VULNERABILITY OF THE EAVE TO DIRECT FLAME CONTACT AND RADIANT EXPOSURES

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ABSTRACT

Every year wildfires destroy numerous homes and other building throughout the United States. Whereas anecdotal evidence can provide some guidance regarding the relative vulnerability of individual components (i.e., roof, windows, decks, and siding), the vulnerability of the soffit / eave area is harder to discern. The vulnerability of the eave will likely depend on overhang design and construction (boxed in or open framing) overhang width, topography and subsequent siting of the building on the property. The eave can be a vulnerable component if fire can move into the soffited enclosure (in the case of a soffited- or boxed-in eave) or directly into the attic (in the case of open-eave construction). Also contributing to the potential vulnerability of the eave will be the type of vegetation management and storage of combustible materials in the area immediately adjacent to the building, and the relative combustibility of the siding material. Consequently eaves can be subjected to a combination of radiant and flame contact exposures.

The vulnerability of the eave will be evaluated through a series of laboratory experiments where different designs and materials were subjected to direct flame contact exposures developed from a gas diffusion burner and radiant exposure from a radiant panel. Eave variables included open- and soffited-eave construction and width of overhang.

INTRODUCTION

Material and design guides for buildings located in wildfire prone areas have indicated that the under-eave area can be vulnerable to typical wildfire exposures, including ember (firebrand), radiant and direct flame contact. Under eave design variables include open-eave construction, where the roof rafters and sheathing are exposed, a boxed-in design where panels or boards are attached to the underside of the roof rafters, and a soffited-eave design where panels or boards enclose the underside of the eave by extending horizontally back to the exterior wall (i.e., they don't follow the slope of the roof rafters).

Slack [1] reported that an open-eave design can trap "hot air and gases" from the wildfire and recommended a boxed-in or soffited-eave to reduce the vulnerability of this area. The International Wildland-Urban Interface Code[2] does not explicitly specify a boxed-in or soffited eave design, but a National Fire Protection Association standard does[3]. A technical fact sheet published by the Federal Emergency Management Agency[4] recommends installing soffited eaves and also suggests a design feature that minimizes or eliminates the roof overhang. This fact sheet acknowledges the importance of overhang width to protecting walls from rainfall. Reducing or eliminating the overhang is supported by observations made after the 1991 Oakland Hills fire, where it was observed that buildings that survived had minimal or no roof projection [5,6].

Cohen [7] reported that the roof overhang could protect the under-eave area during a wildfire. In that study, the radiant exposure to the mock structure was from a crown fire burning above the wall and roof section. A radiant exposure can occur in an under-eave area when a building is located upslope from a burning wildfire or building (Figure 1). Under this scenario, the radiant exposure would vary depending

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on the building location on the slope and amount of setback when located at the top of a slope. Increasing or decreasing slope would also influence the degree of attachment of the flame to the slope, and therefore also affect radiant exposure to the under-eave area[8]. If the fire can burn close enough to the building, the radiant exposure could result in a direct flame contact exposure. Similarly, embers igniting near-building vegetation could also result in a radiant and/or a direct flame contact exposure. Embers could also lodge in joints that occur between materials used in eave construction and enter directly through vents into unconditioned spaces. The vulnerability of joints and vents to embers was not investigated in this study.

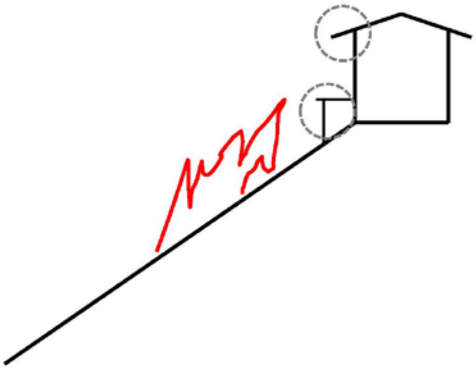

Figure 1. Fire burning upslope to a building, or a burning building down slope of another building, could provide a radiant exposure to the under-eave area, as well as to the underside of an attached deck, if present.

