cover types and pedestal pads/paver trays, separate testing may be needed to quantify the coefficient of friction between the two surfaces. Testing should reflect any slip sheets that may be used. Since movement of any panel defines failure, the static coefficient of friction may be used in lieu of the dynamic value. While the wet coefficient of friction often yields a lower value, test data reflects that the dry value is lower in some cases.

Testing needs to be conducted in a boundary layer wind tunnel (BLWT) rather than an aerospace wind tunnel (AWT). While similarities exist between the two, the BLWT simulates wind flow toward a building by providing obstructions between where the wind enters the tunnel and the scaled building model. Typically, an open terrain or Exposure C is simulated. The simulated building is often a flat rigid object. This design allows the wind to hit the wall of the model, flow over it, and create turbulence and vortices that cause higher uplift pressures, particularly at the perimeter and corner areas. Such a realistic effect is not provided when using an aerospace wind tunnel.

Even in BLWT, internal building pressure effects and potential vertical movement of the roof cover are not simulated. The building models used in a BLWT test are very rigid and do not represent the behavior of a mechanically fastened roof cover (see Figure 3.4.1-1), which may billow when exposed to wind pressure. Such vertical movement of the roof cover can increase the drag and lift coefficients for the PV panels and can make the results of the BLWT invalid. The results of the BLWT test are more applicable to a fully adhered roof cover. PV panels must be mechanically fastened if installed over a mechanically fastened roof cover.

Fig. 3.4.1-1. Mechanically fastened roof cover billowing when subjected to wind pressure

While aerospace wind tunnels are numerous, a limited number of BLWTs exist. The following locations perform BLWTs:

- Western University (formerly the University of Western Ontario or UWO), Ontario, Canada
- Cermak, Peterka and Peterson (CPP) in Colorado and Australia
- Rowan, Williams, Davies and Irwin, Inc. (RWDI), Canada

Experimental wind load estimates on roof-mounted solar panels outside the qualified BLWT facilities listed above can be inaccurate for the following reasons:

1. The experiments were conducted without considering the effect of the building on the solar panels. The testing includes experiments that were conducted in an aerospace wind tunnel, which is used for testing cars and aircraft. These types of wind tunnels produce smooth wind at a constant speed, and at very low turbulence intensity (≤0.5%). To study the wind load on roof-mounted solar panels, experiments must be conducted in a BLWT where the wind is turbulent and gusty with high turbulence intensity (≤10%). The wind tunnel experiments must also be conducted in accordance with ASCE 49-21, *Wind Tunnel Studies of Buildings and Other Structures*.
2. The experiments were conducted only for a single wind direction. Just like the roof itself, the tilted solar panels can experience substantial wind loads from cornering winds.

Wind load estimates obtained using only computational fluid dynamics simulations on roof-mounted solar panels are not recommended by ASCE and may be inaccurate for the following reasons:

1. The simulations were performed without considering the effect of the building on the solar panels.
2. Validation of the computational fluid dynamic simulations with existing literature or with BLWT experiments was not performed.

3.4.2 Increased Ballast or Securement Around Openings and Aisle Spaces

Often, aisle spaces that provide firefighter or maintenance access will exist around other roof-mounted equipment or between arrays and will break the continuity of the interconnection between panels. This break reduces the wind load distribution and also reduces the shielding affect that the outer panels in the array provide for those panels farther in from the aisles. To account for this reduction, additional ballast or securement (typically 50% more) should be provided for the panels immediately around the openings.

3.4.3 Existing Ballasted Installations

3.4.3.1 (Reserved)

3.4.4 Distribution of Ballast Weight for Ballasted PV Arrays

3.4.4.1 (Reserved)

3.4.5 PV Systems Fastened to Standing Seam Roofs (SSR)

Rigid PV panels can be mechanically fastened to SSRs and can be FM Approved in accordance with FM 4478. For more information on SSRs, see Data Sheet 1-31. SSR panels are seamed to the internal clips, which are pre-fastened at each deck rib to each steel purlin or to a continuous substrate. The wind design for SSR assumes the wind load is distributed evenly to each internal clip. An external seam clamp, like those used to enhance the wind resistance of SSRs, is used to connect PV panels to the SSR deck ribs (see Figures 3.4.5-1 and 3.4.5-2). These clamps do not penetrate the seam. One clamp should be provided at each standing seam rib near the down-slope and up-slope edges of the PV panels. Otherwise, the wind load transferred from the PV panels may: 1) buckle the deck ribs or 2) fail the internal SSR clip and screws securing the clip to the top flange of the purlin. The spacing between clamps may vary from about 3 to 10 ft^2 (0.3 to 1.0 m^2) per clamp, depending on the SSR rib spacing and the distance between internal clips along the deck seams. Ensuring that the individual clamp is designed to fit the specific seam of the SSR is important. For an example problem, see Appendix C.

Fig. 3.4.5-1. Solar panels secured to standing seam roofs using external seam clamps

Fig. 3.4.5-2. Unacceptable arrangement unless specifically tested and FM Approved: clamp missing from SSR rib below middle of outer panel edge

3.4.6 Lap Seam Roofs (LSR)

3.4.6.1 (Reserved)

3.4.7 Insulated Metal Panel (IMP) Roofs

3.4.7.1 (Reserved)

3.4.8 Single-Ply Membrane (SPM) Roofs

3.4.8.1 (Reserved)

3.4.9 PV Installation Over Existing Roofs

3.4.9.1 (Reserved)

3.4.10 Effective Wind Area

The effective wind area (EWA) is the area of a given assembly component to which the wind load is distributed or shared. For a fastener, the EWA is assumed to be the area supported by the fastener.

For ballasted PV arrays, determining the EWA for wind uplift can be complicated; as it is contingent on the amount of ballast provided and the strength of the PV system racking. Ensuring the use of an accurate EWA is critical. As the EWA increases, the wind pressure coefficient decreases. Using an unrealistically large EWA in the design calculations will result in wind resistance that is too low. The EWA for a ballasted array varies, depending on the location of the panel within the array (i.e., corner, edge, or interior), as well as the rigidity of the hardware or racking that connects the panels. The EWA can be determined using one of the following methods:

A. Finite Element Analysis (FEA) of the hardware or racking assembly (see Section 3.4.11)

B. A full scale VLT as outlined below

Racking members for roof-mounted PV arrays vary in stiffness. To quantify the array's ability to share wind uplift loads, VLT testing is needed. In these tests, the results should consider both a) when failure or permanent deformation occurs, and b) when the vertical displacement becomes excessive. If displacement is excessive, the PV array may no longer be represented by the wind tunnel model and the respective pressure coefficients. It may also negate the positive effects of wind deflectors in reducing uplift forces.

