Considerations of Module Position on Roof Deck During Spread of Flame Tests
Phase 5

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Introduction

The research described herein expands on previous work conducted over multiple phases of a broader project[1,2,3,4] to determine the effect of rack mounted photovoltaic (PV) modules on the fire rating of roof assemblies. In general, the experiments demonstrated that the flame spread ratings of the roof are not maintained when PV modules are installed elevated above the roof. An initial study measured the surface temperature and incident heat flux of a noncombustible room with a noncombustible PV module surrogate installed at 10, 5 and 2.5 inches above the roof. An analysis of the data indicated the 5 inch gap height to be the most critical of the three that were evaluated in terms of increased radiant flux and roof surface temperature. All three gap configurations increased the surface temperature and heat flux on the roof assembly higher than those measured in the absence of the PV module.

A subsequent second project further investigated rack mounted PV modules on roof decks to determine (1) the effect of PV modules mounted at angles (positive and negative) to steep and low sloped roofs, (2) the impact of PV modules mounted at zero clearance to the roof surface and with the ignition source directed in the plane of the roof or the plane of the PV surface, and (3) the heat release rate and transfer to roof surface of Class A, B, C brands and common materials such as leaf debris and excelsior (wood wool).

A third project investigated the critical flux for ignition of roofing and PV products. While the individual values varied, most were within the range of the flux values measured on the roof in the original experiments without the PV module in place.

Then a fourth project was undertaken to validate the performance of two approaches thought to mitigate the effect of rack mounted PV modules on the fire ratings of roofs - a minimum separation gap and a sheet metal flashing to block the passage of flames between the PV module and the roof assembly. A continuous flashing was determined to effectively block the passage of flame along the roof under a PV module. A minimum distance of 12 inches above a steep slope (shingled) roof was determined to sufficiently separate the two surfaces to maintain the roof's original fire rating. Experiments up to a height of 24 inches above a low slope roof resulted in flame spread in excess of the performance criteria for a Class A roof.

This report of Project 5 describes a series of experiments to investigate a modification of the current UL 1703 spread of flame test to (1) expose a PV module to flames originating from the UL790 (ASTM E108) ignition source, (2) allow those flames to generate on a representative roof section, and (3) observe the propagation of the flames underneath the candidate PV module being tested. Previous research within Project 1 had been conducted with the PV module installed in a position where both the roof and the module were subjected to the ignition source with zero set back and with only modest set back distances (24 inches or less). The

[1] Effect of Rack Mounted Photovoltaic Modules on the Flammability of Roofing Assemblies, Dated September 30, 2009, Revised March 5, 2010,

[2] Effect of Rack Mounted Photovoltaic Modules on the Fire Classification Rating of Roofing Assemblies, Dated January 30, 2012

[3] Characterization of Photovoltaic Materials – Critical Flux for Ignition / Propagation Phase 3 Dated January 16, 2012,

[4] Determination of Effectiveness of Minimum Gap and Flashing for Rack Mounted Photovoltaic Modules. Phase 4 Dated March 29, 2012

repositioning of the PV module was conducted to investigate an application of first item (roof) / second item (module) ignition sequence. This concept was investigated to refine the understanding of the effect of a rack mounted PV array on the fire rating of a Class A roof. Experiments were conducted on low and steep slope roofs.

The results of this investigation could be used to:

1. draft a proposal of a revised test method for consideration by the UL 1703 Standards Technical Panel (STP) for inclusion into the standard,
2. provide quantitative data to support code revisions, and
3. develop a test methodology to establish details of PV installations which can be described generically for use by industry and potentially adopted in code regulations.

Samples

Commercially available PV modules and roofing product samples were acquired either through industry donation or purchased from local retailers. The PV modules were a Class C fire rated metal framed glass on polymer design. A surrogate representation of a PV module was simulated using a noncombustible sheet for some experiments.

