American National Standard for Flexible Photovoltaic Modules

ANSI/FM Approvals 4476-2014 (2022)
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Foreword

NOTE: This foreword is introductory only and is not part of American National Standard FM 4476.

This standard is intended to verify that the product as described will meet minimum specific stated conditions of performance, safety and quality, useful in determining the potential suitability for end-use conditions of these products. It describes minimum performance requirements for materials that are intended for use in roof assemblies by evaluating the ability of the materials and, in turn, the system components to withstand simulated wind uplift resistance.

This American National Standard has been developed according to the essential requirements of due process for standards development of the American National Standards Institute (ANSI). FM Approvals is an ANSI-accredited standards developer (ASD).

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Approval of an American National Standard requires verification by ANSI that the principles of openness and due process have been followed and that a consensus of those directly and materially affected by the standard has been achieved. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution. Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached.

The American National Standards Institute does not develop standards nor will it in any circumstances give an interpretation of any American National Standard. Requests for interpretations of this test standard should be addressed to FM Approvals.

ANSI regulations require that this American National Standard shall be revised, reaffirmed or withdrawn within five years of the date of publication.

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1 INTRODUCTION

1.1 Purpose

This standard states test requirements for flexible photovoltaic modules that are used with a roof assembly.

1.2 Scope

1.2.1 This standard applies to all flexible photovoltaic modules when adhered to, or mechanically fastened to or through, a single-ply, polymer-modified bitumen sheet, built-up roof, liquid applied or metal roof cover assembly.

1.2.2 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 evaluates flexible photovoltaic modules for their performance in regard to fire from above the structural deck, simulated wind uplift, susceptibility from hail storm damage, and heat aging effects on the substrate.

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

1.2.5 This standard does not intend to qualify rigid photovoltaic modules.

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.

1.4 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. Appendix A lists the selected units and conversions to SI units for measures appearing in this standard. Conversion of U.S. customary units is in accordance with *Standard for Use of the International System of Units (SI): The Modern Metric System*, BSR/IEEE/ASTM SI 10.

1.5 Applicable Documents

The following standards, test methods, and practices are referenced in this standard:

- *Evaluating the Simulated Wind Uplift Resistance of Roof Assemblies Using Static Positive and/or Negative Differential Pressures*, American National Standard, ANSI/FM Approvals 4474
- *Fire Tests of Roof Coverings,* ASTM E108, ASTM International
- *Standard Test Methods for Sampling and Testing of Modified Bituminous Sheet Material*, ASTM D5147, ASTM International
- *Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials*, ASTM G 154, ASTM International

1.6 Definitions

For purposes of this standard, the following terms apply:

Adhesive – Adhesive is used in roof construction to adhere roof coverings to roof coverings as in lap construction. It is also used to bond roof coverings to the substrate below, to adhere insulation to the substrate or to adhere flexible photovoltaic modules to the roof covering. Depending on the use, the adhesive could be in either a liquid form, semi liquid form or a solid form as in a seam tape or as in hot asphalt which is solid until heated

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

Delamination **-** Separation of the plies in a roof membrane or system in any laminated roofing material or component, e.g., laminated layers of rigid insulation or the felt plies in a built-up roof or separation of any membrane from the substrate to which it is adhered. This includes the separation of the photovoltaic modules from the roof cover.

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

Fully Adhered **-** Fully adhered describes components such as photovoltaic modules that have been bonded to the substrate using a compatible adhesive throughout the entire surface.

Mechanically Fastened **-** Mechanically fastened describes roof covers, base sheets or photovoltaic modules that have been attached to the substrate at defined intervals using fasteners with or without stress distributors.

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 (0.28 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.

Flexible Photovoltaic Module – A device that converts solar energy into electricity using the photovoltaic effect. Flexible modules are generally not installed with a frame system. They are installed over a solid, supporting substrate such as a roof cover.

Roof Assembly **-** A system 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.

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

2 GENERAL INFORMATION

2.1 Product Information

Flexible photovoltaic modules are submitted in either sheet or roll form. They are installed using either mechanical fasteners and plates, welding techniques, or adhesives. Modules that are mechanically fastened are installed on site during or after the installation of the roof system. Modules that are installed using adhesives can be adhered to the roof cover during the manufacturing process or installed on site during or after the installation of the roof system.

3 GENERAL REQUIREMENTS

3.1 Review of Documentation

During the initial investigation and prior to physical testing, the manufacturer's specifications and details of installation shall be reviewed.

3.2 Calibration

All examinations and tests performed in evaluation to this standard shall use calibrated measuring instruments traceable and certified to acceptable national standards.

3.3 Markings

3.3.1 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 shall be universally recognizable and permanent.

3.3.2 The product trade name, model number, or model type identification shall correspond with the manufacturer's catalog designation. The manufacturer shall not place this trade name or model type identification on any other product unless covered by a separate agreement.

3.3.3 All markings shall be legible and durable.

3.4 Manufacturer’s Installation Instructions

The manufacturer shall provide the user with printed instructions to demonstrate proper installation procedures to be followed by installers.

