American National Standard
for
Roof Mounted
Rigid Photovoltaic Modules

ANSI/FM Approvals 4478-2014
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Foreword

NOTE: This foreword is introductory only and is not part of American National Standard FM 4478.

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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1 INTRODUCTION

1.1 Purpose

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

1.2 Scope

1.2.1 This standard applies to all rigid photovoltaic modules intended to be 1) mechanically fastened through or adhered to a single-ply, polymer-modified bitumen sheet, built-up roof, liquid applied roof cover or steep slope roof, 2) mechanically fastened or adhered to a metal roof cover assembly using clamps or other types of fasteners, adhesive or welding or 3) loose laid and ballasted over a fully adhered single-ply, polymer-modified bitumen sheet or built-up roof cover assembly.

1.2.2 This standard also applies to panels 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.

1.2.3 The standard is intended to evaluate only those hazards investigated and is not intended to determine suitability for the end use of a product.

1.2.4 This standard evaluates rigid photovoltaic modules for their performance in regard to fire from above the structural deck, simulated wind uplift, susceptibility from hail storm damage, and seismic performance requirements.

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

1.2.6 This standard does not apply to flexible 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:

ASTM International

- *Fire Tests of Roof Coverings,* ASTM E108

- *Standard Specification for Concrete Roof Pavers,* ASTM C1491

American National Standard Institute

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

American Iron and Steel Institute

- *North American Specification for the Design of Cold-Formed Steel Structural Members, 2007 Edition*, AISI S100-200

American Society of Civil Engineers

- *Minimum Design Loads for Building and Other Structures*, Standard ASCE/SEI 7-05

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

Ballast – for the purposes of this document, the only acceptable ballast shall be concrete paver blocks.

Coefficient of Friction – The ratio of the force that maintains contact between an object and a surface and the frictional force that resists the motion of the object.

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. For insulation boards, often a crack will form on the opposite face.

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.

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

Fasteners - A fastener is a mechanical securement device used alone or in combination with other components such as 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.

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 components 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.

Permanent Deformation—Any displacement 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 displacement shall not be considered permanent deformation.

Photovoltaic Module – A device that converts solar energy into electricity using the photovoltaic effect.

Rigid Photovoltaic Module –An arrangement of photovoltaic cells or material, mounted on a surface and/or in a frame that are not able to be bent or flexed without damage with the cells exposed freely to incoming sunlight.

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.

Service Wind Load – The uplift load resulting from a windstorm that a roof assembly must resist. The service load is equal to one half of the rated load in psf (kPa).

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 metal tabs, is roll-formed into the panel seam.

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.

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 modules are submitted in panels or a panel array. They can be installed using either mechanical fasteners, clips, mounting brackets, adhesives, loose laid and/or ballasted.

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.

3.6 Seismic Loads

Rigid photovoltaic modules, installed at locations within Zones 50 year, 100 year, 250 year or 500 year, shall be designed in accordance the Design Procedure for Seismic Design of Rigid Photovoltaic Modules to withstand the seismic loading experienced in these areas. Rigid photovoltaic modules located in >500 year zones are considered non-seismic and do not require analysis for seismic design. The design shall be certified by a Professional Engineer competent in this area of practice. Calculations shall be submitted to verify compliance with design requirements for the range of rigid photovoltaic modules.

The 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 for a base shear coefficient (acceleration). 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. A seismically rated rigid photovoltaic module can be erected in earthquake zones 50- through 500-year as long as the rated base shear coefficient is greater than the design base shear coefficient calculated according to this standard. 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 should, 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 10% of the 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.

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. Equal to zero for a ground supported rigid photovoltaic module.
h – total height of the supporting structure measured from the ground, in feet.
$\bar{h}$ – 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. Calculated using $M_p = F_p \cdot \bar{h}$

3.6.3 Base Shear Coefficient

The seismic base shear coefficient shall be calculated as follows:

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

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

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

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 (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_{DS} shall be the 475-year return period value of 0.2 second period 5% damped "firm" rock spectral acceleration adjusted for local soil conditions, or two-thirds of the 2,475 return period value of 0.2 second period, 5% damped "firm" rock spectral acceleration adjusted for local soil conditions.