UL 790/ASTM E 108 Class A rated roof deck assemblies consisted of:

- 3 tab shingles over ¾" plywood – Note: three manufacturers of shingles were used in the experiments.
- 60 mil LSFR EPDM (low slope, fire retardant, ethylene propylene diene monomer) over 4 inch thick polyisocyanurate insulation board mechanically fastened to a noncombustible deck

Experiments

Fire performance of the PV modules/surrogate on roof deck assemblies was investigated by Spread of Flame tests as described in UL 790 "Standard Test Methods for Fire Tests of Roof Coverings" and UL 1703 "Standard for Safety, Flat-Plate Photovoltaic Modules and Panels".

For these experiments, the objective was to conduct the experiments with the module subjected to a thermal exposure resulting primarily from the burning roof. This was accomplished by positioning the module at a distance beyond exposure of the test fixture ignition source, but within range of the flame progression along the surface of the roof. Baseline experiments were conducted to establish the flame propagation along the roof's surface in the absence of a PV module.

Low Slope Results

Six experiments were conducted with low slope roofs. Maximum flame spread distances and the corresponding time at which they occurred for the various low slope roof assembly experiments are listed in Table 1. The baseline experiment without a PV module present demonstrated a maximum flame spread distance along the roof of approximately 5 ft., which is Class A compliant.

A noncombustible PV surrogate was installed at a gap height of 5 in and an offset of 48 in. The flame spread along the roof extended under the PV module and the total spread of flame along the roof was 8 ft. (Class A, noncompliant.) The same configuration, but with an offset of 52 in., exhibited a flame spread of 8.5 ft.(Class A, noncompliant).

A series of experiments were conducted with aluminum framed glass on polymer PV modules installed at a gap height of 5 in. With the module installed at an offset of 48 in and parallel to the roof (0° inclination), the flame spread extended to 8 ft. (Class A, noncompliant). A third roof / PV experiment was conducted with the module offset at 48 in., but with the module installed at a slight angle to the roof (10° inclination) resulting in a flame spread of 4 ft.(Class A compliant). A final experiment was conducted with two modules angled to the roof (10° inclination), the first offset 24 in. and the second spaced 12 in. from the first. Flame spread across the roof surface with both modules fully involved with flames extending beyond the deck.

Table 1 - Summary of Repositioning Experiments – Low Slope

						Roof						PV						
		Gap		Module		Time of Flame Spread			Max				Time Flame Spread					
	System	Height	Angle	Offset		3.0'	3.5'	4.0'	Distance	Time		Ign	1'	2'	3'	4'	Full Panel	
System #	Notes	(in)	(deg)	(in)		(m:s)	(m:s)	(m:s)	(ft)	(m:s)		(m:s)	(m:s)	(m:s)	(m:s)	(m:s)	(m:s)	Pass/Fail
Tests conducted June 6, 2012																		
12	Baseline	N/A	N/A	N/A		3:07	NR	4:33	5	10:00		N/A	N/A					Pass
14	With PV	5	0	48		2:45	3:08	4:01	8	7:08		4:33	4:52	5:27	5:38	5:54	6:19	Fail
15	NC	5	0	48		2:30	NR	3:02	8	5:58								Fail
15	NC	5	0	52		2:10	2:40	3:05	8.5	5:58								Fail
17	With PV	5	10	48		2:51	NR	3:39	4	10:00								Pass
Tests conducted June 7, 2012																		
14	2 PV, 12" apart	5	10	24		2:48	2:50	2:51	6.5	4:04								Fail

NR = Not Recorded

NC = Noncombustible

LSFR EPDM over 4" Poly iso

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Figure 1 – Figure Illustrating Flame Spread of System 14 - Low Slope Roof / PV Module LSFR EPDM, 5” Gap, 0° Inclination and 48” Offset Experiment

Figure 2 – Figure Illustrating Flame Spread of System 15 - Low Slope Roof / Noncombustible PV Surrogate LSFR EPDM, 5” Gap, 0° Inclination and 48” Offset Experiment

Figure 3 – Figure Illustrating Flame Spread of System 15 - Low Slope Roof / Noncombustible PV Surrogate LSFR EPDM, 5” Gap, 0° Inclination and 52” Offset Experiment