A VLT procedure has been developed by FM Research to estimate the load sharing factor (LSF) for a ballasted, roof-mounted PV array. The LSF factor can then be used like the Effective Wind Area (EWA) to determine the wind loads, and subsequently, the required ballast weight needed to secure the ballasted, roof-mounted PV panel arrays. Knowing the LSF is critical to determine the loads on the PV array and how much ballast weight is needed to resist those loads.

Where an acceptable and valid VLT cannot be supplied by the designer, this VLT procedure can be used to test a proposed array.

Steps to estimate the LSF are as follows:

1. The selected test array should represent the actual installation in structure and ballast configuration. The results of a larger array cannot be applied to an array that has fewer panels in one or more directions.
2. The VLT should be applied to panels within the corners, edges and interiors of the array. All non-symmetric corners and edges should be tested. Loads should be applied to one panel at a time (to represent the lowest EWA and highest-pressure coefficients).
3. Tests should be conducted with the maximum expected ballast for the PV array (determined by the manufacturer per the design). Alternatively, the test is performed without ballast. Use the determined EWA to calculate the maximum ballast weight, per the wind load calculations in SEAOC PV2 or the wind tunnel report. That calculated value can then be used in the actual test for maximum ballast weight.
4. An uplift load should be applied to the panels at four locations as shown in Figure 3.4.10-1. Use two locations along each long side (shown in the red circles below). Attachments along the panel should be symmetric. Measure the uplift displacements (shown in the green triangles) at the middle of the panel and at the two edges and take the average of all three. Use Ls equal to the distance between connection points of the PV panel to the frame, and b equal to the distance between each loaded point and the center of the panel long side, such that b = Ls/6. The panel should then be lifted in vertical steps (approximately 0.1 in. [2.5 mm] increments). This method will allow for constructing a smooth uplift load vs. vertical displacement curve.
5. The applied vertical load versus the average displacement of the three points (green triangles in Figure 3.4.10-1) should be plotted (example below in Figure 3.4.10-2).

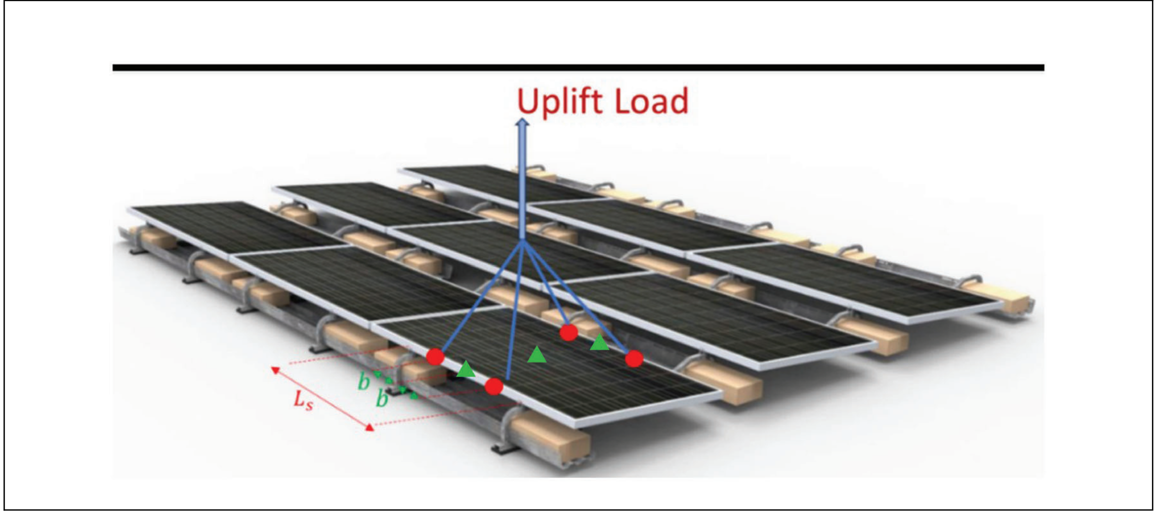

Fig. 3.4.10-1. Loading conditions of a corner panel as an example, where Ls is the distance between connections that attach the panel to the PV frame and b = L_s/6

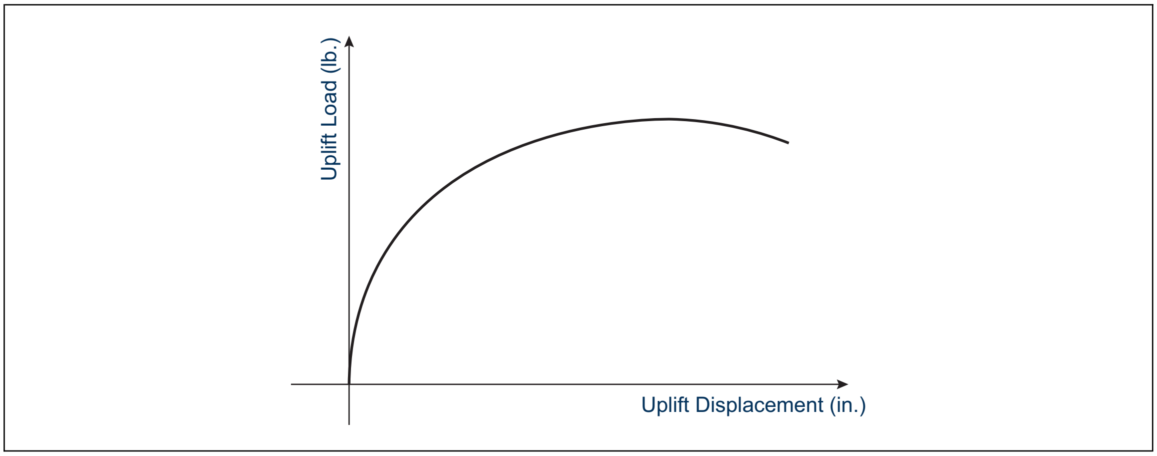

Fig. 3.4.10-2. Hypothetical load-displacement curves to be derived through the VLT procedure

Figure 3.4.10-3 shows the structural load capacity, Fm_0, using the displacement curve and the bi-linear method. The displacement associated with this load is the maximum displacement allowed.

