Designation: E2766 – 13

Standard Practice for Installation of Roof Mounted Photovoltaic Arrays on Steep-Slope Roofs[1]

This standard is issued under the fixed designation E2766; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice details minimum requirements for the installation of roof mounted photovoltaic arrays on steep-sloped roofs with water-shedding roof coverings. These requirements include proper water-shedding integration with the roof system, material properties, flashing of roof penetrations, and sufficient anchoring per regional design load requirements.

1.1.1 This practice does not apply to building-integrated or adhesively attached photovoltaic systems that are applied as roof-covering components.

1.2 This practice does not cover the electrical aspects of installation.

1.3 Installation considerations are divided into two distinct aspects: the interface between the photovoltaic module and the array mounting structure, and the interface between the array mounting structure and the roof or roof structure.

1.4 Safety and hazard considerations unique to this application, such as worker fall protection, electrical exposure, accessibility of modules, and roof clearance around the perimeter of the array are addressed by other codes, standards, or authorities having jurisdiction.

1.5 This practice is intended to provide recommended installation practices for use by installers, specifiers, inspectors, or for specification by photovoltaic module manufacturers.

1.6 This practice provides minimum guidelines and should be used in conjunction with module and mounting system manufacturers' instructions. This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice may be applicable in all circumstances. This ASTM Standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title means only that the document has been approved through the ASTM consensus process.

1.7 This practice is not intended to replace or supersede any other applicable local codes, standards or Licensed Design Professional instructions for a given installation.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific hazards are given in Section 8.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1079 Terminology Relating to Roofing and Waterproofing

D1761 Test Methods for Mechanical Fasteners in Wood

E136 Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C

E772 Terminology of Solar Energy Conversion

2.2 *AAMA Standards:*[3]

AAMA 800 Voluntary Specifications and Test Methods for Sealants

2.3 *ASCE Standards:*[4]

ASCE 7 Minimum Design Loads for Buildings and Other Structures

2.4 *IEC Standards:*[5]

IEC 61730–1 (2004–10) Photovoltaic (PV) Module Safety Qualification–Part One: Requirements for Construction

[1] This practice is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.09 on Photovoltaic Electric Power Conversion.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Architectural Manufacturers Association (AAMA), 1827 Walden Office Sq., Suite 550, Schaumburg, IL 60173, http://www.aamanet.org.

[4] Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, http://www.asce.org.

[5] Available from International Electrotechnical Commission (IEC), 3, rue de Varembé, P.O. Box 131, CH-1211 Geneva 20, Switzerland, http://www.iec.ch.

2.5 *UL Standards:*[6]
UL 1703 Standard for Flat-Plate Photovoltaic Modules and Panels
UL 746C Polymeric Materials—Use in Electrical Equipment Evaluations
UL 60950–1 Table J.1 Electrotechnical Potentials (V)

2.6 *Other Standards:*
IBC International Building Code[7]
IEC International Electrical Code[7]
IFC International Fire Code[7]
NFPA 1 Fire Protection Code[8]
NDS National Design Specification for Wood Construction[9]

3. Terminology

3.1 *Definitions:* Definitions of terms used in this standard may be found in Terminology D1079 and E772.

3.1.1 *steep-slope, adj—in roofing*, that which commonly describes an incline of a roof which is greater than 25 % (14° or 3:12 vertical rise to horizontal run). D1079.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *array mounting structure, n*— all structural and mechanical materials used to support and anchor the photovoltaic modules on the roof system between the attachment system and the roof deck.

3.2.2 *attachment system, n*—all structural and mechanical materials used to support and anchor the photovoltaic modules to the array mounting structure.

3.2.3 *design life, n*—the period of time during which a system component is expected to perform its intended function, without significant degradation of performance and without requiring major maintenance or replacement. **E772**

3.2.4 *licensed design professional, LDP, n*—an individual licensed to approve structural designs in the state or jurisdiction where the roof mounted photovoltaic array will be installed.

3.2.5 *representative section, n*—one or more modules connected to an array mounting structure utilizing the same connecting devices as would be used in an installation.

