Wildfire Research

Near-Building Noncombustible Zone

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Introduction

Wildfire activity is on the rise, burning 5 million acres in 2007 to almost 10 million acres in 2017 (National Interagency Fire Center). With this increase in wildfire activity comes an increased impact on buildings, including homes and businesses, in the wildland-urban interface. Residents and business owners can take steps to reduce the risk to their property located in wildfire-prone areas. Eliminating fuels from the immediate area surrounding the building, as referred to as defensible space, can decrease its ignition potential by reducing the possibility of a direct flame contact and radiant heat exposure to the building.

Historically there have only been two defensible space zones, 0–30 ft and 30–100 ft (or to the property line) [California Public Resources Code, 2010], which are referenced in building codes related to wildfire. As far back as 2011, educational organizations such as the National Fire Protection Association (NFPA) and IBHS have been advocating for dividing the 0–30 ft zone into two separate zones (0–5 ft and 5–30 ft), acknowledging that ember ignition of combustible materials immediately near the building poses a threat to the building from direct flame contact and radiation. IBHS wildfire preparedness guidance currently recommends creating and maintaining a 0–5 ft noncombustible zone around a building, including the entire footprint of an attached deck. This zone is designed to protect the building from ignition that can result from wind-blown embers that can accumulate at the base of the exterior wall, and from exposure to radiant heat or direct flame contact that would occur due to the ignition of combustible materials located near the building or under an attached deck. Landscaping and vegetation management in the 5-30 ft zone should prevent the fire from climbing into the upper portions of trees or shrubs and to stop any fire from burning directly to the building. Wind-blown embers may still be able to ignite individual islands of plants in the 5–30 ft zone, which is why the near-building noncombustible zone is critical.

Current guidance is to create and maintain a 5-ft near-building noncombustible zone, based on expert judgement. The objective of this research project was to provide scientific data to evaluate the effectiveness of the 0–5 ft noncombustible zone as currently defined and determine whether a larger or smaller distance for this zone is warranted.

Experimental Setup

Figure 1 (below) shows an overview of the experimental setup at the IBHS Research Center, which includes the test building, instrumented wall, and fire source, which was either a gas burner or stacked wooden cribs (not shown in Figure 1). The building was painted black on the instrumented side to create a clear contrast between the foreground (flame) and the background (wall) for image processing purposes.

The instrumented wall was movable along the side of the test building so it could be positioned at one of the test locations: middle (M), quarter-right (Q-R), and end-right (E-R) as indicated in Figure 2. The E-R position was located directly at the corner of the building, with the M and Q-R positions located at 20 ft and 10 ft from the end of the building, respectively. The instrumented wall was equipped with four thermocouples and nine heat flux gauges. Figure 3 shows the arrangement of these sensors on the wall. The test building was placed on a turntable, enabling the evaluation of the effect of wind angle on heat exposure to the building.

Figure 1. Overview of experimental setup with 30-ft x 40-ft building. This image shows a 45-degree test with the building rotated so the corner is closest to the fans.

A 12-in. x 24-in. natural gas burner was used as a surrogate for combustible materials that could be located close to a building (for example, a wood pile or medium-sized vegetation). In addition to using the gas burner as a fire source, stacks of cribs were used to evaluate exposure from burning combustible material (see Figure 4). The fire source was placed 3 ft or 5 ft away from the edge of the instrumented wall at the middle (M), quarter-right (Q-R), and end-right (E-R) locations (see Figure 2). The test building was mounted on a turntable and experiments were conducted with the building at 90-degree and 45-degree wind angles. In the 90-degree tests, the long side of the building (see Figure 2) was perpendicular to the wind flow. In the 45-degree tests, the building was rotated 45 degrees counterclockwise so that a corner was the closest point to the fans. Corner fire exposure tests (Figure 2) were for three noncombustible zone distances: 3 ft, 5 ft, and 7 ft. In some tests, the instrumented wall was centered with the burner, and in others they were off-center (for example, fire source at Q-R, wall at E-R).

