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Effect of Rack Mounted Photovoltaic Modules on the Flammability of Roofing Assemblies – Demonstration of Mitigation Concepts

Project Number: 08CA39594, 09CA40917
File Number: IN15911, R26475
Date: September 30, 2009
Revised: February 10, 2010

Bob Backstrom[1], Mahmood Tabaddor, PhD[2]
[1]Senior Staff, Corporate Research
[2]Staff, Corporate Research

Reviewed by:
Pravinray Gandhi, PhD PE[3]
[3]Director of Engineering Research, Corporate Research

Underwriters Laboratories Inc.
333 Pfingsten Road, Northbrook, IL 60062-2096 USA
T:: 847.272.8800 / F:: 847.272.8129 / W:: ul.com

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ACKNOWLEDGMENTS

The authors would like to acknowledge the following individuals for their contributions including development of design of experiments, suggestions of mitigation techniques, guidance and support for this project:

Bill Brooks of Brooks Engineering
Larry Sherwood of Sherwood Associates
Kevin Lynn of the Department of Energy (DOE)
Andy Rosenthal of New Mexico State University

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EXECUTIVE SUMMARY

An analysis of the data generated by the experiments carried out in a previous study for Solar ABCs pointed to the following key findings:

- The presence of a rack mounted PV module on a roof has an adverse effect on the fire performance of the roof regardless of the fire rating of the roof or the Class rating of the PV panel based on Spread of Flame test method described in UL 790 (UL 1703).
- The extent of the degradation on fire performance of a roof depends upon PV installation parameters such as setback distance and gap between roof and PV module.
- The presence of a rack mounted PV module on a roof could adversely affect the fire performance of the roof when subjected to burning brands placed on the roof based on the Burning Brand test method described in UL 790.

In this investigation, additional experiments were conducted at the request of Solar ABC's to examine the efficacy of some simple mitigation concepts.

FIRE HAZARD MITIGATION – SPREAD OF FLAME

Based upon the analysis of results from previous testing, several simple design concepts were devised to assess their effectiveness in improving the fire performance of the roof systems (roof and rack mounted elevated PV module). These included (i) use of flashing at the leading edge of the roof with control of separation between roof and flashing, and (ii) use of noncombustible back sheet. The results of the mitigation tests are presented in Table E1.

Results showed the limited success of three different mitigation strategies using setback, angled flashing and a screen.

- Using only setback as a mitigation strategy, a 36 in setback did not demonstrate compliance to the requirements of Class A for the single test run.

- An angled flashing only demonstrated compliance when combined with a 36 in. setback to the requirements of Class A for the single test run.

- The 24 and 36 in setback experiments with small sized opening screens were investigated and neither demonstrated compliance to the requirements of Class A.

- A vertical flashing (continuous from roofing surface to PV top surface) demonstrated compliance to the requirements of Class A with setbacks of 0, 3 and 12 inches.

Table E1 – Results from Selected Mitigation Techniques

Gap (in)	Setback (in)	Roof Rating	PV Rating	Mitigation	Fire Performance
5	24	Class A	Class C	Small opening screen	Not compliant to Class A
5	36	Class A	Class C	Small opening screen	Not compliant to Class A
5	36	Class A	Class C	Angled flashing with 1 in separation	Compliant to Class A
5	24	Class A	Class C	Angled flashing with 1 in separation	Not compliant to Class A
5	36	Class A	Class C	Set back only	Not compliant to Class A
5	0	Class A	Class C	Vertical flashing with 0 in separation	Compliant to Class A
5	3	Class A	Class C	Vertical flashing with 0 in separation	Compliant to Class A
5	12	Class A	Class C	Vertical flashing with 0 in separation	Compliant to Class A

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PROJECT BACKGROUND

This research project was supported by the Department of Energy (DOE) under award number DE-FC36-07GO17034. The lead for this project was New Mexico State University, Las Cruces, NM. UL was a subcontracted partner under this initiative.

NEED FOR RESEARCH

An analysis of the data generated by experiments carried out in a previous study resulted in the following key findings:

- The presence of a rack mounted PV module on a roof has an adverse effect on the fire performance of the roof regardless of the fire rating of the roof or the Class rating of the PV panel based on Spread of Flame test method described in UL 790 (UL 1703).
- The extent of the degradation on fire performance of a roof depends upon PV installation parameters such as setback distance and gap between roof and PV module.
- The presence of a rack mounted PV module on a roof could adversely affect the fire performance of the roof when subjected to burning brands placed on the roof based on the Burning Brand test method described in UL 790.

