Comprehensive Reference Information & Materials About Wildfires & Homes

Contents

Adapting to Wildfire

From Fire Safe Marin Website 2 3 2022

https://firesafemarin.org/harden-your-home/how-homes-ignite/

How Homes Ignite

Buildings ignite as a result of embers, radiant heat, and/or direct flames.

Embers

Embers are the most common cause of home ignition. They are light enough to be blown through the air and can result in the rapid spread of wildfire by spotting (in which embers are blown ahead of the main fire, starting other fires). Should these embers land on or near your house, they could just as easily ignite nearby vegetation, accumulated debris, or enter the home (through openings or vents).

Recent research indicates that two out of every three homes destroyed during the 2007 Witch Creek Fire in San Diego County were ignited either directly or indirectly by wind-dispersed, wildfire-generated, burning, or glowing embers (Maranghides and Mell, 2009), and not from the actual flames of the fire. Watch this simulation of a home ignited by embers to see just how dangerous wind-blown embers can be.

Radiant Heat

Near-home ignitions can subject some portion of your house to either a direct flame contact exposure (where the flame actually makes contact) or radiant heat exposure (the heat felt when standing next to a campfire or fireplace). If the fire is close enough to combustible material, or the radiant heat is high enough, an ignition will most likely result. Even if the radiant exposure is not large enough or long enough to result in ignition, it can preheat surfaces thus making them more vulnerable to ignition from a flame contact exposure. With any one of these exposures, if no one is available to extinguish the fire and adequate fuel is available, the initially small fire will grow into a large one.

Direct Flames

One of the misconceptions about home loss during wildfires is that the loss occurs as the main body of the fire passes. Research and on-the-ground observation during wildfires have shown that the main flame front moves through an area in a very short period of time – anywhere from one to ten minutes, depending on the vegetation type (Butler et al., 2003; Ramsay and Rudolph, 2003). Homes do not spontaneously ignite; they are lost as a result of the growth of initially small fires, either in or around the home or building.

The wildfires that are clearly remembered by the general public are those where hundreds of homes are lost. During these events, many homes were lost because the wildfire became an urban fire where the home-to-home spread of fire became more significant than wildland-to-home spread of fire, especially with decreasing separation between homes (Cohen 2008; Institute for Business and Home Safety, 2008).

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https://anrcatalog.ucanr.edu/pdf/8393.pdf

Publication 8393 | May 2010

Resources Advisor, Plumas-Sierra County

Home Survival in Wildfire-Prone
Areas: **Building Materials and Design Considerations**

STEPHEN L. QUARLES, UCCE Natural Resources Advisor, Contra Costa County; YANA VALACHOVIC, UCCE Forest Advisor, Humboldt County; GARY M. NAKAMURA, UCCE Area Forestry Specialist, Shasta County; GLENN A. NADER, UCCE Natural Resources Advisor, Sutter-Yuba Counties; and MICHAEL J. DE LASAUX, Natural Resources Advisor, Plumas-Sierra County

Summary

A wildfire-safe home (fig. 19) must be an ember-ignition-resistant home, so that even if the flames do not reach your home, it will be able to with-stand the exposure to embers that may have been blown a mile or more in front of a wildfire. To provide maximum wildfire protection for your home, a combination of near-home vegetation management, appropriate building materials, and related design features must be used. These points are summarized in table 1. Preparing and maintaining adequate defensible space will guard against flame contact and radiant exposures from nearby vegetation—but because of the likely ember exposure to your home during a wildfire, you cannot ignore building material and design considerations. Similarly, if you ignore your defensible space (i.e., you do not have it or do not maintain it), the wildfire will produce maximum ember, flame, and radiant exposures to your home. It is very unlikely that even hardened buildings can survive such exposure, as a weak link will likely exist somewhere in the building enclosure.

Fire Resistant Plants

www.firesafemarin.org/plants

Choose only fire resistant plants, and remove or avoid fire prone (pyrophytic) plants. Remember that all plants can burn if they aren't properly irrigated or are poorly maintained.

Ground Covers
Carpet Bugle
Common Thrift
Snow-in-Summer
Creeping Coprosma
White Trailing Ice-plant
Rosea Iceplant
Winter Creeper
Beach Aster
Beach Strawberry
Wood Strawberry
Bush Iceplant
Evergreen Candytuft
Giant Turf Lily
Ivy Geranium
Common Lippia
Alpine Cinquefoil
Green Lavender Cotton
Stonecrop
Blue Chalksticks
Creeping Thyme
Perennial Verbena
Creeping Red Fescue
+60 More online!

Shrubs & Hedges
English Laurel
Privet, Glossy Privet
Bird of Paradise
Creeping Mahonia
Angel's Trumpet
Bush Anemone
Breath of Heaven
Bush Morning Glory
Coreopsis
Escallonia
Lantana
Lavender
Malva Rose (Tree Mallow)
Catalina Cherry
Pomegranate
India Hawthorn
Rhododendron
Azaleas
Blueberry
Yucca
Lavender Cotton
+20 more online!

Trees
Maple
Strawberry Tree
Carob
Western Redbud
Mountain Ironwood
Citrus
Beech
Pineapple Guava
Ash
Macadamia Nut
New Zealand Xmas
Chinese Pistache
African Sumac
Oaks (all varieties)
+20 more online!

Mulches

Use only gravel mulch within 5' of structures. From 5' to 30', use compost or heavy bark or wood chip mulches greater than 1/2" diameter. Avoid fine or shredded bark - it's highly combustible and ignites easily from embers.

FIRE HAZARDOUS PLANTS

Certain shrubs and trees, like **juniper, cypress, pampas/jubata grass, bamboo, and many conifer trees** are so flammable that they should be removed. Replace with fire resistant species.

EVACUATION PREPAREDNESS

Prepare in Advance & Leave Early

www.firesafemarin.org/evacuation

Prepare long before a fire strikes: register for both Alert Marin & Nixle; assemble a "Go Kit;" train your family in advance. Each family member and pet should have an easily accessible Go Kit stored in a backpack. Keep a change of cotton or wool clothing and sturdy boots with your kit to wear while evacuating. Your car should be your first choice to quickly evacuate to wide, open areas near the valley floor. Don't panic in traffic. If trapped, sheltering in a building or car is often safer than being exposed on foot.

1. PREPARE IN ADVANCE
Prepare yourself, your family, your pets, and your home in advance. Register for **Alert Marin and Nixle**. Pack a "Go Kit" for everyone (including pets), create defensible space, and harden your home. Complete a Family Communications Plan and practice regularly.

2. MONITOR CONDITIONS
Monitor weather and local fire conditions to understand when risk is highest. During "Red Flag Warnings," take steps to prepare: review your evacuation checklist; double-check your Go Kit; charge your phones; monitor TV & radio.

3. LEAVE EARLY
Leave immediately if ordered. If a fire is burning nearby (especially during a Red Flag Warning), dress appropriately and prepare to evacuate. Allow firefighters time and access to respond. Leave if ordered, if conditions change, or you feel unsafe or unsure.

4. STAY CALM
Take the fastest & most protected route to a valley floor. Carpool! Stay in your car or a refuge area if trapped. Don't panic in traffic! A wide road on the valley floor is one of the safest places you can be. Monitor AM/FM news radio.

WILDFIRE & EMERGENCY "GO KIT"

- ☐ Full coverage goggles, N95 respirator, leather gloves, cotton bandana
- ☐ Water bottle(s) and food
- ☐ Map marked with two or more evacuation routes to valley floor (if possible)
- ☐ Prescription medications
- ☐ Change of clothing
- ☐ Spare glasses or contact lenses
- ☐ Extra set of car keys, credit cards, cash
- ☐ First aid kit
- ☐ Flashlight *and* headlamp with spare batteries
- ☐ Battery-powered AM/FM radio and spare batteries
- ☐ Copies of important docs (birth certificates, passports, insurance policies)
- ☐ Family Communication Plan with phone numbers
- ☐ Pet food, water, leashes, pet supplies & medications
- ☐ Spare chargers for cell phones & electronics.
- ☐ Sanitation supplies

Items to take only if time allows:

- ☐ Easily carried valuables
- ☐ Family photos and other irreplaceable items
- ☐ Personal computer and digital backups on hard drives and/or disks

www.AlertMarin.org

Sign up to receive emergency alerts!

Alert Marin is Marin's primary emergency notification system. You must register your cell phones, VoIP phones, and landlines to receive emergency alerts.

Register contact information for all family members so they'll receive a warning when emergencies threaten your home address. Practice evacuation drills regularly!

Working to Reduce Wildfire Risk Since 1991

FIRESafe MARIN is a non-profit organization dedicated to reducing the risk and hazard of wildfires and improving fire-safety awareness in Marin County, CA. We encourage community involvement by building strong partnerships and providing resources to mitigate fire danger.

FIRESafe MARIN
P.O. Box 2831
San Anselmo, CA 94979
www.firesafemarin.org
info@firesafemarin.org
(415) 570-4376 [4FSM]

WILDFIRE
PARTNERSHIPS
PLANNING
PREVENTION
PREPAREDNESS
PROTECTION

"FIRESafe MARIN is Marin's most valuable resource for preventing and preparing for wildfires. They foster community involvement in wildfire safety by building partnerships and encouraging cooperation among public and private stakeholders."

Katie Rice
FIRESafe MARIN Chairperson.
Supervisor, 2nd District

MAKE A TAX-DEDUCTIBLE DONATION TODAY!

FIRESafe MARIN depends on community support through volunteers, donations, and grants to conduct our mission of improving awareness and reducing wildfire hazards.

FIRESafe MARIN is a 501(c)3 non-profit. Your donation may be tax-deductible.

www.firesafemarin.org/donate Tax ID #68-0375763

HOMEOWNER'S GUIDE TO WILDFIRE PREPAREDNESS IN MARIN COUNTY

photo courtesy of Todd Barbee

The number of homes destroyed by wildfire has soared in the US in the last decade. In 2018, more than 30,000 structures were destroyed in California alone. Nearly 100 lives were lost. *Marin is at risk.*

To reverse this trend, homeowners must understand how homes ignite during wildfires and take action to protect their own property. There are easy and often inexpensive ways to make homes safer, many of which are required by law.

By following the simple strategies outlined in this guide, Marin residents can reduce their wildfire risk and minimize the danger to their homes, families, and communities.

Review our detailed online resources and tools for more comprehensive information about wildfire preparedness at:

www.firesafemarin.org

2019 V2

Zone Zero: 0′-5′ 0

Zone 0 extends 5 feet from structures. There should be "zero" combustibles in "Zone Zero."

Remove *all* combustible materials and protect vents and openings where wind-blown embers can enter.

Zone 1: 5′-30′ 1

Zone 1 extends from 5 to 30 feet from buildings, decks, and other structures.

Keep this area "Lean, Clean, and Green," and be sure to maintain regularly throughout fire season!

Zone 2: 30′-100′ 2

Zone 2 is the space extending 30 to 100 feet from buildings, decks, and other structures.

Reduce fuel for fire, and separate trees and shrubs in this area. Remove dead vegetation regularly.

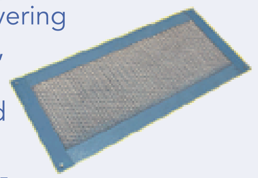
Access Zone: 0′-10′ 3

Property owners are responsible for vegetation adjacent to roads and driveways.

Roadway clearance is critical for evacuation and first responder access. Maintenance is required year-round.

"Hardening" your home is critical

Embers are the most significant cause of home ignitions during wildfires. Protecting your home from embers is critically important, and can be as simple as retrofitting vents, covering openings, sealing doors and windows, and caulking gaps and cracks.



Install "Class A" roofing and keep your roof and gutters clean at all times, focusing on areas like dormers where vertical surfaces meet the roof.

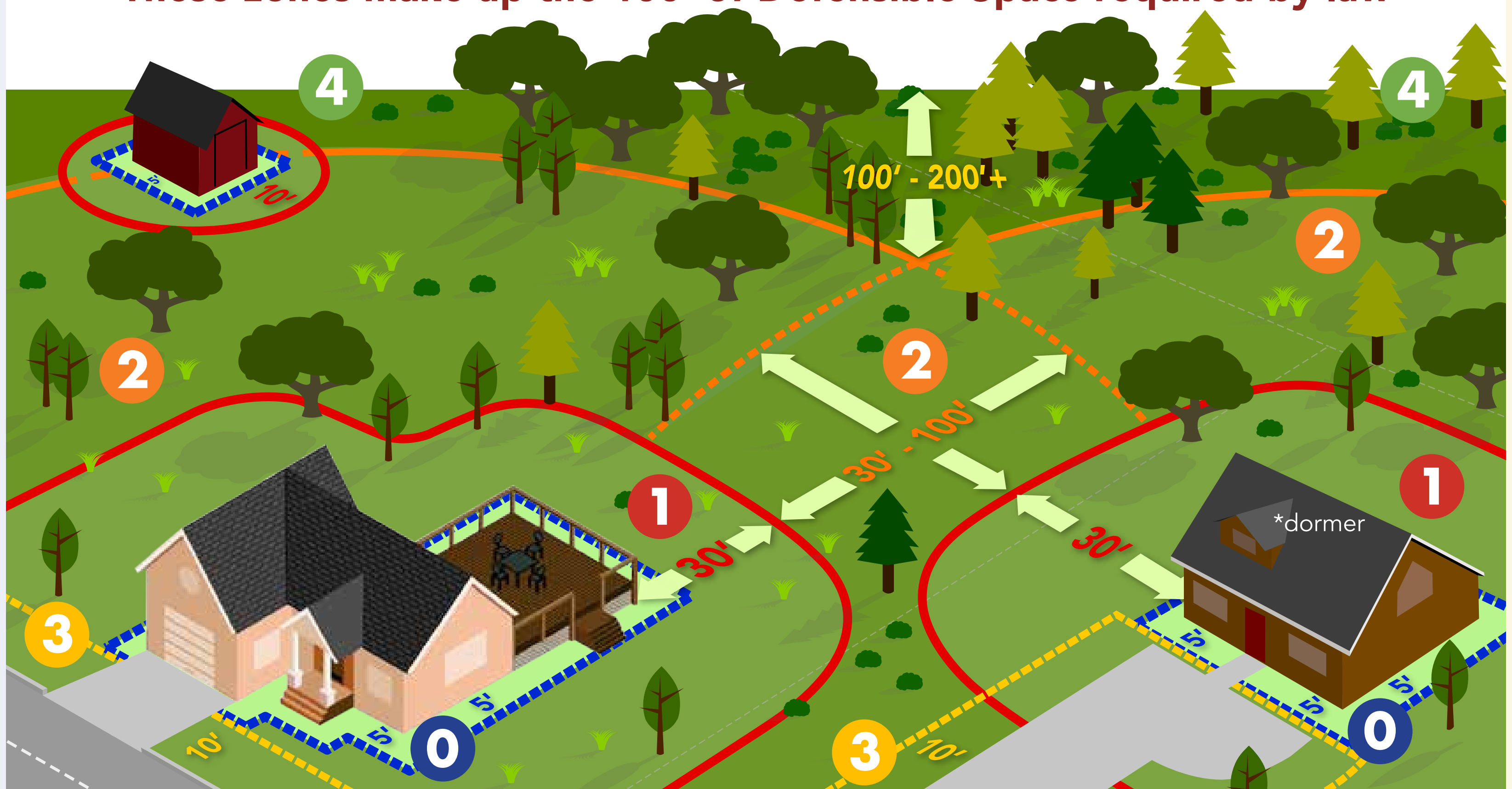
Other measures, such as retrofitting ember and flame resistant vents, installing tempered, dual-pane windows, and installing fire resistant siding can make a home significantly more fire resistant.

Attachments & Fences

Wood fences, gates, and other combustible structures should not be attached directly to the house. Use fire resistant materials instead, such as steel, aluminum, or masonry. Protect fences by removing vegetation and other fuels within 5 feet.

Learn more: www.firesafemarin.org/home-hardening

These zones make up the 100′ of Defensible Space required by law



1. Clear vegetation 14′ overhead and 10′ from sides of roads and driveways in the same manner as Defensible Space Zone 1.
2. Maintain 12′ of unobstructed pavement for passage of vehicles.
3. Choose only fire resistant plants and ensure that they do not extend into the roadway.
4. Address numbers must be clearly visible from the road. Use 4″ reflective or lighted numbers on a contrasting background.
5. Create vertical spacing between shrubs and lower tree limbs.

Public Right of Way: *Your Responsibility*

Property owners are responsible for vegetation adjacent to roads and driveways, even in the public "right of way." Ensure that vegetation is maintained near roads on all sides of your property, especially if your lot extends between two streets.

1. Use only inorganic, non-combustible mulches such as stone or gravel.
2. Choose metal outdoor furniture instead of wood or wicker.
3. Remove or relocate all combustible materials including firewood, garbage and recycling containers, lumber, and trash.
4. Replace jute or natural fiber doormats with heavy rubber or metal grates.

5. No vegetation is recommended in Zone 0.
6. Remove tree limbs that extend into this zone.
7. Clean fallen leaves and needles regularly, focusing on the roof, gutters, decks, & the base of walls.

8. Don't store combustibles on or under decks. Keep decks clean at all times.
9. Install hardscaping and paths of stone, gravel, or concrete around the perimeter of structures.

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1. Remove all dead grasses, weeds, plants, & foliage.
2. Remove all fallen leaves, needles, twigs, bark, cones, and small branches.
3. Remove "Gorilla Hair" or shredded bark mulch.
4. Use compost or heavy bark mulch in this zone to maintain soil moisture and control erosion.
5. Choose only fire resistant plants, and keep them healthy and well irrigated.
6. Remove fire-prone plants.
7. Provide spacing between shrubs, at least 2 times the height of the mature plant. Add space on slopes.
8. Trim trees to remove limbs 6′ to 10′ from the ground.
9. Remove branches that overhang your roof or within 10′ of chimneys.
10. Move firewood & lumber out of Zone 1, or cover in a fire resistant enclosure.
11. Remove combustibles around and under decks and awnings.
12. Clear vegetation around fences, sheds, outdoor furniture, play structures.
13. Outbuildings and LPG storage tanks should have at least 10′ of clearance.
14. Maintain regularly, focusing on the areas closest to the structure.

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1. Cut annual grasses and weeds to a maximum height of 4″.
2. Provide horizontal spacing between shrubs & trees.
3. Create vertical spacing between grass, shrubs and lower tree limbs.
4. Allow no more than 3″ of loose surface litter (consisting of fallen leaves, needles, twigs, cones, and small branches) if needed to protect from erosion.
5. Remove all piles of dead vegetation.

Work with your neighbors

Many homes don't have 100′ of space between structures and parcel lines. Property owners are required to maintain defensible space only to their property line. You *may*, however, be required to **maintain vegetation on your property that threatens neighbor's homes**, even if it's more than 100′ from your structures. Check with your local fire department for details.

Work with neighbors to help provide defensible space for their homes, and ask for help if their property threatens yours. In most cases, the most effective solution to mitigate hazards is a cooperative approach between neighbors.

Plant and Tree Spacing

Mature trees don't *usually* need to be removed. In all zones, clear shrubs and grasses beneath trees. Remove limbs at least 6′ to 10′ above the ground (or 1/3 the height of tree) to eliminate a "fire ladder."

Beyond 100′ & Open Spaces 4

Work with neighbors & land managers to reduce fuel on nearby properties and create fuel breaks to protect your community. Contact FIRESafe MARIN and your local fire department for help organizing neighbors to create a Firewise USA® site.

NFPA

FIREWISE USA

Residents reducing wildfire risks

www.firesafemarin.org/firewise

Fire Sprinklers

FEMA

Home Builder's Guide to Construction in Wildfire Zones **Technical Fact Sheet No. 15**

Purpose

To provide guidance on the installation of interior and exterior fire sprinkler systems on buildings in wildfire zones. The guidance pertains to both new and existing buildings.

Key Issues

- During a wildfire, firebrands and airborne debris can breach windows, and convective heat and embers can penetrate utility openings, gaps around doors, and other openings. The interior of a building can ignite even when the exterior does not. Fire sprinklers are not common in residential construction, but they can be effective in preventing damage from a wildfire.
- Exterior building components that are combustible such as overhangs and recessed alcoves can trap embers, firebrands, and hot gases, leading to ignition of the building. Exterior sprinklers can help extinguish flames before the building has been substantially damaged.
- A building that has ignited can endanger nearby buildings and contribute to the spread of a wildfire. Interior and exterior sprinklers can prevent substantial damage to the building, protect nearby buildings, and prevent the fire from igniting nearby combustible vegetation.

Interior Fire Sprinklers

Common Misconception	*Fact*
All sprinklers in a system activate simultaneously.	Only sprinkler heads that are in an area of high heat are activated. Typically, only one or two heads activate during a fire. Sprinkler heads are activated only by heat, not by smoke.
Sprinklers can activate accidentally.	According to the U.S. Fire Administration, only 1 in 16 million sprinkler heads activates accidentally.
Water damage from sprinklers is more expensive to repair than damage from the fire.	Water damage from sprinklers is usually considerably less expensive to repair than damage caused by water from fire hoses, smoke, and fire. Quick-response sprinklers release 8 to 24 gallons of water per minute, while fire hoses release 50 to 125 gallons per minute.
Interior sprinkler systems are obtrusive and not aesthetically pleasing in residences.	Interior fire sprinklers for single-family residences are smaller than traditional commercial or industrial fire sprinklers and can be coordinated with any room décor. Sprinkler heads come in a variety of styles, models, and colors and can be mounted flush with the ceiling (see Figure 1) or concealed behind covers.

Characteristics

- Interior fire sprinkler systems can detect a developing fire quickly and activate automatically. Systems do not require manual intervention.
- Interior sprinkler systems can include a warning system that notifies occupants and emergency response personnel of a developing fire.
- Interior sprinklers can be installed during new construction or in an existing home.

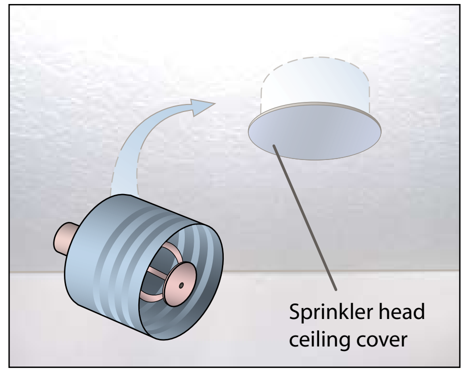


Figure 1. A concealed, aesthetically pleasing fire sprinkler.

Guidance

- Installing sprinklers in unoccupied, enclosed spaces such as attics should be considered because doing so can provide additional protection if fire penetrates the exterior of the space.
- Water pressure and supply must both be adequate for an interior sprinkler system to be effective. Water is typically supplied by the water main from the municipal water supply. During a wildfire, firefighting resources often exhaust the available water pressure. If existing water pressure is inadequate or the source of water is a well, a holding tank can be used as a water source. To ensure that water is available to the system during a wildfire, a pressurized holding tank should be considered, even if the structure is connected to the municipal water supply.

Considerations

- The majority of the cost of an interior sprinkler system is associated with the piping material. Options for materials include steel alloys, copper, and fire-resistant plastics. Plastic piping is less expensive than steel alloys and copper, but its melting point is as much as five times lower than copper piping.
- Hazard insurance rates are typically discounted for homes with interior sprinkler systems.
- An interior sprinkler system is relatively easy to install during new construction. The system increases the total cost of construction by approximately 2 percent; complex and multi-story installations may increase the cost more. Installing an interior sprinkler system can be done when the roof is replaced or upgraded, and doing so may cost less than standard installation.
- The cost of installing an interior sprinkler system during new construction is about half the cost of installing a system in an existing building.

Effectiveness

Internal sprinklers extinguish the fire at an early stage and prevent substantial damage from heat and smoke or total loss of the structure. They are effective in all Fire Severity Zones.

Exterior Fire Sprinklers

Characteristics

- The purpose of an exterior fire sprinkler system is to saturate the exterior of the building.
- Exterior sprinkler systems can be installed during new construction or on existing buildings. They are commonly installed on the roof along the ridge line or underneath the eaves and along soffits.
- Exterior sprinklers can be activated automatically by low-voltage heat detectors or manually by occupants before they evacuate the home.
- Exterior sprinklers can include a warning system that notifies occupants and emergency response personnel of a developing fire.
- Some landscape sprinklers are designed and installed to provide protection from a wildfire to landscape areas immediately surrounding a building.
- An exterior sprinkler system can be installed so that it is substantially hidden from view.

