Effect of Rack Mounted Photovoltaic Modules on the Fire Classification Rating of Roofing Assemblies
Phase 2

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DISCLAIMER

EXECUTIVE SUMMARY

The subject of this report is a second phase continuation of a research project conducted to determine the effect of rack mounted photovoltaic (PV) systems on the flammability classification rating of roofing materials. The original Phase 1 of the project was conducted in response to fire and building code officials' interest in determining if a Class C rated module would reduce the fire resistance performance and/or fire rating of some Class A rated roof systems. And if so, which roof systems are impacted and to what extent.

An analysis of the data generated by the experiments carried out in the first study [1]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 *Standard for Safety for Standard Test Methods for Fire Tests of Roof Coverings*, Eighth Edition, dated April 22, 2004 and UL 1703, *Standard for Safety for Flat-Plate Photovoltaic Modules and Panels*, Third Edition, Dated March 15, 2002,

- 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 separation 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.

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

This second phase of the project further investigated rack mounted PV modules on roof decks to determine:

- The effect of PV modules mounted at angles (positive and negative) to steep and low sloped roofs,
- The impact of PV modules mounted at zero clearance to the roof surface with the ignition source directed in the plane of the roof or the plane of the PV surface,
- 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).

Continuation of Fire Safety Research Project

This project was conducted to expand on previous empirical data for consideration by manufacturers of PV and roofing products, regulatory officials such as Authorities Having Jurisdiction, code and standards development organizations. It is anticipated that the results of these experiments will lead to potential code and standards revisions.

Summary of Findings

Based on this series of experiments, the following findings were determined:

- Some PV modules mounted at angles (positive and negative) to steep and low sloped roofs impacted the fire classification rating of the supporting roof assembly. The extent of the impact was dependent on the angle of the module relative to the roof and the type of roofing system,
- PV modules mounted at zero clearance to the roof surface demonstrated no impact to the fire rating of the roof when the ignition source flame was directed to the front vertical surface of the module or when the ignition source flame was directed along the horizontal face of the module,
- The heat release rate and heat transfer to the roof surface of Class A and Class C brands did not demonstrate a direct correlation to common materials that may collect between PV modules and the roof surface, such as leaf debris and excelsior (wood wool). The Class A brand yielded results significantly greater than the leaf debris and wood excelsior while the Class B brand yielded results significantly less than the leaf debris and wood excelsior. While the Class B brand was not included in the experiments, the deduction of these experiments is that the representation of common materials is closest to the Class B brand in terms of heat release and heat transfer to the roof surface.

Acknowledgments

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Andy Rosenthal of New Mexico State University

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Introduction

This research project described herein expands on work conducted in Phase 1. Phase 1 of this project sought to address regulatory concerns over the installation of Class C fire rated PV modules over Class A fire rated roofs. As such, the work concentrated on PV arrays installed in a most critical geometry – modules installed parallel to the roof at critical installation heights above the roof (such as 5 inches). Subsequently, interest was expressed in characterizing the effect of arrays installed at various angles to the roof. There was also interest in understanding the effect of flame spread with the ignition source impinging at the top surface of the PV panel (PV surface plane) mounted at 0 in. clearance installation height above the roof.

In addition, the Phase 1 work led to questions on the comparison of the UL790 Class A and C brands, as used in the Phase 1 experiments, to common materials that may collect between PV modules and the roof surface. These common materials were represented by leaf debris and wood excelsior (wood wool). A basic demonstration comparison of Class A versus Class C burning brands was conducted. Heat release rate and transfer to the roof of Class A and C brands as well as common materials, represented by leaf debris and excelsior (wood wool), was recorded.

Task 1 – PV Arrays Installed at Various Angles to the Roof and at Zero Clearance

Objectives and Technical Plan

The objective of this task was to conduct experiments on a variety of PV module/roof combinations to demonstrate how PV modules installed above the roof at various angles impacts the fire classification rating of a roof system.

The technical plan consisted of conducting UL 790 / UL1703 flame spread experiments on the low and steep slope roofs PV modules installed at angles positive and negative to the roof.

Samples

Assemblies used in these experiments were constructed using PV modules donated by industry and roofing products obtained from local retailers. The PV modules were of a metal framed glass on polymer design, representative of Class C fire classification rating. Class A steep slope roofs were constructed with 3 tab shingles installed over typical roofing felt on a combustible deck. For the steep slope roof assemblies, the roof was inclined to horizontal at a 5 / 12 pitch.

Class A low slope roofs were constructed with a single ply FR EPDM (ethylene propylene diene monomer), 60 mil thickness membrane mechanically fastened to a noncombustible deck. One experiment was conducted with single ply FR EPDM (ethylene propylene diene monomer), 60 mil thickness membrane installed, over a single layer of polyisocyanurate (iso) insulation board and mechanically fastened to a noncombustible deck. For the low slope roof assemblies, the roof was flat (0 pitch).

Experimental

The fire performance systems of PV modules on roof deck assemblies were investigated as described in UL 790 / UL 1703 Spread of Flame tests. For the spread of flame test, the roofing material and the PV fire rating were as noted with the angle of the module being the experimental parameter of interest (Table 1). With the exception of experimental systems 2 and 11, the ignition source flame was directed into the gap formed between the top of the roof surface and the bottom of the PV module. Figure 1 illustrates the PV / roof assembly combinations and ignition flame impingement.

Figure 1 – Figures Illustrating Positive and Negative Angles, and Ignition Source Impingement Points

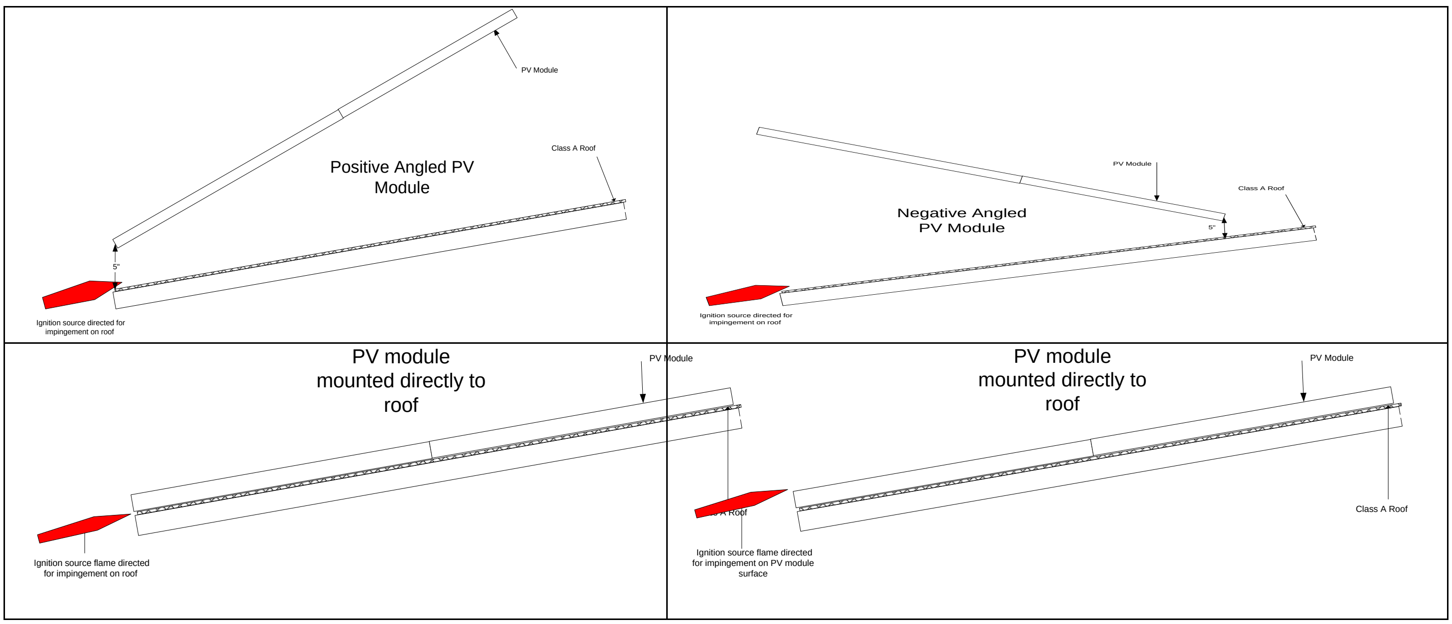

Table 1 Experiment PV Module and Roof Sample Details

System	Test	Roof Type	Roof Class	Panel Class	Panel Installation Gap, in.	Panel Installation Angle	Comments	Flame Impingement
PV Modules Mounted Directly on Deck								
1	Spread of flame	Shingle 3 - 3 tab	A	C	0	Standard 5/12	PV over roof - no air gap	Roof level
2	Spread of flame	Shingle 3 - 3 tab	A	C	5	Standard 5/12	PV over roof - no air gap	Flame @ top of module
Variations of PV Inclination to Roof Slope								
3	Spread of flame	membrane*	A	C	5	Standard 0	PV parallel (flat)	Roof level
4	Spread of flame	membrane*	A	C	5	Standard 0	positive tilt 22 degrees	Roof level
5	Spread of flame	membrane*	A	C	5	Standard 0	positive tilt 45 degrees	Roof level
6	Spread of flame	membrane*	A	C	5	Standard 0	negative tilt 22 degrees	Roof level
7	Spread of flame	membrane**	A	C	5	Standard 0	negative tilt 22 degrees	Roof level
8	Spread of flame	Shingle 3 - 3 tab	A	C	5	Standard 5/12	PV parallel	Roof level
9	Spread of flame	Shingle 3 - 3 tab	A	C	5	Standard 5/12	positive tilt 22 degrees	Roof level
10	Spread of flame	Shingle 3 - 3 tab	A	C	5	Standard 5/12	negative tilt 22 degrees	Roof level
11	Spread of flame	Shingle 3 - 3 tab	A	C	5	Standard 5/12	PV parallel	Flame @ top of module

Notes:

*- Single ply EPDM (ethylene propylene diene monomer), 60 mil membrane, mechanically fastened to a noncombustible deck

** - Single ply EPDM (ethylene propylene diene monomer), 60 mil membrane, over a single layer of “iso” insulation board mechanically fastened to a noncombustible deck

Results

Spread of flame test results are shown in Table 2:

Table 2 Spread of Flame Test Results

				Flame Spread Data			
				Roof		PV	
System	Roof Type	Comments	Flame Impingement	Distance (feet)	Time (min:sec)	Distance (feet)	Time (min:sec)
PV Modules Mounted Directly on Deck							
1	Shingle 3 - 3 tab	PV over roof - no air gap	Roof level			0.5	7:47
2	Shingle 3 - 3 tab	PV over roof - no air gap	Flame @ top of module			3.5	9:54
Variations of PV Inclination to Roof Slope							
3	membrane*	PV parallel (flat)	Roof level	> 8.5	1:17	Same	
4	membrane*	positive tilt 22 degrees	Roof level	> 8.5	1:21	Same	
5	membrane*	positive tilt 45 degrees	Roof level	4.5	1:55	> 8.5 [1]	1:55
6	membrane*	negative tilt 22 degrees	Roof level	4.5	9:07	No Propogation	
7	membrane**	negative tilt 22 degrees	Roof level	> 8.5 [2]	2:20	Same	
8	Shingle 3 - 3 tab	PV parallel	Roof level	> 8.5	2:01	Same	
9	Shingle 3 - 3 tab	positive tilt 22 degrees	Roof level	5 [3]	4:18	4	4:18
10	Shingle 3 - 3 tab	negative tilt 22 degrees	Roof level	4.5 [4]	7:02	No Propogation	
11	Shingle 3 - 3 tab	PV parallel	Flame @ top of module	3.5 [5]	8:43	6	8:43

Notes:
* - denotes sample constructed with single ply FR EPDM (ethylene propylene diene monomer), 60 mil, mechanically fastened to a noncombustible deck
** - denotes sample constructed with single ply FR EPDM (ethylene propylene diene monomer), 60 mil, over a single layer of "iso" insulation board, mechanically fastened to a combustible deck
> - denotes flames observed beyond reported value, typically beyond the end of the Class C deck - 13'
1 - propagation along roof surface 4.5', propagation on the underside of PV modules greater than 10'
2 - propagation along roof surface beyond 13', propagation on the underside of PV modules ~ 4.5 from the end mounted 5" above the roof deck
3 - propagation along the underside of the PV module - 4' Note: PV panel fell prior to conclusion of experiment
4 - no fire propagation along the underside of the PV module - did not ignite
5 - PV glass panel fell to roof deck @ 7:40

Zero Clearance Experiments: - In both of the experiments where the modules were mounted directly to the roof surface, the flame propagation of the PV / roof assembly met the requirements of Class A.

