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Examination Standard for Roof-Mounted Rigid Photovoltaic Module Systems

Class Number 4478

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Foreword

This standard is intended to verify that the products and services described will meet stated conditions of performance, safety and quality useful to the ends of property conservation. The purpose of this standard is to present the criteria for examination of various types of products and services.

Examination in accordance with this standard shall demonstrate compliance and verify that quality control in manufacturing shall ensure a consistent and reliable product.

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1 INTRODUCTION

1.1 Purpose

1.1.1 This standard states the testing and certification requirements for rigid photovoltaic modules that are installed with a certified roof assembly.

1.1.2 Testing and certification criteria may include performance requirements, marking requirements, examination of manufacturing facility(ies), audit of quality assurance procedures, and a surveillance program.

1.2 Scope

1.2.1 This standard applies to all rigid photovoltaic module systems that are:

- Mechanically fastened through a single-ply, polymer-modified bitumen sheet, built-up roof, or liquid applied roof cover certified per FM Approvals Examination Standard 4470.
- Adhered to a single-ply, polymer-modified bitumen sheet, built-up roof, or liquid applied roof cover certified per FM Approvals Examination Standard 4470.
- Mechanically fastened through a steep slope roof assembly certified per FM Approvals Examination Standard 4475.
- Mechanically fastened to a panel roof cover assembly certified per FM Approvals Examination Standard 4471 (using clamps or other types of fasteners).
- Loose laid and ballasted over a fully adhered single-ply, polymer-modified bitumen sheet or built-up roof cover assembly certified per FM Approvals Examination Standard 4470.
- Secured to racks and/or rack framing which are independently secured to the building structure, roof deck, or metal roof cover or ballasted. It also applies to the rack itself and its securement.

1.2.2 This standard evaluates rigid roof-mounted photovoltaic module systems as part of a finished roof assembly for their performance in regard to fire from above the structural deck, simulated wind uplift, susceptibility from hail damage, seismic performance requirements and gravity load resistance. The standard is intended to evaluate only those hazards investigated and is not intended to determine suitability for the end use of a product.

1.2.3 This standard only addresses the photovoltaic module system and does not address any other electrical component utilized to supply the generated electrical power to the facility.

1.2.4 This standard does not qualify flexible photovoltaic modules. Flexible photovoltaic systems are evaluated per FM Approvals Examination Standard 4476.

1.3 Basis for Requirements

1.3.1 The requirements of this standard are based on experience, research, and testing, and/or the standards of other organizations. The advice of manufacturers, users, trade associations, jurisdictions and/or loss control specialists was also considered.

1.3.2 The requirements of this standard reflect tests and practices used to examine characteristics of rigid photovoltaic modules for the purpose of obtaining certification.

1.4 Basis for Certification

Certification is based upon satisfactory evaluation of the product when used as part of a certified roof assembly:

1.4.1 Examination and tests on production samples shall be performed to evaluate:

- the suitability of the product for use in a roof assembly,
- the performance of the product as part of a roof assembly as specified by the manufacturer and required for certification,
- the durability and reliability of the product.

1.4.2 An examination of the manufacturing facilities and audit of quality control procedures may be made to evaluate the manufacturer's ability to consistently produce the product which is examined and tested, and the marking procedures used to identify the product. Subsequent surveillance may be required by the certification agency in accordance with the certification scheme to ensure ongoing compliance.

1.5 Basis for Continued Certification

The basis for continual certification may include, but is not limited to, the following based upon the certification scheme and requirements of the certification agency:

- production or availability of the product as currently certified;
- the continued use of acceptable quality assurance procedures;
- compliance with the terms stipulated by the certification;
- satisfactory re-examination of production samples for continued conformity to requirements; and
- satisfactory surveillance audits conducted as part of the certification agencies product surveillance program.

1.6 Effective Date

The effective date of this certification standard mandates that all products tested for certification after the effective date shall satisfy the requirements of this standard.

The effective date of this standard is eighteen (18) months after the publication date of the standard for compliance with all requirements.

1.7 System of Units

Units of measurement used in this Standard are United States (U.S.) customary units. These are followed by their arithmetic equivalents in International System (SI) units, enclosed in parentheses. The first value stated shall be regarded as the requirement. The converted equivalent value may be approximate. Conversion of U.S. customary units is in accordance with ANSI/IEEE/ASTM SI 10.

1.8 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the cited edition applies.

