Effect of Rack Mounted Photovoltaic Modules on the Fire Classification Rating of Roofing Assemblies

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EXECUTIVE SUMMARY

As a result of the increased use of PV in homes and commercial buildings, in combination with efforts to mitigate the effects of fires, fire officials are interested in understanding the effect that a rack mounted PV system has on a Class A roof   To date, there are few Class A rated PV modules or building-integrated photovoltaic (BIPV) products from all the several hundred listed modules. At present, the effect of fire on UL 790 fire Class A rated roofing materials when Class C rated PV modules are installed is not well understood. For instance will a Class C rated module reduce the fire resistance performance and/or fire rating of some Class A rated roof systems? If so, which roof systems are impacted and to what extent?

NEW FIRE SAFETY RESEARCH PROJECT

A review of the National Fire Incident Reporting System (NFIRS)[1] statistics offers minimal insights into fire hazards associated with photovoltaic (PV) modules installed on roofs. While NFIRS data does not provide detailed information on PV modules as a cause or fire hazard contributing to home structural fires, the impact of these modules on the fire rating of roofing assemblies has been a concern to the California State Fire Marshals[2]. In response to these concerns, UL in partnership with Solar America Board for Codes and Standards (Solar ABCs) contracted with New Mexico State University to design and conduct a research project with funding from the Department of Energy (DOE) under award number DE-FC36-07GO17034.

This research project was undertaken to generate critically needed test data to help speak to pertinent fire safety questions and issues associated with the use of a rack mounted PV modules over Fire Class rated roofing materials. A cross-functional team, consisting of members from UL's Corporate Research, Primary Designated Engineers, and Conformity Assessment Services organizations was established to develop and execute the project. The research project was consisted of 2 phases.

During Phase 1, the objective was to study the influence of a rack mounted PV module on a roof deck under exposure from standard fire tests such as UL 790[3]. These tests utilized a PV surrogate constructed of non-combustible materials over a non-combustible roof deck to isolate the effect of the installation of a module on a roof[4]. All assemblies were instrumented with thermocouples and heat flux gauges to obtain temperature and heat flux data at different points along the roof and PV. In addition, limited burning brand tests and spread of flame tests were conducted using actual PV modules to demonstrate the current state. These tests were conducted to measure the effects of multiple installation configurations including:

[1] www.nfirs.fema.gov

[2] osfm.fire.ca.gov/training/photovoltaics.php

[3] UL 790, Standard Test Methods for Fire Tests of Roof Coverings, 8th Edition, Underwriters Laboratories Inc., 2004.

[4] For all tests conducted in this study, the rack mounted PV module was parallel to the surface of the roof.

- *Establish baseline data of fire exposure on roof deck samples without PV according to UL 790*
- *The effect of PV module stand-off height above the roof and leading edge distance*
- *Orientation of the PV module mounting rails on the roof surface*

Based on the results of the Phase 1, test parameters were identified for Phase 2. In this phase, tests were performed on PV modules with combinations of different roofing materials. The key objectives of the Phase 2 were as follows:

- *Develop baseline data on the fire exposure during standard tests for roof with no PV module according to UL 790*
- *Determine the effect of varying selected PV installation parameters*
- *Document the impact of lesser fire rated PV modules on common roofing assemblies*

SUMMARY OF FINDINGS

Based on the findings in this report, the installation of a rack mounted PV module on a roof has an impact on the fire resistance ratings of the roof system, regardless of the fire rating of the roof or PV module. For instance, the increase in distance (setback) between the leading edge of the roof and the PV module lessens the chances that the flame will be captured in the gap between the PV panel and roof surface that might otherwise lead to significant burning during the spread of flame test.

INFLUENCE OF A RACK MOUNTED PV MODULE ON ROOF

Results from Phase 1 of this investigation showed that for a surrogate rack mounted PV module parallel to the roof surface, the fire exposure from the Spread of Flame test resulted in greater temperatures on the roof surface in the area underneath the PV module. In addition, the heat flux on the roof surface also increased. The magnitude of these effects was dependent on the gap size between the module and the roof, as well as the setback distance of the module from the roof leading edge.

For the parameters in this study, it was found that when the gap between the rack mounted PV module and the roof was reduced from 10 inches to 5 inches the measured surface temperatures increased[5]. It was observed that both the 10 inch and 5 inch gap captured all of the flames, however the smaller gap also reduced the amount of entrained air into the fire plume thus elevating the temperature of exposed surfaces. When the gap size was reduced further to the value of 2.5 inch, the measured surface temperatures did not increase but rather lowered, as the gap was sufficiently decreased to capture only a portion of the flames.

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[5] This does not suggest that a 5-inch gap leads to worst case as compared to all values of gap size but only for those gap size increments selected in the tests described in this report.

The influence of the setback of the PV module on the measured temperature and heat flux on the roof surface was highest when the PV module was in line with the leading edge (i.e., no setback distance). The measured temperatures and heat flux exposure lessened as the setback distance was extended.

INTERACTION BETWEEN PV MODULE AND FIRE RATED ROOF SYSTEM

Results from Phase 1 study showed that installation of PV modules on roofs had an adverse affect on the Fire Class Rating of the roof assembly. For further confirmation, more experiments were conducted in Phase 2 with the PV module placed at the roof leading edge (0 in. setback distance) with a 5 in. gap between the PV module and roof surface. The results from PV modules on fire rated roof systems for the Spread of Flame tests are listed in Table E1. These results suggest that the presence of a PV module adversely affects the fire rating of a roof. If a roof is noncombustible, the flame spreads through the gap between the roof and the PV module in excess of 8 ft.

Table E1 – Influence of PV Module During Spread of Flame Test

Roof Rating	PV Rating	Flame Spread
A	C	Greater than 8 ft.
A	A	Greater than 8 ft.
C	C	Greater than 8 ft.
Noncombustible	C	Greater than 8 ft.
Noncombustible	A	Greater than 8 ft.

Some results of PV modules on fire rated roof systems for the Burning Brand Tests are described in Table E2. In the brand test involving Class A rated roof and Class C rated PV panel with the brand located on the roof, it was observed that the PV panel sagged and collapsed onto the roof allowing flames to vent vertically. This prevented the flame from penetrating the roof. However, though the results from two tests did meet the requirements for Class A, a third test did not. Since there was one case where the results were not in compliance with Class A requirements, clearly the random nature of fire growth and spread of the PV module affects the outcome of these particular tests.

Table E2 - Brand Test

Roof Rating	PV Rating	Brand Size / Position	Fire Performance Result
A	C	Class A / PV	Compliant
A	C	Class A / Roof	2 Compliant/ 1 not compliant
C	C	Class C / Roof	Not compliant
A	A	Class A / Roof	Not compliant

For the test involving a Class A rated roof with a Class A rated PV with the brand located on the roof, the results were not compliant. The Class A module increased the thermal load on the roof.

For the case of a Class A rated roof and a Class C rated PV with the brand located on the PV module, the results of the test meet Class A requirements as the module simply provides an additional barrier between the brand and the roof for some period of time.

For the Burning Brand tests for the Class C roof with Class C PV module with the brand located on the roof, where the results were not compliant with the requirements, the PV panel remained intact, thereby trapping the heat between the panel and the roof. This led to a breach of the fire through the roof surface and the observed non-compliance.

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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

The growth of solar Photovoltaic (PV) has been substantial in the last few years (Figure 1) especially in California with 58% of all grid-tied PV capacity in the US in 2007. As a consequence of the prevalence of solar PV modules on roofs and plans for additional deployment, fire safety officials are concerned about the potential fire risks when a rack mounted PV array is installed on a rooftop. However, insufficient data exists on the precise nature of the risk and possible remedies. As California State Fire Officials are preparing to implement a statewide requirement for Class A fire rating of all roofing products including PV panels, the need for comprehensive data to help guide discussions and decisions is even more pressing.

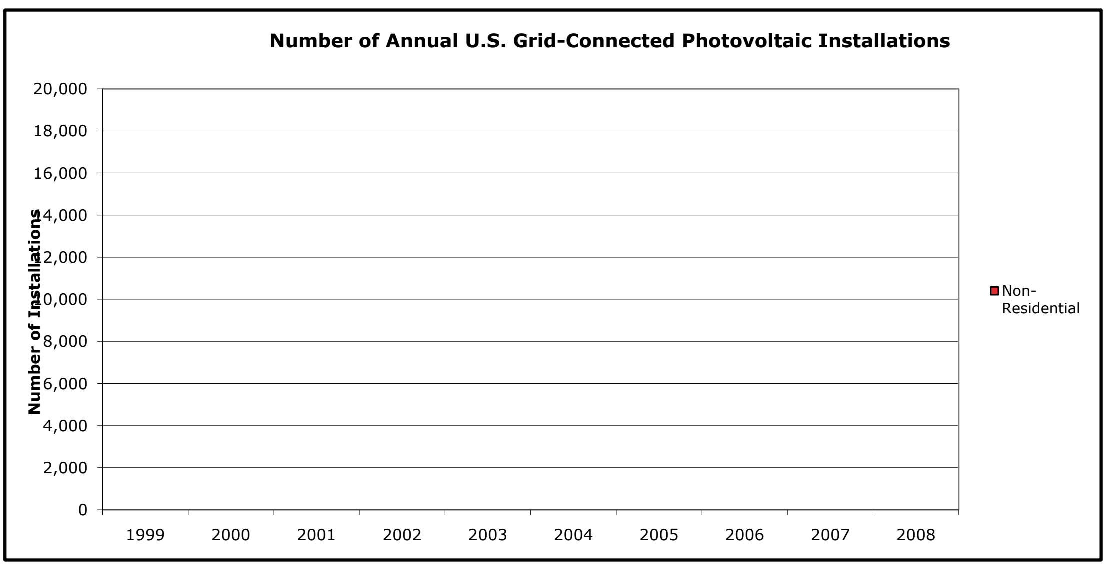

Figure 1 – Increase in Photovoltaic Module Deployment[6]

Though the electric and fire hazards associated with PV arrays have been known for some time[7], most of the research on the fire risks of PV modules has focused on the PV as a fire source due to internal shorting or arcing. Some research in this area has focused on heat

[6] Source: U.S. Solar Market Trends 2008, Interstate Renewable Energy Council, 2009

[7] P.D. Moskowitz, et al., Rooftop Photovoltaic Arrays: Electric Shock and Fire Health Hazards, Solar Cells, 1983, pp. 327-336.

transfer aspects of PV[8] and some limited fire performance[9], however, only a single research paper was found that quantified the effect on flame spread of a rack mounted solar collectors on a roof deck. The researchers[10] at the National Bureau of Standards (now National Institute of Standards and Technology) tested roofs with different types of solar collector module mountings as shown in Figure 2. For the spread of flame tests, the results were primarily for a Class C test conditions.

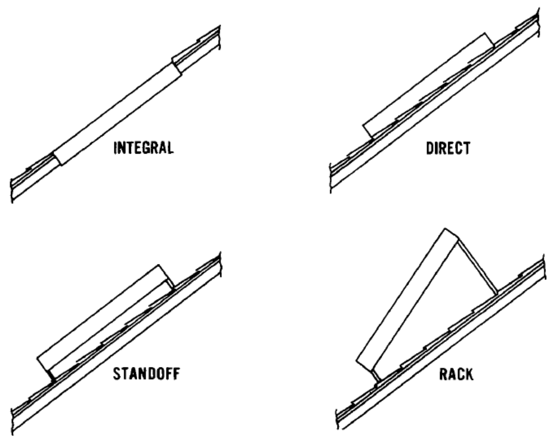

Figure 2 – Collector mounting configurations described in paper by Waksman[10].