Table 1. Suggested values of the 0.2 second short-period 5% damped spectral acceleration for various Zones

Zone	S_{DS}
50-year	1.3 g
100-year	0.9 g
250-year/500-year	0.55 g

3.6.5 Design Loads for Supporting Structure

The design base shear is calculated as follows:

$$F_p = A_p \cdot W_p \quad (3)$$

The design overturning moment is calculated as follows:

$$M_p = F_p \cdot \bar{h} \quad (4)$$

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.

4 PERFORMANCE REQUIREMENTS

This standard is intended to evaluate a rigid 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 seismic performance requirements.

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 and/or rigid photovoltaic module shall be in accordance with ASTM E108, Fire Test of Roof Coverings. Two conditions are evaluated: 1. Tests are run with the top surface of the roof cover at the eave height of the apparatus; 2. Tests are run with the top surface of the rigid photovoltaic module at the eave height of the apparatus. If different ratings are obtained from each test, the lower rating is granted to the completed assembly. In both cases the leading edge of the PV module is placed flush with the leading edge of the test sample.

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 or rigid photovoltaic module 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 Rigid Photovoltaic Module with the Panel Attached at the Same Slope as the Roof Cover

For wind uplift resistance, the rigid photovoltaic module is tested using two methods. These two methods are simulated wind uplift pressure test with the photovoltaic module attached to a test frame using a pleated air bag and tensile loading of the fasteners/clips. The rating assigned to the assembly shall be the lower 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 Test Procedure, Appendix B. The minimum rating granted shall be 60 psf (0.7 kPa). Ratings shall be stated in 15 lbs/ft^2 (0.7 kPa) increments.. The maximum rating available is 990 psf (11.6 kpa). The rating assigned to the assembly shall be the maximum simulated uplift pressure which the assembly maintained for one (1) minute without failure.

<u>In addition, the assembly must maintain one-half the service wind load for one (1) minute without visible cracking or visible creasing.</u>

- Multiple cracks in the same component, which would impair performance is indicative of catastrophic 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 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 fasteners and 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 or within themselves (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 and/or plates and batten bars is allowed up to ultimate failure provided water-tightness (roof cover) is maintained or ultimate failure (rigid photovoltaic module) does not occur; 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, or allow for fastener withdrawal.

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 exceptions given above.

4.2.2 Pull Out and Pull Through Tests for Photovoltaic Clamp/Frame Combinations, Pull Through Tests for Photovoltaic Frame/Fastener Combinations and Pull Out Tests Fastener/ Roof Deck Combination

Testing for simulated wind uplift resistance shall be in accordance with Test Procedure, Appendix B. The minimum rating granted shall be 60 psf (0.7 kPa). Ratings shall be stated in 15 lbs/ft^2 (0.7 kPa) increments.. The maximum rating available is 990 psf (11.6 kpa). The rating assigned to the assembly shall be the maximum simulated uplift pressure which the assembly maintained for one (1) minute without failure.

4.2.2.1 Conditions of Acceptance for Pull Out and Pull Through Tests for Photovoltaic Clamp/Frame Combinations, Pull Through Tests for Photovoltaic Frame/Fastener Combinations Pull Out Tests Fastener/ 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. The results of all tests 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 rigid photovoltaic module will be divided by the total number fasteners/clamps used to secure the module, the result will be the contributory area for each fastener/clamp in ft^2 (m^2). The 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 with the Panel Attached at a Different Slope than the Roof Cover.

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 bag and tensile loading of the fasteners/clips. The rating assigned to the assembly shall be the lower rating obtained during all testing.