American National Standard Institute

- *Evaluating the Simulated Wind Uplift resistance of Roof Assemblies Using Static Positive and/or Negative Differential Pressures*, ANSI/FM 4474

- *Impact Resistance Testing of Rigid Roofing Materials by Impacting with Freezer Ice Balls,* ANSI/FM 4473

- *Flat Plate Photovoltaic Modules and Panels*, ANSI/UL 1703

American Iron and Steel Institute

- *North American Specification for the Design of Cold-Formed Steel Structural Members,* AISI S100
-

American Society of Civil Engineers

- *Minimum Design Loads and Associated Criteria for Buildings and Other Structures,* ASCE/SEI 7

American Society for Testing Materials

- *Standard Test Methods for Fire Tests of Roof Coverings,* ASTM E108

International Electrotechnical Commission

- *Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval,* International Standard IEC/EN 61215-1, IEC/EN 61215-1-1, and IEC/EN 61215-2

- *Photovoltaic (PV) module safety qualifications – Part 2: Requirements for Testing,* International Standard IEC/EN 61730-2

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

- *Examination Standard for Class 1 Panel Roofs*, FM 4471

- *Examination Standard for Class 1 Steep Slope Roof Covers*, FM 4475

Structural Engineers Association of California

- *Wind Design for Solar Arrays,* PV2-2017

1.9 Terms and Definitions

For purposes of this standard, the following terms apply:

Adhesive – Adhesive is used in construction to adhere components together. Depending on the use, the adhesive could be in either a liquid form, semi liquid form, reactive liquid form or a solid form as in a tape or as in hot asphalt which is solid until heated.

Anchored – an anchored system is a system that is secured to the roof structure or any part of the roof assembly.

Ballast – heavy material used to impede movement of the photovoltaic module or frame resulting from wind forces. Ballast does not impede lateral (sliding) earthquake movement since both the lateral force and resisting frictional force are functions of the weight, but may resist earthquake overturning. For the purposes of this document, the only acceptable ballast shall be concrete paver blocks.

Coefficient of Friction – The ratio between the friction force that resists the movement of an object and the normal force between the object and the surface.

Crack – During wind uplift testing, when a component is stressed to the point that it separates from itself while continuing to maintain the applied uplift pressure without catastrophic failure of the test assembly.

Crease - During wind uplift testing, when a component is stressed to the point that it bends at a sharp, defined angle, without breaking. Often a crack will form on the opposite face of the component.

Deck - The structural component of the roof assembly to which the roof system is secured.

External Seam Clamps – A securement for attaching photovoltaic modules or racking to the seam of a standing seam roof.

Fasteners - A mechanical securement device used alone or in combination with a stress distributor to secure various components of a roof assembly.

Frame or Racking System – used to fix solar panels on surfaces.

Identified (ID) Component – ID component recognition can be granted to PV modules themselves. They are placed under the certification agency's surveillance program. They are not certified in and of themselves but have selected certified performance ratings.

Lap Seam Roof Cover – A lap seam roof cover consists of metal or plastic panels which are through fastened to structural members. A lap seam occurs where overlapping materials are seamed, sealed or otherwise bonded.

Mechanically Fastened - Mechanically fastened describes roof covers or base sheets that have been attached to the substrate at defined intervals using fasteners with, or without, stress distributors and also describes a photovoltaic module that has been attached to the substrate at defined intervals using fasteners or clamps with, or without, stress distributors.

Metal Panel — (1) A single metal sheet formed into a specified profile. (2) A composite assembly formed to a specified profile and consisting of an insulating core or batten material with an exterior metal skin.

Minor Delamination – In wind uplift testing, an area approximately 1% of the test sample. For a 12 x 24 ft. (3.7 x 7.3 m) test an area of 3 ft^2 (2.8 m^2); for a 5 x 9 ft. (1.5 x 2.7 m) test an area of 0.5 ft^2 (0.05 m^2), whereby two adhered components which are intended to be in contact are not in contact.

Permanent Deformation—Any deformation of a panel or component that remains after the load has been removed. Panel deflection that can be removed by mechanical means not involving special equipment and without additional deformation shall not be considered permanent deformation.

Photovoltaic Module – A device that converts solar energy into electricity.
Rated Wind Load – The wind resistance rating given to a roof assembly based on ultimate failure load in psf (kPa).

Rigid Photovoltaic Module –An arrangement of photovoltaic cells or material, mounted on a rigid surface with the cells exposed freely to incoming sunlight.

Roof Assembly - A group of interacting roof components (including the roof deck) designed to weatherproof and, normally, to insulate a building's top surface.

Roof Cover - The exterior surface of a roof assembly designed to protect the building components from the weather.

Roof System - A group of interacting roof components (not including the roof deck) designed to weatherproof and, normally, to insulate a building's top surface. The roof system includes the rigid photovoltaic module if it is fully adhered or mounted directly above the roof cover and no air space exists between the roof cover and the photovoltaic module.

Service Wind Load – The uplift load (unfactored) resulting from wind that a roof assembly must resist.