The authors observe that 'the presence of any type of collector case material (either combustible or noncombustible) directly above the roof covering appears to increase or enhance radiative heat transfer to the roof …'. However, they conclude that 'it is not known whether or not this [*increase in flame spread*] will result in a substantial increase in hazard in reducing the fire integrity of the roof deck itself.'

FIRE CLASSIFICATION RATINGS OF ROOFING MATERIALS

Roofing materials are evaluated for classification of fire ratings by tests conducted in accordance with UL 790: Tests for Fire Resistance of Roof Covering Materials. They are rank ordered in fire performance hierarchy of Class A, Class B or Class C.

- *Class A assemblies are considered to be effective against severe fire test exposures*
- *Class B assemblies are considered to be effective against moderate fire test exposures*
- *Class C assemblies are considered to be effective against light fire test exposures*

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[8] Z. Zhu, et al., Numerical Analysis of Heat Transfer in A Photovoltaic Module, I:Indoor Cases, International Communication of Heat and Mass Transfer, Vol. 29, No. 4, 2002, pp. 497-508.
[9] T. Ohuchi et al., Improvement of the Fire-Proofing and Fire-Resistance Properties of PV Modules for Building's Exterior Walls, IEEE, 2000, pp. 1533-1538.
[10] D. Waksman, et al., Fire testing of solar collectors by ASTM E 108, Fire Technology, Vol. 18, No. 2, 1982.

The fire performance ratings are determined from the results of three different fire tests described in UL 790: (i) Spread of flame test, (ii) Intermittent flame test and, and (iii) Burning brand test. In this research, the focus will be on Spread of Flame and Burning brand tests since these are the required fire tests in UL 1703.

SPREAD OF FLAME TEST

The Spread of Flame Test measures the potential for flame spread across the surface of the roof assembly using a constant flame source. The setup for the test is shown in Figure 3.

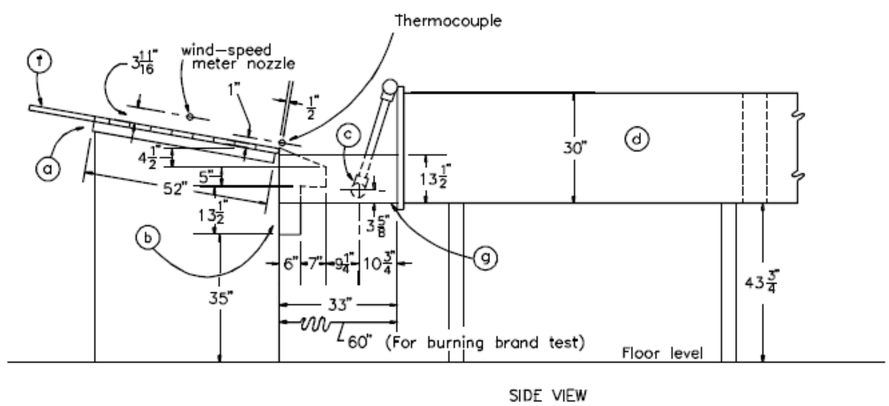

Figure 3 Test setup for UL 790

The flame source is approximately triangular in shape, measuring 3 feet (0.9 m) wide at the leading edge of the deck. The gas supply is regulated so that the flame is within the range from 21,000 to 22,000 Btu per minute (369 to 387 kWh) for Class A and 18,000 to 19,000 Btu per minute (316 to 334 kWh) for Class C samples. For a Class A test, the gas flame is to be applied continuously for 10 minutes or until the spread of flame (flaming of the material being tested) permanently recedes from a point of maximum spread, whichever is the shorter duration. For a Class C test, the gas flame is to be applied for 4 minutes and then removed.

Class A is achieved if the maximum flame spread does not exceed 6 feet. Class B is achieved if the maximum flame spread does not exceed 8 feet. Class C is achieved if the maximum flame spread does not exceed 13 feet. For all classifications, the fire cannot spread laterally to both edges of the test deck, burning or glowing particles cannot fall to the floor and continue to burn or glow, and a combustible roof deck cannot be exposed (visible) at the conclusion of the test. For all classifications, air is introduced over the surface of the test sample at a velocity of 12 mph. For Class A & B, the test duration is 10 minutes. For Class C, it is a 4-minute test.

INTERMITTENT FLAME TEST

The Intermittent Flame Test measures the potential for fire to penetrate from the outside of the roofing assembly to the underside (inside the building) of the combustible roof deck using a variable flame source. The flame temperature and wind speed are identical to those listed in the Spread of Flame Test. Successful results are achieved provided there is no sustained flaming (a continuous burning flame) of the underside of the test deck and burning or glowing particles do not fall to the floor and continue to burn or glow. It should be noted that the intermittent flame test is not required in the standard for PV modules, UL 1703 Flat-Plate Photovoltaic Modules and Panels and was not part of this research project.

Test conditions are shown in the following in Table 1.

Table 1

	Ignition On (min)	Sequence Off (min)	Number of Cycles	Duration After Last Cycle (min)
Classification				
A	2	2	15	60
B	2	2	8	60
C	1	2	3	30

Burning Brand Test

The Burning Brand test measures the potential for fire to penetrate from the outside of the roofing assembly to the underside (inside the building) of the combustible roof deck using a burning brand fire source. The brands (Figure 4) are positioned on the top surface of roof assembly at locations as described in the standard. Successful results are achieved provided there is no sustained flaming (a continuous burning flame) of the underside of the test deck and burning or glowing particles do not fall to the floor and continue to burn or glow.

Brand A Brand B Brand C

Figure 4 – UL 790 - Burning Brands

FIRE CLASSIFICATION RATINGS OF PV MODULES

PV modules are evaluated for fire classification rating by tests conducted in accordance with UL 1703 Flat-Plate Photovoltaic Modules and Panels[11]. The standard uses the Spread of Flame Test and the Burning Brand Test described in UL 790. In the test, the PV module is placed directly on the roof deck. The Burning Brand test is conducted with the brand(s) placed on top surface of the PV module. The PV modules are rank ordered in a performance in a hierarchy of Class A, Class B or Class C consistent with roofing products.

The performance criteria in UL 1703 for the spread of flame test are as follows:

"At no time during or after the tests shall:

> *a) Any portion of the module or module be blown off or fall off the test deck in the form of flaming or glowing brands;*
>
> *b) Portions of the roof deck, or portions of a module or module intended for installation integral with or forming a part of the building roof structure, fall away in the form of glowing particles;*
>
> *c) The flame spread beyond 6 ft (1.82 m) for Class A, 8 ft (2.4 m) for Class B, or 13 ft (3.9 m) for Class C rating. The flame spread is to be measured from the leading edge of the sample; or*
>
> *d) There be significant lateral spread-of-flame from the path directly exposed to the test flame. Spread-of-flame includes flaming on both the top surface (the surface to which the external flame is applied) and in any intermediate channel, such as the space between stand-off or integral modules and a shingle roof."*

The performance criteria in UL 1703 for the burning brand test are as follows:

"At no time during or after the tests shall:

> *a) Any portion of the module or module or be blown off or fall off the test deck in the form of flaming or glowing brands;*
>
> *b) The brand burns a hole through the roof covering or through any part of the module or module;*
>
> *c) Portions of a module or module intended for installation integral with, or forming a part of, the building roof structure fall away in the form of glowing particles; or*
>
> *d) There be sustained flaming of the module or module."*

As a result of catastrophic fires in California, State Fire Officials are considering a statewide requirement for Class A fire rating of all roofing products including photovoltaic (PV) modules. To date, there are few Class A rated PV modules or building-integrated photovoltaic (BIPV) products from all the several hundred listed modules. At present, the effect of fire on UL 790 fire Class A rated roofing materials when Class C rated PV modules are installed is not

[11] http://ulstandardsinfonet.ul.com/

well understood. For instance will a Class C rated module reduce the fire resistance performance and/or fire rating of some Class A rated roof systems? If so, which roof systems are impacted and to what extent?

RESEARCH INVESTIGATION

RESEARCH OBJECTIVES

The objectives of this research project:

- *Develop baseline data on the fire exposure during standard fire tests such as UL 790*
- *Determine the effect of installation parameters for elevated PV modules on roofs*
- *Document the impact of lesser fire rated elevated PV modules on common roofing materials*

To meet these objectives, the research was conducted in three phases as depicted in Figure 5.

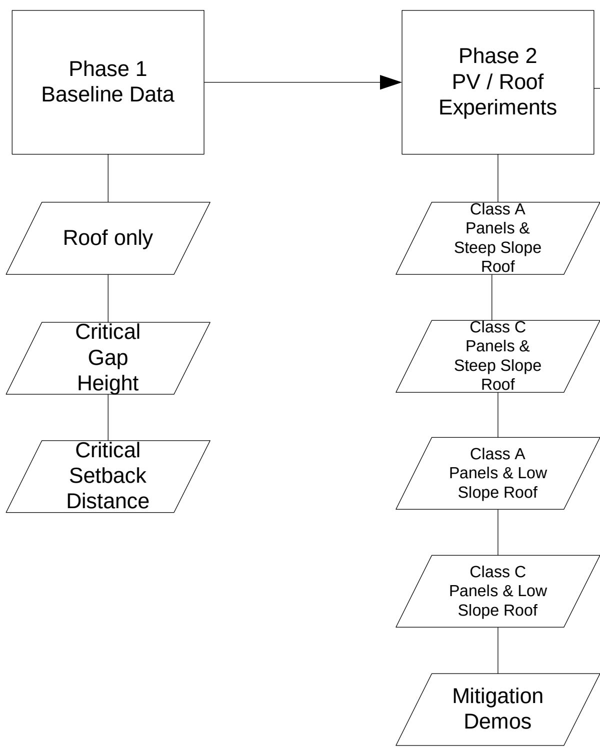

Figure 5 Outline of Research Investigation

For Phase 1, the interaction of the module and the roof as an assembly was investigated during standard fire tests described within UL 790. Experiments were carried out using instrumented simulated noncombustible PV panel and roof deck to study the influence on fire hazard of different PV installation parameters such as (i) gap or standoff height above the roof, (ii) PV set back from the roof edge, and (iii) orientation of the non-combustible mounting rails for the PV module. In addition, a limited number of experiments were conducted using actual PV modules mounted on Class A rated roof shingles to demonstrate impact to the fire classification rating of roofing during Spread of Flame and Burning Brand tests.

Based on the results of the Phase 1 tests, a Phase 2 test program was designed to investigate the fire performance of fire rated roof mounted PV modules on specific Fire Class roofing materials.

TECHNICAL PLAN

The technical plan consisted of the following tasks for each phase of this investigation:

Phase 1:

Task 1 - Select and acquire test samples.

Task 2 - Perform experiments with noncombustible roof and noncombustible PV module surrogate.