3.5 Test Sample Production

All products submitted for testing shall be representative of production run material.

4 PERFORMANCE REQUIREMENTS

This standard is intended to evaluate a flexible photovoltaic module as part of a finished roof assembly for its performance as it relates to fire from above the structural deck, simulated wind uplift, susceptibility from hail storm damage and heat aging effects on the roof cover.

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

The use of screening tests are 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 the scale tests described in sections 4.1 through 4.5 below. Alternate components must perform to an equal or higher level than the component qualified via full scale testing.

When a test specimen fails to meet the acceptance criteria for a given classification or rating, two successful test specimens of the same or similar construction must meet the acceptance criteria to qualify for the given classification or rating.

Prior to testing, samples shall be permitted to cure for a maximum period of 28 days.

4.1 Combustibility From Above the Roof Deck

Testing for combustibility from above the roof deck shall be in accordance with ASTM E108, *Fire Test of Roof Coverings.*

4.1.1 Conditions of Acceptance for Combustibility from Above the Roof Deck

4.1.1.1 Spread of Flame test

- For Class A, the maximum flame spread of the sample materials shall not exceed 72 in (1830 mm).
- For Class B, the maximum flame spread of the sample materials shall not exceed 96 in (2440 mm).
- For Class C, the maximum flame spread of the sample materials shall not exceed 156 in (3960 mm).
- There shall be no excessive lateral flame spread which is defined as flames extending to the two lateral edges of the exposed roof covering or coating beyond 12 in (305 mm) from the ignition source.
- There shall be no portion of the roof covering material blown or falling off of the test deck in the form of flaming or glowing brands that continue to glow after reaching the floor.
- There shall be no portion of the roof deck that fall in the form of particles that continue to glow after reaching the floor.

4.1.1.2 For assemblies constructed over combustible decks, Intermittent Spread of Flame and Burning Brand tests shall be performed for Classes A, B, or C

- There shall be no portion of the roof covering material blown or falling off of the test deck in the form of flaming or glowing brands that continue to glow after reaching the floor.
- There shall be no exposure of the deck or sustained flaming on the underside of the deck.
- There shall be no portion of the roof deck that fall in the form of particles that continue to glow after reaching the floor.

4.2 Wind Uplift Resistance for Roof Assemblies Other than Flexible Photovoltaic Modules Adhered to Metal Panel Roof Coverings

Testing for wind uplift resistance shall be in accordance with ANSI/FM Approvals 4474, *Evaluating the Simulated Wind Uplift Resistance of Roof Assemblies Using Static Positive and/or Negative Differential Pressures*. The minimum rating required is Class 1-60. The maximum rating available is Class 1-990. Ratings between 1-60 and 1-990 are available in increments of 15 psf (0.72 kPa). The rating assigned to the assembly shall be the maximum simulated uplift resistance pressure which the assembly maintained for one (1) minute without failure.

4.2.1 12 x 24 ft (3.7 x 7.3 m) Simulated Wind Uplift Pressure Test

The 12 x 24 ft (3.7 x 7.3 m) simulated wind uplift pressure test procedure is to be used to determine the simulated wind uplift resistance of the following types of roof assemblies:

1) assemblies other than those evaluated via the uplift pull test or 5 x 9 ft (1.5 x 2.7 m) uplift pressure test.

2) assemblies that utilize mechanical fasteners, adhesives, hot asphalt, heat welding or combination thereof, to secure the flexible photovoltaic module to the roof cover or to the roof deck.

3) assemblies that utilize battens bars or rows of fasteners spaced less than, or equal to, 144 in (3660 mm) on center with maximum in-row spacing of 48 in (1220 mm).

4.2.1.1 Conditions of Acceptance for 12 x 24 ft (3.7 x 7.3 m) Simulated Wind Uplift Pressure Test

4.2.1.1.1 All fasteners and stress plates 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 insulations 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 insulation boards do not fracture, crack or break.

EXCEPTIONS: cracking at fastener plates shall be permitted provided ultimate pull through does not occur.

4.2.1.1.3 All membranes or photovoltaic modules shall: a) not tear, puncture, fracture or develop any through openings; b) not delaminate or separate from adjacent components (exception: 1) mechanically fastened modules or membranes shall be permitted to separate and deflect from adjacent components at locations where they are not fastened, 2) partially adhered membranes or modules shall be permitted to separate and deflect from adjacent components at locations where adhesive placement was not intended).

EXCEPTIONS: a) tearing of membrane or module at fastener plates and batten bars is allowed up to ultimate failure provided water-tightness is maintained; b) minor areas of delamination are allowed provided they do not continue to grow in size by more than 50% during a given pressure level.

4.2.1.1.4 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.

EXCEPTION: minor areas of delamination shall be permitted provided they do not continue to grow in size by more than 50% during a given 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, (this is covered by 4.2.1.1.3 and eliminated the issue of minor delamination at deck fasteners etc.) or allow for fastener withdrawal or backout.

