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Wildfire Ignition Resistant Home Design (WIRHD) Program: Full-scale Testing and Demonstration Final Report

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Executive Summary

The primary goal of the Wildfire Ignition Resistant Home Design (WIRHD) program was to develop a home evaluation tool that could assess the ignition potential of a structure subjected to wildfire exposures. This report describes the tests that were conducted, summarizes the results, and discusses the implications of these results with regard to the vulnerabilities to homes and buildings.

The Insurance Institute for Business & Home Safety (IBHS) and the Savannah River National Laboratory (SRNL) collaboratively developed the capability to perform ember and radiant exposure testing at the IBHS Research Center.

The ember exposure capability consisted of five individual ember generators located in the test chamber. Each ember generator consisted of a large metal combustion chamber and a fan that pushed the burning embers vertically upward and out of the chamber into one of three steel ducts that terminated at different distances above grade. The radiant panel used in this project was 50 in. (1270 mm) wide and 63 in. (1600 mm) tall. It consisted of 50 infrared natural gas burner heads arranged in five rows of ten burners each and was capable of generating a 35 kW/m^2 exposure when the target material was located 20 in. (508 mm) from the panel.

Testing for ember exposure was conducted on a full sized building that was constructed and moved into the test chamber. The test building was designed to enable evaluation of certain potential vulnerabilities of a building, including roofing materials and designs, selected attic vents, siding materials, decking materials, and mulches. The vulnerabilities of selected building materials, components and assemblies were evaluated based on the results from the series of ember exposure tests. Most radiant panel tests were conducted on windows mounted in 4 ft by 8 ft modular wall sections or exterior siding installed on 8 ft by 8 ft modular wall sections.

Included in the ember tests were (1) ember entry through vents; (2) vulnerability of roof coverings and design features (e.g., valley, dormers); (3) vulnerability of debris filled gutters to ignition from wind-blown embers; (4) performance of window screens in resisting ember entry; (5) ignition potential and impact of common mulch products and landscaping vegetation located near the exterior wall, and (6) vulnerability of attached decks and common combustible materials stored under and on top of decks. The results of these tests demonstrated the ability of embers to ignite vegetative debris (e.g., pine needles) that can accumulate on the roof and gutters and combustible materials stored on and under decks. Once ignited, a direct flame contact exposure can result to the edge of roof and adjacent materials, siding, and the underside of the deck. Vents whose exposed face was perpendicular to the wind and ember flow (e.g., a gable end vent) were vulnerable to ember entry.

Included in the radiant panel testing were (1) evaluating combustible and noncombustible siding materials; (2) evaluating window glass, frame material, screens and curtains behind the window, and (3) evaluating selected corner configurations, including a re-

entrant wall corner, an open-eave/wall assembly, and a soffited eave/wall assembly. Results of these tests predominately provided video and photographic images for use in the assessment tool. These results provided confirmational data on the relative importance of window components and screening (the glass is the most vulnerable component and window screens reduce the amount of radiant heat transmitted into the building). Results also supported heat flux calculations indicting that curtains located behind a closed window with annealed or tempered glass will ignite only after the glass breaks and falls out. The dual-pane tempered glass window did not break at the 35 kW/m^2 exposure used in this series of tests.

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1. Introduction

The primary goal of the Wildfire Ignition Resistant Home Design (WIRHD) program was to develop a home evaluation tool that could assess the ignition potential of a structure subjected to wildfire exposures. The interactive software, entitled "Wildfire Ignition Resistance Estimator (WildFIRE) Wizard," will allow the user to create a home or building using software tools and specify and position vegetation and other components located in the area surrounding the building. The area surrounding the home is referred to as either the home ignition zone (HIZ) or the home's defensible space. This zone usually consists of an area that extends out from the exterior wall of the home 100 ft (30 m), or to the property line. The tool will assess the ability of the exterior construction materials and landscaping vegetation to resist the typical wildfire exposure of embers (also known as firebrands), direct flame contact and radiant heat. Additionally, the tool will provide recommendations to the user for reducing the wildfire ignition potential.

To provide material property data and to support the educational component of the software, the Insurance Institute for Business & Home Safety (IBHS) and the Savannah River National Laboratory (SRNL) collaboratively performed two types of tests at the IBHS Research Center. These included ember (also known as "firebrand") exposures and exposure to radiant heat.

This report describes the tests that were conducted, summarizes the results, and discusses the implications of these results with regard to the vulnerabilities to homes and buildings. Photographs taken during testing are included with the descriptions of tests, and all photographs were provided by the IBHS Research Center. Opportunities for future work are also discussed. This report does not include a detailed analysis of the data collected from the tests.

2. Test Equipment and Setup

2.1. Ember Exposure

Ember tests were conducted in the IBHS Research Center windstorm simulator facility. This facility uses 105 vane-axial fans to blow winds through a 145-ft (44 m) wide by 145-ft (44 m) long test chamber with a 60-ft (18 m) clear height to the roof framing. The inlet to the test chamber is 65-ft (20 m) wide by 30-ft (9 m) tall. The outlet is about 10 % larger and located in the test chamber wall opposite from the inlet. Active control of fan speeds and vanes are used to reproduce desired windstorm characteristics.

The ember exposure capabilities at the IBHS Research Center consisted of five individual ember generators[1]. Each ember generator consisted of a large metal combustion chamber and a fan that pushed the burning embers vertically upward

[1] The ember generator design was based on a similar smaller-scale device developed by the National Institute of Standards and Technology (NIST) Fire Research Division.

and out of the chamber into one of three steel ducts that terminated at different distances above grade. The five chambers were uniformly spaced across the inlet to the test chamber. The chambers were located below grade in a five-ft wide pit, as were the fans. Each chamber was loaded with approximately 40 lbs. (18 kg) of combustible bark mulch and wooden dowels. A slotted 1-in. (25 mm) diameter steel pipe, located at the bottom of each chamber, served as a propane gas burner (Figure **1**). This burner ignited the bark mulch and wooden dowel raw material mixture, and then the below-grade fan pushed the burning embers up through the vertical ducts and into the wind stream of the wind tunnel (Figure **2**).

A test building was constructed and moved into the test chamber. The test building was designed to enable evaluation of certain potential vulnerabilities of a building, including roofing materials and designs, selected attic vents, siding materials, decking materials, and mulches. The test building was placed on a 55-ft (17 m) diameter turn table in the test chamber. Rotating the turn table enabled all four sides of the building to be subjected to ember exposures. The vulnerabilities of selected building materials, components and assemblies were evaluated based on the results from the series of ember exposure tests.

Figure 1. Flames from gas burner at the bottom of the combustion chamber (without mulch mixture).

Figure 2. Ember generators discharging during test.

2.2. Radiant Panel

The radiant panel designed and built for use in this project was 50 in. wide (1270 mm) and 63 in. (1600 mm) tall. It consisted of 50 infrared natural gas burner heads arranged in five rows of ten burners each (Figure **3**). When ignited, the surface temperature of each burner was approximately 1700°F (925°C). The radiant heat exposure to the target material was adjusted by moving the target closer to or further away from the radiant panel. In order to calibrate the radiant panel, heat flux sensors were embedded in a ceramic fiber, noncombustible rigid panel.