4.3.1 Rigid Photovoltaic Simulated Wind Uplift Pressure Test

Testing for simulated wind uplift resistance shall be in accordance with Test Procedure, Appendix B. The minimum rating granted shall be 60 psf (0.7 kPa). Ratings shall be stated in 15 lbs/ft^2 (0.7 kPa) increments.. The maximum rating available is 990 psf (11.6 kpa). The rating assigned to the assembly shall be 80% of the maximum simulated uplift resistance pressure which the assembly maintained for one the maximum simulated uplift pressure which the assembly maintained for one (1) minute without failure. The sample will be tested with pressure loads beginning at 40 psf (1.92 kPa) increasing the tested sample in 20 psf (0.96 kPa) increments.

<u>In addition, the assembly must maintain the service load for one (1) minute without visible cracking or visible creasing.</u>

- Multiple cracks in the same insulation board or component, which would impair performance is indicative of catastrophic 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.

4.3.1.1 Conditions of Acceptance for Rigid Photovoltaic Simulated Wind Uplift Pressure Test are as follows:

4.3.1.1.1 Conditions of Acceptance are identical to those outlined in 4.2.1.1.

4.3.2 Pull Out and Pull Through Tests and Conditions of Acceptance are per 4.2.2.

4.4 Wind Uplift Resistance for Rigid Photovoltaic Module Loose Laid and Ballasted.

For wind uplift resistance for loose laid and ballasted assemblies, the rigid photovoltaic module are evaluated using the methods described in Appendix D.

4.4.1 Rigid Photovoltaic Simulated Wind Uplift Evaluation

Three ratings are available: 60 psf (2.9 kPa); 75 psf (3.6 kPa) and 90 psf (4.3 kPa). These systems shall only be used as loose laid and ballasted over fully adhered single ply, BUR, Liquid Applied or Modified bitumen roof covers.

4.4.1.1 Conditions of Acceptance for Rigid Photovoltaic Loose Laid and Ballasted - Prescriptive Method

4.4.1.1.1 The combined average uniform weight of the photovoltaic module, racking, concrete paver blocks and all components shall be equal to, or greater than, the loads outlined in the table in Appendix D.

4.5 Hail Damage Resistance Test

Testing for hail damage resistance shall be in accordance with Test Procedure, Appendix E. The minimum rating required is Class 2.

4.5.1 Conditions of Acceptance for Hail Damage Resistance

4.5.1.1 The photovoltaic module shall show no signs of cracking, splitting, separation, or rupture when examined under 10X magnification.

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

AREA:

in^2 -“square inches”; (mm^2 -“square millimeters”)

$mm^2 = in^2 \times 6.4516 \times 10_2$

ft^2 –‘‘square feet’’;(m^2 -‘‘square meters’’)

$m^2 = ft^2 \times 0.0929$

APPENDIX B: Test Procedures

Wind Uplift Resistance for Rigid Photovoltaic Modules

B-1 Introduction

B-1.1 The 12 x 24 ft (3.7 x 7.37 m) Simulated Wind Uplift Pressure Test Procedure and 5 x 9 ft (1.5 x 2.7 m) Wind Uplift Tests for Rigid Photovoltaic Modules are designed to evaluate the performance of rigid photovoltaic modules 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 or 5 x 9 ft (1.5 x 2.7 m) test sample. A larger test sample and test apparatus shall be permitted to be used.

B-1.1.1 The 5 × 9 ft (1.5 x 2.7 m) Simulated Wind Uplift Test Procedure shall be permitted to be used to evaluate various types of roof assemblies **except** those noted below. The Simulated Wind Uplift Resistance Rating obtained using this procedure shall be limited to a maximum of 90 lbs/ft^2(4.3 kPa).

