

Rooftop Solar Panel Attachment: Design, Installation, and Maintenance



FEMA

HURRICANES IRMA AND MARIA IN THE U.S. VIRGIN ISLANDS

Recovery Advisory 5, April 2018

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Purpose and Intended Audience

The purpose of this Recovery Advisory is to provide guidance on existing code requirements as well as recommend best practices for attachment design, installation, and maintenance of rooftop solar panels, also known as photovoltaic (PV) panels, to increase panel wind resistance in the U.S. Virgin Islands. This guidance was informed by lessons learned after Hurricanes Irma and Maria in 2017 and is primarily intended for architects, engineers, and contractors. However, it also provides helpful information for facility operators, building and home owners as well as for manufacturers of PV panels and attachment devices.

Key Issues:

1. **Planning and Designing for Rooftop PV:** Designers should calculate wind loads on the PV array, specify assemblies and their associated attachments that have sufficient strength to resist the specified loads and specify/detail attachment of the assemblies.
2. **Commissioning:** During construction, contractors should implement quality control and quality assurance procedures to ensure that the design intent is met.
3. **Existing PV systems:** It is recommended that the building owner hire a qualified architect or engineer to perform a wind vulnerability assessment on their existing PV systems. If significant vulnerabilities are identified, a corrective action plan should be developed to mitigate those vulnerabilities.
4. **Maintenance:** It is recommended that the property owners or operators have maintenance staff or a contractor annually check tightness of the PV array's bolted connections with a torque wrench. It is recommended that 100% of the panel clamps be checked and that spot checks be made for bolts that connect rails to clip angles or posts.
5. **Preparations prior to hurricane landfall:** It is recommended that the property owners or operators have maintenance staff or a contractor adequately prepare their PV systems prior to landfalling hurricanes or forecasted severe windstorms by performing the following:
 - Remove debris from roof drains, scuppers and gutters.
 - Remove loose objects such as buckets, lumber and sheet metal from the roof and surrounding areas.
 - If there is sufficient time, check tightness of the PV array's bolted connections with a torque wrench.
6. **After a severe wind storm:** It is recommended that the property owners or operators have maintenance staff or a contractor perform post severe windstorm assessments of damage and take any actions needed for repairs or improvements to their system, including the following:
 - Check the PV array for damage.
 - Remove, replace, or temporarily secure loose panels.
 - Check the roof covering for damage caused by wind-borne PV panels or other debris.
 - Check tightness of the PV array's bolted connections using the guidance given in Key Issue 4 (this task could be scheduled to occur a few months after the storm).

Terminology

External seam clamp: A clamp used to attach items to the seam (rib) of a standing seam metal roof (Figure 12).

Panel clamp: A clamp used to attach solar panels to a rail, rack, or external seam clamp (Figure 13).

Post (support stand): A device used to attach rails or racks to the roof support structure and/or roof deck. (Figure 10).

Solar array: Any number of rooftop solar panels grouped closely together (Figures 1-5).

Solar panel: A device to receive solar radiation and convert it into electricity or heat energy. Typically, this is a photovoltaic (PV) module or solar thermal panel. Panels are commonly mounted on rails or racks that are attached to the roof or are ballasted (Figure 7).

T-bolt: Bolt used to attach panel clamps to rails (Figure 8).

Wind Deflector: A component of the photovoltaic panel or racking system that is designed to turn the flow of air away from the underside of the photovoltaic panel.

This Recovery Advisory Addresses Rooftop PV Systems as They Relate to The Following:

- Facilities in the planning stage and existing facilities (including post-event repairs) including residential, commercial buildings, industrial buildings and critical facilities
- Design and construction guidance for improved wind resistance of solar panels that are mechanically attached to the roof support structure and/or roof deck¹
- Maintenance and preparations prior to hurricane landfall

Note, this Recovery Advisory does not address electrical safety, electrical performance, or fire performance of rooftop solar panels.

For seismic considerations, see the Structural Engineers Association of California (SEAOC) report, *Structural Seismic Requirements and Commentary for Rooftop Solar Photovoltaic Arrays* (SEAOC PV1-2012).