4.2.1.1.6 Stresses induced to steel roof decking shall be determined by rational analysis and shall not exceed the allowable stresses per the latest edition of the *North American Specification for the Design of Cold-Formed Steel Structural Members,* AISI S100-200.

4.2.1.1.7 All other components, including photovoltaic modules, seams, base sheets, base plies, plies and cap plies, shall not tear, puncture, fracture, disengage, dislodge, disconnect, delaminate or develop any through openings. See allowable exception given above in 4.2.1.1.3.

4.2.1.1.8 The theoretical load per fastener (pressure x contributory area) does not exceed the pullout resistance of the fastener per Appendix E.

4.2.2 5 x 9 ft (1.5 x 2.7 m) Simulated Wind Uplift Pressure Test

The 5 x 9 ft (1.5 x 2.7 m) simulated wind uplift pressure test procedure is used to determine the simulated wind uplift resistance of the following types of roof assemblies with a maximum wind uplift rating of Class 1-90:

1) Assemblies that utilize mechanical fasteners, adhesives, hot asphalt, heat welding, self adhesive components or combination thereof, to secure insulations, a base ply, plies or a cap ply sheet, exterior coverings and other components, in single or multi-layered constructions, to one another and to the roof deck. Note: Adhesive securement to steel roof deck is not permitted.

2) Assemblies that utilize air pervious decks to include cementitious wood fiber, steel, wood or fiber reinforced plastic roof decks.

3) Assemblies with mechanically secured roof covers with securement row spacing less than, or equal to, 48 in (1220 mm) on center with maximum in-row spacing of 24 in (610 mm).

4) Assemblies with mechanically secured roof covers with securements (spot or grid affixed) spacing less than, or equal to, 24 x 48 in (610 x 1220 mm) on center.

5) Assemblies with mechanically secured insulation (maximum 48 x 96 in (1220 x 2440 mm) board) with a maximum contributory securement area of 5.33 ft^2 (0.50 m^2) per fastener, e.g. 6 fasteners on a 48 x 96 in (1220 x 2440 mm) board size.

4.2.2.1 Conditions of Acceptance for 5 x 9 (1.5 x 2.7 m) Simulated Wind Uplift Pressure Test

4.2.2.1.1 All fasteners and stress plates 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.

4.2.2.1.2 All insulations 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 insulation boards do not fracture, crack or break.

EXCEPTIONS: cracking at fastener plates shall be permitted provided ultimate pull through does not occur.

4.2.2.1.3 All membranes or photovoltaic modules shall: a) not tear, puncture, fracture or develop any through openings; b) not delaminate or separate from adjacent components (exception: 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 or modules shall be permitted to separate and deflect from adjacent components at locations where adhesive placement was not intended).

EXCEPTIONS: a) tearing of membrane or module at fastener plates and batten bars is allowed up to ultimate failure provided water-tightness is maintained; b) minor areas of delamination are allowed provided they do not continue to grow in size by more than 50% during a given pressure level.

4.2.2.1.4 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.

EXCEPTION: minor areas of delamination shall be permitted provided they do not continue to grow in size by more than 50% during a given pressure level.

4.2.2.1.5 All roof decks shall: a) maintain their structural integrity during the entire classification period; b) not fracture, split, crack, (this is covered by 4.2.2.1.3 and eliminated the issue of minor delamination at deck fasteners etc.) or allow for fastener withdrawal or backout.

4.2.2.1.6 Stresses induced to steel roof decking shall be determined by rational analysis and shall not exceed the allowable stresses per the latest edition of the *North American Specification for the Design of Cold-Formed Steel Structural Members,* AISI S100-200.

4.2.2.1.7 All other components, including photovoltaic modules, seams, base sheets, base plies, plies and cap plies, shall not tear, puncture, fracture, disengage, dislodge, disconnect, delaminate or develop any through openings. See allowable exception given above in 4.2.2.1.3.

4.2.2.1.8 The theoretical load per fastener (pressure x contributory area) does not exceed the pullout resistance of the fastener per Appendix E.

4.2.3 Simulated Wind Uplift Pull Test

The simulated wind uplift pull test shall be used to evaluate fully adhered photovoltaic modules used with: fully adhered roof coverings having substrates (cover board layer, insulation layer(s) vapor retarder layer) either partially, or fully, adhered to monolithic structural concrete roof decks or gypsum or lightweight concrete cast over monolithic structural concrete. When substrates are partially adhered, the maximum row spacing to be evaluated is 12 in (305 mm).

1) Assemblies where the single ply roof cover is fully adhered to a cover board, insulation or deck.

2) Assemblies where the multi ply roof cover is partially adhered to a cover board, insulation or deck.

3) Assemblies with a perforated base sheet partially adhered to an insulation or deck and with a rigid insulation adhered above the perforated base sheet.

4) Assemblies with a maximum rigid insulation board size of 48 x 48 in (1220 x 1220 mm).

4.2.4 Conditions of Acceptance for Simulated Wind Uplift Pull Test

4.2.4.1 All components shall 1) not fracture or break; 2) not delaminate or separate from adjacent components to which they have been adhered.