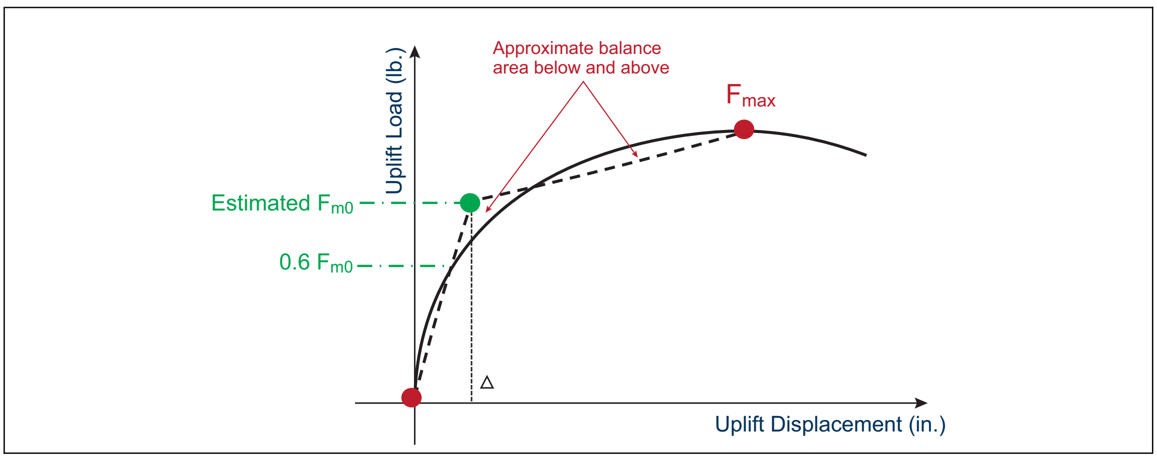

Fig. 3.4.10-3. Structural load capacity identified by means of the bi-linear method

6. Determine the LSF using the bi-linear method (Figure 3.4.10-3).

   − LSF = F_m/W

   − F_m = Maximum vertical load at the uplift displacement limit (UDL)

   − UDL = Minimum of “Structural Displacement Limit (SDL) at F_{m0}” or the “Aerodynamic Vertical Displacement Limit (AVDL) at F_{m1}”

   − W = Total weight (of loaded panel + structural components + ballast)

The SDL is the vertical load capacity, F_m, that should not cause deformation or structural damage (yielding, buckling, or brittle failure) to any of the PV mechanical components in the array.

For the SDL, the test data should demonstrate that none of the connections show visual damage or deformation up to the uplift load F_m. The data should also demonstrate that the load at the displacement limit is not larger than the load at four times the displacement limit (which is the point at which permanent deformation occurs under stress). Otherwise, a reduced uplift load should be chosen.

The array displacement limit should not exceed the AVDL and is determined by a wind tunnel test. This measurement can be used to find the uplift load for this limit.

The maximum design wind load for a given PV system should not exceed the above value of Fm.

The larger the ballast weight, the smaller the LSF (which is why the VLT should be conducted with the maximum ballast weight expected in the array). The stresses that result from the maximum ballast weight will produce the above failures at lower loads.

The displacement in an array should not exceed the Aerodynamic Vertical Displacement Limit (AVDL). The AVDL has been proposed by RWDI Wind Tunnel Consultants based on multiple BLWT tests for different panel configurations and tilt angles. The AVDL can be used to find the uplift load for this limit, Fm1, on the load-displacement curve. However, the AVDL for various PV systems needs to be determined by a BLWT test. Therefore, the AVDL may be different than the proposed values mentioned above.

3.4.11 Finite Element Analysis (FEA)

The structural design engineer can use finite element analysis to establish structural capacity curves of the ballasted PV array for a range of applicable ballast weights. Tributary area can be determined from the intersection of the structural capacity curve and the design wind load (which can be calculated using SEAOC PV. Effective wind area is assumed to be the same as the tributary area. The following steps explain the procedure to calculate the structural capacity curve.

Step 1: Identify the governing loading areas (i.e., corner, edge and interior area of the PV array).

Step 2: For each loading area, define the loading scenarios that can result in the least resistance or structural capacity (i.e., one panel loaded, two panels loaded, three panels loaded, etc.).

Step 3: For each loading area, perform nonlinear finite element analysis of the PV array for each loading scenario and ballast weight. Consider uniform wind load on each panel and applicable boundary conditions and materials of the PV array as built. During the analysis, increase the wind load until the system reaches any failure criterion, such as permanent deformation or maximum uplift displacement of a portion of the PV array.

Step 4: For each loading area, plot the wind loads (from the analysis) of different loading scenarios (number of panels loaded) for each ballast weight. Repeat this procedure, and add the curves for all other ballast weights to the same plot. The resulting plot is the capacity curve for the applicable loading area.

Step 5: Repeat Steps 2-5 to obtain the structural capacity curves for all governing loading areas.

3.4.12 Prescriptive EWA for Ballasted PV Arrays

3.4.12.1 (Reserved)

3.4.13 Roof Aggregate

The presence of roof aggregate near roof-mounted PV panels could result in windborne debris damage to the panels. If ballasted PV pedestals or paver trays are installed directly on top of roofing aggregate, it can adversely affect the arrays' resistance to sliding. Roof cover ballast should be continuous over the entire roof cover and consist of concrete paver blocks designed in accordance with Data Sheet 1-29, *Roof Deck Securement and Above-Deck Roof Components*. The amount of ballast in each roof zone will be acceptable if a sufficient weight of concrete paver blocks is provided above the solar panel pedestals or paver trays to deliver the needed wind resistance for the solar panels.

3.4.14 Limits on Use of Pressure Coefficients

The use of pressure coefficients from BLWT tests requires that the limits of the test configuration be followed to be valid for use in wind design. Variables such as height of panels off the roof surface, panel slope, panel dimensions, roof slope, panel location, etc. have limits. Exceeding these limits will change the wind characteristics of the tested arrangement and invalidate the pressure coefficients for use in design calculations.

Parallel panel systems are sometimes raised off the roof surface to reduce fire exposure. If raised up high enough, pressure coefficients used in the wind design will no longer be valid. At heights of approximately 7 ft (2.1 m) above the surface, the system will function as a carport. At heights of more than 2 ft (0.6 m) off the roof surface, prescriptive and BLWT pressure coefficients will not be valid.