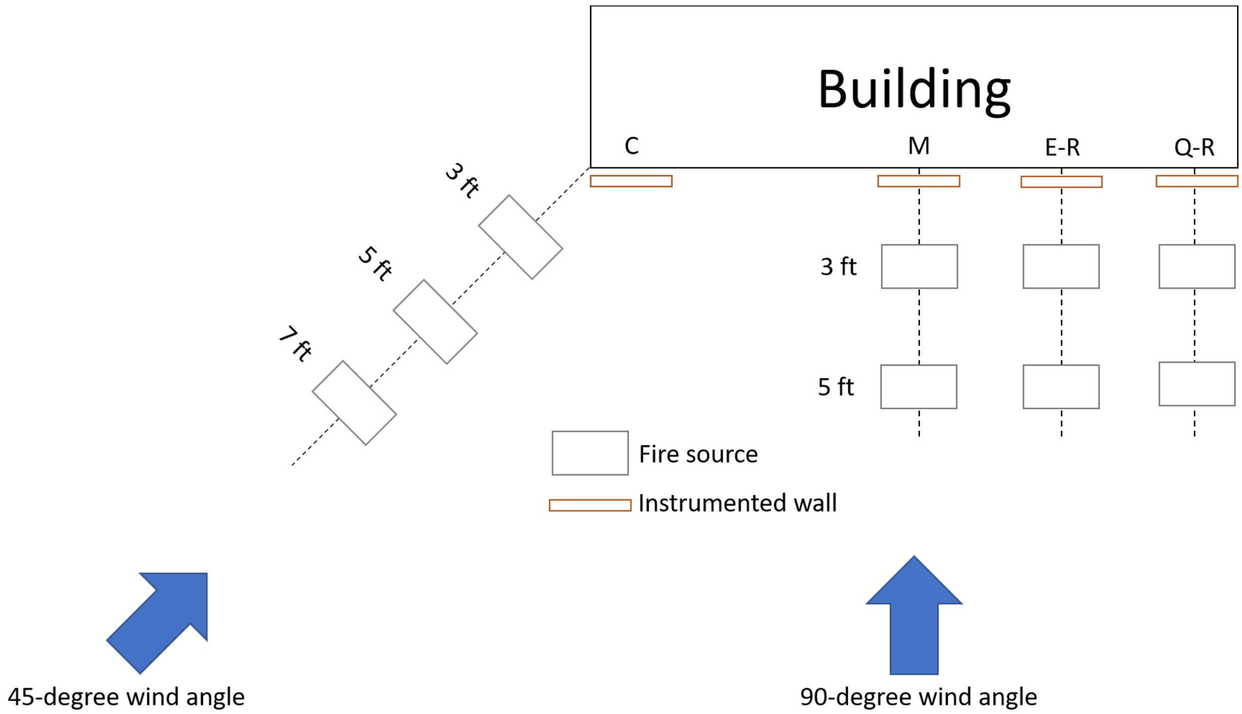

Figure 2. Schematic of experimental setup showing the building orientation for 90-degree and 45-degree wind angles, the locations of the instrumented wall (corner [C], middle [M], quarter-right [Q-R], and end-right [E-R]), and fire source relative to the building and placement of the fire source from the building (3 ft, 5 ft, and 7 ft).

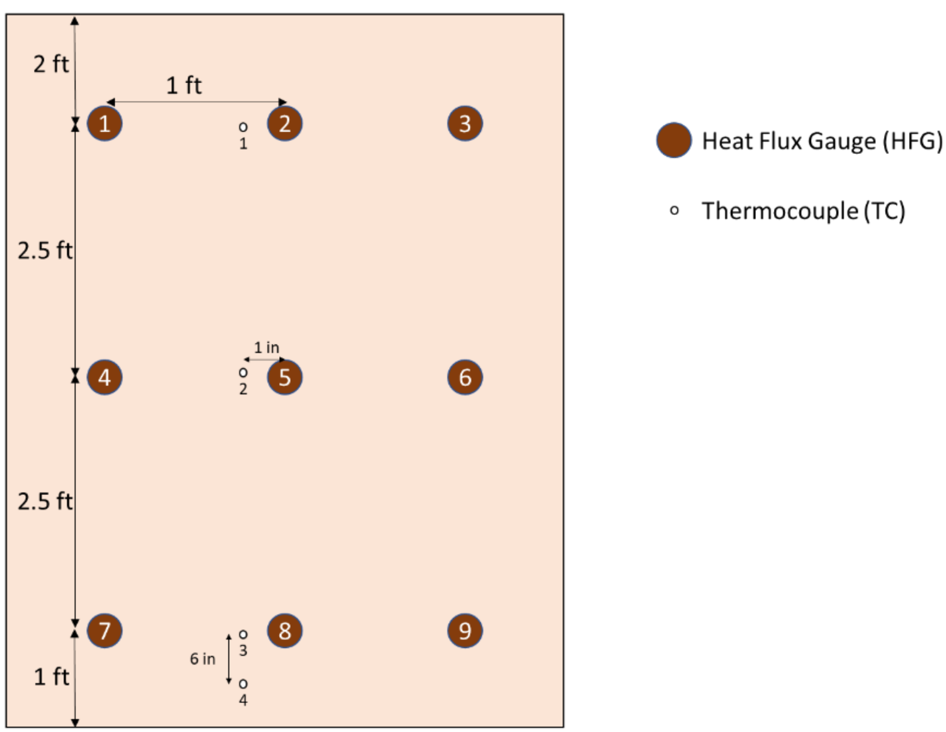

Figure 3. Schematic of the instrumented wall with location of heat flux gauges and thermocouples.

Figure 4. Stacks of cribs (left) and gas burner (right) were used as to simulate fire exposure on a building from burning ornamental vegetation.

Procedure

As discussed above, fire exposures were simulated using two methods in the current study, natural gas burner and wood cribs, both of which simulated burning ornamental vegetation. The experimental procedure for both was similar, which is explained in this section, and differences between the two fire exposures are noted.

The noncombustible zone was created by placing the fire exposure 3 ft, 5 ft, and 7 ft (45-degree building orientation only) from the surface of the instrumented wall. After ignition of the fire source, instrumentation on the wall began collecting temperature and heat flux data. Several cameras were set up in the test area to obtain views from different orientations. An infrared camera (FLIR T620) was used to take a thermal image of the instrumented wall and ground surrounding the fire source.

Three different wind speeds (idle, medium, and high) were used in thus study. The mean value and 3-second peak gust averages are provided in Table 1. As shown in Table 1, the idle wind speed is constant and is missing the wind speed fluctuations typically found in natural winds. In contrast, the medium and high wind speeds replicate typical wind gust found in the atmospheric boundary layer. See Standohar-Alfano et al. (2017) for a complete discussion.

Table 1. Winds speeds used for each test configuration

	Mean Wind Speed	Peak 3-Second Gust Average
Idle	6.4 m/s	6.8 m/s
Medium	8.9 m/s	11.3 m/s
High	14.6 m/s	16.5 m/s

During each of the gas burner tests, the burner was operated for 5 minutes. When burning wood cribs, the test continued until the crib collapsed. The wood cribs were conditioned in a kiln (110°F, 32% relative humidity, 27% wet-bulb depression, and 5.5% equilibrium moisture content) prior to each test to achieve a target moisture content of 5% (oven-dry basis). To facilitate rapid ignition and enable development of a uniform and sustained flame, the wood cribs were soaked in isopropyl alcohol for 5 minutes prior to each test. Tests were conducted at all locations and wind speeds when using the burner. Based on the tests with the burner, the highest temperatures on the wall were observed during the idle and medium wind conditions, as such tests using the cribs were only run at idle and medium wind speeds.

In addition, a series of 11 tests were run to evaluate fire spread in mulch placed in different patterns in the vicinity of the flame to demonstrate what happens if the noncombustible zone is not maintained around a building. The test details are provided in the "Mulch Tests" section.

Results and Discussion

Surface temperature has been used as criterion for ignition of solids (Babrauskas, 2003) and strongly correlates with the net heat flux at the surface. The incident flux may originate from either direct flame contact or radiant heat from the flame itself. The net received heat flux on the surface depends on a few parameters, including the surrounding temperature, and the wind speed and flow pattern around the building. When the incident flux exceeds surface cooling, the temperature will increase. Depending on the magnitude of the net flux, exposure time, and characteristics of the surface's material, the surface temperature may reach a critical value required for ignition over time (Babrauskas, 2003). Piloted-ignition temperatures for cellulosic materials from the literature can range from 203°C to 400°C (397°F to 752°F). Due to this large range and because specifying exact wall cladding elements is outside the scope of the current study, a conservative approach is adopted whereby wall temperatures greater than 200°C are considered hazardous and ignition is considered possible.