Task 3 - Perform limited experiments with combustible roofs and combustible PV modules to demonstrate effects on the fire classification rating of roof assemblies using the spread of flame spread and burning brand tests.

Phase 2:

Task 4 - Perform experiments with various fire classification rated classified roof assemblies/PV module combinations.

PHASE 1/ TASK 1 – SELECT AND ACQUIRE TEST SAMPLES

ROOFING MATERIALS

A review of commercially available roofing products was performed in an effort to develop a representative sample of various technologies applied to low and high-sloped roofing systems. Within Class A, roofing materials exhibit varying degrees of performance and can be further described as nominal or good performance. One example is the difference between standard three tab shingles (nominal) as compared to architectural shingles (e.g., laminated or dimensional shingles). The architectural shingles are typically constructed of a heavier base mat and are multi layered, and typically perform better in fire classification tests than the standard three tab shingles.

As result of the survey, 5 different roofing products (along with one noncombustible board) were selected for evaluation. The materials were purchased from a local retailer. The roofing materials are listed in Table 2. The fire performance ratings for roofing material ratings were obtained from UL database based on the manufacturers of the selected roofing materials.

Table 2 - Description of Roof Assemblies

Test Material	Description	Rating
Shingle	Asphalt impregnated fiberglass mat three tab shingle	A
Shingle	Asphalt impregnated fiberglass laminated mat or 'architectural' shingle	A
Shingle	Cedar shake shingle	C
Membrane	2" thick rigid Isocyanurate foam covered with a single ply of Ethylene propylene diene monomer (EPDM) membrane	A
Hot Mopped	Asphalt-coated glass-fiber mat (felt) – Type G1 (ply sheets), and a Type G3 (granular-surfaced cap sheets)	A
Board	4 x 8 ft. non combustible board	A

PHOTOVOLTAIC MODULES

PV modules were donated by manufacturers and provided to UL by Solar ABCs. The PV modules were not identified with respect to the model or their manufacturer. The fire performance ratings for the PV modules were simply assigned based on the observed construction of the module i.e., metal back plane = Class A, plastic back plane = Class C.

PHASE 1/TASK 2 – EXPERIMENTS WITH NONCOMBUSTIBLE ROOF AND PV MODULE

The objective of this task was to develop fire characteristics of a roof mounted PV module on a roofing assembly subject to the standard fire tests such as UL 790/UL 1703.

TEST MATRIX

Based upon discussion with SolarABCs representatives, installation variables were selected that would be expected to influence the fire performance of a rack mounted PV module on a roof. These included (i) installation gap between the bottom of the PV module and the roof surface and (ii) distance of the installed PV module from the leading edge or setback of the roof. Specific gap and setback distances selected for this study are shown in Table 3.

Table 3 – Selected Gap and Setback Distances

Item	Selected Distances (in.)
Gap	2.5, 5, 10
Setback	0, 12, 24

A test matrix was developed as presented in Table 4. The test matrix included a baseline test on the roof assembly to develop temperature and heat flux data from the flame exposure for comparative purposes.

Table 4 – Phase 1 Test Matrix

Test Run #	Gap (in)	Setback (in)	Rail
1	No Module	No Module	N/A
2	2 1/2	0	N/A
3	2 12	12	N/A
4	2 1/2	24	N/A
5	5	0	Vertical
6	5	0	Horizontal
7	10	0	N/A
8	10	12	N/A
9	10	24	N/A
10	5	0	N/A
11	5	24	N/A
36	5	12	N/A

TEST SET-UP

In this task, both the roof and the PV module were simulated using a noncombustible board to isolate the influence of the installed module on the thermal impact to the roofing assembly. Experiments were conducted using UL's standard roofing fire test assembly.

The noncombustible roof assembly was constructed with frame of 2 x 4 in. wood studs as supports. The surface of the roof was covered with ¼ in noncombustible material. The simulated PV module was constructed with a frame of 2 x 4 in. wood studs as supporting members. The top and bottom surfaces of the structure were covered with ¼ in. noncombustible material. The leading edge of the simulated PV module was protected with ¼ in noncombustible material.

All tests were performed in this investigation at a roof slope of 5 inches vertical to the horizontal foot, 5/12 (23°) with the PV module configured parallel to the roof. The simulated PV module was supported on the roof surface with metal rods. The supports could be adjusted to control the gap between the module and the top of the roof surface. A typical set up is shown in Figure 6.

Figure 6 Photograph of Noncombustible PV Module & Roof Deck Test Fixture

INSTRUMENTATION

The test assembly was fitted with thermocouples, heat flux gages and bi-directional velocity probes as shown in Figure 7.

Thermocouples

The thermocouples were type K (chromel–alumel, 24-gauge, fiberglass insulated with exposed tip) fabricated by UL laboratory staff. The thermocouples were mounted along the centerline of the roof deck and simulated PV module surface.

Heat Flux Gauges

Heat flux gauges were manufactured by Medtherm Corporation of Huntsville, AL, model 64-5SB-20, 0-50 kW/m^2 range. The gauges were mounted on the surface of the roof deck along the centerline.

Bi-directional probe and Pressure Transducer

The bi-directional probe was manufactured by Select Metals, Elmhurst, IL. The pressure transducer was manufactured by MKS Instruments of Methuen, MA, model 220DD-0000-1B2B, 0-1 Torr (0-1 mm/hg) range. The bi-directional probe was mounted along the centerline and in the approximate middle of the gap formed by the roof deck and simulated PV module.

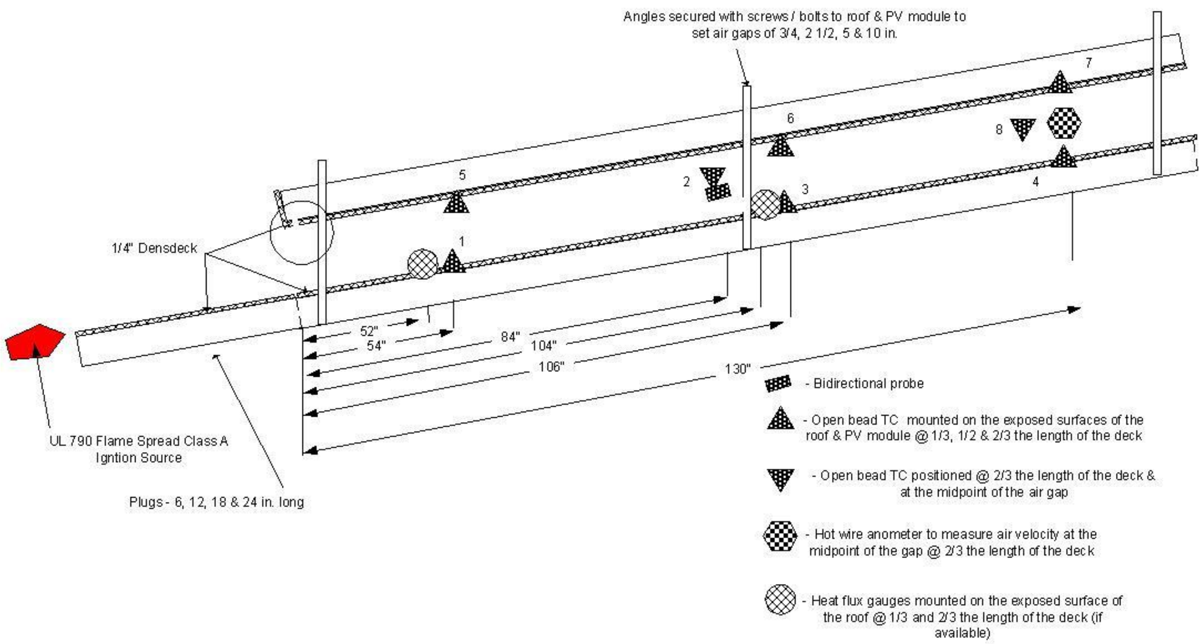

Figure 7 Illustration of Instrumentation

Video and Photography

The experiments were documented using video and still photography.

Data Acquisition

An automated data acquisition system was used to record the temperature, heat flux, and velocity data during the tests at a scan rate of 1 s.

TEST PROCEDURE

A baseline test was first conducted to develop temperature and heat flux data from the flame exposure in accordance with Class A Spread of Flame test described in UL 790. For all other tests, a simulated PV module was mounted to the roof with the selected gap and setback distances. The assembly was exposed to flame exposure in accordance with Class A Spread of Flame test described in UL 790. The test duration was 5 minutes.

RESULTS

The temperature and heat flux data from the fire tests are summarized in Table 5 for the twelve experiments.

Table 5 - Results for Spread of Flame test on simulated PV module and roof

Assembly ID	Gap (in)	Setback (in)	Rail	Temperature @ 5 mins			Average Temp Rise (last 30 sec)			Heat Flux Max	
				1 (°F)	3 (°F)	4 (°F)	1 (°F)	3 (°F)	4 (°F)	1 (kW/m^2)	2 (kW/m^2)
1	N/A	N/A	N/A	502	177	151	371	93	65	15	3
7	2 1/2	0	N/A	948	465	362	859	355	260	23	9
9	2 12	12	N/A	747	384	292	679	313	211	16	8
11	2 1/2	24	N/A	457	294	232	261	175	135	7	6
12	5	0	Vertical	974	768	562	-	-	-	29	22
17	5	0	Horiz.	1008	751	604	909	688	513	34	17
22	10	0	N/A	630	373	327	-	-	-	19	9
24	10	12	N/A	551	374	332	458	292	246	17	7
26	10	24	N/A	490	317	280	381	223	183	11	7
34	5	0	N/A	1066	719	576	939	637	508	41	25
35	5	24	N/A	600	430	369	499	334	279	12	9
36	5	12	N/A	865	518	406	703	428	316	23	12

Photographs from select test runs are presented in Figure 8 through Figure 12. Of particular interest is physical capture or deflection of the source flames in the channel formed between the bottom of the module and the top of the roof surface.

Figure 8 Photograph of Spread of Flame test baseline (Assembly 1)

Figure 9 Photograph of Non-combustible Roof and Simulated PV Module Spread of Flame Test with 0" Setback and 10" Gap (Assembly 22)

Figure 10 Photograph of non-combustible Roof and Simulated PV Module Spread of Flame test with 0” Setback and 2.5” Gap (Assembly 7)

Figure 11 Photograph of non-combustible Roof and Simulated PV Module Spread of Flame test with 0” Setback and 5” Gap (Assembly 12)

Figure 12 Photograph of Non-combustible Roof and Simulated PV Module Spread of Flame test with 12" Setback and 5" Gap (Assembly 36)

ANALYSIS OF DATA

Next, the temperature and heat flux data are analyzed. For the figures in this section, the legend may be interpreted as follows:

- *TC – Thermocouple data*
- *HF – Heat flux gauge data*
- *A-xx – Assembly ID (Table 5)*

For example, TC-1 A-1 refers to thermocouple position 1 of assembly 1 and HF-1 A-34 refers to heat flux gage position 1 of assembly 34. Sensor numbers are based upon Figure 7.

Figure 13 shows the temperature measurements from forward thermocouples placed on the noncombustible roof. From this figure, it is clear that the 5" gap (A-34) leads to the highest temperatures followed by the 2.5" gap (A-7). The 10" gap (A-22) case is approximately 100° F above the roof-only case (A-1). For all these cases, it can be seen that there is an initial rapid rise – within 20 seconds - in temperatures followed by a more gradual increase over the 300 second testing period.