Figure 3. The radiant panel during a window test.

Thermocouples and heat flux sensors were used to collect temperature and heat flux data on selected exterior siding materials and window components. Walls containing siding and windows were subjected separately to a radiant exposure derived using the radiant panel. Selected siding materials were subjected to a combined radiant and convective exposure resulting from direct flame contact. The flame contact exposure was generated from ember-ignited mulch at the base of the test building. Some of this data was incorporated into the software to characterize the ignition potential of construction materials. Video clips and photographs taken during testing will be embedded in the assessment tool to demonstrate to the user the vulnerabilities of certain materials and construction features.

3. The Data Acquisition System

The Data Acquisition System (DAQ) was designed to collect analog input data from a maximum of 32 K-type thermocouples and a maximum of six heat flux sensors. The temperatures at the walls and windows were read by Omega Type K Quick Disconnect Thermocouples (KQSS-11U-12) and Omega Type K Cement-On Thermocouples (CO3-K), respectively. The thermocouples were mounted on the test walls by drilling through the back surface of the wall panel material so that the thermocouple probe tip would be on the surface of the wall panel facing the radiant panel. The cement-on thermocouples were fastened to the surface of the window glass by applying a thin layer of quick dry cyanoacrylate adhesive. A layer of OMEGABOND 400 High Temperature Cement was applied over the top surface of thermocouple. The thermocouples were connected by thermocouple extension wire (FF-K-205-TWSH-SLE) fitted with male connectors to a 19 in. (480 mm) Jack Panel (19SJP2-44-K) mounted on the DAQ enclosure box.

The heat flux was determined using Medtherm water-cooled total heat flux sensors (Schmidt-Boelter design, Model 64 series). These sensors were water cooled by pumping room temperature water through the sensor's water tubes, allowing water to circulate through the body of the sensor. A pump system was designed to transport water from a reservoir to the sensors in a closed-loop system. The heat flux sensors for the radiant panel tests were installed so that the face of the sensor was positioned 0.6 in. (15 mm) beyond the surface of wall panels. The face of the heat flux sensor was placed flush with the surface of the wall panel for the landscape tests during ember testing. For the window tests, the heat flux sensors were mounted on a stand so that the face of the lower section sensor was positioned 1 in. (25 mm) behind (i.e., on the unexposed side) of the glass. The schematic showing the placement of the sensors for each radiant panel test is shown in Appendix A.

The DAQ enclosure box held the FP-1000 RS232/RS485 Network Module (777517-00) which connected to four FP-TC-120 16-Bit Thermocouple Input Modules (777518-120). The heat flux sensors were connected into the enclosure and connected to one FP-AI-110 module. The modules were powered by a Sola power supply which was connected into a 120 V outlet. An RS-485 cable ran from the network modules in the enclosure to an RS-485 to RS-232 converter. The RS-232 cable ran to the nine-pin serial port on a Panasonic Toughbook CF-52 laptop. The data was collected and read by Fieldpoint Explorer 3.0 and Labview 6.1 software. Data were taken at a sample rate of one sample every six seconds for all radiant panel tests unless otherwise specified during calibration testing.

4. Ember Testing

A series of ember tests was conducted using the full-scale Wildland Urban Interface (WUI) test building to evaluate and demonstrate the vulnerability of common building components and materials to embers. Included in this series of tests were (1) ember entry through vents; (2) vulnerability of roof coverings and design features (e.g., valley, dormers); (3) vulnerability of debris filled gutters to ignition from wind-blown embers; (4) performance of window screens in resisting ember entry; (5) ignition potential and impact of common mulch products and landscaping vegetation located near the exterior wall, and (6) vulnerability of attached decks and common combustible materials stored under and on top of decks. A steady stream of burning embers was produced from each of the five ember generators inside the test chamber. The ember generators were loaded with dried mulch and wood dowels of various sizes. The duration of the ember exposure for each test was about 10 minutes.

4.1. Vent Testing

Several types of under eave attic vents and one gable end vent were included in this series of tests.

Under eave vents included:

- Open framing, rectangular vents in between truss blocking. One-quarter (¼) and one-eighth in. (6 mm and 3 mm) noncombustible corrosion resistant mesh screening was evaluated.
- Open eave framing with frieze block vents consisting of three 2 in. round holes cut into the nominal 2 by 4 blocking in each truss bay. Use of one-quarter in. and one-eighth in. (6 mm and 3 mm) noncombustible corrosion resistant mesh screening was evaluated.
- Soffited (boxed-in) eave, fiber cement vented soffit material with one-eighth in. (3 mm) vent holes. Installation with vented portion of panel located (1) near the exterior wall and (2) near the roof edge.
- Vinyl soffit vented over entire width
- Plywood soffit with 2 in. wide aluminum strip vent located (1) near the exterior wall and (2) near the roof edge.

High-definition video was captured for this series of tests with cameras located at selected areas within the attic. Layers of cheesecloth were placed in the eave area of the attic behind the vents to collect embers that entered the attic space. The relative number of embers that entered through a given vent was qualitatively evaluated. According to the video footage, the cheesecloth did not collect a large number of the entering embers. Embers that entered the attic space either landed on the cheesecloth, were carried further back into the attic, thereby missing the cheese cloth, or entered the attic through the gap between top of the fascia and the roof sheathing and dropped on top of the soffit material, again missing the cheesecloth (Figure **4**). This latter option occurred with the soffited eave construction.

Figure 4. Trapped embers in the fascia-to-roof sheathing gap.

The size of embers entering the attic was a function of the screen size of the mesh. The physical dimension of an ember entering the attic was never larger than the screen opening, or in the case embers entering through the gap at the roof edge, no larger than that opening. Embers entering through this gap could have come from either one of the five ember generators or ignited debris in the gutter that generated its own embers.

The number of embers entering the attic was a function of the type of vent. Conclusive information regarding the vulnerability of vents to ember entry cannot be provided here since a variety of vents were not included in the Phase 1 experimental design. According to the test results, the vents that presented a perpendicular face to the wind stream were more vulnerable to ember entry. These included the gable end vent and the under eave vents in the open eave design. Ember entry through the soffit vents was minimal. By viewing the video in slow motion, embers were observed entering the attic space through the gap between the fascia and roof sheathing. It was also clear from these tests that ember entry at this location could be eliminated if metal angle flashing was installed to cover this gap.

4.2. Testing of Roof Coverings and Gutters

Several roof configurations and materials were incorporated into this series of tests to demonstrate vulnerabilities to ember exposure (Figure **5**). The roof materials tested were clay tile, asphalt fiberglass composition shingles, and wood shakes not treated with a fire retardant. The roof was a Dutch-hip design that incorporated a dormer on one side and a gable roof on the other that provided roof-to-wall intersections and valley construction details, respectively. Siding on one side of the dormer consisted of a fiber cement product and a wood composite product on the other. Untreated wood shakes were installed on one hip roof surface (installation of the shakes is shown in the foreground of Figure **5**). A clay barrel tile roof was installed on the opposite hip surface (not visible in the view shown in Figure **5**). Asphalt composition shingles were installed on the remaining roof surfaces. The dormer and roof valleys are visible on the right and left hand sides of this figure, respectively. Pine needles were used to represent "vegetative debris" that can accumulate on the roof and in gutters at the roof edge. Pine needles were distributed in the roof valley of the Class A fire-rated asphalt composition shingles, at the intersection between the asphalt composition roof and the dormer, and in metal and vinyl gutters attached at the edge of the roof. Pine needles were lightly distributed over the untreated wood shake roof and the clay barrel tile roof.