4.2.4.2 All adhesive 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.

4.2.4.3 All other components, including seams, vapor retarders, base or ply sheets, shall not tear, puncture, fracture, disengage, dislodge, disconnect, delaminate or develop any through openings.

4.3 Wind Uplift Resistance for Roof Assemblies with Flexible Photovoltaic Modules Adhered to Metal Panel Roof Coverings

Testing for wind uplift resistance for flexible photovoltaic modules adhered to metal panel roof covers shall be in accordance with the Test Procedure in Appendix B. The minimum rating required is Class 1-60. The maximum rating available is Class 1-990. Ratings between 1-60 and 1-990 are available in increments of 15 psf (0.72 kPa). The rating assigned to the assembly shall be the maximum simulated uplift resistance pressure which the assembly maintained for one (1) minute without failure. The maximum simulated uplift resistance pressure will be the minimum value from either of the required tests. Both tests are required.

4.3.1 12 x 24 ft (3.7 x 7.3 m) Simulated Wind Uplift Pressure Test

The 12x24 ft (3.7 x 7.3 m) simulated wind uplift pressure test shall be used to evaluate adhered photovoltaic modules used with metal panel roof covering. Testing for wind uplift resistance for flexible photovoltaic modules adhered to metal panel roof covers shall be in accordance with the Test Procedure Appendix B.

4.3.1.1 Conditions of Acceptance for 12 x 24 ft (3.7 x 7.3 m) Simulated Wind Uplift Pressure Test

4.3.1.1.1 The candidate panel roof assembly comprised of a specific combination of components shall possess adequate physical properties to resist 1) a specified minimum uplift pressure without disengagement or fracture of any component and 2) half the specified minimum uplift pressure without any permanent deformation of any component. Any separation, permanent deformation, withdrawal, or fracture within the panel roof assembly is considered a failure.

4.3.2 1 x 4 ft (0.3 x 1.2 m) Wind Uplift Test

The 1x4 ft (0.3 x 1.2 m) simulated wind uplift reduced pressure tests shall be used to evaluate adhered photovoltaic modules used with metal panel roof covering. Testing for wind uplift resistance for flexible photovoltaic modules adhered to metal panel roof covers shall be in accordance with the Test Procedure Appendix B. The photovoltaic module will be subjected to the 1x4 ft (0.3 x 1.2 m) wind uplift test on the same roof system as the 12x24 ft (3.7 x 7.3 m) Simulated Wind Uplift Pressure Test after the 12x24 ft (3.7 x 7.3 m) test is completed.

4.3.2.1 Conditions of Acceptance for 1 x 4 ft (0.3 x 1.2 m) Wind Uplift Test

4.3.2.1.1 All photovoltaic modules and/or membranes shall not delaminate or separate from adjacent components.

4.3.2.1.2 All adhesive 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.

4.4 Hail Damage Resistance Test

Testing for hail damage resistance shall be in accordance with Test Procedure, Appendix C. The minimum rating required is Class 1-MH.

4.4.1 Conditions of Acceptance for Hail Damage Resistance

4.4.1.1 The photovoltaic module shall show no signs of cracking or splitting. Under adhered conditions, minor separation (an area less than the size of impact) of the module from the roof cover or roof cover from the substrate directly under the impact area is acceptable for monolithic decks only (i.e. structural concrete, lightweight insulating concrete, or cast-in-place gypsum). The photovoltaic module shall show no signs of cracking, splitting, separation, or rupture when examined under 10X magnification.

4.5 Heat Aging Affects

Testing for affects of heat aging from a photovoltaic modules applied to a roof cover shall be in accordance with Test Procedure, Appendix D, if the roof covering is not made from asphalt or modified bitumen. Roof covers made from asphalt or modified bitumen are required to meet the compound stability test per ASTM D5147, *Standard Test Methods for Sampling and Testing of Modified Bituminous Sheet Material*. No heat aging testing is required for Approval over metal panel roof covers due to the type of material.

4.5.1 Conditions of Acceptance for Heat Aging Affects

4.5.1.1 For non-asphaltic roof covers:

4.5.1.1.1 After 60 days of exposure, the roof cover bent over a 3 in (76 mm) diameter mandrel shall not show any signs of cracking or splitting when examined under 10X magnification.

4.5.1.2 For asphaltic or modified bitumen roof covers:

4.5.1.2.1 No flowing, dripping or drop formation on the lower edge of the specimen shall be observed at 215 ˚F (102 ˚C).

APPENDIX A: UNITS OF MEASUREMENT

LENGTH:	in - "inches"; (mm - "millimeters") mm = in x 25.4
	ft - "feet"; (m - "meters") m = ft x 0.3048
PRESSURE:	psi - "pounds per square foot"; (kPa - "kilopascals") kPa = psf x 0.04788
TEMPERATURE:	°F "degrees Fahrenheit"; (°C "degrees Celsius") °C = (°F - 32) x 0.556
MASS:	lbs –‘‘pounds’’; (kg –‘‘kilograms’’) kg=lb x 0.454
ENERGY:	ft lb – “foot pounds”; (J – “Joules”) g = lb x 1.3558