Wind speed will influence surface temperature by affecting the rate at which heat is removed; however, it can also influence the impingement angle of the flame pushing it toward or away from the wall. When the flame tilts toward the building, it is more likely to have a direct flame contact, leading to a dramatic increase in the heat exposure to the wall. When the flame is pushed away from the wall due to the wind, convective cooling increases, reducing the temperature on the wall. In certain circumstances, for example, high wind speed and fire exposure at the middle location (M), the flame can become horizontal (i.e., hugs the ground), which can lead to increased fire spread along surface fuels (Drysdale, 2011).

When the fire exposure was at the middle location (M) at either 3 ft or 5 ft (see Figure 2), wind perpendicular to the test wall created a large horseshoe vortex at the base of the wall, creating a recirculation zone that pushed the flame away from the wall. In this case, the radiation view factor (the fraction of the radiation emitted from a surface that strikes another surface) between the flame and the ground behind the flame increased, which led to significant increase in ground temperature. When the fire exposure was at the corner location (C), the free stream flow pushed the flames downward toward the building and caused the ground temperature to increase in front of the flame.

Due to the flame being pushed toward the building, the corner case may represent a greater hazard to the building than the other locations as there is the potential for direct flame contact to the building, which depends on the separation distance and the size of the flame. Figure 5-A presents the temperatures for a burning crib case at the middle location (M), while Figure 5-B presents the temperature for a burning crib at the corner location (C), at 3 ft and 5 ft from the wall. In both images, the yellow/orange ring on the ground is above 450°C (842°F). The rings' radiuses from the center of the cribs are 2.2 ft and 4.1 ft in Figures 5-A and 4-B, respectively. This shows that if combustible material were on the ground in this area, they would be likely to ignite.

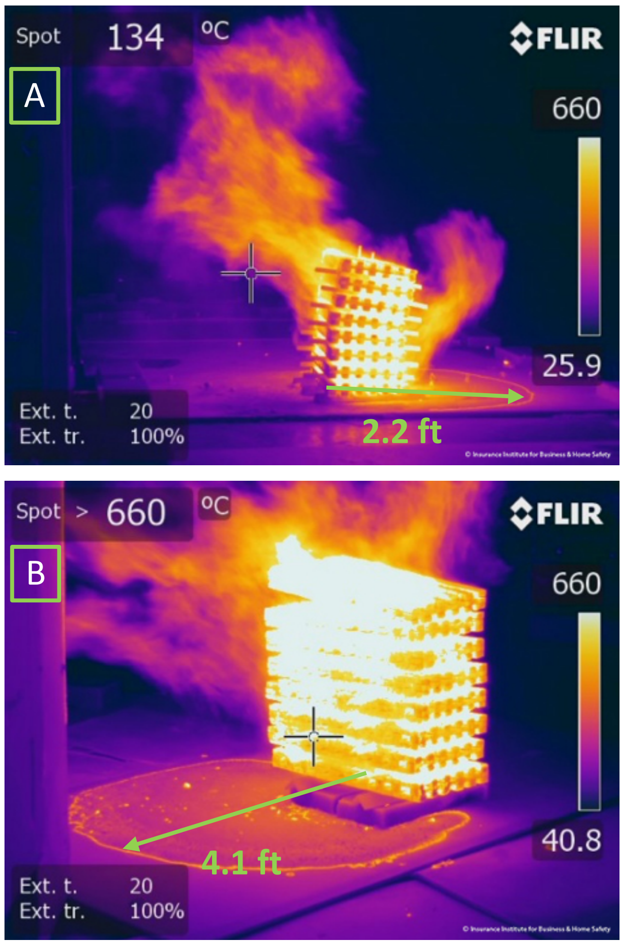

Figure 5. Thermal images of the burning wood crib showing the temperature of flames and ground surrounding the fire. In the top image (middle location) the flames are heating the ground upwind, away from the building. The bottom image (corner location) shows the flames heating the ground downwind, toward the building.

Clearly, as discussed above, the flame impingement angle (i.e., the angle of the flame from vertical) can significantly affect the hazard of direct flame contact on the building. For the current study, positive impingement angles imply the flame is tilted toward the building and negative impingement angles imply it is tilting away from the building with 0 degrees being a perfectly vertical flame. A recirculation zone near the wall during 90-degree building orientation tests prevented the flame from being blown horizontal and closer to the ground. In these tests, taller flames were observed and direct flame contact to the wall was less likely to happen. A tall flame does create a large surface area that radiates heat toward the wall. Ground temperature measurements are discussed in “Mulch Tests” on page 14.

Figure 6. Burner and instrumented wall at the at E-R location, 5-ft separation from building, idle wind speed. Dashed-blue circles indicate areas from previous tests where flame scorched the ground.

Figure 7 shows a frame of a pre- (A and B) and post-processed (C and D) video from tests conducted at the high and medium wind speeds and 90-degree building orientation. To obtain these images, each frame of the recorded videos was analyzed to determine the flame’s profile.