Repairing Wind Damaged Rooftop PV Systems on Public Facilities Using the FEMA Public Assistance (PA) Program

According to the FEMA Public Assistance Program and Policy Guide (FEMA PAPPG, 2018), additional grant funding may be available on eligible repairs to provide hazard mitigation against future events. For more information, see the PAPPG, Appendix J, Section III, B. Roof-Mounted Equipment: "Secure to rooftop via a continuous load path, using tie-downs, straps, or other anchoring systems that will resist expected wind forces."

PV Array Design and Construction Mitigation Guidance

This section provides an overview of codes, standards, and guidelines that pertain to attachment of PV arrays. It also provides examples of various levels of PV array performance and failure modes observed after the 2017 hurricanes, and it provides design and construction mitigation guidance.

Codes, Standards and Guidelines

American Society of Civil Engineers *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 7-16, 2017): The 2016 edition of ASCE 7 added wind load criteria for rooftop solar panel systems (Chapter 29). Criteria are given for roofs that have slope angles $\leq 7^{\circ}$. Criteria are also given for roofs with other slopes, provided that the panels are parallel to the roof slope (with a tolerance of 2°).

Structural Engineers Association of California *Wind Design for Solar Arrays* (SEAOC PV2-17, 2017): The 2012 edition of SEAOC PV2 formed the basis for the new PV provisions in ASCE 7-16. The 2017 edition of PV2 references the ASCE 7-16 provisions, incorporates knowledge from research since 2012, and provides background and recommendations beyond those in ASCE 7-16. SEAOC PV2-17 also provides example problems and illustrates specific aspects of the calculation methods.

SEAOC PV2-17 includes provisions that are not in ASCE 7-16; these are intended to clarify or provide extensions to the ASCE-16 requirements. Following these more detailed provisions of PV2-17 may reduce the design wind load on portions of an array. If these load-reduction procedures are taken, it is recommended that the authority having jurisdiction approve the reduction.

¹ Ballasted solar panels, flexible PV modules (building-integrated photovoltaic [BIPV]) installed directly to the roof surface, and PV shingles were not observed by FEMA's Mitigation Assessment Team; therefore, they are not included in this Recovery Advisory.

International Code Council (ICC) *International Building Code (ICC IBC)* and *International Residential Code (ICC IRC)*: The 2015 editions of the IBC and IRC require rooftop PV panel systems to be designed for component and cladding loads. However, the referenced criteria are not specific to PV systems. The PV provisions in the 2018 editions indirectly reference PV wind load criteria in ASCE 7-16.

ICC Evaluation Report AC 428, *Acceptance Criteria for Modular Framing Systems Used to Support Photovoltaic (PV) Panels (ICC AC 428, 2012)*: This report requires all elements of rooftop PV panel systems to be designed for component and cladding pressures per ASCE 7-10. (The 2010 edition of ASCE 7 does not have criteria specific to PV systems.) For friction clips or connections that resist loads through a clamping mechanism, the nuts are required to have a self-locking mechanism intended to prevent the nut from loosening. Special testing criteria are also specified for this type of connection. The manufacturer's installation instructions are required to specify the use of a calibrated torque wrench for torquing fasteners in friction connections. Special inspection criteria are specified. ICC AC 428 also addresses seismic issues.

UL Standard for Flat-Plate Photovoltaic Modules and Panels (UL 1703 2002): This Standard primarily addresses issues other than wind; however, it does address uplift resistance of PV panels. It is referenced in the 2015 and 2018 editions of the IBC.

UL Standard for Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels (UL 2703, 2015): This standard primarily addresses wind uplift and other issues associated with PV panel mounting systems. It is referenced in the 2015 and 2018 editions of the IBC.

FM Global Approval Standard for Roof-Mounted Rigid Photovoltaic Module Systems (FM 4478, 2016): This document requires laboratory uplift testing of the PV system; however, the test method does not evaluate a system's resistance to long duration dynamic loading (such as induced by hurricanes). FM 4478 requires the installation to be in accordance with FM Global Property Loss Prevention Data Sheet 1-15 (see below). FM 4478 also has optional seismic criteria. If the building is insured by FM Global, the PV system is required to have an FM Approval.

FM Global Property Loss Prevention Data Sheet 1-15 Roof Mounted Solar Photovoltaic Panels (FM 1-15, 2014): This document provides design, installation, and maintenance guidance. It includes guidance for attaching PV panels to standing seam ribs of metal roof panels. It recommends inspecting solar panel assemblies at least annually to ensure mechanical connections between panels and supports have not loosened or become corroded.