3.5 Hail Resistance

Hail resistance of rigid PV panels should be determined by ice ball testing in accordance with FM 4478. Hail resistance of flexible PV panels should be determined by steel ball testing in accordance with FM 4476.

Impact from hail larger than that for which the panels were successfully tested could cause extensive damage to the PV panels.

3.6 Earthquake Concerns

Seismic load considerations differ from wind loads, with seismic design placing greater emphasis on lateral forces. While building codes allow limited lateral movement for life safety, excessive displacement can cause significant damage to PV panels.

PV arrays often rely on ballast to resist vertical wind loads, which are typically more critical than lateral wind pressures. Although the added weight increases frictional resistance against seismic lateral forces, those forces also scale with the system's total dead load. As a result, increasing ballast beyond wind design requirements can unintentionally amplify lateral seismic demands.

Lateral loads distribute more uniformly across a PV array, while vertical loads remain highly localized. Installing mechanical anchorage around the array perimeter is the preferred approach to minimizing PV panel damage during seismic events.

3.7 Collapse

Additional guidance is provided in FM Loss Prevention Data Sheet 1-54, *Roof Loads and Drainage*.

3.8 Fires and Electrical Ignition Sources

3.8.1 Ground Fault Protection

Numerous fires in U.S. roof mounted PV installations have been linked to inadequate ground fault protection. Many systems use intentionally-grounded conductors, paired with detection equipment designed for faults in ungrounded conductors. They rely on conservative leakage current assumptions to prevent nuisance trips. Because these systems use fuses with insufficient sensitivity, ground faults can go undetected. As these installations age, the likelihood of such failures—and resulting fires—may increase.

Electrical fires are a known risk in roof mounted PV arrays due to the presence of combustibles such as roof coverings, insulation and PV panels. PV modules can also redirect flames and radiate heat, increasing the potential for fire spread compared with unobstructed roofs. Adhering to the electrical guidance in this document can reduce—but not fully eliminate—the risk of fire.

The objective is to detect the first ground fault before a second occurs. Recent incidents show that older, NEC compliant, fuse based ground fault protection lacked sufficient sensitivity, creating "blind spots" where initial faults went unnoticed. A subsequent ground fault can then release enough energy to ignite a roof top fire.

The NEC requires reducing array voltage during emergencies or maintenance, a feature known as panel level rapid shutdown. This feature is most commonly achieved through module level shutdown devices, such as DC optimizers, which lower voltage within the array when activated.

In addition to detecting ground faults, panel level power electronics can provide arc fault circuit interruption (AFCI) and monitoring. These devices also eliminate reliance on fuses for ground fault protection.

3.8.2 Preventing Fires from DC Ground Fault in PV Arrays

A ground fault in a PV array is an unintended short circuit between ground and one or more current carrying conductors. These faults can create DC arcs, damage insulation, and pose significant fire hazards—especially if a second ground fault occurs. Common causes include:

A. **Cable insulation failure** (e.g., animal damage)

B. **Accidental contact** between conductors and grounded components (e.g., inside junction boxes)

C. **Internal PV panel faults** (e.g., cell contact with grounded frames due to deterioration from aging, impact, or moisture)

D. **Abraded insulation** from installation damage or thermal movementTo mitigate these risks, NEC 70 requires ground fault protection capable of detecting fault current, interrupting it, and providing a clear fault indication.

To mitigate these risks, NEC 70 requires ground fault protection capable of detecting fault current, interrupting it, and providing a clear fault indication.

3.9 Information Needed for FM Plan Review

For an FM plan review of the fire and natural hazard design of insured locations, the following details and documents are required:

Fire:

1. Will the existing roof cover remain? If yes, indicate the type of roof cover, type of insulation, whether a noncombustible cover board is provided immediately below the roof cover and whether the roof cover is fully adhered to the roof component below. Provide a sketch of the roof expansion joints, including the type of insulation within them, considering Figure 2.1.1.6-1.
2. If a new roof cover is proposed, submit complete details for the roof cover, insulation and cover boards, securement methods, and description of the roof expansion joints, considering Figure 2.1.1.6-1.

Wind:

The following details and information are needed, specifically relating to the installation and design calculations. (Many of these items can be found in a summary spreadsheet for the installation, which should also be provided):

- Array layout with setback distances
- Zone dimensions
- Building dimensions, height, roof slope
- Panel zoning
- Panel zone factors, if applicable (corner, edge, interior)
- Panel edge factors
- Parapet height factors
- Effective wind area
- Pressure coefficients on each panel
- Wind loads on each panel
- Demand loads on each panel (load combinations)
- Anchor/ballast layout
- Demand loads on the anchors, ballast and any other connections in the load path
- Design documents demonstrating that all PV elements (including PV frame, connections and anchors) can provide a safety factor (SF) greater than or equal to 2.0
- 100-yr. MRI windspeed in full windstorm evaluation areas
- Importance factor
- PV panel slope
- Gaps between panels in and between rows
- Height of PV panels from roof at higher and lower ends

- Panel chord length
- Panel width
- Orientation of panel

Hail:

- Identify hail test standard utilized.
- Provide test results, including: hail ball size and type (steel or ice), kinetic energy, angle of impact, etc.
- Provide top and bottom glass type and thickness.

4.0 REFERENCES

4.1 FM

Data Sheet 1-2, *Earthquakes*
Data Sheet 1-20, *Protection Against Exterior Fire Exposure*
Data Sheet 1-28, *Wind Design*
Data Sheet 1-29, *Roof Deck Securement and Above-Deck Roof Components*
Data Sheet 1-31, *Panel* Roof Systems
Data Sheet 1-34, *Hail Damage*
Data Sheet 1-42, *Maximum Foreseeable Loss Limiting Factors*
Data Sheet 1-54, *Roof Loads and Drainage*
Data Sheet 1-57, *Plastics in Construction*
Data Sheet 5-11, *Lightning and Surge Protection for Electrical Systems*
Data Sheet 5-19, *Switchgear and Circuit Breakers*
Data Sheet 5-20, *Electrical Testing*
Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems*
Data Sheet 7-106, *Ground-Mounted Solar Photovoltaic Power*

ANSI/FM 4473, *Specification Test Standard for Impact Resistance Testing of Rigid Roofing Materials by Impacting with Freezer Ice Balls*

FM 4470, *Examination Standard for Single-Ply, Polymer-Modified Bitumen Sheet, Built-Up Roof (BUR) and Liquid Applied Roof Assemblies for use in Class 1 and Noncombustible Roof Deck Construction*

FM 4476, *Examination Standard for Flexible Photovoltaic Modules*

FM 4478, *Examination Standard for Rigid Photovoltaic Modules*

FM 4484, *Examination Standard for Retrofit Coatings for Roof-Mounted Rigid Photovoltaic Module Systems*

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APPENDIX A GLOSSARY OF TERMS

Aerospace wind tunnel: A wind tunnel that simulates horizontal wind forces acting directly on an object. It does not simulate conditions between the fans and the object within the lower portion of the boundary layer. This simulation is necessary to replicate the surface roughness exposure related to the wind design of the building and rooftop equipment. Nor does it replicate wind flow over a wall of a modeled structure below the rooftop equipment. This wind flow is required to simulate actual suction effects in addition to the horizontal forces.