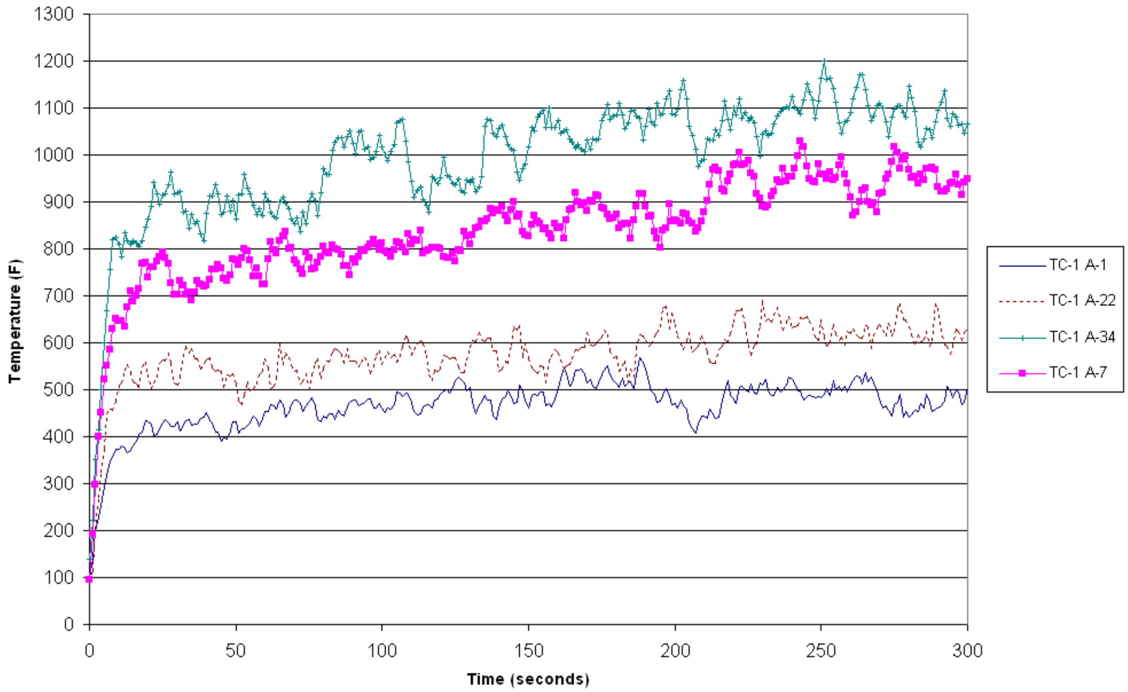

Figure 13 Influence of Gap Distance on Roof Temperature – 54 inches from the Roof Leading Edge

Figure 14 shows the temperatures for two thermocouples placed along the noncombustible roof located at 106 and 130 inches from the roof leading edge. For all cases, the thermocouple reading at the middle was higher than that of the end of the roof. Once again, the 5" gap case generated the highest temperatures along the roof surface while the 2.5" gap was the next lowest. The thermocouple reading for the end of the 2.5" gap case was very close to the readings from both thermocouples for the 10" gap case. The readings for the 10" gap case show that the difference between the middle and end thermocouple measurements was much less than that for the two previous cases. Finally, the case with roof-only component shows the lowest temperatures.

Figure 15 shows readings from the forward thermocouple located on the underside of the non-combustible simulated PV module. For the case with roof only, the reading is simply that of ambient air. These readings display similar trends and values as seen in Figure 13.

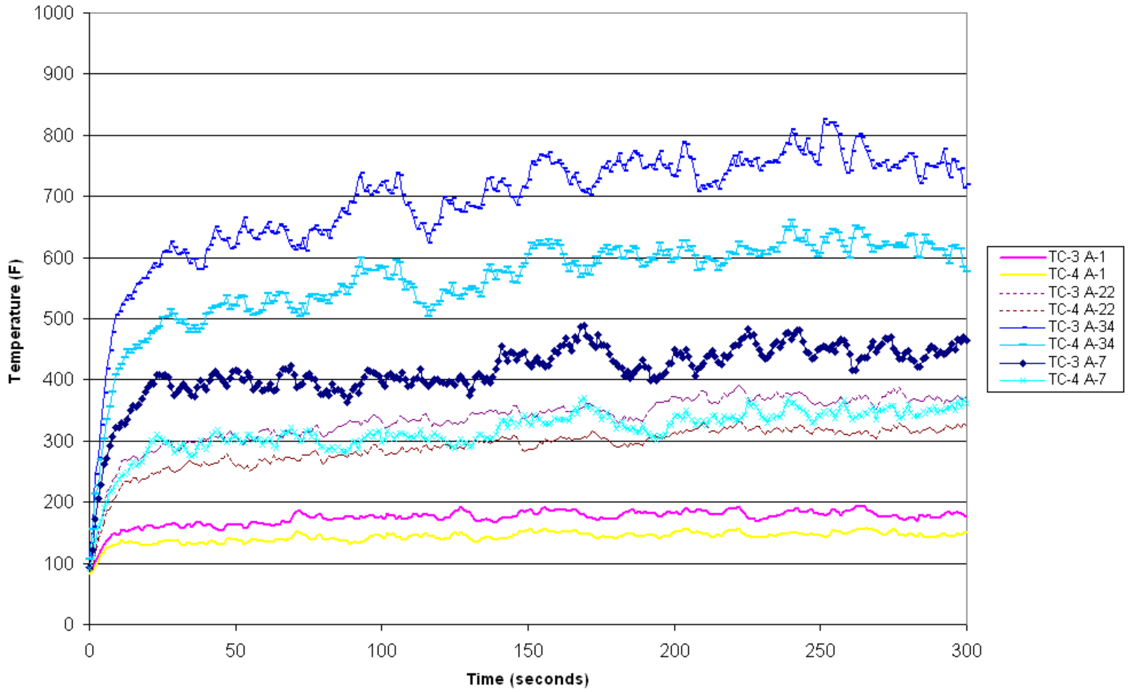

Figure 14 Influence of Gap on Roof Temperature: 106 and 130 inches from the Leading Edge

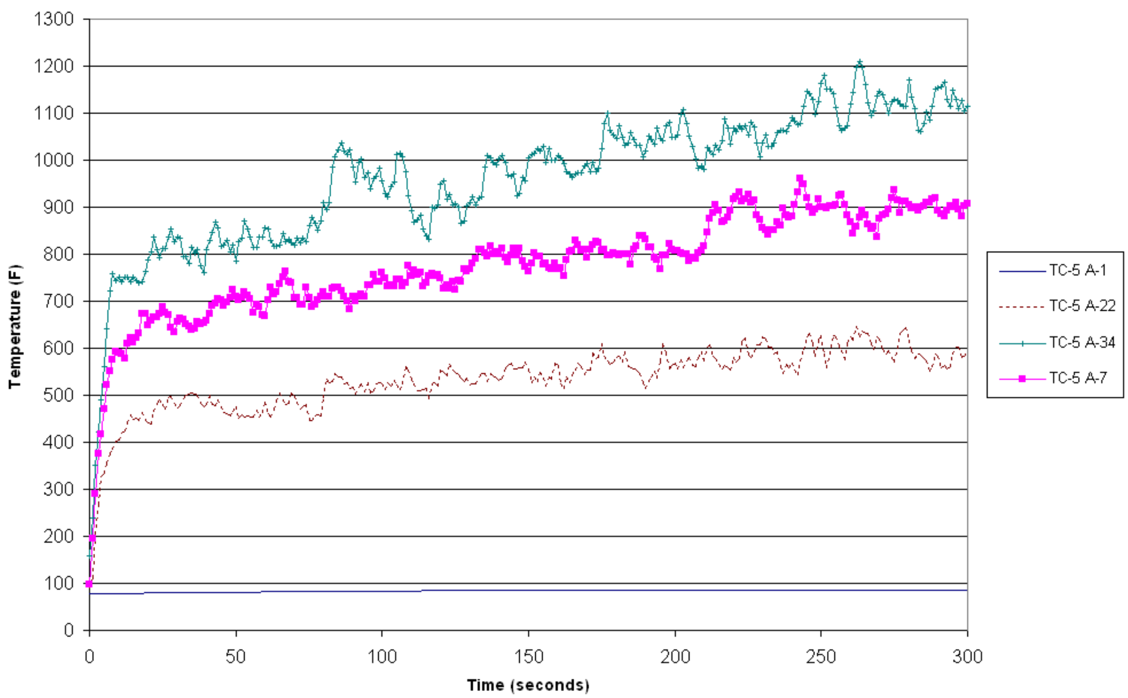

Figure 15 Temperature a the Bottom Surface Simulated PV Module – 54 inches from the Roof Leading Edge

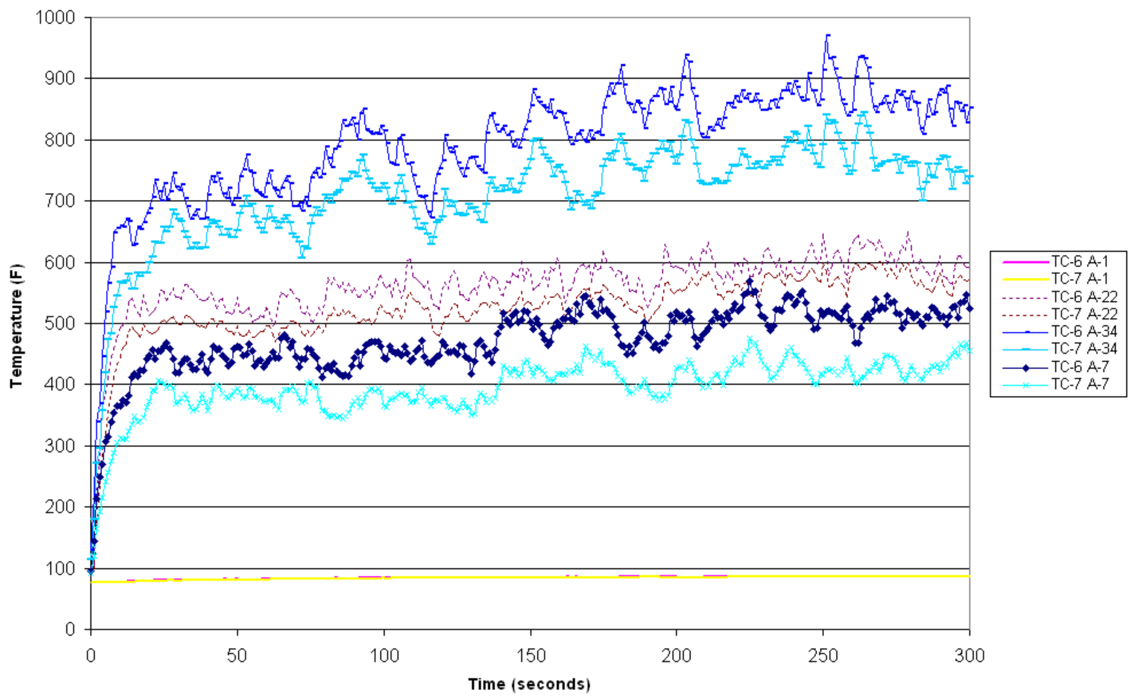

Figure 16 Temperature at Bottom Surface of Simulated PV Module: 104 and 130 inches from the Roof Leading Edge

Figure 16 shows readings from thermocouples located at 106 and 130 inches from the leading edge on the bottom surface of the noncombustible simulated PV module. It is interesting to note that these temperatures are higher than those recorded by the middle and end thermocouples on the surface of the noncombustible roof for each respective case. The 5" gap case still generated the highest temperatures. However, the next highest temperatures were generated for the 10" gap case, not the 2.5" gap case, as was seen for the roof surface temperature readings in Figure 13.