National Roofing Contractors Association (NRCA) *Guidelines for Rooftop-Mounted Photovoltaic Systems (NRCA 2018)*: This document provides guidance on integrating a PV array with a roof system. Discussion is provided on the equivalent service life, wherein it is recommended that the roof system (new or existing) have an expected service life that is equal to or greater than the PV system. This is recommended to avoid having to remove the PV system to replace a roof system that reaches the end of its service life before the end of the PV system's service life. It also provides guidance on enhancements for new roof systems in order to make them "PV ready." Guidance is likewise provided for the design of flashing details at PV system penetrations through the roof covering. The document additionally provides information on a certification program for roofing professionals, "Certified Solar Roofing Professional."

National Electrical Manufacturer Association (NEMA) Standards Publication 250-2003, *Enclosures for Electrical Equipment (1000 Volts Maximum)*: This Standards Publication, as well as all other NEMA publications, are available from IHS at 800-854-7179 or <https://www.global.ihs.com>.

PV Array Wind Performance

Figures 1-5 show seven different buildings with solar panels that were attached to rails with panel clips. The rails were attached to the roof support structure and/or the roof deck with clip angles or posts (support stands). Observed building types include residential, commercial, and critical facilities. Slopes include steep- and low-slope, with arrays ranging from a few to a very large number of panels.



Figure 1. A two-panel array on a residence. The rails were attached with clips that were anchored through corrugated metal roof panels and into the roof structure and/or roof deck. No damage to the PV array was apparent.



Figure 2. A relatively large PV array on a commercial building. Several metal roof panels were blown off the overhang (red arrows), but there was no apparent damage to the array.



Figure 3. All the PV panels in the top row (red line) were blown off. Most of the panels in the middle and bottom rows were also blown away at this residence. All the panels detached from the rails.



Figure 4. Three of the four rows of panels at this residence were blown off; they detached from the rails. The rails were attached to posts. Three of the remaining ten panels were damaged by wind-borne debris.

Wind-Borne Debris

- Neither ASCE 7, IBC, IRC, ICC AC 428, nor FM 4478 has wind-borne debris requirements for solar panels.
- In hurricane-prone regions, it is recommended that designers specify solar panels that have a damage rating of “VSH” (very severe hail) per FM 4478.

Note, the momentum of the hail test missile is substantially less than that of test missile D used to evaluate wind-borne debris resistance of glazing and storm shutters. Hence, solar panels that meet the VSH testing may be damaged by wind-borne debris that has large momentum. However, panels that meet VSH should be more resistant to lower momentum debris than panels that do not.

Figure 5 is a partial view of a school campus that had PV arrays installed on six different roofs (three of the roofs are shown). Two of the roofs had all the panels blown off. Several panels were blown off, and several were damaged by wind-borne debris at another roof (Figure 5). All the panels that blew off detached from the rails. At some panels, the PV film detached from the panel frame (Figure 6). Two of the roofs had no apparent damage, and one roof may have lost one or two panels. Panels were sourced from at least two different manufacturers. The PV systems were installed in different years and by different contractors.



Figure 5. Roof where several adjacent panels were blown off (red lines). See Figure 6 for the area within the red oval. There was no apparent damage at the PV array at the lower left building. The array at the lower right building may have lost a panel or two.