4. Significance and Use

4.1 With the rapid growth of the use of photovoltaic systems in buildings, roof mounted arrays continue to be one of the most prevalent forms of installations. These roof mounted arrays typically feature penetrations into the roof system, which can result in water leakage issues if not properly flashed or applied to the roof system.

4.2 Structural integrity and durability of the application of the roof mounted array to the roof system must be adequate per applicable codes and regulations. This applies to both the photovoltaic module-to-array mounting structure interface and the array mounting structure-to-roof interface.

4.3 The installation of roof mounted arrays presents certain hazards that must be addressed, which include fall protection, carrying loads up ladders, wind and rain exposure during installation, and electrical exposure during connections.

4.4 The topics covered in 4.1 through 4.3 are potentially a significant barrier to broad acceptance of roof mounted photovoltaic systems if not adequately addressed.

5. Material Requirements

5.1 *Design Life Alignment between the Array and the Roof*—In many cases, the design life of the photovoltaic array may be significantly longer than the estimated design or remaining life of the roof covering. The condition of the roof structure and surface shall be evaluated to determine whether it is sufficient to meet the design life of the roof mounted array. Consultation with a roofing professional and building owner is recommended.

5.2 *Design Life (Exposure and Durability) of Array Mounting Structure*—Materials used in the array mounting structure shall be selected such that the expected design life of the array mounting structure is no less than the design life of the photovoltaic modules. Test data from similar exposure applications is acceptable.

5.2.1 Polymeric based materials used in the array mounting structure shall maintain structural integrity through expected thermal exposure. Any polymeric materials in the structure shall have a relative thermal index (RTI), as defined in UL 746C, of at least 90°C. The thermal resistance of any polymeric material in direct contact with the module shall be specified by the module manufacturer.

5.3 *Adhesive Sealant Requirements:*

5.3.1 *Adhesives Used in Structural Elements*—Bond strength must be sufficient to withstand structural loading as determined by 6.1 and be durable through the expected design life of the array mounting structure. The structural integrity of the bond joining the components of the mounting structure to the array (or to each other) shall be verified through system testing per the structural requirements detailed in Section 6.

5.3.2 *Adhesives Used in Non-Structural Bonding*—Sealants (such as for glazings or other components) must be verified to meet the criteria for exterior perimeter sealants set forth in Section 808.3 of AAMA 800.

5.4 *Corrosion of Resistance of Metals:*

5.4.1 Dissimilar metals in direct contact may corrode. Use appropriate precautions per UL 60950-1 Table J.1 Electrochemical Potentials (V).

5.4.2 Requirements for the array mounting structure shall be the same as the corrosion requirements for the module as set forth in UL 1703 Sections 37 and 14 and Section 4.2 in IEC 61730-1.

5.5 *Material Combustibility*—Where applicable by local jurisdiction fire code, materials used for the array mounting structure to the roof shall be made of non-combustible material per the requirements set forth in Test Method E136. If not

[6] Available from Underwriters Laboratories (UL), 2600 N.W. Lake Rd., Camas, WA 98607-8542, http://www.ul.com.
[7] Available from International Code Council (ICC), 500 New Jersey Ave., NW, 6th Floor, Washington, DC 20001, http://www.iccsafe.org.
[8] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, http://www.nfpa.org.
[9] Available from the American Wood Council, http://www.awc.org

specified, the fire resistance of materials used in the array mounting structure shall be reviewed by the LDP.

6. Structural Requirements

6.1 *Design Considerations for the Installation of Photovoltaic Modules onto Array Mounting Structure:*

6.1.1 Manufacturers of array mounting structures shall provide a pre-engineered, pre-tested system. The structure design, sizing method and attachment method shall be reviewed by an LDP or a representative section be tested for wind load resistance.

NOTE 1—The mounting and fastening method shall comply with the array mounting structure manufacturer's recommendations subject to engineering requirements. If slots or multiple mounting holes are provided on either the array mounting structure or the connections, the worst-case mounting positions shall be selected for testing purposes in order to subject the array mounting structure to the maximum stresses.