Standing Seam Roof Cover - The standing seam roof cover generally consists of metal sheets or panels, field seamed to adjacent sheets by a roll-forming machine to create an upstanding seam (rib) of folded metal along the sheet sidelaps. The panels are secured to the building framing with clips. The clip, which contains tabs, is roll-formed into the panel seam.

Stress Distributor/Plate - A metal or plastic disk or bar designed to distribute a concentrated load over a larger surface area.

Weld – A weld is a type of securement whereby metal or plastic materials are joined together through heat or solvent fusion.

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.

2 GENERAL INFORMATION

2.1 Product Information

Rigid photovoltaic module systems are submitted in panels or a panel array. They can be installed using either mechanical fasteners, clips, mounting brackets, adhesives, welding or loose laid or ballasted.

2.2 Certification Application Requirements

The manufacturer shall provide the following preliminary information with any request for certification consideration:

- A complete list of all models, types, sizes, and options for the modules being submitted for certification consideration.
- The components that make up each roof assembly. All components in the finished roof assembly must be identified by manufacturer, product trade name, method of installation and the ratings desired for each combination.
- All ratings which are desired or expected for each assembly:
  - Maximum roof slope
  - Wind Uplift Rating, Class 1-45, 1-60, etc.
  - Hail Damage Rating, Class 2, 3, 4 or VSH
  - (Optional) Seismic Load Rating, Non-Seismic, or maximum allowable S_{DS} (g) value
  - (Optional) Gravity Load Rating
  - For ID component recognition of PV modules, only the Hail Damage Rating desired is required.
- The number and location of manufacturing facilities. Required for certification and ID component recognition.
- A document from the certified roof cover manufacturer acknowledging that the photovoltaic module will be installed over their roof cover and is compatible with it. Required for certification only.
- Certification documentation for IEC/EN 61730 or ANSI/UL 1703 and IEC/EN 61215 shall be submitted to the certification agency prior to completion of the certification program. This documentation shall include a copy of the test report as well as the certification of compliance. These are required for certification and ID component recognition of PV modules.
- All documents shall contain the manufacturer's name, document number or other form of reference, title, date of last revision and revision level. All documents shall be provided in English

2.3 Requirements for Samples for Examination

2.3.1 Following authorization of a certification examination, the manufacturer shall submit samples for examination and testing based on the following:

- Sample requirements shall be determined by the certification agency

2.3.2 Requirements for samples may vary depending on design features, results of prior or similar testing and results of any foregoing tests.

2.3.3 The manufacturer shall submit samples representative of production. Any decision to use test data generated using prototypes is at the discretion of the certification agency.

2.3.4 It is the manufacturer's responsibility to provide any special tools, such as those which may be required to evaluate the products for certification.

3 GENERAL REQUIREMENTS

3.1 Review of Documentation

During the initial investigation, and prior to physical testing, the manufacturer's specifications and details shall be reviewed to assess the ease and practicality of installation and use. The certification examination results may further define the limits of the final certification.

3.2 Markings

3.2.1 Marking on the product or, if not possible due to size, on its packaging or label accompanying the product, shall include the following information:

- name and address of the manufacturer or marking traceable to the manufacturer;
- date of manufacture or code traceable to date of manufacture or lot identification;
- model number, model type, and/or product name, as appropriate.

When hazard warnings are needed, the markings should be universally recognizable.

3.2.2 The product trade name, model number, or model type identification shall correspond with the manufacturer's catalog designation and shall uniquely identify the certification agency's mark of conformity (certification or ID component as applicable).

3.2.3 The certification agency's mark of conformity (certification or ID component as applicable) shall be displayed visibly and permanently on the product and/or packaging, as appropriate and in accordance with the requirements of the certification agency. The manufacturer shall exercise control of this mark as specified by the certification agency and the certification scheme.

3.2.4 For ID component products, as detailed in Section 3.7 of this standard, "Specification Tested: Identified Component" shall be displayed visibly and permanently on the product and/or packaging, as appropriate. The manufacturer shall not use this mark on any other product unless such product is covered by a separate report. Identified Components are not permitted to claim by mark, symbol, or words that the product is certified.

3.2.5 All markings shall be legible and permanent.

3.3 Manufacturer's Installation and Operation Instructions

The manufacturer shall provide the user with printed instructions to demonstrate proper installation procedures to be followed by installers. As part of the certification examination, and at the discretion of the certification agency, at least one inspection of the field installation during and/or after completion may be required. In some cases, a continued program of inspections shall be necessary to assess the application procedures or changes within the application techniques.