Guidance

Exterior sprinklers mounted on the building can be configured to use water piping through the attic or roof or to use piping on the exterior of the structure. If interior pipes are used, exterior sprinklers can be installed in conjunction with interior sprinklers (see Figure 2). A stand-alone system that includes a pressurized holding tank can be considered to ensure an adequate water supply. See the information about water supply under interior fire sprinklers above.

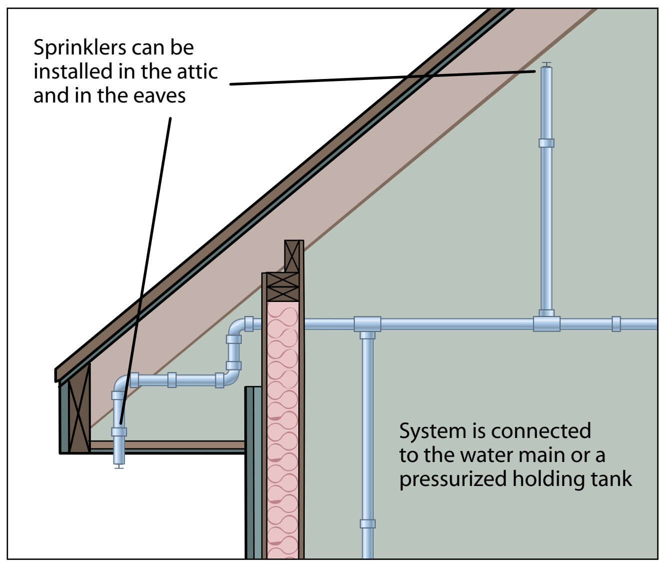


Figure 2. Interior and exterior fire sprinklers can be installed in conjunction with each other, such as this system with a sprinkler in the attic and along the eave.

Considerations

- If exterior sprinklers are installed in areas where freezing temperatures occur, special provisions such as dry sprinklers are required to prevent water in the piping from freezing and rupturing it. In a dry sprinkler system, the portion of piping that is vulnerable to freezing is not charged with water until a fire opens a valve and releases water into the piping.
- Exterior sprinklers can provide added protection when used in conjunction with fire-resistant construction materials (see Fact Sheets #5–14) and defensible space (see Fact Sheet #4, Defensible Space).
- Polymer gels, Class A foam products, and other long-term fire retardants can be applied to structures prior to fire impingement and provide greater thermal protection than water alone.

Many of these products are available to homeowners in self-contained application units and can be applied with an attachment to a garden hose or integrated into the home's exterior sprinkler systems.

Effectiveness

- If exterior fire sprinklers require manual activation, occupants must activate the system expeditiously for the system to be effective.
- High winds that are frequently a byproduct of major fire activity can significantly degrade the effectiveness of an exterior sprinkler system.
- Manually applied fire-protection materials such as Class A foam products can be effective if time is available to treat the home. To be effective, the fire-protection material must be applied within the time frame identified by the product manufacturer.

Resources

FireSafety.gov. *Residential Fire Sprinklers*. http://www.firesafety.gov/citizens/ sprinklers/index.shtm.

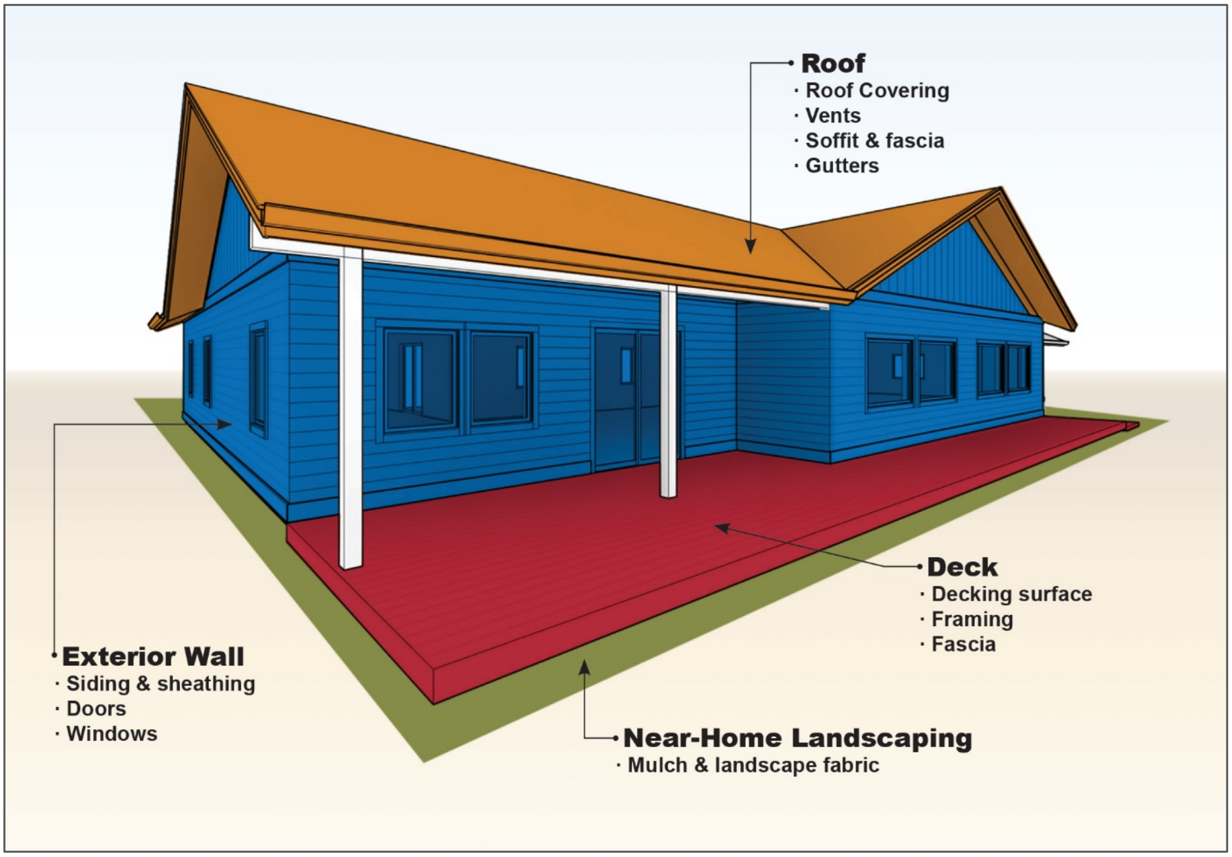
National Fire Protection Association. 2007. NFPA 13D: *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes*. http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=13D.

National Fire Sprinkler Association. Information about residential sprinkler systems. http://www.nfsa.org.

A Research Paper by

HEADWATERS ECONOMICS

Building a Wildfire-Resistant Home: Codes and Costs



November 2018

Building a Wildfire-Resistant Home: Codes and Costs

PUBLISHED ONLINE:
https://headwaterseconomics.org/wildfire/homes-risk/building-costs-codes

ABOUT HEADWATERS ECONOMICS

Headwaters Economics is an independent, nonprofit research group whose mission is to improve community development and land management decisions.

ABOUT INSURANCE INSTITUTE FOR BUSINESS & HOME SAFETY

The Insurance Institute for Business & Home Safety (IBHS) is an independent, nonprofit, scientific research and communications organization supported solely by property insurers and reinsurers. The mission of the IBHS is to conduct objective, scientific research to identify and promote the most effective ways to strengthen homes, businesses and communities against natural disasters and other causes of loss.

AUTHOR INFORMATION

Stephen L. Quarles, Ph.D. | squarles@ibhs.org | 415-233-1141
Dr. Quarles was the Chief Scientist for Wildfire and Durability at the Insurance Institute for Business & Home Safety when this document was prepared.

Kelly Pohl, M.Sc. | kelly@headwaterseconomics.org | 406-599-7841
Ms. Pohl is a Researcher and Policy Analyst with Headwaters Economics.

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HEADWATERS ECONOMICS

P.O. Box 7059
Bozeman, MT 59771
https://headwaterseconomics.org

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I. EXECUTIVE SUMMARY

This study examines the cost differences between a typical home and a home constructed using wildfire-resistant materials and design features. Decades of research and post-fire assessments have provided clear evidence that building materials and design, coupled with landscaping on the property, are the most important factors influencing home survivability during a wildfire. With one-third of all U.S. homes in the wildland-urban interface[1] and more than 35,000 structures lost to wildfire in the last decade,[2] more communities are considering adopting building codes that require new home construction to meet wildfire-resistant standards.

While codes and standards have been developed for building in wildfire-prone lands, the perceived cost of implementing such regulations is a commonly cited barrier to consideration and adoption by some communities. However, little research has previously examined how much it would actually cost the homeowner or builder to comply with such regulations.

This study compares existing codes and standards for wildfire-resistant construction and estimates cost differences in constructing a wildfire-resistant home compared to a typical home. It also examines the cost of retrofitting a typical home to be more wildfire-resistant. Key findings include:

- A new home built to wildfire-resistant codes can be constructed for roughly the same cost as a typical home.
- Costs vary for retrofitting an existing home to be wildfire-resistant, with some components such as the roof and walls having significant expense. Some of these costs can be divided and prioritized into smaller projects.
- Many wildfire-resistant home features have additional benefits, such as a longer lifecycle and reduced maintenance.

This study was completed in partnership with The Insurance Institute for Business & Home Safety (IBHS) and was prepared at the request of Park County, Montana, as part of the Community Planning Assistance for Wildfire (CPAW) program. CPAW is a program of Headwaters Economics and is funded by the U.S. Forest Service, the LOR Foundation, and other private foundations.

Wildfire-Resistant Codes and Standards

While certain jurisdictional codes have been established, three existing statewide or national building codes and standards guide wildfire-resistant construction. They are:

- the International Code Council's International Wildland Urban Interface Code (IWUIC),[3]
- the National Fire Protection Association's Standard for Reducing Structure Ignition Hazards from Wildland Fire (Standard 1144),[4] and
- the California Building Code Chapter 7A—Materials and Construction Methods for Exterior Wildfire Exposure.[5]

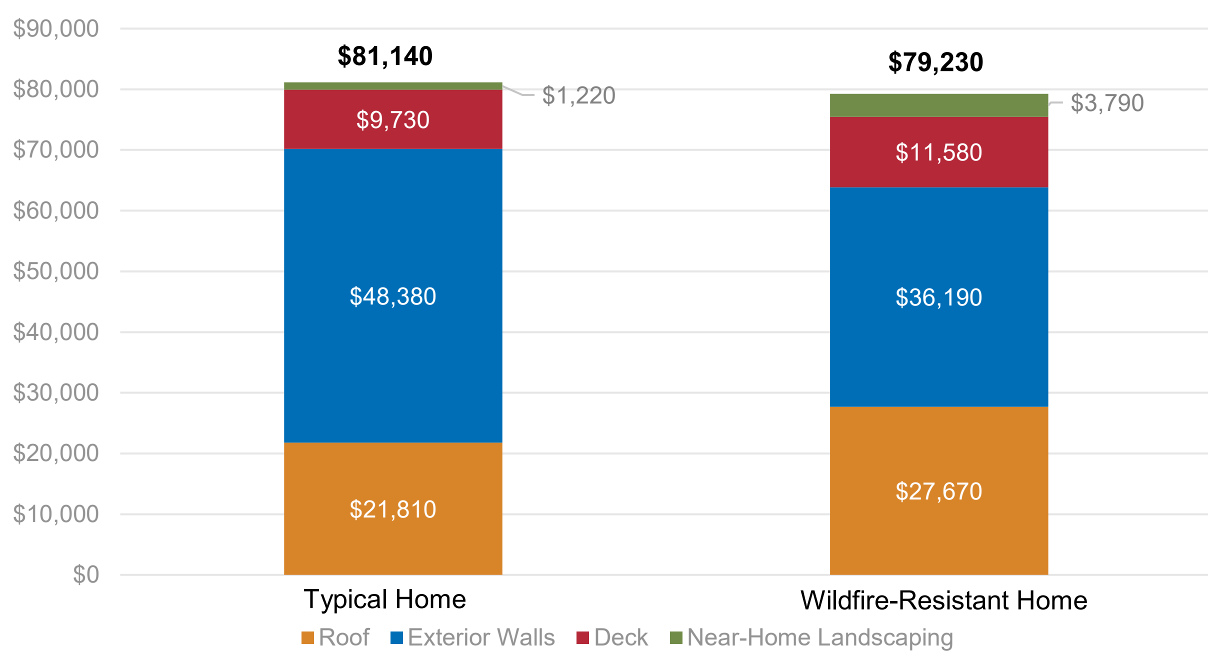
These three documents address construction requirements of the home by component parts (e.g., roof, walls, etc.) and often provide multiple options for complying with the provision. Many of the requirements in these documents are based on standard laboratory testing methods that evaluate the ability of a material or assembly to resist ignition or fire spread. California is one of only a few states to have adopted a wildfire-related building code at the state level for areas of high hazard, but many cities and counties have adopted portions of the IWUIC or other wildfire-related codes. In some communities, the inaccurately assumed cost of constructing a home to comply with a wildfire-resistant building code is a barrier to implementing such codes.

Wildfire-Resistant Construction Costs

To identify whether the cost of constructing to a wildfire-resistant building code differs from typical construction, this study priced new construction and retrofitting expenses for a three-bedroom, 2,500-square-foot, single-story, single-family home representative of wildland-urban interface building styles in southwest Montana, one of the fastest-growing regions in the country. The typical home was assumed to have an asphalt shingle roof, wood siding, dual-pane windows, and a wood deck. Wildfire-resistant materials were selected for similar aesthetics but also comply with wildfire-resistant building codes. Costs were primarily derived from *RSMeans*,[6] a database that averages material and labor pricing from hundreds of U.S. cities and includes materials, labor, and contractor overhead and profit.

We examined costs in four vulnerable components of the home: the roof (including gutters, vents, and eaves), exterior walls (including windows and doors), decks, and near-home landscaping. Overall, the wildfire-resistant construction cost 2% less than the typical construction (Figure 1.1), with the greatest cost savings resulting from using wildfire-resistant fiber cement siding on exterior walls, in lieu of typical cedar plank siding. While cedar plank siding is typical in the wildland-urban interface of western Montana, fiber cement siding is already a common choice in many regions because of its relative affordability, durability and low maintenance needs. Wildfire-resistant changes to the roof resulted in the largest cost increase, with a 27% increase in gutters, vents, and soffits. The following sections describe the wildfire-resistant mitigations for each component.

Figure 1.1. New construction costs by component in typical home and wildfire-resistant home.

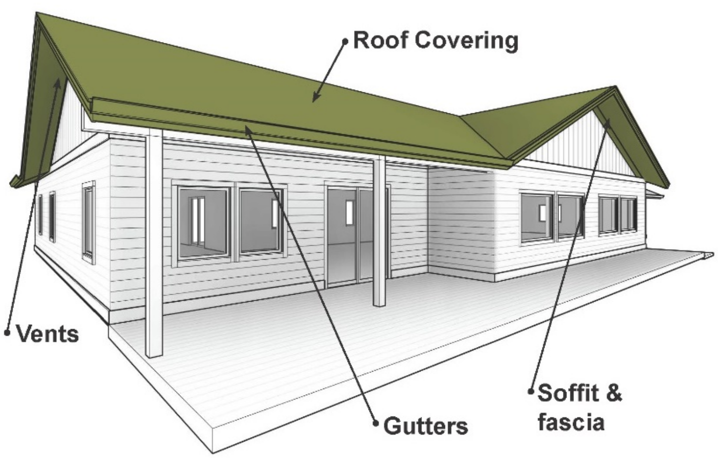


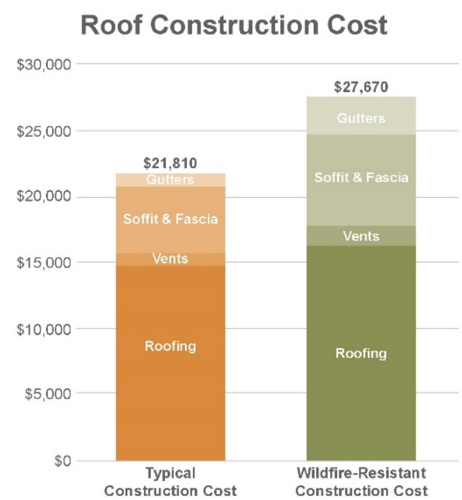
Roof

The roof is arguably the most vulnerable area of the home because of its large surface area. Embers can ignite vegetative debris that has accumulated on the roof surface or in gutters. Embers also can enter the attic through roof and under-eave vents. Also, unenclosed eaves and overhangs can trap embers and heat.

Wildfire-resistant modifications to roofing, vents, fascia, soffits, and gutters added $5,860 (27%) to the cost of the typical roof (Figure 1.2), assuming both homes use Class A (fire-rated) asphalt composition shingles. Retrofitting an existing roof to be wildfire-resistant approached the cost of new construction, totaling $22,010 for the model home. However, many of the wildfire-resistant roof materials have longer lifespan and reduced maintenance needs as compared to typical materials.

Figure 1.2. Roof subcomponents and new construction cost.



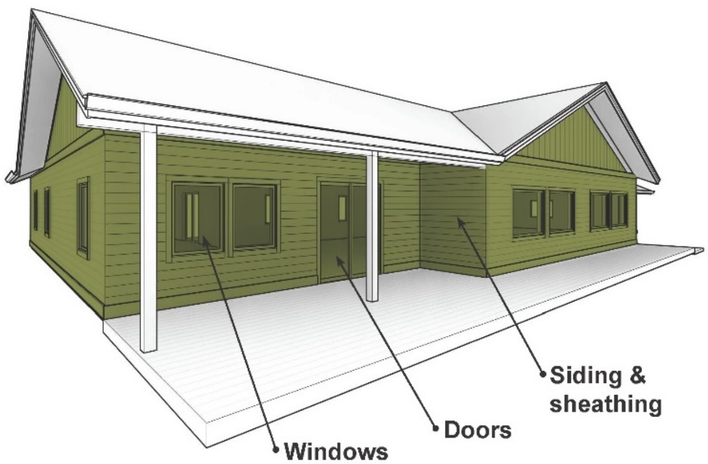


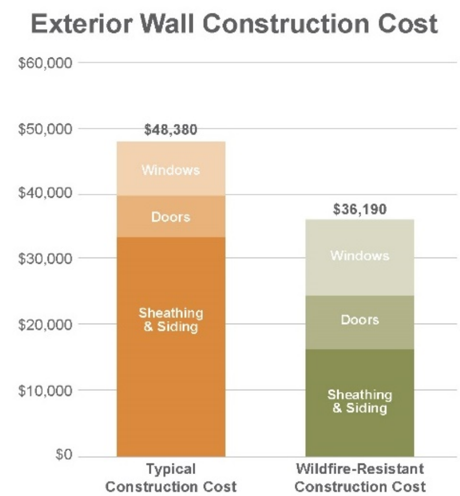
Exterior Walls

Exterior walls are especially vulnerable from exposure to flames or prolonged exposure to radiant heat, such as from burning vegetation or a neighboring home. These exposures can potentially ignite combustible siding products. Some plastic siding products (e.g., vinyl) can also melt, exposing underlying sheathing. Wind-blown embers can accumulate in gaps or pass through openings around windows and doors. Glass in a window or door can break from radiant heat or flame contact, exposing the interior of the home. Wildfire-resistant siding and installation design features, tempered glass in windows, wildfire-resistant doors, and weather-stripping can reduce home vulnerability. The relative importance of each of these items varies depending on home-to-home spacing and location of vegetation on the property. Siting on the property relative to topography and typical wind directions can also be important factors in determining necessary external wall mitigations.

Wildfire-resistant construction for exterior walls was $12,190 (25%) less expensive than the typical home, with the cost savings resulting from the difference in using wildfire-resistant fiber-cement siding as compared to cedar plank siding (Figure 1.3). Fiber cement siding is already a common siding option in many regions and several styles mimic the look of wood siding. While the change in siding reduced the cost of the wildfire-resistant home, cost increases for other exterior wall features are $5,370 (29%) more than typical exterior wall features. Retrofitting the exterior walls (including windows and doors) on the model home totaled $40,750. Depending on neighboring home spacing, not all retrofitting activities may be necessary, but several of these activities will have added benefits such as improved energy efficiency (e.g., multi-pane windows) and reduced maintenance.

Figure 1.3. Exterior walls subcomponents and new construction cost.

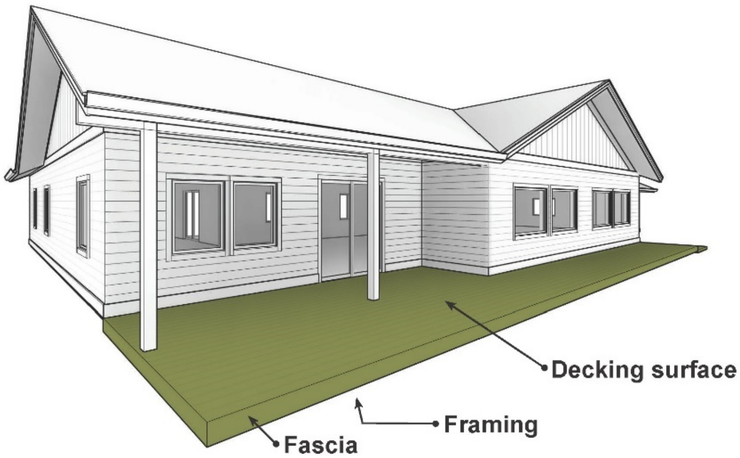


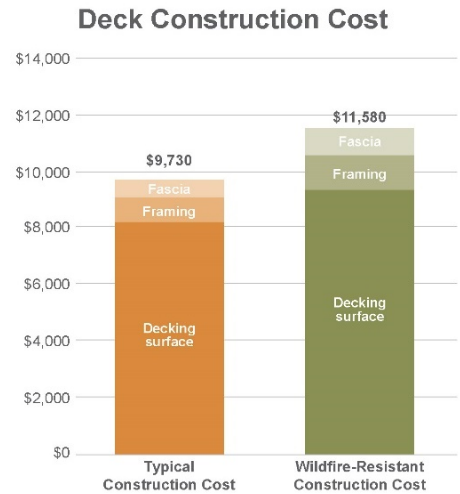


Deck

Embers can ignite vegetative debris or other combustible material stored or accumulated on top of the deck. If ignited, the burning deck could expose walls, windows, and doors to radiant heat. Embers can ignite decking materials directly when they accumulate on the surface of vulnerable decking, typically occurring in the gaps between deck boards. Decks can also ignite from below when vegetation or stored materials ignite beneath the deck. Mitigations to make a deck wildfire-resistant include using wildfire-resistant materials for walking surface (e.g., composite boards), using foil-faced bitumen tape on the top surface of the support joists, and creating a noncombustible zone underneath the deck. The wildfire-resistant deck added $1,850 (19%) to the cost of the typical deck (Figure 1.4). Some wildfire-resistant decking materials can have a longer lifespan and require less maintenance than typical materials.

Figure 1.4. Deck subcomponents and new construction cost.

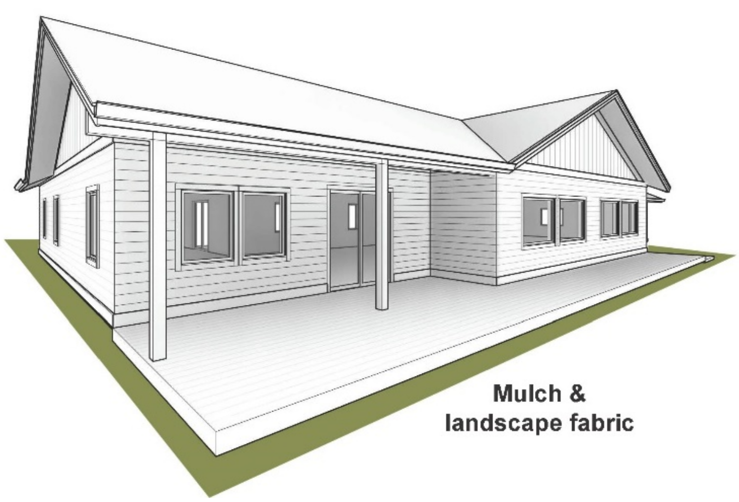




Near-Home Landscaping

If ignited by wind-blown embers, burning vegetation and other combustible materials near the home can allow flames to touch the home or subject it to an extended radiant heat exposure, potentially igniting siding or breaking glass in windows. Maintaining a noncombustible zone of five feet around the entire perimeter of the house and outer edges of the deck can significantly reduce the vulnerability of the home. Mitigations include using rock instead of bark mulch on top of landscape fabric. Placing landscape fabric underneath the area can reduce the growth of weeds, thereby minimizing the maintenance needed by the homeowner. These modifications increased the cost of near-home landscaping by $2,570 (210%) (Figure 1.5). Rock has a longer lifespan than bark mulch and landscape fabric will reduce the maintenance required in the near-home landscaping area.