The ember exposure testing demonstrated two findings:

1. The untreated wood shake roof ignited in several locations and burned through the shingle layers and into the underlying roof sheathing before the fire was extinguished.

2. Pine needles in the roof valley were easily ignited by embers, as was the debris on top of and at the entrance to the clay barrel tile roof and at the roof-to-dormer intersection. The asphalt composition shingles were damaged but there was no burn through into the attic (Figure **6**).

Metal and vinyl gutters were also tested with and without debris present. The gutters that were free from debris did not ignite and remained in place during the ember exposure period. The pine needle debris in the vinyl gutters was ignited by embers, after which the gutter detached from the fascia and fell to the ground, thereby contributing to any flame contact exposure to the side of the building (e.g., from ignited combustible mulch). Debris in the metal gutter also ignited. The metal gutter remained attached to the fascia; the burning debris inside resulted in a flame contact and ember exposure with the roof edge.

Figure 5. A view of the WUI test building showing the Dutch-hip design.

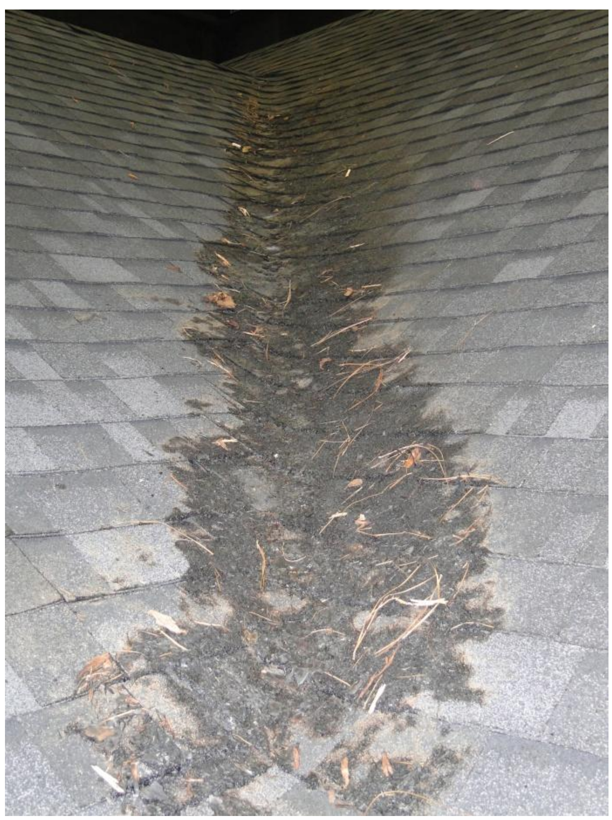

Figure 6. Damage to the roof covering after ignition of the pine needle debris in the valley.

4.3. Landscape, Deck Testing, and Window Screen Testing

Landscape materials were placed in metal mesh trays positioned at the base of the exterior walls. Mulch materials made from recycled rubber, pine straw (pine needles), bark, and stones were selected to represent a number of combustible and noncombustible landscaping products that are commercially available. The exterior walls behind the pine straw and rubber mulch products were instrumented with thermocouples and heat flux sensors. The thermocouple and sensor locations are shown in Appendix A, Figure A1.

All of the combustible mulch products (recycled rubber, pine needles, and bark) ignited from the ember exposures. As expected, the noncombustible rock mulch did not ignite. Because of the dark smoke that was produced after ignition, the rubber mulch was extinguished shortly after it ignited (Figure **7**). The measured heat flux during the rubber mulch burn did not exceed 2 kW/m^2, and the maximum measured temperature was less than 38°C (100°F). The pine straw was not extinguished and burned quickly. The maximum recorded temperature was 255°C (490°F). The heat flux from one of the sensors in the ember-ignited pine needles is given in Figure 8, and it can be seen that there was a rapid rise and fall of heat flux to the exterior cladding, typical of burning debris and small landscaping vegetation. The maximum heat flux was approximately 80 kW/m^2, but this level was maintained for only a few seconds. Burning pine needles are shown in Figure 9, and this product was quicker to ignite compared to the bark mulch product to the left of the pine needles. Ignited pine needle debris can also be seen adjacent to the dormer (on the roof).

Figure 7. Ember-started ignition in the recycled rubber mulch bed.

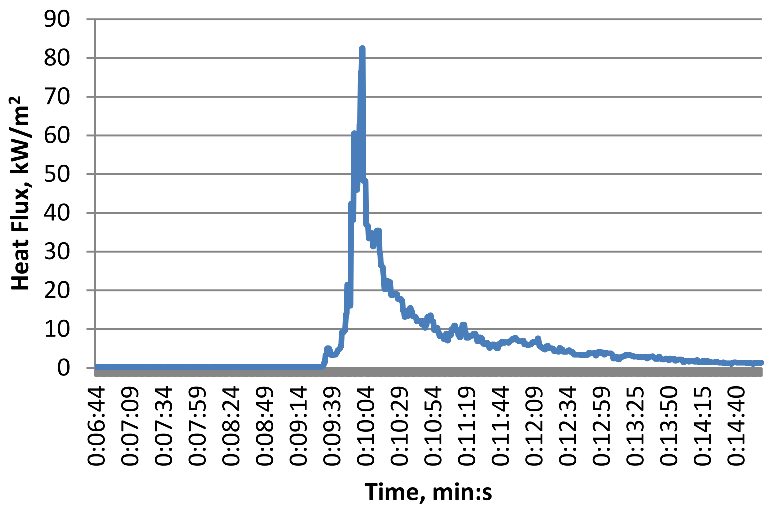

Figure 8. Recorded heat flux from ember-ignited pine needles. Source: IBHS Research Center.

Figure 9. Burning pine needle mulch (center) and bark mulch (left). Pine needle debris next to the roof dormer also ignited.

The vulnerability of different decking materials and combustible materials placed on and beneath the deck were evaluated using small 4 ft by 3 ft (1.2 m by 1 m) deck sections with different deck board materials. The deck board materials tested included two wood-plastic composites and a preservative treated solid-wood decking. One of the composites complied with Chapter 7A of the California Building Code and the other one did not. A broom and pine needles were placed on top of each deck, and a wood pile with pine needles inserted into the pile was placed beneath all deck sections. The fine fuels represented by the pine needles and brooms were easily ignited as a result of the ember exposure. In one case, the broom did not ignite. The flame contact exposure to the deck board was not usually sufficient to result in a flaming ignition. Flaming ignition did occur on the solid wood deck. The Chapter 7A non-compliant wood-plastic composite did not ignite. The compliant wood plastic composite product smoldered for 45 minutes until it was extinguished.