3.4 Calibration

3.4.1 Each piece of equipment used to verify the test parameters shall be calibrated within an interval determined on the basis of stability, purpose, and usage. A copy of the calibration certificate for each piece of test equipment is required. The certificate shall indicate that the calibration was performed against working standards whose calibration is certified and traceable to an acceptable reference standard and certified by an ISO/IEC 17025 accredited calibration laboratory. The test equipment shall be clearly identified by label or sticker showing the last date of the calibration and

the next due date. A copy of the service provider's accreditation certificate as an ISO/IEC 17025 accredited calibration laboratory should be available.

3.4.2 When the inspection equipment and/or environment is not suitable for labels or stickers, other methods such as etching of control numbers on the measuring device are allowed, provided documentation is maintained on the calibration status of thus equipment.

3.5 Test Sample Production

All products submitted for testing shall be representative of production run material. The need to monitor the manufacturer of the test specimens shall be at the sole discretion of the certification agency.

3.6 Seismic Loads (Optional)

The design shall be certified by a Registered Professional or Chartered Engineer competent in this area of practice. Calculations shall be submitted to verify compliance with design requirements for the range of rigid photovoltaic modules for which certification is sought.

The Certification Design Procedure for Seismic Design of Rigid Photovoltaic Modules is as follows:

3.6.1 General

The rigid photovoltaic modules and racking systems (if used) shall be rated (certified) for a base shear coefficient (acceleration) at the mounting level. The manufacturer shall demonstrate (through tests or analysis) that the rigid photovoltaic modules and racking systems (if used) shall remain intact and operational when subjected to the rated base shear coefficient. The anchorage of the rigid photovoltaic modules and racking systems (if used) to the supporting structure shall be designed for the base shear, overturning moment about the two principal axes and torque about the vertical axis. The supporting structure shall be designed for the loads transmitted from the rigid photovoltaic modules. The seismic loads calculated according to this standard are intended for use in Load and Resistance Factor Design (LRFD) or Strength Design, also known as Ultimate Limit State Design, and shall, therefore, be used in LRFD load combinations with a load factor of 1.0 applied to the seismic loads.

If the weight of the rigid photovoltaic module and racking systems (if used) exceeds 25% of the seismic weight of the supporting structure, the dynamic interaction between the rigid photovoltaic modules and the supporting structure shall be considered in calculating the base shear coefficient; the simple procedure presented in this standard cannot be used for such rigid photovoltaic modules and an alternative design method satisfactory to the certification agency must be used. The procedure presented in this standard cannot be used for unanchored, ballast only systems.

3.6.2 Nomenclature

A_p – base shear coefficient (acceleration in g's)
S_{DS} – 0.2 second (short period) 5% damped design spectral response acceleration (g's)
a_p – dynamic amplification factor. Equal to 1 for rigid photovoltaic modules.
R_p – component response modification factor. Equal to 1.5 for rigid photovoltaic modules.
z – height of the base of the rigid photovoltaic module above ground, in feet. Need not exceed the value of the average roof height "h"
h – average roof height of the supporting structure measured from the ground, in feet
$\overline{h}$ – height of the center of gravity (C.G.) of the rigid photovoltaic module from the base of the rigid photovoltaic modules, in ft
S_{MS} – 0.2 second (short period) 5% damped free surface spectral acceleration adjusted for site soil properties
F_p – design base shear

W_p – weight (dead load) of the rigid photovoltaic module, in lbs
M_p – design overturning moment
I_p – component importance factor = 1.0

3.6.3 Base Shear Coefficient

The seismic base shear coefficient shall be calculated as follows:

$$F_p = A_p W_p = \frac{0.4 a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)} \left(1 + 2\frac{z}{h}\right) \quad (1)$$

A_p shall not be less than 0.3 $I_p S_{DS}$ and need not be more than 1.6 $I_p S_{DS}$

Note that $\frac{z}{h} \leq 1$

3.6.4 Short-period design spectral response acceleration (S_{DS})

The short-period design spectral response acceleration SDS for which the rigid photovoltaic modules and racking systems (if used) will be rated should equal or exceed the largest value for locations at which they are expected to be installed.

For sites within the USA, the short-period design spectral response acceleration S_{DS} shall be calculated according to the ASCE 7 standard, as follows.