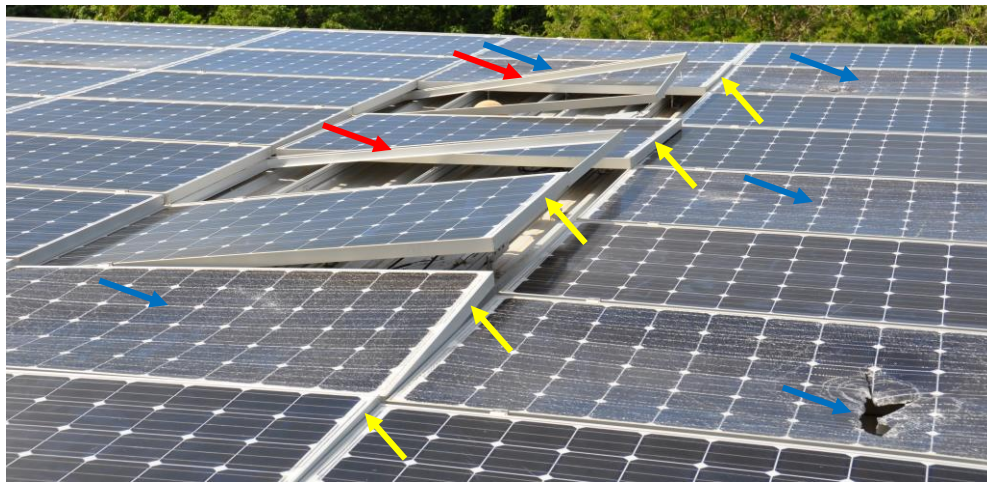


Figure 6. On these PV panels, the PV film detached from the panel frame (red arrows). Some panels lifted but did not blow away (yellow arrows). Some panels were damaged by wind-borne debris (blue arrows).

Variable Wind Performance

Several different factors can influence wind performance of PV systems, including angle of wind attack (arrays may be sensitive to certain wind directions), shielding by other buildings or topography, building height, Exposure, abrupt changes in topography, wind resistance provided by the PV panels and support system, variability in installation workmanship, and degradation of resistance due to aging.

SEAOC PV2-17 states that edges of arrays tend to be more flexible and easier to peel upward by wind than interior portions of arrays. Also, wind pressure demands on the edges of arrays tend to be more sensitive to uplift movement than panels at the interior of the array. However, several instances of interior panel damage were observed by the FEMA Mitigation Assessment Team (Figure 6). The observed interior panel damage may have been related to inadequate wind resistance for those specific panels rather than wind loads exceeding the design level event.

Figure 7 shows a missing panel at an array on a courthouse rooftop. The panel clamps were designed to attach both the adjoining panels. With this clamp design, if a panel blows away or a panel frame is damaged by wind-borne debris (Figure 9), the remaining panels may shift, thereby making them more susceptible to being blown off. This illustrates the importance of checking PV arrays for correct torquing prior to storms and assessing damage after a severe wind storm.

At the damaged arrays that were assessed by the FEMA MAT, the panel clamps were typically connected to extruded aluminum rails with stainless steel T-bolts. Each T-bolt had a single flange nut. The underside of the flange was serrated (the serrations are intended to prevent loosening). At most of the clamps that were examined, the nut serrations had dug into the clamp. At most of the failed panel clamps, the T-bolt nuts could be freely spun. T-bolts from three different manufacturers were examined. One of the damaged arrays had stainless steel panel clamps. All the other arrays that were investigated had extruded aluminum clamps. At a large array at a school, at least one rail was blown off; the rails were attached with clips that were anchored through the metal roof and into the roof support structure. None of the assessed arrays had wind deflectors.

Design Guidance

As an initial step in the design process, it is recommended that designers calculate wind loads on PV arrays in accordance with ASCE 7-16 or the local building code, whichever procedure results in the highest loads. It is recommended that the design criteria in SEAOC PV2-17 also be considered. Note, the Risk Category for rooftop PV is required to be not less than that for the building on which the equipment is located, nor that for any other facility to which the equipment provides a necessary service (ASCE 7-16, C29.3.1).

For hurricane-prone regions, including the U.S. Virgin Islands:

- Recommend mechanically anchored PV rails or racks be specified, rather than ballasted racks, or rails/racks that are attached to the roof surface with adhesive.
- Specify panels that have a VSH rating per FM 4478.
- Recommend using microinverters where appropriate. Although these generally cost more than central or string inverters; they have several advantages. Unlike string inverters, microinverters have a greater chance of allowing undamaged panels of a PV array to continue to produce electrical power even if one panel is blown away or damaged by wind-borne debris. In an array using string inverters, if one panel is damaged, all the panels on the string will be offline.
- Recommend configuring PV power systems such that they can provide power to the building even if the municipal power is not operational.