Agrivoltaics: An area that is used for both farming and solar, photovoltaic energy production. Solar photovoltaic panels are co-located on the same land as agricultural production.

Allowable stress design (ASD): A structural design method in which the allowable stresses contain a safety factor, because the structure is designed to stress levels that are only a percentage of the failure stresses.

Arc-fault circuit interrupter (AFCI): A device intended to provide protection from the effects of arc faults by 1) recognizing characteristics unique to arcing and 2) deenergizing the circuit when an arc fault is detected.

Arc prevention: Technology that uses advanced arc prevention techniques to prevent arcs from forming. This technology exceeds the minimal requirements stated in NEC and UL 1699B, but it is used by some manufacturers of panel level power electronics today. Limits low energy levels (200 Joules).

Array size: The number of interconnected PV panels (the minimum number of panels within each row and each column) and the gross plan area occupied within a given array. Usually, a slight (fraction of an inch) separation exists between panels in the east-west direction; and sufficient separation exists (depending on panel slope) between rows to prevent shadowing. Wind tunnel or field model tests should replicate the minimum array size required. Data for a larger array does not justify the design for a smaller array.

Automatic panel/module-level DC shutdown: Systems that have built-in panel/module-level power electronics and safety features that deenergize the PV array at the panel/module level. These systems may be automatically triggered by a loss of grid power, high temperatures, ground faults, arc faults, faulty connectors, faulty wiring, rodent damage, etc. This configuration is sometimes referred to as “safe DC.”

Ballasted: Not adhered to the roof cover below, nor fastened to the roof deck or structure. Resistance to wind loads is provided by the weight of the panels, mounting equipment and any additional ballast.

Boundary layer wind tunnel: A wind tunnel with a long transition between the fans and the object, having obstructions to replicate the lower portion of the boundary layer and the surface roughness exposure related to wind design of the building and rooftop equipment. Testing is performed with scaled models of rooftop equipment and building upon which it is installed.

Closed mounting system: A PV mounting system that has a wind deflector on the high side (north side in northern hemisphere and south side in southern hemisphere) of each row of panels. It may or may not have deflectors on the east and west ends of each row.

Coefficient of friction (μ): A dimensionless coefficient used to quantify resistance to lateral movement (in this case, between the undersides of the panel mounts and the top surface of the roof cover). It is equal to the lateral load resistance divided by the force normal (perpendicular) to the two mating surfaces. This value will vary, depending on the construction of the underside of the panel mount and the type of roof cover. Such construction includes, but is not limited to, stainless steel, aluminum, coated metal, or metal with a pad (such as a piece of single-ply roof cover material or rubber) adhered to its underside.

Commissioning: The process of verifying through functional testing that the electrical connections, grounding, polarity, voltage, current, power and energy output of the PV system are within design specifications. Functional testing of the protection devices, inverters, meters, monitoring systems and other components is also conducted to verify they are operating safely and within design specifications. Commissioning includes verification that the equipment has been securely mounted and installed, per the approved specifications and drawings. This information should be documented and used as an established baseline of system operation.

Computational fluid dynamics (CFD): A form of computer modeling that uses numerical methods and algorithms to analyze and solve problems involving fluid flows. Computers are used to perform the calculations required to simulate the interaction of fluids with surfaces defined by boundary conditions. Validation of such software is performed using a wind tunnel.

Coverboard: A board stock product used directly over insulation, but directly under the roof membrane. A coverboard is only applied as the top layer of a multilayer insulation assembly. Coverboard must be made of a noncombustible material. Examples are foam glass, minimum 1/4 in. (6 mm) of gypsum, minimum 1 in. (25 mm) of mineral wool, or minimum 1/2 in. (13 mm) of perlite.

FM Approved: Products or services that have satisfied the criteria for Approval by FM Approvals. Refer to RoofNav, an online resource of FM Approvals, for a complete list of roofing products and services that are FM Approved.

Inverter: An electrical device used to convert direct current (DC) electrical power to alternating current (AC) electrical power.

Load and resistance factor design: Also known as “strength design” or “ultimate design”. A structural design method that applies safety factors to the loads, and in some cases, a lesser safety factor to the resistance of the materials.

Moderate Hail (MH) hazard area: Areas in which the hail size does not exceed 1.75 in. (44 mm) for the 15-year mean recurrence interval (MRI).

Non-sheltered PV panels: PV panels located on the exterior side of the perimeter row(s) of panels that are not sheltered from the wind load from other panels, and for which the wind load may be greater than that of the interior, sheltered panels.

Open mounting system: A PV-mounting system that does not have a wind deflector on the high side (north side in northern hemisphere and south side in southern hemisphere) of each row of panels.

Photovoltaic (PV) system: A system that uses solar panels to convert sunlight into electricity. It consists of PV panels, support framework, and electrical connections/equipment to regulate and convert electrical output from DC to AC.

PV panel or PV module: An individual unit consisting of numerous cells, usually 60 or 72. It is usually about 39.4 in. (1 m) in the north-south direction and 65 to 77 in. (1.65 to 2.0 m) in the east-west direction. In most cases, it is bounded by edge framing. In some cases, panels are also referred to as modules, particularly when ballasted. For anchored installations, three or four connected panels/modules may be considered a panel.

PV system: A set of components used to convert sunlight to electricity. These components include PV panels/modules, mounting structure or racking, combiner boxes and inverters, used together to produce power.

Rapid shutdown of PV systems on buildings: PV system circuits that include a rapid shutdown function to reduce shock hazard for emergency responders. Installed on or in buildings.