Figure 4 – Figure Illustrating Flame Spread of System 17 - Low Slope Roof / Noncombustible PV Surrogate LSFR EPDM, 5” Gap, 10° Inclination and 48” Offset Experiment

Figure 5 – Figure Illustrating Flame Spread of System 14 - Low Slope Roof / 2 PV Modules LSFR EPDM, 5” Gap, 10° Inclinations and First Module 24” Offset, Second Module Spaced 12” Experiment

Steep Slope Results

Ten experiments were conducted on steep slope roofs constructed using Class A, 3 tab shingles produced by three different manufacturers. Maximum flame spread distances and the corresponding time at which they occurred for the various steep slope roof assembly experiments are listed in Table 2. Two baseline experiments without PV modules present were conducted on shingle manufacturer 1, and single baseline experiments were conducted on the remaining two shingles, manufacturers 2 and 3. All baseline experiments without the PV modules present demonstrated flame spread along the roof surface of approximately 4 ft (Class A compliant).

When a noncombustible PV surrogate was installed at a gap height of 5 in. and an offset of 36 in., the flame spread along the roof extended to 4 ft. (Class A compliant). When a noncombustible PV surrogate was also installed at a gap height of 5 in. and an offset of 24 in., the flame spread along the roof extended to 8 ft (noncompliant Class A).

Two experiments were conducted with aluminum framed, glass on polymer PV modules installed at a gap of 5 in, an offset of 42 in., and parallel to the roof (0° inclination). For the experiment conducted with manufacturer 1, shingles resulted in a flame spread of 3.5 ft (Class A compliant), and the second experiment conducted with shingles from manufacturer 3 resulted in a flame spread of 4 ft (Class A compliant).   Two additional experiments were conducted with the modules installed at an offset of 36 in. The experiment conducted with shingles from manufacturer 1 developed a flame spread of 4 ft, (Class A compliant), and manufacturer 3 developed a flame spread of 4.5 ft. (Class A compliant)

Table 2 - Summary of Repositioning Experiments – Steep Slope

								Roof						PV						
				Gap		Module		e of Roof Flame Spr			Max. Flame Spread			Time of PV Underside Flame Spread						
System		Shingle	System	Height	Angle	Offset		3.0'	3.5'	4.0'	Distance	Time		Ignition	1'	2'	3'	4'	Full Panel	
#	Slope	Material	Notes	(in)	(deg)	(in)		(m:s)	(m:s)	(m:s)	(ft)	(min:sec)		(m:s)	(m:s)	(m:s)	(m:s)	(m:s)	(m:s)	Pass/Fail
Tests conducted June 6, 2012																				
11	Steep	Mfg 3	Baseline	N/A	N/A	N/A		6:31	7:12	8:04	4	10:00		N/A	N/A					Pass
1	Steep	Mfg 1	Baseline	N/A	N/A	N/A		4:16	5:04	8:42	4	10:00		N/A	N/A					Pass
4	Steep	Mfg 2	Baseline	N/A	N/A	N/A		4:41	6:07	7:04	4	10:00		N/A	N/A					Pass
6	Steep	Mfg 1	PV	5	0	42		5:18	7:03	NR	3.5	10:00								Pass
Tests conducted June 7, 2012																				
6	Steep	Mfg 3	PV	5	0	42		6:10	NR	7:20	4	10:00		7:55	8:30					Pass
2	Steep	Mfg 1	PV	5	0	36		7:01	8:11	8:49	4	10:00								Pass
3	Steep	Mfg 1	NC	5	0	36		5:00	5:48	7:15	4	10:00		N/A						Pass
7	Steep	Mfg 2	NC	5	0	24		4:16	4:36	5:13	8	7:01		N/A						
8	Steep	Mfg 3	PV	5	0	36		4:08	4:53	5:41	4.5	10								
9	Steep	Mfg 1	Baseline	NA	NA	NA		5:33	6:11	7:11	4	10		N/A	N/A					Pass