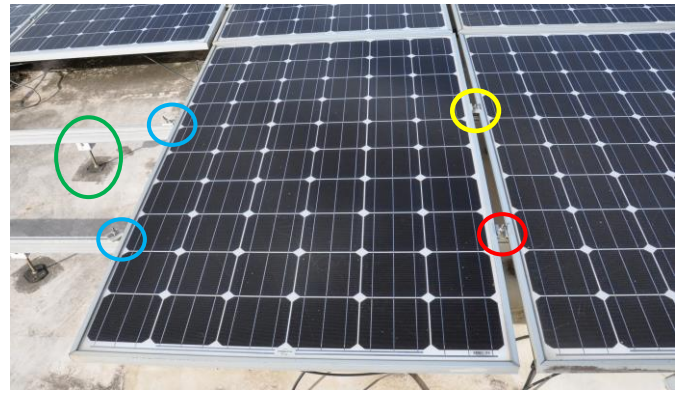


Figure 7. View of a missing panel and condition of panel clamps at the remaining panel: A rail and post (green oval), panel clamps that are no longer engaged with the remaining panel (blue circles), clamp that is engaged (yellow circle), location of the T-bolt and clamp at Figure 8, which is no longer engaged (red circle).



Figure 8. T-bolt with dislodged clamp.

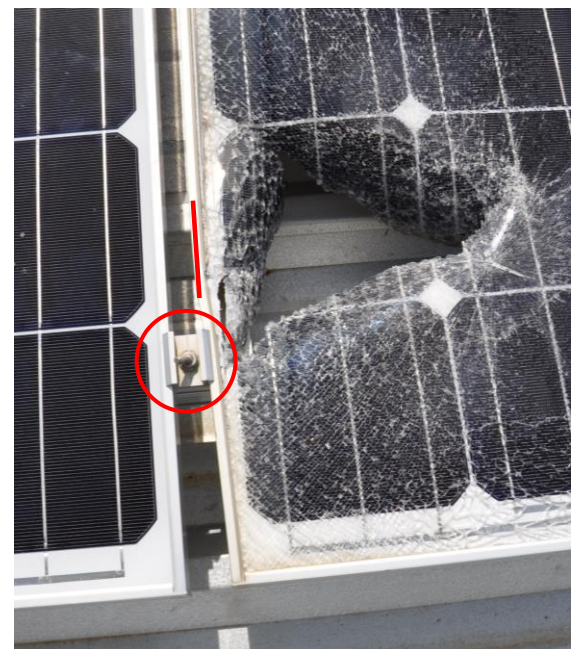


Figure 9. Wind-borne debris ruptured the PV film and distorted the panel frame (red line). However, in this instance, the panel clamp (red circle) still engaged both panels.

For all regions:

- Specify PV panels that have sufficient uplift resistance to meet the calculated wind loads. Also specify the panel attachment to rails/racks, specify the attachment of rails/racks to clips or posts, and design the attachment of the clip or post to the roof support structure and/or the roof deck. If attachment is to the roof deck, verify that the deck has adequate attachment to resist the additional uplift load imparted by the clips or posts.
- Specify PV panels and rail/rack systems that have UL 1703 and UL 2703 listing (as applicable), and an ICC AC 428 evaluation report. If the building is insured by FM Global, specify that the PV system have an FM 4478 approval.
- Specify double-nutting the panel clamp bolts. For the first nut, specify nuts that are furnished with T-bolts. For the second nut, specify a stainless-steel lock nut with a nylon insert.
- Specify that all bolted connections be made with a calibrated torque wrench and torqued as specified by the PV system manufacturer.
- Specify that PV panels are not installed over roof drains (Figure 10) and that walkways be provided to each drain so that drains can be easily checked for debris, cleaned and maintained as appropriate.
- Specify a walkway between rows of PV panels so that bolted connections can be checked annually (Figure 11). When panels are butted as shown in Figure 6, it is very challenging to adequately check connections.
- For seismic considerations, see SEAOC PV1.



Figure 10. PV panels extended over this roof drain (yellow oval), thereby making it difficult to check for clogging and removal of debris. The red arrow indicates a rail support post.