Figure 1.5. Near-home landscaping subcomponents and new construction cost.



Constructing a Wildfire-Resistant Home Is Similar in Cost to a Typical Home

Laboratory research and post-fire analysis have determined that local ignitability of the home itself, largely determined by the building materials and design features, is an important factor in determining survivability during a wildfire. Existing codes and standards provide ample guidance for how to construct a wildfire-resistant home and reduce vulnerability. This study demonstrates that a new home can be constructed to such standards for approximately the same cost as a typical home, and some of these materials have added benefits such as longer lifespan and reduced maintenance.

City, county, and state governments must weigh many issues when considering new regulations, but the cost of constructing a home to meet wildfire-resistant building codes need not be a barrier. If communities continue to allow growth in wildfire-prone lands, adopting wildfire-resistant building codes may be one of the most effective tools for reducing home loss. Absent such requirements, homeowners and builders can take steps to protect the home by carefully designing and constructing (or retrofitting) the most vulnerable components—the roof, walls, deck, and landscaping—to be wildfire-resistant. The long-term benefits may include longer lifecycle and reduced maintenance.

As recent wildfire disasters have demonstrated, the converging trends of rapid growth in the wildland-urban interface, fuel accumulation after a century of fire suppression, and a warming climate will make wildfires more costly and dangerous in years to come. Just as the cause of this problem is multipronged, there is no single solution to protecting lives and property, and we must employ a suite of solutions that include land use planning, vegetation management, and emergency preparedness. Constructing homes to be wildfire-resistant is a critical and cost-effective piece of the puzzle.

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II. BACKGROUND

Trends in the Wildland-Urban Interface

Home development in the wildland-urban interface (WUI)—the area where housing and burnable vegetation meet or intermingle—is growing faster than in other land use types in the United States.[1] Homeowners in the WUI often are attracted to the natural scenery, access to public lands, privacy, and a rural lifestyle, but these amenities are accompanied by a rapidly growing risk.

Wildfires in the U.S. are bigger and burn longer than just a few decades ago, and danger to communities is increasing. Since the 1990s, the average acreage burned in U.S. wildfires has more than doubled.[2] In the western U.S., the average wildfire season is nearly three months longer than in the 1970s,[3] and globally it is an average of one month longer.[4] Since 2000, more than 3,000 U.S. communities saw 100 acre or larger wildfires within 10 miles of town.[5]

Current climate projections are likely to exacerbate the problem in the future. Fuel aridity is increasing in the western U.S. and climate trends are expected to expand the potential for wildfire activity.[6] Earlier spring snowmelt in the West is also drying fuels in areas previously snow-covered into late spring, expanding the geographic and temporal extent of wildfires.

The spatial and seasonal expansion of wildfire is compounded by the expanding WUI and the increasing presence of people near wildland vegetation. Human-ignited wildfires account for 84% of all U.S. wildfires from 1992-2012, causing wildfires in places and during times of the year that would not typically occur.[7]

Due to these trends, the costs of wildfire in the U.S. are on the rise. In the last decade, federal fire suppression expenditures cost taxpayers an average of $3.7 billion per year.[8] Federal managers estimate that 50 to 95% of suppression costs are directly related to protecting homes in the WUI.[9]

While these numbers are staggering, the true costs are even higher. Wildfire suppression represents less than 10% of the full costs of wildfire to communities, and communities bear nearly half of the full costs of wildfire.[10] Long-term damages can have devastating impacts, such as lost business and tax revenue, physical and mental health effects, watershed rehabilitation, and property and infrastructure repairs. Loss of human life in wildfire disasters causes immeasurable harm to families and communities.

Since 2008, wildfires have damaged or destroyed more than 35,000 structures in the U.S.,[11] putting insurance claims at $5.1 billion.[12] Although firefighters successfully control most wildfires, WUI disasters generally occur when extreme weather conditions result in rapid fire spread that overwhelms firefighting resources.

Decades of research and post-fire analyses have resulted in guidance that can reduce the vulnerability of buildings located in wildfire-prone areas and improve their ability to survive when wildfire threatens. Nevertheless, few communities have adopted requirements for wildfire-resistant building materials and design in high-risk areas. Two documents establish model building codes and standards: the National Fire Protection Association's *Standard for Reducing Structure Ignition Hazards from Wildland Fire*[13] and the International Code Council's *International Wildland-Urban Interface Code* (IWUIC).[14] Each addresses vulnerabilities of structures subjected to wildfire exposures. Most states have not adopted a building code on a state-wide level, but rather have left local jurisdictions to decide whether and how to adopt such model codes as regulations. California is a notable exception, having adopted *Materials and Construction Methods for Exterior Wildfire Exposure* as Chapter 7A of the state building code in 2008.[15]

For some local jurisdictions, a barrier to implementing WUI building regulations is the perceived cost. Although research has shown that the benefits of wildfire-resistant construction far outweigh the costs to a community,[16] little research has examined the immediate costs to homeowners and builders. Communities often assume that implementing wildfire-resistant building regulations will cost too much for homeowners and the homebuilding industry. The purpose of this study is to identify the cost differences of constructing or retrofitting a home to wildfire-resistant standards as compared to a typical home, not built to wildfire-resistant standards.

How Homes Are Lost to Wildfire

Home vulnerability is primarily driven by the home's local ignitability, based on the home materials and design features and landscaping selections and maintenance on the property.[17] Modern wildland fire suppression is extremely successful, quickly controlling 97 to 99% of wildfires.[18] Most WUI disasters occur during the 1 to 3% of events when severe weather conditions and terrain align to create rapid fire growth rates and widespread ember showers leading to extreme fire intensities that overwhelm firefighting capabilities.[19] Post-fire studies have shown that most buildings ignited during a wildfire have been completely destroyed.

Buildings can be ignited from three types of wildfire exposure (listed in order of significance): wind-blown embers (also called firebrands), radiant heat, and direct flame contact.

Embers

Most homes lost in WUI disasters are burned not by the flame front of the wildfire, but rather by direct ember ignition, or from low-intensity fires ignited by embers near the home.[20] In dry and windy conditions often associated with extreme weather events, embers can be cast a mile ahead of the fire front, igniting spot fires across broad areas in advance of the wildfire front. In recent post-fire analyses, it was not uncommon to find more than two-thirds of home losses were from embers or low-intensity fires.[21, 22, 23]

Direct ember ignition can occur when embers enter the building through openings such as vents or an open or broken window. Once inside, embers can ignite furnishings or other combustible materials stored there. Direct ember ignition can also occur when embers accumulate and ignite combustible parts of the building, such as a wood shake roof, combustible decking, or debris accumulated on a roof or in a gutter.

Embers can also result in an indirect ignition scenario if they ignite vegetation or other nearby combustible materials that cause a spot fire, subjecting a portion of a building to either a direct flame contact exposure where the flames touch the building or a radiant heat exposure.

Radiant Heat

Radiant heat can be generated by burning tree canopies or shrubs, landscape vegetation, neighboring buildings, or other nearby fuel. The vulnerability of a building to radiant heat depends on the intensity and duration of the exposure. If the radiant heat level is high enough and the duration long enough, it can result in the ignition of a combustible product (for example, wood siding), or it can break the glass in windows and doors, making ember-ignition of interior materials more likely. Exposures to lower levels of radiant heat can pre-heat materials, making them easier to ignite if exposed to flames.

Direct Flame Contact

Direct flame contact from the wildfire as it passes the property can be the trigger that leads to ignition of a building component, such as combustible siding. Once a building component ignites it is easier for the fire to enter the building through the component or through the stud cavity behind a component, such as wall siding. Fire can also spread vertically up the wall, impinging on and possibly breaking glass in windows or doors, or enter the attic through the eave or eave vent. Once glass breaks, embers can readily enter the building and ignite interior furnishings.

Building Wildfire-Resistant Homes & Communities

Although the factors affecting whether a home survives a wildfire are complex—including weather, topography, fuels, and fire suppression capabilities—empirical research and laboratory experiments have demonstrated that building construction and design play a major role in home survival.[24, 25] Building wildfire-resistant homes and communities requires addressing all wildfire vulnerabilities, including provisions to make buildings less vulnerable to ember exposures, reducing the opportunity for the fire to reach the building, and minimizing the opportunity for radiant heat exposures from landscaping vegetation, outbuildings, or other nearby combustible materials.

Reducing home losses to wildfire requires a coupled approach, addressing two primary sources of home vulnerability:[26, 27]

1. The selection, location, and maintenance of vegetation and other combustible materials within approximately 100 feet surrounding the home, referred to as the "home ignition zone" (HIZ).

2. The building materials and design features used in construction of the home itself.

Home Ignition Zone (HIZ)

Developing wildfire-resistant properties for HIZ (also referred to as defensible space) generally involves managing vegetation, landscaping, debris, and other combustible materials (like wood piles and outbuildings) in a 100-foot area around the home. Research has found that defensible space beyond that radius has little effect on a home's survivability.[28] In general, the area is broken into three subzones:[29]

- Zone 1: 0 to 5 feet;
- Zone 2: 5 to 30 feet; and
- Zone 3: 30 to 100+ feet.

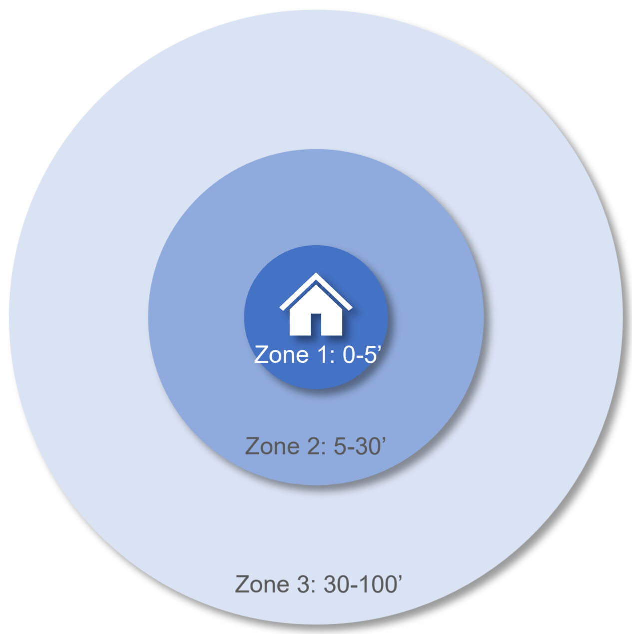

Figure 2.1. The Home Ignition Zone (HIZ), comprising three sub-zones.

The exact recommendations for each zone will vary depending on topography, the siting of the home on the property, and the vegetation type, but the objectives are to reduce the energy of the fire and minimize the chance it will burn directly to the home, and, if present, to allow for safe fire suppression activities to protect the home.

Reducing potential fire energy and spread in Zones 2 and 3 involves carefully selecting and maintaining vegetation, creating separation between plant groupings, and eliminating vertical continuity of fuels, also known as ladder fuels. Information about creating, designing, and maintaining defensible space for different climatic regions, fuel types, and topography is readily available through state and local agencies and will not be further addressed in this report.

Zone 1, also called the near-home zone or the "noncombustible zone," includes the 0- to 5-foot area immediately adjacent to the home where, if ignited, landscaping and other combustible materials could spread to and ignite the home. The strong likelihood of ember attack in most wildland fire events means that homes are most vulnerable to ignition in this near-home area. Although a completely noncombustible zone is desirable (e.g., use of rock mulch or other hardscape features), vegetation considered to be less combustible could also be used. This "less-combustible" vegetation would be restricted to an irrigated lawn and non-woody, low-growing, herbaceous vegetation, both of which must be well-maintained. Given the ability of wind-blown embers to pass over the defensible space created on most properties, incorporating a noncombustible zone provides additional protection by reducing the opportunity for a flame to directly contact the home as a result of ember-ignited combustibles located immediately adjacent to the home. The near-building zone is described in additional detail in Chapter VIII.

Definitions

Many of the terms used to describe favorable performance are used interchangeably, even though they may have different technical definitions. Different wildfire codes may have discrepancies, but are generally based on traditional laboratory tests that determine a material's response or reaction to fire.

Wildfire-Resistant. A general term used in this report to describe a material and design feature that can reduce the vulnerability of a building to ignite, either from wind-blown embers or other wildfire exposures.

Fire-Resistant. Materials and systems that resist the *spread* of fire from the fire-exposed to a non-exposed side of an assembly (i.e., a wall or roof).

Ignition-Resistant. Material that resists *ignition* or sustained flaming combustion. Materials designated ignition-resistant have passed a standard test that evaluates flame spread on the material.

Noncombustible. Material of which *no part will ignite or burn* when subjected to fire or heat, even after exposure to moisture or the effects of age. Materials designated noncombustible have passed a standard test.

Building Materials & Design Features

The materials used to construct a home and their arrangement and design can have a major influence on survivability. Several components of single-family homes are most vulnerable to wildfire and must therefore be built and designed to specifically withstand ignition from embers, radiant heat, and direct flame contact. These components include:

- Roof, including vents, gutters, and eaves/soffits
- Exterior walls, including siding, windows, and doors
- Decks and other exterior attachments.

Given the relatively large surface area of the roof, this component generally is considered the most vulnerable. One recent study found that window preparation was especially important, but defensible space in the near-home area was as important as building construction.[30] Because of the many complex ways wildfire interacts with the landscape and fuels—including combustible materials used in construction—home vulnerability must be addressed through both property-level landscaping and the building materials and design.

Even if constructed with wildfire-resistant materials and design features, the home and its landscaping must be maintained to retain the necessary level of performance. The potential for extended radiant heat exposure and/or direct flame contact will depend on the defensible space and on the proximity of any neighboring homes or outbuildings. Therefore, overall land use planning decisions—including where homes should or should not be allowed on the landscape, proximity of neighboring homes, and siting of a home on an individual lot relative to neighboring structures, topography, and primary wind direction—are also important factors.

The Costs to Homeowners and Builders

The cost of building a single-family home using wildfire-resistant materials and design has not been previously analyzed in detail. Studies at the individual home level have mostly been tied to creation and management of defensible space. Australian studies have found the cost for retrofitting a home to be wildfire-resilient averaged $19,000,[31] and the cost of preparation is approximately $8,000[32] (U.S. 2018 dollars), but most of the modifications were related to management of the vegetation on the property and purchase of equipment to defend the home, not the construction of the home itself. Similarly, little research exists on the effects of WUI regulations on home or property values. A 2017 report by the National Institute of Building Sciences estimated a savings of $4 for every $1 of additional construction cost by implementing the IWUIC at the community scale.[33]

Researchers have investigated the costs of building codes that address other natural disasters, such as hurricanes and tornadoes. A recent study in Moore, Oklahoma, found that implementation of new regulatory building codes to address severe tornado risk did not impact the quantity of homes sold, price of homes, or the number of permits for construction.[34] An analysis of Florida's state building code—implemented after the devastation of Hurricane Andrew—not only was successful in reducing losses by up to 72% from major windstorm events, but also realized a benefit of $6 for every $1 of added cost.[35]

In addition, some research has shown that buyers were willing to pay a premium for safety. In Florida, homes built under more recent, stronger building codes saw a 10% higher price than older homes built before the code change.[36] Anecdotal evidence from wildfire-prone areas suggests that some housing markets use wildfire-resistance as an advertising and marketing strategy.

To address the research gap in the cost to construct a home to meet wildfire-resistant building codes, this study compares the three most well-known wildfire-resistant building codes and then examines the cost to build a home to those requirements.

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III. WUI CODES AND STANDARDS

> **Codes vs. Standards**
>
> **Codes** are model sets of rules recommended by experts and informed by research. Codes can be adopted by state or local jurisdictions as-is, or customized for local conditions to become law. Codes explain *what* needs to be done.
>
> **Standards** include definitions, procedures for testing materials, and technical guidelines. They are intended to provide standardization and a common reference, explaining *how* to meet minimum requirements referenced in a building code.

Before examining the cost of constructing a home built to wildfire-resistant standards, it is helpful to understand the primary guiding documents for wildfire-resistant construction in the U.S. This chapter compares the three most well-known building code options for construction in wildfire prone areas: the International Code Council's Wildland-Urban Interface Code (IWUIC),[1] the National Fire Protection Association Standard for Reducing Structure Ignition Hazards from Wildland Fire (NFPA 1144),[2] and Chapter 7A in the California Building Code (Materials and Construction Methods for Exterior Wildfire Exposure).[3] Even though building codes are generally reserved for new construction or significant remodels that meet certain thresholds, they can be useful for improving resistance to wildfire risks when retrofitting.

This report focuses on the portion of the documents related to building design and construction, although the three codes incorporate additional information related to home survival during wildfire such as infrastructure (like water supply and roads), landscaping and site requirements, and fire protection systems. Some communities may adopt a stand-alone code specifically designed to address wildfire in at-risk portions of the community (generally called a "WUI Code"), but wildfire-related issues may also be incorporated into a variety of other existing regulations (e.g., building codes, zoning regulations, landscaping ordinances).

Few states have adopted wildfire-related codes at the state level, with some notable exceptions. California adopted Chapter 7A as part of the California Building Code in 2008. NFPA 1144 has not been adopted in its entirety by any state. In 2018, the State of Washington adopted portions of the 2018 IWUIC into its building code, specifically those sections related to ignition-resistant construction (IWUIC Section 504).[4]

Similarities Among the Codes

Each of the three wildfire-related documents (IWUIC, NFPA 1144, and California Chapter 7A) is similar in some respects. All acknowledge the importance of vegetation and vegetation management. In the IWUIC, construction requirements are tiered depending on the wildfire hazard zone. These zones typically are referred to as "fire hazard severity zones" – the levels escalate from "moderate" to "very high" or "extreme."

Construction requirements divide the home or building into component parts (such as roof, exterior wall, vents, and decking) and provide material or assembly (i.e., "system") options for the component (or assembly). An example of an assembly would be an exterior wall that includes the siding material, sheathing, framing, and other components used in the wall construction. In many cases, multiple options for complying with the provisions for a given component are provided. These options are separated by "or" statements in the code or standard. While these options are compliant, they do not necessarily provide equivalent protection. Table 3.1 summarizes the building requirements for the principal components specified in the IWUIC, NFPA 1144, and Chapter 7A.

Many of the material and assembly requirements in these codes and standards are based on "reaction to fire" and "resistance to fire" standard test methods. "Reaction to fire" standards provide procedures to evaluate whether a material can be considered noncombustible or ignition-resistant. "Resistance to fire" standards provide procedures to evaluate the ability of an assembly to resist fire spread from the fire-exposed side to the non-fire-exposed side.

The response of the building and construction materials to a direct ember exposure is largely either assumed or inferred from flame or radiant heat exposures. Until recently the ability to generate a realistic ember exposure in a laboratory environment has been lacking. Based on efforts by researchers at the National Institute of Standards and Technology (NIST), an apparatus that can generate an ember exposure was developed. This design has now been modified and adopted by others, including the Insurance Institute for Business & Home Safety.[5] Standard test methods may be developed in the future.

Specifics of Each Code

Each of the three wildfire-related documents (IWUIC, NFPA 1144, and California Chapter 7A) is described and compared below and in Table 3.1

International Code Council: International WUI Code (IWUIC)

Chapter 5 in the IWUIC provides specifications for three ignition-resistant (IR) construction classes, designated IR 1, IR 2, and IR 3. The ignition-resistant class level depends on the fire hazard severity zone, and whether the water supply and defensible space requirements are in compliance. IR 1 has the most restrictive requirements and IR 3 the least restrictive. The three-tier set of requirements is unique to the IWUIC. By comparison, NFPA 1144 and Chapter 7A in the California Building Code have only one level of building construction requirements, which are applicable regardless of the fire hazard severity zone ranking.

The IWUIC provides explicit language about the need to maintain buildings, vegetation, and defensible space. Maintenance is a critical component for homes and landscapes.

NFPA 1144: Standard for Reducing Structure Ignition Hazards from Wildland Fire

NFPA 1144 is designated as a standard, but if adopted by a jurisdiction, it can serve as a building code. This standard provides a methodology for assessing the potential for wildland fire ignition around existing buildings and provides minimum requirements for reducing the potential for ignition. A feature of this standard, as well as other wildfire-related building codes used in the United States, is linking building survival with vegetation selection and placement on the property, and construction materials and design.

This standard provides the user with information to do an assessment of the building components and vegetation on the property (Chapter 4). The assessment results in a list documenting materials and components used on or attached to the building, location on the property relative to topographical features and location on slope, and location of vegetation. The standard also provides specific minimum requirements for new construction (Chapter 5) and information for modifying vegetative fuels in the structure ignition zone.

California Building Code: Chapter 7A

Chapter 7A of the California Building Code was implemented in two phases. It is applicable in all fire hazard severity zones in State Responsibility Areas (SRA) and only in Very High Fire Hazard Severity Zones (VHFHSZ) in Local Responsibility Areas (LRA), as defined by CAL FIRE. In the SRA, fire protection is provided by the state. In LRA, fire protection is not provided by the state, but rather by the local jurisdiction.

Like the other codes and standards, Chapter 7A acknowledges the importance of well-maintained near-home (landscaping) vegetation to a fire-safe building by requiring compliance with Public Resource Code (PRC) 4291 and Government Code (GC) 51182. PRC 4291 applies to SRA land and GC 51182 applies to LRA land.

Building Components

The IWUIC, NFPA 1144, and Chapter 7A typically discriminate between the performance of materials and designs based on the response to direct flame contact or radiant heat exposure. However, as research results provide options, some sections are being added to address ember exposures. Since an ember exposure that results in damage or loss of a building is ultimately caused by a flaming and/or radiant exposure, selecting materials based on these exposures can be useful.

Roofs

Building codes rely on a standard test method to provide a fire rating for roof coverings. This standard test incorporates three separate components to evaluate the fire rating of the covering: (1) fire-resistance (fire-penetration), (2) flame spread, and (3) the ember generation potential of the roof covering and assembly (Figure 3.1). The "Class A" fire rating is the highest level of protection.

Figure 3.1. During a standard test to determine the fire rating of a roof covering. For this test, a Class A burning brand (wooden crib) was placed on top of the roof covering. Flames on the underside of the roof indicate that, as constructed, this roof covering is not Class A. Photo: Stephen L. Quarles

This test method does not address vulnerabilities that can occur at the edge of the roof, particularly where a gap occurs between the roof covering and the roof deck. Codes acknowledge this vulnerability and require that any gaps between the roof covering and the roof deck at the edge be plugged with a fire-stop or "bird-stop" material.

Roof vulnerabilities and mitigations are discussed in more detail in Chapter VI.

Wall and Eave Assemblies

For wall and eave assemblies, building codes provide the option of using noncombustible materials or combustible materials that meet fire-resistance and/or flame spread test procedures. These tests address only one of the vulnerabilities of a wall—the ability of fire to penetrate from the outside to the inside of the building. They do not directly address flame spreading up or laterally over the siding. Depending on the flame spread characteristics of the material, use of the fire-resistance rating to the exclusion of other requirements may just transfer the vulnerability of an exterior wall to another component (e.g., to a window, eave, vent) (Figure 3.2). Therefore, conservative use of combustible materials that meet fire-resistance test procedures is recommended.

Exterior wall vulnerabilities and mitigations are discussed in more detail in Chapter VII.

Figure 3.2. Vertical flame spread after exterior siding ignites can threaten other components on the wall, such as windows and the under-eave area. Photo: Stephen L. Quarles

Decks and Attachments

Treatment of decks and other attachments in the building codes is challenging and complex. Like walls and eave assemblies, building codes provide the option of using noncombustible materials or combustible materials that meet fire-resistance test procedures. There are few noncombustible decking products available. The three wildfire-related documents reviewed in this report treat combustible materials differently.