APPENDIX B: TEST PROCEDURES

Wind Uplift Resistance for Roof Assemblies with Flexible Photovoltaic Modules Adhered to Metal Panel Roof Coverings

B-1 Introduction

B-1.1 The 12 x 24 ft (3.7 x 7.37 m) Simulated Wind Uplift Pressure Test Procedure and 1 x 4 ft (0.3 x 1.2 m) Wind Uplift Tests for Flexible Photovoltaic Modules adhered to Standing Lap Seam and Composite Panel Roof Coverings is designed to evaluate the performance of metal panel roof assemblies with Flexible PV modules adhered to the roof cover to resist wind uplift forces on building roofs. The test method described below utilizes a nominal 12 x 24 ft (3.7 x 7.37 m) test sample and test apparatus in conjunction with a 1 ft x 4 ft (0.3 m x 1.2 m) vacuum chamber test apparatus. A larger test sample and test apparatus shall be permitted to be used.

B-1.2 The objective of the test is to provide a method of evaluating the uplift resistance of a completed roof assembly and its individual components when applied within a completed assembly.

B-1.3 The test method is intended to be used to determine the simulated wind uplift resistance of the types of roof assemblies shown below.

- standing/lap seam metal roof systems with adhered flexible PV modules ;

B-1.4 The test method is designed to measure the stability of the roof assembly on its supports and to evaluate the ultimate strength of the individual components in the completed roof under static conditions which simulate the uplift loads imposed by wind forces on the roof system.

B-1.5 This standard is not intended to be used to evaluate loose laid ballasted roof assemblies.

B-2 Design of the Test Apparatus

B-2.1 The 12 x 24 ft (3.7 x 7.37 m) Simulated Wind Uplift Test Apparatus is a steel pressure vessel arranged to apply and maintain air pressure at pre-established pressure levels from below the roof assembly (test sample). This roof assembly, when secured in place, forms and seals the top of the pressure vessel.

B-2.2 The pressure vessel shall measure a minimum of 24 ft x 12 ft x 2 in deep (7.3 m x 3.7 m x 51 mm). It shall be fabricated from nominal 8 in. (203 mm) deep steel channel sections as the perimeter structure with nominal 6 in (152 mm) deep steel beams spaced 2 ft ± 1 in (0.6 m ± 25 mm) on center (o.c.) running parallel to the 12 ft (7.3 m) side. Other structural shapes, sizes and materials of construction shall be permitted to be used as long as the frame will provide a rigid base for the test sample. The bottom of the pressure vessel shall be sheathed with a minimum 7 ga (4.8 mm) thick steel plate spot welded to the top of the steel beams and continuously welded to the inside perimeter channels.

B-2.3 The air supply into the sealed vessel is provided by an inlet manifold construction with a nominal 4 in (102 mm) diameter PVC pipe. Four openings, equally spaced, penetrate the bottom steel plate and serve as the air inlet on the bottom of the pressure vessel. A ¼ in ±⅛ in (6.4 mm ± 3.2 mm) opening on the bottom of the vessel serves as the manometer connection. A gasket shall be placed between the top channel of the pressure vessel and the sample construction frame to minimize air leakage when the sample is clamped in place.

B-2.4 Air shall be supplied to the inlet manifold by a Turbo Pressure Blower, or equivalent, having the capability of generating 600 ft^2 /min (17 m^2 /min) or as needed to attain the desired uplift pressure. Pressure readings are obtained from a water filled manometer calibrated to be read directly in lbs/ft^2 (kPa) and capable of being read in minimum increments of 2 lbs/ft^2 (0.1 kPa). As an alternative, other types of pressure measuring devices shall be permitted to be used provided that the alternative device(s) have an equivalent or tighter gradation and tolerance levels.

B-2.5 The 1 x 4 ft (0.3 x 1.2 m)Vacuum Chamber is a wood and/or steel box (pressure vessel), open on the bottom, designed to apply and maintain reduced air pressure at pre-established pressure levels from above the adhered photovoltaic module. The photovoltaic module, when secured in place, forms and seals the bottom of the pressure vessel.

B-2.6 The vacuum chamber is used to exhaust air from above the test sample. The vacuum chamber shall be a nominal 1 ft by 4 ft x 1 ft high (0.3 m by 1.2 m by 0.3 m high) chamber. It shall be sized to fit snuggly over the test sample and be capable of withstanding the anticipated pressures. Air is exhausted from an opening located on one side of the chamber. A ¼ in ±1/8 in (6 mm ± 3 mm) opening on one side of the chamber serves as the manometer connection. A gasket shall be placed between the bottom channel of the vacuum chamber and the top of the test sample to minimize air leakage when the chamber is placed above the sample.

B-2.7 The vacuum chamber shall have interior lighting and a minimum of one window on each long side to allow visual observation of the test sample.