The objectives of this study were to investigate the effect of eave design and overhang width on the vulnerability of buildings subjected to radiant and direct flame contact exposures. Open- and soffited-eave designs were investigated.

EXPERIMENTAL

Direct flame contact exposure testing was conducted at the University of California Richmond Field Station, Richmond, CA during September and October, 2010. The radiant exposure testing was conducted at the Western Fire Center, Kelso, WA in November, 2010.

Building materials were purchased at lumber yards near each facility. A 4:12 roof slope was used for all eave assemblies. For the open-eave specimens, the exposed surfaces included the 50 by 90 mm (2 by 4 in) Douglas-fir (*Pseudotsuga menzensii*) roof rafters and 13 mm (0.5 in) ACX plywood roof sheathing, with the higher quality “A” side exposed to the diffusion burner or radiant panel. The exposed surface for the soffited-eave specimens consisted of 13 mm (0.5 in) ACX plywood, with the higher quality “A” side exposed to the diffusion burner or radiant panel. For the open-eave specimens, an ACX plywood-to-oriented strand board (OSB) roof sheathing joint was created above the blocking. This was done to replicate common construction practice, incorporating the higher cost ACX plywood product only where needed to serve its aesthetic function. The OSB sheathing was 11 mm (7/17 in) thick. A Select Structural grade nominal 50 by 150 mm (2 by 6 in) Douglas-fir fascia board was used for both eave designs. Roofing felt and covering was not applied to the top of the test specimens.

The wood members used in these tests were not conditioned prior to testing. The moisture content at the time of testing was typically determined by randomly sampling sheathing and framing members using a moisture meter. A capacitance (plate-type) meter was used on materials tested at the University of California (Richmond) and a conductance (pin-type) meter was used on materials tested at the Western Fire Center (Kelso, WA). The conductance meter used 6 mm (0.25 in) non-insulated pins. The moisture content from four 150 by 150 mm (6 by 6 in) samples, randomly taken from the ACX plywood sheathing used at the Western Fire Center, was determined gravimetrically (i.e., by oven-drying the samples).

Direct Flame Contact Exposure

A 3.6 m (12 ft) wide, 1.5 m (5 ft) tall wall was used for all direct flame contact exposure testing. The vertical wall consisted of three sections, each 1.2 m (4 ft) wide (Figure 2). Each section was framed using nominal 50 by 100 mm (2 by 4) stud material, with studs spaced 635 mm (24 in) on-center. Oriented strand board (OSB) sheathing was attached directly to the studs. On the outer 1.2 m (4 ft) sections, fiber cement panels were applied over the OSB sheathing. The middle 1.2 m (4 ft) section was clad with two layers of 13 mm (0.5 in) ceramic fiber board. A nominal 25 by 50 mm (1 by 2 in) wood trim piece was attached to the top of the wall at the interface with the eave assembly. The components of the middle section eave assembly (open-eave or soffited-eave) were replaced for each replication. The eave materials (sheathing, rafter, and if applicable, blocking) in the outer sections were replaced as needed based on the fire damage incurred during a given test as a result of lateral flame spread.

Overhang widths included 150 mm (6 in), 460 mm (18 in) and 915 mm (36 in). Open-eave and soffited-eave designs were built and tested with each overhang width. For the open-eave tests, the joint between the wall and blocking was stuffed with ceramic fiber batting on the non-fire exposed side. The flame impingement exposure to the bottom of the open- and soffited eaves was created by a 1 m (39 in) long, 100 mm (4 in) wide gas diffusion burner that was centered on the middle 1.2 m (4 ft) wall section. Flame length was adjusted visually so that flames reached the wall-to-eave intersection. Each eave-overhang configuration was replicated three times.

Each test was recorded using a video camera and also photo-documented. An infrared (IR) camera was either position at the side of the wall, or behind the wall during all direct flame contact tests. IR images were recorded at 10 s intervals. Measurements included the time required for the eave assembly to initiate flaming ignition. The observed ignitions were non-piloted (autoignition). Other observations included flame spread to and beyond the fascia and whether or not lateral spread occurred into the outer wall sections. Lateral flame spread observations were limited to the direct flame contact tests.