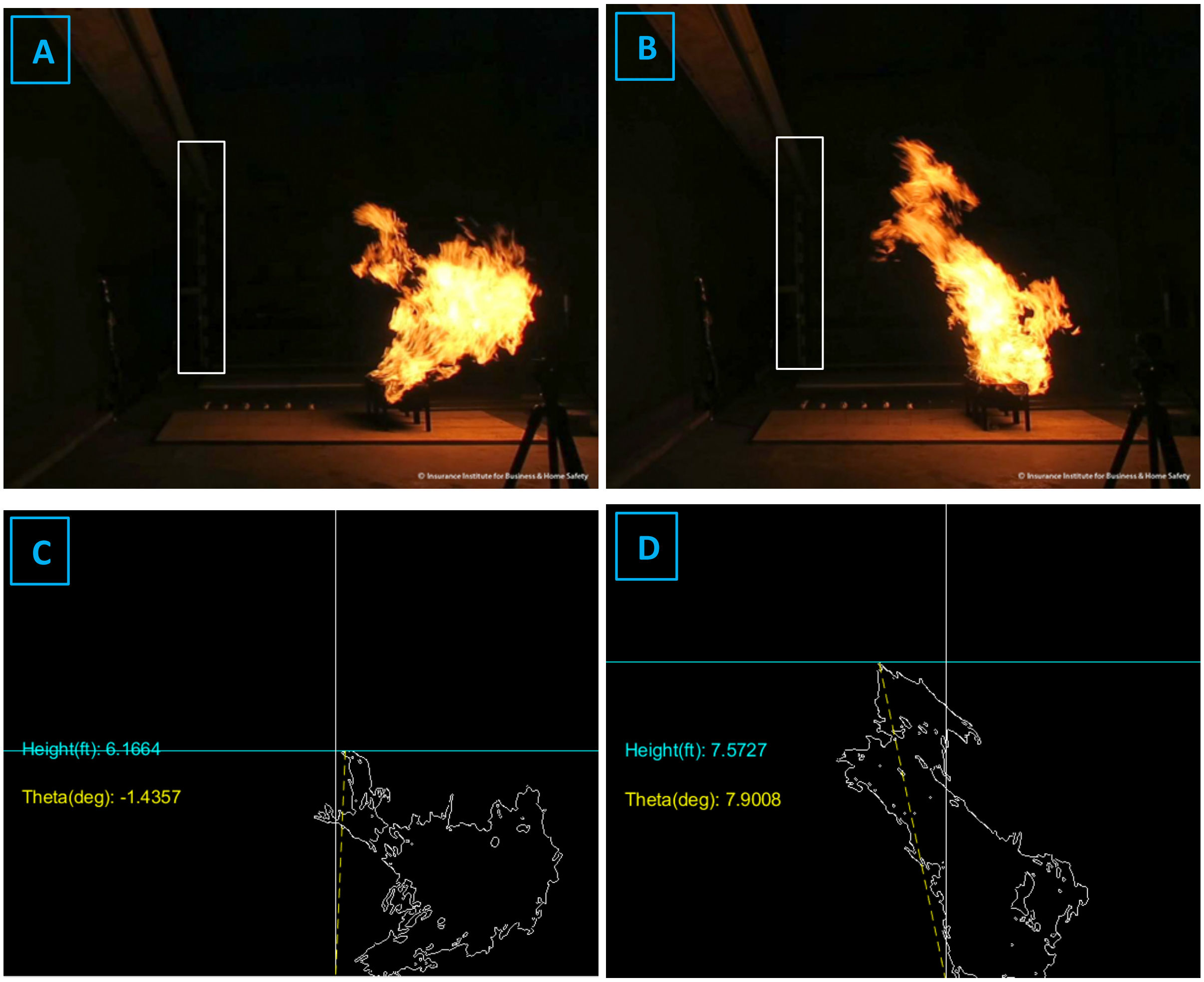

Figure 7. Pictures A and B are samples taken from tests with the fire source at location M at high and idle wind speed, respectively. The white rectangle highlights the 8-ft reference ruler used to measure the flame. Images C and D are post-processed using MATLAB to determine flame height and impingement angle.

The results show that when the fire source is at location M (Figure 2), as wind speed increased, the average flame height and angle decreased. This empirical data will be helpful in future efforts to model the heat exchange between the flame and the building. The relationship between wind speed on the average vertical flame height and impingement angle with the fire source at the middle location (M) are shown in the graphs in Figure 8. Over the range of wind speeds tested, as the wind speed increased, the average flame height decreased. In these tests, the average flame impingement angle shifted from positive (tilted toward to the building) to negative (tilted away from the building) at the high wind speed.

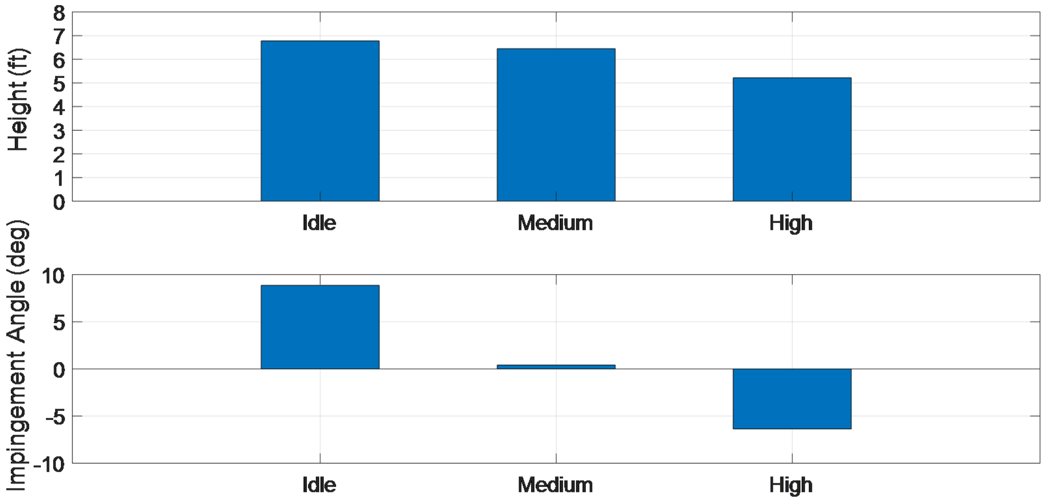

Figure 8. Effects of wind on the average flame height and flame impingement angle with gas burner at middle location (M) for different mean wind speeds.

Figure 9 plots the temperature variation on the wall at idle wind speed measured by thermocouple 1 (see Figure 3) with a burner located 3 ft and 5 ft from the wall at the middle location (M). At 3 ft, the temperature on the wall reached the maximum at 200°C, while at 5 ft, the temperature was always less than 200°C and seemed to asymptote to 100°C. At 3 ft, the wall temperature is more responsive to the instantaneous changes in flame profile, while at 5 ft, the wall temperature is less sensitive to the instantaneous changes in the flame profile. Hence, we see more variability in the temperature profile for the 3-ft test. Although the maximum temperature was found to be approximately 100°C at 5 ft, Figure 10 clearly shows that under this configuration the gutter was exposed to flames as a result of tall flames. In fact, for the idle wind condition, flames were found to be as tall as 11 ft from the burner as compared to approximately 5 ft for the high wind speed.