IWUIC and NFPA 1144 limit combustible decking materials to only those that are ignition-resistant, which excludes the use of the most commonly used decking products (such as solid wood without fire-retardant treatment and plastic composite decking). However, Chapter 7A restricts the use of combustible decking products based on the heat release rate, which is the amount of energy released after the deck is ignited by a specified gas burner. Solid wood and plastic composite decking products comply with Chapter 7A, but not with IWUIC and NFPA 1144.

Chapter 7A explicitly states that only the walking surfaces of the deck are considered in the standard—the structural support members are not. IWUIC and NFPA 1144 both allow the use of a one-hour fire-resistance-rated assembly as one option for complying with the deck requirements. The one-hour-rated assembly implies the use of either a horizontal or vertical deck enclosure, thereby implicitly addressing the support members. Although not explicitly stated, this effectively excludes the use of deck boards unless, for example, a deck platform is placed on top of a lightweight concrete surface. If traditional deck boards were allowed without other ventilation or moisture removal requirements, moisture-related degradation (decay in wood timbers and joists, corrosion of metal fasteners and connectors) would eventually develop in the under-deck area.

Deck vulnerabilities and mitigations are discussed in more detail in Chapter VIII.

Fencing is not addressed in any of the reference codes or standards. Guidance provided by education and outreach organizations state that a noncombustible section of fencing, typically 5 to 8 feet in length, should attach to an exterior wall to stop the spread of fire from the fence to the home.

Vents

Except for Chapter 7A, reducing ember intrusion through vents is accomplished exclusively by specifying maximum mesh size for the screen material and by restricting where vents can be located. The allowable screen mesh size in these documents ranges from about 1/16-inch to 1/4-inch. Chapter 7A specifies screen mesh information, but also allows vents with design features that resist entry of embers and flames. A standard test method to evaluate resistance to embers and flame intrusion has been developed and published by the American Society for Testing and Materials (ASTM) and accepted for use by the California Office of the State Fire Marshal.[6]

NFPA 1144 and IWUIC restrict the use of vents in the under-eave area. Chapter 7A allows the use of vents in under-eave areas if the specified provisions have been met. The restriction of vents in an under-eave area comes largely from anecdotal evidence that these areas would be vulnerable to ember entry. Recent testing at the IBHS Research Center and at NIST has demonstrated that ember entry was more dependent on the eave construction than on the general eave area. Vents in open-eave construction (i.e., vents in the between-joist blocking) were more vulnerable to ember entry than vents located in a soffited eave. Gable end vents were particularly vulnerable to ember entry. This suggests that a design approach to vent location and type in high-hazard areas would also be valuable in minimizing the vulnerability of buildings to wildfire.

Vents are addressed in more detail in Chapter VI in conjunction with roof vulnerabilities and mitigations.

Near-Home Zone

Although the near-home noncombustible zone (the area within a 5-foot perimeter around a house) has been incorporated into educational materials developed and distributed by education and outreach organizations, including IBHS, NFPA-Firewise, and Nevada's Living with Fire, this guidance is not explicitly specified in any of the codes or standards. The vulnerability of the near-home zone is important when considering ember accumulation exposures either on or adjacent to exterior-use materials and assemblies.

Near-home vulnerabilities and mitigations are discussed in more detail in Chapter IX.

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[2] National Fire Protection Association. 2018. NFPA 1144. Standard for Reducing Structure Ignition Hazards from Wildland Fire. 2018 Edition.
[3] 2016 California State Building Code, Part 2, Volume 1, Chapter 7A. https://codes.iccsafe.org/public/chapter/content/9997/
[4] 2018 Washington State Building Code. Revised Code of Washington, 2018, §19.27.560. http://app.leg.wa.gov/RCW/default.aspx?cite=19.27.560
[5] Insurance Institute for Business & Home Safety. 2011. Wildfire Demonstration. https://disastersafety.org/ibhs/research-center-demo-wildfire-2011/. Also see video highlights at: https://vimeo.com/79340385
[6] ASTM E2886. 2014. Standard Test Method for Evaluating the Ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement. West Conshohocken, PA.

Table 3.1: Comparison of WUI Codes and Standards			
Component	**IWUIC (2018) (Ignition-Resistant Class 1)**	**NFPA 1144 (2018)**	**California Building Code Chapter 7A (2013)**
Roof			
Roof	Class A fire-rated covering required. Plug gaps at the end (i.e., bird-stop) and underlayment full length of any valleys.	Class A fire-rated covering required. Roof covering must be tested using all components in the as-built assembly. Where gaps exist between covering and roof deck, a roll-roofing product shall be laid over the entire deck surface and gaps at end and ridge plugged with a noncombustible material.	Requires a fire-rated covering, actual rating (Class A, B or C) dependent on fire hazard severity zone. Plug gaps at ends (i.e., bird-stopped, fire-stopped). A minimum 36-inch-wide cap sheet must be installed under metal valley flashing.
Eaves & Fascia	Eaves and soffits protected by ignition-resistant material or one-hour fire-resistant-rated construction, or 1-inch fire-resistant treated lumber, or ¾-inch plywood. Fascias required, protected by ignition-resistant material or 1-hour fire-resistant-rated construction, or 2-inch dimensional lumber.	Eaves must be enclosed with fire retardant-treated wood, ignition-resistant materials, noncombustible materials, or materials exhibiting resistance to wildfire penetration. Metal drip-edge required on eave edges.	Soffited or open-eave allowed. If open-eave, nominal 2x material required as blocking.
Gutters	Noncombustible gutter (vinyl gutters not allowed). Use of gutter cover is required.	Use of noncombustible gutter and gutter cover device required.	Metal and vinyl gutters allowed. Installation of a gutter cover is required.
Vents	Vents covered by 1/4-inch mesh screen. Vents in exterior walls shall not exceed 144 square inches or shall be designated/approved to prevent flame or ember penetration into the structure. Vents not allowed in under-eave areas. Gable end and dormer vents shall be >10 feet from lot line. Underfloor vent openings located as close to grade as practical.	Vents covered by 1/8-inch mesh screen or use of vents designed to resist flame intrusion and embers. Vents not allowed in under-eave area.	General requirement for vents to resist intrusion of embers and flame through ventilation openings. 1/16- to 1/8-inch mesh screening is specified. Vents not allowed in under-eave area unless vent has been accepted as ember- and flame-resistant.

Component	IWUIC (2018) (Ignition-Resistant Class 1)	NFPA 1144 (2018)	California Building Code Chapter 7A (2013)
Exterior Walls			
Siding	Specifies compliance with one of five methods: 1) one-hour fire-resistant-rated construction, 2) approved noncombustible materials, 3) heavy timber or log wall construction, 4) fire-retardant-treated wood on exterior side (rated for exterior use), or 5) ignition-resistant materials on exterior side.	Specifies ignition-resistant material (including exterior fire-retardant-treated wood) or an assembly with at minimum a one-hour fire rating. Six-inch noncombustible vertical separation required between a horizontal surface and siding.	Four options for compliance: 1) noncombustible material, 2) ignition-resistant material, 3) heavy timber construction, 4) log wall assembly, or 5) assembly complying with State Fire Marshal 12-7A-1 (10-minute direct flame exposure test).
Windows	At a minimum, all windows (including doors and skylights) shall be dual pane (multilayered) with tempered glass, or glass blocks or fire-resistant rated of not less than 20 minutes.	Requires all windows (including in doors and skylights) to be tempered glass, multilayered glazed panels, glass block, or fire-resistance rating of not less than 20 minutes.	Four options for compliance: 1) multi-pane glazing with a minimum of one tempered pane, 2) glass block units, 3) fire-resistance rating of not less than 20 minutes, or 4) meeting performance requirements of SFM 12-7A-2.
Doors	Approved noncombustible construction, solid-core wood not less than 1¾-inches thick, or fire protection rating of not less than 20 minutes.	Solid-core wood not less than 1¾-inches thick, constructed of noncombustible material, or fire protection rating of not less than 20 minutes.	Four options for compliance: 1) Noncombustible exterior surface or cladding, 2) solid core wood meeting thickness specifications, 3) fire resistance rating of not less than 20 minutes, or 4) meeting the performance requirements of SFM Standard 12-7A-1.
Decks			
Decks	One-hour fire-resistant-rated construction, heavy timber construction, or constructed with noncombustible materials, or fire-retardant-treated wood or other ignition-resistant materials. A deck extending over a slope greater than 10% must be enclosed to within 6 inches of the ground using same exterior wall construction standards.	Requires heavy timber, noncombustible materials, fire-retardant-treated wood, or other ignition-resistant material, or be a one-hour fire-resistance-rated assembly.	Only applies to the walking surfaces of the deck. Four options for compliance: 1) ignition-resistant material that complies with SFM Standard 12-7A-4, 2) exterior fire-retardant wood, 3) noncombustible material, or 4) comply with SFM Standard 12-7A-4.
Near-Home Landscaping			
Near-Home Landscaping	Does not explicitly address near-home landscaping but addresses fuel modifications in 30+-foot defensible space area.	Does not explicitly address near-home landscaping but addresses location and maintenance of vegetation in two zones, including from the home to 30-feet, and from 30-feet to 100-feet, or to the property line.	Hazardous vegetation and fuel management required based on different fire hazard severity zones. Does not explicitly address near-home landscaping.

IV. METHODS

This study involves two cost analyses: (1) the cost of constructing a wildfire-resistant home compared to a typical home; and (2) the cost of retrofitting an existing home to be more wildfire-resistant. Similar methods were employed for both analyses. For the wildfire-resistant home, we selected materials that would comply with one or more of the codes or standards described in Chapter III.

Cost Data: *RSMeans*

For both analyses, we used *RSMeans,*[1] a national database of construction materials, labor, and contractor overhead and profit costs. *RSMeans* is updated quarterly, includes average construction cost indices from more than 700 cities, and uses the latest negotiated wages across 21 building trades. It includes national averages as well as cost indices to compare regional variability across the country.

While using a national database like *RSMeans* provided consistency for this study, it also has limitations. The values included in the database are averages and do not reflect local conditions such as product and contractor availability, managerial efficiency, competitive conditions, or local building or union requirements. In reality, many wildland-urban interface communities are growing rapidly and face highly competitive conditions and a short supply of contractors, which may raise overall prices for any style of home—wildfire-resistant or otherwise. Demand for contractors can also be especially high during reconstruction periods following wildfire disasters.

When *RSMeans* provided multiple options for building materials, we used mid-range products typical of construction in southwest Montana. Expert judgment and guidance was provided by Bechtle Architects[2] in Bozeman, Montana, who queried the *RSMeans* database for this study. In some instances, wildfire-resistant materials were not available in *RSMeans*. For these cases, we acquired pricing directly from the manufacturer or received bids from retailers or local distributors and added labor, overhead, and profit rates at national averages using the appropriate cost indices from *RSMeans*.

The monetized values include only the immediate costs of construction and do not account for long-term maintenance and replacement costs of the features. In many cases, wildfire-resistant materials have added benefits such as reduced maintenance, longer lifespan, and energy efficiency. We have noted where such co-benefits exist, even when they are not fully quantifiable.

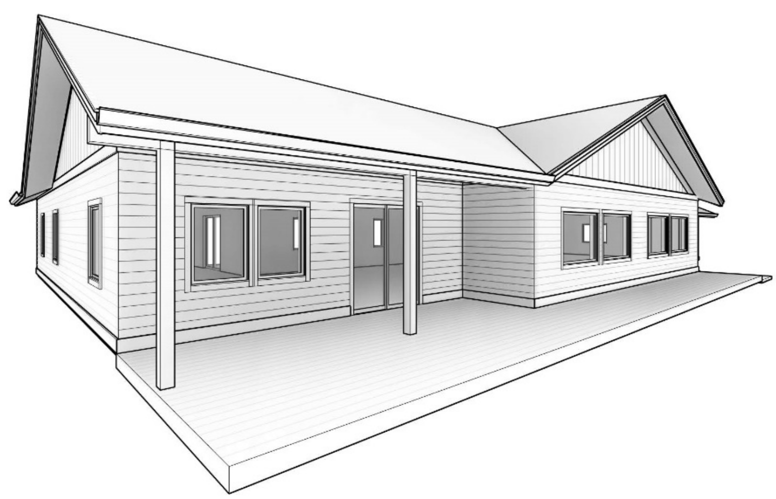

Figure 4.1. Architectural rendering of the home used in this study. The home is representative of typical construction in Park County, Montana and is approximately 2,500 square feet.

Model Home and Selection of Features

To compare costs, we required a baseline home representative of typical building styles found in the wildland-urban interface in southwest Montana, one of the fastest-growing WUI regions in the country. The home used in this study is a mid-range home constructed in 2017 in Park County, Montana. It is a three-bedroom, 2,500-square-foot, single-level, single-family home with two exterior decks and a two-car garage. It was constructed for approximately $140 per square foot, or a total of $350,000 (Figure 4.1).[3]

For the purposes of this analysis, we made many assumptions about the typical home features, some of which would reduce or increase the cost difference with the wildfire-resistant home. We made these assumptions based on expert input about regional preferences for southwest Montana. The primary assumptions include that the typical home has a Class A asphalt roof, cedar plank siding, and a wood deck. Using a home typical of southwest Montana will make the cost comparisons less applicable in other regions due to different aesthetic preferences, climatological differences, functional needs, and local building code requirements. For several features, we include alternative product options to show how different choices and regional preferences may affect cost.

We identified the individual features on the home that make it vulnerable to wildfire, based on the best available science about home ignitions. We included features from four components of the home: roof, exterior walls (including windows and doors), deck, and landscaping.

New Construction Comparison

To compare the cost of constructing a wildfire-resistant home with the typical home, we priced: (a) typical building materials (including labor and contractor overhead and profit) representative of typical WUI construction in southwest Montana, and (b) wildfire-resistant building materials (including labor and contractor overhead and profit) that comply with or exceed the International WUI Code (IWUIC) for the vulnerable features. We did not only price materials, but also included labor and contractor overhead and profit because installation of some wildfire-resistant features may require more labor. We did not compare features that are unlikely to pose wildfire vulnerability issues (for example, the foundation, exterior building sheathing and framing, and interior walls).

This report shows a percentage increase in changing from typical to wildfire-resistant components but does not reflect a percentage increase as related to the entire cost associated with constructing a home. Because we did not evaluate the cost of constructing the entire home using *RSMeans*, it is not possible to extrapolate precisely what percentage of the total home these costs represent. However, the costs associated with constructing wildfire-resistant components represent only a fraction of the total costs of constructing a home.

Retrofit Analysis

To examine the cost of retrofitting vulnerable features in the baseline home with wildfire-resistant materials, we priced: (a) labor costs for demolition of typical building materials (including contractor overhead and profit), and (b) wildfire-resistant building materials (including labor and contractor overhead and profit) that comply with or exceed the IWUIC. Where possible, we include the total cost of retrofitting the feature in the baseline home as well as a per-unit cost.

It is important to note that *RSMeans*' labor costs for demolition do not include disposal costs, onsite retaining of material (i.e., a dumpster), nor do they account for challenges finding contractors willing to take on small demolition projects. Finding a contractor willing to take on a relatively small job, like swapping out a gutter or roof vent, may be difficult in many markets.

However, some of the retrofitting techniques described here can be combined into a larger job that may be more attractive to contractors or completed independently by handy homeowners. Where possible, we have tried to indicate the difficulty of the retrofitting job for those inclined to D-I-Y. We have also tried to rank retrofitting tasks for each vulnerable feature to help identify where homeowners can achieve the most benefit for the least cost.

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[1] RSMeans Online. 2018. Version 8.7. Gordian. https://www.rsmeans.com/
[2] Bechtle Architects: http://bechtlearchitects.com/
[3] Andrew Ford, Ford Woodworks, LLC, Clyde Park, Montana. Personal communications.

V. RESULTS

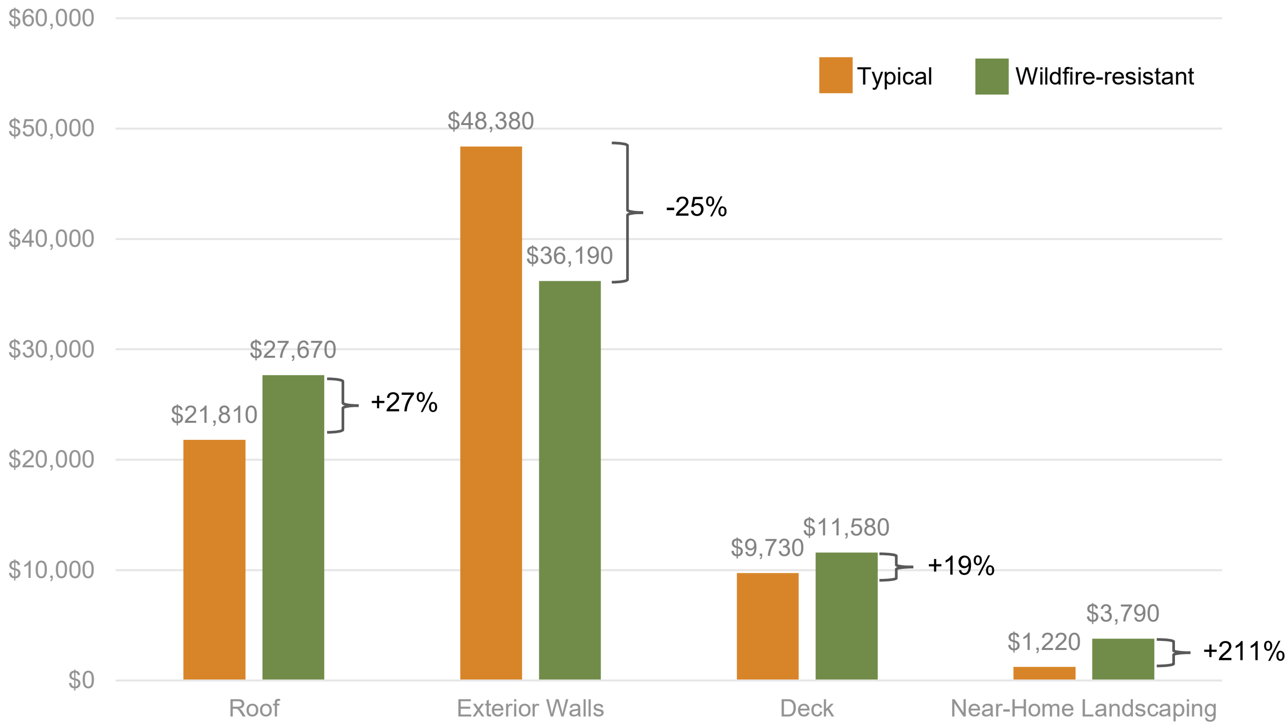
New Construction

This analysis finds that a new home constructed to comply with a wildfire-resistant building code, as defined by the International WUI Code (IWUIC), can be constructed for roughly the same cost as a typical home. In fact, our model wildfire-resistant components cost approximately $1,910, or 2% less than the typical home (Table 5.1). The roof, deck, and landscaping all added costs, while switching from wood to fiber cement siding for the exterior walls created a cost savings. Proportionally, the wildfire-resistant landscaping saw the greatest increase over the typical home, but in absolute dollars, the roof added the most cost (Figure 5.1).

Table 5.1: Cost and Proportional Difference of Components in New Construction for Typical and Wildfire-Resistant Scenarios

	Typical	Wildfire-Resistant	Difference	
Roof				
Roofing	14,870	16,380	1,510	10%
Vents	930	1,560	630	68%
Soffit & Fascia	5,080	6,970	1,890	37%
Gutters	930	2,760	1,830	197%
Subtotal	**$21,810**	**$27,670**	**$5,860**	**27%**
Exterior Walls				
Siding	29,930	12,360	(17,570)	-58%
Sheathing	3,810	4,180	370	10%
Doors	6,170	8,120	1,950	32%
Windows	8,470	11,530	3,060	36%
Subtotal	**$48,380**	**$36,190**	**-$12,190**	**-25%**
Deck				
Decking surface	8,230	9,430	1,200	15%
Framing	930	1,230	300	32%
Fascia	570	920	350	61%
Subtotal	**$9,730**	**$11,580**	**$1,850**	**19%**
Near-Home Landscaping				
Mulch (bark vs. rock)	1,220	3,250	2030	166%
Landscape Fabric	0	540	540	-
Subtotal	**$1,220**	**$3,790**	**$2,570**	**211%**
All Components				
Total	**$81,140**	**$79,230**	**-$1,910**	**-2%**

Figure 5.1. Cost difference and percent change between typical and wildfire-resistant new construction. Orange bars are typical; green bars are wildfire-resistant.



Retrofit

Retrofitting costs for each component are detailed in Table 5.2. The cost of retrofitting the roof and exterior walls for the model home are both substantial if undertaken in whole. Retrofitting the roof, assuming removal of wood shingles and replacement of vents and gutters, approaches the cost of new construction at $22,000. Retrofitting exterior walls, assuming removal and demolition of vinyl siding and wood-framed windows, came to $40,350, which is more than the cost of new construction due to the expense of demolition of siding and sheathing. We did not price the cost of retrofitting the deck or landscaping, as these would be similar to new construction, but variable depending on demolition of existing conditions. Although retrofitting the roof or exterior walls in their entirety has substantial costs, there is also significant benefit as these can be especially vulnerable areas of the home.

Further, roof and exterior wall retrofitting can be broken into phases and prioritized based on existing conditions and neighborhood and landscape context. For example, many homes already have asphalt shingles that provide wildfire-resistance, so they would only need new vents and gutters to improve their wildfire-resistance. Homes that are 30 feet or more from neighboring structures and that have well-maintained landscaping are unlikely to be exposed to extended radiant heat and may not need siding to be replaced everywhere on the home. Homeowners may be able to prioritize siding replacement only at locations where radiant heat exposures are more likely (such as where other buildings are nearby, where walls face slopes, or on sides of the home facing common wind aspects) or in areas where flame contact from ember-ignited debris or vegetation is possible (such as at roof-to-wall junctions or within approximately 6 inches of the ground).

Table 5.2: Cost of retrofitting roof and exterior wall from typical to wildfire-resistant. Costs shown are for model home and assume removal of wood shingles on the roof and wood siding on the walls, to be replaced with the same wildfire-resistant materials described in the new construction scenario.

Roof	
Roofing	13,180
Vents	370
Soffit & Fascia	5,600
Gutters	2,860
Subtotal	**$22,010**
Exterior Walls	
Sheathing and Siding	20,580
Doors	8,120
Windows	12,050
Subtotal	**$40,750**

In the following chapters, detailed analyses of vulnerabilities, mitigations, new construction cost differences, and retrofitting options are provided for each component of the home. Detailed data tables can also be downloaded at https://headwaterseconomics.org/wildfire/homes-risk/building-costs-codes-appendix. For the roof, exterior wall, and deck components, prices for alternative materials are included to show the range of potential costs. Prioritization of retrofitting activities and co-benefits are also described.

VI. ROOF VULNERABILITIES, MITIGATIONS, AND COST

This chapter analyzes the vulnerabilities, mitigations, code requirements, and detailed costs related to constructing a wildfire-resistant roof. For the purposes of this study, roof is defined as the peak of the roof ridgeline to and including the gutters and under-eave area. This includes the roofing materials and underlayment, ridge vents, soffit vents, soffit covering, and gutters.

Vulnerabilities

Roof coverings are vulnerable because of their relatively large surface area that can be exposed to wind-blown embers. Complex roof shapes that include dormers, split-level designs, and components with other roof-to-wall junctions increase the vulnerability of the roof because embers can accumulate in these joints. In these same junctions, vegetative debris can also accumulate, providing fuel that is easily ignited by embers (Figure 6.1).

Figure 6.1. Complex roof showing roof-to-siding junction where pine needle debris has accumulated on top of asphalt composition shingle roofing (a Class A fire-rated covering), adjacent to wood shingle siding. The vulnerable component of this roof is the siding, should the pine needle debris ignite. Photo: Stephen L. Quarles

The edge of the roof where a gutter can be attached and locations where the roof intersects with a vent can also be vulnerable locations, particularly when vegetative debris has accumulated in the gutter or at the inlet to the vent (Figure 6.2).

Figure 6.2. Debris accumulation at the entry of a (plastic) ridge vent. Ember ignition of this debris could result in ignition of the ridge vent. Photo: Stephen L. Quarles

Roof vents are important for circulation of air to remove excess moisture in the attic but are also susceptible to ember and flame entry. The under-eave area is also vulnerable as construction detailing allows embers to be trapped in gaps. An open eave also traps heat, if near home vegetation (or other combustibles) ignite. If under-eave vents are present, they can be an entry point for embers to pass into the attic.