Low Slope Experiments:

- For systems 3 and 4, experiments which incorporated a single layer of membrane roof material mounted directly to a noncombustible deck (with no insulation), with the PV module elevated 5" above the roof and at angles with a positive tilt of 0° (parallel to the roof) and 22°, flame propagation along both the roof and the underside of the modules were in excess of the 6 foot maximum flame propagation. These system results did not meet the requirements of Class A,
- For system 5, at a positive tilt 45° angle, the flame propagation along the roof was less than 6 feet, but the flame propagation along the underside of the modules exceeded 6 feet,

- For the same configuration, but with the PV modules at a negative tilt 22° angle opposite of the roof (system 6), the fire propagation along the roof met the requirements of Class A. For this experiment, there was no flame propagation along the nderside of the modules,
- However, for this same basic configuration with a single layer of 2" polyisocyanurate insulation added beneath the membrane, system 7, the fire propagation along both the roof and the underside of the PV modules exceeded 6 feet and did not meet the requirements of Class A.

So, the inclusion of a typical layer of insulation used in low-slope roofs increased the fuel of the roof assembly resulting in noncompliant flame spread in less than 2 ½ minutes. It should be noted that for systems 3 through 6 experiments, flames were extinguished and the experiment was terminated prior to the prescribed 10 minute test duration as the flame had propagated beyond the end of the roof deck.

Steep Slope Experiments:

- For the experiment, system 8, which incorporated a 3 tab shingle material mounted over roofing felt and fastened to a combustible deck, with the PV module elevated 5" above the roof and at angles with a positive tilt of 0° (parallel to the roof), flame propagation along both the roof and the underside of the modules exceeded 6 feet and did not meet the requirements of Class A,
- For the same configuration but at a 22° angle positive to the roof, system 9, the flame propagation along both the roof and the underside of the PV module met the requirements of Class A. It should be noted that the PV module collapsed prior to the end of the test,
- With the PV modules mounted at a 23° angle negative to the roof, system 10, the flame propagation along both the roof and the underside of the module met the requirements of Class A,
- The final experiment, system 11, was conducted with ignition source directed to the top surface of the PV module mounted elevated and parallel to the roof. Under this configuration the flame propagation along both the roof and the PV module met the requirements of Class A. It should be noted that the PV module glass superstrate fell to the roof surface at 7:40.

Visual results are provided in the following photographs. Please note, the photographs were taken during various times of the experiment and do not represent maximum fire propagation as noted in Table 2.

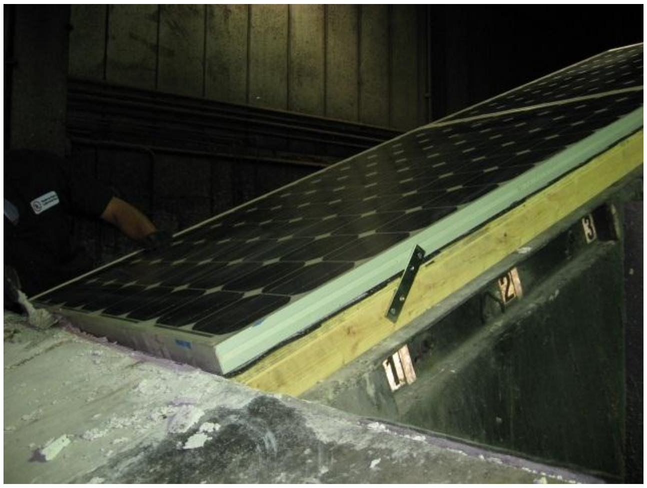

Figure 2 – System 1 Spread of Flame Experiment with PV Modules Mounted Directly to Shingled Deck, Ignition Source Directed at Roof Surface Set Up

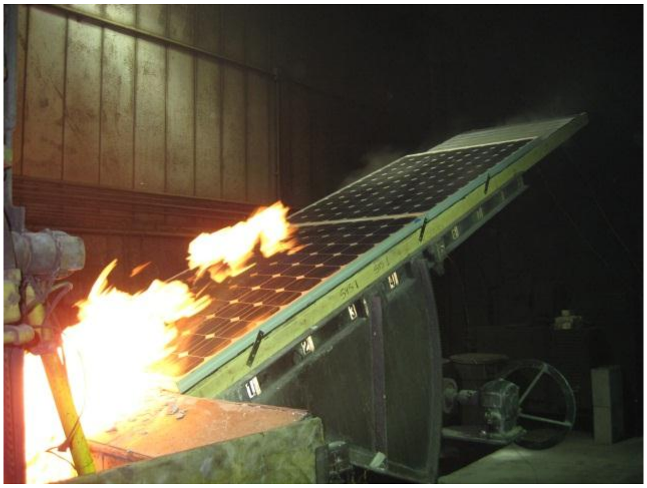

Figure 3 –System 1 Spread of Flame Experiment with PV Modules Mounted Directly to Shingled Deck, Ignition Source Directed at Roof Surface

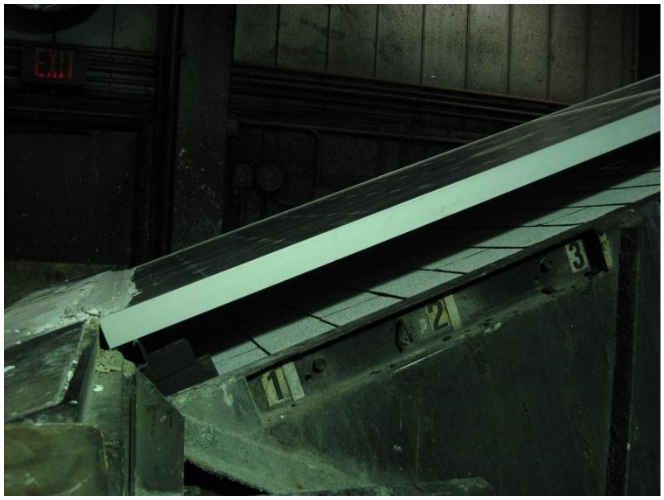

Figure 4 – System 2 Spread of Flame Experiment with PV Modules Mounted Directly to Shingled Deck, Ignition Source Directed at PV Superstrate Surface Set Up

Figure 5 – System 2 Spread of Flame Experiment with PV Modules Mounted Directly to Shingled Deck, Ignition Source Directed at PV Superstrate Surface

Figure 6 – System 3 Spread of Flame Test PV with Module Mounted Parallel to Low Sloped Roof, 5" Gap Set Up

Figure 7 – System 3 Spread of Flame Test PV with Module Mounted Parallel to Low Sloped Roof, 5" Gap

Figure 8 – System 4 Spread of Flame Test PV with PV Module Mounted 22° to Low Sloped Roof (Positive) Set Up

Figure 9 – System 4 Spread of Flame Test PV with PV Module Mounted 22° to Low Sloped Roof (Positive)

Figure 10 – System 5 Spread of Flame Test PV with PV Module Mounted 45° to Low Sloped Roof (Positive) Set Up

Figure 11 – System 5 Spread of Flame Test PV with PV Module Mounted 45° to Low Sloped Roof (Positive)

Figure 12 – System 6 Spread of Flame Test PV with PV Module Mounted 45° to Low Sloped Roof (Negative) Set Up

Figure 13 – System 6 Spread of Flame Test PV with PV Module Mounted 45° to Low Sloped Roof (Negative)

Figure 14 – System 7 Spread of Flame Test PV with PV Module Mounted 22° to Low Sloped Roof with 2" Polyisocyanurate Foam (Negative) Set Up

Figure 15 – System 7 Spread of Flame Test PV with PV Module Mounted 22° to Low Sloped Roof with 2" Polyisocyanurate Foam (Negative)

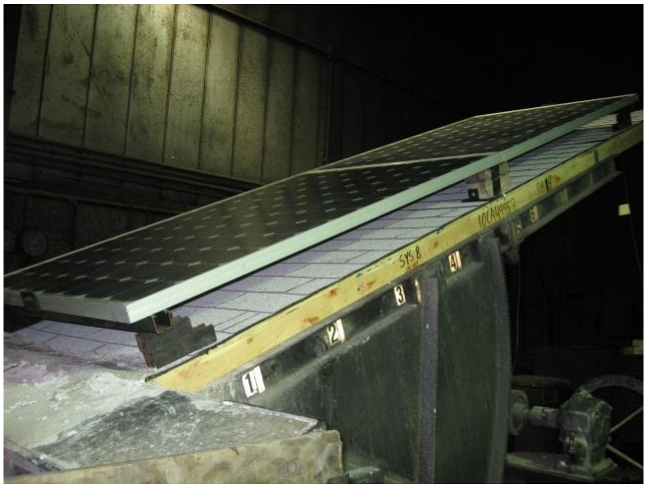

Figure 16 – System 8 Spread of Flame Test PV Module Mounted Parallel to Steep Sloped Roof, 5" Gap Set Up

Figure 17 – System 8 Spread of Flame Test PV Module Mounted Parallel to Steep Sloped Roof, 5" Gap

Figure 18 – System 9 Spread of Flame Test with PV Module Mounted 22° to Steep Sloped Roof (Positive) Set Up

Figure 19 – System 9 Spread of Flame Test with PV Module Mounted 22° to Steep Sloped Roof (Positive)

Figure 20 – System 10 Spread of Flame Test with PV Module Mounted 22° to Steep Sloped Roof (Negative) Set Up

Figure 21 – System 10 Spread of Flame Test with PV Module Mounted 22° to Steep Sloped Roof (Negative)

Task 1 - Summary

The following is a summary of the results:

- PV arrays mounted at zero clearance to the roof surface, with the ignition source directed towards the plane of the roof, or the plane of the PV surface, do meet the requirements of Class A flame spread performance,

- PV arrays mounted on representative low slope membrane roof coverings at initial heights of 5 inches above the roof and parallel, and at positive angles of 22° and 45° did not meet the requirements of Class A flame spread performance,

- PV arrays mounted on representative low slope membrane roof coverings at initial heights of 5 inches above the roof and at a negative angle of did meet the requirements of Class A flame spread performance with no polyisocyanurate foam. However, when the same construction employed polyisocyanurate foam, the construction did not meet the requirements of Class A flame spread performance,

- PV arrays mounted on representative steep slope constructions with 3 tab shingles at initial heights of 5 inches above the roof and parallel to the roof did not meet the requirements of Class A flame spread performance.

- PV arrays mounted on representative steep slope constructions with 3 tab shingles at initial heights of 5 inches above the roof and at both positive and negative tilt angles of 22° to the roof did meet the requirements of Class A flame spread performance.

Overall, these experiments demonstrated that PV arrays mounted at various positive and negative angles to the roof with an initial elevation of 5 inches above the roof can, in some cases, affect the Class A performance of low or steep slope roofs. These experiments demonstrated that PV arrays mounted at zero clearance to the roof surface, with the ignition source directed towards the plane of the roof, or the plane of the PV surface, do meet the requirements of Class A flame spread performance.

Other installation parameters including low slope insulation thickness and formulations such as polystyrene and initial elevations would provide a more complete understanding of PV / roof assembly fire classification performance.