- assemblies with batten or fastener row spacing in excess of 4 ft (1.2 m) on center
- assemblies with fasteners (spot or grid affixed) spaced greater than 2 ft × 4 ft (0.6 m × 1.2 m) on center
- assemblies with a contributory fastener area greater than 8 ft^2 (0.7 m^2) per fastener
- assemblies that incorporate an air barrier
- assemblies that utilize structural concrete, lightweight insulating concrete, fiber reinforced cement or gypsum roof decks
- standing/lap seam metal roof systems

B-1.1.2 12 × 24 ft (3.7 x 7.37 m) Simulated Uplift Test Procedure shall be used to evaluate roof assemblies when the methods shown above are not applicable.

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-1.4 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.

12x24 ft (3.7 x 7.37 m) Simulated Wind Uplift Pressure Test

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 test sample.

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-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 roof) and shall be permitted to cure under laboratory conditions for a period of time not to exceed 28 days.

B-3.1.1 Construction of the roof assembly (except for the deck) shall be excluded from the test sample if both of following conditions are met:

- Roof cover is fully adhered.
- The rigid photovoltaic module is mechanically fastened through the roof cover to the structure, purlins or deck.

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 Prior to installing the rigid photovoltaic modules, a minimum 0.006 in. (0.15 mm) thick polyethylene sheet or unreinforced EPDM is positioned in the frame so that all loads may be carried directly by the photovoltaic modules.

B-3.4 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 psf (0.7 kPa) for 4.2 tests or 40 psf (1.9 kPa) for 4.3 tests 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 the target pressure, 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 psf (0.7 kPa) pressure level noted above may be omitted. This results in the initial pressure level being 30 psf (1.4 kPa) for 4.2 tests. Subsequent pressure increases shall be as described in B-4.2.

B-4.1.2 Depending on the type of 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 psf (0.7 kPa) or 20 psf (0.9 kPa) increments by introducing additional air at the rate and within the tolerance described above. Upon reaching the next 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) or 20 psf (0.9 kPa) increments.

B-4.3 The sequence described in B-4.2 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 4.2 and 4.3 of this document) are no longer being met or until the pressure level is no longer able to be maintained.

B-4.4 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 shall be stated in increments of 15 psf (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. In the case of Section 4.3 tests, rounding down to the nearest multiple of 15 may be required.

5x9 ft (1.5 x 2.7 m) Simulated Wind Uplift Pressure Test

B-6 Design of the Test Apparatus

B-6.1 The intermediate-scale 5 × 9 ft (1.5 x 2.7 m) Simulated Wind Uplift Pressure Test Apparatus is a steel pressure vessel arranged to apply air pressure at pre-established standard rates from below the test sample which forms the top of the test apparatus.

B-6.2 The pressure vessel measures 5 ft ± ½ in. × 9ft ± 1 in. (1.5 m ±13 mm × 2.7 m ± 25 mm). It shall be a minimum of 2 in. (51 mm) deep and be fabricated from structural steel channels as the perimeter structure. The bottom of the pressure vessel shall be sheathed with a steel plate sealed with a continuous weld to the perimeter channels.

B-6.3 The test specimen frame, containing the installed roof assembly, is placed on the pressure vessel and is sealed by a gasket located between the top of the pressure vessel and the bottom of the test specimen frame. Contact between the pressure vessel and the test sample frame is made at the perimeter.

B-6.4 The air supply for the sealed vessel is provided by an inlet manifold construction with a nominal 4 in. (102 mm) PVC pipe. The opening shall be centered along one of the long dimensions of the apparatus [±3 in. (± 76 mm)] and be 12 in. ± 3 in. (305 mm ± 76 mm) from the edge of the apparatus. A ¼ in. ±1⁄16 in. (6 mm ± 1.6 mm) opening on the opposite 9 ft (2.7 m) side, located 1½ in. ± ½ in. (38 mm ± 13 mm) from the edge of the apparatus, serves as the manometer connection. A gasket that lies between the top channel of the pressure vessel and the test sample construction frame minimizes air leakage when the sample is clamped in place.