There are two types of ventilation openings to provide circulation in attic spaces: one for inlet air and one for exiting air. Inlet air comes from vents located in the under-eave area, at the edge of the roof. Under-eave vents are located either:

- in the blocking, in the case of open-eave construction (Figure 6.3), or
- in the soffit material, in the case of soffited-eave construction (Figure 6.4).

Exiting air leaves through vents located on or near the roof. Exiting air vents are either:

- placed at the ridge of roof (called "ridge vents"),
- placed in an off-ridge location on the roof, or
- located on the exterior walls, at the end of the home (called "gable end vents").

Ridge and off-ridge vents are considered "through-roof" vents. Embers and flames can enter the attic space of a home through any of these vent openings.

Mitigation

Use of a Class A fire-rated roof covering is the most common mitigation strategy. Depending on the roof covering, an underlayment with an enhanced fire resistance rating may be needed to attain the desired fire rating. In addition, removal of debris from the roof and gutter on a regular basis can reduce the likelihood of ignition of this material from embers when wildfire threatens the house.

Use of flashing where the roof meets other features will help reduce the vulnerability of materials at these locations to flame and radiant heat exposures. Examples include use of 1) metal drip edge at the roof edge (i.e., where gutter meets roof) (Figure 6.5), and 2) metal flashing at the base of the wall

Figure 6.3. Vent located in the blocking space in open-eave construction. Photo: Stephen L. Quarles

Figure 6.4. Under-eave strip vent located in a soffit. Photo: Stephen L. Quarles

Figure 6.5 Metal drip edge installed at the edge of the roof. In this case, the drip edge was part of the gutter. Photo: Stephen L. Quarles

where roof meets siding. Use of a noncombustible material can be necessary to plug gaps that can occur with certain roof coverings that create a gap between the covering and roof deck (e.g., barrel tile). This is sometimes referred to as "bird stopping" (Figure 6.6). Gutter cover devices are sometimes recommended or required to minimize the accumulation of debris in gutters.

Figure 6.6. Use of a mortar mix to provide an effective "bird stop" at the edge of this barrel style roof (this photograph was taken during a retrofit project while the work was in progress). Photo: Stephen L. Quarles

Treatment in Codes

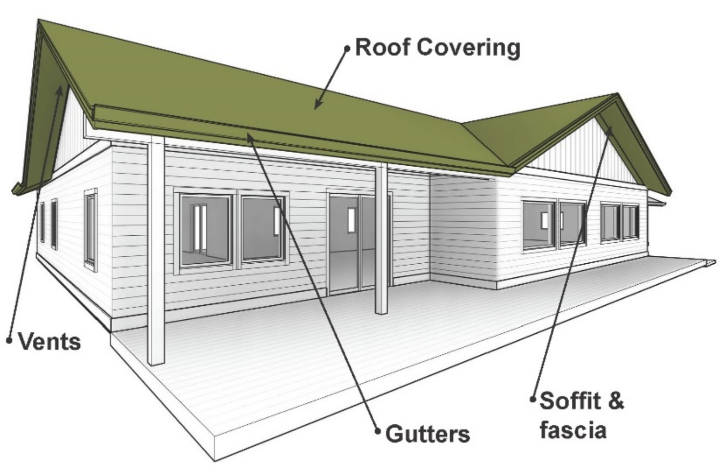
Building codes require a specified fire rating for the roof coverings. The specific fire rating depends on the designated fire hazard rating in the area. Because of the widespread availability of Class A roof coverings, these are most commonly used. Building codes also address ember exposures at some roof-to-wall or other roof intersection areas. The most common requirement is for providing bird stops at the roof edge and use of a gutter cover device.

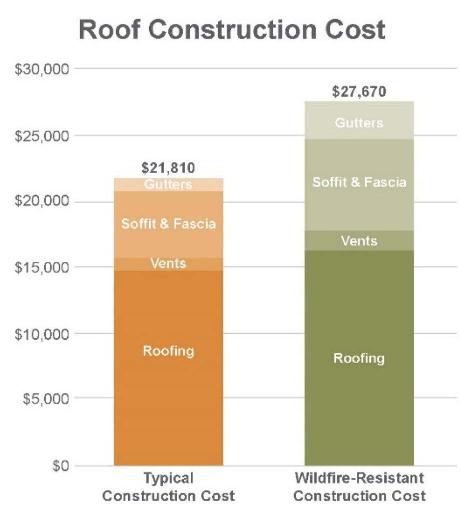
New Construction Comparison

Four key roof features were modified for wildfire-resistance:

- Roofing and underlayment
- Ridge and soffit vents
- Fascia and soffit covering
- Gutters

Figure 6.7. Roof subcomponents and new construction cost.





A wildfire-resistant roof can be constructed for an approximate 27% increase in cost (Figure 6.7). One of the most expensive features of the roof—the roofing material—was assumed on both the typical and wildfire-resistant home to be Class A asphalt shingles, a fire-resistant material and the most popular roofing material in North America. Wildfire-resistant additions to the roofing underlayment, vents, soffits, and gutters resulted in an increase of $5,860 or a 27% increase. Several of the materials selected here exceed the requirements of IWUIC, including wildfire-resistant sheathing, membrane, and vents that have been approved in California as being "ember and flame resistant." More expensive roofing materials that would comply with IWUIC such as metal or clay tiles, or more expensive gutter options, can increase the cost difference to $33,340, or an increase of 153% (Table 6.1).

The typical sheathing of oriented strand board (OSB) was replaced with CDX plywood underlayment to reduce the potential for fire penetrating into the attic space. In the wildfire-resistant home, mineralized roll roofing was added in the roofing valleys to improve the fire resistance in this area because of the tendency of debris to accumulate in the roof valley area. When a roof covering allows for a gap between the covering and roof deck (e.g., a tile roof), one option to protect the roof deck is to install an asphalt fiberglass composition product.

Ridge and soffit vents in the typical home were replaced with vents designed specifically for fire-resistance that have finer-grained mesh and ember- and flame-resistant features. We examined a variety of manufacturers and found pricing to be in similar ranges. As an alternative to vents, we also priced an unvented attic option, which involves applying spray foam insulation to the underside of the roof deck, making the attic space part of the insulated building enclosure. Although removing vents eliminates the opportunity for ember entry, an unvented attic design can result in moisture-related performance issues.[1] It is important to manage moisture movement from the occupied portion of the home into the attic space. Additional measures—not priced in this study—will be necessary, such as applying a vapor retarder to the ceiling in the occupied portion of the home and sealing all gaps at through-ceiling penetrations.

On the wildfire-resistant home, the soffit was enclosed with fiber cement siding instead of plywood, resulting in a modest price increase. Cedar fascia was replaced with fire-retardant-treated redwood.

Vinyl gutters in the typical home were replaced with aluminum gutters. A metal drip edge was added to provide additional protection against flame and embers at the edge of the roof. A gutter cover device was added to reduce the accumulation of debris in the gutter.

Homes in cold climates will have added expenses for managing snow and ice when gutter cover devices are used. Gutter covers can increase the potential for ice damming and cause the gutter to detach from the building. Although it does not provide any direct benefit from a wildfire vulnerability perspective and may not be necessary in all climates, heat tape is necessary in cold climates and was priced here. Heated gutters were priced as an alternative.

As a complete alternative to gutters, a perimeter drain system was also evaluated. A perimeter drain eliminates the need for gutters and downspouts by using French drains around the perimeter of the house. This requires burying piping around the foundation of the home. Perimeter drain systems are not possible or advisable in all locations, depending on site conditions such as groundwater depth and foundation depth and material, for example. However, they can reduce vulnerability of the gutter by eliminating the ember-ignition likelihood from the accumulation of debris in the gutter.

Retrofit Analysis

Since the roof is one of the most vulnerable areas of the home to wildfire, retrofitting the roof to be more wildfire-resistant can be one of the most cost-effective and important actions a homeowner can take. Depending on which component is replaced and the size of the home, the cost can be as inexpensive as a few hundred dollars, to several thousand (Table 6.2). In the model home, complete retrofit of the entire roof to be wildfire-resistant totaled $22,010. Individual replacement of features ranged from $370 for replacing ridge vents to more than $20,000 for an unvented attic option.

Co-Benefits and Efficiencies

Energy Efficiency

The roof is a key component of a home's natural ability to ventilate and moderate temperatures. A well-insulated and ventilated roof can improve the heating and/or cooling of the home. All of the features included here would contribute to improved venting (except an unvented attic) and efficiency.

Lifespan and Maintenance

Asphalt composition shingle roofs are very low-maintenance and can last several decades.

Gutter cover devices will reduce the amount of gutter cleaning required and can help reduce risk of falls during cleaning because fewer trips up the ladder will be required. When gutter cover devices are used in snowy climates, heat tape or heated gutters may be necessary to reduce the potential for ice damming. Use of heated gutter options require maintenance to ensure proper seasonal operation.

No matter what wildfire-resistant materials are used, none eliminate the need for ongoing maintenance. Homeowners should plan on regularly inspecting and maintaining the roof and gutters to remove accumulated debris.

[1] Quarles, L. and A. TenWolde. 2005. Attic and Crawlspace Ventilation: Implications for Homes Located in the Urban-Wildland Interface. In Conference Proceedings: Woodframe Housing Durability and Disaster Issues, October 2004. Forest Products Society, Madison, WI.

Table 6.1: Roof New Construction						
Feature		**Typical**	**Wildfire-Resistant**	**Cost Diff.**	**Percent Diff.**	**Notes**
Roofing	Roof covering	Asphalt shingles, class A architectural	Asphalt shingles, class A architectural	0	0%	
			Alternative: Steel roofing	8,060	86%	A
			Alternative: Clay tile	23,280	250%	A
	Valley flashing	Metal	Metal	0	0%	B
	Sheathing	Oriented strand board (OSB)	CDX Plywood	1,160	25%	
	Roll roofing	(none)	Mineral surface roll roofing in roof valleys	300		
	Membrane	(none)	APP bituminous membrane	40		
	Roofing subtotal			**$1,500 – 24,780**	**10% - 167%**	
Vents	Ridge vents	Flexible roll	Fire- and ember-resistant	-130	-28%	B
	Soffit vents	Aluminum strips	Fire- and ember- resistant with 1/8" mesh screen	760	161%	B
	Vents subtotal			**$630**	**68%**	
Soffit & Fascia	Fascia	Cedar band board	Fire retardant treated redwood	1,280	60%	B
	Soffit covering	Plywood	Fiber cement	620	21%	
	Soffit & fascia subtotal			**$1,900**	**37%**	
Gutters	Gutters	Vinyl	Aluminum	290	31%	
	Drip edge	(none)	Aluminum	750		
	Gutter cover device	(none)	Aluminum mesh	640		
	Heat tape	(none)	Flexible heat tape	150		B, C
	Heated gutter with cover	(none)	Alternative: heated gutter with guard	6,030	649%	A, B
	Perimeter Drain	(none)	Alternative: perimeter drain system	3,760	405%	A, D
	Gutters subtotal			**$1,830 - 6,030**	**197% - 649%**	
TOTAL				**$5,860 - 33,340**	**27% - 153%**	

Download detailed data tables at: https://headwaterseconomics.org/wildfire/homes-risk/building-costs-codes-appendix.

Notes

A. Denotes an alternative to another material; a home would not utilize all materials listed. Totals columns account for range depending on which alternative is selected.

B. Materials priced from manufacturer, online retailer, or local distributor. Labor priced from RS Means.

C. Perimeter drain systems are not possible or advisable in all locations, depending on site conditions such as groundwater depth, frequency of wind-driven rain events, foundation depth and material, and site drainage.

Table 6.2: Retrofitting roof features to be wildfire-resistant				
Feature	**Description**	**Cost for model home**	**DIY**	**Priority Rank**
Roof covering	Removal of existing wood shake roof covering and replacement with Class A roof covering. (Asphalt architectural shingles were priced for this study).	$13,180	Not recommended	Highest
Vulnerable Roof Vents	Removal of existing vulnerable attic vents and replacement with wildfire-resistant ridge vent, including replacement of surrounding shingles. (Other types of wildfire-resistant attic vents are available but were not priced for this study.)	$370	Not recommended	High
Gutters	Removal of vinyl gutters and replacement with new metal gutter and gutter cover device.	$2,110	Moderate skill required	High
Metal Drip Edge	Addition of a metal drip edge where gutter attaches at roof edge.	$750	Moderate skill required	High
Soffit	Enclosing the roof overhang with wildfire-resistant fiber cement soffit material including needed ventilation.	$5,600	Not recommended	High
Unvented Attic	As an alternative to ridge or other attic vents. An unvented attic requires removal of insulation in attic and replacement with spray polyurethane foam, as an alternative to replacing vents. Cost varies depending on climate zone and necessary thickness of foam. Cost does not include sealing the ceiling in occupied space below attic. Can be difficult in a retrofit scenario.	$20,650 - $32,910	Not recommended	-

VII. EXTERIOR WALLS VULNERABILITIES, MITIGATIONS, AND COST

This chapter analyzes the vulnerabilities, mitigations, code requirements, and costs related to constructing wildfire-resistant exterior walls, including sheathing and siding, doors, and windows.

Vulnerabilities

Exterior walls and components in the wall assembly can be vulnerable if exposed to flames or prolonged exposure to radiant heat from ignited items located relatively close to a home. Combustible items include bark mulch, vegetation, or nearby structures like neighboring homes, tool sheds, and fences. Fire can ignite combustible siding and penetrate gaps or joints in the siding and/or spread vertically and laterally to impinge on other wall components such as windows and the under-eave area. Walls that extend close to the ground (or, as already discussed, close to the roof) can be vulnerable to ignition if embers accumulate at the base of the wall and ignite it or components in the wall assembly (e.g., wood-based sheathing).

Doors and windows can also be vulnerable when exposed to flames or embers. Glass in a window can break from radiant heat or flame contact exposure. When a window is broken, the combustible materials inside the home (e.g., furniture, carpeting, drapes) can be ignited. Wood and vinyl framed windows can be vulnerable, burning or melting when exposed to radiant heat or flames if siding is ignited. However, studies have shown that glass is the most vulnerable component of a window.[1] Doors (including window glass set in doors) and door frames can fail for the same reasons. Small gaps between the door and frame can also create opportunities for wind-blown embers to lodge and ignite the door framing material and potentially the weather sealing material.

Mitigation

To minimize the chance of an ignition from an ember exposure, a vertical noncombustible zone of at least 6 inches should be created between the ground and the start of the siding. Some mitigation strategies for exterior wall features are dependent on home-to-home spacing. If the exterior wall is within 30 feet of neighboring homes, a noncombustible or ignition-resistant material should be used for the siding. In some cases, additional sheathing can provide added protection by enhancing the fire resistance of the wall.

Figure 7.1. This window frame was exposed to radiant heat. The metal-reinforced member (in the back) did not deform when exposed during the exposure interval. The member without the metal reinforcement deflected downward, allowing insulated glass unit to fall out (without initial glass breakage), exposing the interior of the home. Photo: IBHS.

Research has consistently shown that glass is the most vulnerable component of window failure during a fire. Multi-pane tempered glass windows should be used to reduce the likelihood of a window breaking when exposed to radiant heat. Vinyl frames are more susceptible to damage from radiant heat than other frame types. The horizontal interlock member in a vinyl-framed single- or double-hung window can be vulnerable to radiant heat or direct flame contact if a metal reinforcement member isn't included (Figure 7.1). Aluminum or other metal window screens can help protect against ember entry if the glass breaks or if a window is inadvertently left open. When home-to-home spacing is less than 30 feet, metal shutters can provide added protection from embers, airborne debris, and radiant heat exposures.

Weather stripping around pedestrian and vehicle access doors can reduce the ability of embers to pass through openings between door and jamb but can also be vulnerable if embers accumulate against it and cause it to ignite or melt. The location of weather stripping on outswing doors is more vulnerable than inswing doors. Weather stripping containing fire retardants can reduce the vulnerability of this component.

Regardless of home spacing, mitigation strategies for exterior walls include creation and maintenance of an effective defensible space to reduce the chance of extended radiant heat or flame contact exposure to the siding, including a 0-5-foot noncombustible zone. This strategy is further discussed in a subsequent section.

Treatment in Codes

Code requirements for siding include specifying a noncombustible or ignition-resistant material. A specific kind of gypsum board can be used as an additional sheathing material that will improve the fire resistance of the exterior wall. This type of construction improves the ability of the wall assembly to resist the passage of fire from one side of the wall to the other. Care should be exercised when taking this approach as this is typically taken when a more vulnerable combustible material is used as the siding material. When using this option, siding materials with demonstrated lower flame spread should be used. This option will be problematic since a more vulnerable combustible material will most likely exhibit a higher flame spread.

Code requirements for the exterior wall also include multi-pane tempered glass windows and fire-resistant doors. Codes are typically silent on window frame material, meaning any framing material can be used.

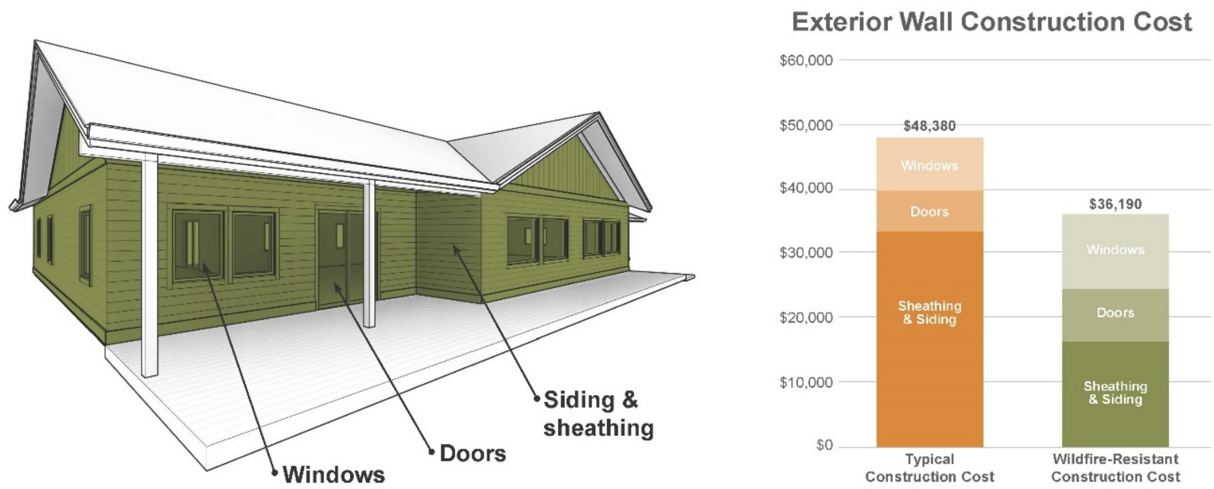
New Construction Comparison

Wildfire-resistant exterior wall features are approximately 75% of the cost of typical features, creating a $12,190 savings for this model home (Figure 7.2). These savings result primarily from using a fiber cement lap siding in the wildfire-resistant home, which is nearly one-third the cost of the typical cedar lap siding product. Some homeowners may have a preference to the aesthetics of wood siding over fiber cement siding. However, many fiber cement options on the market today mimic the look and texture of natural wood, as did the fiber cement product priced for this study. Alternative siding costs were also examined, including stucco (a 28% savings over cedar lap siding) and fire-retardant-treated cedar lap siding (a 20% additional cost to cedar lap siding). The wildfire-resistant home also uses wildfire-resistant sheathing (CDX plywood instead of typical Oriented Strand Board), which exceeds the requirements in the International WUI Code (IWUIC).

Fire-resistant doors cost 28-37% more, or an increase of $1,640 to $2,220, in the model home. The bulk of this cost comes from replacing vinyl-framed deck sliding doors with steel-framed doors. A cost savings was realized from replacing the vinyl garage door with steel. IWUIC is silent on garage doors, so this modification exceeds IWUIC. A range of different front and side door options were also priced, including steel fire doors and fiberglass doors.

Windows cost approximately 36% more, increasing the model home by $3,060. Most of this increase is from using tempered glass in the windows, which increased their cost by an estimated 25%. This cost may be less for standard-sized windows or more for odd-sized windows, and may be less in markets where tempering is in higher demand or required by code. Tempered glass is specified as a requirement in IWUIC.

Figure 7.2. Exterior walls subcomponents and new construction cost.



Retrofit Analysis

To address the vulnerability of existing exterior walls to wildfire, several important components can be updated in pieces or in whole. Retrofitting the exterior walls of the model home (including doors and windows) to be wildfire-resistant cost $40,750—more than the cost of new wildfire-resistant construction. Removing all siding and assembly, including vapor barrier and sheathing, and replacing with wildfire-resistant materials varies in cost depending on the type of siding to be removed.

In some situations, not all siding would need to be retrofitted to be wildfire-resistant. The prioritization of retrofitting many exterior wall features is dependent on home-to-home separation and home siting. If home spacing is more than 30 feet and good defensible space is established—including incorporation of the noncombustible near-home landscaping zone—the siding material and underlayment is less of a priority. However, if neighboring homes are closer together, if a home is near a slope, or if a side of the home faces the primary wind direction, noncombustible siding and multi-pane tempered glass windows become more important. Although not included in this cost analysis, metal shutters can provide improved protection from flames and extended radiant heat exposures, especially when neighboring homes are closely spaced, and are a viable alternative to replacing windows.

Co-Benefits and Efficiencies

Energy Efficiency

Heat gain and loss from windows account for 25-30% of residential heating and cooling energy use. Replacing old windows in an existing home with better insulated, multi-pane windows can significantly decrease energy usage. Tempered glass is also safer because it is approximately four times more resistant to heat (compared to annealed glass) and does not form sharp shards when it breaks, but rather breaks into smaller chunks.

Lifespan and Maintenance

In addition to costing considerably less than cedar siding, fiber cement siding can have a longer lifespan and requires less maintenance.

[1] Bowditch, P.A., A.J. Sargeant, J. E. Leonard, and L. Macindoe. 2006. Window and glazing exposure to laboratory-simulated brushfires. Brushfire CRC. East Melbourne, Australia. http://www.bushfirecrc.com/publications/citation/bf-1263

Table 7.1: Exterior Walls New Construction						
Feature		**Typical**	**Wildfire-Resistant**	**Cost Diff.**	**Percent Diff.**	**Notes**
Walls	Sheathing	Oriented strand board	CDX Plywood	370	10%	
	Siding	Cedar clapboard siding	Fiber cement lap siding (woodgrain texture for aesthetics)	-17,570	-59%	
			Alternative: Stucco	-8,520	-28%	A
			Alternative: Fire retardant treated cedar horizontal lap siding	5,940	20%	A, B
	Walls Subtotal			**-$17,200 - 6,310**	**-51% - 19%**	
Doors	Front door	Birch solid core	Birch solid core	0	0	
			Steel fire door	330	144%	A, C
			Fiberglass	370	162%	A
	Side door (garage)	Steel insulated	Steel insulated	0	0%	
			Steel fire door	-210	-27%	A
			Fiberglass	-170	-22%	A
	Sliding door (deck)	Vinyl	Aluminum	1,870	94%	B
	Garage Door	Fiberglass	Steel	-490	-17%	
	Weather stripping	Vinyl threshold weather stripping and door sweeps	Silicone, fire-rated weather stripping and aluminum door sweep	100	86%	B
	Garage door bottom	Rubber	Aluminum and neoprene	460	293%	B
	Doors Subtotal			**$1,730 - 2,310**	**28% - 37%**	
Windows	Windows	Vinyl frames; dual-pane insulated glass; no screens	Metal-clad wood frames; dual-pane tempered glass; aluminum screens	3,060	36%	B, D
	Windows Subtotal			**3,060**	**36%**	
TOTAL				**-$12,410 - 11,680**	**-26% - 24%**	

Download detailed data tables at: https://headwaterseconomics.org/wildfire/homes-risk/building-costs-codes-appendix.

Notes
A. Denotes an alternative to another material; a home would not utilize all materials listed. Totals columns account for range depending on which alternative is selected.
B. Materials priced from manufacturer, online retailer, or local distributor. Labor priced from RS Means.
C. Steel fire doors have weather stripping integrated, so cost of weather stripping would be eliminated.
D. Based on pricing from manufacturer, we added 25% to all window cost for tempered glass. We also added 2% for aluminum screens.