The MCE_R (risk targeted maximum considered earthquake) value of the 5% damped 'firm' rock spectral acceleration at 0.2 second (S_S) is read from the maps in ASCE 7. This is multiplied by the NEHRP (National Earthquake Hazard Reduction Program) soil amplification factor F_a (2) to obtain the free-surface spectral accelerations S_{MS}:

$$S_{MS} = S_S \times F_a \quad (2)$$

S_{DS} shall be taken as two-thirds of S_{MS}:

For locations outside the USA, S_{MS} shall be estimated as the 475-year return period value of 0.2 second period 5% damped "firm" rock spectral acceleration adjusted for local soil conditions multiplied by a factor of 1.8, or the 2,475 year return period value of 0.2 second period, 5% damped "firm" rock spectral acceleration adjusted for local soil conditions. The 0.2 second period, 5% damped "firm" rock spectral acceleration at 475- or 2475-year return periods can be estimated as the corresponding peak ground acceleration multiplied by a factor of 2.5. S_{DS} shall be taken as two-thirds of this estimated S_{MS}. If the 475-year or 2475-year accelerations are not available, S_{DS} can be estimated from other sources acceptable to FM Approvals, or a SDS value of 1.6 can conservatively be used.

3.6.5 Design Loads for Supporting Structure

The design base shear is calculated as follows:

$F_{\mathrm{p}} = A_{\mathrm{p}} \cdot W_p$ (3), see equation (1) above.

The design overturning moment is calculated as follows:

$$M_{\mathrm{p}} = F_{\mathrm{p}} \cdot \bar{h} \quad (4)$$

Where applicable, the torque produced by mass eccentricity shall be considered in the design of the support structure.

3.6.6 Design Loads for Base Anchors

The design loads (shear, overturning moment and torque) applied to the base anchors shall be based on R_P equal to 1.5.

3.6.7 LRFD Load Combinations

Examine load combinations below to determine the design loads:

3.6.7.1 Operational condition dead load.

(1.2 × Dead Load) + [1.0 × Seismic Load (F_p)] + (0.2 × Roof Snow Load)

Note that the roof snow load should be based on a mean recurrence interval of 50-years.

3.6.7.2 Operational condition minimum dead load

(0.9 × Dead Load) + [1.0 × Seismic Load (Fp)]

3.7 Identified Components

3.7.1 Modules of PV systems can be recognized by the certification agency as Identified Components.

3.7.2 An observation of test sample production, as detailed in Section 3.5, shall be at the discretion of the certification agency.

3.7.3 An examination of the manufacturing facilities, audit of quality assurance procedures, and a surveillance audit program shall be required at each Identified Component manufacturing facility.

3.7.4 Requirements from the following sections shall apply to Identified Components:

- Section 3.1-3.4 - General Requirements, and
- Section 5 - Operations Requirements.

3.7.5 An Identified Component for PV modules requires performance requirements per Sections 4.4-4.6.

3.7.6 Certification is not granted as part of Identified Component recognition.

4 PERFORMANCE REQUIREMENTS

This standard is intended to evaluate a rigid roof-mounted photovoltaic module for its performance as it relates to fire from above the structural deck, simulated wind uplift, susceptibility from hail storm damage, seismic performance requirements (optional) and gravity load testing (optional) .

Tests of alternate constructions are permitted to be waived if considered less hazardous than those previously tested.

The use of screening tests is permitted to be used to determine critical components to be used for full scale testing or to evaluate components as alternate to those already tested and found to be satisfactory via the full scale tests described in sections 4.1 through 4.8 below. Alternate components must perform to an equal or higher level than the component qualified via large scale testing. Acceptable screening tests shall be at the discretion of the certification agency.

Additional tests may be required, at the sole discretion of the certification agency, depending on design features and results of any foregoing tests. A re-test of an identical assembly following a failure shall be acceptable at the discretion of the certification agency and with a technical justification of the conditions or reasons for failure. When a test specimen fails to meet the certification acceptance criteria for a given classification or rating, two successful test specimens of the same or similar construction must meet the certification acceptance criteria to qualify for the given classification or rating. Any test specimen that fails more than three times is no longer considered a candidate for certification.

Prior to testing, assemblies shall be permitted to cure for a maximum period of 28 days under laboratory conditions.

4.1 Combustibility from Above the Roof Deck

Testing for combustibility from above the roof deck and/or rigid photovoltaic module shall be in accordance with a modified version of the ASTM E108 Class A Spread of Flame Test. The modifications are as follows:

The samples shall have rigid PV on top of the roof covers. The length of the test deck for the Spread of Flame test shall be 8 ft (2.4 m) minimum to a maximum of 16 ft (4.9 m). The samples shall be long enough to accommodate 2 panels if the combined length of 2 panels is greater than 13 ft. (4.0 m) or long enough to accommodate 3 panels if the combined length of 2 panels is less than 13 ft. (4.0 m). If the combined length of 2 panels is less than 13 ft. (4.0 m) and the combined length of 3 panels is longer than 16 ft. (4.9 m) then the test shall be run with 2 panels. The test deck sample shall be minimum 3 ft – 4 in. (1 m) wide up to a maximum of 6 ft -8 in. (2 m) wide. The samples shall be wide enough to accommodate 2 panels in a tent shape arrangement or 1 panel if the slopes are south facing.