Based on these findings a need for simple mitigation strategies that do not affect other roof performance criteria was identified. Demonstration of potential techniques were required to be examined and results in improving fire performance of the roof documented.

RESEARCH INVESTIGATION

RESEARCH OBJECTIVES

The objective of this research project was to demonstrate various potential mitigation techniques to improve the flammability of for elevated PV modules on roofs

To meet these objectives, a series of experiments were conducted to demonstrate the effectiveness of possible mitigation techniques.

OBJECTIVE

The objective of this project was to conduct experiments to determine the effect of potential simple mitigation methods on a variety of PV module/roof combinations to demonstrate if the flammability of a roof system/PV module assembly can be improved.

MITIGATION EXPERIMENTS – VERTICAL FLASHING AND FIRE BARRIER

Experiments were conducted using the Spread of Flame as specified in UL 790 and UL 1703. No Burning Brand tests were conducted for this research study. For this set of tests, the roofing material, the fire rating of the PV module, the mitigation concept, and the setback distance were adjusted. The specific mitigation concepts examined included noncombustible flashing at the leading edge of the roof with variable opening size (between flashing and PV module) and a commercial fire barrier sheet applied to the back plane of the PV module.

RESULTS

Test observations are summarized in Table 1. Initial designs of a fire stop which was terminated above the roof providing an opening for roof water shedding and ventilation of the back of the PV module. The opening size was based on the initial tests from the previous PV module / roofing flammability project.

Table 1 Test Results for Mitigation Tests

Assembly ID	Gap (in)	Setback (in)	Roof Rating	PV Rating	Flame Spread Data		Comments
					Distance (feet)	Time (Min:Sec)	
15	5	0	Noncombustible	C	8	2:35	Noncombustible flashing, 2" vertical gap
16	5	0	Noncombustible	C	8	3:00	Noncombustible flashing, 1" vertical gap
17	5	0	Noncombustible	C	0		1/4" noncombustible module applied to back plane of PV module
18	5	0	Noncombustible	C	6	5:26	Commercial fire barrier sheet applied to back plane of PV module
19	5	0	Noncombustible	A	8	5:47	
20	5	0	A - 3 Tab Shingle	C	0		7 " (height) noncombustible flashing, PV module at 0" setback
21	5	3	A - 3 Tab Shingle	C	0		7 " (height) noncombustible, PV module at 3" setback
23	5	12	A - 3 Tab Shingle	C	0		7" (height) noncombustible flashing, PV module at 12" setback

Visual results are provided in the photographs as shown in Figure 1 through Figure 15.

Figure 1 Photograph of noncombustible roof with Class C PV and modified vertical noncombustible flashing with 2" gap between bottom of flashing and roof surface

Figure 2 Photograph of Spread of Flame Test for Setup described in Figure 1.

Figure 3 Photograph of noncombustible roof with Class C PV and modified vertical noncombustible flashing with 1” gap between bottom of flashing and roof surface.

Figure 4 Photograph of Spread of Flame Test for Setup described in Figure 3.

Figure 5 Photograph of noncombustible roof with Class C PV modified with a noncombustible 1/4" board mounted directly to the bottom of the module

Figure 6 Spread of Flame Test for Setup in Figure 5.

Figure 7 Photograph after the Spread of Flame test for noncombustible roof (right) and Class C PV (left) modified with noncombustible ¼" board mounted directly to the back of the PV

Figure 8 Photograph of Class C PV with commercially available fire barrier sheet mounted directly to the bottom of the module

Figure 9 Spread of Flame Test for noncombustible roof with PV noted in Figure 8.

Figure 10 Photograph of Class C PV with commercially available fire barrier sheet mounted directly to the bottom of the module after the Spread of Flame test

Figure 11 Setup for Class A Shingle (3 tab) roof with Class C PV modified with noncombustible flashing connecting leading edges of PV and roof

Figure 12 Spread of Flame test for setup shown in Figure 11.

Figure 13 Setup for Class A roof with a Class C PV modified with noncombustible flashing with a 0" vertical gap and the module's leading edge 3" from the flashing

Figure 14 Spread of Flame Test for Setup shown in Figure 13

Figure 15 Setup for Class A roof with Class C PV modified with noncombustible flashing with 0" vertical gap and 12" distance from module leading edge

Analysis

Mitigation solutions examined in this portion of the project were split in limiting flame propagation < 6 ft during the flame-spread test. Although initial fire stop flashing designs incorporated an opening size based on positive results from a previous study, using simulated PV panel, that indicated a significant decrease in temperature and heat flux, the positive performance was not duplicated with experiments using combustible PV panels and roofing materials.