Table 7.2: Retrofitting exterior wall features to be wildfire-resistant				
Feature	**Description**	**Cost for model home**	**DIY**	**Priority Rank**
Siding	Removing existing siding and replacing with fiber-cement. Siding demolition cost varies depending on type to be removed. Siding replacement can also be prioritized in only the most vulnerable locations (e.g., only at roof-to-wall junctions)	$15,240	Not recommended	High if home-to-home spacing is less than 30 feet
Sheathing and Vapor Barrier	Removing existing vapor barrier and sheathing and replacing with wildfire-resistant materials, as an add-on when replacing siding.	$5,340	Not recommended	High if home-to-home spacing is less than 30 feet
Doors	Replacing all doors and weather-stripping with wildfire-resistant materials.	$8,120	Moderate skill required	Moderate priority
Windows	Removing existing windows and replacing with windows with tempered glass. Price varies significantly depending on type of frame to be removed and window sizes. Window demolition cost varies depending on frame type. Cost of new tempered glass window is approximately +25% cost of standard glass.	$12,050	Not recommended	Higher if home-to-home spacing is less than 30 feet or if defensible space is not established

VIII. DECK VULNERABILITIES, MITIGATIONS, AND COST

This chapter analyzes the vulnerabilities, mitigations, code requirements, and costs related to constructing a wildfire-resistant deck, including the decking (i.e., walking surface), the framing, and the fascia.

Vulnerabilities

Attached decks are a vulnerable component to a home because a burning deck could result in an extended radiant heat exposure to the side of the house. A burning deck could also result in a flame contact exposure to the home. Even if the home has noncombustible siding, the glass in access doors could be vulnerable to breakage, resulting in fire being able to enter the home.

Although metal deck boards are available, most deck board products are combustible (including wood and plastic composite boards). Decks with a noncombustible walking surface, such as light-weight concrete or a flagstone product, are available, but these decks are typically more expensive. Regardless of the walking surface, decks are typically supported by solid wood joists, beams, and columns that have been treated with a preservative to reduce the effects of moisture. Because dual treatments for fire and water are not available, preservative-treated wood members are more commonly used because of the more likely water-related degradation of decks and decking (e.g., from rain or snow).

Decks are vulnerable to wildfire if they are susceptible to ignition from wind-blown embers (firebrands) or from flames impinging from the underside of the deck. A flame contact exposure from the underside of the deck could result from ember-ignited debris or combustible materials stored under the deck or from burning vegetation located downslope from the deck.

Mitigation

When considering ways to make any component better able to resist wildfire exposures, the combination of managing vegetation and the use of wildfire-resistant materials and design features should always be considered. In the case of decks, vegetation management should include location of other combustible materials on the property. To minimize the potential for a flame contact exposure to the underside of the deck, the near-home noncombustible zone should extend under the entire footprint of any attached deck. When a home is located on a slope and an attached deck extends out over that slope, vegetation should be selected, located, and maintained in such a way as to reduce the opportunity for fire to impinge on the underside of the deck.

Regardless of the actions taken to minimize the opportunity for flames to contact the deck, when threatened by a wildfire, it will have to resist ignition from wind-blown embers. Higher-density deck board products, including plastic composites and the tropical hardwood products such as Ipe, are much more resistant to ignition from embers than the lower-density softwood deck board products (such as redwood and cedar) that are more commonly used. Fire-retardant treated (FRT) wood products are also more resistant to ignition from embers.

Deck enclosure is sometimes recommended to reduce the vulnerability of decks to wildfire. Whereas deck enclosure could protect the underside of a deck from a flaming exposure, caution should be used with certain enclosure techniques that can result in water-related degradation of the deck (e.g., fungal decay and insect damage). Such enclosure techniques restrict the ability of wet deck boards and framing members to dry out. They can also result in corroded fasteners.

When using combustible decking products, use of a foil-faced bitumen product, applied to the top surface of the support joists, has been shown to reduce the vulnerability of combustible decking products, particularly the non-fire-retardant treated medium-density solid wood products such as redwood and cedar (Figure 8.1). The foil-faced tape will result in deck boards self-extinguishing before the fire propagates far from the support joists if the deck boards are ignited by embers. The tape should extend about halfway down the side of the joist.

Figure 8.1. Placing foil-faced tape on the top and sides of a deck joist has been shown to reduce vulnerability of deck boards, especially combustible products like cedar or redwood. Photo: IBHS.

Other mitigation strategies for decks include increasing the gap between deck boards (e.g., from 1/8-inch to 1/4-inch) and increasing between-joist spacing from 16-inch on-center to 24-inch on-center. Structural and safety requirements should be confirmed before changing deck board or joist spacing.

Treatment in Codes

The three wildfire reference documents—the IWIUC, NFPA 1144, and California's Chapter 7A—all have provisions that address the deck. All three focus on the walking surface of the deck, but there are differences in what is permitted by each document.

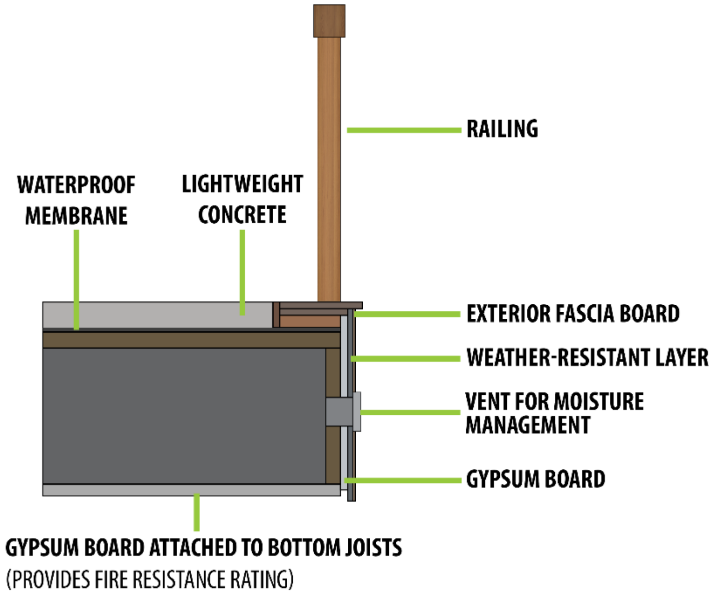


Figure 8.2. One-hour fire rated assembly for a deck.

IWUIC and NFPA 1144 don't allow for the use of non-fire-retardant treated wood. The only nominally combustible decking products that are allowed are those that qualify as "ignition resistant material." Currently none of the commercially available plastic composite products comply with this requirement, so technically no non-fire-retardant-treated wood or plastic composite deck board products could be used. Both documents have a provision that allows for a fire-rated assembly to be used (this is referred to as a "one-hour fire rated assembly") (Figure 8.2). When using deck boards this type of construction would likely make the deck more vulnerable to moisture-related degradation. This leaves few deck options that comply with IWUIC and NFPA 1144.

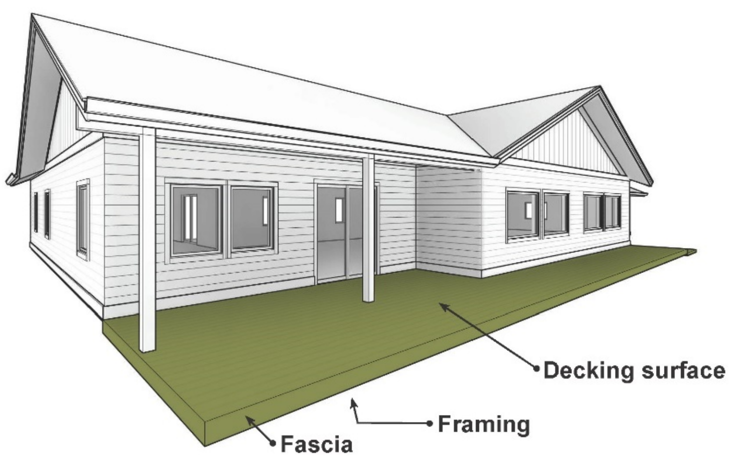
California's Chapter 7A allows for the use of decking products that can pass a performance-based under-deck flame impingement test. Unlike the ICC IWUI Code and NFPA 1144, non-fire-retardant-treated wood and several plastic composite deck board products can comply with the standard test method and are therefore permitted under California's Chapter 7A.

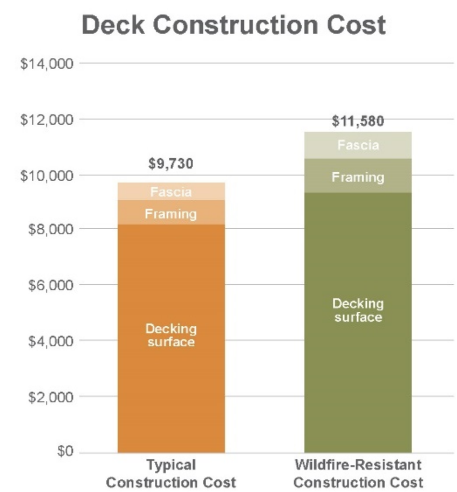
This approach has been controversial. Recent research has demonstrated that some non-fire retardant treated solid wood decking products are more easily ignited by wind-blown embers.[1] Use of foil-faced tape can reduce the vulnerability of these products. Some plastic composite products can be more vulnerable to a flame impingement exposure. To minimize the vulnerability of all combustible decking products, the noncombustible zone must include the entire footprint of the deck.

New Construction Comparison

The cost of a wildfire-resistant deck was 19 to 43% more than the typical deck, increasing the cost by $1,860 to $6,060 for the model home (Figure 8.3). This deck would not be compliant with IWUIC or NFPA 1144, but would be compliant with California Chapter 7A.

Figure 8.3. Deck subcomponents and new construction cost.

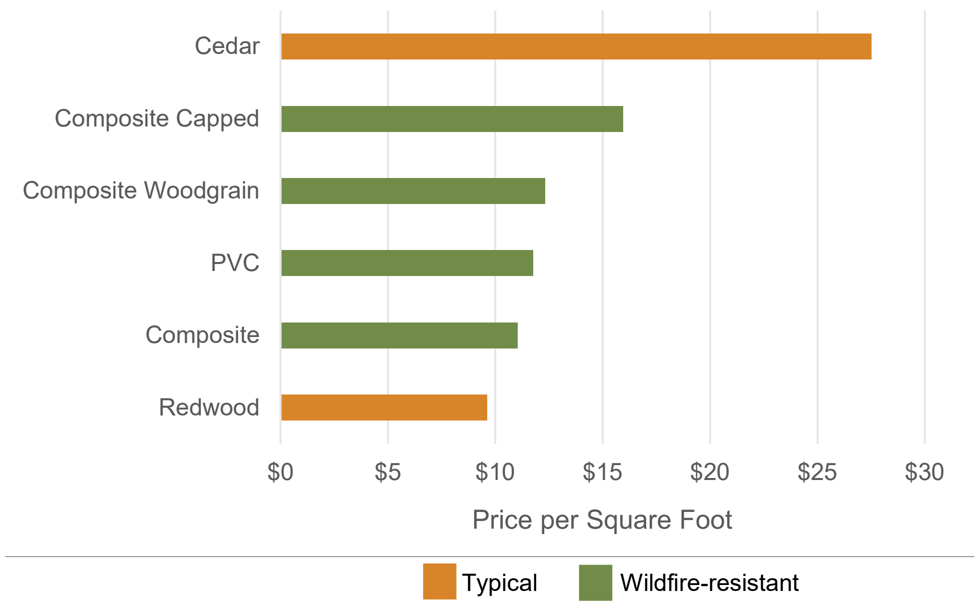




The majority of this price increase resulted from the deck boards. We compared costs of several options for both the typical and wildfire-resistant models and found that prices varied significantly for typical materials, ranging from approximately $10 per square foot for redwood to $28 per square foot for cedar, whereas wildfire-resistant materials all fell into the range of $11 to $16 per square foot (Figure 8.4).

Moderate price increases were realized from modifications to the deck framing and fascia. Rough-sawn cedar columns visible on the deck were given fire-retardant treatment and foil-faced tape was added to the tops and sides of joists to reduce the likelihood of fire propagating from the anticipated ember exposure. The fascia board was also changed from rough-sawn cedar to fire-retardant-treated redwood.

Figure 8.4. Cost of decking boards per square foot. Orange bars are baseline, non-wildfire-resistant; green bars are more wildfire-resistant. (Wildfire-resistance, in this case, is primarily related to resistance to ember ignition.)



Even the wildfire-resistant (ember-ignition resistant) materials priced here—polyethylene (PE) and PVC composite deck boards—are combustible and would currently only comply with California Chapter 7A—not with IWUIC or NFPA 1144. Prices for materials compliant with IWUIC and NFPA 1144 were difficult to find in the Montana market. Fire-retardant treated (FRT) wood is the most common option that would comply. Some estimates suggest a 20-25% cost increase for treatment, which would put the cost at a similar range to some composite options. However, availability and shipping of FRT deck boards may be challenging in remote, rural markets.

Testing shows that many products are not highly combustible in isolation. Deck fires become large when other fuel sources contribute, such as pine needles that accumulate on deck surfaces and in gaps between deck boards, combustible material stored under or on top of the deck, and decks overhanging slopes with combustible vegetation. Avoiding storage of combustibles under the deck and ongoing maintenance of defensible space are key to deck ignition-resistance.

Solid-surface decks provide an alternative to standard decking boards. These options can provide a noncombustible walking surface. Structural integrity and engineering requirements for sub-framing of a heavier, solid-surface deck are highly dependent on site conditions and local building codes, so they were not priced for this study.

Co-Benefits and Efficiencies

Lifespan and Maintenance

Plastic composite deck boards are reported to require less maintenance than wood deck boards, which can require regular cleaning and refinishing. Some of the composite decking products are resistant to fading and stains, and because of the plastic content are typically more resistant to rot, mold, and insect-related degradation. Some brands come with 25-plus year warranties and are made from recycled plastic and wood.

Regardless of decking materials used, ongoing maintenance of the deck is required. Regularly removing vegetation underneath the deck, as well as from between deck board gaps, is critical. In advance of an approaching wildfire, it is also important to remove furniture and other combustible materials from the surface of the deck.

Table 8.1: Decking New Construction

Feature	Baseline	Wildfire-Resistant	Cost Diff.	Percent Diff.	Notes
Decking Surface	Redwood decking	Composite (non-capped, non-woodgrain)	1,200	15%	
		Alternative: PVC	1,820	22%	A
		Alternative: Composite Woodgrain	2,310	28%	A
		Alternative: Composite Capped	5,410	66%	A
	Decking Surface Subtotal		**$1,200 - 5,410**	**15% - 66%**	
Framing	Preservative - treated lumber	Preservative-treated lumber	0	0%	
	Cedar rough sawn columns (visible on porch)	Exterior fire-retardant treated cedar rough sawn columns	50	19%	B
	(none)	Foil-faced tape for joist top and sides	250		B
	Framing Subtotal		**$300**	**32%**	
Fascia	Cedar rough sawn band board	Fire-retardant treated redwood band boards	350	59%	B
	Fascia Subtotal		**$350**	**59%**	
Total			**$1,850 - 6,060**	**19% - 62%**	

Download detailed data tables at: https://headwaterseconomics.org/wildfire/homes-risk/building-costs-codes-appendix.

Notes
A. Denotes an alternative to another material; a home would not utilize all materials listed. Totals columns account for range depending on which alternative is selected.
B. Materials priced from manufacturer, online retailer, or local distributor. Labor priced from RS Means.

[1] Quarles, S. L. and C. D. Standohar-Alfano. 2017. Ignition potential of decks subject to an ember exposure. Insurance Institute for Business & Home Safety. http://disastersafety.org/wp-content/uploads/2017/10/Deck-Ember-Testing-Report-2017_IBHS.pdf

IX. NEAR-HOME LANDSCAPING VULNERABILITIES, MITIGATIONS, AND COST

This chapter analyzes the vulnerabilities, mitigations, code requirements, and costs related to developing wildfire-resistant near-home landscaping. For the purposes of this study, the near-home landscaping component includes the mulch and landscape fabric in a 5-foot zone immediately around the home, as well as under all attached decks.

Vulnerabilities

Landscaping makes the home vulnerable when, if ignited, it allows fire to burn to the home. Ignition of near-home mulch from ember exposure will allow flames to touch the home, regardless of how well defensible space has been planned and maintained.

Mitigation

Mitigation strategies include selection, placement, and maintenance of vegetation that reduces the chance fire can burn directly to the home. Professionals usually discuss this process by dividing the property into two to three zones where vegetation and other combustible materials are managed in such a way as to reduce the chance that fires can burn to the home. The incorporation of a near-home zone (typically specified as 5 feet wide, extending out from the building), where all combustible materials are removed (e.g., bark mulch, combustible vegetation, and stored materials like firewood) can minimize the opportunity of ignition.

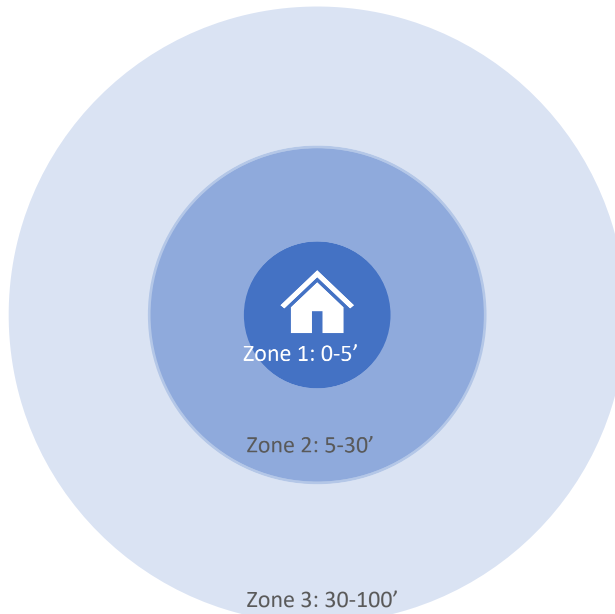


Figure 9.1. Landscaping zones for wildfire-prone areas. All codes lump Zones 1 and 2 into a single description, neglecting to emphasize the importance of the 0-5’ near-home landscaping area.

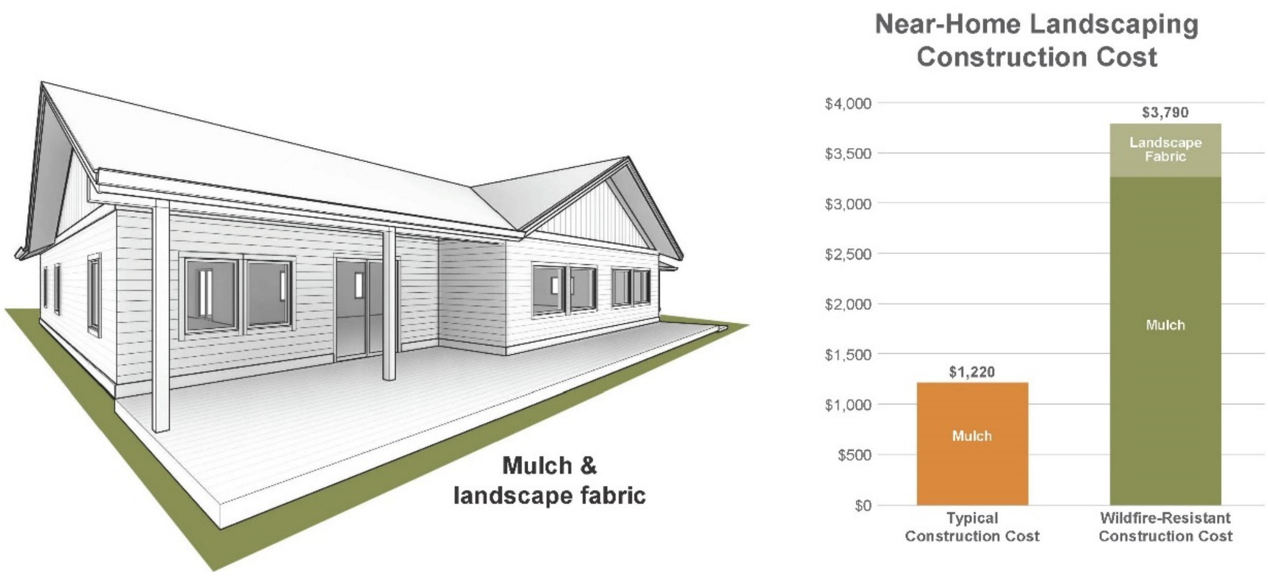
Treatment in Codes

Codes specify development and maintenance of two zones, the first zone being from the edge of the home to 30 feet from the home and the second in the 30- to 100-foot area. It is common for “or to the property line” to be included in the text. None of the major codes require the 0- to 5-foot noncombustible zone (Figure 9.1).

New Construction Comparison

To make the model home wildfire-resistant, bark mulch was replaced with pea gravel. Weed and erosion control fabric was added in a 5-foot zone around the home and in the spaces under the deck. This resulted in a 210% cost increase over the typical materials, or an increase of $2,570 (Figure 9.2).

Figure 9.2. Near-home landscaping subcomponents and new construction cost.



Co-Benefits and Efficiencies

Lifespan and Maintenance

Compared to organic mulch, pea gravel has a much longer lifespan and requires little to no maintenance, whereas organic mulch will need to be replenished annually as it decomposes. However, organic mulch can be more efficient at maintaining soil temperatures and absorbing water. In drier climates or for xeriscaping, pea gravel can promote healthy soil drainage and prevent unwanted vegetation.

Table 9.1: Landscaping New Construction

Feature	Typical	Wildfire-Resistant	Cost Diff.	Percent Diff.	Notes
Mulch	Bark mulch	Pea gravel	2,030	166%	
Landscape fabric	(none)	Polypropylene mesh erosion control fabric	540	-	A
TOTAL			**$2,570**	**210%**	

Download detailed data tables at: https://headwaterseconomics.org/wildfire/homes-risk/building-costs-codes-appendix.

Notes
A. Includes fabric under the deck.

X. CONCLUSION

Wildfire-Resistant Building Codes and Standards Add Minimal Cost to Homeowners and Builders

Converging trends of hotter, longer, more severe fire seasons and growth in the wildland-urban interface put more people and communities at risk to wildfire disasters. Laboratory research and evidence from post-fire assessments have demonstrated that local ignitability of the home itself and the nearby landscaping are major factors determining home survivability in a wildfire. Three existing building codes and standards provide ample guidance for how to construct wildfire-resistant homes. Such regulations can reduce wildfire loss, and more communities are considering their implementation.

City, county, and state governments must weigh many issues when considering new regulations, but the cost of constructing to comply with wildfire-resistant building codes need not be a barrier. The results of this study demonstrate that the cost of constructing new homes to be wildfire-resistant is not substantively different than the cost of typical construction. Retrofitting existing homes can have substantial costs, but components can be prioritized based on neighborhood and landscape context. Other factors, such as material availability and builder knowledge of wildfire-resistant construction techniques may vary from region to region. For example, IWUIC-compliant decking options were difficult to locate in Montana. However, communities can customize portions of the model codes and standards to address such regional variability. As wildfire-resistant construction becomes more common and in higher demand in wildfire-prone landscapes, these limitations are likely to decrease.

Beyond protecting individual homes, wildfire-related building codes and standards are likely to have many long-term benefits to communities. Reducing wildfire losses can lessen the long-term and profound consequences and disruption borne at the local level following disasters, such as lost business and property tax revenue, physical and mental health impacts, and damage to public infrastructure. Constructing homes to modern wildfire-resistant standards delivers additional benefits to homeowners and the environment, as many components are more sustainable, require reduced maintenance, and provide added energy efficiency.

Key Mitigations Can Be Implemented by Any Builder or Homeowner

Regardless of whether it is required by code within a jurisdiction, individual builders and homeowners can act to mitigate wildfire vulnerabilities with little added cost. Home survival in wildfire-prone areas depends on effective implementation of a coupled approach where 1) vegetation (and other combustible materials) on the property is wisely selected, located, and maintained; and 2) materials and design features of the home are selected that will reduce vulnerability to anticipated wildfire exposures. Homes threatened by wildfires will always be subjected to wind-blown embers. Therefore, all homes in wildfire-prone areas should include design details that minimize vulnerability to embers. The likelihood of a long-term radiant heat or flame contact exposure will be less likely on properties that have developed and continue to maintain an effective defensible space in terms of selection, location, and maintenance of vegetation and other combustible materials on the property.