4.1.1 Conditions of Acceptance for Combustibility from Above the Roof Deck/Photovoltaic Module

4.1.1.1 There shall be no fire damage to the roof cover nor to the PV panel within 6 in (152 mm) of the end of the last PV module.

4.2 Wind Uplift Resistance for Rigid Photovoltaic Module

For wind uplift resistance, the rigid photovoltaic module will be tested using two methods. These two methods are a simulated wind uplift pressure test with the photovoltaic module attached to a test frame using a pleated air bag with the load applied to the photovoltaic module and tensile loading of the fasteners/clips, if used. The rating assigned to the assembly shall be the lowest rating obtained during all testing.

4.2.1 Rigid Photovoltaic Simulated Wind Uplift Pressure Test

Testing for simulated wind uplift resistance shall be in accordance with the 12 × 24 Simulated Wind Uplift Pressure Test Procedure per ANSI/FM 4474. The reduced wind pressure loading shall be applied to the PV system using a pleated airbag. The minimum rating in psf required for certification is 45 psf (1.4 kPa) for Class 1-45. The maximum rating in psf available is 990 psf (47.3 kPa) for Class 1-990. Ratings between 1-45 and 1-990 are available in 15 psf (0.72 kPa) increments. The rating assigned to the assembly shall be the maximum simulated uplift resistance pressure which the assembly maintained for one (1) minute without ultimate failure. Adjustments to the pressure applied over the test area are made to account for the tributary area of only the PV panels and mounting system.

In addition, the assembly must maintain the service wind load (50% of the ultimate failure pressure) for one (1) minute without any visible cracking or visible creasing.

- Multiple cracks in the same component, which would impair performance is indicative of ultimate failure, shall not be permitted.
- Crack length in excess of one half the minimum component dimension, e.g., 24 in. (1220 mm) for a 48 x 96 in. (1220 x 2440 mm) component shall not be permitted.

4.2.1.1 Conditions of Acceptance for Rigid Photovoltaic Simulated Wind Uplift Pressure Test

4.2.1.1.1 All fasteners, clamps and stress distributors shall: a) remain securely embedded into, or through, the roof deck and other structural substrates to which they are being fastened to or through; b) not pull through, become dislodged, disconnected or disengaged from plates, battens, seams or substrates; c) not fracture, separate or break.

4.2.1.1.2 All components shall: a) not fracture, break or pull through, or over, fastener heads, plates or battens; b) not delaminate or separate from their facers or adjacent components to which they have been adhered; c) be permitted to deflect between points of mechanical securement provided that the components do not fracture, crack or break.

EXCEPTION: Visible cracking or visible creasing, when less than or equal to one half the minimum component dimension, shall be permitted provided ultimate failure does not occur as noted in 4.2.1.

4.2.1.1.3 All membranes shall: a) not tear, puncture, fracture or develop any through openings; b) not delaminate or separate from adjacent components.

EXCEPTIONS: 1) Mechanically fastened membranes shall be permitted to separate and deflect from adjacent components at locations where they are not fastened, 2) partially adhered membranes shall be permitted to separate and deflect from adjacent components at locations where adhesive placement was not intended, 3) tearing of membrane at fastener/stress distributors is allowed up to ultimate failure, 4) minor areas of delamination are allowed provided they do not continue to grow in size by more than 50% from the end of one pressure level through the end of the following pressure level.

4.2.1.1.4 All adhesives and welded bonds shall maintain full contact between all the surfaces of all components to which it has been applied to, or comes in contact with, without any separation, delamination, fracture, cracking or peeling of the adhesive or its bond.

EXCEPTION: Minor delamination is allowed provided it does not continue to grow in size by more than 50% from the end of one pressure level through the end of the following pressure level.

4.2.1.1.5 All roof decks shall: a) maintain their structural integrity during the entire classification period; b) not fracture, split, crack, permanently deform or allow for fastener withdrawal.

4.2.1.1.6 Stresses induced to steel roof decking shall be determined by rational analysis, supplied by the test sponsor and shall not exceed the allowable stresses per AISI S100.

4.2.1.1.7 All photovoltaic modules shall: a) not puncture, fracture, crack or develop any through openings; b) not delaminate or separate from the frame.

EXCEPTION: Mechanically fastened modules shall be permitted to separate and deflect from adjacent components at locations where they are not fastened.

4.2.1.1.8 All other components, including seams, base sheets, base plies, plies and cap plies, shall not tear, puncture, fracture, disengage, dislodge, disconnect, delaminate or develop any through openings.

4.2.1.1.9 The theoretical load per fastener (pressure x contributory area) shall not exceed the pullout resistance of the fastener per Section C.6.1, FM 4470.