Experiments which incorporated a noncombustible vertical flashing that provided either a 1 in. or 2 in. opening above the roof allowed sufficient energy to ignite the PV back plane and roofing surface. Once ignited, flame propagation exceeded the length of the deck (> 8 ft.) thus not in compliance of the requirements for Class A (< 6 ft.). A continuous noncombustible vertical flashing attached directly to the leading edge of the PV module and extending down to the roof surface (no opening) was successful in prevented the ignition flame entering the gap between the PV module and the roof surface. Flame propagation for this experiment is reported as 0 ft. Experiments incorporating the same noncombustible fire block flashing but with the PV module spaced 3 in and 12 in. away from the flashing were also successful in preventing ignition of the underside of the PV module or the roof surface. Flame propagation for both of these experiments is reported as 0 ft. Two experiments which incorporated protection fastened directly to the back of the PV module were also successful in limiting flame propagation. A ¼ in. noncombustible rigid board demonstrated flame propagation of 0 ft. A commercially available fire barrier sheet material limited flame propagation to 6 ft, which is at the threshold of the Class A requirement.

MITIGATION EXPERIMENTS – SET BACK, SCREENS AND ANGLED FLASHING

OBJECTIVE

The objective of this task was to conduct experiments to determine the effect of additional potential mitigation methods to demonstrate if the flammability of a Class A roof system / PV module assembly is improved. Since PV modules require airflow on underside to enable more effective heat transfer from the modules, methods that were expected to improve air movement, were considered.

EXPERIMENTAL PARAMETERS

Experiments were conducted using the Spread of Flame as specified in UL 790 and UL 1703. The experiments conducted were consistent with those of previous work with the exception of the mitigation technique, which included:

- *PV modules were set back from the edge of the roof 12, 24 and 36 inches*
- *An angled flashing mounted to the leading edge of the PV module*
- *Screening mounted to the leading edge of the PV module*

Initials experiments were conducted using a noncombustible PV module surrogate mounted over a noncombustible roof deck while altering the setback distance and the mitigation concept. These tests were followed up with a series of tests with Class A roofing materials and Class C PV module while altering setback distance and mitigation concept. For these tests, visual observations of flame extension beyond the barrier were used to determine the efficacy of the technique.

MITIGATION CONCEPTS

Setback

For the experiments, which explored setback as a potential mitigation technique, the simulated PV module was positioned 0, 12, 24 and 36 in back from the leading edge of the roof deck.

Screens

Two metal screen types were evaluated. One was an expanded metal with diagonal openings measuring approximately ½ in by ¼ in. The second screen was typical insect screen material with 18 openings per inch. Photographs of the screening material are shown in Figure 16.

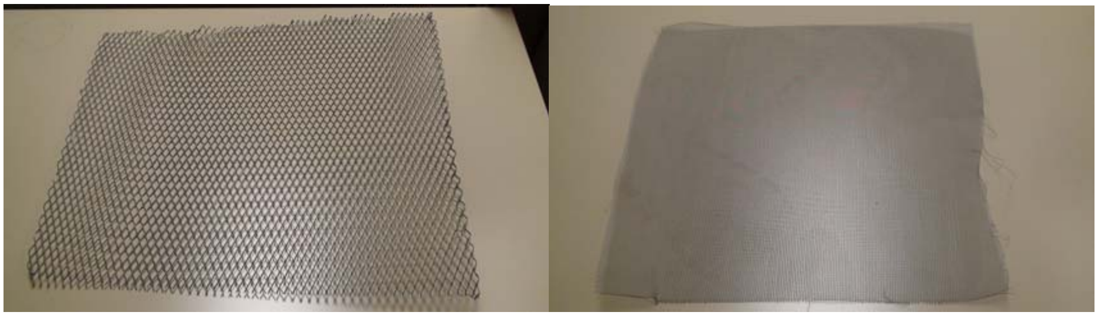

Figure 16 Photograph of large opening (left) and small opening (right) screen materials

Angled Flashing

An angled flashing was constructed using a ½ in noncombustible board. The flashing was attached to the leading edge of the PV module and positioned at 45° and 1 in above the surface of the roof deck.

RESULTS

Visual results are provided in the photographs Figure 17 through Figure 20 and with test observations summarized in Table 2 and Table 3.