The effectiveness of metal and fiberglass screens in reducing ember entry into a building was evaluated using open windows. The open window scenario would most likely be associated with a resident forgetting to close windows when evacuating. As long as screens stayed intact, they did a very effective job in minimizing the entry of embers – some (non-observable) entry of embers smaller than the one-sixteenth in. (1.5 mm) mesh size was possible. A direct flame contact exposure from burning mulch and vegetation resulted in failure of the fiberglass mesh screen, allowing embers and flames to enter.

5. Radiant Panel Testing

A radiant panel was designed and constructed for use in this series of tests. The panel was 50 in. (1270 mm) wide and 63 in. (1600 mm) tall. It consisted of 50 infrared natural gas burner heads arranged in five rows of 10 burners. The surface temperature of each burner was approximately 1700°F (925°C). The radiant heat exposure to the target material was adjusted by moving the target closer to or further away from the radiant panel.

A series of exterior-use construction materials were exposed to radiant heat to demonstrate whether or not the material was combustible and other performance characteristics. The test subjects consisted of exterior siding materials, window glass, frames, and fiberglass screening, open and soffited eave configurations, and an interior (re-entrant) corner. A water-cooled radiator blocking panel was placed between the radiant panel and the test wall for five minutes between each test to allow the radiant panel to achieve the target temperature prior to exposing the test material. The panel was turned off between tests. The setup for testing is shown in Figure 10.

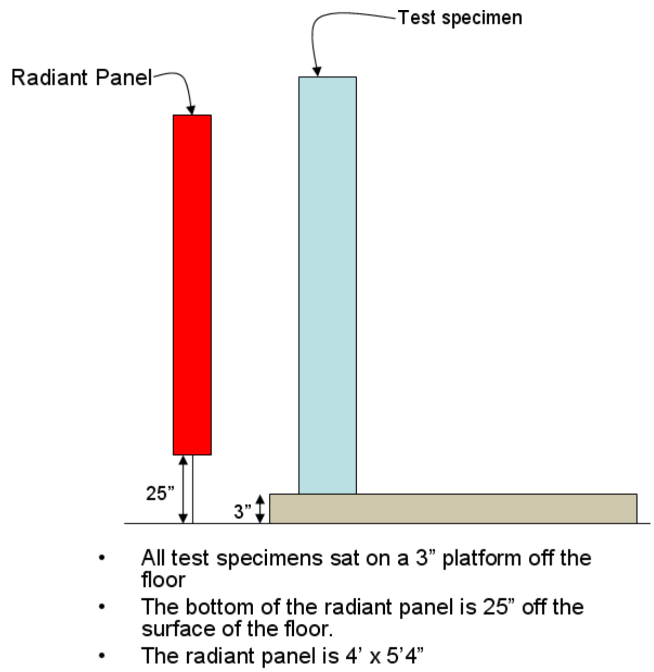

Figure 10. Diagram of radiant panel test setup. Source: IBHS Research Center.

When testing siding materials, either in a flat wall or corner configuration, a gas pilot flame was positioned in the upper part of the assembly, approximately 0.6 in. (15 mm) from the exterior face. The purpose of the pilot flame was to enable the evaluation of piloted ignition. The time to piloted ignition (as opposed to non-piloted ignition) is lower and less variable. Due to significant updraft of off-gassing volatiles in the combustible materials, however, the pilot flame was often extinguished prior to flaming ignition. Therefore, the time to ignition presented here is somewhat greater than what would be expected under a piloted scenario. This qualification will not affect the use of video and still photography demonstrating flaming combustion and other degradation effects from exposure to radiant heat.

A summary of the radiant panel testing is given in Appendix D. Representative photographs of materials after testing are included in this appendix.

5.1. Calibration

An 8 ft by 8 ft noncombustible ceramic fiber board test panel was placed in front of and exposed to the radiant panel to calibrate the panel. Three heat flux sensors were installed in the noncombustible wall (three other sensors were found to be damaged) (Figure A2). The distance between the radiant panel and calibration wall was changed by five-in. increments to develop the relationship between distance and heat flux.

Results of the calibration testing showed that 15 kilowatt per square meter (kW/m^2) and 35 kW/m^2 exposures were obtained at separation distances of 40 in. (1016 mm) and 20 in. (508 mm) respectively (Figure 11). The data are given in Appendix E. Most of the tests were conducted at the 35 kW/m^2 level. Testing involving corner sections (the eave and interior corner wall tests) were conducted at exposure levels less than that, particularly in the corner. The lower level was necessary because of the increased distance between the radiant panel and the corner of the assembly.

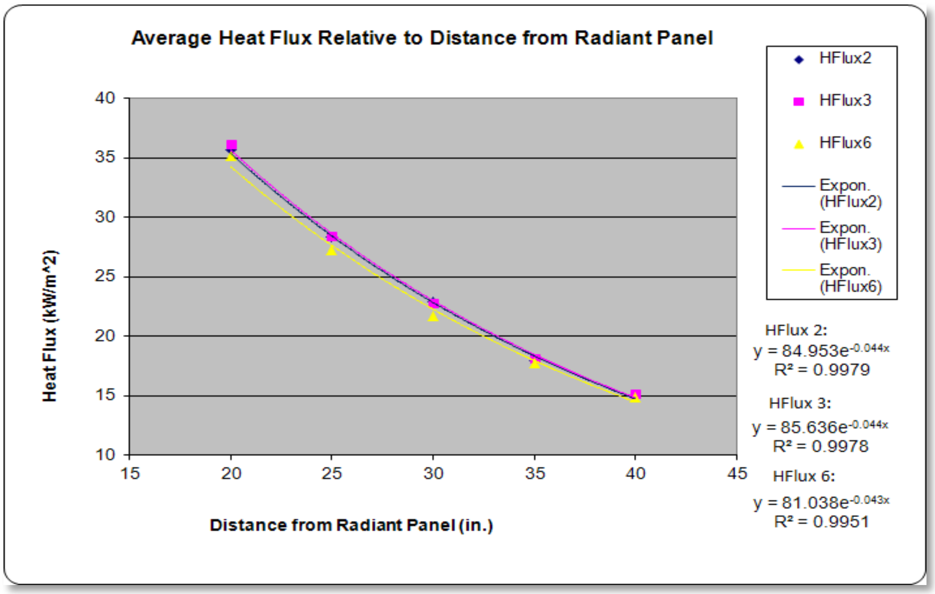

Figure 11. Calibration test results for the radiant panel. Source: IBHS Research Center.

5.2. Siding Tests

Several exterior wall siding materials were tested to evaluate time to ignition or form of degradation when exposed to radiant heat. These included 8 ft by 8ft wood-framed wall section with OSB sheathing and the following claddings:

- Plywood T1-11 panels, painted (half black and half white) and unpainted
- Solid wood lap-siding
- Fiber cement lap-siding
- Vinyl lap-siding, thick, high wind grade and thinner, builder's grade

The time to ignition for the wood and wood-based siding products subjected to the radiant panel exposure ranged from about 4.5 minutes to 16 minutes. Such a range in ignition times is not uncommon, particularly given that the updraft created by the volatiles coming off of the wood and wood-based siding products extinguished the pilot flame located at the top of the wall sections. The time to ignition was quicker for the unpainted T1-11 panel and horizontal lap siding product compared to the painted T1-11 panel. The time to ignition for the flat profile products, in this case the plywood T1-11 panelized siding products, was slower than that for the profiled siding product, in this case a solid wood horizontal lap siding with a bevel profile.