NA = Not Applicable
NC = Noncombustible module surrogate

Figure 6 – Figure Illustrating Flame Spread of System 6 – Steep Slope Roof / PV Module Mfg. #1 Shingle, 5” Gap, 0° Inclination and 42” Offset Experiment

Figure 7 – Figure Illustrating Flame Spread of System 6 – Steep Slope Roof / PV Module Mfg. #3 Shingle, 5” Gap, 0° Inclination and 42” Offset Experiment

Figure 8 – Figure Illustrating Flame Spread of System 2 – Steep Slope Roof / PV Module Mfg. #1 Shingle, 5” Gap, 0° Inclination and 36” Offset Experiment

Figure 9 – Figure Illustrating Flame Spread of System 3 – Steep Slope Roof / Noncombustible PV Surrogate Mfg. #1 Shingle, 5” Gap, 0° Inclination and 36” Offset Experiment

Figure 10 – Figure Illustrating Flame Spread of System 7 – Steep Slope Roof / Noncombustible PV Surrogate Mfg. #2 Shingle, 5” Gap, 0° Inclination and 24” Offset Experiment

Figure 11– Figure Illustrating Flame Spread of System 8 – Steep Slope Roof / PV Module Mfg. #3 Shingle, 5” Gap, 0° Inclination and 36” Offset Experiment

Summary and Recommendations

Summary of Findings

Although the experiments conducted for this report are not exhaustive, an analysis of the generated data point to the following key findings:

Low slope:

- The low slope roof baseline experiment (no PV) exhibited a flame spread of 60 inches.
- Both a noncombustible representation of a PV module or a Class C PV module mounted parallel to and at an elevation of 5 inches above the roof and at offsets of 48 and 52 inches flame spreads were in excess of Class A performance requirements.
- A PV module mounted at a slight inclination (10°) to and at an elevation of 5 inches above the roof and at a 48 inch offset did comply with Class A requirements.
- A single experiment conducted with two modules angled to the roof (10° inclination), the first offset 24 inches and the second space 12 inches from the first did not comply with Class A requirements.
- The overall results of low slope tests with the PVs present were fairly consistent with tests using a surrogate noncombustible PV .

Steep slope:

- The steep slope roof baseline experiments (no PV) exhibited a flame spread of 48 inches.
- A noncombustible representation of a PV module mounted parallel to and at an elevation of 5 inches above the roof with an offset of 42 inches complied with Class A requirements.
- Two experiments conducted with PV modules mounted parallel to and at an elevation of 5 inches above the roof with an offset of 42 inches complied with Class A requirements.
- Two experiments conducted with PV modules mounted parallel to and at an elevation of 5 inches above the roof with an offset of 36 inches complied with Class A requirements.
- An additional experiment was conducted with a noncombustible sheet mounted parallel to and at an elevation of 5 inches above the roof with an offset of 24 inches and did not comply with Class A requirements
- The overall results of steep slope tests with the PVs present were fairly consistent with tests using a surrogate noncombustible PV .

Recommendations

Based on the research study findings, the repositioning approach of examining the first item ignited (roof) and then the second item ignited (PV), was a viable method for assessing the performance of a roof / PV combination. It was observed that this method was of such severity that currently commercially available PV Class C modules would likely have to be modified, or the installation details specified, in order to yield compliant results for both low and steep slope tests. It is important to note that the results of tests with the PVs present were fairly consistent with tests using a surrogate noncombustible PV .

Consequently, the Research Team as well as a focus group present to observe some of these tests supported the following recommendations and suggestions to propose revisions to UL 1703 as follows:

Spread-Of-Flame Tests to be conducted:

- Individually with the module mounted on a noncombustible deck and oriented such that the ignition flame is directed on the top surface of the module or panel.
- With the module installed on a steep slope and low slope roofs as an assembly and oriented such that the ignition flame is directed into the interstitial space below the module and above the roof. The module or panel installation shall be installed:
    a. with a 36 inch (0.91 m) between the edge of the flame test apparatus and the edge of the PV mounting system for steep sloped roofs,
    b. with 42 inch (1.07 m) between the edge of the flame test apparatus and the edge of the PV mounting system for low sloped roofs.