Figure 17 and Figure 18 display heat flux gauge readings of the noncombustible roof surface at 54 and 106 inches from the roof leading edge, respectively. Matching the trends seen in the temperature, the 5" gap case generated the largest values of heat flux after a very rapid rise. In Figure 17 these values reached as high as 40 kW/m^2 especially near the end of the testing period. Even the case without a noncombustible roof component generated heat flux as high as 15 kW/m^2 for a very brief moment while most of the values oscillated about 10 kW/m^2.

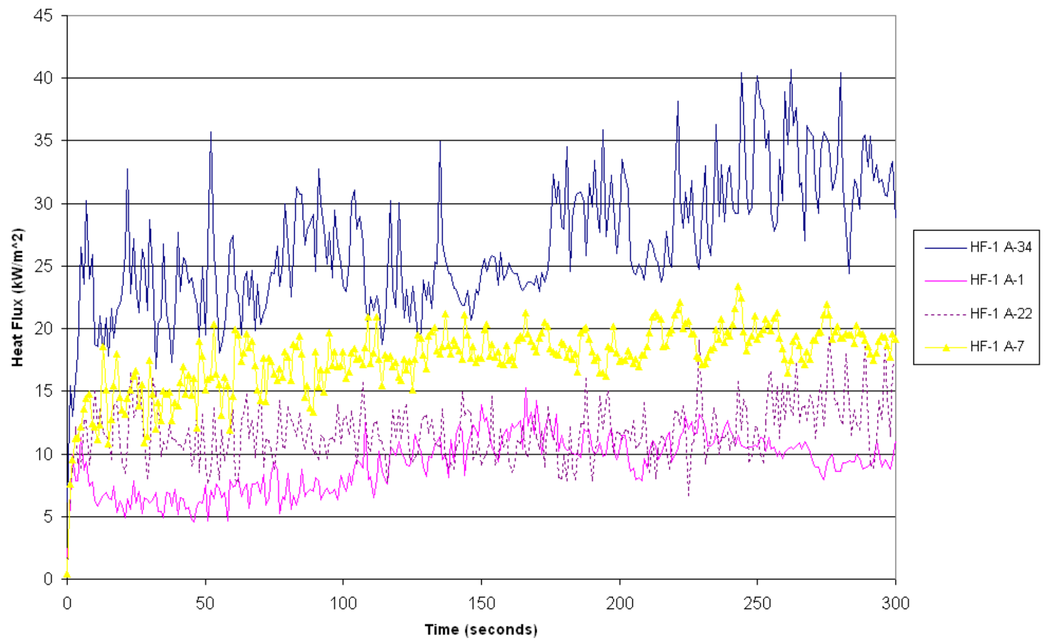

Figure 17 Heat Flux on Roof Surface – 54 inches from the Roof Leading Edge

In Figure 18 once again, the 5" gap case shows the largest amount of heat flux for the middle gauge with values reaching approximately 20 kW/m², almost half that of the forward gage. However the heat flux values for the 2.5" and 10" gaps were indistinguishable while the no PV component case resulted in a nearly steady value of 2-3 kW/m².

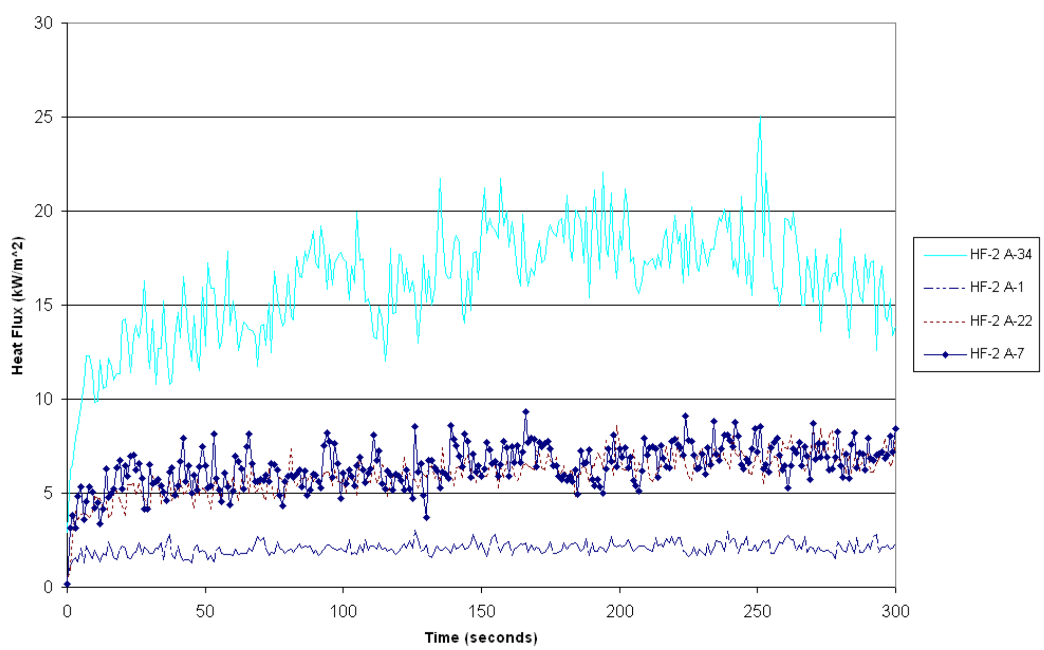

Figure 18 Heat Flux on the Roof: 106 inches from the Roof Leading Edge

Figure 19 shows the effect of the leading edge distances on the temperatures measured on the thermocouple positioned near the front of the non-combustible roof surface for a gap of 5”. This data shows the drop in temperature that occurs as a result of placing the leading edge of the non-combustible simulated PV module further from the roof leading edge and subsequently the fire.

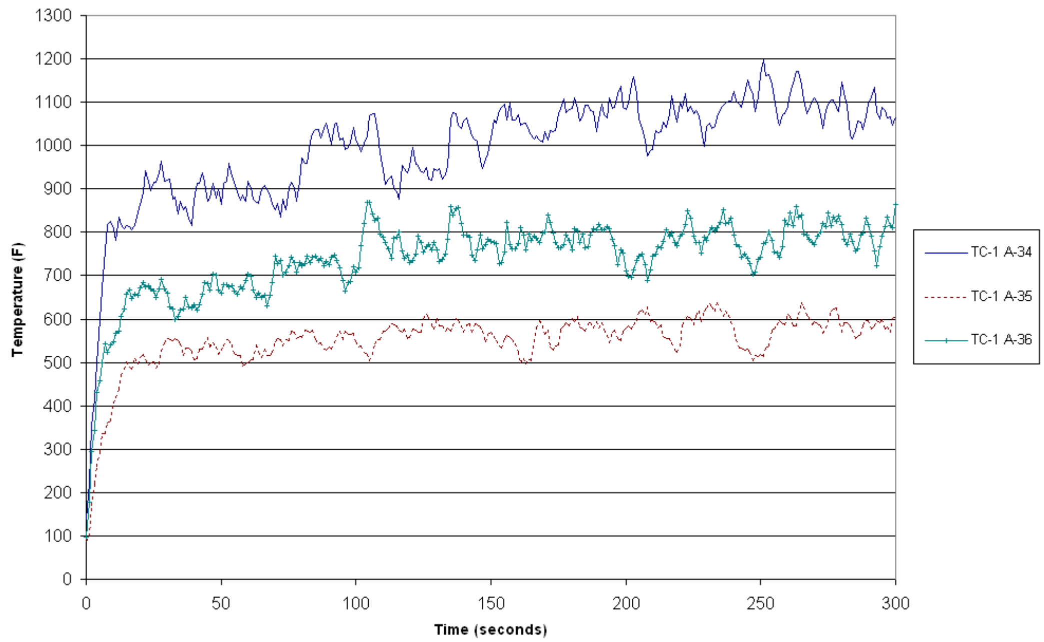

Figure 19 Influence of Setback on Roof Temperature: 54 inches from the Roof Leading Edge

Figure 20 shows the temperature results for thermocouples placed in the middle and near the end of the non-combustible roof component as a function of leading edge distances for a gap of 5”.

The greater the distance of the leading edge of the simulated PV from the leading edge of the roof, the lower will be the surface temperature along the roof. For the 24” leading edge test, the recorded temperature for the leading thermocouple on the roof surface was basically following the test temperatures seen for the 10” gap with no leading edge. Clearly as the setback distance is increased further, it effectively behaves as a roof without PV module for this particular fire setup. These results are expected to hold for the typical ranges of PV/roof gap sizes.

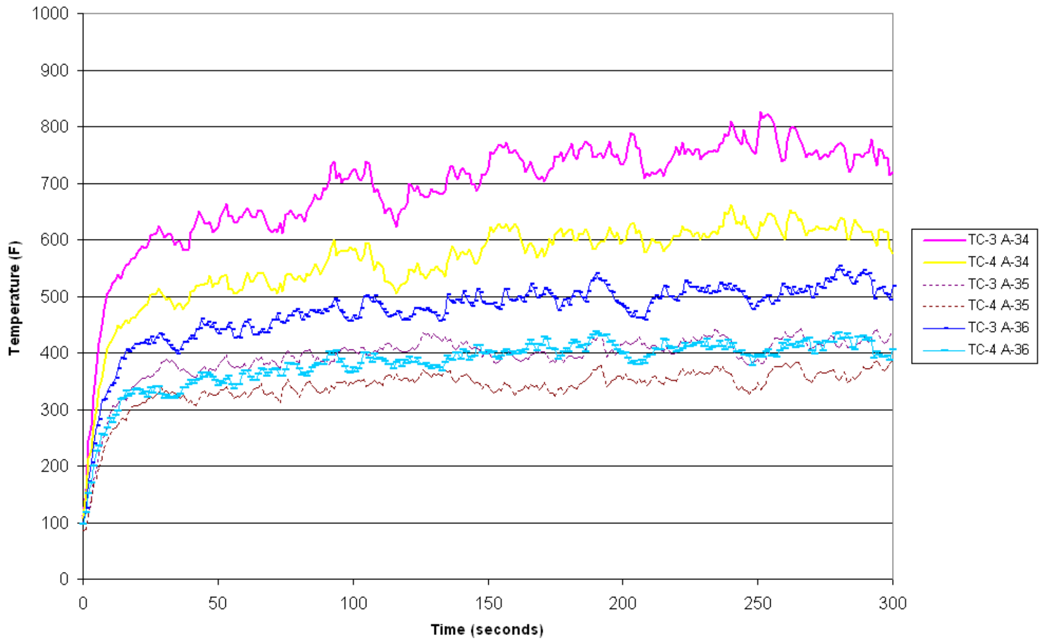

Figure 20 Influence of Setback on Roof Temperature: 106 and 130 inches from the Roof Leading Edge

Figure 21 shows the temperature from the 54-inch location thermocouple on the underside the noncombustible simulated PV module for a gap of 5" as a function of setback. Here again, the same trend is observed for simulated PV temperatures as was seen for the roof temperatures in Figure 13.