Figure 17 Photograph of noncombustible roof with noncombustible PV surrogate modified with a large opening screen flashing

Figure 18 Photograph of Spread of Flame Test showing flame extension through the large opening screen flashing.

Figure 19 Photograph of noncombustible roof with noncombustible PV surrogate modified with a small opening screen flashing

Figure 20 Photograph of noncombustible roof with noncombustible PV surrogate modified with a noncombustible angled flashing

Table 2 Results of Mitigation on Spread of Flame for Noncombustible Roof/PV Module

Assembly ID	Gap (in)	Setback (in)	Roof Rating	PV Rating	Mitigation Concept	Flame Extend Beyond Barrier
5	5	0	Noncombustible	Noncombustible	Small opening screen	Yes
9	5	0	Noncombustible	Noncombustible	Large opening screen	Yes
6	5	12	Noncombustible	Noncombustible	Small opening screen	Yes
7	5	24	Noncombustible	Noncombustible	Small opening screen	Yes
8	5	36	Noncombustible	Noncombustible	Small opening screen	No
4	5	36	Noncombustible	Noncombustible	Angled flashing	No
3	5	24	Noncombustible	Noncombustible	Angled flashing	Intermittent
2	5	12	Noncombustible	Noncombustible	Angled flashing	Yes

Table 3 Results of Mitigation on Spread of Flame for Combustible Roof/PV Module

Assembly ID	Gap (in)	Setback (in)	Roof Rating	PV Rating	Mitigation Concept	Flame Spread Data	
						Distance (feet)	Time (Min:Sec)
10	5	24	Class A	Class C	Small opening screen	8	4:08
11	5	36	Class A	Class C	Small opening screen	8	9:46
12	5	36	Class A	Class C	Angled flashing	3.5	8:58
13	5	24	Class A	Class C	Angled flashing	8	4:39
14	5	36	Class A	Class C	Set back only	8	6:19

ANALYSIS

Mitigation solutions examined in this project were limited in protection of the elevated PV module.

Experiments which incorporated a noncombustible roof / PV module modified with a screen indicated that a 36 in. setback was required to prevent the ignition source flames from extending to the underside of the module. In the Class C roof / non combustible PV module experiment modified with a small screen and 24 in setback, the fire propagated beyond 6 ½ ft (Class A criteria) at 4 min and 36 sec and reached the end of the 8 ft deck at 4 min and 39 sec. An increase in the setback to 26 in slightly improved the performance, however flames reached 2-½ ft at 6 min and 9 sec. The small opening screen did not result in meeting the Class A fire performance criteria.

Experiments which incorporated a noncombustible roof / PV module modified with an angled noncombustible flashing attached to the leading edge of the module and elevated 1 in above the roof deck was similar in performance. At 36 in. setback, ignition source flames did not extend to the underside of the PV module. At a 24 in. setback, ignition source flames extended up along the deck and under the PV module intermittently. At 12 in. setback, flames were continuous. In the Class C roof / non combustible PV module experiment modified with the angled flashing, the 24 in setback was noncompliant, but the 36 in. setback was compliant to Class A flame spread criteria

Experiments which incorporated only a setback (36 in) as a mitigation technique were not compliant to Class A flame spread criteria.

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SUMMARY AND RECOMMENDATIONS

SUMMARY OF FINDINGS

An analysis of the data generated by the experiments carried out in this study point to the following key findings. Simple mitigation strategies that do not affect other roof performance criteria were examined and found to produce mixed results in improving fire performance of the roof. Flashing techniques demonstrated the most potential in minimizing flame spread:

- Vertical Flashing – Vertical continuous (to roof surface) metal flashing mounted to the leading edge of the PV module was successful in blocking flames. Vertical flashing installed with gaps (to the roof surface) were not successful. Continuous metal flashings mounted independent of the PV module as a fire block with set back distances of 3 in and 12 in were successful.
- Fire Barriers – A rigid board mounted directly to the back of the module limited flame extension. A thin sheet mounted directly to the back of the module limited flame was nominally successful.
- Setback – Experiments conducted with only setback as a mitigation technique were not successful.
- Angled Flashing with setback – Angled flashings mounted to the leading edge of the PV module and installed with a 1 in. gap (to the roof surface) were not successful at setback distances of 12 and 24 inches. A 36 in setback was successful with an angled flashing.
- Screen – Experiments conducted to demonstrate the effectiveness of screens to block the entrance of the ignition source flames to limit the impingement on the underside of the elevated PV module and the exposed surface of the roof were not successful.