B-6.5 Air is supplied to the manifold from a Turbo Pressure Blower or equivalent having the capacity to generate 200 ft^2/min (0.09 m^2/s), or as needed to attain the desired uplift pressure. The inlet air flow is regulated and air is exhausted by manually-operated 4 in. (102 mm) diameter butterfly valves. Pressure readings are obtained from a liquid-filled (SG = 1.0) manometer calibrated to be read directly in lbs/ft^2 (kPa) and capable of being read in minimum increments of 2 lbs/ft^2 (0.1kPa). As an alternative, other types of pressure reading devices shall be permitted to be used provided that the alternative device(s) have an equivalent or tighter gradation and tolerance levels.

B-7 Test Sample

B-7.1 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 roof) and shall be permitted to cure under laboratory conditions for a period of time not to exceed 28 days.

B-7.1.1 Construction of the roof assembly (except for the deck) shall be excluded from the test sample if both of following conditions are met:

- Roof cover is fully adhered.
- The rigid photovoltaic module is mechanically fastened through the roof cover to the structure, purlins or deck.

B-7.2 Prior to installing the rigid photovoltaic modules, a minimum 0.006 in. (0.15 mm) thick polyethylene sheet or unreinforced EPDM is positioned in the frame so that all loads may be carried directly by the photovoltaic modules.

B-7.3 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-8 Conduct of Test

B-8.1 test is conducted in an identical manner as described in B-4.

B-9 Results

B-9.1 The results of the 5 × 9 ft (1.5 x 2.7 m) Simulated Uplift Pressure Test shall be stated in increments of 15 lbs/ft^2 (0.7 kPa) of uplift resistance, up to, and including, a maximum of 90 lbs/ft^2 (4.3 kPa).

B-9.2 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. In the case of Section 4.3 tests, rounding down to the nearest multiple of 15 may be required.

APPENDIX C: Test Procedures

Pull Out and Pull Through Tests for Photovoltaic Clamp/Frame Combinations, Pull Through Tests for Photovoltaic Frame/Fastener Combinations and Pull Out Tests Fastener/ Roof Deck Combinations Using Tensile Loading

C-1 Introduction

C-1.1 The Pull Out/Pull Through Tests for Rigid Photovoltaic Clamp/ Photovoltaic Frame Combinations Test Procedure is designed to assess the pull out/pull through strength of the clamps or other attachment component used to secure the rigid photovoltaic module to the frame or racking system using tensile loading.

C-1.2 The Pull Through Tests for Photovoltaic Frame/Fastener Combinations Test Procedure is designed to assess the strength of the photovoltaic frame or racking system in resisting pull though of the fasteners using tensile loading.

C-1.3 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.

C-2 Design of the Test Apparatus

C-2.1 Any load testing equipment capable of the loads and strain rates is acceptable.

C-2.2 Clamp Pull Out and Pull Through: The test jig is made of steel and is capable of securing the photovoltaic clamps, mounting brackets, frame or racking system. The test jib must be strong enough to resist bending or deformation during the test.

C-2.3 Fastener Pull Out: 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. (25 mm) diameter hole in the center.

C-3 Test Sample

C-3.1 Clamp Pull Out of Frame: The test sample consists of a minimum of one full clamp and a section of the photovoltaic frame large enough to secure to the apparatus.

C-3.2 Clamp Pull Through of Fastener: The test sample consists of a minimum of one full clamp and the fastener to be evaluated.

C-3.3 Fastener Pull Out: 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 secured into the center of the sample

C-4 Conduct of Test

C-4.1 When ready for testing:

C-4.1.1 Clamp Pull Out of Frame: The clamp or mounting bracket of the test sample to be evaluated is placed on the section of frame or racking system. The frame and clamp are secured using separate test jigs described in C-2.2. The test jig securing the frame is secured to one stationary jaw of the tensile machine while the test jig securing the clamp is secured to the other end of the tensile machine.