B-3 Test Sample

B-3.1 The components for a test sample are assembled to the desired specifications (thickness, profile and strength of deck or purlins, application method and rate for the adhesives or fasteners, applicable size and thickness of insulation and type of metal panel roof) and shall be permitted to cure under laboratory conditions for a period of time not to exceed 28 days.

B-3.2 When steel decking is used; it shall be secured to a frame capable of withstanding the anticipated loads. This test specimen frame typically includes a structural steel support located along the center line and parallel to the 24 ft (7.3 m) side. In addition, three intermediate structural steel supports are located parallel to the 12 ft (3.7 m) side 6 ft (1.8 m) o.c. The steel deck is then applied parallel to the 24 ft (7.3 m) side. It is welded to the perimeter angle iron with ½ in (13 mm) diameter puddle welds 12 in (305 mm) o.c. along the entire perimeter. In addition, it is fastened at all supports [6 ft (1.8 m) spans for 1½ in (38 mm) deep 22 ga (0.75 mm) steel] 12 in (305 mm) o.c. with fasteners. All deck side laps are fastened with fasteners spaced at a maximum of 30 in (763 mm) o.c. Other structural roof deck assemblies and configurations may be used if requested by the test sponsor. Their application shall be in accordance with the manufacturer's specifications and requirements.

Note 1: The method of securing the steel deck to the test frame shall be permitted to vary when a specific test, as requested by a test sponsor, dictates.

Note 2: When the size of the test frame is different than the minimum size as permitted by Paragraph B-2.2 above, the steel deck shall be installed parallel to the longer dimension.

Note 3: When testing standing seam type roof assemblies, it is permissible to install the panels perpendicular to the long dimension.

B-3.3 When ready for testing, the test specimen frame containing the test sample is placed on the pressure vessel and clamped in place. Clamps shall be permitted to be spaced 24 in ± 6 in (0.6 m ± 0.15 m) on center around the perimeter of the apparatus, or as needed, if excessive air leakage occurs during the test. In addition, the test specimen frame is secured to the pressure vessel as needed with intermediate support clips located near the centerline of the pressure vessel. The appropriate connections are then made to the air supply and the manometer.

B-4 Conduct of Test

B-4.1 Air is introduced from below the sample until the pressure level reaches 15 lbs/ft^2 (0.7 kPa) with a tolerance of +2 lbs/ft^2, -0 lbs/ft^2 (+0.1 kPa, -0 kPa). The air shall be introduced at a rate that will increase the resulting pressure 1.5 lbs/ft^2 /sec ± 1 lbs/ft$^{2\ 2}$/sec (0.07 kPa/sec ± 0.05 kPa/sec). Upon reaching 15 lbs/ft^2 (0.7 kPa), the pressure level shall be maintained for a period of 60 seconds. The 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.

B-4.1.1 Upon mutual agreement between the test sponsor and the testing entity, the 15 lbs/ft^2 (0.7 kPa) pressure level noted above may be omitted. This results in the initial pressure level being 30 lbs/ft^2 (1.4 kPa) with a tolerance of +2 lbs/ft^2, -0 lbs/ft^2 (+1 kPa, -0 kPa). Subsequent pressure increases shall be as described in B-4.2.

B-4.1.2 Depending on the type of roof assembly being tested, it is not always possible to adhere to the 1.5 lbs/ft^2 /sec ± 1 lbs/ft^2 /sec (0.07 kPa/sec ± 0.05 kPa/sec) rate of increase needed to reach the next pressure level. In these situations, the rate of increase between pressure levels shall be conducted as evenly as practical. The 60 second time period required to attain the next pressure level shall not start until the new pressure level has been reached.

B-4.2 After 60 seconds, the pressure level shall be increased in 15 lbs/ft^2 (0.7 kPa) increments by introducing additional air at the rate and within the tolerance described above. Upon reaching the next 15 lbs/ft^2 (0.7 kPa) level, the pressure shall be maintained for a period of 60 seconds. 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. After maintaining this pressure for 60 seconds, the air is allowed to exhaust until no upward pressure is acting on the roof. The sample is again inspected to insure that it continues to meet the Condition of Acceptance. This procedure is repeated with each successive pressure increased by 15 psf (0.7 kPa) increments.

B-4.3 The sequence described in B-4.2 above shall be repeated until the sample reached one half of the expected load at failure from previous testing without adhered flexible PV modules, or at the discretion of the test sponsor.

B-4.4 Prepare the test sample by applying a foam gasket around the 1 x 4 ft (0.3 x 1.2 m) perimeter of the test area. The vacuum chamber is placed on the test area mating the gaskets on the vacuum chamber with the gasket on the test sample. Lights inside the vacuum chamber are turned on.

B-4.5 Connections from the blower to the vacuum chamber and from the manometer to the vacuum chamber are made.

B-4.6 The air exhaust valve from the blower is closed and the blower is turned on and allowed to stabilize.