TASK 2 – Demonstration Comparisons of Class A and Class C Brands

Objective

The burning brand test conducted in UL 790 / UL 1703 is intended to evaluate roofing assemblies to resist the penetration of fire through the assemblies into spaces underneath, such as a cockloft or attic. The objective of this task was to demonstrate the burning behaviors of the standard Class A and C roofing brands, as well as common materials that may collect between the PV modules and the roof surface, represented by wood excelsior and leaves. Temperatures of a noncombustible roof deck were measured directly under the burning item or material to illustrate the heat transfer to roofing materials. In addition, the weight of the burning item / material and the peak heat release rate was also measured. This data was provided to contrast the different fuel packages.

These demonstrations were not intended as a detailed study to compare the heat transfer or thermal stress imposed on a roof.

Samples

Samplers consisted of wood frames with a single ¼ inch thick noncombustible deck. In the final experiment, a roof deck assembly was constructed in accordance with UL 790 Burning Brand test with 3 tab shingles and a 15 lb. felt underlayment. The shingles were purchased from a local building supply retailer and were marked as Class A compliant. In both instances, the roofs were inclined to horizontal at a 5 / 12 pitch.

Experimental

These experiments were conducted under a oxygen consumption product calorimeter using the basic test methods from UL 790 burning brand test. UL 790 specifies an airflow rate of 12 mph or 1056 ft/min over the surface of the roof sample. Forced ventilation of the brand ranged from 0, 350, and 700 ft/min measured in the plane and at the leading edge of the roof. The airflow for these demonstrations was reduced from the standard in order to capture the combustion products for measurement of heat release rate in an oxygen consumption calorimeter. Standard Class A and Class C brands were ignited using the procedure outlined in UL 790. Once ignited, the burning brand was placed on a noncombustible deck which incorporated a thermocouple to measure the temperature of the deck surface. In addition, a single experiment was conducted on a shingled wood deck where temperatures of the exposed surface of the shingle, roofing felt, and unexposed surface of the deck were measured.

For the debris experiments, excelsior and leaf fuel package volumes were established to be the same overall size as the Class A brand. The debris material was ignited with a small open flame. The airflow was set at 350 ft/min for these experiments due to the tendency of the excelsior fibers and leaves to become dislodged and blown off the deck at 700 ft/min.

Results

The results of the experiments are shown in Table 2.

Table 2 Burning Brand/Debris Fire Experiments Results

System	Heat Source	Dimensions (LxWxH) (in)	Condition	Weight (g)	Air Flow (f/min)	Heat Release Peak (kW)	Heat Release Total (MJ)	Deck Bottom (°C)	Deck Top (°C)	Felt (°C)	Shingle (°C)
1	A Brand	12X12X2.5	Assembled	1930	700	70	35.3		1152		
2	A Brand	12X12X2.5	Assembled	1930	0	46	37.8		938		
3a	C Bramd	1.5X1.5X.75	Assembled	11	700	6*	0.6*		274		
3b	C Brand	1.5X1.5X.75	Assembled	11	700	4*	0.3*		216		
3c	C Brand	1.5X1.5X.75	Assembled	11	700	5*	0.8*		614		
4	Excelsior	12X12X5	Fluffed	-	0	57	2.8		548		
5	Leaves	12X12X5	Fluffed	141	0	5*	0.3		507		
6	Excelsior	12X12X5	Fluffed	78	0	44	2.9		264		
7	Excelsior	12X12X5	Compressed	990	0	48	20.7		691		
8	Leaves	12X12X5	Fluffed	181	350	10*	2.8		724		
9	Excelsior	12X12X5	Compressed	1204	350	95	20.4		841		
10	Excelsior	12X12X5	Fluffed	54	350	126	2.8		384		
11	A Brand	12X12X2.5	Assembled	1968	700	82	40.9	198	565	583	807

Notes:
* - Measured Heat Release Rate at the lower threshold of the instrument measurement.

A review of the data indicates an increase in heat release and associated deck surface temperature due to forced ventilation or airflow into the fuel package. This result is expected, since the burning rate is directly related to the amount of oxygen available to the fire. As noted earlier, the maximum airflow used during these experiments was approximately ¾ of the 12 mph (1056 ft/min) as outlined in UL 790. The airflow velocity was reduced from that specified in the standard due to the need to use an appropriately sized calorimeter to measure the relatively low heat release rates (~ 10 to 100 kW) and capture the combustion products. It is reasonable to expect higher heat release rates at the standard 12 mph velocity.

The heat release rate of the Class C brand was substantially lower than the Class A brand both in peak (~5 vs 70 kW) and total energy generated (~0.8 vs 35 MJ). This is also an expected result given the differences in mass, construction and geometry.

For the experiments with wood excelsior and leaf debris, the volumes were arranged and established to be the same as the Class A brand. The airflow was set at 350 ft/min for these experiments due to the tendency of the excelsior fibers and leaves to become dislodged and blown off the deck at 700 ft/min. When compressed, the excelsior fuel package was slightly more than ½ of the weight of the Class A brand. The excelsior generated a peak heat release rate of 95 kW as compared to the brand's 70 kW. The resulting deck surface temperature was 841 °C with the excelsior as compared to 1152 °C for the brand. When fluffed, the weight was approximately 3% of the brand, but generated a greater peak heat release rate (123 kW compared to 70 kW). The exposed deck surface temperature was significantly less (384 °C vs 1152 °C). All leaf experiments were conducted in the 'fluffed' condition as this material, unlike the excelsior would not remain in a compressed form. With a 350 ft/min ventilation condition, the heat release rate of 10 kW was at the low end of the product calorimeter's capability to measure. The deck's surface temperature was 724 °C.

A single test of a Class A brand placed on a shingled, combustible deck generated 82 kW. The exposed surface temperature of the shingle was 807 °C, the roofing felt layer was 583 °C and the surface temperature of the underside of the roof deck was 198 °C.

Visual results are provided in the following Figures 21 through 29. Please note: the photographs were taken during various times of the experiment and do not represent maximum fire propagation as noted in Table 3.

Plots of the temperature and heat release rates recorded during the experiments are shown in Figures 30 through 59.

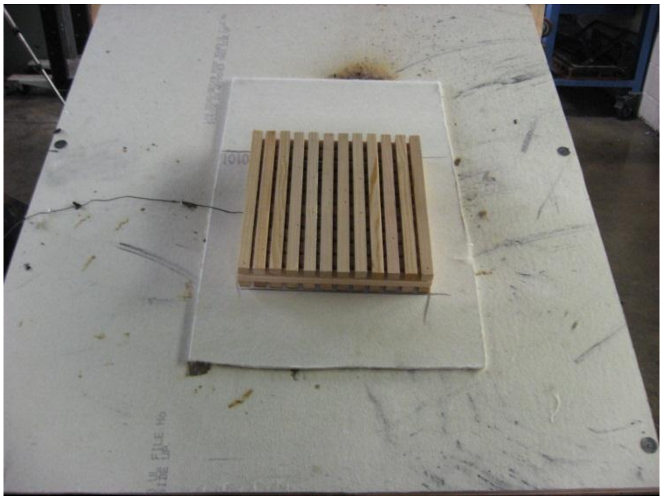

Figure 22 - Class A Brand Over Noncombustible Deck Set Up

Figure 23 - Class A Brand Over Noncombustible Deck

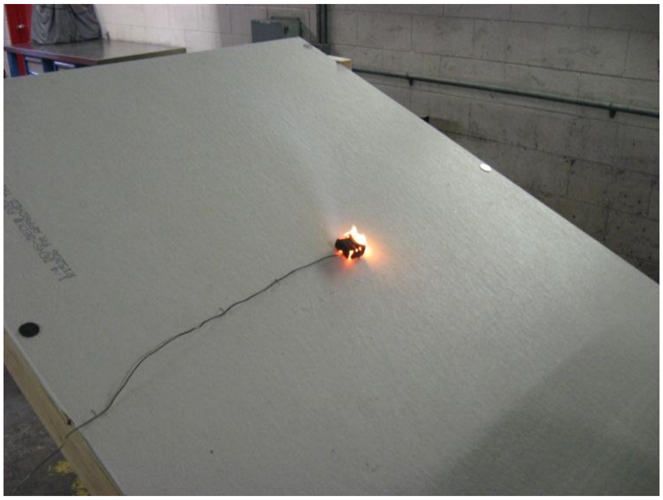
Figure 24 - Class C Brand Over Noncombustible Deck

Figure 25 - Class Wood Excelsior Over Noncombustible Deck Set Up

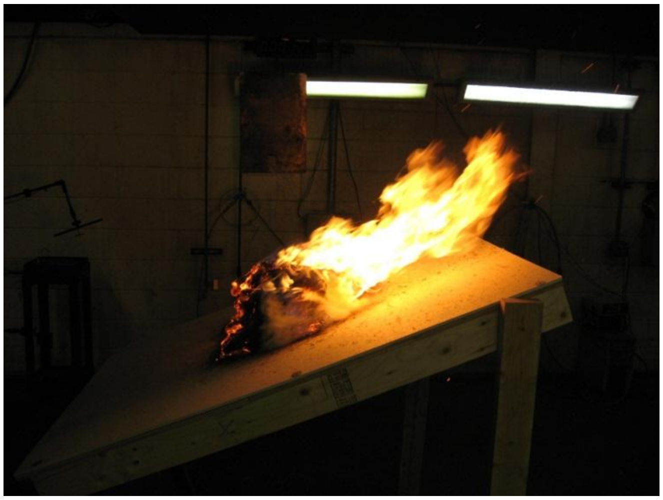

Figure 26 - Class Wood Excelsior Over Noncombustible Deck

Figure 27 - Leave Debris Over Noncombustible Deck Set Up

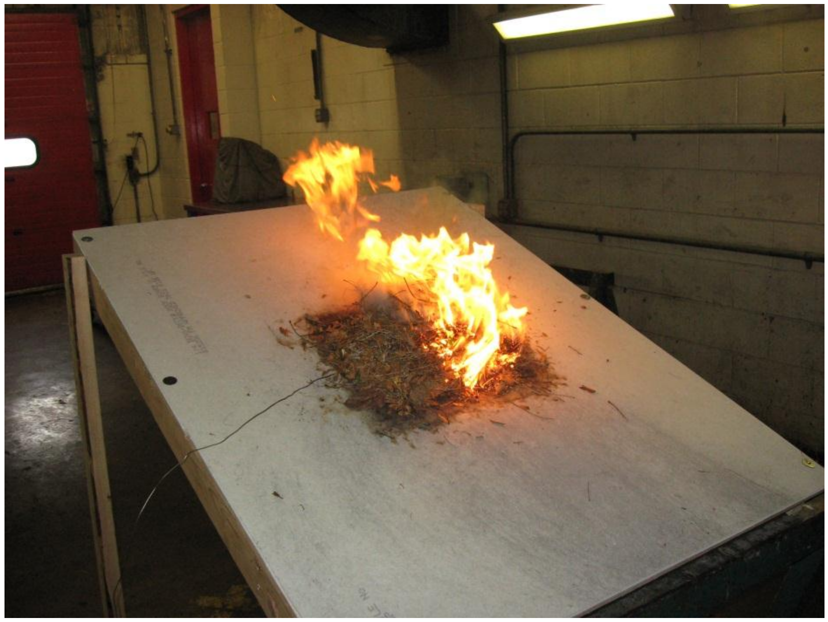

Figure 28 - Leave Debris Over Noncombustible Deck

Figure 29 - Class A Brand Over Shingled Combustible Deck

Figure 30 - Unexposed Surface of Combustible Deck

Test #, sample description, air flow & temperature and HRR plots.