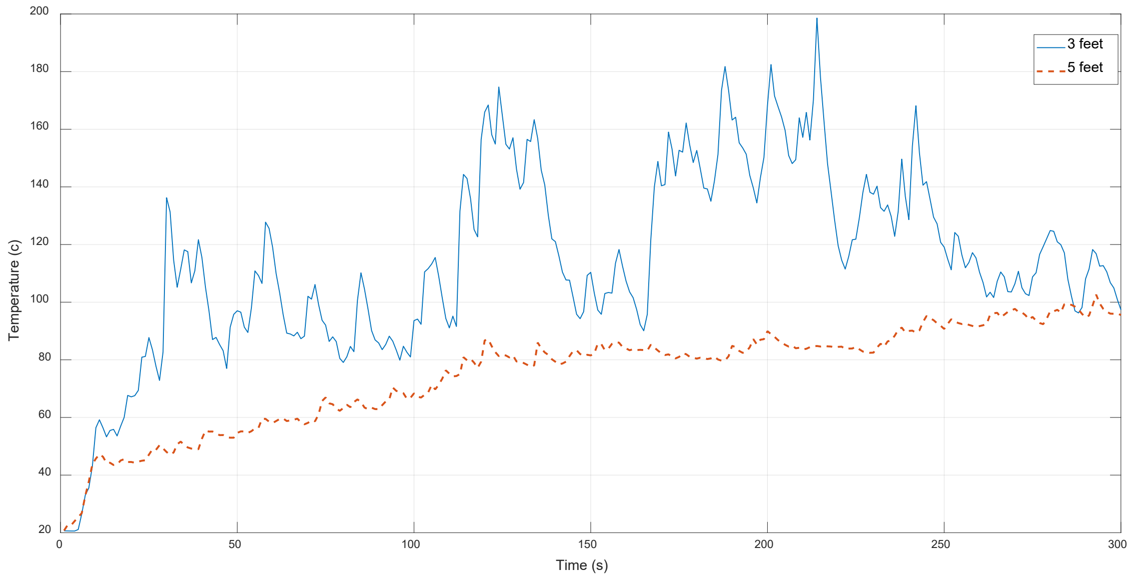

Figure 9. Temperature variation on the wall for 5-ft and 3-ft M point at idle wind.

In the ambient wind condition and with the burner at 5 ft from the wall at location M, there was direct flame contact to the soffit and gutter for almost 4 seconds (Figure 10). The under-eave area is a vulnerable component of the building, particularly to direct flame contact which may lead to ignition. Previous research has shown that closed or "boxed-in" eave designs can be more resistance to flame exposure. This illustrates the need to provide a noncombustible zone around a building, not only for the exterior wall but also the eave and gutters.

Figure 10. Direct flame contact to the soffit and gutter during an ambient wind condition (zero wind speed) test with the fire exposure positioned 5 ft from the building.

The results of the 45-degree building orientation experiments indicated the most vulnerable locations were when the fire source was located at the corner of the test building. During these tests, it was observed that the wind flow increased the flame impingement angle markedly compared to that at a wind angle of 90 degrees. Figure 11 shows a processed frame from the video. In this configuration, the impingement angle was far larger than the 90-degree building orientation experiments (Figure 8) by a factor of five. This increased flame impingement angle increases the potential for direct flame contact to the building and intensified thermal radiation.

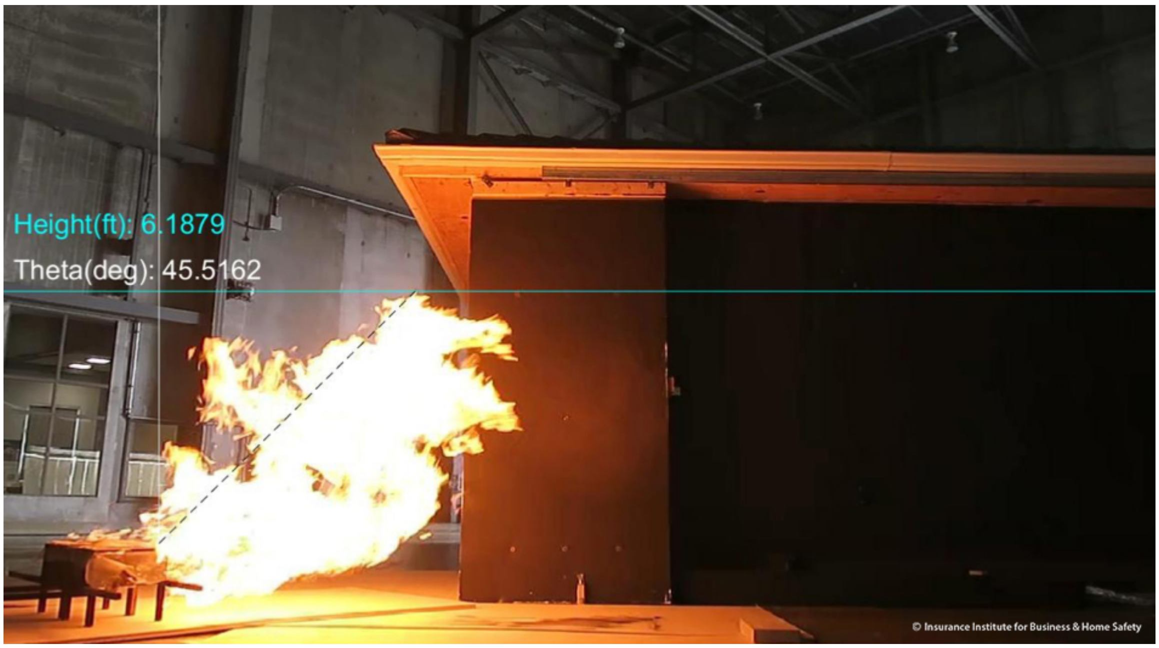

Figure 11. Corner test flame height and impingement angle measured from the vertical.

Figure 12 plots the temperature variation on the edge of the corner. When the fire exposure was at 3 ft and 5 ft, the temperature reached and stayed at or above the critical value of 200°C. When moved back to 7 ft, the wall temperature did not exceed 160°C.