4.2.2 Pull Out Tests for Rigid Photovoltaic Module/ Photovoltaic Clamp Combination, Photovoltaic Clamp/Metal Panel Combinations, Photovoltaic Clamp/Frame Combinations, Photovoltaic Frame/Roof Deck Combinations using Pull Tests

Tests shall be conducted on a constant strain tensile machine as follows: Force is exerted in a direct line perpendicular to the plane of the test jig and clamp, mounting bracket, frame or racking system or roof deck interface at a crosshead speed of 2 in./min (51 mm/min). Continue the testing described above until the sample fails, higher forces are unable to be attained or maintained, or at the discretion of the test sponsor. Failure is considered to occur when the Conditions of Acceptance are no longer being met or until the tensile force is no longer able to be maintained. Upon completion of the test, the sample shall be examined and any item not conforming to the Conditions of Acceptance shall be noted.

4.2.2.1 Conditions of Acceptance for Rigid Photovoltaic Module/ Photovoltaic Clamp Combination, Photovoltaic Clamp/Metal Panel Combinations, Photovoltaic Clamp/Frame Combinations, Photovoltaic Frame/Roof Deck Combinations using Tensile Loading are as follows:

4.2.2.1.1 The result reported shall be the highest force attained by the sample during the test.

4.2.2.1.2 The overall sample results shall be determined based on the average of three (3) tests. If the standard deviation of the three values divided by the mean is greater than 20%, up to two additional tests shall be required until less than or equal to 20% is obtained. The results of all tests (3-5) shall be used to determine the final average.

4.2.2.1.3 The sample result from the above tensile testing will be the load determined in lbf (N). The total area of the element being secured will be divided by the total number of fasteners/clamps used to secure the element, the result will be the contributory area for each fastener/clamp in ft^2 (m^2). The maximum certification rating shall be the load determined from the tensile testing divided by the contributory area rounded down to the next multiple of 15 psf (0.72 kPa).

4.3 Wind Uplift Resistance for Rigid Photovoltaic Module Loose Laid and Ballasted

Installation of the Rigid Photovoltaic Module if loose laid or ballasted shall be in accordance with SEOC PV2 2017 (2nd edition) or ASCE 7 (2016 edition).

4.3.1 The roof cover assembly, over which the photovoltaic modules are installed, shall meet the requirements of FM 4470.

4.4 Hail Damage Resistance Test

4.4.1 Testing for hail damage resistance shall be in accordance with ANSI/FM 4473. The minimum rating required for certification is Class 2.

For the VSH rating, testing is performed with a Class 4 size ice ball with an increased speed to achieve a kinetic energy between 53 – 58 ft-lb (72 – 79 J) for each impact. Impacts with kinetic energy greater than 58 ft-lb (79 J) are considered acceptable if the impact area meets the acceptance criteria.

4.4.1.1 Condition of Acceptance for Hail Damage Resistance

4.4.1.2 After completion of the impact testing, the photovoltaic module shall show no signs of cracking or splitting, misaligned external surfaces, or rupture when examined under 10X magnification.

4.5 Electrical Performance

Testing for electrical performance shall be in accordance with IEC/EN 61215-1, IEC/EN 61215-1-1 and IEC/EN 61215-2.

4.5.1 Condition of Acceptance for Electrical Performance

4.5.1.1 All test samples must meet all test requirements in IEC/EN 61215-1, IEC/EN 61215-1-1 and IEC/EN 61215-2.

4.6 Electrical Safety

Testing for electrical safety shall be in accordance with IEC/EN 61730-2, or ANSI/UL 1703.

4.6.1 Condition of Acceptance for Electrical Safety

4.6.1.1 All test samples must meet all tests requirements in IEC/EN 61730-2 or ANSI/UL 1703.

4.7 Gravity Load Resistance Test (Optional)

For gravity load resistance, the rigid photovoltaic module will be tested using two methods. These two methods are simulated gravity load pressure test with the photovoltaic module attached to a test frame inversely using a pleated air bag and structural loading of the fasteners/clips. The rating assigned to the assembly shall be the lowest rating obtained during all testing.

4.7.1 Rigid Photovoltaic Simulated Gravity Load Pressure Test

Testing for simulated gravity load resistance shall be in accordance with the 5 × 9 Simulated Wind Uplift Pressure Test Procedure outlined in ANSI/FM 4474 with the following modifications. The pressure load shall be applied to a PV module mounted upside down using a pleated airbag. Air is introduced by opening the air supply valve on the blower until the pressure level reaches one half of the pressure load requested by

the test sponsor. For example, if the test sponsor wants a rating of 32 psf (1.5 kPa) then introduce air to a pressure level of 16 psf (0.75 kPa) with a tolerance of +2 psf, -0 psf (+0.1 kPa, -0 kPa). Upon reaching ½ of the requested rating pressure, the pressure level shall be maintained while the perimeter clamps are checked and that there are minimal air leaks from the pressure vessel. Adjustments shall be permitted as necessary in order to maintain a constant reading. While the sample is being maintained at this pressure level, the sample shall be visually examined to ensure that it continues to meet the conditions of acceptance.