Roof control joint: A construction joint that provides a break in the continuity of above-deck roof components to prevent damage to the roof cover from thermal movement. This joint does not provide a break in the roof deck.

Roof expansion joint: A joint that provides a break in the continuity of the building framing, roof deck and above-deck roof components to prevent damage to the building from thermal movement (a.k.a control, dilatation or construction joint).

Roof–PV system: A system comprised of roofing components (e.g., cover board, roof membrane and insulation, vapor barrier, etc.) and a photovoltaic system (held in place by ballast or mechanically attached) installed on top of the roof cover.

Setback: The distance between the outside edge of a roof supporting solar panels and the outer edge of the solar array.

Severe Hail (SH) hazard area: Areas in which the hail size exceeds 1.75 in. (44 mm) but does not exceed 2 in. (51 mm) for the 15-year mean recurrence interval (MRI).

Shadowing: Shade created by neighboring objects that necessitate relocation of solar panels and sometimes openings within the array. These openings can create wind forces on solar panels immediately adjacent to the opening that are higher than the forces on the interior of the array.

Sheltered PV panels: PV panels located on the interior side of the perimeter row(s) of PV panels that are somewhat sheltered by the perimeter panels and for which the wind load is somewhat less than for the perimeter panels.

Very Severe Hail (VSH) hazard areas: Areas for which the hail size exceeds 2 in. (51 mm) for the 15-year mean recurrence interval (MRI)

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

April 2026. Full revision. Improved clarity and incorporated updated fire and natural hazard mitigation recommendations. A new section on agrivoltaics was added.

October 2025. Interim revision. Changes made to include the option of a FM Approved coating.

April 2025. Interim revision. Changes include the following:

A. Provided guidance on rooftop photovoltaics combined with vegetative roofs and agrivoltaics.

B. Provided guidance on arc and ground fault protection.

C. Provided guidance on space separations for skylights and elevated modules.

D. Developed guidelines for commissioning and ongoing maintenance of mechanical and electrical components associated with photovoltaics.

E. Added guidance for conducting vertical load tests (VLT) for ballasted PV arrays.

January 2024. Interim revision. Minor editorial changes were made.

July 2023. Interim revision. Minor clarifications were made.

January 2023. The following significant changes were made:

A. Additional guidance related to the recommended wind Importance Factor (IF) was added.

B. Guidance related to minimum and maximum roof slopes has been clarified.

C. Recommendations related to fire concerns were added, as supported by loss experience.

D. The example problem in Appendix C was modified.

January 2021. Interim Revision. Minor editorial changes were made.

October 2020. Interim revision. Minor editorial changes were made.

July 2020. Interim revision. Minor editorial changes were made.

February 2020. Interim revision. The following changes were made:

A. Simplified the electrical recommendations section and added references to the 2017 edition of the *National Electrical Code*.

B. Simplified wind design guidance for PV arrays that are parallel to and within 5 to 10 in. (125 to 250 mm) of the roof surface.

C. Expanded wind design guidance for sun-facing, sloped PV arrays.

October 2014. Interim revision. Added additional diagram (Figure 12B, *One-line example diagram to a PV system with ground faults*).

July 2014. This is the first publication of this document.

APPENDIX C SAMPLE PROBLEM: PV MODULES PARALLEL TO ROOF

C.1 Example

A proposed PV array is to be secured to an existing metal, standing seam roof (SSR) that has 24 in. (610 mm) wide panels, using extruded aluminum external seam clamps (ESC). The roof slope is 1/4 in. per ft (1.2°). The PV panels will be installed parallel to the roof surface. The distance between the flat part of the roof deck and the top edge of the integral aluminum frame of the PV panel will be 5 in. (127 mm). The PV panels are 39 in. (1 m) wide and 66 in. (1.68 m) long. The long side of the PV panels will run across the deck ribs. Three ESC will be used to secure each long edge of the PV panel to the roof deck ribs in accordance with Figure C.1-1. The horizontal space between panels will be 6 in. (152 mm) in their longitudinal direction and 1 in. (52 mm) in the opposite direction. A minimum of 800 panels must be installed to provide the required electrical output. The building is just slightly above sea level. Other details are as follows:

H = 33 ft (10 m), Wind Exposure Category C, K_Z = 1.0 per Table 3.8

W_L = 246 ft (75 m), W_S = 140 ft (42.7 m)

V = 110 mph (49 m/s) allowable wind speed per Data Sheet 1-28

K_{ZT} = 1.0 K_D = 0.85 per Data Sheet 1-28

K_e = 1.0 per Data Sheet 1-28

With ESC installed at each deck rib, the wind load from the PV panels to the building structure follows the same path as for the design of the SSR. The wind-load path goes from the deck ribs to an internal clip, then through self-drilling screws securing the internal clips into the top flange of steel purlins.

The fire service requires a minimum 6 ft (1.8 m) wide aisle every 100 ft (30.5 m). The goal is to minimize the wind load transferred to the existing roof.