Two different vinyl siding products were tested, including a standard product and a “heavy” product. These products differed in their thickness, with the “heavy” product being about 0.01 in. (0.25 mm) thicker. There was a similar response by both of the vinyl siding products to the imposed radiant exposure. Neither ignited in flaming combustion, but both began deforming immediately and completely exposed the underlying sheathing material about a minute into the test.

The sensor locations for this series of tests are shown in Figure A3 and Figure A5. Thermocouple and heat flux data files are given in Appendices F – K.

5.3. Window and Glass Tests

The first set of tests was to demonstrate the effectiveness of screens on reducing the amount of radiant heat transmitted to the glass. Three different single-hung vinyl-framed, dual pane annealed glass windows were tested to failure in this series, one without a screen covering the lower section, one with a metal screen and one with a fiberglass screen covering the lower section of the window. These windows were not instrumented with thermocouples. Two heat flux sensors, each centered on either the upper or lower section and located 1 in (25 mm) from the surface of the inside glass pane, were used to measure heat flux. Results from this series of tests are shown in Figure 12. In the figure, the upper most (black) line is from the window that was used in the curtain ignition test. These results showed that metal or fiberglass screening were each effective in reducing the amount of radiant heat being transmitted through the window glass, reducing the amount transmitted by about one-third. This figure also demonstrated the effectiveness of glass in reducing the amount of radiant heat being transmitted into the building.

The next test was conducted to document the potential for transmitted radiant heat to ignite curtains behind a window. For this test, a 100 % cotton curtain was selected. A vinyl frame window similar to that used for the screen tests was used. The curtain did not ignite until approximately two minutes after the glass fell out.

The heat flux data for the screen and curtain tests are given in Appendices L – O.

The remaining window tests demonstrated the vulnerabilities between single- and dual-pane windows, annealed and tempered glass, and frame materials. The windows in these tests were instrumented with cement-on thermocouples. The locations of the thermocouples are shown in Figure A4.

These results support the general findings indicating the importance of glass in determining the vulnerabilities of windows to radiant heat exposures. Tempered glass did not fail under the 35 kW/m^2 exposure (published results show tempered glass failure at a heat flux of approximately 45 kW/m^2). Vinyl frames deformed and glass did fall out, but only after the glass had broken. Wood frames ignited but fire did not burn into the interior during the test period. The best performing option among the combinations used in this series of tests was the dual-pane tempered glass, aluminum-framed window. Thermocouple and heat flux data from this series of tests is given in Appendices P – T.

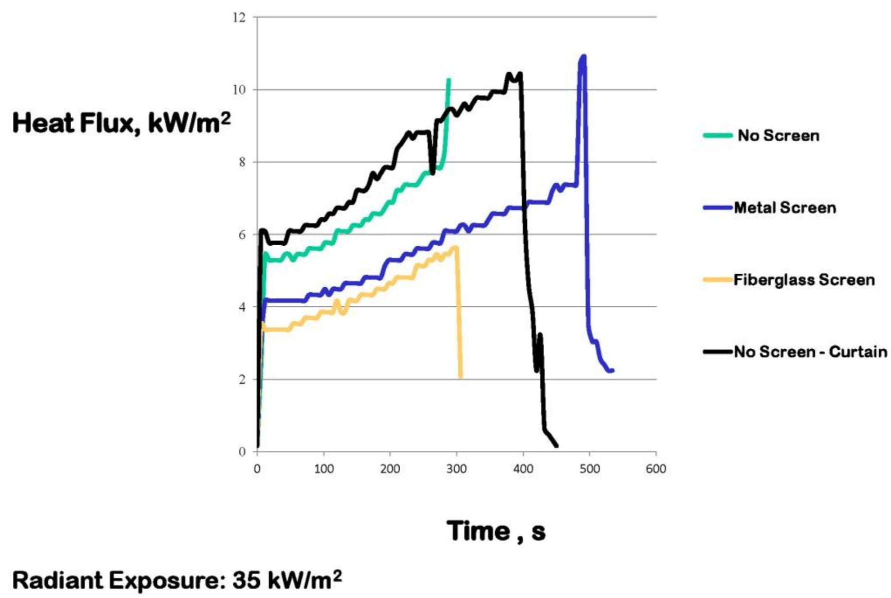

Figure 12. Effect of screens on the transmission of radiant heat through a dual-pane window. Source: IBHS Research Center.

5.4. Eave Tests

The eave testing conducted in this series was to evaluate the potential vulnerability of the surfaces under the eave to a radiant exposure. The wildfire scenario is depicted in Figure 13, which shows that the under eave (and under deck) area of a building located at the top of a slope could experience a radiant exposure from a fire burning up the slope. Two 4-ft (1.2 m) eaves were constructed in an open and soffited configuration using nominal 2 in. by 4 in. framing and plywood. Each section was propped at a 20 degree angle relative to the perpendicular to the radiant panel with the underside of the eave facing the panel. The bottom of the eave section was positioned 6 in. (150 mm) above the bottom of the radiant panel. The inside corner of the open eave, the corner at which the wall and eave meet, was 31 in. (790 mm) from the surface of the radiant panel, and the soffited eave was 32 in. (812 mm) from the surface of the radiant panel. A pilot flame, centered 2 in. (50 mm) over the edge of the eave, remained lit throughout each test. The soffited eave section ignited at the leading edge (closest to the radiant panel) at approximately 16:30 minutes. Exposure to the open eave sample was terminated after 21 minutes. Flaming ignition did not occur. In both cases, the plywood sheathing was completely charred through by the end of the test. The sensor locations are shown in Figure A6.

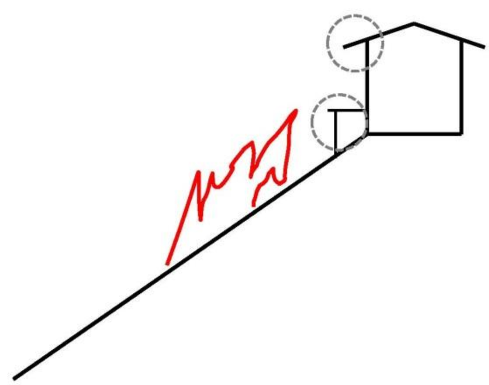

Figure 13. A diagram showing the potential for exposure to the under-deck and under- eave area of a building located at the top of a slope. Source: IBHS Research Center.

5.5. Re-entrant (Interior) Corner Test

The objective of this test was to record the heat flux up the vertical length of an exterior inside corner of a building when exposed to radiant heat. Two fiber cement lapped siding panels (a 4 ft. by 8 ft. wall faced the radiant panel) were set perpendicular to each other. The configuration of this test is shown in Figure 14. The wall section parallel to the radiant panel was placed 26.75 in. (680 mm) from the face of the radiant panel. The pilot flame was located 7 in. (178 mm) from the top heat flux sensor on the parallel section (26 in. [660 mm] from the top of the wall). The test was terminated when the OSB sheathing under the siding in the perpendicular section ignited, after approximately 33 minute exposure to the radiant panel. This result would indicate the vulnerability of the re-entrant corner is more dependent on flame contact exposure from burning debris and vegetation and winds than a purely radiant exposure. The sensor locations are shown in Figure A**7**.