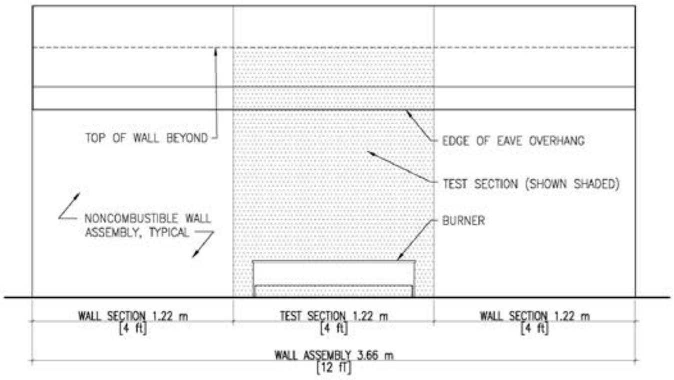

Figure 2. Overview of the direct flame contact test wall. Only the middle 1.2 m (4 ft) test section was subjected to the flame impingement exposure. The eave construction was continuous over the entire 3.6 m (12 ft) wall.

Radiant Exposure

A 1.5 by 1.5 m (5 by 5 ft) vertically oriented, fixed, radiant panel was used to expose the test specimens. Two nominal radiant exposure levels, 20 and 35 kW/m^2, were used. Both the open- and soffited-eave configurations were used. The radiant exposure testing was limited to the 460 mm (18 in) overhang. Testing on each configuration was replicated three times.

A 915 mm (3 ft) wide, 610 mm (2 ft) tall wall section was used in all radiant tests. The test section consisted of either an open- or soffited-eave attached to the 915 mm (3 ft) wide wood-framed wall section. The eave assembly (open-eave or soffited-eave) was attached to the top of a wood-framed wall section for each replication. Cladding was not attached to the wall section, but rather a ceramic fiber blanket was draped over the wall prior to subjecting the eave to the radiant exposure. Prior to each test, the test specimen was placed in a support frame constructed with 50 by 200 mm (2 by 4 in) lumber and centered within the width of the radiant panel (Figure 3). The support frame was wrapped with a ceramic fiber blanket. The radiant panel was not adjustable, so the test sections were positioned on their side in front of the radiant panel (Figure 4) in order to simulate the exposure from fire moving upslope toward the building (Figure 1). The distance between the radiant panel and eave was adjusted depending on the desired (20 or 35 kW/m^2) radiant exposure.

Each test was recorded using a video camera and also photo-documented. An infrared (IR) video camera was positioned to the side of or behind the radiant panel during all tests. IR images were recorded periodically during the tests. Measurements included time to flaming ignition. The observed ignitions were non-piloted (autoignition). Other observations included the sequence of flame spread over the exposed surface.

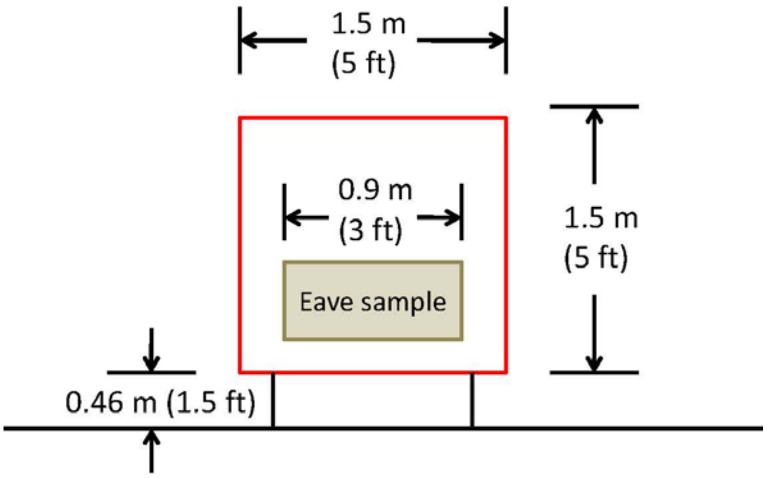

Figure 3. The 915 mm (3 ft) wide open- and soffited-eave samples were centered in front of the 1.5 by 1.5 m (5 by 5 ft) radiant panel.