Test 1 - Sample=A Brand - Instrumented Roof Deck - 700 fpm

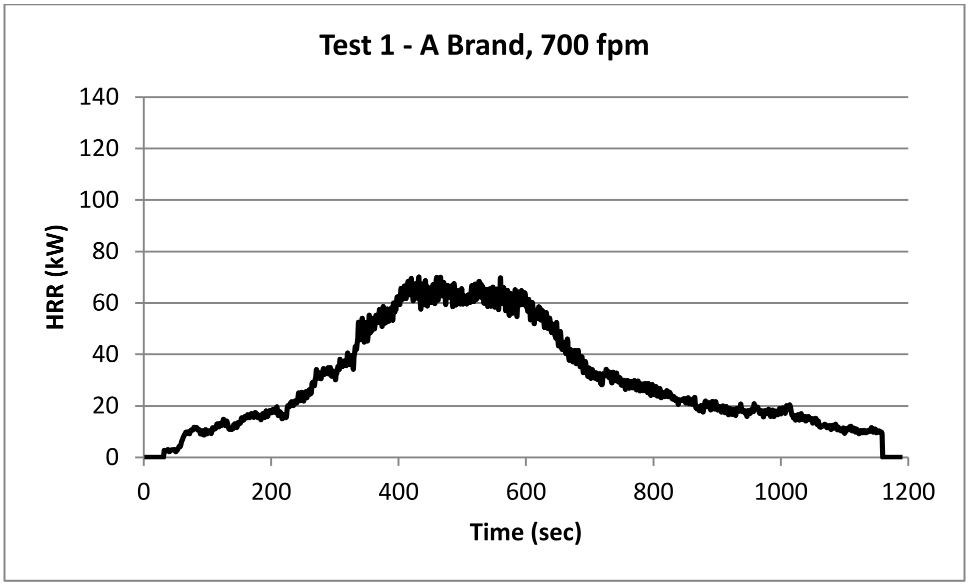

Figure 31 - Graph of Heat Release Rate (HRR) in kilowatts

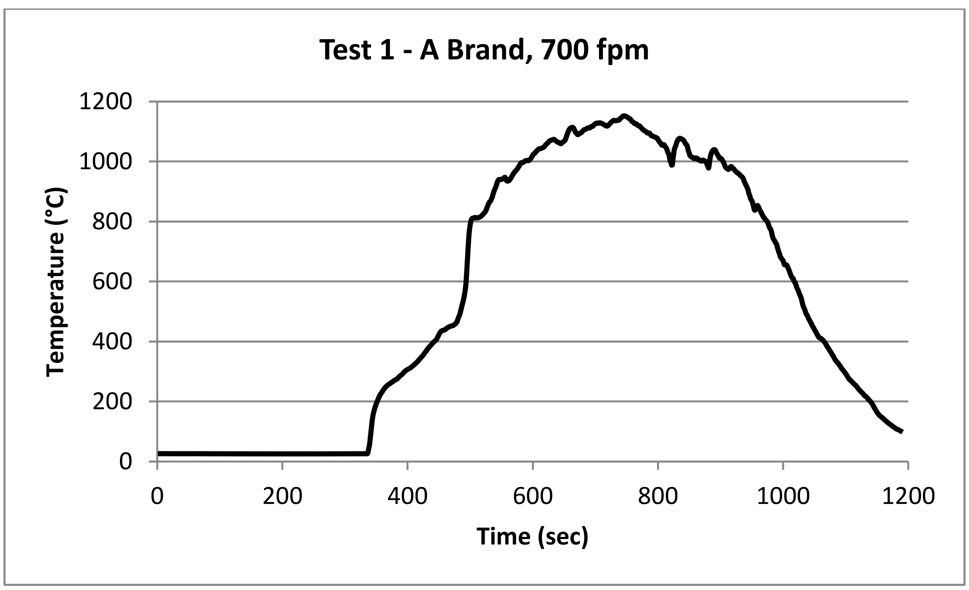

Figure 32 - Graph of Deck Surface Temperature (°C)

Test 2 - Sample=A Brand - Instrumented Roof Deck - 0 fpm

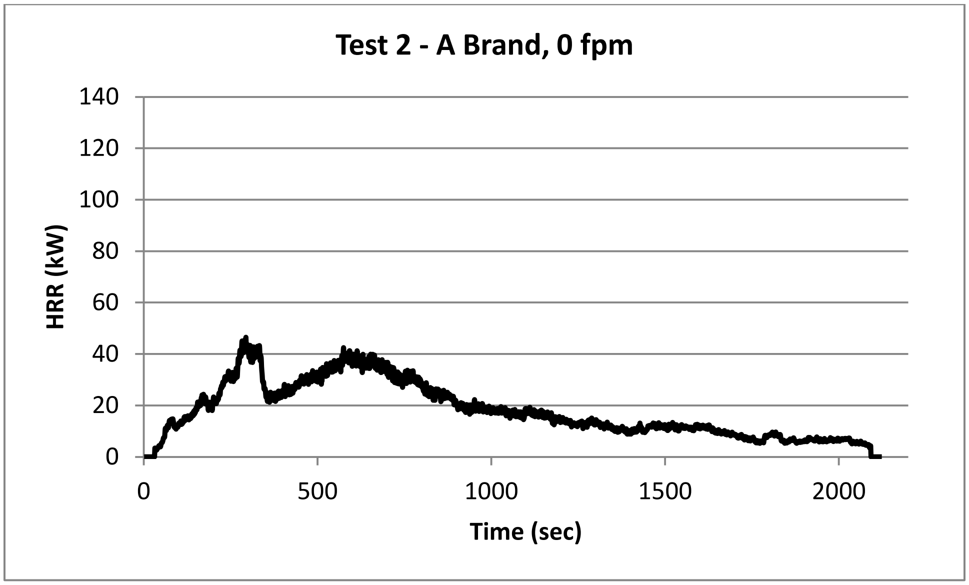

Figure 33 - Graph of Heat Release Rate (HRR) in kilowatts

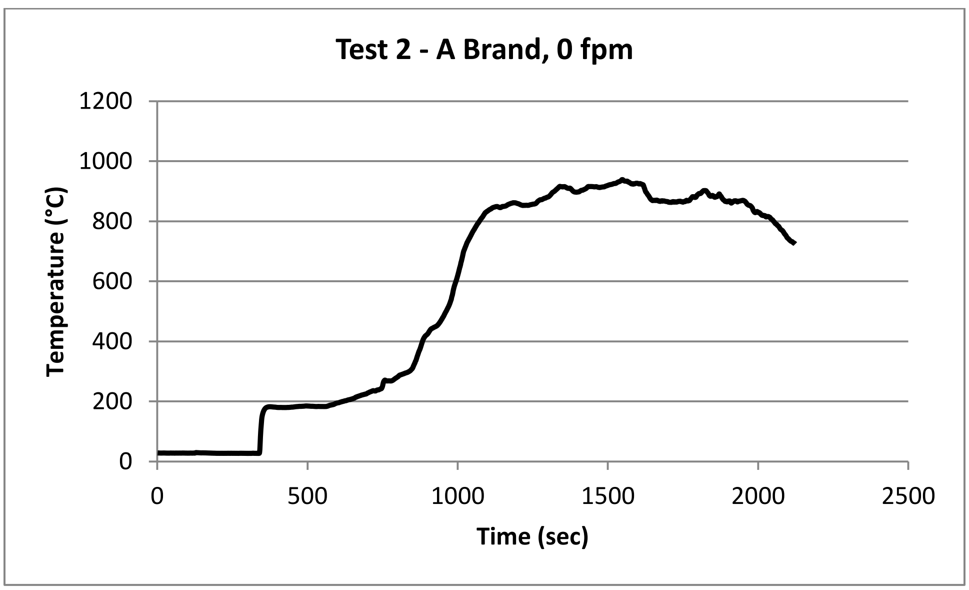

Figure 34 - Graph of Deck Surface Temperature (°C)

Test 3A - Sample=C Brand - Instrumented Roof Deck - 700 fpm

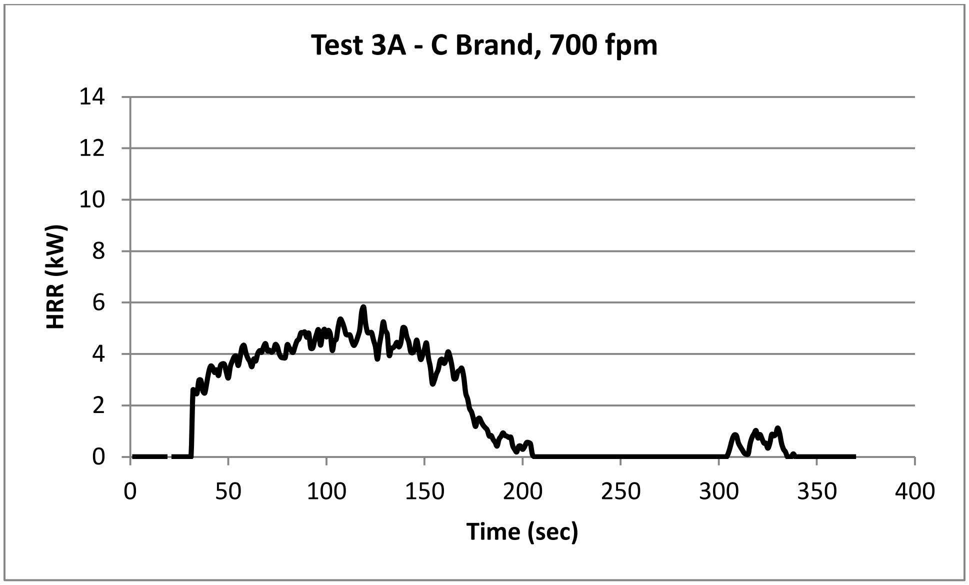

Figure 35 - Graph of Heat Release Rate (HRR) in kilowatts

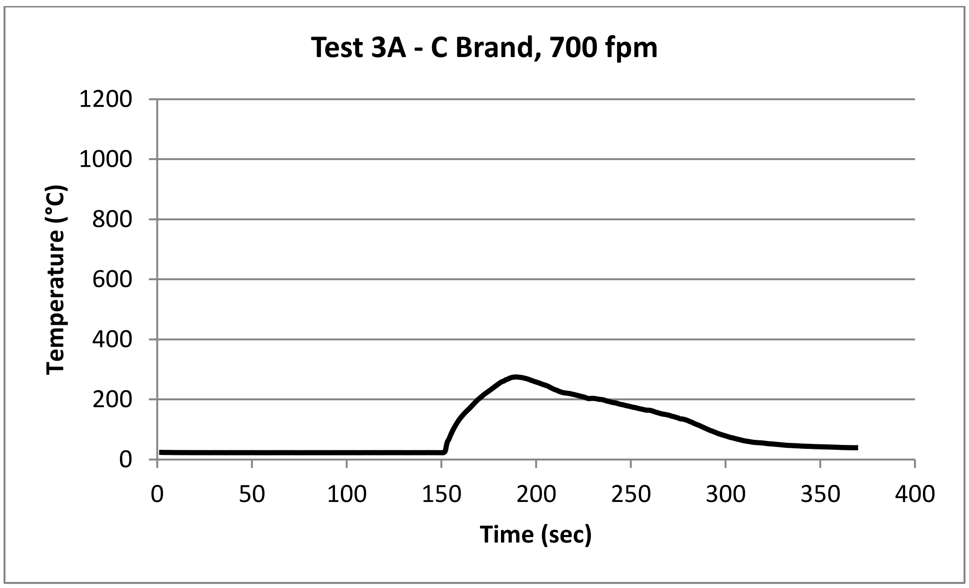

Figure 36 - Graph of Deck Surface Temperature (°C)