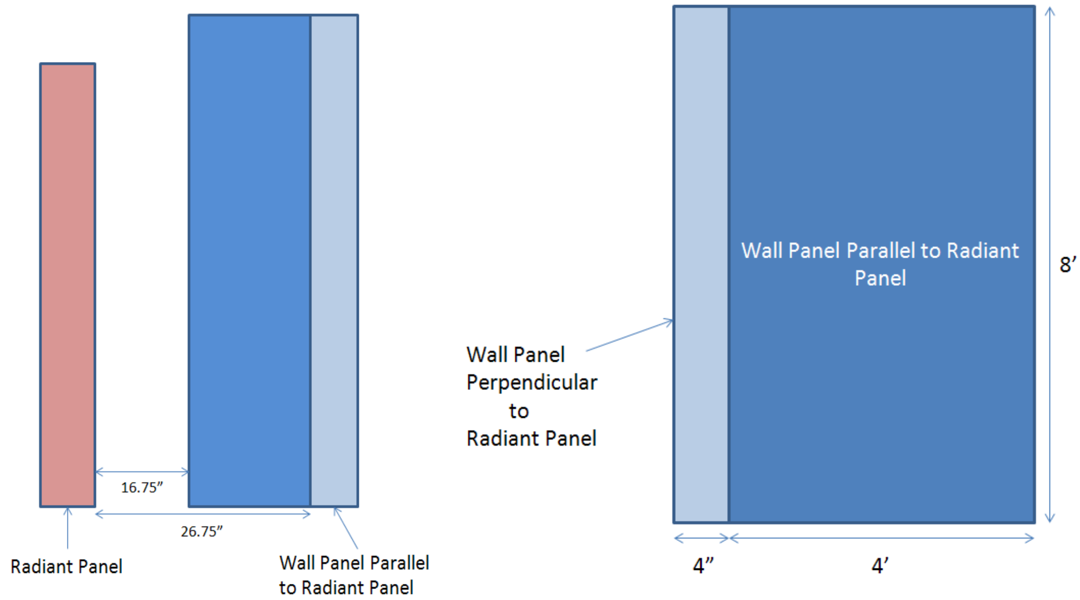

Figure 14. Re-entrant corner test setup. Source: IBHS Research Center.

6. Future Work

IBHS has purchased new heat flux sensors for use in future radiant panel research. Video and photographs from this series of tests will be incorporated in the WildFIRE Wizard assessment tool.

An experimental plan for further testing and research has been developed for Phase 2 of this project. Proposed testing includes additional work using the ember generators developed in Phase 1 and the radiant panel, also designed and built during Phase 1.

Appendix A. Test Sensor Locations

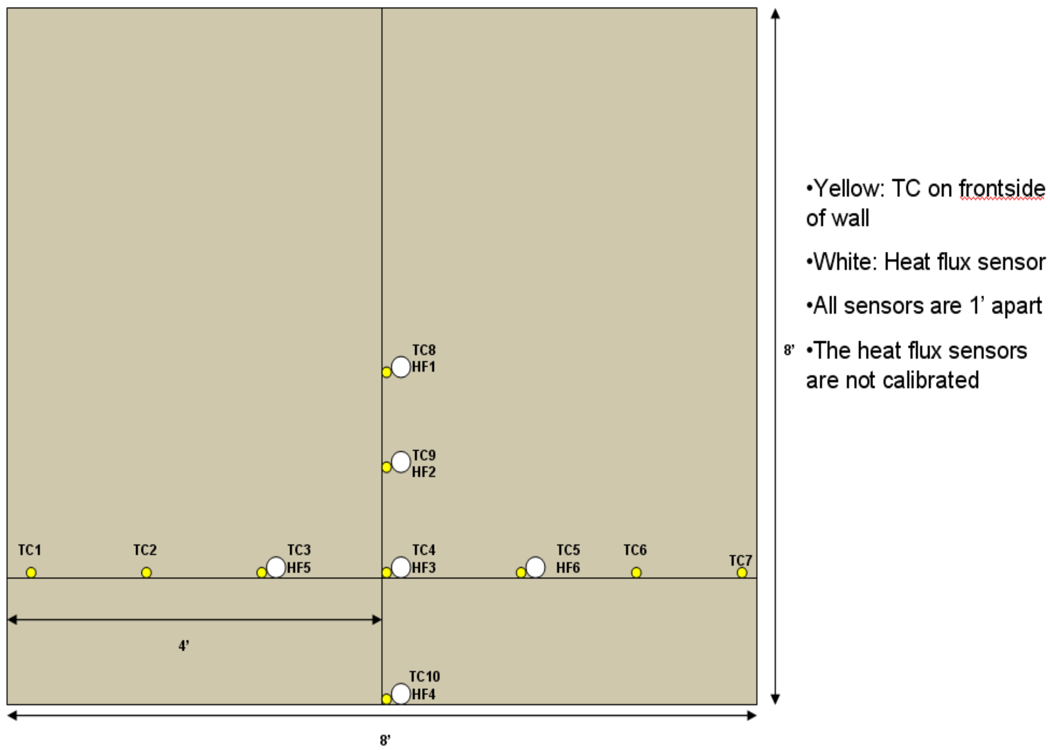

Figure A1. The location of heat flux sensors and thermocouples on the instrumented walls used in the tests of rubber mulch and pine needle mulch. Source: Savannah River National Laboratory.