6.1.2 *Design Load Requirements*—The module, the array mounting structure, and the interface between the module and array mounting structure shall be able to withstand regional design loads as defined in applicable code, or calculated according to ASCE 7 (whichever is more stringent), including a minimum safety factor, such as from the Aluminum Association design manual for Aluminum or AISC steel construction manual for steel.

6.1.3 The structural load of the attachment system shall not be less than the design load requirements set forth in 6.1.2. The structural load bearing capacity of the attachment system of the module to the array mounting structure shall be specified by the mounting structure manufacturer and be consistent with the module manufacturer's requirements.

6.2 *Design Considerations for the Installation of Array Mounting Structure onto Roof Structure*—The interface between the mounting array and the roof shall meet the same structural requirements as specified in 6.1. The roof structure shall be evaluated by a LDP to assure that the roof structural members are sufficient for added load of PV modules and mounting structures and the intended mounting does not create unacceptable point loads either due to snow, wind or seismic, or similar live loading.

6.3 *Anchoring for Regional Load Requirements*—All fastening shall be into structural members of the roof. The manufacturer of the array mounting structure shall report representative fastener installations pull out values into Hem-Fir (G=0.43) wood per the National Design Specification for Wood Construction (NDS). Fasteners not covered by the NDS shall be tested per the requirements of Test Method D1761 and the pullout values reported. For a given location, the uplift or down load force may vary based on local wind, snow and seismic requirements, but the overall array mounting structure shall be designed to resist a minimum of 30 psf (146 kg/m^2) uplift.

6.3.1 For existing roofs, the installer shall inspect the roof structure for suitability of attachment; the photovoltaic system shall not be installed into damaged (soft spots, droops, unusual discoloration) structural material, such as decking material, rafters, or roof support, unless approved by the LDP.

6.4 *Special Damage Considerations*—Before installation, consider the effects of extreme weather (hail, hurricanes, heavy snow), natural hazards (fire), and other potentially hazardous objects (rocks, golf balls, insects, birds, chimney ash, sand, dust) on the performance of the array mounting structure.

7. Integration with Existing Roof Systems

7.1 *Flashing Roof Penetrations*—Penetrations into the roof shall be flashed in a manner that prevents moisture from entering the roof system. Materials used to flash the fasteners and mounting device to the roof shall be sufficiently durable and compatible with existing roof to maintain performance through the design life of the installation.

7.1.1 The integration of the mounting system shall be compatible and aligned with the water shedding principles of the roof system with proper flashing and sealing. Appropriate design, materials, installation, and maintenance are essential to the durability of the roof integration.