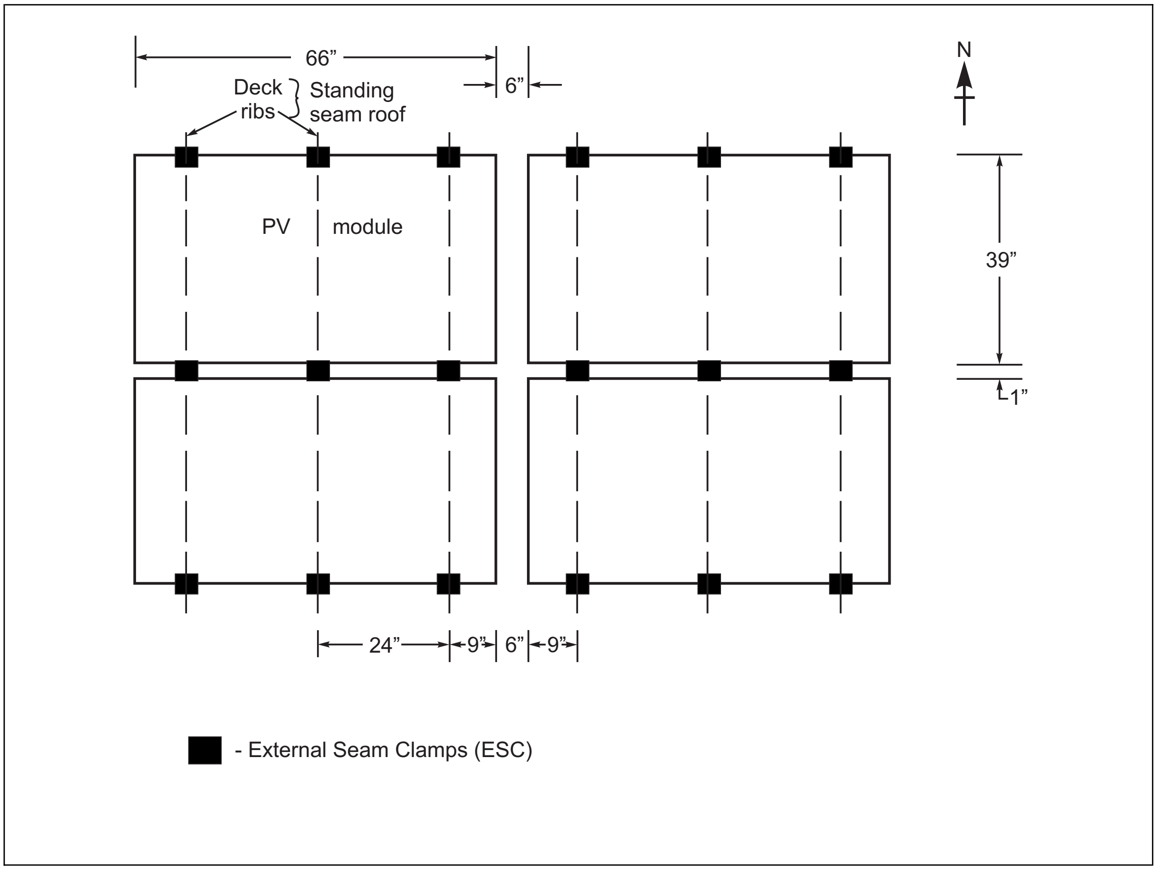

Fig. C.1-1. Plan view of proposed layout for PV modules and clamps

C.2 Solution

STEP 1: The PV panels are parallel to the roof surface and within 5 in. of the flat part of the roof deck. Per ASCE 7-22 and SEAOC PV2, the wind design load may be based on that used for a low slope (less than or equal to 7°) gable roof. The value for GCP = is determined from Figure 30.3-2A of ASCE 7-22 and Data Sheet 1-28. (See Table C.2-1.)

STEP 2: As explained in Section 2.0 of this document, an edge factor (Ω(E) = 1.25) must be applied to the exposed PV panels located along each outer row closest to the roof edge, and adjacent to aisles between arrays of all widths. Since the largest area supported by any ESC is between 6.50 and 8.53 ft^2 (0.6 and 0.8 m^2) the GCP will be based on an **effective wind area (EWA) ≤ 10 ft^2 (1 m^2)**.

STEP 3: Since the top edge of the module is 5 in. (127 mm) from the flat part of the roof surface ($h_1 = h_2$), and the minimum gap (G) between modules in each direction is greater than or equal to 3/4 in. (19 mm), for an EWA ≤ 10 ft^2 (1 m^2), $\gamma_A = 0.6$. The unfactored loads are as follows:

$q_H = 0.00256 K_Z K_{ZT} K_D K_e V^2 = 0.00256 (1.0) (1.0) (0.85) (1.0) (110)^2 = 26.3$ psf

$p = q_H (GC_P) \Upsilon_E \Upsilon_A$

The dimensions of the individual roof zones are noted in Figures C.3-1 and C.3-2.

Zone 3:
p = (26.3) (-3.2) (1.25) (0.6) = -63.2 psf for the first row of exposed modules
p = (26.3) (-3.2) (1.0) (0.6) = -50.6 psf for the interior rows of modules

Zone 2:
p = (26.3) (-2.3) (1.25) (0.6) = -45.4 psf for the first row of exposed modules
p = (26.3) (-2.3) (1.0) (0.6) = -36.3 psf for the interior rows of modules

Zone 1:
p = (26.3) (-1.7) (1.25) (0.6) = -33.5 psf for the first row of exposed modules
p = (26.3) (-1.7) (1.0) (0.6) = -26.8 psf for the interior rows of modules

Zone 1':
p = (26.3) (-0.9) (1.25) (0.6) = -17.8 psf for the first row of exposed modules
p = (26.3) (-0.9) (1.0) (0.6) = -14.2 psf for the interior rows of modules

Allowable or design Wind pressures are summarized in Table C.3-1.

Table C.2-1. Values of GC_p per ASCE 7-16 and Data Sheet 1-28

Roof Slope ≤7°	
GC_p per ASCE 7-16	
Zone	GC_p
1	3.2
2	2.3
1	1.7
1'	0.9

Note: All values of GC_p are based on an effective wind area (EWA) of 10 ft^2 (1 m^2)

C.3 Summary

A. Wind design pressures shown in Table C.3-1 should be used.

B. The following modules located in an outer row or column are considered "exposed" and should be designed using the higher wind loads that include an edge factor = 1.25:

1. The north and south edges of Arrays 1 and 2.
2. The west edge of Array 1 and the east edge of Array 2.
3. Also, the east edge of Array 1 and the west edge of Array 2 require an edge factor = 1.25.

C. The tempered glass for the proposed solar panel is 3.2 mm (1/8 in.) thick. Per ASTM E 1300, the allowable wind pressure (short duration) is only 102 psf. A test of the PV panel indicated that the aluminum frame failed catastrophically at 105 psf (5.0 kPa). That pressure is equivalent to an allowable load of only 65.6 psf (3.1 kPa) with a factor of 1.6 applied. Given sufficient room on the roof, providing a minimum setback of 20 ft (6.1 m) for the PV panels, installed per Figure C.3-2, is a preferred solution.