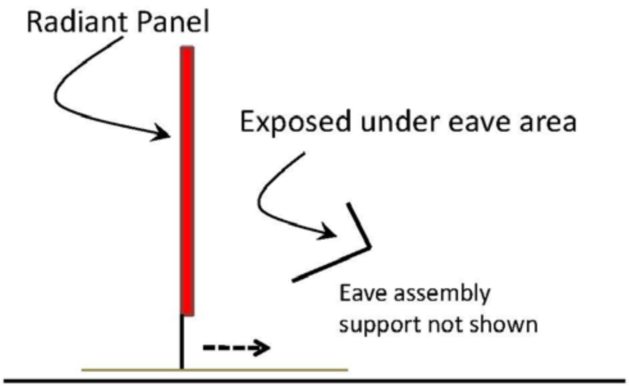

Figure 4. The test specimens were positioned on their side to simulate the radiant exposure to the underside of the eave.

RESULTS AND DISCUSSION

Information included in this paper will be limited to ignition time as a function of eave type and, in the case of the direct flame contact exposure, overhang width.

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Moisture Content Measurements

The moisture meter readings taken on the ACX and OSB sheathing were consistently between 10 and 12%. The average moisture content of the sheathing used at the Western Fire Center, and determined gravimetrically (i.e., by the oven-dry method), was 14%. The moisture content of all of the nominal 50 by 100 mm (2 by 4 in) framing members and the nominal 50 by 150 (2 by 6 in) fascia material used at the Western Fire Center, ranged between 15 and 20%. Moisture meter readings for the fascia used at the University of California was greater than 30%. Non-kiln dried lumber was purchased for the tests conducted at the University of California. Kiln-dried lumber (i.e., SDRY, or "19% or less") was available and used for tests conducted at the Western Fire Center.

The moisture content of materials used in this study were elevated relative to those expected for exterior use wood and wood-based materials subjected to the temperature and relative humidity that would occur when severe wildfires occur. The ignition times reported here would be expected to be shorter at the lower moisture contents.

Direct Flame Contact

The time to flaming ignition for the direct flame contact wall tests is given in Table 1. The overall average ignition time for the open-eave and soffited-eave tests, averaged over all overhang widths, were 308 s and 512 s, respectively, indicating that the soffited-eave design was overall less vulnerable to a flame contact exposure that the open-eave design used in these experiments. This result is in agreement with some of the wildfire construction and mitigation guides [1, 4], indicating that the cavity created between the exterior wall, roof rafters, and fascia can more effectively trap heat, allowing the exposed construction materials to reach ignition temperature more quickly. Although not part of the experimental design, one test wall with open-eave construction, and a 915 mm (36 in) overhang, without the fascia board, was built and tested. The time to flaming ignition for this sample was 547 s, similar to the ignition time for the soffited-eave tests, indicating that the missing fascia allowed for heat to more readily escape, thereby increasing the time need to reach ignition temperature.

The trend observed in the time-to-ignition values indicated increasing time-to-ignition with increasing overhang width with open-eave construction and decreasing time-to-ignition with increasing overhang width with soffited-eave construction. Although a statistical analysis has not yet been run, the variability in the time-to-ignition data indicate that statistical difference between these measurements is unlikely. Slight changes in flame height as a result of visual adjustment at the beginning of each test may have contributed to the variability in ignition times.

With the soffited-eave specimens, adjusting flame height to reach the wall-to-eave intersection resulted in a shorter flame height with increasing overhang width. Assuming a fixed wall height and roof slope, and assuming ultimate flame height would depend on other factors (e.g., type and condition of vegetation, type if cladding), adjusting flame height in this way could provide an advantage to the wider overhangs that would not actually be present in homes located in wildfire prone areas.