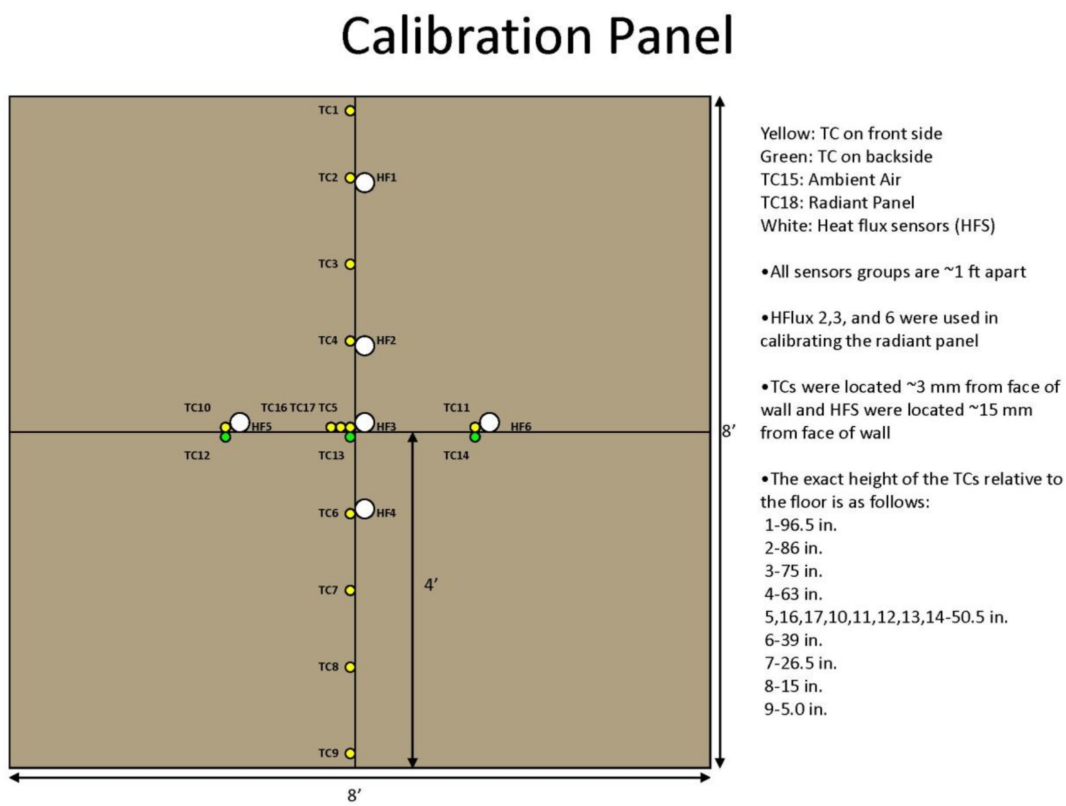

Figure A2. Planned location of heat flux sensors and thermocouples on the calibration panel. HF2, 3, and 4 were used in calibrating the radiant panel. Source: IBHS Research Center.

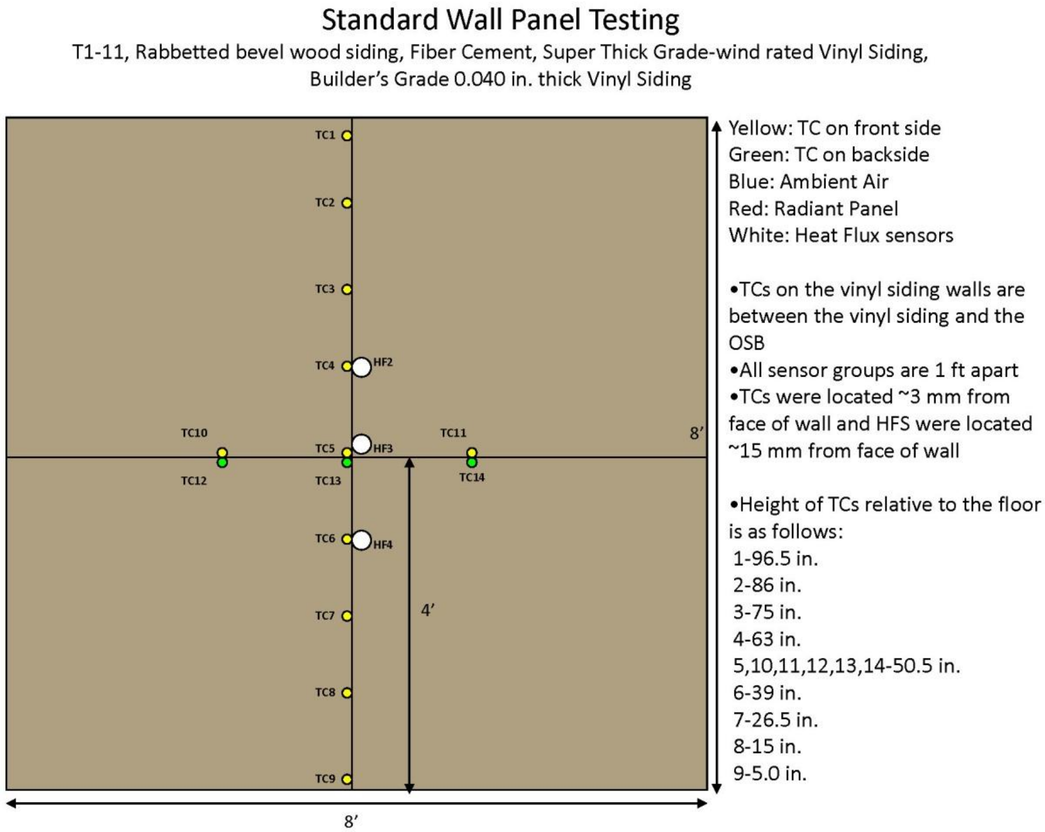

Figure A3. Standard wall panel test of T1-11, rabbetted bevel wood, fiber cement, and vinyl sidings. Source: IBHS Research Center.

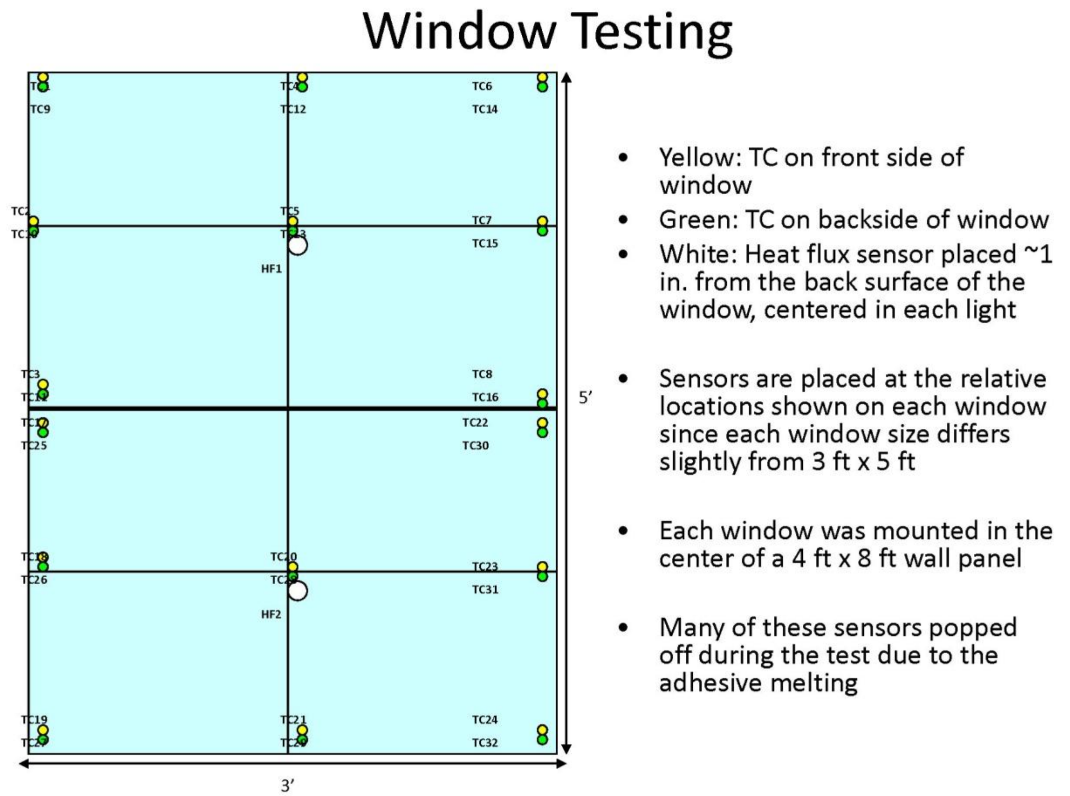

Figure A4. Thermocouple placement on the instrumented windows. Source: IBHS Research Center.