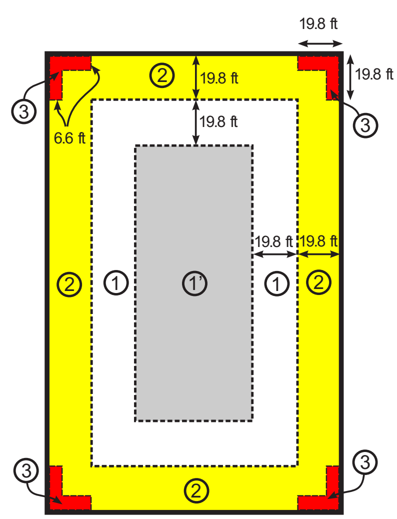

Fig. C.3-1. Wind zones for low-slope roofs (≤ 7°) per ASCE 7 and DS 1-28

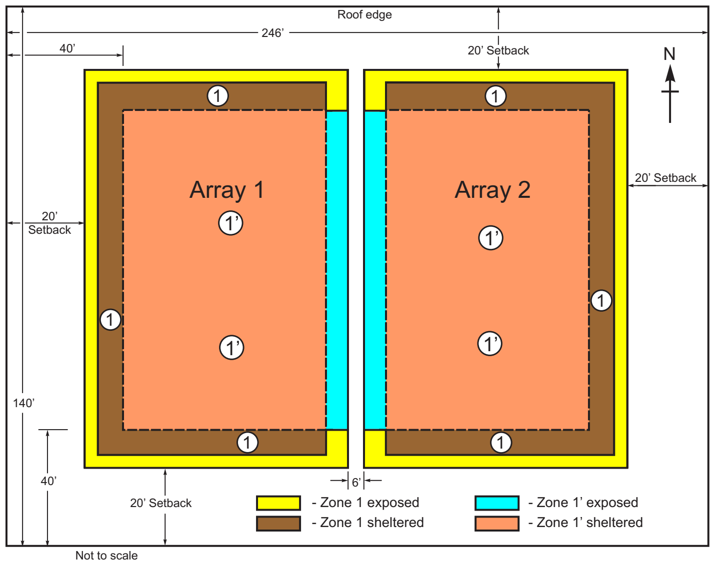

Fig. C.3-2. Various wind zones for proposed PV array in the example

Table C.3-1. Preliminary Wind Design Pressures

Zone	*GCP*	*ESC Location*	*Edge Factor (E)*	*Zone Dimensions*, ft (m)*	*Allowable Wind Uplift Pressure, Psf (kPa)*	*Ultimate Resistance with SF = 1.6 for PV Modules*	*Ultimate Resistance with SF = 2.0 for Clamps*	*Ultimate Load on at Each PV Connection lbs (kN)*
3	-3.2	Outer Edge/ Exposed	1.25	L-shaped, 6.6 (2.0) Perpendicular to roof edges, by 19.8 (6.0) parallel to roof edges	- 63.2 (3.0)	- 101 (4.8)	- 126.4 (6.1)	822 (3.66)[1]
		Shielded	1.0		- 50.6 (2.4)	- 80.9 (3.9)	- 101.2 (4.8)	658 (2.93)
2	-2.3	Outer Edge/ Exposed	1.25	Between roof edge, Zone 3 and a point19.8 (6.0) perpendicular to roof edges	- 45.4 (2.2)	- 72.6 (3.5)	- 90.8 (4.3)	590 (2.63)
		Shielded	1.0		- 36.3 (1.7)	- 58.1 (2.8)	- 72.6 (3.5)	472 (2.10)
1	-1.7	Outer Edge/ Exposed	1.25	Between 19.8(6.0) and 39.6 (12.1) in from roof edges	- 33.5 (1.6)	- 53.6 (2.6)	- 67.0 (3.2)	436 (1.94)
		Shielded	1.0		- 26.8 (1.3)	- 42.9 (2.1)	- 53.6 (2.6)	348 (1.55)
1'	-0.9	Outer Edge/ Exposed	1.25	Beyond 39.6 (12.1) in from the roof edges	-17.8 (0.9)	- 28.5 (1.4)	- 35.6 (1.7)	231 (1.03)
		Shielded	1.0		-14.2 (0.7)	-22.7 (1.1)	-28.4 (1.4)	185 (0.82)

Note 1. Maximum area of the PV clamp 6.5 ft^2 (24 x 39 in.)/(144 $in.^2/ft^2$).

The ultimate load transferred to the deck ribs with PV connections at each rib is (6.5 ft^2) [see Note 1 above] x (126.4 psf) = 822 pounds per PV connection ([0.60 m^2] x [6.05 kPa] = 3656.4 N). If the purlin spacing is less than or equal to 40 in. (1.0 m), assume that load is transferred to the internal clip. If the purlin spacing is 60 in. (1.5 m), the maximum load on the internal clip would be 822 lb. (1.67) = 1372 lb. (620 kg). Since one PV connection is directly over a purlin connection, PV connections will also transfer one-third of the load from each PV connection on either side.

This analysis is not required if the PV-roof assembly has been FM Approved for the needed PV wind pressure.

C.4 Discussion

Several options were considered to provide the required number of panels, while minimizing wind forces applied to the roof. Limiting the distance between the panels and roof surface to 5 in. (635 mm) and providing a minimum gap of 3/4 in. (19 mm) between panels provides a significant reduction in the wind uplift design pressure, as as Υ_A is reduced to 0.6. Note that this reduction is allowed per SEAOC PV2-2017 and ASCE 7-22.

Another factor is the setback distance from the edge of the roof to the first row of PV panels, which often is 10 ft (3.05 m) to 15 ft (4.6 m) on all four sides of the building. Table C.3-2 indicates that the wind pressure was considerably reduced by **increasing the setback distance to 20 ft** (6.1 m) on all sides and placing the panels in Zone 1 and 1’, not in Zone 2 or 3.

The local fire service requires a minimum 6 ft (1.8 m) wide access aisles at maximum distances of 100 ft (30.5 m). Thus, the panels along each side of the aisle must use an edge factor = 1.25; since the aisle is greater than 4 ft (1.2 m) wide.

This configuration will still allow enough room for the required minimum of 800 panels by installing the panels in two arrays of approximately 100 by 100 ft (30.5 by 30.5 m). Each array contains 30 rows of 14 panels. (See Figure C.3-2.) This setup allows for up to a total of 840 panels. It also simplifies the allowable wind design, which is summarized in Table C.4-1.

Table C.4-1. Final Wind Design Pressures

*Zone**	*GC_P*	*ESC Location*	*Edge Factor (E)*	*Zone Dimensions, ft (m)*	*Allowable Wind Uplift Pressure, Psf (kPa) **
1	-1.7	Outer Edge/ Exposed	1.25	Between 19.8 (6.0) and 39.6 (12.1) in from roof edges	-33.6 (1.6)
		Shielded	1.0		-26.9 (1.3)
1’	-0.9	Outer Edge/ Exposed	1.25	Beyond 39.6 (12.1) in from the roof edges	-17.8 (0.85)
		Shielded	1.0		-14.2 (0.7)

* See Table C.3-2 for factored pressures.