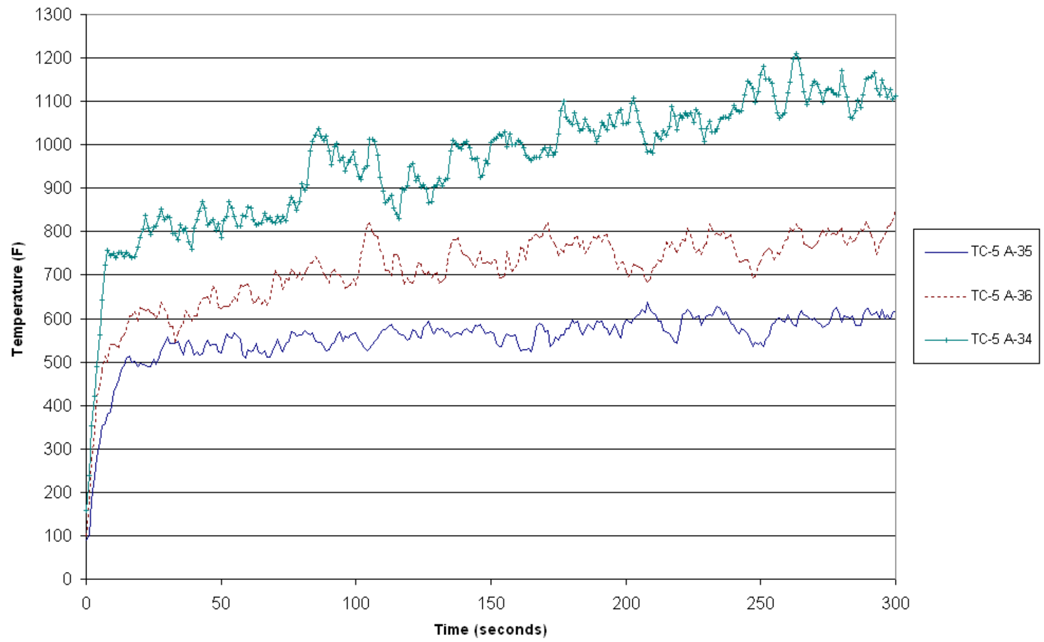

Figure 21 Influence of Setback on Simulated PV Module temperature: 54 inches from the Roof Leading Edge

Figure 22 shows the temperatures from thermocouples placed near the middle and the end of the underside of the noncombustible PV component for a gap of 5" as a function of setback distance.

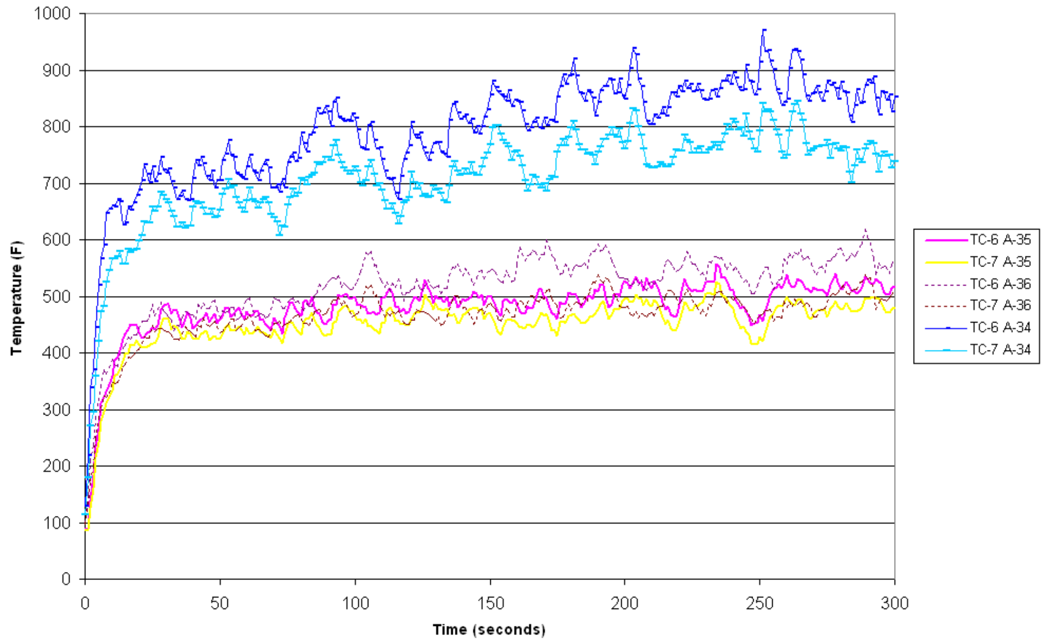

Figure 22 Influence of Setback on Simulated PV Module temperature: 106 and 130 inches from Roof Leading Edge

For these measurements, the same drop in temperature is observed as the setback distance is increased. However, for this particular case, changing the setback distance from 12" to 24" has minimal effect on the measured temperatures.

PHASE 1/TASK 3 LIMITED EXPERIMENTS WITH COMBUSTIBLE ROOFS AND PV

OBJECTIVE

The objective of this task was to conduct experiments on a limited number of PV module/roof combinations to demonstrate if the fire classification rating of a roof system is affected by the presence of a rack mounted PV module.

EXPERIMENTAL PARAMETERS

Experiments were conducted using the Spread of Flame and Burning Brand ignition sources as specified in UL 790 and UL 1703. The following combinations were demonstrated:

- Spread of Flame Test - Class A Shingle Roof w/ Class C PV, Vertical Mounts, 0" Set Back, 5.0" Gap
- Spread of Flame Test - Class A Shingle Roof w/ Class C PV, Horizontal Mounts, 0" Set Back, 5.0" Gap
- Burning Brand on Module - Class A Shingle Roof w/ Class C PV, 0" Gap – Burning Brand on Module
- Burning Brand Between Module and Roof - Class A Shingle Roof w/ Class C PV, 5" Gap

To quantify the effects of these variables, a series of demonstration experiments were conducted to document the results of standard Flame Spread and Burning Brand tests. Experiments were conducted using the standard method and test fixture as outlined in UL 790 and UL 1703. Modules were mounted above the roof surface at a gap of 5 inches.

RESULTS

- The experiment conducted subjecting a Class A shingle roof with a Class C PV incorporating *vertical* supports to the Spread of Flame ignition source resulted in flames extending beyond the roof deck in excess of 8 ft. – not in conformance with Class A requirements. (Figure 23 to Figure 26)

- The experiment conducted subjecting a Class A shingle roof with a Class C PV incorporating *horizontal* supports to the Spread of Flame ignition source resulted in flames extending beyond the roof deck in excess of 8 ft. – not in conformance with Class A requirements. (Figure 27 to Figure 30)

- The experiment conducted subjecting a Class A shingle roof with a Class C PV to a Class A burning brand positioned on the module surface was in conformance with the requirements. (Figure 31 to Figure 34)

- The experiment conducted subjecting a Class A shingle roof with a Class C PV to a Class A burning brand positioned between the PV module surface and the roof was in conformance with the requirements. (Figure 35 to Figure 38)

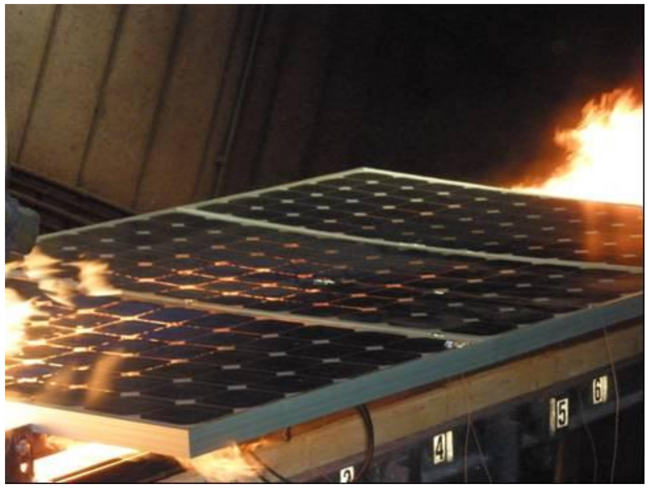

Figure 23 Photograph of Spread of Flame Test for Class A Shingle Roof with Class C PV and Vertical Mounts and 0" Leading Edge and 5" Gap

Figure 24 Photograph of Spread of Flame Test for Class A Shingle Roof with Class C PV and Vertical Mounts and 0" Leading Edge and 5" Gap

Figure 25 Photograph of Spread of Flame Test for Class A Shingle Roof with Class C PV and Vertical Mounts and 0" Leading Edge and 5" Gap

Figure 26 Photograph of Spread of Flame Test of Class A Shingle Roof with Class C PV and Vertical Mounts and 0" Leading Edge and 5" Gap

Figure 27 Photograph of Spread of Flame Test for Class A Shingle Roof with Class C PV and Horizontal Mounts and 0" Leading Edge and 5" Gap


Figure 28 Photograph of Spread of Flame Test for Class A Shingle Roof with Class C PV and Horizontal Mounts and 0" Leading Edge and 5" Gap

Figure 29 Photograph of Spread of Flame Test for Class A Shingle Roof with Class C PV and Horizontal Mounts and 0" Leading Edge and 5" Gap


Figure 30 Photograph of Spread of Flame Test for Class A Shingle Roof with Class C PV and Horizontal Mounts and 0" Leading Edge and 5" Gap

Figure 31 Photograph of Burning Brand on Module for Class A Shingle Roof with Class C PV and 0" Gap

Figure 32 Photograph of Burning Brand on Module for Class A Shingle Roof with Class C PV and 0" Gap

Figure 33 Photograph of Burning Brand on Module for Class A Shingle Roof with Class C PV and 0" Gap

Figure 34 Photograph of Burning Brand on Module for Class A Shingle Roof with Class C PV and 0" Gap

Figure 35 Photograph of Burning Brand Between Module and Roof for Class A Shingle Roof with Class C PV and 5" Gap

Figure 36 Photograph of Burning Brand Between Module and Roof for Class A Shingle Roof with Class C PV and 5" Gap

Figure 37 Photograph of Burning Brand between Module and Roof for Class A Shingle Roof with Class C PV and 5" Gap

Figure 38 Photograph of Burning Brand between Module and Roof for Class A Shingle Roof with Class C PV and 5" Gap

ANALYSIS

Spread of flame experiments conducted on Class A roof with Class C rated PV mounted on horizontal (parallel to roof edge) or vertical (perpendicular to roof edge) support rails illustrated no difference in the flame spread – both resulted in noncompliant flame spread in excess of the required maximum of 6 ft for Class A rated roof systems. These limited series of experiments indicate that the fire rating of the Class A roof is compromised in this situation.