Test 3B - Sample=C Brand - Instrumented Roof Deck - 700 fpm

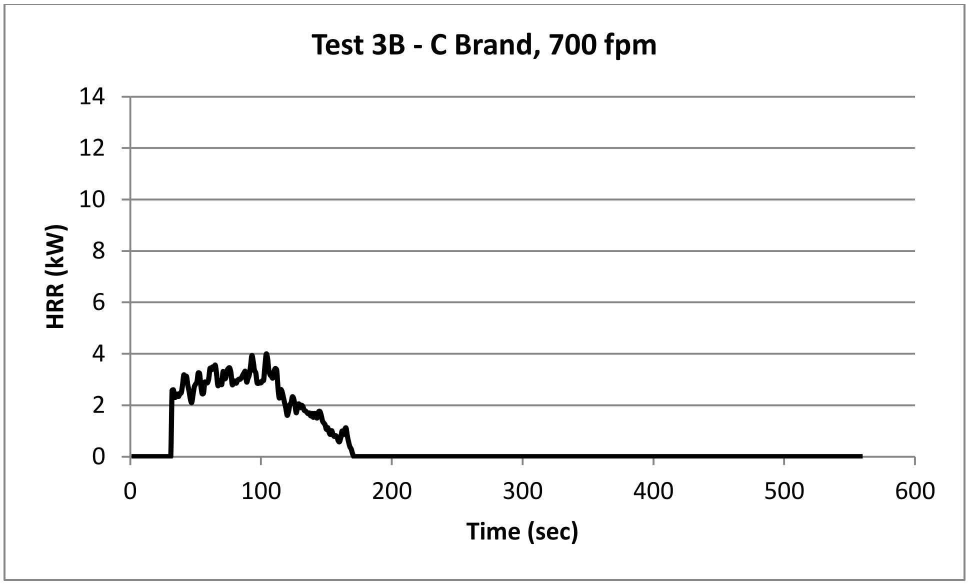

Figure 37 - Graph of Heat Release Rate (HRR) in kilowatts

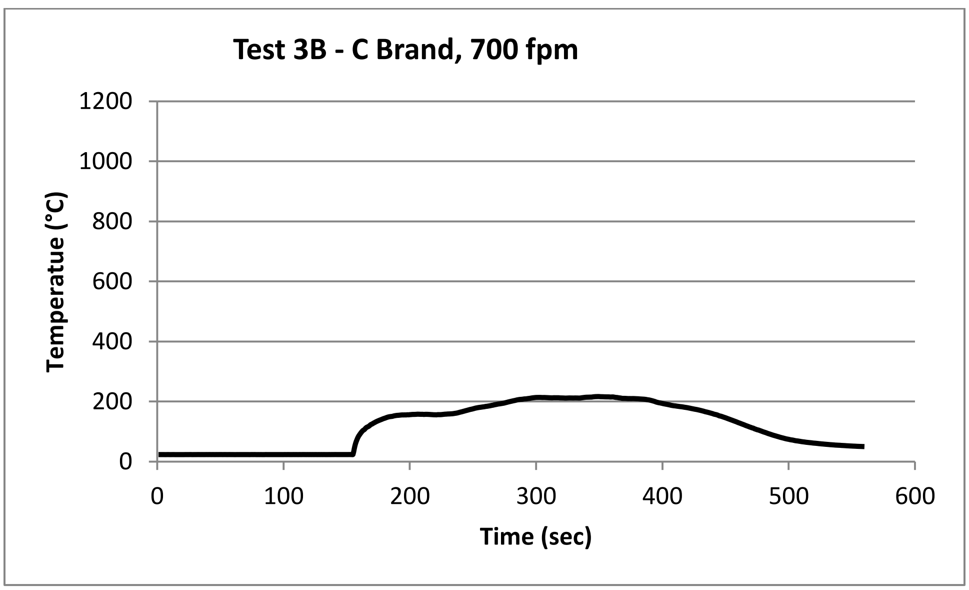

Figure 38 - Graph of Deck Surface Temperature (°C)

Test 3C - Sample=C Brand - Instrumented Roof Deck - 700 fpm

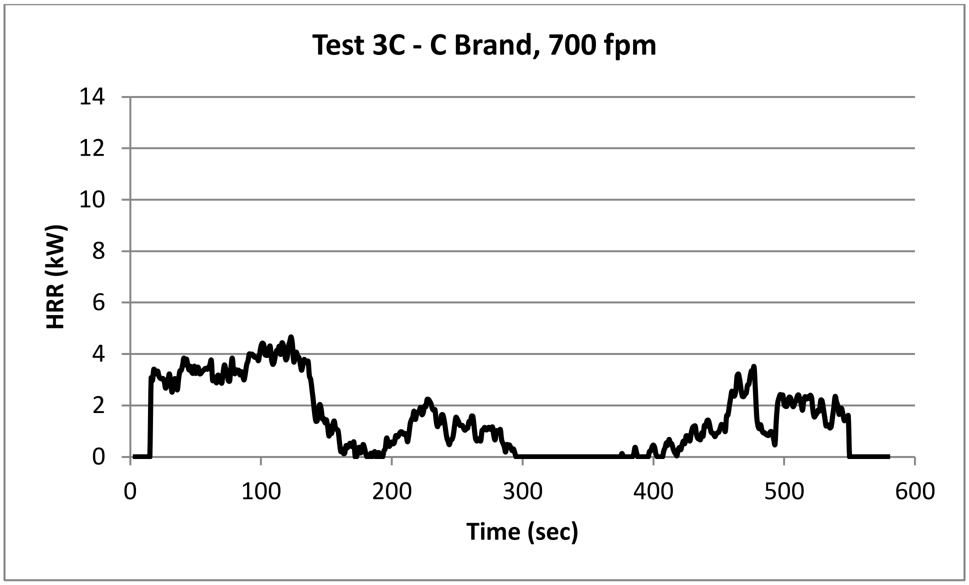

Figure 39 - Graph of Heat Release Rate (HRR) in kilowatts

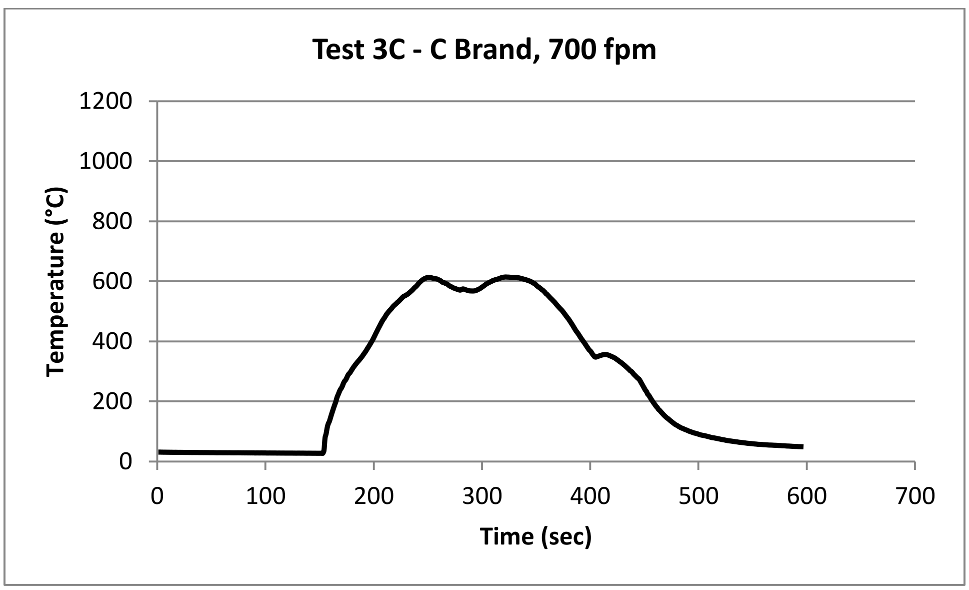

Figure 40 - Graph of Deck Surface Temperature (°C)

Test 4 - Sample=Excelsior Wood Wool - Instrumented Roof Deck - 0 fpm

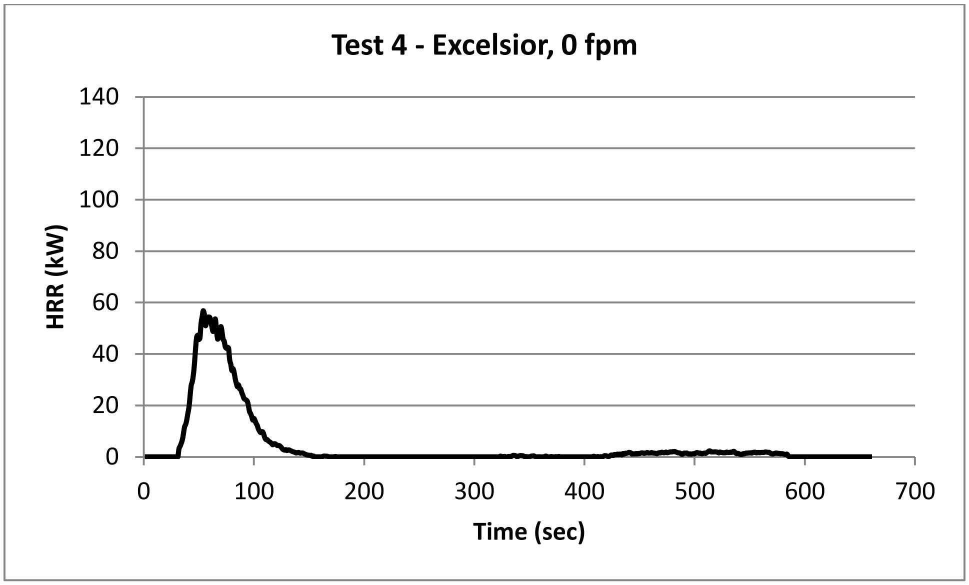

Figure 41 - Graph of Heat Release Rate (HRR) in kilowatts

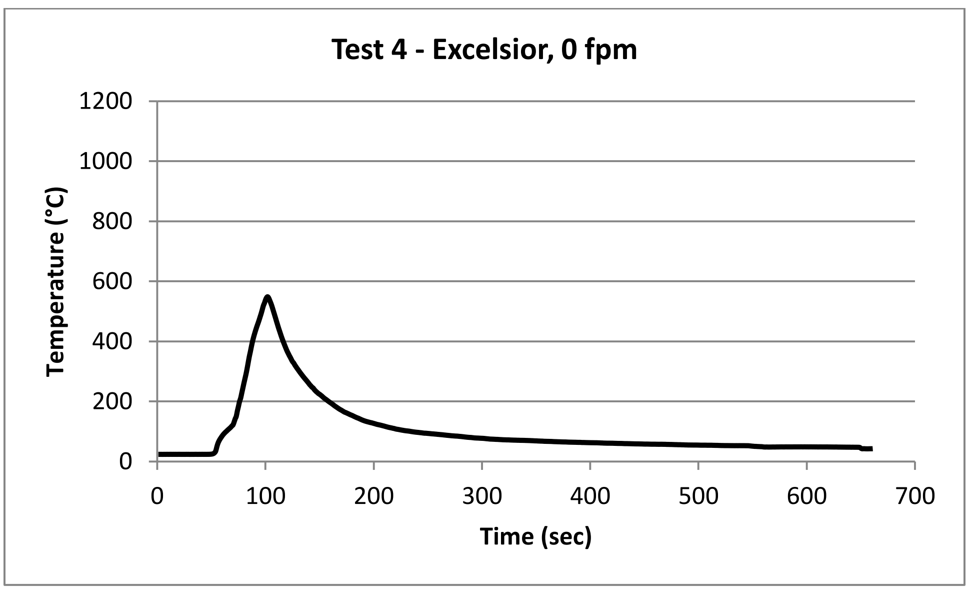

Figure 42 - Graph of Deck Surface Temperature (°C)