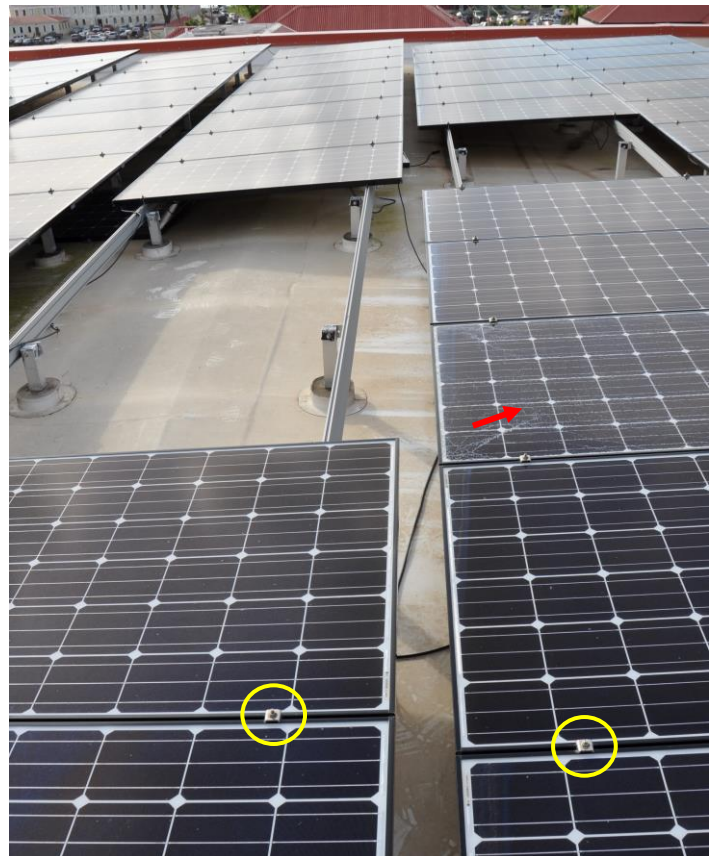


Figure 11. This array had rows between panels, which facilitate checking the tightness of panel clamps (yellow circles) and replacement of panels that were damaged by debris (red arrow) or that blew away. However, the rows were so narrow that it would have been very difficult to check the tightness of the rail/post bolts.

Involvement of a qualified roof consultant and/or a professional roofing contractor in the design and construction of the PV system is recommended. Design involvement might include providing roof system and flashing recommendations for new construction or assessing the condition of an existing roof assembly in determining the suitability of installing a PV array over it. A professional roofing contractor can help with important construction details such as including appropriate flashing for penetrations through the roof covering and providing guidance for protecting the roof system during PV system installation.

PV panels may be attached to standing seam metal roof ribs with panel clamps attached to external seam clamps (Figure 12), or panels may be attached to rails that are attached to the ribs. Use of rails can result in overstressing the concealed clips that attach the metal panels. Accordingly, in lieu of rails, it is recommended that external seam clamps be used to attach PV panels to standing seam ribs. The external seam clamps should be located so that they do not interfere with the thermal expansion and contraction between the metal panels and the concealed clips.

If an array is to be attached to a standing seam metal roof that is yet to be installed, the loads on the PV panels and roof panels, and the load path from the PV panels to the concealed clips, should be considered. Prior to attaching an array to an existing standing seam metal roof, the designer should consider whether the concealed clips may be overstressed by the additional wind uplift load imparted by the PV panels.

Construction Guidance

- Implement quality control and quality assurance procedures to ensure that the design intent is met.
- Use a calibrated torque wrench for all bolted connections, and torque as specified by the PV system manufacturer.
- Implement procedures during PV system application that do not damage the roof system.
- Have flashings at PV system penetrations through the roof covering flashed by a professional roofing contractor.

Post-Construction Guidance

- Annually check tightness of the PV array's bolted connections. See Key Issue 4 for specific criteria.
- Preparations prior to hurricane landfall: See Key Issue 5.
- After a severe wind event: See Key Issue 6 and Figure 13.



Figure 12. These PV panels were attached directly to the standing seam ribs with panel clamps that were attached to external seam clamps (yellow arrow). Note that several panels in the foreground were damaged by wind-borne debris (reportedly a collapsed antenna).



Figure 13. View of a PV panel clip after the 2017 hurricanes. Although there was no apparent loosening of the nut, the bolt could be wobbled with finger pressure. A loose nut such as this is susceptible to further loosening and loss of the clamp's ability to keep the panels in place.

Water Infiltration

To avoid entrance of wind-driven rain into the building via conduits, it is recommended that electrical pull boxes and conduits associated with solar panels be specified and installed to inhibit water leakage.

References and Resources

References

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Resources

FEMA. 2018. *FEMA U.S. Virgin Islands*. Facebook page. <https://www.facebook.com/FEMAUSVirginIslands>

Note: this page was specifically setup for the Hurricanes Irma and Maria recovery process and is regularly updated with useful information.

For more information, see the FEMA Building Science Frequently Asked Questions Web site at <https://www.fema.gov/frequently-asked-questions-building-science>.

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