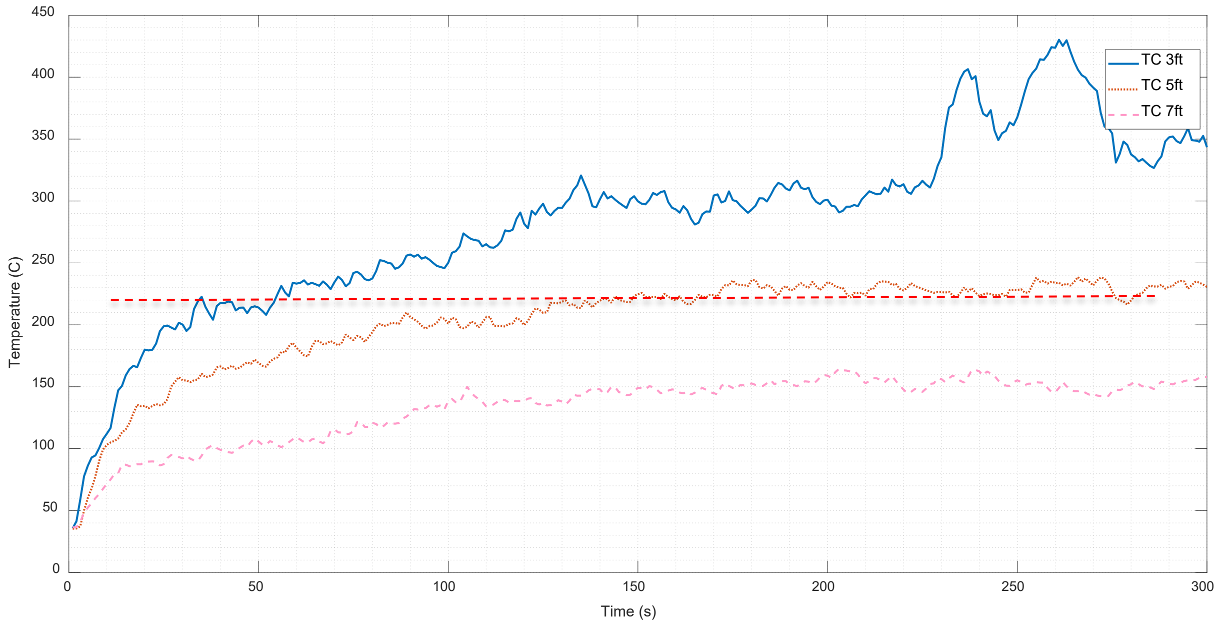

Figure 12. Temperature on the edge of the building in the corner tests.

Figure 13 summarizes the findings of these experiments. For most configurations, a 3-ft noncombustible zone limited the heat exposure from the fire source to the exterior wall, keeping the surface temperature safely below the conservative piloted-ignition temperature threshold indicated by a dark-green box. At some building orientations and wind speeds, the exterior wall at the middle location (M) experienced elevated temperatures, occasionally reaching the conservative temperature threshold indicated by a light-green box. As discussed previously, the building corner created flows that caused the flame to make direct contact with the building. With a 3-ft noncombustible zone, the instrumented wall experienced surface temperatures well-above the threshold that may cause ignition, a hazardous condition indicated by a red box. Corner exposure tests with a 5-ft noncombustible zone caused surface temperatures at the wall to reach the threshold value, but with a 7-ft noncombustible zone the corner wall surface temperature stayed well below the conservative piloted-ignition temperature. Creation and maintenance of a 5-ft noncombustible zone around the building and under (for example, decks) should be a priority for home and building owners. Consideration should be given to an increased noncombustible zone at corners of the building due to the potential for increased heat exposure from wind-driven flames.

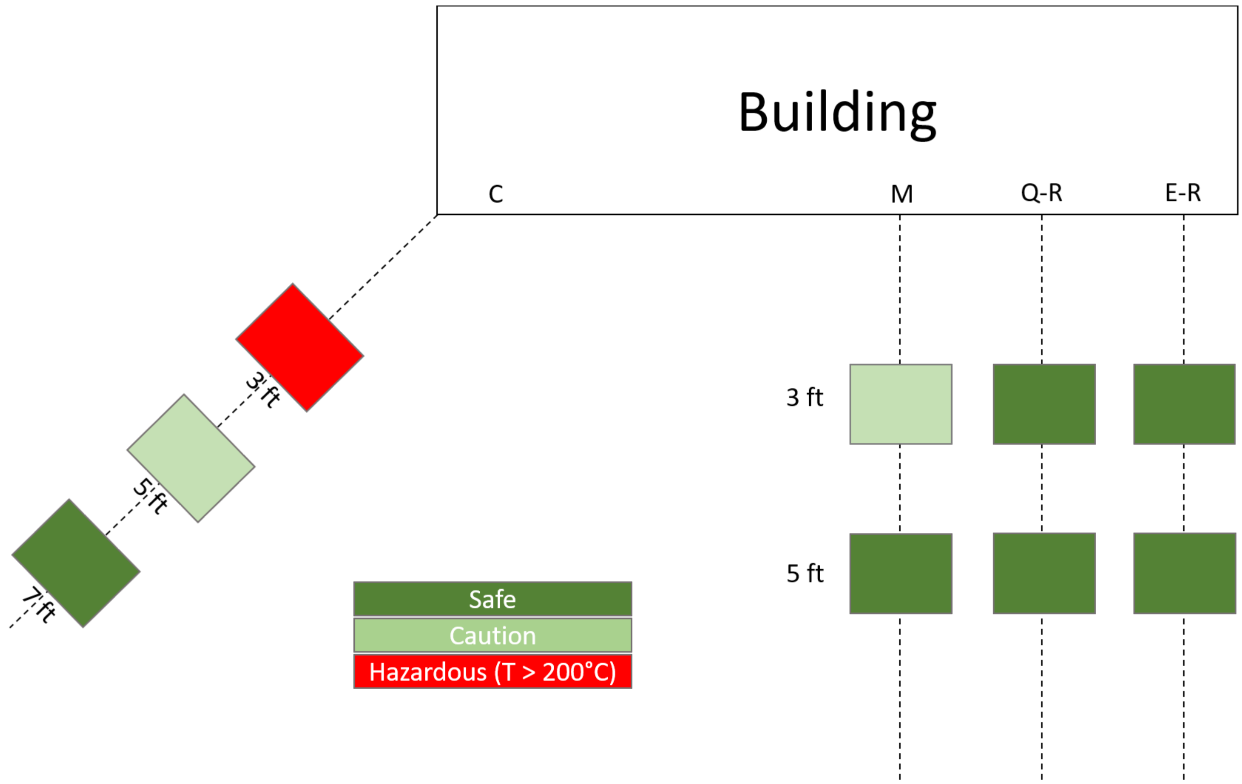

Figure 13. Safe and hazardous locations.