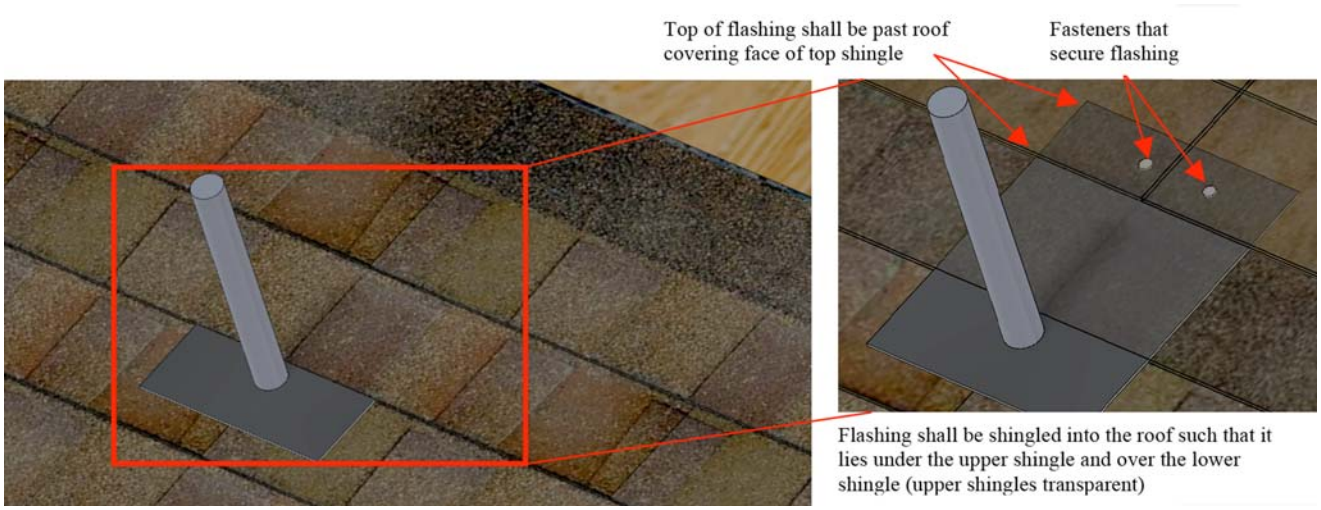

FIG. 1 Example of Flashing Integration with Asphalt Shingle Roof System, Top View (left) and with Overlapping Tiles (right)

7.1.2 For shingled roof systems, the mounting feet shall be integrated under the shingles in correct shingle fashion. See Fig. 1 for an example using asphalt shingles. If shingles were removed to attach the flashing, the shingles shall be reattached after the installation of the flashing components. New shingles shall be applied if the prior shingles are damaged.

7.1.3 For roof systems other than asphalt shingles, such as tile, slate, wood, synthetic or standing seam metal roof systems, follow the recommendations of the LDP.

7.2 *Drainage Around and Under the Array*—The photovoltaic array shall be designed and installed in such a manner to minimize the accumulation of debris or other material that can result in blockage either under or around the array, causing potential damming, ice buildup, or fire hazard around the frame. Additionally, the array shall have sufficient access to allow for removal of any debris that may accumulate during the life of the system. A minimum stand-off height may be specified by the module manufacture to maintain their designed operating temperatures.

7.3 *Servicing of the Roof and Array*—The designer shall allow means to test modules to ensure proper grounding, service and repair, per IFC or NFPA 1. Means shall be provided to allow for servicing of the roof and to access interior regions of the array.

8. Hazards

8.1 *Fall Protection of Installers During Installation*—Refer to applicable Occupational Safety and Health Administration (OSHA) regulations for Personal Protective Equipment (PPE) requirements appropriate for roof slope and height. Avoid installing in inclement weather, such as wet, windy, or icy conditions.

8.2 *Electrical Exposure*—Photovoltaic modules produce electricity with sunlight exposure and proper care needs to be taken with handling and wiring. Individual modules and modules connected in series can produce dc current and hazardous voltages even under low light conditions.

8.3 *Module Damage*—Photovoltaic module surfaces and solar cells are fragile. Walking on modules should be avoided, as it can lead to electrical shock exposure or module damage; refer to module manufacturer's guidelines.

8.4 *Fire and Arcing:*

8.4.1 *System Design and Installation*—Fire and arcing hazards exist both during and after installation. Risks from fire and arcing can be significantly reduced by using properly sourced system components and proper installation techniques.

8.4.2 *Partial Shading*—A shadow cast upon part of a photovoltaic array from adjacent buildings, trees, or other objects at any point during the day may cause hot-spot damage and increase the risk of fire if photovoltaic modules and systems are not adequately protected.

8.5 *Array Perimeter Clearance*—Allow minimum clearance per applicable code requirements around perimeter and interior of array (to gutter, roof edge, eave, chimneys, skylights, and ridge) and roof penetrations for accessibility by installers, or emergency services, such as IFC or NFPA 1.

8.6 *Falling Snow or Ice*—Heavy snow or ice accumulation on the module may present a hazardous situation of snow or ice sliding off the roof, causing potential building damage or personal injury.

9. Documentation:

9.1 The following information shall be provided by the manufacturer or verified by the designer:

9.1.1 Design load for mounting system.

9.1.2 Material test results for mounting system.

9.1.3 Module, Mounting, and Anchoring System resistance to design loads.

9.1.4 Conditions of specific installation—location, date, size of installation, structure height and roof slope, age, type and condition of roofing materials.

10. Keywords

10.1 array mounting systems; photovoltaic (PV); photovoltaic (PV) installations; racking systems; roof penetration flashing; steep-slope roofing; structural loading