Test 5 - Sample=Leaves - Instrumented Roof Deck - 0 fpm

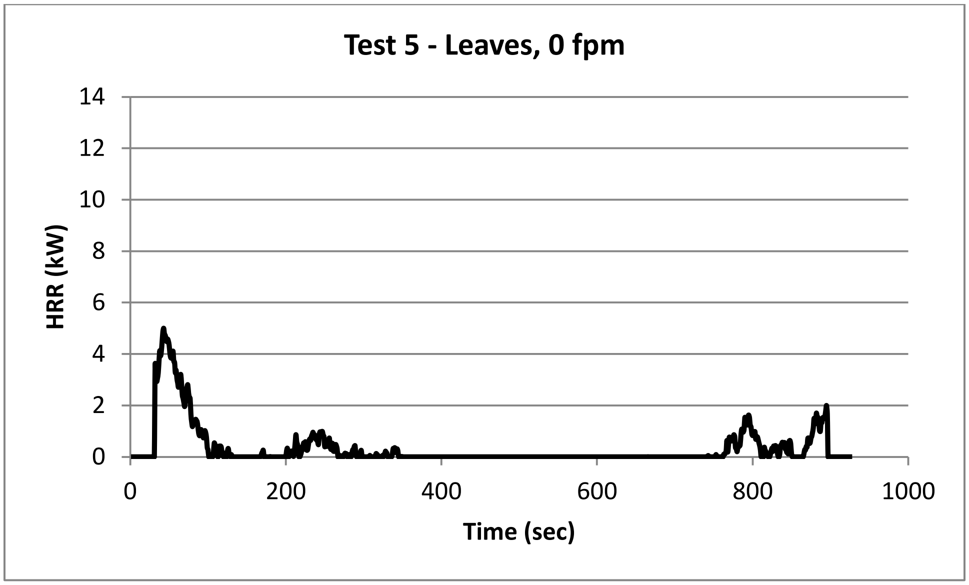

Figure 43 - Graph of Heat Release Rate (HRR) in kilowatts

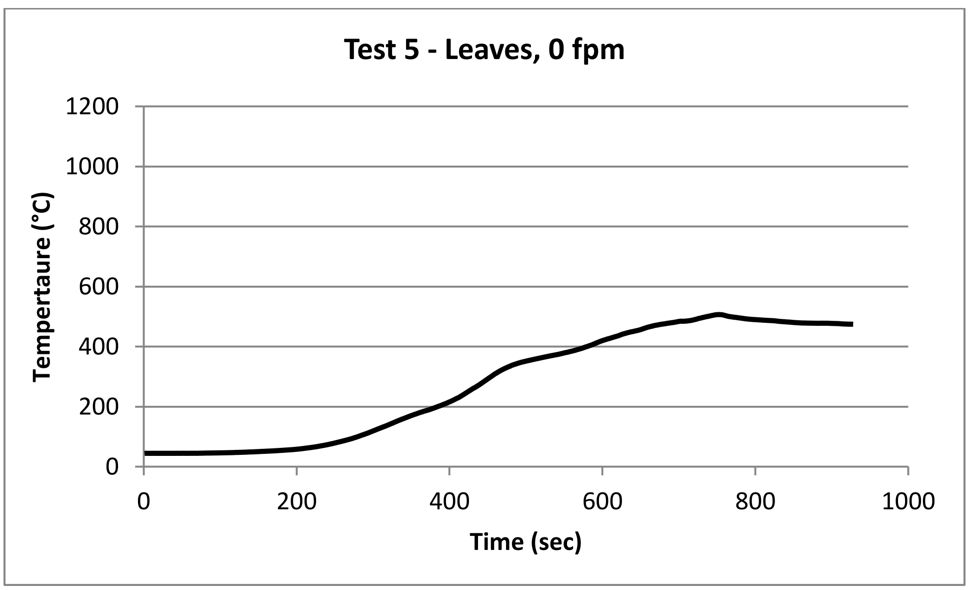

Figure 44 - Graph of Deck Surface Temperature (°C)

Test 6 - Sample=Excelsior Fluffed - Instrumented Roof Deck - 0 fpm

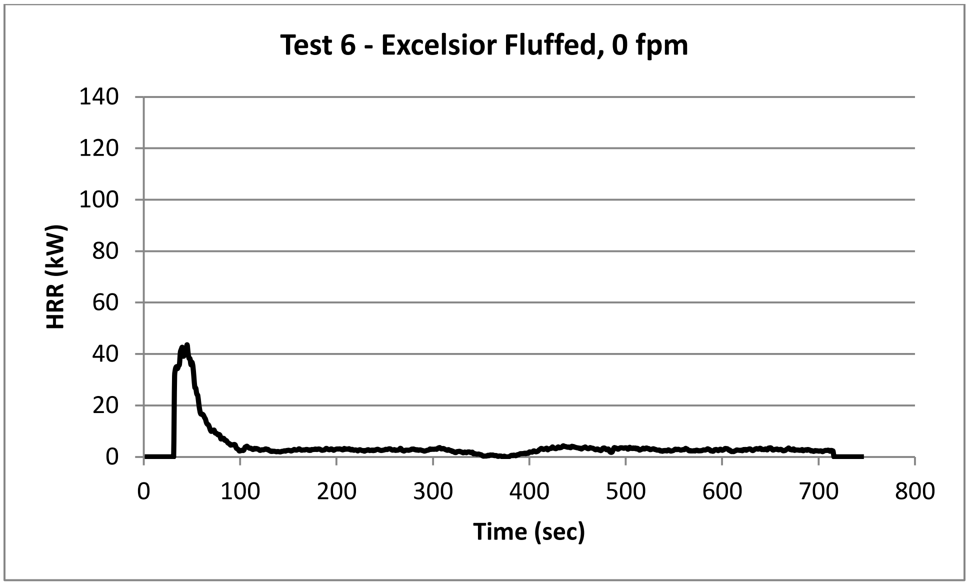

Figure 45 - Graph of Heat Release Rate (HRR) in kilowatts

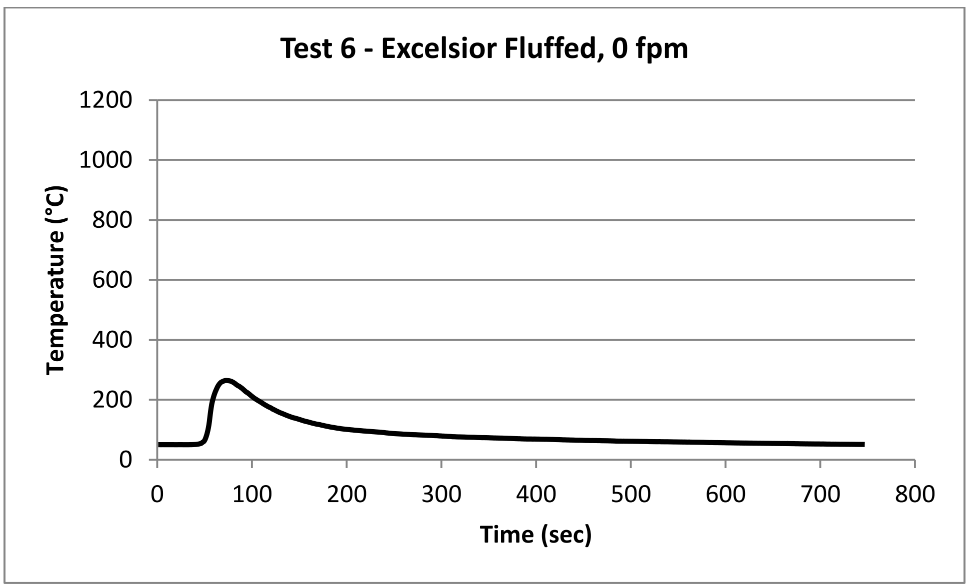

Figure 46 - Graph of Deck Surface Temperature (°C)

Test 7 - Sample=Excelsior Compressed - Instrumented Roof Deck - 0 fpm

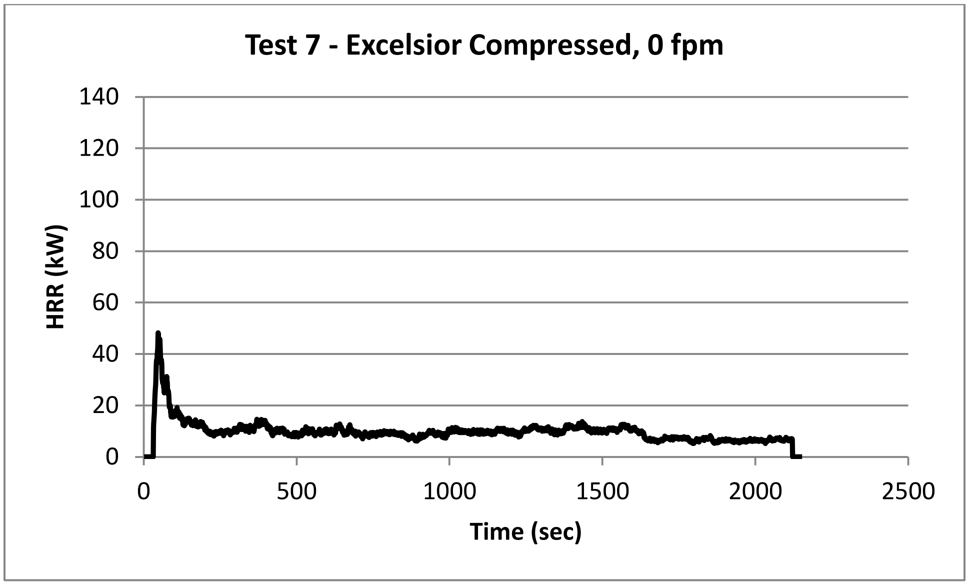

Figure 47 - Graph of Heat Release Rate (HRR) in kilowatts

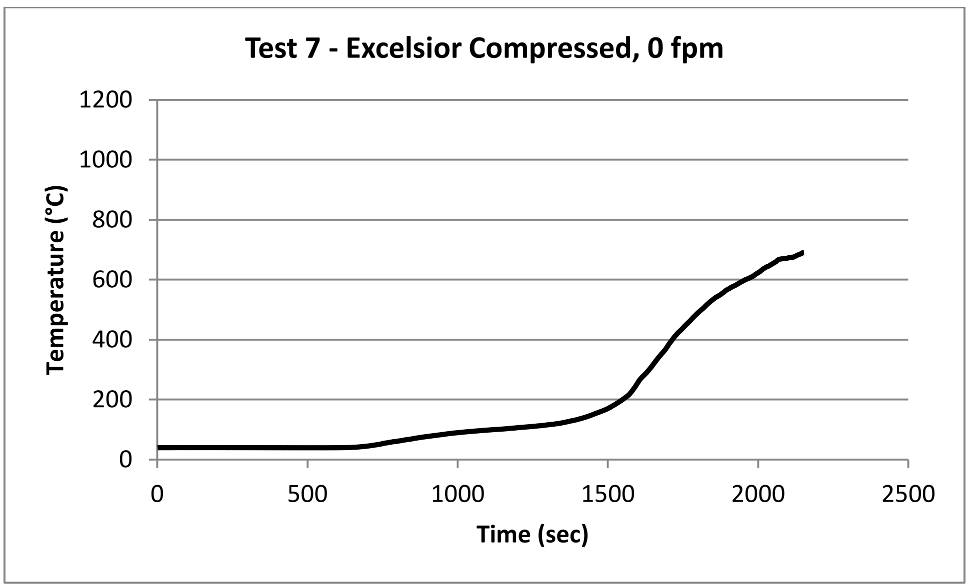

Figure 48 - Graph of Deck Surface Temperature (°C)