Black and White T1-11 Testing

- Locations of instruments are centered with the radiant panel
- Location of instruments are same for the black side
- TCs were located ~3 mm from face of wall and HFS were located ~15 mm from face of wall

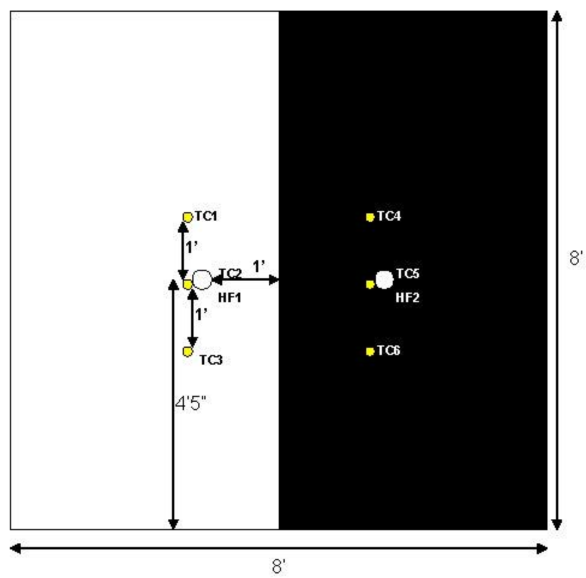

Figure A5. Location of the thermocouples and heat flux sensors on the T1-11 siding panel. Source: IBHS Research Center.

Eave Testing

- Yellow: TC on front side of eave
- TC15: Ambient Air
- TC18: Radiant Panel
- White: Heat flux sensor
- All sensors are placed 64 mm (2.5 in.) from the corner of the wall and the eave
- TCs were located ~3 mm from face of eave and HFS were located ~15 mm from face of eave

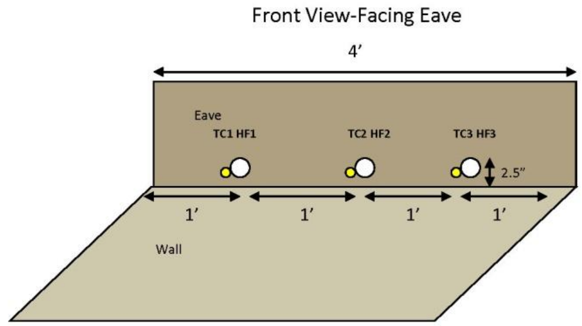

Figure A6. Thermocouple and heat flux locations for the eave tests. Source: IBHS Research Center.

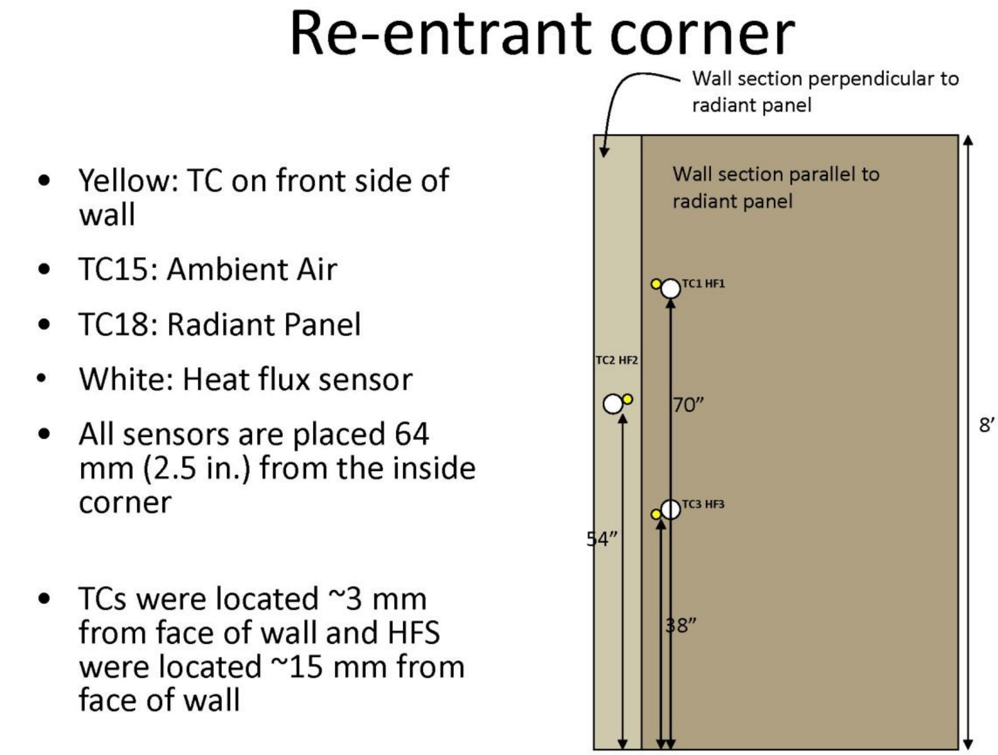

Figure A7. Thermocouple and heat flux sensor location on the re-entrant corner wall. Source: IBHS Research Center.

Appendix B. Thermocouple and Heat Flux Readings for the Instrumented Wall

Ember Exposure Testing of Recycled Rubber Mulch

(Note: Rubber mulch was ignited during the ember exposure and was extinguished while fire was small. As a result, temperature and heat flux readings area low.)

Appendix C. Thermocouple and Heat Flux Readings for the Instrumented Wall

Ember Exposure Testing of Pine Needle Mulch

Appendices – Radiant Panel Test Data

Appendix D: Summary of radiant panel testing.

Appendix E: Results of the radiant panel calibration tests.

Appendix F: Thermocouple and heat flux data for the unpainted T1-11 plywood wall.

Appendix G: Thermocouple and heat flux data for the painted (black and white) T1-11 plywood wall.

Appendix H: Thermocouple and heat flux data for the solid wood lap-siding wall.

Appendix I: Thermocouple and heat flux data for the fiber cement lap-siding wall.

Appendix J: Thermocouple and heat flux data for the wind-rated vinyl siding wall.

Appendix K: Thermocouple and heat flux data for the builder's grade vinyl siding wall.

Appendix L: Heat flux data for the screen test, no screen present.

Appendix M: Heat flux data for the screen test, fiberglass screen present.

Appendix N: Heat flux data for the screen test, metal screen present.

Appendix O: Heat flux data for the curtain test, no screen present.

Appendix P: Thermocouple and heat flux data for the window tests, single-pane, wood frame.

Appendix Q: Thermocouple and heat flux data for the window tests, dual-pane, wood frame.

Appendix R: Thermocouple and heat flux data for the window tests, dual-pane, vinyl frame.

Appendix S: Thermocouple and heat flux data for the window tests, dual-pane, aluminum frame.

Appendix T: Thermocouple and heat flux data for the window tests, dual-pane, tempered glass, aluminum frame.

Appendix U: Thermocouple and heat flux data for the soffited eave test.

Appendix V: Thermocouple and heat flux data for the open eave test.

Appendix W: Thermocouple and heat flux data for the re-entrant corner test.