C-4.1.2 Clamp Pull Through of Fastener: The clamp or mounting bracket of the test sample is secured using the test jigs described in C-2.2. 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 tensile machine stationary jaw.

C-4.1.3 Fastener Pull Out 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 tensile machine stationary jaw.

C-4.2 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).

C-4.3 Continue the testing described in C-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 C-5 of this document) are no longer being met or until the tensile force is no longer able to be maintained.

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

C-5 Conditions of Acceptance

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

C-6 Results

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

C-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.

APPENDIX D: Table For Prescriptive Wind Uplift Ratings

D-1 Ballast Requirements:

Table D.1 Combined Needed Equivalent Average Weight of Panels, Racking & Pavers

Roof Uplift Rating	Combined Average Uniform Weight psf (kg/m2)	Minimum Array Area (ft2)	Minimum Coefficient of Friction (μ)
Class 1-60	8 (39)	1000	0.75
Class 1-60	8 (39)	1650	0.65
Class 1-60	8 (39)	2500	0.50
Class 1-75	10 (49)	1000	0.75
Class 1-75	10 (49)	1650	0.65
Class 1-75	10 (49)	2500	0.50
Class 1-90	12 (59)	1000	0.75
Class 1-90	12 (59)	1650	0.65
Class 1-90	12 (59)	2500	0.50

The above criteria shall only be for rigid photovoltaic module systems and racking system that are constructed in a rigid interlocking array such that the connection from a single panel is capable of transferring vertical load to each panel it is directly connected to distribute the combined average uniform weight from the Table D.1. The minimum area of the rigid interlocking array shall be 1000 ft^2 (92.9 m^2). The ballasted photovoltaic modules shall be limited to a maximum slope of 15%. Ballasted photovoltaic modules shall only be used over fully adhered single ply, BUR, Liquid Applied or Modified bitumen roof covers with a roof slope equal to 0.25 in 12.

D-2 Ballast tray or pedestals shall be designed to prevent sliding of concrete paver blocks in all directions. This shall be accomplished using either of the following methods:

D-2.1 By extending the vertical edges of ballast trays above the lower edge of the highest paver.

D-2.2 Installing concrete pavers that interlock to the pedestals.

D-3 Concrete paver block requirements:

D-3.1 Concrete paver blocks must have a minimum plan area of 128 in^2 (0.093 m^2).

D-3.2 Concrete paver blocks must be a minimum of 9 lbs (4.1 kg).

D-3.3 Concrete paver blocks must have a minimum unit weight of 10 psf (48.8 kg/m^2).

D-3.4 Concrete paver blocks must meet ASTM C1491.

D-4 Sliding resistance requirements:

D-4.1 Coefficient of friction between the roof cover and the photovoltaic modules or racking system shall be measured per ASTM D1894

D-4.2 Coefficient of friction described above as measured per ASTM D1894 shall be per table D.1.

D-5 Wind deflector requirement:

D-5.1 Wind deflectors shall be provided on the high edge of each row of photovoltaic panels.

APPENDIX E: Test Procedures

Determining the Susceptibility to Hail Damage of Rigid Photovoltaic Modules

E-1 Introduction

E-1.1 The Hail Damage Test Procedure is designed to assess the potential for damage to a rigid photovoltaic module. It was developed to determine the potential for to the photovoltaic module resulting from hail storms when the module is installed over its tested substrate.

E-1.2 The objective of the test is to provide a method of evaluating the susceptibility to hail damage of rigid photovoltaic modules when installed over a roof assembly.

E-2 Design of the Test Apparatus

E-2.1 **Ice Ball Launcher** – a device capable of propelling ice balls at speeds necessary to develop intended kinetic energy. The device utilizes flex bands to launch ice balls in a range of diameters and at speeds appropriate for simulated hailstone impact testing. Aiming accuracy of the launcher must be sufficient to assure that the ice balls strike the specified target impact areas; otherwise, the surrounding area must be masked for protection against inadvertent impacts.