Test 8 - Sample=Leaves - Instrumented Roof Deck - 350 fpm

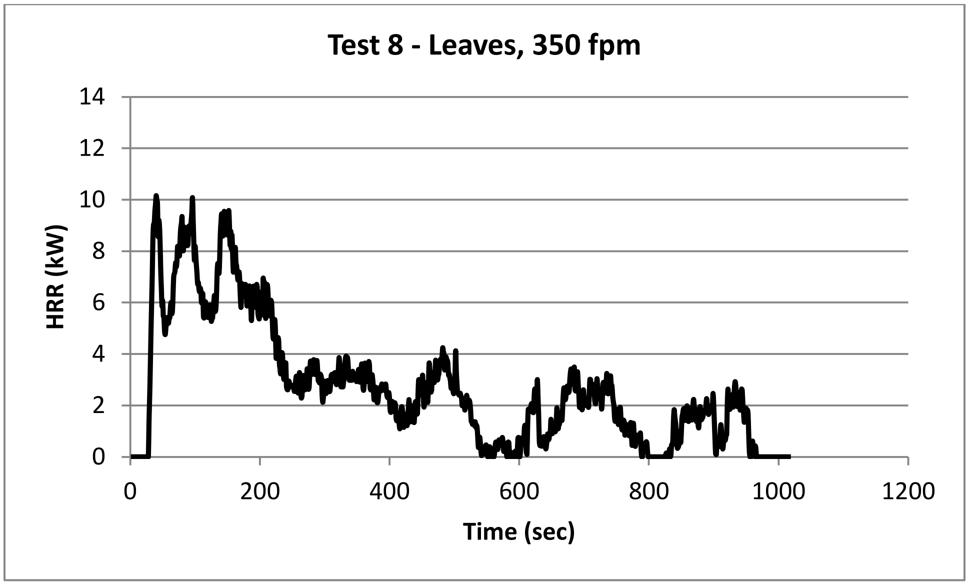

Figure 49 - Graph of Heat Release Rate (HRR) in kilowatts

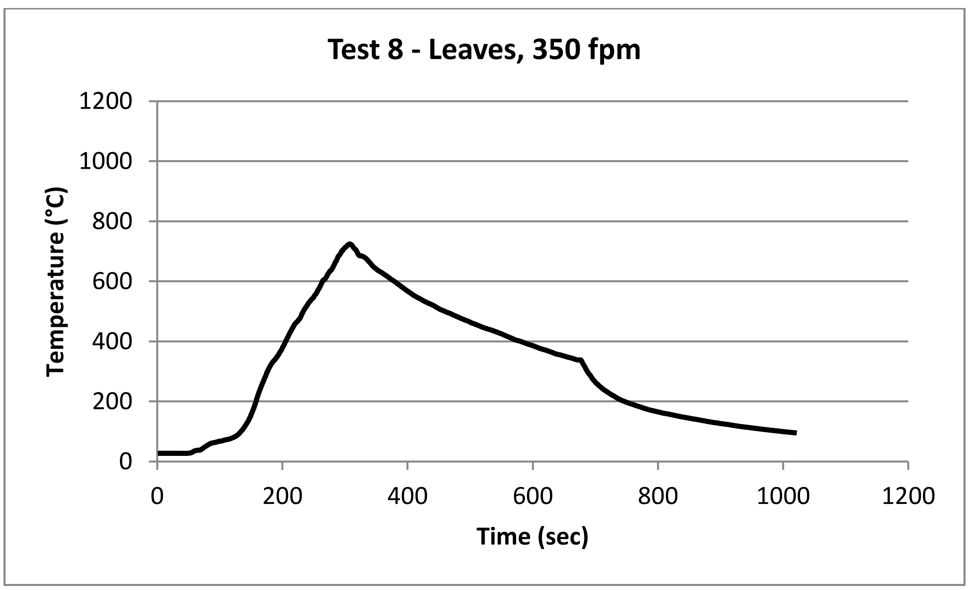

Figure 50 - Graph of Deck Surface Temperature (°C)

Test 9 - Sample=Excelsior Compressed - Instrumented Roof Deck - 350 fpm

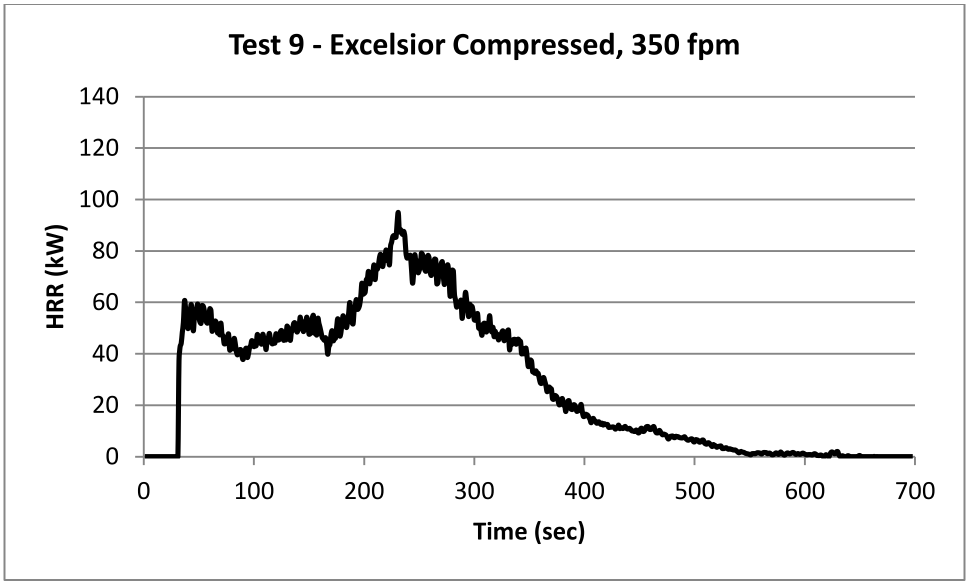

Figure 51 - Graph of Heat Release Rate (HRR) in kilowatts

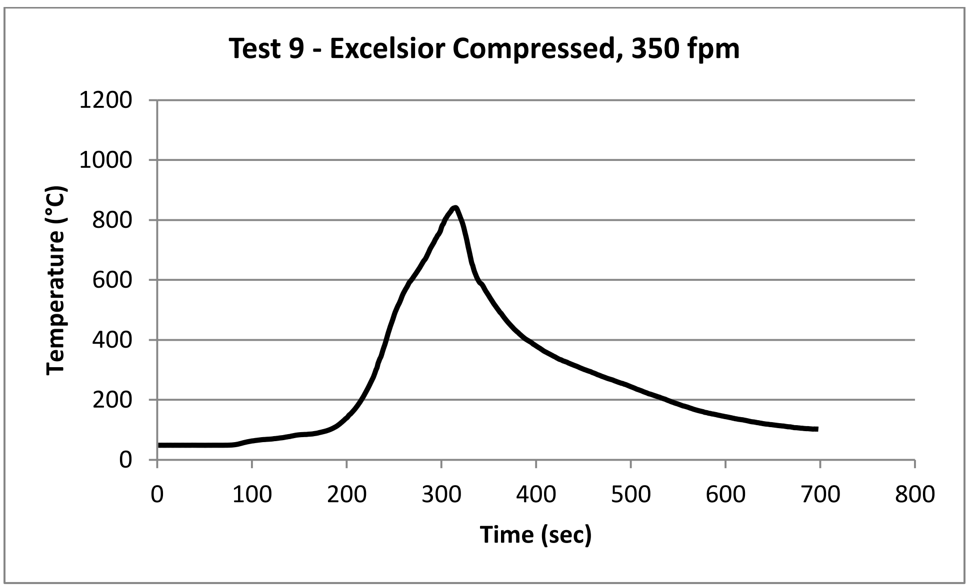

Figure 52 - Graph of Deck Surface Temperature (°C)

Test 10 - Sample=Excelsior Fluffed - Instrumented Roof Deck - 350 fpm

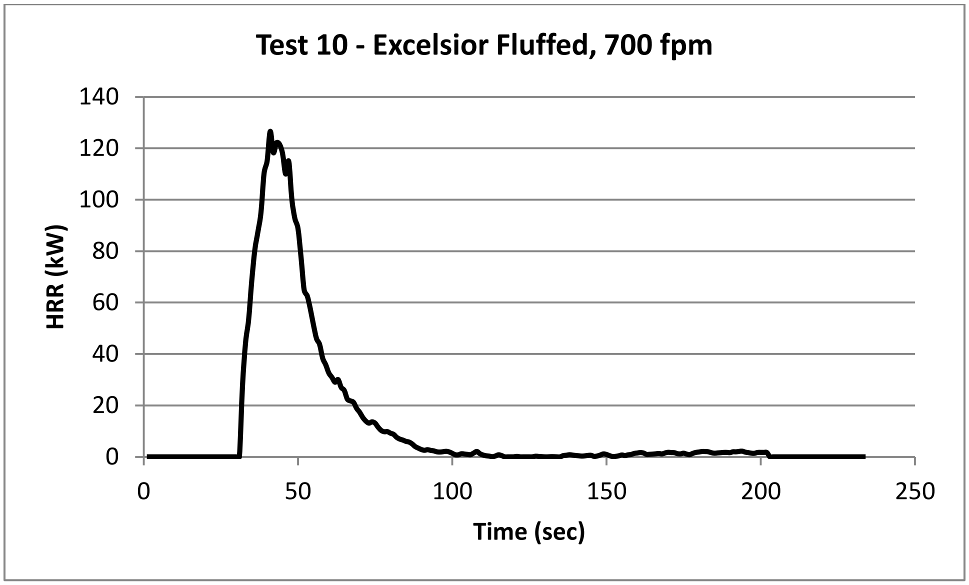

Figure 53 - Graph of Heat Release Rate (HRR) in kilowatts

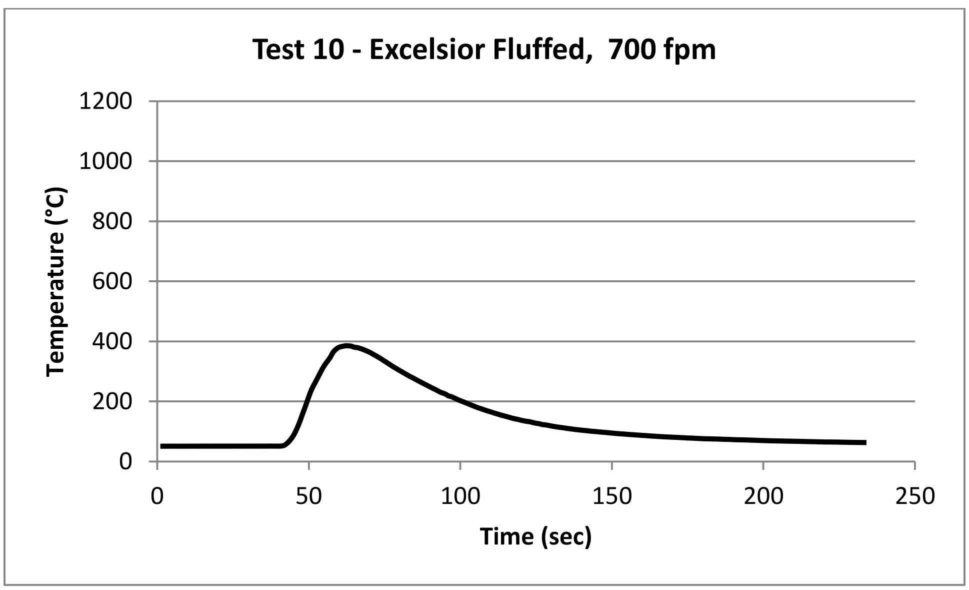

Figure 54 - Graph of Deck Surface Temperature (°C)