Mulch Tests

As part of this research project, a series of tests were conducted to demonstrate the impact of not maintaining the noncombustible zone around a building. Wood mulch is commonly used for landscaping in the area immediately adjacent to homes. A total of 60 cubic ft of hardwood, medium-chunk bark mulch was conditioned in a kiln for a week at 140°F and 4% relative humidity to achieve a moisture content less than 5%, representative of conditions in wildfire-prone areas. In each test, approximately 2 cubic ft of the mulch was laid out in one of three patterns (see Figure 14). The gas burner fire exposure was used as the heat source to ignite the mulch and was turned off as soon as a sustained flame was observed on the mulch.

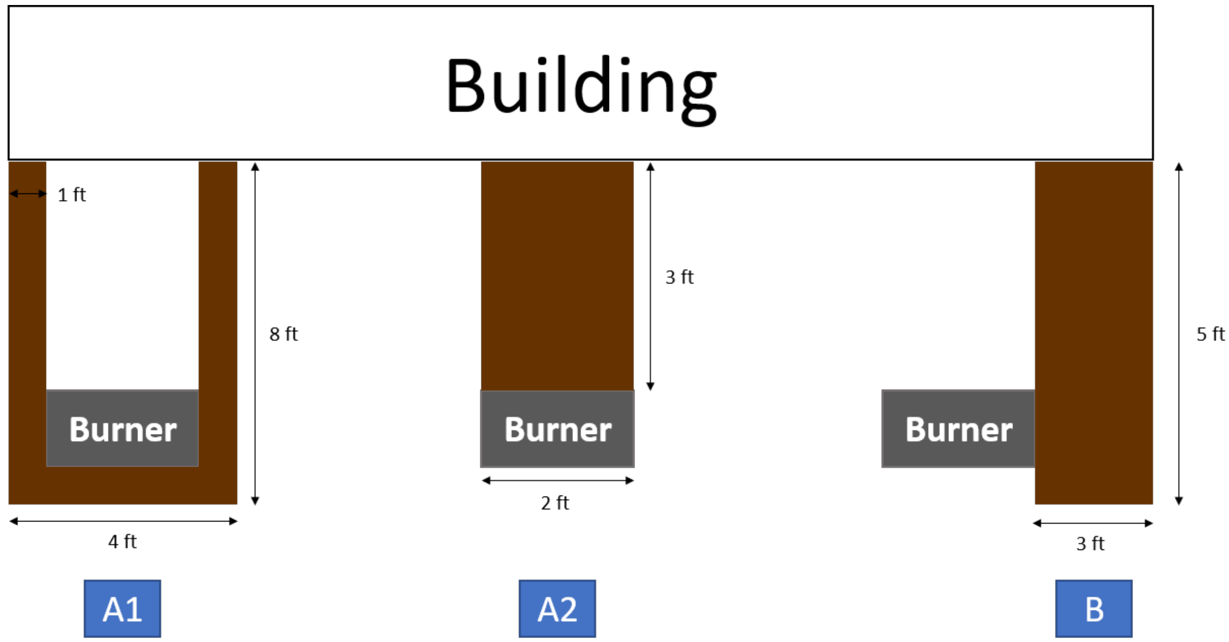

Figure 14. Bark mulch layout patterns.

It was observed that the wind speed and relative location of the flame to the test building affected ignition potential of the mulch and the time needed for the ignited mulch to propagate toward the building. The propagation time from ignition point to building ranged from 5 to 30 minutes for these tests. As shown in Figure 15, the flames were pushed away from the building due to the vortices near the building, which led to a backing (slow) fire spread toward the building. It was observed that beneath the mulch surface, flame spread moved slowly toward the building due to bark-to-bark fire spread, either by radiant or conductive heat transfer.

For most of the end-right (E-R) locations (shown in Figure 15), the fire initially started in the dashed yellow circle area shown in Figure 15. Subsequent fire spread is affected by the flow pattern around the building. For this test, it then crept slowly toward the building and reached the wall after almost 20 minutes. As the fire approaches the building, the temperature at the base of the instrumented wall far exceeded the piloted-ignition temperatures reviewed (Figure 16). The fire propagation line was parabola-shaped for A2 layout pattern, as shown in Figure 15. In each case, the test was stopped only after the propagating fire had reached the exterior wall of the test building.

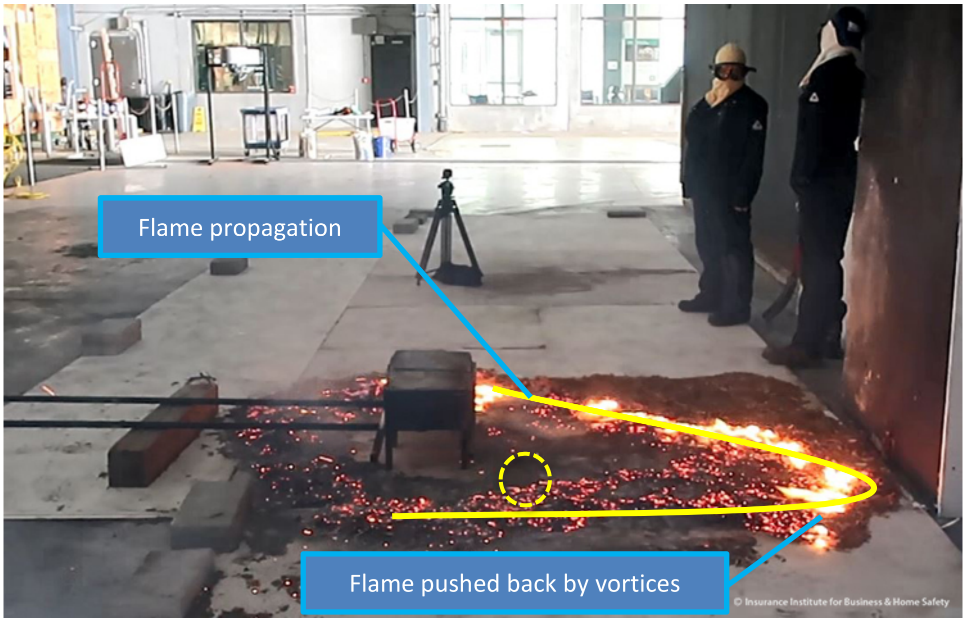

Figure 35. Flame propagation toward the wall, almost a parabola shape (yellow line).