Burning brand experiments conducted with a Class A brand positioned either on the surface of the module or on the surface of the roof resulted in compliant results for Class A requirements. This initial series of experiments indicate the fire rating of the Class A roof is not affected with a rack mounted Class C PV module. When the brand resides on the module which is elevated above the roof, there is a clearly a buffer helping increase fire resistance to fire brands. With the brand placed on the roof, the Class C PV burns and sags, creating an opening, which allows the flames to vent vertically. If the nature of the fire growth and spread on the PV should alter the ability of venting, then it might be possible to reduce the fire performance. For this reason, some of these tests were repeated in Phase 2.

PHASE 2/TASK 4 - EXPERIMENTS WITH VARIOUS FIRE-RATED ROOF ASSEMBLIES/PV MODULE COMBINATIONS

OBJECTIVE

The objective of this task was to conduct experiments, extending the work from Phase 1, on a variety of PV module/roof combinations to demonstrate how a PV module installed above the roof affects the classification of a fire-rated roof system.

EXPERIMENTAL PARAMETERS

Experiments were conducted using the Spread of Flame and Burning Brand ignition sources as specified in UL 790 and UL 1703. For the spread of flame test, the roofing material and the PV fire rating were the experimental parameters (Table 6). Similarly, for the Burning Brand test, the roofing material and the PV fire rating were experimental parameters along with the location of the Burning Brand (Table 7).

RESULTS

All spread of flame experiments (Class C PV / Class A 3 tab shingle roof, Class C P V / Class C wood shake shingle roof, Class A PV / Class A membrane roof, Class C PV / Class A laminated shingle roof, and Class C PV / Class A built-up roof) resulted in flame propagation beyond the length of the roof deck (>8 ft), which was not in conformance with the requirements of Class A roofing systems (<6 ft).

Table 6 Phase 2 Spread of Flame Test Results

Assembly ID	Gap (in)	Setback (in)	Roof Rating	Roof Slope (in/in)	PV Rating	Flame Spread Data Distance (feet)[1]	Flame Spread Data Time (min:sec)
5	5	0	A - 3 Tab Shingle	5/12	C	>8	4:17
1	5	0	Noncombustible	5/12	C	>8	2:03
7	5	0	C - Wood Shake	5/12	C	>8	0:47
14	5	0	A - membrane	0.5/12	A	>8	1:00
3	5	0	A - Architectural Shingle	5/12	C	>8	1:57
11	5	0	A - Hot Mopped	0.5/12	C	>8	1:43
19	5	0	Noncombustible	5/12	A	>8	5:47

Note: 1 – The flames extended beyond the length of the deck (8 ft).

The Burning Brand experiment conducted with a Class C PV/Class A shingle roof with the brand positioned on the surface of the module was in conformance with the requirements for Class A roofs. The Burning Brand experiment conducted with a Class C PV/Class C wood shake shingle roof with the brand positioned on the surface of the roof was not in conformance with the requirements for Class C roofs. Tests conducted with a Class C PV/Class A shingle roof with the brand positioned on the roof surface resulted in inconsistent results – one in conformance, one not in conformance with the requirements for Class A roofs.

Table 7 Phase 2 Burning Brand Test Results

Assembly ID	Brand Location	Gap (in)	Setback (in)	Rail	Roof Rating	PV Rating	Duration (Hr:Min:Sec)	Pass / Fail
1	PV surface	5	0	Horizontal.	A - 3 Tab Shingle	C	0:45:00	Pass
2	Roof surface	5	0	Horizontal	A - 3 Tab Shingle	C	1:30:16	Pass
4	Roof surface	5	0	Horizontal	C - Wood Shake	C	0:30:09	Fail
3	Roof surface	5	0	Horizontal	A - 3 Tab Shingle	A	0:16:47	Fail

Visual results are provided in the following photographs.

Figure 39 Photograph of Spread of Flame Test for Class C Wood Shake Roof with Class C PV and 0" Leading Edge and 5" Gap – before start of experiment

Figure 40 Photograph of Spread of Flame Test for Class C Wood Shake Roof with Class C PV and 0" Leading Edge and 5" Gap

Figure 41 Photograph of Spread of Flame Test for Class A Membrane Roof with Class A PV and 0" Leading Edge and 5" Gap – prior to start of experiment

Figure 42 Photograph of Spread of Flame Test for Class A Membrane Roof with Class A PV and 0" Leading Edge and 5" Gap

Figure 43 Photograph of Spread of Flame for Class A Laminated (Architectural) Shingle Roof with Class C PV with 0" Leading Edge and 5" Gap – before start of experiment

Figure 44 Photograph of Spread of Flame for Class A Laminated (Architectural) Shingle Roof with Class C PV with 0" Leading Edge and 5" Gap

Figure 45 Photograph of Spread of Flame for Class A Built Up Roof (Hot Mopped Asphalt) with Class C PV and 0” Leading Edge and 5” Gap – before start of experiment

Figure 46 Photograph of Spread of Flame for Class A Built Up Roof (Hot Mopped Asphalt) with Class C PV and 0” Leading Edge and 5” Gap

Figure 47 Burning Brand Test for Class A Shingle (3 tab) with Class C PV where Class A brand is located on the surface of the roof under the module

Figure 48 Burning Brand Test for Class A Shingle (3 tab) Roof with Class C PV where Class A brand is located on the surface of the roof under the module

Figure 49 Underside of Roof Deck View: Burning Brand Test for Class A Shingle (3 tab) roof with Class C PV where Class A brand was located on the surface of the roof under the module

Figure 50 Burning Brand Test for Class C Wood Shake Roof with Class C PV where Class C brand was located on the surface of the roof

Figure 51 Burning Brand Test for Class C Wood Shake Roof with Class C PV where Class C brand was located on the surface of the roof

Figure 52 Underside of Roof Deck View: Burning Brand Test for Class C Wood Shake Roof with Class C PV where Class C brand was located on the surface of the roof

Figure 53 Burning Brand Test for Class A Shingle (3 tab) Roof with Class A PV where Class A brand was located on the surface of the roof under the module

Figure 54 Burning Brand Test for Class A Shingle (3 tab) Roof with Class A PV where Class A brand was located on the surface of the roof under the module

Figure 55 View of Deck Underside: Burning Brand Test for Class A Shingle (3 tab) Roof with Class A PV where Class A brand was located on the surface of the roof under the module

ANALYSIS

All Spread of Flame experiments (Class C PV / Class A 3 tab shingle roof, Class C P V / Class C wood shake shingle roof, Class A PV / Class A membrane roof, Class C PV / Class A laminated shingle roof, and Class C PV / Class A built-up roof) resulted in flame spreads that were noncompliant for Class A rating. These Phase 2 test results validate the Phase 1 experiments and strongly point out that the fire rating of the Class A roof is decreased when PV modules are mounted above a roof with a gap allowing for fire spread between the products.

This series of Burning brand experiments indicate that wood shake shingle fire performance is decreased when a Class C PV module is elevated above the roof and the fire is located between the module and the roof. In the case of a Class C PV elevated above a Class A shingle roof the fire performance is not affected when the fire is located on the surface of the module. In the case of a Class C PV / Class A shingle roof with the fire located between the module and the roof the fire performance may or may not be decreased.

SUMMARY OF FINDINGS

An analysis of the data generated by the experiments carried out in this study point to the following key findings:

- A baseline of the temperature and heat flux exposure to the roof under the UL 790 test conditions was established and is shown in Figure 56.

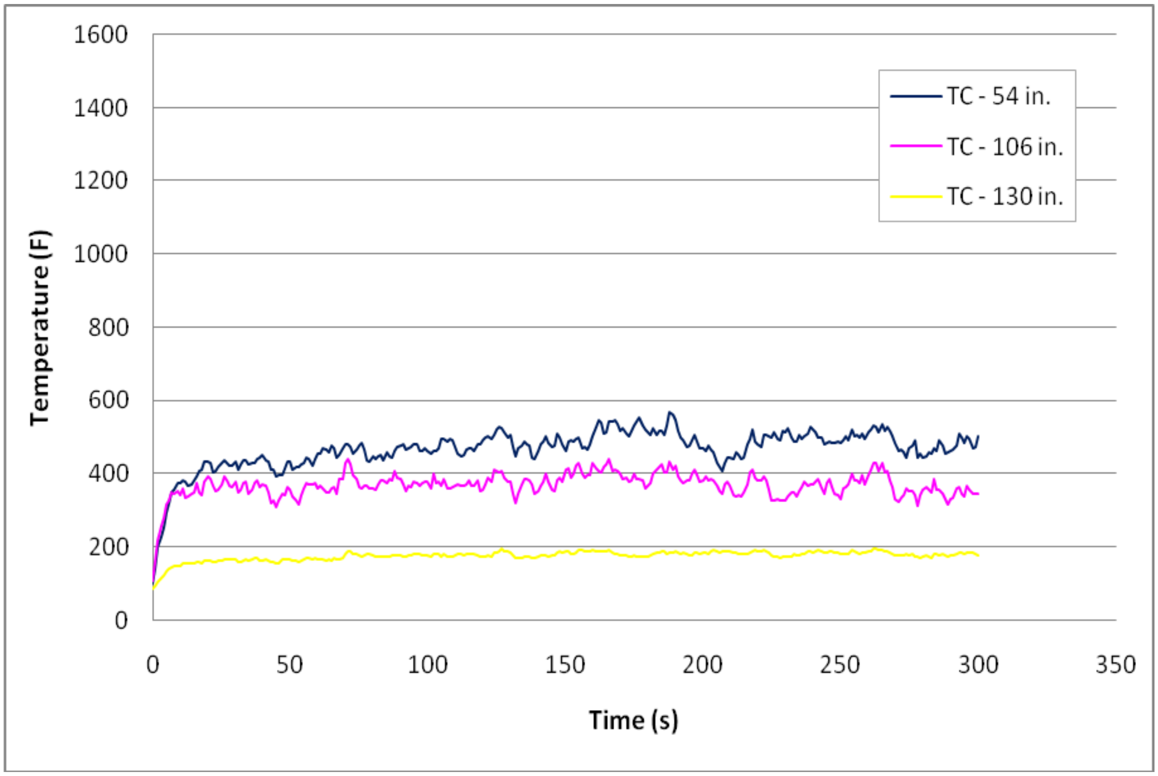

Figure 56 - Baseline Temperature

- The effect on roof temperature of a PV module mounted at a height of 5 inches above the roof surface and varying the setback of the module from the edge of the roof was measured and are shown in Figures 57 through 59.