B-4.7 Air is exhausted by opening the air exhaust valve on the blower until the pressure level in the vacuum chamber reaches 15 lbs/ft^2 (0.7 kPa) with a tolerance of +2 lbs/ft^2, -0 lbs/ft^2 (+0.1 kPa, -0 kPa). The air shall be exhausted at a rate that will increase the resulting pressure 1.5 lbs/ft^2/sec ± 1 lbs/ft^2/sec (0.07 kPa/sec ± 0.05 kPa/sec). Upon reaching 15 lbs/ft^2 (0.7 kPa), the pressure level shall be maintained while the perimeter of the sample is checked to insure that there are minimal air leaks into the vacuum chamber. Adjustments shall be permitted as necessary 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.

B-4.8 Upon mutual agreement between the test sponsor and the testing entity, the 15 lbs/ft^2 (0.7 kPa) pressure level noted above may be omitted. This results in the initial pressure level being 30 lbs/ft^2 (1.4 kPa) with a tolerance of +2 lbs/ft², -0 lbs/ft² (+1 kPa, -0 kPa). Subsequent pressure increases shall be as described in B-4.9.

B-4.9 After 60 seconds, the pressure level shall be increased in 15 lbs/ft² (0.7 kPa) increments by exhausting additional air at the rate and within the tolerance described above. Upon reaching the next 15 lbs/ft² (0.7 kPa) level, the pressure shall be maintained for a period of 60 seconds. The exhaust air shall 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.

B-4.10 The sequence described in B-4.9 above shall be repeated until the sample fails, additional pressure levels 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 (as defined in Section 4.3 of this document) are no longer being met or until the pressure level is no longer able to be maintained.

B-4.11 Upon completion of the test, the sample shall be examined and any item not conforming to the Conditions of Acceptance noted.

B-5 Results

B-5.1 The results of the 12 x 24 ft (3.7 x 7.37 m) Simulated Wind Uplift Pressure Test and 1 x 4 ft (0.3 x 1.2 m) test shall be stated in increments of 15 lbs/ft² (0.7 kPa) of uplift resistance.

B-5.2 The uplift resistance rating shall be the highest level attained by the assembly that was held for the full 60 seconds and continued to meet the Conditions of Acceptance.

APPENDIX C: TEST PROCEDURES

Determining the Susceptibility to Hail Damage of Flexible Photovoltaic Modules

C-1 Introduction

C-1.1 The Hail Damage Test Procedure is designed to assess the potential for damage to a photovoltaic module when adhered or attached directly to a roof assembly. It was developed to determine the potential for to the photovoltaic module resulting from hail storms when the module is applied over its tested substrate.

C-1.2 The objective of the test is to provide a method of evaluating the susceptibility to hail damage of flexible photovoltaic modules when adhered or attached to a roof assembly.

C-2 Design of the Test Apparatus

C-2.1 The **Class 1-SH** test apparatus consists of a section of tubing supported above the sample. A 2 in (51 mm) diameter steel ball weighing 1.19 lb (540 g) is dropped from a height of 141.5 in (3595 mm) onto the sample. This procedure generates impact energy of approximately 14 ft-lb (19 J) over the impact area of the 2 in (51 mm) diameter ball.

C-2.2 The **Class 1-MH** test apparatus consists of a section of tubing supported above the sample. A 2 in (51 mm) diameter steel ball weighing 1.19 lb (540 g) is dropped from a height of 81 in (2055 mm) onto the sample. This procedure generates impact energy of approximately 8 ft-lb (10.8 J) over the impact area of the 2 in (51 mm) diameter ball.

C-2.3 Ultraviolet Weathering Cabinet – a fluorescent ultraviolet condensation-type weathering apparatus using the ASTM G 154 Test Method.

C-3 Test Sample

C-3.1 Two identical roof cover samples measuring a minimum of 12 x 24 in (305 x 610 mm) containing at least one photovoltaic module is selected from the material to be tested:

C-3.1.1 The first sample is prepared with the photovoltaic module applied to the selected substrate in accordance to the manufacturer's specifications. After preparation, the sample is cured for up to 28 days. This unconditioned (unweathered) sample is subjected to impact testing as described in C-4.2 below.

C-3.1.2 The second sample is prepared with the photovoltaic module applied to the selected substrate in accordance to the manufacturer's specifications. The sample is conditioned (weathered) for 1000 hours in an Ultraviolet Weathering Cabinet (described in C-2.3 above). The sample is subjected to impact testing as described in C-4.2 below.

C-4 Conduct of Test

C-4.1 For either Class 1-SH or Class 1-MH testing; position the sample directly below the appropriate Simulated Hail Damage Test Apparatus.

C-4.2 Subject each sample to a series of impacts (ten drops of a steel ball from the appropriate Susceptibility to Hail Damage Test Apparatus (See C-2.1 and C-2.2 above).

C-4.3 Monitor the sample during the test and record the effect of the test on the sample. The sample shall be examined post hail. Failure is considered to occur when the Conditions of Acceptance (as defined in Paragraph 4.4 of this standard) are no longer being met.

C-5 Results

C-5.1 The hail rating shall be stated as either Class 1-SH or Class 1-MH.