Test 11 - Sample=A Brand - Instrumented Shingled Roof Deck - 700 fpm

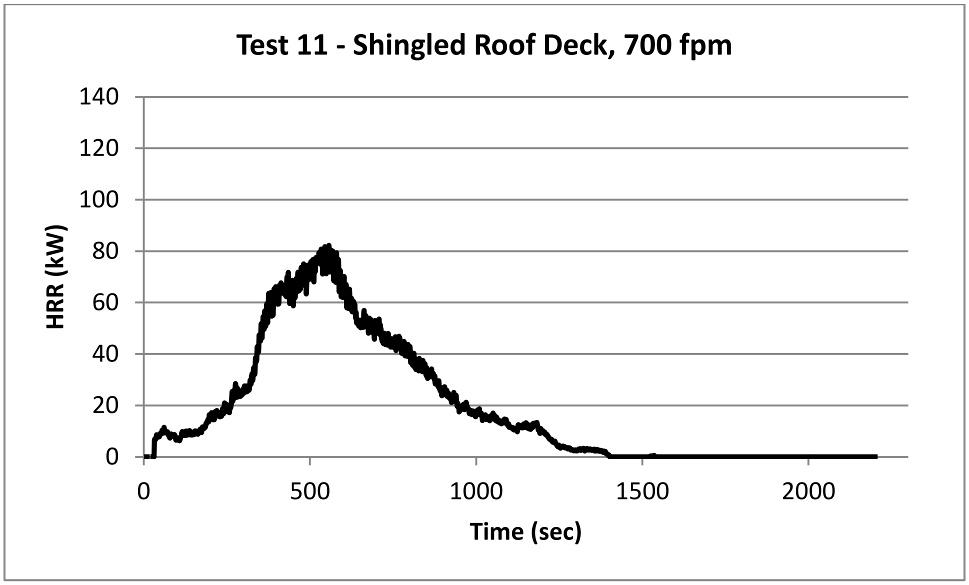

Figure 55 - Graph of Heat Release Rate (HRR) in kilowatts

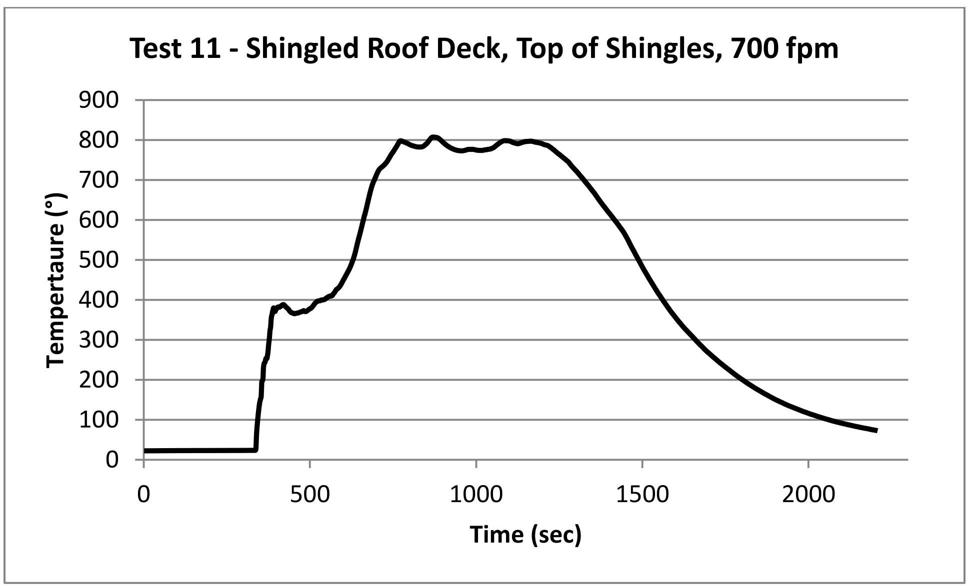

Figure 56 - Graph of Shingle Surface Temperature (°C)

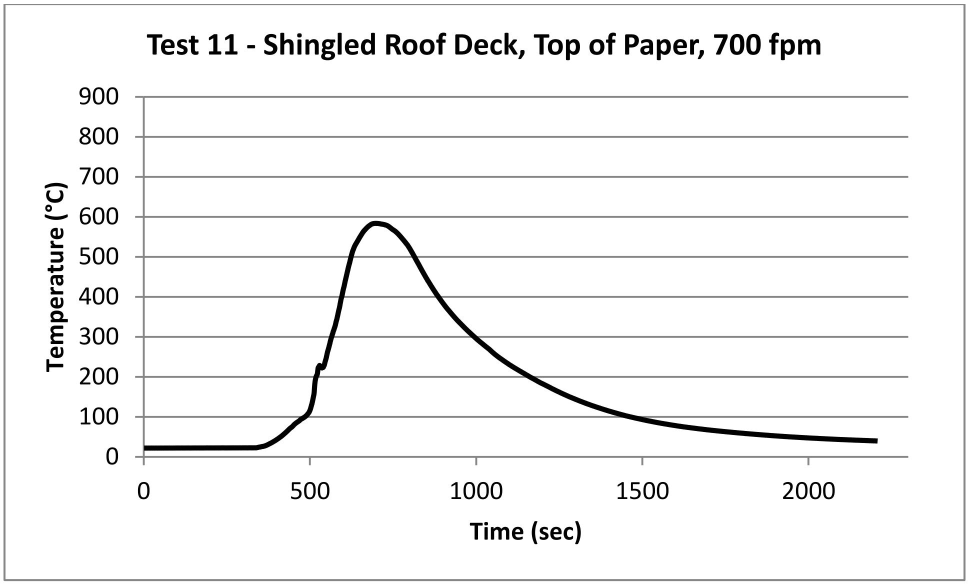

Figure 57 - Graph of Tar Paper Surface Temperature (°C)

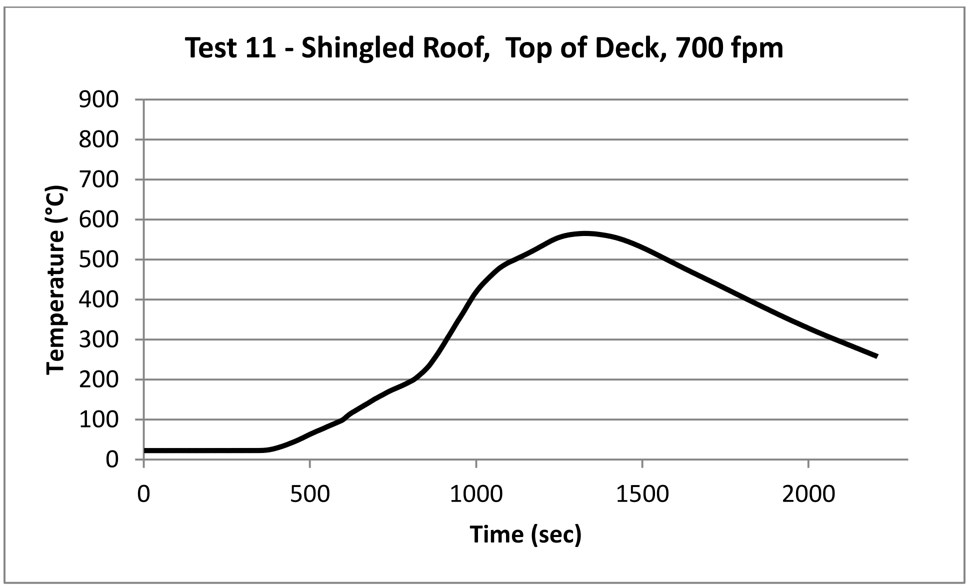

Figure 58 - Graph of Deck Surface Temperature (°C)

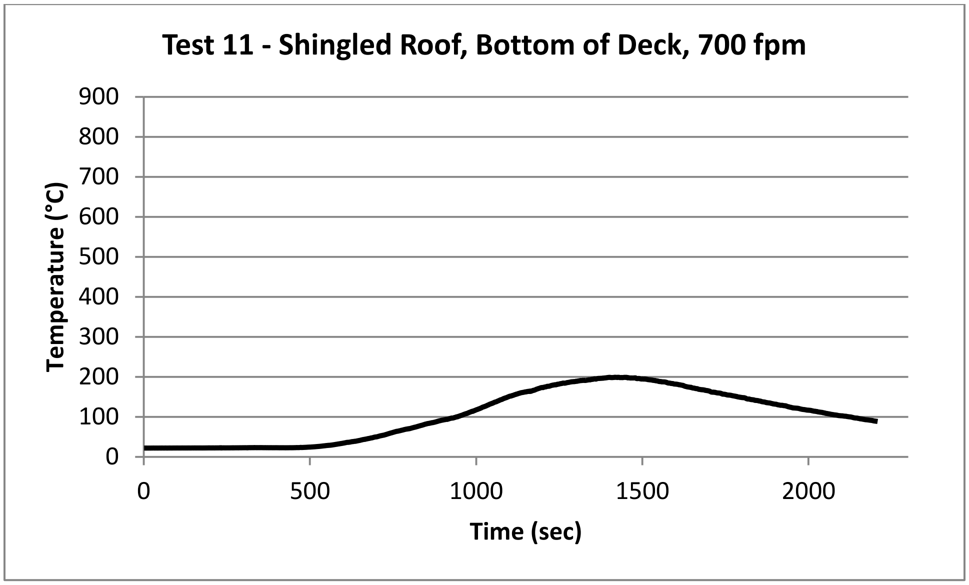

Figure 59 - Graph of Underside of Deck Surface Temperature (°C)

Task 2 - Summary

The following is a summary of the results:

- Under similar wind conditions of 700 fpm, the Class A brand developed a significantly greater amount of energy than the Class C brand both in peak and total.
- The leaf debris and excelsior generated substantially less energy than the Class A brand, but significantly greater than an individual Class C brand. One significant challenge with the use of leaf debris or excelsior is an expected variation of energy generated due to the nature of the material.
- As expected, air flow increased the peak energy generated, as illustrated by the Class A brand experiments under an airflow of 700 fpm and 0 fpm.

Overall, the heat release rate and heat transfer to the roof surface of Class A and Class C brands did not demonstrate a direct correlation to common materials that may collect between PV modules and the roof surface, such as leaf debris and excelsior (wood wool). The Class A brand yielded results significantly greater than the leaf debris and wood excelsior while the Class B brand yielded results significantly less than the leaf debris and wood excelsior. While the Class B brand was not included in the experiments, the deduction of these experiments is that the representation of common materials is closest to the Class B brand in terms of heat release and heat transfer to the roof surface.

The data generated provides a base understanding of the burning characteristics of the standard brands, wood excelsior and leaf debris. Where peak heat release rate indicates a magnitude, the total heat release provides some relative data for comparison of duration of burning items. While heat release rate is an important quantification of a fire, it does not by itself describe the complete thermal stress imposed by a burning object onto a roof.

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:

- Some PV modules mounted at angles (positive and negative) to steep and low sloped roofs impacted the fire classification rating of the supporting roof assembly. The extent of the impact was dependent on the angle of the module relative to the roof and the type of roofing system,

- PV modules mounted at zero clearance to the roof surface demonstrated no impact to the fire rating of the roof when the ignition source flame was directed to the front vertical surface of the module or when the ignition source flame was directed along the horizontal face of the module,

- The heat release rate and heat transfer to the roof surface of Class A and Class C brands did not demonstrate a direct correlation to common materials that may collect between PV modules and the roof surface, such as leaf debris and excelsior (wood wool). The Class A brand yielded results significantly greater than the leaf debris and wood excelsior while the Class B brand yielded results significantly less than the leaf debris and wood excelsior. While the Class B brand was not included in the experiments, the deduction of these experiments is that the representation of common materials is closest to the Class B brand in terms of heat release and heat transfer to the roof surface.

RECOMMENDATIONS

Based on the research conducted in this study, the Research Team would like to make the following recommendations:

- Consider additional installation parameters including low slope insulation thickness and formulations such as polystyrene and initial elevations. This will provide a more complete understanding of PV / roof assembly fire classification performance,

- Continue research in this area to evaluate the sensitivity of the fire performance of roofing systems to the various PV installation methodologies. As a matter of practicality, it is unlikely that a manufacturer would submit every possible PV and roofing product installation configuration to a standard fire test. Further work is needed to determine a generic roofing material which can be specified as a worst case for testing of PV modules,

- This research should be shared with the external fire community and key stakeholders and internally through the UL 790 and UL 1703 Standards Technical Process (STP),

- The Standards Technical Panel should specifically consider the findings in this Report on the burning behaviors of burning brands and the common materials that may collect between PV modules, as they propose revisions to test methods and performance criteria for the burning brand requirements in UL 1703,

- If additional research is undertaken, continued input from a broad fire safety community including firefighters, fire marshals, and authorities having jurisdiction (AHJ) should be solicited in addition to industry representatives such as PV manufacturers and associated equipment manufacturers.