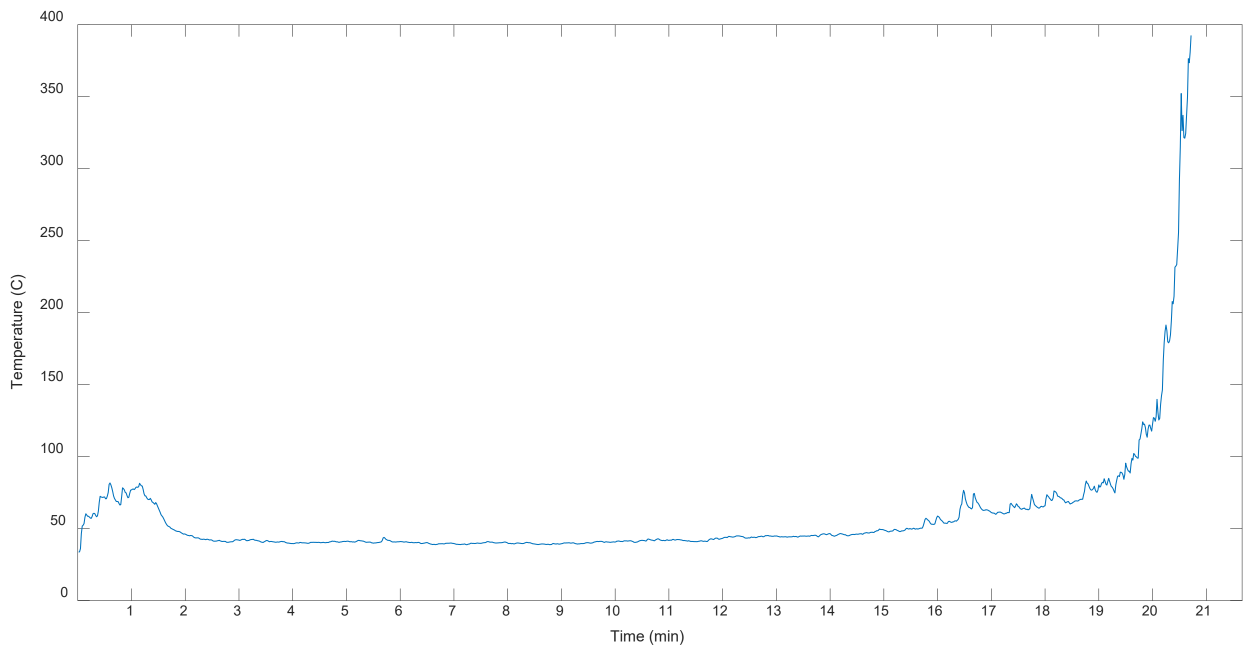

Figure 46. Temperature measurement at base of the wall. The gas burner was turned off after approximately 90 seconds.

Figure 17 is an infrared image showing the temperature of the burning mulch. This image shows that the temperature reached 600°C (1112°F), creating a heat source that affects the wall temperature (Figure 16). The burning mulch generated numerous embers that have the potential to ignite remote (non-preheated) mulch outside of the test setup.

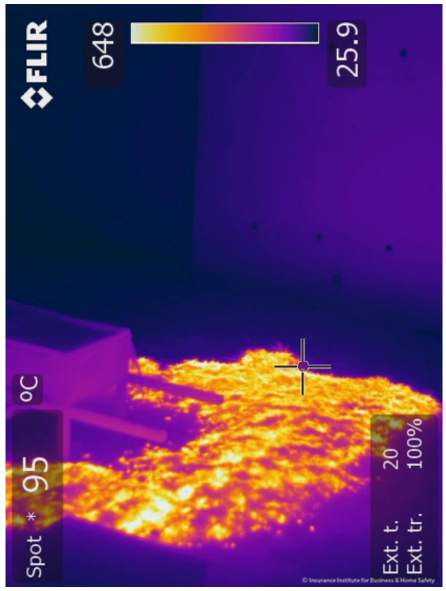

Figure 57. Temperature distribution of the burning mulch.

Summary and Conclusion

To verify the effectiveness of a 5-ft noncombustible zone around a building, 174 tests were conducted to evaluate the flame profile and the temperature distribution on the exterior wall and the ground. A gas burner and wood cribs were used to simulate the fire exposure from burning combustible materials near a building. An instrumented wall (containing four thermocouples and nine heat flux gauges) measured the radiant heat reaching the exterior wall. Three noncombustible zone distances (3 ft, 5 ft, and 7 ft [corner exposure only]) and two wind angles (45 degrees and 90 degrees) were evaluated.

Thermal impact was evaluated at four locations on the exterior wall: middle (M), quarter-right (Q-R), end-right (E-R) and corner (C) locations. It was observed that at 90 degrees, the flames were taller compared to that at 45 degrees. Taller flames could radiate more heat toward the wall. However, at 45 degrees, the flames were shorter and more horizontal and therefore were in close proximity to the ground. This phenomenon is extremely hazardous because as the flames spread, they were fueled by the combustible material nearby.

With a 5-ft noncombustible zone, the temperature on the wall was continuously below 200°C (potential ignition temperature), except at the corner configuration. Given that the critical temperature is a conservative threshold and that it is not likely that wind blows at the same angle at the corner for a long time, the testing confirms that the current 0–5 ft noncombustible zone recommendation provides a proper noncombustible zone.

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