Flaming ignition of the soffit material and subsequent flame spread out to the fascia did not occur in the second replication of the 460 mm (18 in) soffited-eave test, resulting in the missing data point in Table 2. Flame spread to the fascia did not occur because of flame penetration at a joint between two soffit panels (Figure 5). The test was ended when flame began to propagate within the soffited eave. Flame penetration to the non-fire exposed side of the wall occurred occasionally with both open- and soffited-eave walls. Penetration always occurred at a joint. In soffited-eave construction, flame penetration at a joint allowed fire to enter the enclosed area and spread laterally within the soffited-eave and also into the attic space. Use of a batten strip at joints in a soffited-eave could delay flame penetration. Specific board and batten designs have been approved for use in wildfire prone areas in California [9], indicating that a batten of a particular width and thickness can resist penetration at between-board joints in board-and-batten cladding when subjected to a direct flame contact exposure. In open-eave construction, flame penetration typically occurred at the edge or end of the blocking, most often at the lower edge or end allowing flames to penetrate into the attic space. Flame penetration occasionally occurred at the top edge of the blocking, at the plywood-to-OSB joint, which would provide a flame contact exposure to the underside of the roof covering material. In all cases, these examples provide examples of the importance and vulnerability of joints typically found in construction to direct flame exposure.

With both open- and soffited-eave construction, the time between initial flaming ignition at the wall-to-eave intersection and outward spread to the fascia was almost immediate, occurring within 1 to 2 s, regardless of the overhang width. Once the flame reached the fascia, it immediately wrapped under and extended beyond it into the open air, similar to a flash over condition in compartment fires. In the case of the soffited-eave construction, the fascia only extended below the soffit material a few millimeters. The rapid flame spread to the fascia indicated that the exposed under eave surface area was sufficiently pre-heated during the exposure time prior to flaming ignition.

In addition to ignition time, the propensity of the flame to spread laterally along the wall was observed. Whereas the time required for flame to spread laterally along the wall varied somewhat, it consistently occurred in open-eave construction, usually spreading to the ends of the wall, or near it, within 30 to 60 s (Figure 6). Lateral flame spread in the soffited-eave specimens was not as extensive, and usually did not spread far onto the plywood surface in the adjacent wall sections. In both open- and soffited-eave specimens, flaming combustion often subsided in charred areas while the burner flame was still on (Figure 7).

Table 1. Results of time-to-flaming-ignition testing for the direct flame contact exposure specimens. The standard deviation for the average ignition time is given within the parenthesis.

Eave Design	Overhang Width, mm (in)	Replication	Ignition Time, s	Average (std dev)
Open	150 (6)	1	402	264 (120)
		2	182	
		3	208	
	460 (18)	1	260	280 (108)
		2	398	
		3	183	
	915 (36)	1	324	379 (70)
		2	355	
		3	457	
Soffited	150 (6)	1	410	582 (346)
		2	356	
		3	980	
	460 (18)	1	765	535 (325)
		2	-----	
		3	306	
	915 (36)	1	393	459 (126)
		2	380	
		3	604	

Figure 5. Flame penetration at a between-panel joint allowing for flame propagation to occur within the enclosed soffit cavity. This test was terminated prior to ignition of the soffit material and flame propagation to the fascia.

Radiant Exposure

The radiant exposures selected for these tests were based on Bushfire Attack Level (BAL) information provided in the Australian Standard AS 3959 [10], where it is stated that radiant exposure levels greater than 40 kW/m^2 are more likely associated with a direct flame contact exposure. This was therefore set as the upper limit for the radiant exposure used in these tests. The lower exposure level was set at approximately half the upper level.