Roof

The roof—with a large surface area and potential for accumulation of combustible vegetative debris—is one of the most vulnerable parts of a home. Key mitigations for the roof include:

1. Install a Class A fire-rated covering or assembly.
2. Where applicable, install bird stops at roof edge, including any ridges. An additional layer of protection can be attained if a layer of roll roofing is installed over the surface of the roof deck.
3. For complex roof designs where there are junctions between a roof and a wall (e.g., dormers), consider noncombustible siding.
4. The under-eave area should be constructed using a soffited eave design.
5. Both inlet (under-eave) and outlet (roof or gable) vents can be vulnerable to ember entry.
    - Vents should be covered with 1/8- to 1/16-inch noncombustible and corrosion-resistant screening. Vents covered with 1/16-inch screening should be cleaned regularly so that they can perform their moisture management function.
    - Ridge or off-ridge vents are less vulnerable than gable end vents.
    - Use of vents approved by the California Office of the State Fire Marshal Building Materials Listing Program, which have demonstrated a resistance to ember and flame exposures.[1]

Exterior Walls

Exterior walls and windows are especially vulnerable when exposed to flames or radiant heat for extended periods, such as from vegetation or neighboring homes that have ignited. Doors and windows can also be vulnerable to wind-blown embers and flames. If there is a home or neighboring building within 30 feet, the potential for radiant heat from that structure—should it ignite—may be enough to ignite siding or break glass in windows, so additional mitigations may be necessary. Key mitigations for exterior walls include:

1. Make sure there is, at a minimum, a 6-inch noncombustible zone at the base of the wall (i.e., between the ground and start of siding).
2. Install multi-pane windows having tempered glass.
3. When vinyl windows are used, make sure single- and double-hung windows include metal reinforcement in interlock members.
4. If there is a home or neighboring building within 30 feet, use ignition-resistant or noncombustible siding and metal shutters.

Decks

Attached decks can ignite from embers landing on top of the deck and from ignited vegetation or materials underneath the deck. An ignited deck provides radiant heat exposure to the home's siding, doors, and windows. Current wildfire codes and standards are inconsistent in their recommendations for decks, but key mitigations for decks include:

1. For deck boards, use noncombustible materials, fire-retardant treated wood, or decking products that meet the requirements of an ignition-resistant material. Non-fire-retardant treated redwood and cedar are vulnerable to ignition from ember exposures. Higher density decking products (e.g., plastic composite or imported tropical hardwood decking products) are less vulnerable to ignition from ember exposures. If used, plastic composite decking products should comply with the requirements of the California Office of the State Fire Marshal Building Materials Listing Program.[1]

2. To reduce the likelihood of sustained flaming of ignited decking, install deck boards using a 1/4-inch gap between deck boards and install a foil-faced bitumen tape product on the structural support joists.
3. If an attached deck overhangs a steep slope, particularly with shrub or woodland vegetation that is not on the property or that cannot be maintained, use of a solid surface deck with an enclosed underside is a better option.
4. Incorporation of a noncombustible zone under the footprint of all attached decks is critical.

Near-Home Landscaping and the Home Ignition Zone

Managing vegetation and other combustible items on the property is important for reducing the energy and potential spread of fire. Regardless of vegetation maintenance and defensible space on the larger property, combustible vegetation and mulch in the near-home, 5-foot area immediately around the home can ignite and allow flames to touch the home. Key mitigations for landscaping include:

1. Follow readily available guidance on creating an effective defensible space on your property in a radius of at least 100 feet from the home (or to the property line).
2. Create a near-home noncombustible zone within 5 feet of the home and under the entire foot print of any attached deck.
3. A noncombustible fence section should be used for 5 to 8 feet where the fence connects to the home.

[1] California Office of the State Fire Marshal Building Materials Listing Program. Available at: http://osfm.fire.ca.gov/strucfireengineer/strucfireengineer_bml

HEADWATERS
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Vulnerability of Vents to Wind-Blown Embers

AUGUST 2017

Stephen L. Quarles, Ph.D.

Introduction

Wind-blown embers are the principal cause of building ignitions. Although the importance of embers (also called brands or firebrands) has been understood for a number of years, the ability to evaluate them in a laboratory setting has been a relatively recent development.

Reports from the November 1961 Bel Air fire in Southern California, where 484 homes were destroyed, was an early example in North America that provided clear evidence of the importance of ember ignitions. Greenwood (1999) reported that "There was no contiguous fire boundary. Instead, there were scores of large fires scattered over a wide area, each sending thousands of brands into the air to swarm out to ravage new sections." These isolated spot fires were caused by wind-blown embers. Steinberg (2013) also discussed the importance of embers and the specific implication to building ignitions, again as pertaining to the 1961 Bel Air fire by referring to "destroyed buildings surrounded by unconsumed vegetation." An investigation after a January 1944 wildfire in Victoria, Australia, also clearly showed the importance of embers to building ignition and destruction. Barrow (1945) reported that "Although the damage was caused primarily by the external fire, practically all the houses ignited inside, i.e., in the roof space, in rooms, or under the floors, due to the ingress of flame, sparks, *and embers* through openings such as ventilators, eaves, and windows" (emphasis added).

Embers can ignite combustible construction materials directly and, as indicated in the Bel Air fire report already discussed, can also cause spot fires that can in turn result in a flame and/or radiant heat exposures to a building. Examples of direct ember ignitions include those resulting from a deposition of embers directly on or immediately adjacent to a combustible material. This scenario is most commonly thought of for exterior use materials such as wood shakes or shingles on a roof or combustible siding materials. Without adequate suppression capabilities, this scenario would result in fire spreading from the outside of the building inwards. A direct ember ignition scenario can also occur if a sufficient number of embers pass through a penetration in the exterior envelope, potentially resulting in a building burning from the inside out. Common examples of vulnerable penetrations include open windows and vents.

Ember entry through vents that resulted in interior (attic) fires have been discussed in post-fire reports. Maranghides et al. (2015) reported that an attic fire was successfully extinguished during the 2012 Waldo Canyon fire, indicating that ember entry into the attic was a likely scenario. Maranghides and McNamara (2011) reported evidence of attic fire with a possible source from an attic vent during the February 2011 fires in Amarillo, Texas. In a Texas Forest Service case study of the 2005 Cross Plains fire, Gray et al. (2007) reported a suspected home ignition from firebrands that entered through screened attic vents. This house was reported to have burned from the inside out. These observations support the importance of embers as a cause of building ignitions in general, and provide evidence of the vulnerability of vents to ember intrusion, with subsequent ignition of interior combustibles as one cause of building ignition.

Building codes and standards that apply to new construction and existing buildings have specific requirements for attic and sub-floor (crawl space) vents. Current editions of the International Code Council's International Wildland Urban Interface Code (ICC IWUIC, 2012) and the National Fire Protection Association (NFPA) Standard 1144 (2013) specify a minimum ¼-in. (6 mm) noncombustible mesh screen covering for vents. Chapter 7A in the California Building Code addresses new construction in designated wildfire-prone areas in the state. Chapter 7A specifies noncombustible mesh screen covers between $^{1}/_{16}$ in. (1.5 mm) and ⅛ in. (3 mm). Chapter 7A also provides a performance-based path for compliance by allowing vents that "resist the intrusion of flames and burning embers" to be used. This standard also limits the use of vents in the under-eave area. This section of the code was based on best judgement at the time the code was developed, judgement that indicated an increased vulnerability in the under-eave area.

Chapter 7A was fully implemented in 2008. In support of that standard, the California Office of the State Fire Marshal (OSFM) had developed State Fire Marshal (SFM) standard test methods to evaluate the performance of certain components, including decking and siding. However, a standard test method was not provided to evaluate the ability of a vent to "resist the intrusion of flames and burning embers" (California Building Code, 2010). A standard test method was developed through the American Society for Testing and Materials (ASTM), but not until 2014 (ASTM 2886). In the time between 2008 and the present, vents that were accepted for use by the State Fire Marshal's office did so by conducting tests at one of the commercial fire test laboratories approved by the California OSFM. The commercial fire laboratory followed the procedures of the current version of the ASTM draft standard test method.

During the 2011 wildfire experiments conducted at the IBHS Research Center, it was observed that embers readily entered through the gable end vent used in the attic of the test building. It was also observed that the number of embers passing though attic vents located in the under-eave area depended on the type of eave construction, with entry through vents in the blocking of open-eave construction exceeding entry through vents installed in a soffited-eave. At the same time that our experiments were being conducted, Manzello et al. (2011) reported on a laboratory experiment that evaluated the vulnerability of a gable end vent to ember entry. The gable end vent was reported to be vulnerable to ember entry. Results of modeling indicated that vents located in an enclosed (soffited) eave would be less vulnerable. The open-eave construction option was not modeled.

The experiments reported here expand on observations made during the 2010–2011 Wildfire Ignition Resistant Home Design (WIRHD) project where it was observed that certain vent designs were more vulnerable to ember entry. External funding for the 2013–2014 experiments was secured from a CSAA Community Safety Foundation Grant.

The objective of this study was to clarify the relative importance of vents, including style, type and location to the entry of wind-blown embers. At the time this project was conducted, three vents had been accepted for use by the California OFSM. These vents were incorporated into the experimental design.

Experimental Design

Attic vent area calculations used to determine the number and size of vents used in the test building were based on a 1:300 ratio, providing 1 ft^2 (0.1 m^2) of net free vent area for each 300 ft^2 (28 m^2) of building floor area (Beall, 1998). The test building used for these experiments had a floor area of 1,200 ft^2 (111 m^2), resulting in the need for 4 ft^2 (0.4 m^2) of total vent area. Since inlet and outlet vent areas are typically split 50:50, approximately 2 ft^2 (0.2 m^2) of net free vent area was allocated for inlet vents (always the under-eave vents) and 2 ft^2 (0.2 m^2) was allocated for outlet vents (vents that penetrated through the roof or those located in the gable end of the building). Only one type of outlet vent was installed for a given test. The experimental design enabled evaluation of the effectiveness of vent-related mitigation strategies for new and existing buildings. Four-mesh (i.e., ¼-in. [6 mm]) noncombustible screening located in a gable end vent was used as the control condition.

Two types of under-eave (inlet air) vents were used. These included (1) open-eave vents that are incorporated into the solid-wood blocking inserted between roof rafters (or trusses), and (2) vents that are incorporated into the soffit material in "boxed-in" construction, as shown in Figures 1 and 2, respectively. A standard overhang width of 18 in. (460 mm) was used on all sides of the test building. An interior attic partition was constructed to separate the two inlet vent sections of the test building (i.e., the open-eave and soffited-eave sections) used for these experiments (Figure 3).

Figure 1. *Vents located in between-rafter blocking in the under-eave area of a building that used open-eave construction.*

Figure 2. *A strip vent located in the soffit of a building that used soffited-eave construction.*

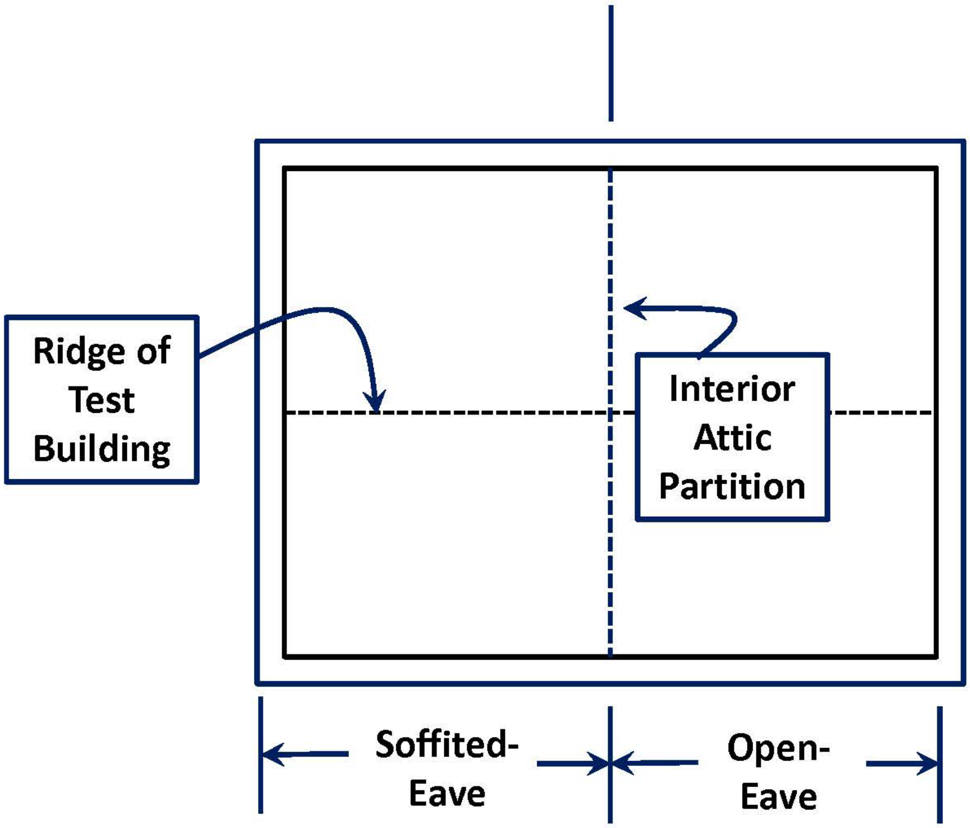

Figure 3. *A plan view diagram of the test building showing the location of the two types of inlet (under-eave) vents used in this series of experiments.*

The three types of outlet vents were evaluated during these experiments. Only one outlet vent type was evaluated at a time. Outlet vent type and products included:

1. **Gable end vent.** During these experiments, the gable end vent was covered with one of four different mesh screens—¼-in. (6 mm), ⅛-in. (3 mm) or $^{1}/_{16}$-in. (1.5 mm) square mesh, or ⅛-in. (3 mm) diamond mesh—or a vent that had been accepted for use by the California OSFM at the time these experiments were conducted. These vents had been accepted[1] for use because the vent manufacturers had provided sufficient testing information, conducted by an OSFM-approved commercial fire testing laboratory, to demonstrate resistance to

[1]The term "accepted" is used because at the time these experiments were conducted, there was no approved standard test method for evaluating the ability of a vent to resist the intrusion of embers and flames and therefore no way to "approve" a vent for use. The California OSFM was accepting these vents for use on construction projects they managed. Authorities having jurisdiction (AHJs) in other jurisdictions could do the same based on the procedure developed and used by the OSFM. Now there is an accepted method to evaluate the performance of vents—ASTM E2886, Standard Test Method for Evaluating the Ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement.

the entry of wind-blown embers and flames. The accepted vents used in this study included (1) a vent that incorporated a baffle construction and a ⅛-in. diamond mesh screen in the design, and (2) a vent that incorporated an intumescent-coated honeycomb mesh material and $^{1}/_{16}$-in. mesh screening.

2. **Off-ridge vent.** During these experiments, one of three different off-ridge vents were installed—a turbine vent, a flat-faced vent covered with ¼-in. diamond mesh screening, or an off-ridge California OSFM-accepted ember- and flame-resistant vent that incorporated a steel wool fill in the vent design.

3. **Ridge vent.** During these experiments, a Miami-Dade wind-driven-rain-rated vent (complying with Testing Application Standard [TAS] 100A), or this vent modified by removing the external baffle, was installed (Figure 4).

A diagram showing the locations of the outlet vents is given in Figure 5. As indicated, only one outlet vent was used during any individual test.

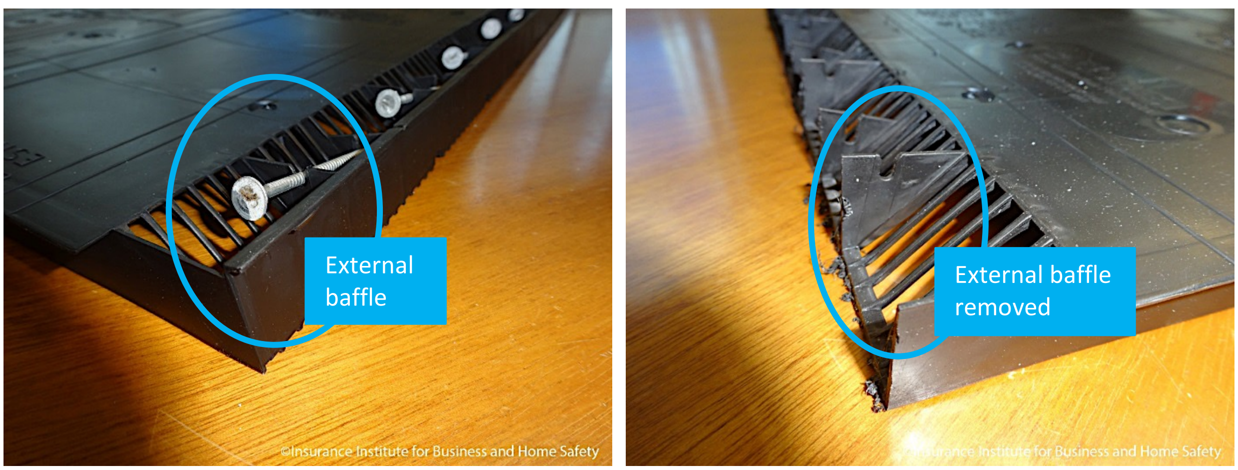

Figure 4. *A Miami-Dade wind-driven-rain-compliant ridge vent (left) and the same vent modified by removing the external baffle (right).*

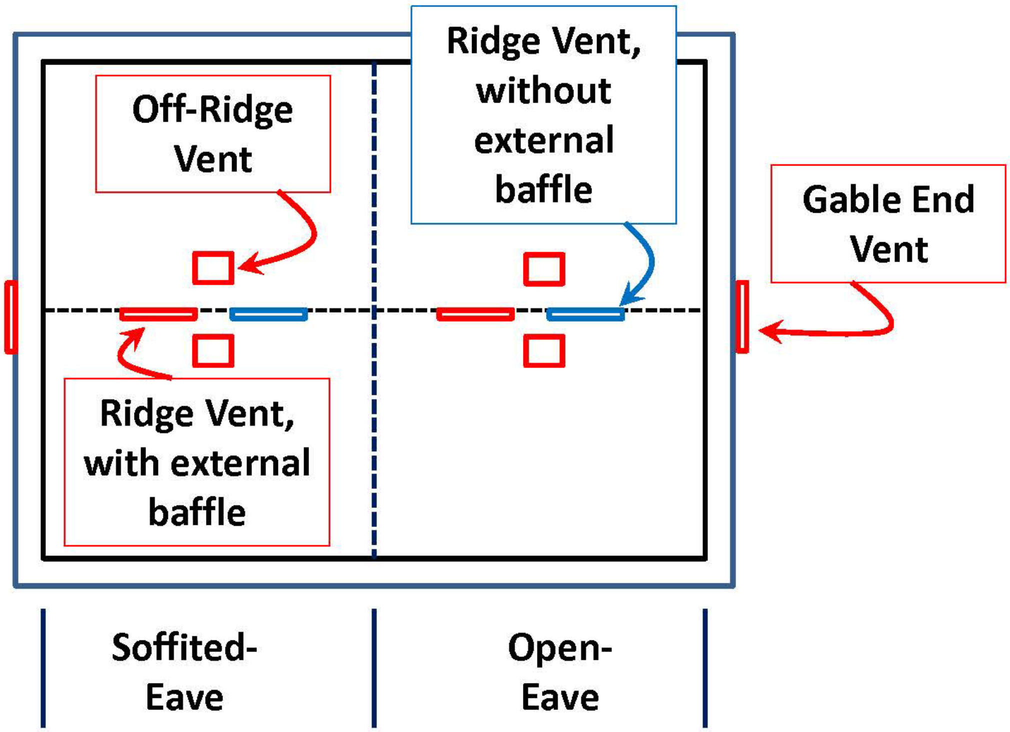

Figure 5. *Locations of gable end, ridge, and off-ridge vents. Only one of these vent types was installed during a given experimental series.*

Three fluctuating wind speed records (Figure 6) were used to evaluate the influence of wind speed on ember entry through vents for selected wind directions. Wind speed records were nominally labeled low, medium and high. The low-level wind speeds ranged from 16 to 20 miles per hour (mph) [7–9 m/s]. Medium speeds ranged from 25 to 31 mph (11–14 m/s) and high speeds ranged from 45 to 60 mph (20–27 m/s). The low and high wind speed records were scaled based on the medium record. The low record was 0.85 of the medium wind record and high was 1.75 of the medium wind record. Building orientations used to assess the effect of wind direction on ember entry are shown in Figure 7.

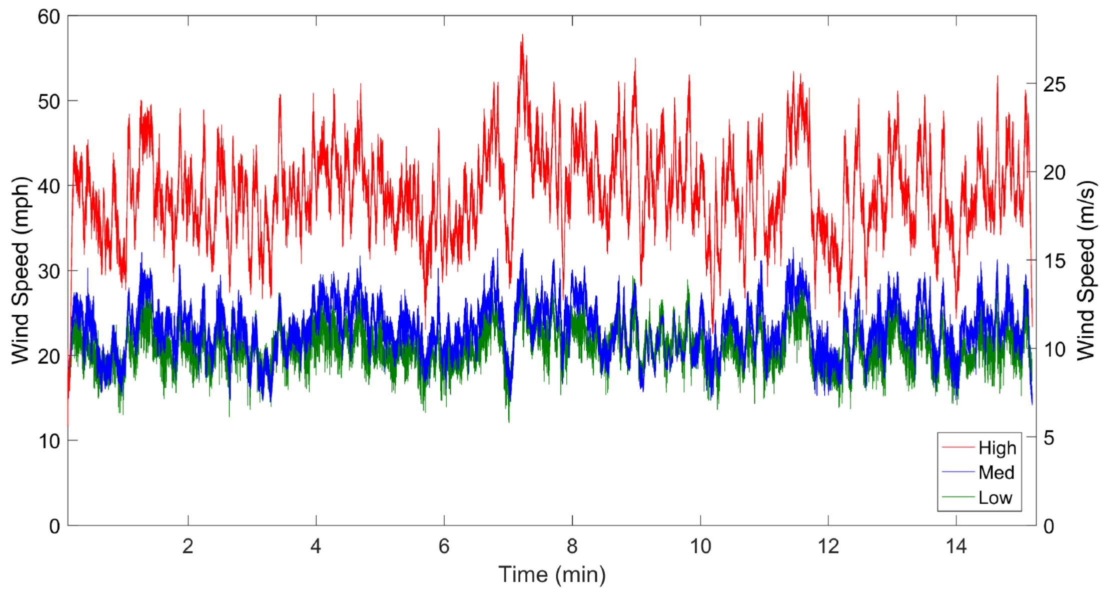

Figure 6. *The first nine minutes of the three fluctuating wind speed records used in these experiments.*

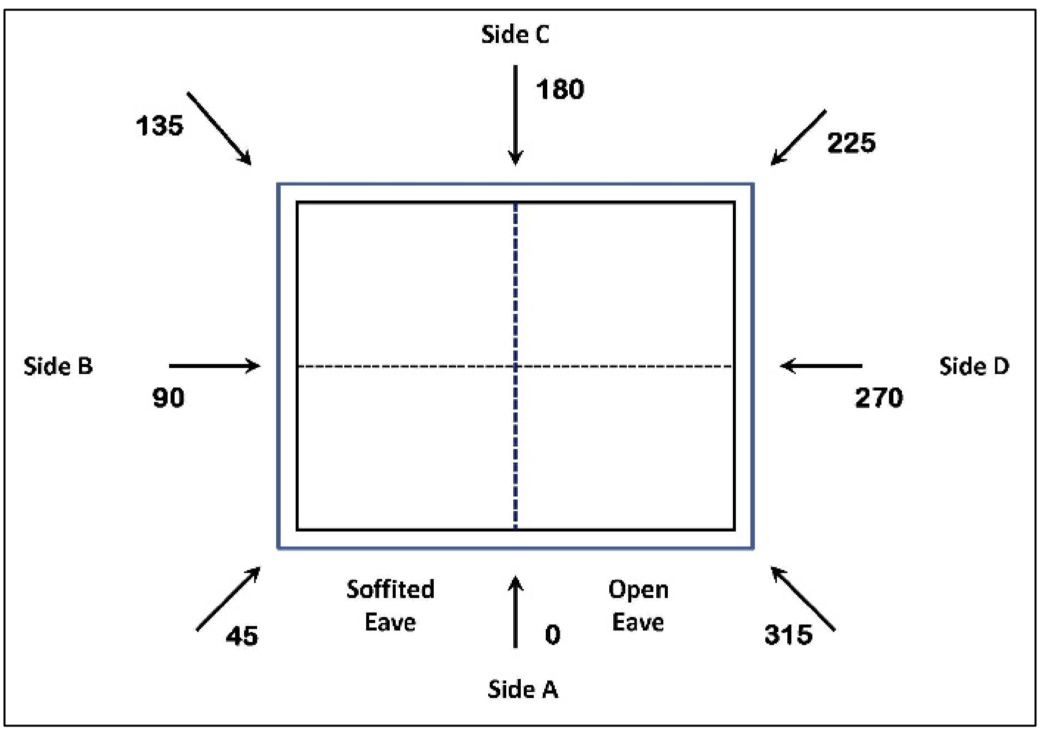

Figure 7. *Building orientations used to evaluate the effect of wind direction on ember entry through attic vents.*

One of the seven ember generators used in this study is shown in Figure 8. Each generator consisted of a cylindrical burn chamber and a raw material hopper. An auger feed screw conveyed the wood-based feed stock for the generators out of the hopper and into a chute that dropped the feed stock onto a metal mesh screen positioned just above a natural gas burner located near the bottom of the burn chamber. The gas burner ignited the raw material that accumulated on the metal screen.