APPENDIX D: TEST PROCEDURES

Determining the Heat Aging Affects of Flexible Photovoltaic Modules on Roof Coverings

D-1 Introduction

D-1.1 The Heat Aging Affects of Flexible Photovoltaic Modules on Roof Coverings Test Procedure is designed to assess the potential for damage due to heat aging of roof coverings when a flexible photovoltaic (PV) module is adhered or mechanically fastened through a roof covering.

D-1.2 The objective of the test is to provide a method of evaluating the susceptibility of the roof covering to heat aging when flexible photovoltaic modules when adhered or attached to the roof covering.

D-2 Design of the Test Apparatus

D-2.1 The Forced Hot Air Oven test apparatus consists of an oven with racks that is set at 280±3.6°F (138±2°C). The oven contains racks that have a minimum of 6 x 22 in (152 x 559 mm) sample conditioning area.

D-2.2 The 3 in (76 mm) diameter mandrel test apparatus consists of metal pipe that is 3 in (76 mm) in diameter.

D-2.3 A calibrated infrared thermometer capable of measure the surface temperature of the test sample.

D-3 Test Sample

D-3.1 One roof cover sample measuring a minimum of 6 x 22 in (152 x 559 mm) is selected from the material to be tested:

D-3.1.1 The test sample is a piece of the roof cover only. Photovoltaic modules shall not be applied to the surface of the roof cover.

D-4 Conduct of Test

D-4.1 Place the sample described in D-3.1 into the forced hot air oven at 280±3.6°F (137±2°C). Take care to insure that the test sample is laying flat in the racks. Parchment paper, aluminum foil or other means are permitted to be used under the sample to prevent the sample from sticking to the racks.

D-4.2 After the test sample has been in the oven for 60 days remove the sample from the oven and allowed to cool to laboratory conditions as follows: after the test sample surface temperature (measured with an infrared thermometer) has returned to a temperature of 73.4±3.6°F (23±2°C), the bend test is conducted.

D-4.3 Additional test samples shall be permitted to be placed in the test environment and evaluated prior to the 60 day time frame at the client's request.

D-4.4 The test sample is bent over the 3 in (76 mm) diameter mandrel with the top surface of the roof cover facing outward and held in that position during the sample inspection. The sample shall be monitored during the test and the effect of the test on the sample shall be recorded. The sample shall be viewed under 10x magnification. Failure is considered to occur when the Conditions of Acceptance (as defined in Section 4.5 of this standard) are no longer being met.

D-5 Results

D-5.1 The test sample shall be given a passing rating if it meets the Conditions of Acceptance.

APPENDIX E: TEST PROCEDURES

Pull Out Tests for Fastener/Roof Deck Combinations Using Tensile Loading

E-1 Introduction

E-1.1 The Pull Out Tests for Fastener/Roof Deck Combinations Using Tensile Loading Test Procedure is designed to assess the pull out strength of fasteners into various roof decks by using tensile loading.

E-2 Design of the Test Apparatus

E-2.1 The Tinius Olsen machine utilizes two screw threads to move the support platform in a vertical direction. Various test jaws can be inserted into the stationary portion to secure the test sample. The Tinius Olsen machine is connected to a computer with a data acquisition program which captures the data, creates graphs of the output and can average sets of data produced.

E-2.2 The test jigs included two solid metal plates made of minimum 0.5 in (13 mm) thick steel. The plates are a minimum 6 x 6 in (150 x 150 mm), one with a 0.5 in (13 mm) diameter hole in the center and the other with a 1 in 925 mm) diameter hole in the center. The plates must be strong enough to resist bending or deformation during the test.

E-3 Test Sample

E-3.1 The test sample consists of a minimum 6 x 6 in (150 x 150 mm) piece of the decking to be evaluated with the fasteners screwed into the center of the sample

E-4 Conduct of Test

E-4.1 When ready for testing, the fastener of the test sample to be evaluated is placed through the hole in the test jig. The test jig is then placed on the underside of the opening in the stationary platform with the fastener head facing down. The fastener tip is then secured in the Tinius Olsen stationary jaw. Zero the Tinius Olsen machine to clear data before the first sample is tested.

E-4.2 Force is exerted in a direct line perpendicular to the plane of the test jig and stress plate, batten bar or roof deck interface at a crosshead speed of 2 in./min (51 mm/min). While the sample is being tested, the sample shall be visually examined to ensure that it continues to meet the Conditions of Acceptance.

E-4.3 Continue the testing described in E-4.2 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 (as defined in Section E-5 of this document) are no longer being met or until the tensile force is no longer able to be maintained.

E-4.4 Upon completion of the test, the sample shall be examined and any item not conforming to the Conditions of Acceptance noted.

E-5 Conditions of Acceptance

E-5.1 The surface of the test jig shall remain flush with the surface of the moving crosshead.

E-6 Results

E-6.1 The result shall be the highest force attained by the sample during the test.

E-6.2 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 (2) additional tests shall be conducted to bring the standard deviation of all values divided by the mean to less than, or equal to, 20%. If after five (5) tests the standard deviation of all five (5) values divided by the mean remains greater than 20%, the results of all five (5) tests shall be used to determine the final average.