The radiant exposure was calibrated at a level 915 mm (36 in) from the floor. The open- and soffited-eave specimens were positioned such that the leading edge of the outer most wood member at that elevation would be exposed to the targeted radiant exposure level (i.e., 20 or 35 kW/m^2). For the soffited-eave specimens, the outer most component was the plywood soffit; for the open-eave specimens, the outer most member was the rafters, with the plywood sheathing being an additional 90 mm (3.5 in) from the panel. Because the specimens were built using a 4:12 roof slope, the fascia was always the closest member to the radiant panel, as would be the case in the actual scenario given in Figure 1. In these series of tests, the time to the first observation of flaming combustion was recorded. Because of the narrow overall wall width used in the radiant tests, lateral flame spread observations were not possible. The time to flaming ignition for the radiant wall tests are given in Table 2.

Figure 6. Lateral flame spread in the open-eave specimens usually spread to the end of the test wall within 30 to 60 s.

Table 2. The time to (initial) flaming ignition for the radiant exposure specimens. The standard deviation for the average ignition time is given within the parenthesis.

Eave Design	Radiant Exposure, kW/m^2	Replication	Ignition Time, s	Average (std dev)
Soffited	20	1	798	1039 (211)
		2	1193	
		3	1126	
	35	1	113	192 (135)
		2	348	
		3	116	
Open	20	1	1695	1616 (78)
		2	1540	
		3	1613	
	35	1	119	122 (8)
		2	131	
		3	115	

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Figure 7. Lateral flame spread was not as extensive in the soffited-eave specimens. In both open- and soffited-eaves specimens, flaming combustion often subsided in charred areas, as shown here. Flaming combustion is more active at the fascia-to-soffit intersection. Flaming in this area was likely enhanced by the addition of a small trim piece that was attached to the soffit material, behind the fascia

The observed times to flaming ignition are similar to those reported for autoignition of wood under similar radiant exposures [11]. In all cases, once flaming ignition occurred, spread was fairly rapid over the entire exposed surface. Based on these results, there was little difference between the ignition times for open- and soffited-eave specimens at the 35 kW/m^2 exposure, particularly if Replication No. 2 of the soffited-eave specimens is not considered. With Replication No. 2 removed, ignition time occurred at approximately 120 s, regardless of eave design. At the 20 kW/m^2 exposure, flaming ignition began earlier in the soffited-eave specimens. The difference in time-to-flaming ignition can partially be explained by the closer proximity of the entire plywood surface to the radiant panel. In two of the three soffited-eave specimens, charring occurred through the entire thickness in localized areas prior to the initiation of flaming ignition. However, the location of the observed initial flaming in the open-eave specimens was not consistent. In the three open-eave specimens, initial flaming was observed at three different locations, including 1) at the base of the wall-to-blocking interface (the greatest distance from the radiant panel), 2) on the plywood in one of the joist cavities, and 3) at the leading edge of the fascia (closest to the radiant panel) (Figure 8). These results indicated that proximity to the radiant panel cannot explain all the observed differences. In any event, given the time needed to reach flaming ignition at the 20 kW/m^2 exposure (an average of approximately 17 min for the soffited-eave specimens and 27 min for the open-eave specimens), it is unlikely any differences regarding vulnerabilities to radiant exposures that may exist between open- and soffited-eaves would provide any meaningful advantage in building survivability.

Figure 8. Flaming ignition at the fascia in an open-eave specimen exposed to a 20kW/m^2 radiant exposure.

CONCLUSIONS

Results from these tests have shown that, compared to soffited-eave designs, open-eave designs that incorporate a fascia board, are more vulnerable to direct flame contact exposures. Differences were not readily observed regarding the effect of overhang width. A flame contact exposure can result from ignition of underlying vegetation and/or ignition of combustible exterior cladding with subsequent vertical flame spread to the under-eave area. The joints in both open- and soffited-eaves were vulnerable to the penetration of flames into areas behind the joints.

No differences were observed between open- and soffited-eaves when subjected to the 35 kW/m^2 radiant exposure. Flaming ignition occurred at similar times and flames spread rapidly over the entire exposed surfaces. The open-eave design performed somewhat better than the soffited-eave when subjected to the 20 kW/m^2 exposure, but given the extended exposure time required to reach flaming ignition, this advantage may be limited, particularly given the performance of the open-eave design when subjected to a direct flame contact exposure.

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