E-2.2 **Ice Ball Molds –** devices used for casting spherical ice balls of appropriate diameters.

E-2.3 **Speed Meter –** a device capable of measuring the velocity of ice balls within ± 1 mph (0.45 m/s).

E-3 Test Sample

E-3.1 Test Sample - At least one rigid photovoltaic module and mounting system if the mounting system is exposed above the module.

E-3.2 Ice Ball Preparation - Molds of water for casting spherical ice balls of 1-1/2, 1-3/4, and 2 in. (31.8, 38.1, 44.5 and 50.8 mm) diameters are placed in a freezer at a controlled temperature of -7° ± 7°F (-22 ± 4°C) until frozen solid (a minimum of 48 hours). Acceptable ice balls will be free of cracks and air bubbles and will meet the following criteria within +/- 10% of the values listed:

Class	Nominal ice ball diameter (in. [mm])	Mass (lbs [gr])
2	1-1/2 [38.1]	0.0584 [26.5]
3	1-3/4 [44.5]	0.0928 [42.1]
4	2 [50.8]	0.1385 [62.9]

E-3.2.1 Ice Balls shall be molded as follows:

- The bottom half of the room temperature mold is filled to a point just below the top edge with water.
- The top half of the mold is placed on the bottom, gently pressing the pieces together.
- The mold is placed in the freezer overnight.
- Using ice water; perform the second fill by placing a small amount of water into the mold very slowly three times. Between pours allow a brief time period to prevent cracking. The fill the mold to approximately 90%.
- The mold is placed in the freezer for a minimum of 6 hours.
- Using ice water, completely fill the mold.
- The mold is placed in the freezer for a minimum of 2 hours.

- Remove ice balls by gently separating the mold.

E-4 Conduct of Test

E-4.1 Position the test sample so the trajectory of the ice ball is perpendicular (90° ± 5 degrees) to the test panel.

E-4.2 Determine and identify target impact locations of the test specimen that are particularly sensitive to impact damage using the table below.

Impact location #	Location
1	A corner of the module, not more than 2 in. (51 mm) from either edge
2	An edge of the module, not more than 0.5 in. (13 mm)
3-5	Randomly in the middle of the module (at points that are most vulnerable to hail damage)

E-4.3 Launch an ice ball at a target impact point based upon examination of vulnerability. Each target location shall be impacted twice, with a maximum 0.5 in. (13 mm) distance between impacts. Impact locations will include, but are not limited to edges, corners, unsupported areas, overlaps and joints. The outside edge of the ice ball shall be a minimum 1/4 in. (6.4 mm) from the edge of the test specimen. Provide a minimum 6 in. (152 mm) distance between impact locations so that the effects of each impact location are independent.

E-4.4 Record the mass of the ice ball with a calibrated scale, the speed of each Ice Ball with the calibrated Speed Meter, and calculate the kinetic energy of each ice ball impact using the following equation:

$$KE = (mV_t^2)/64.34$$

Where: KE = ice ball kinetic energy (foot pound)

The kinetic energy must be equal to or greater than the impact kinetic energy shown below:

Class	Nominal Ice Ball Diameter (in. [mm])	Kinetic Energy (ft-lb [j])
2	1-1/2 [38.1]	7.77 [10.4]
3	1-3/4 [44.5]	14.95 [20.3]
4	2 [50.8]	26.81 [36.4]

E-4.5 After impact testing, visually scrutinize top and bottom surfaces of the test specimen. Record any damage to the specimen such as splits, punctures, fractures, disengagement of lap elements, exposure of materials not so intended, etc.

E-4.6 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 4.5.1 of this standard) are no longer being met.

E-5 Results

E-5.1 The hail rating shall be stated as Class 2, Class 3 or Class 4.