After 60 minutes, the pressure level shall be increased to the full pressure rating requested with a tolerance of +2 psf, -0 psf (+0.1 kPa, -0 kPa). Upon reaching the next pressure level, the pressure shall be maintained for a period of 60 minutes. The supply air and clamps shall be permitted to be adjusted as necessary in order to maintain a constant reading. While the sample is being maintained at this pressure level, the sample shall be visually examined to ensure that it continues to meet the conditions of acceptance.

The rating assigned to the assembly shall be the maximum simulated gravity load which the assembly maintained for one (1) hour without ultimate failure.

4.7.1.1 Conditions of Acceptance for Rigid Photovoltaic Simulated Gravity Load Pressure Test

4.7.1.1.1 All fasteners, clamps, racking, framing and stress distributors shall: a) remain securely embedded into, or through, the substrates to which they are being fastened to or through; b) not pull/push through, become dislodged, disconnected, or disengaged from plates, battens, seams or substrates; c) not fracture, separate or break.

4.7.1.1.2 All components shall: a) not fracture, break or pull/push through, or over, fastener heads, plates or battens; b) not delaminate or separate from their facers or adjacent components to which they have been adhered; c) be permitted to deflect between points of mechanical securement provided that the components do not fracture, crack or break.

4.7.1.1.3 All adhesives shall maintain full contact between all the surfaces of all components to which it has been applied to, or comes in contact with, without any separation, delamination, fracture, cracking or peeling of the adhesive or its bond.

4.7.1.1.4 All photovoltaic modules shall: a) not puncture, fracture, crack or develop any through openings; b) not delaminate or separate from the frame.

EXCEPTION: Mechanically fastened modules shall be permitted to separate and deflect from adjacent components at locations where they are not fastened.

5 MANUFACTURER'S REQUIREMENTS

5.1 Demonstrated Quality Control Program

5.1.1 A quality assurance program is required to assure that subsequent products produced by the manufacturer shall present the same quality and reliability as the specific products examined. Design quality, conformance to design, and performance are the areas of primary concern.

- Design quality is determined during the examination and tests and may be documented in the certification report.
- Continued conformance to this standard is verified by the certifiers surveillance program.
- Quality of performance is determined by field performance and by periodic re-examination and testing.

5.1.2 The manufacturer shall demonstrate a quality assurance program which specifies controls for at least the following areas:

- existence of corporate quality assurance guidelines;
- incoming quality assurance, including testing;
- in-process quality assurance, including testing;
- final inspection and tests;
- equipment calibration;
- drawing and change control;
- packaging and shipping; and
- handling and disposition of non-conforming materials.

5.1.3 Documentation/Manual

There should be an authoritative collection of procedures/policies. It should provide an accurate description of the quality management system while serving as a permanent reference for implementation and maintenance of that system. The system should require that sufficient records are maintained to demonstrate achievement of the required quality and verify operation of the quality system.

5.1.4 Records

To assure adequate traceability of materials and products, the manufacturer shall maintain a record of all quality assurance tests performed, for a minimum period of two years from the date of manufacture.

5.1.5 Drawing and Change Control

- The manufacturer shall establish a system of product configuration control that shall allow no unauthorized changes to the product. Changes to critical documents, identified in the certification report, may be required to be reported to, and authorized by the certification agency prior to implementation for production.
- Records of all revisions to all certified products shall be maintained.

5.2 Surveillance Audit

5.2.1 An audit of the manufacturing facility may be part of the certification agencies surveillance requirements to verify implementation of the quality assurance program. Its purpose is to determine that the manufacturer's equipment, procedures, and quality program are maintained to ensure a uniform product consistent with that which was tested and certified.

5.2.2 Certified products or services shall be produced or provided at, or provided from, location(s) disclosed as part of the certification examination. Manufacture of products bearing a certification mark is not permitted at any other location prior to disclosure to the certification agency.

5.3 Product Modifications

5.3.1 The manufacturer shall notify the certification agency of changes in product construction, components, raw materials, physical characteristics, coatings, component formulation or quality assurance procedures prior to implementation.

6 BIBLIOGRAPHY

ISO/IEC 17025, *General Requirements for the Competence of Testing and Calibration Laboratories*.