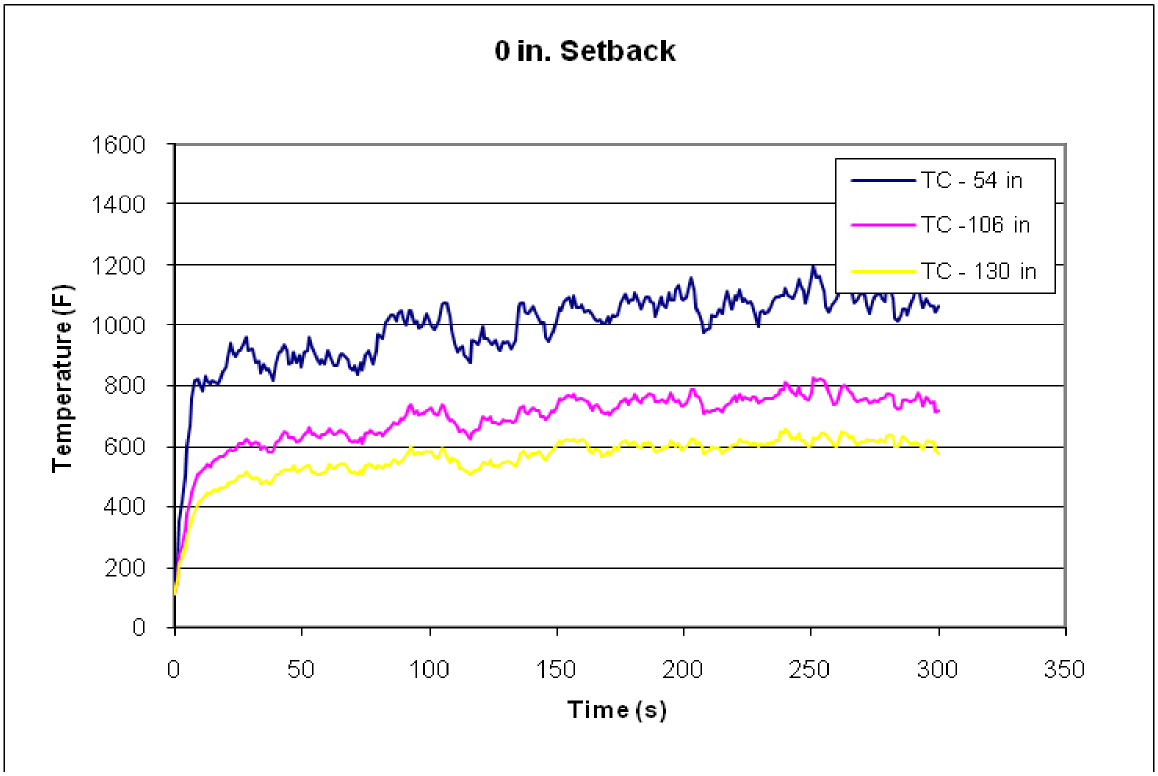

Figure 57 - Temperature of Roof with PV Module Mounted at 5" with 0" setback

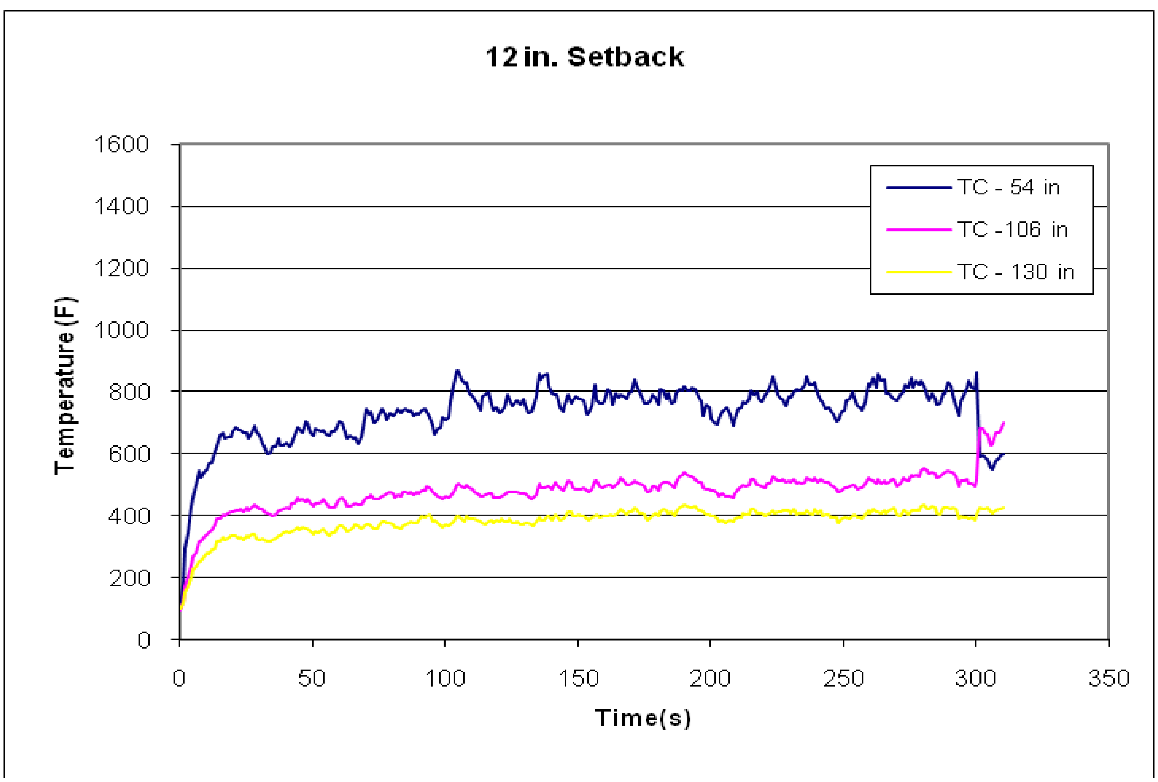

Figure 58 - Temperature of Roof with PV Module Mounted at 5” with 12” setback

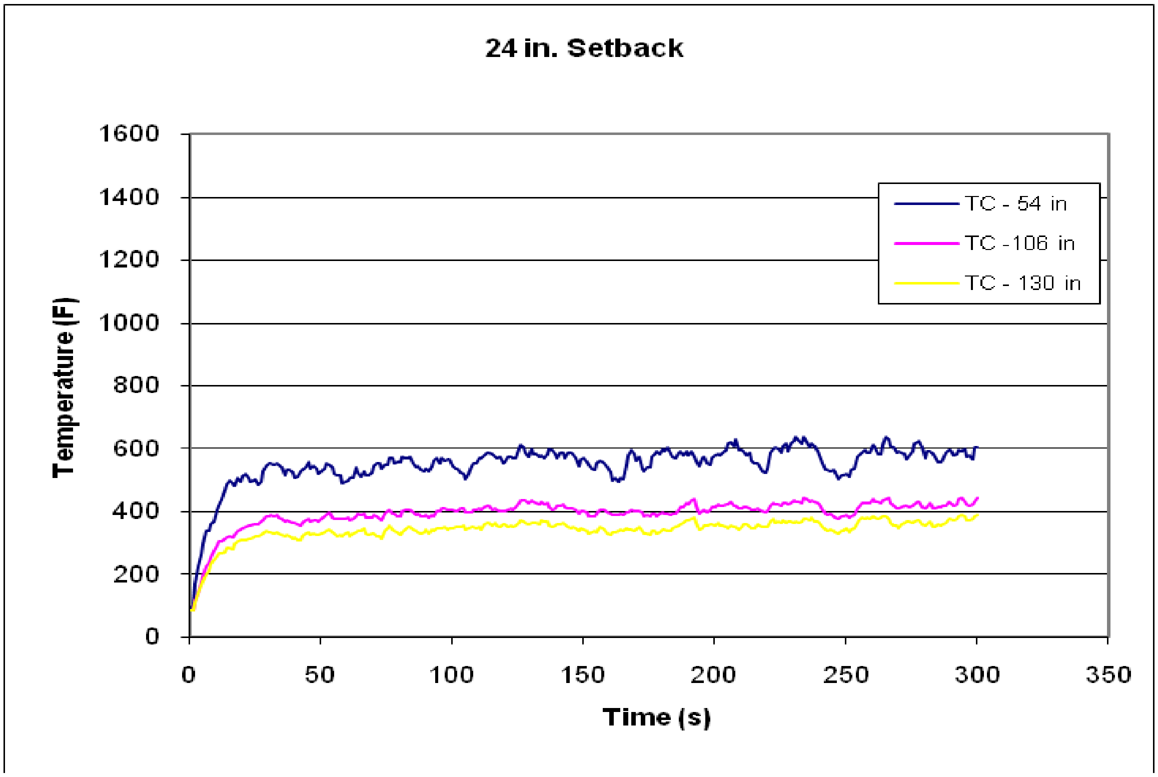

Figure 59 - Temperature of Roof with PV Module Mounted at 5” with 24” setback

- The effect various gaps on roof temperature of a PV module mounted at heights of 2.5, 5, and 10 inches above the roof was measured and is shown in Figure 60.

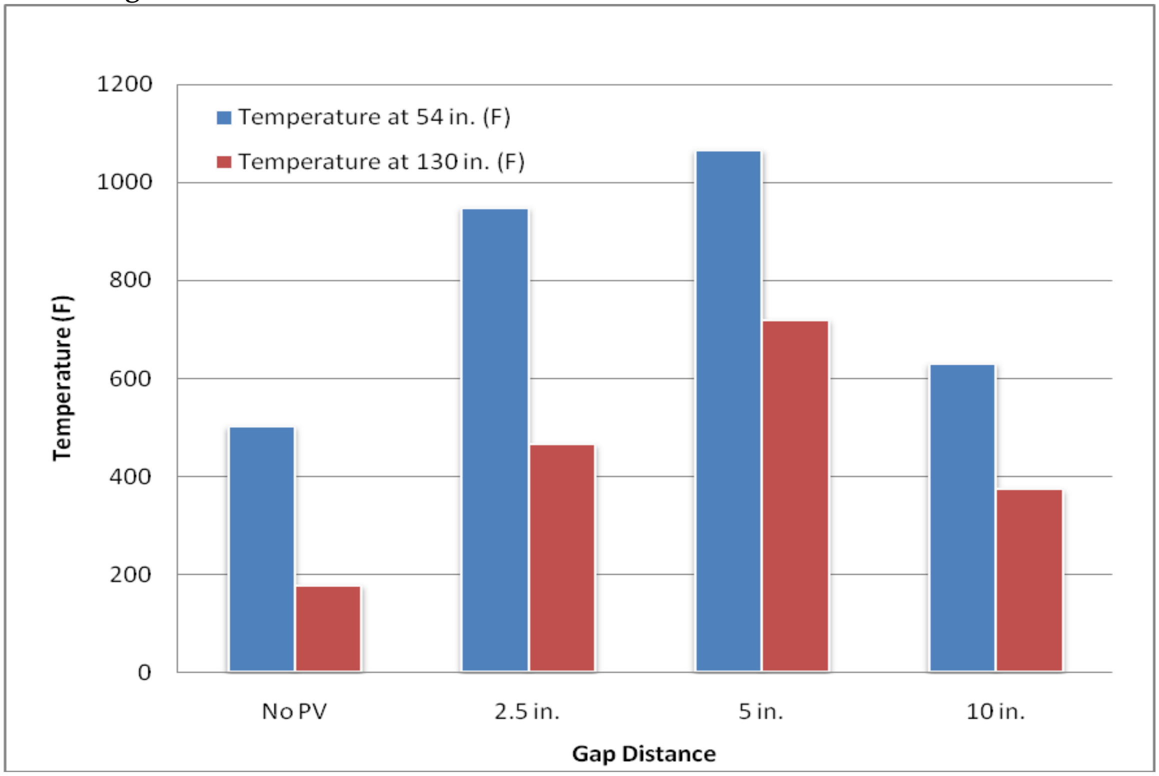

Figure 60 -Temperature of Roof with PV Module Mounted at heights of 2.5", 5", and 10" and With No Module

- 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 with respect to flame spread 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.