The raw material used to generate embers was locally sourced southern yellow pine wood chips and commercially available hardwood (typically birch) dowels. The wood chips were dried in a dehumidification kiln located at the IBHS Research Center prior to use. The targeted ratio of chips to dowels was 85:15 (by weight). Each test was 15 minutes in duration. Longer tests could be run by intermittently reloading the raw material storage hoppers.

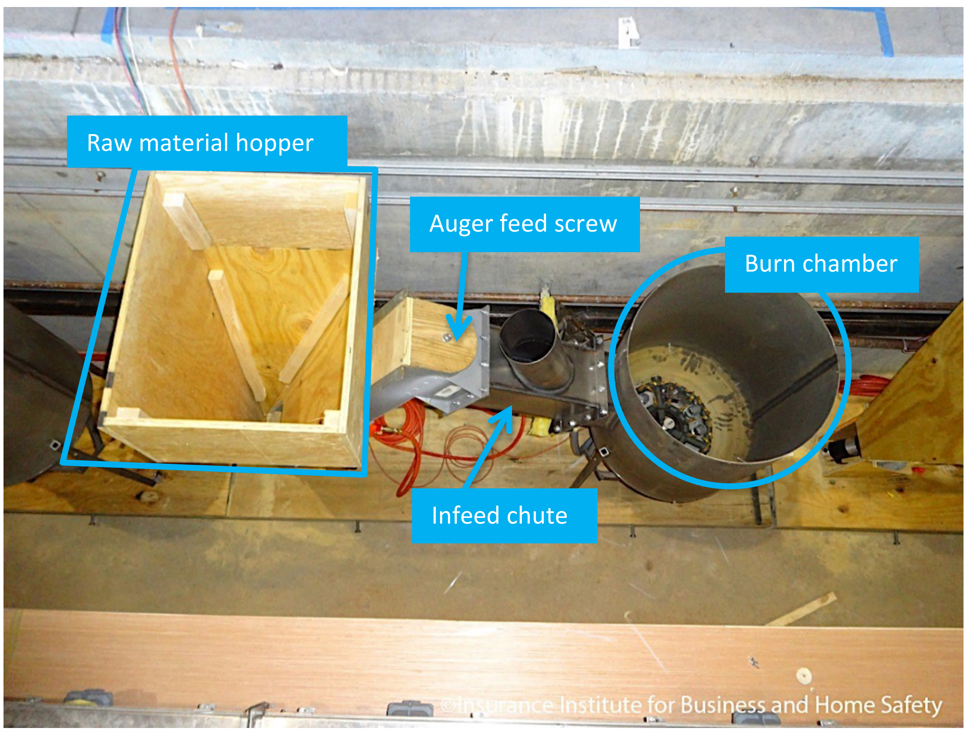

Figure 8. *The ember generation system consisted of the raw material storage hopper (left) and a burn chamber (right). An auger feed screw delivered the raw material to the burn chamber through an in-feed chute. These components of the ember generation and delivery system were located below grade in a trench.*

An overview photograph of the seven ember generators is shown in Figure 9. This figure shows the vertical ducts that carry the burning (glowing) embers from the burn chamber into the wind stream of the test chamber. It also shows one-half of the air supply and distribution system used for the generators. Another air supply and distribution system was located on the opposite side of the chamber. The air supply system served two purposes: (1) to deliver air to an opening in the bottom of each generator, thereby providing the force needed to push the lofting embers out of the burn chamber and out of the vertical duct, and (2) to deliver air to the top of the infeed chute, which provided sufficient positive pressure to confine the fire to the burn chamber, and keep it from moving up the infeed chute and into the raw material hopper.

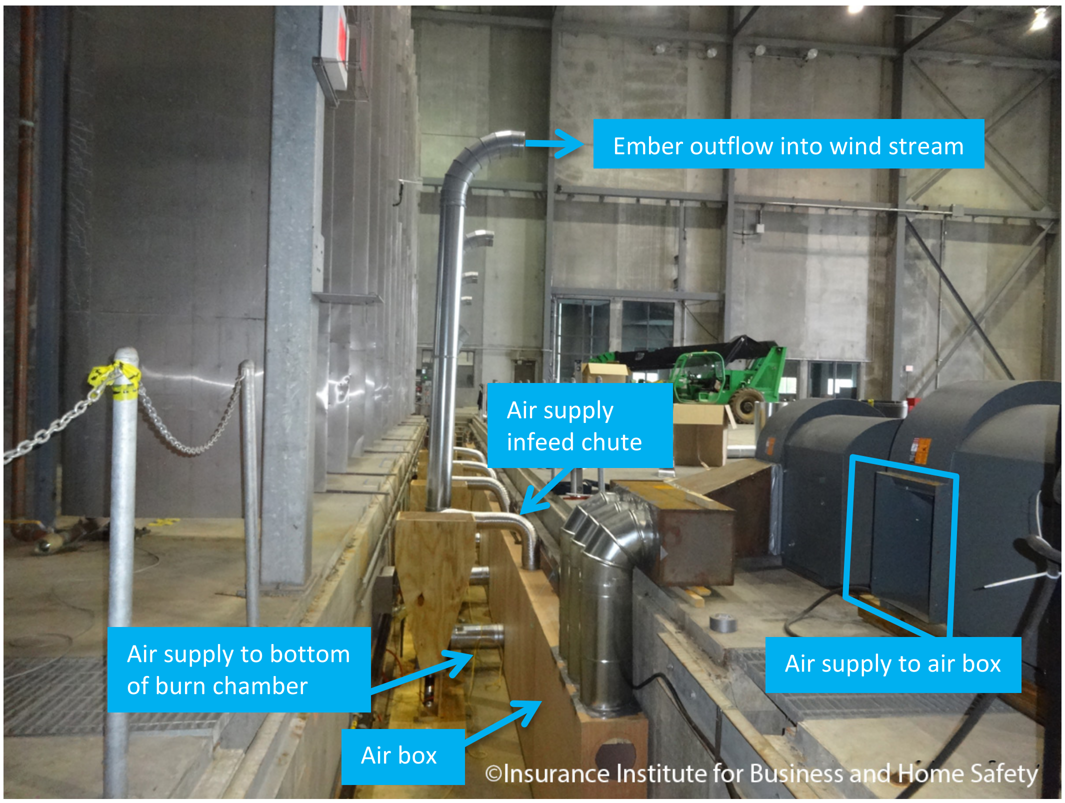

Figure 9. *Overview of ember generation system. The charged air box supplied air to bottom of burn chamber (pushing lofting embers into vertical ducts and then into wind stream of wind tunnel fans) and to the top of the infeed chute (minimizing heat exchange between burn chamber and raw material hoppers).*

All seven ember generators were run during each test. A representative photograph of these generators is shown in Figure 10.

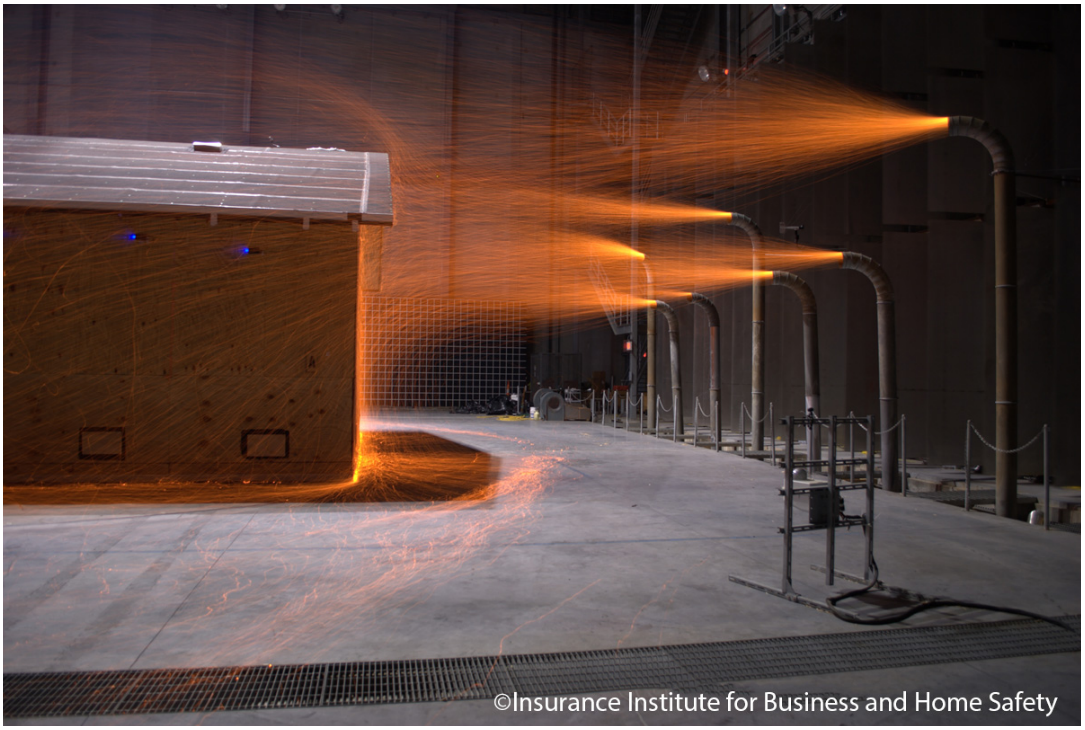

Figure 10. *Ember generators operating during a test.*

Analysis

Video- and non-video-based measurements were used to evaluate the ability of a given vent to resist the intrusion of wind-blown embers. For each test, cameras were positioned at interior location(s) to capture video of embers that entered through one or more vent openings. In the case of inlet (under-eave) vents, the field of view of a given video camera was sufficient to capture entry through two or three vent openings. For gable end and through-roof vents, cameras were only able to capture ember entry for an individual vent. A post-processing procedure using a particle tracking algorithm was used to count embers. Typical camera setups are shown in Figures 11 and 12.

Figure 11. *Typical video camera setup used to evaluate ember entry through the gable end vent.*

Figure 12. *Typical video camera setup used to evaluate ember entry into a through-roof vent.*

During the gable end vent tests, a 3 ft x 8 ft (0.9 m x 2.4 m) section of a wood-based panel was placed below the inlet of the vent (Figure 13). After each test, the embers that landed on the panel were collected and weighed.

During gable end and through-roof vents tests, a cotton pad was placed on a horizontal surface near (under) the entry area for the vent. In the case of the gable end vent, the cotton was placed on the panel previously mentioned (Figure 14). In the case of other through-roof vents, the cotton was placed on an elevated platform (Figure 12). The cotton was used to evaluate the ability of embers to ignite fine fuels in an attic space. Cotton served as a surrogate for all combustible fine fuels that could be in an attic space. Cotton was selected because it was the combustible materials selected for use in the ASTM standard test method to evaluate the performance of vents (ASTM E2886). Cotton is also used in other ASTM fire test standards. This standard evaluates vent performance by evaluating the ability of embers that pass through a given vent to ignite the cotton substrate.

Figure 13. *Embers that landed on the 3 ft by 8 ft (0.9 m x 2.4 m) panel (blocked in blue) were collected and weighed after each test. This technique provided means to quantify ember entry through the gable end vent. Note that embers (the black particles) landed on and off the panel. Only embers that landed and accumulated on the panel were weighed.*

Figure 14. *A cotton pad was placed on a horizontal surface, near the entrance of gable end and all through-roof vents to evaluate the ability of entering embers to ignite a combustible material.*

Results and Discussion

Common types of attic vents were evaluated during these tests. Inlet vents were always in the under-eave area. Outlet vents were located either on the gable end wall or on the roof. A summary of types of vents, their location and relative vulnerability to ember entry is given in Table 1. Relative vulnerability is based on a composite of the methods used to evaluate performance (i.e., post-processing of video footage, visual observations and notes made during a given test, weighing of accumulated embers on the panel, and observations made of ember strikes on the cotton pad).

As indicated in Table 1, vents that provided a vertical face to the wind were more vulnerable to the entry of wind-blown embers. These included all gable end vents, the generic through-roof off-ridge vent, and vents in the blocking of open-eave construction. In each of these cases, wind flow was perpendicular to the vertical face of the vent. The number of embers that ultimately entered through a given vent depended on the location and size of the vent opening and other design features built into the vent that have a positive influence on reducing entry. Gable end vents are installed in the vertical triangular wall of the attic at a gable end. They are limited in number and therefore tend to have a larger surface area compared to through-roof outlet vents. The vertical face and large area alone make the gable end vent location more vulnerable to ember entry than other outlet vent locations. Vent design features and smaller mesh sizes will reduce the size and number of embers that enter through a gable end vent. While gable end vents are designed to provide an outlet for hot attic air, they allow the free flow of air into and out of the attic. Consequently, when the vent is on a windward face, wind, embers and wind-driven rain can also enter through the vent.

For vents in the under-eave area, ember entry increased with increasing wind speed. Vents located in the soffit were less vulnerable to ember entry than those located in between trusses/rafters (truss bay or rafter bay blocking) in open-eave construction. The vent opening in the soffited-eave locations was parallel to the wind flow; however, recirculation of the wind in the under-eave area allowed for some ember entry to occur. The number of embers passing from the enclosed portion of the eave to the attic space (i.e., to the space above the occupied portion of the building) also increased with increasing wind speed. This relationship was reversed for ridge and turbine vents, where ember entry decreased with increasing wind speed.

Table 1. Description of vents evaluated in this series of experiments and their relative performance in terms of ability to resist the entry of wind-blown embers.

Vent Function	Location	Vent Type	Vent Description	Relative Performance
Inlet	Under-eave	Open-eave	¼-in. square mesh screening	Poor
		Soffit	⅛-in. square mesh screening[1]	Best
Outlet	Gable end	Mesh	¼-in. square mesh screening	Poor
			⅛-in. square mesh screening	Fair
			⅛-in. diamond mesh screening	Fair
			1/16-in. square mesh screening	Good
		Wildfire-resistant vent	Baffled-design wildfire -resistant vent with ⅛-in. diamond mesh backing	Good
			Honeycomb mesh, wildfire -resistant vent with 1/16-in. square mesh backing	Good
	Through-roof off-ridge	Generic	¼-in. square mesh screening	Poor
		Turbine	No screen	Good
		Wildfire-resistant vent	Louvers and steel wool fill	Best
	Through-roof ridge	Miami-Dade wind-driven-rain-compliant	External baffles present	Best
		Non-Miami-Dade wind-driven-rain-compliant	External baffles removed	Fair

[1] Soffited construction is best. Though this study used ¼-in. mesh, ⅛-in. mesh is recommended.

Vents are designated “inlet” or “outlet” vents based on air flow into and out of the attic space under natural convection conditions. Under the elevated wind speed scenarios used in this tests (and typically present during wildfires), all under-eave and the non-turbine off-ridge vents on the windward side of the building were inlet vents (Figure 15), and those on the leeward side of the building were outlet vents (Figure 16), regardless of their nominal designation. The ridge (Miami-Dade-compliant and non-Miami-Dade-complaint) and turbine vents were consistently outlet vents (Figure 17).

Figure 15. As indicated by the action of the ribbons, on the windward side of the building, the off-ridge through-roof vent (left) and open-eave vent (right) were inlet vents.

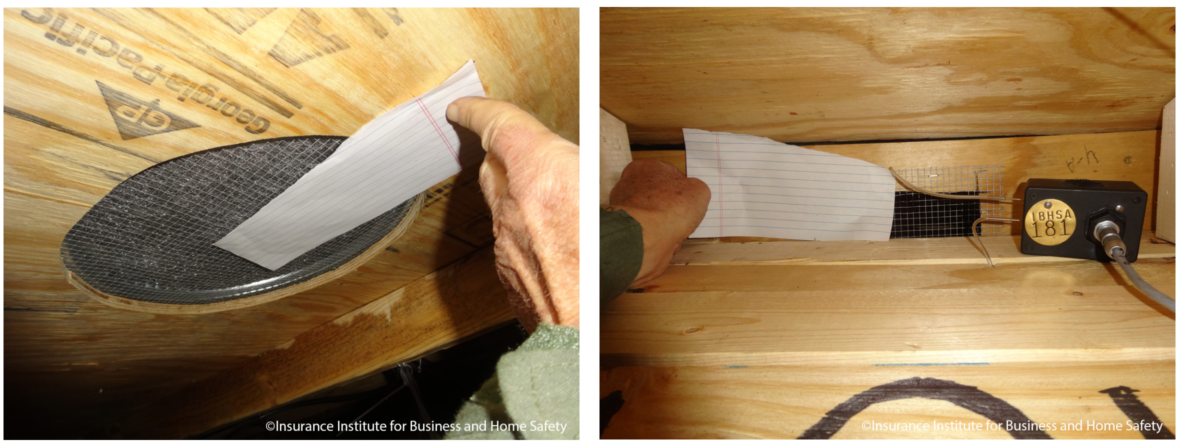

Figure 16. As indicated by the action of the ribbons, on the leeward side of the building, the off-ridge through-roof vent (left) and open-eave vent (right) were outlet vents.

Figure 17. *As indicated by the action of the ribbons, the ridge vent (left) and turbine vent (right) were consistently outlet vents.*

In these series of experiments, the external baffle on the Miami-Dade-compliant ridge vent was effective in eliminating ember entry into the attic space. The response of the non-Miami-Dade-compliant ridge vent and the turbine vent to wind speed (i.e., always an outlet vent) explained their response to ember entry, where increased wind speed increased their effectiveness as outlet vents. The momentum of the ember entering the vent resulted in embers being carried across the opening of the attic space to the vent exit. This is graphically depicted for the ridge vent in Figure 18. At higher wind speeds, ember entry into the attic space was minimal. At lower wind speeds, smaller embers would be carried across the opening and through the exit on the opposite side. Larger, heavier embers would drip into the attic. Because lower wind speeds will likely occur during wildfires, attaching ⅛-in. metal mesh screening to the roof sheathing under these vents would be an additional precaution to reduce the number of embers that enter the attic space. For turbine vents, it would also be important to ensure they are in good working order (i.e., they spin freely). All commercially available ridge vents (Miami-Dade-compliant and non-Miami-Dade-compliant) are made of plastic materials. The greatest vulnerability to these vents could be the ember ignition of vegetative debris (e.g., pine needles) that can accumulate at the inlet of the vent, and the subsequent flaming exposure to the plastic components that would result.

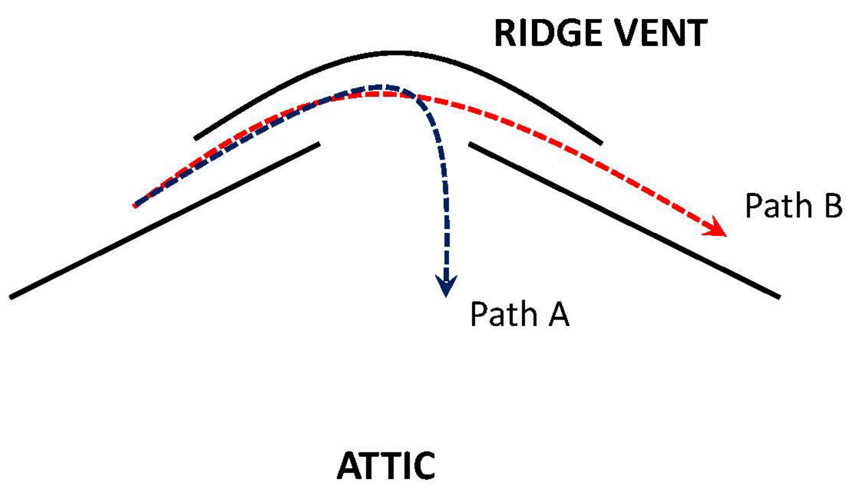

Figure 18. *A diagram depicting a non-Miami-Dade-compliant ridge vent. At higher wind speeds, embers that entered the vent would be carried over the opening to the attic and through the exit on the opposite side (Path B). At lower wind speeds, the heavier embers would drop out of the air stream and into the attic space (Path A).*

Three vents that were accepted for use in California were incorporated into the experimental design. These vents were the "wildfire-resistant vents" listed in Table 1. The wording in the California Building Code required vents that resisted the entry of burning (typically glowing) embers *and* flames. Our experiment focused only on ember resistance. Whereas the embers entering the attic space through the $^{1}/_{16}$-in. (1.5 mm) mesh of the "screened wildfire" vent were smaller than those that passed through the vent that incorporated a baffle design and ⅛-in. (3 mm) diamond mesh, the number of embers entering the attic through each of these vents was less than those passing through the $^{1}/_{16}$-in. and ⅛-in. diamond mesh alone, respectively. Note that the camera used to count embers was placed close to the entrance inside the attic space. It was observed that the smaller embers, those passing through the $^{1}/_{16}$-in. (1.5 mm) mesh screening in particular, would self-extinguish before reaching the floor of the attic. In the case of the vent with the baffle design, the baffle itself had a positive influence in resisting ember entry, possibly due to increased retention time in the vent or mechanical damage to the embers when passing through the vent. The screened wildfire vent also incorporated an intumescent paint–coated honeycomb mesh material, approximately 1-in. thick, and louvers. Whereas the primary function of the honeycomb mesh material was for flame resistance, the thickness of the mesh and possibly the use of louvers on the outside of the vent could have had a positive effect on reducing the entry of wind-blown embers. The steel wool infill used in the off-ridge through-roof vent was effective in minimizing ember entry into the attic space.

As previously indicated, a cotton pad was used during these experiments to evaluate the ability of entering embers to ignite an easily combustible material. The cotton pads were dried in an oven with a temperature set point of 212°F (100°C) for 24 hours prior to the test. Although the ember strikes were often sufficient to result in short-term smoldering combustion of cotton pads, particularly with the coarser mesh screens in the gable end vents, in no case did combustion transition to flaming. A cotton pad after a gable end test with ¼-in. (6 mm) mesh screening is shown in Figure 19.

Figure 19. *A cotton pad positioned on the attic floor at the base of a gable end vent showing numerous ember strikes. The cotton exhibited short-term smoldering combustion, but always self-extinguished without transitioning to flaming combustion.*

Testing that was conducted during the development of the ASTM standard to evaluate the ember resistance of vents (ASTM E2886, 2012) demonstrated that a cotton pad (and a shredded paper fine fuel) could easily be ignited by embers that passed through ⅛-in. (3 mm) mesh screening. This information was reported in the Appendix (ASTM E2886, 2012). During these tests, three different apparatuses were being evaluated: one where the generated embers flowed vertically through the vent and onto the target materials, and two others where the embers flowed horizontally to the vent. Modifications, such as baffles or other materials that directed the embers to a pre-determined location, were made to each apparatus to maximize the number of embers that impacted the target material. During the experiments reported here, the embers that passed through the vent were allowed to follow air currents in the attic space (Figure 20). Baffles or other materials to direct the embers to a pre-determined location *were not* installed in the attic space. As a result, embers that entered the attic space followed the fluctuating wind currents and patterns inside the attic. This resulted in a greater dispersion of embers and the resulting inability to reach sufficient deposition rate on the cotton pad to result in flaming combustion. From a practical perspective, this means that combustible materials that can be stored in the attic should be stored at a distance from a vent. Cardboard boxes stored adjacent to a vent, for example, could stop embers and allow them to accumulate on the attic floor next to the box. This could result in flaming ignition of the box, and other nearby materials.

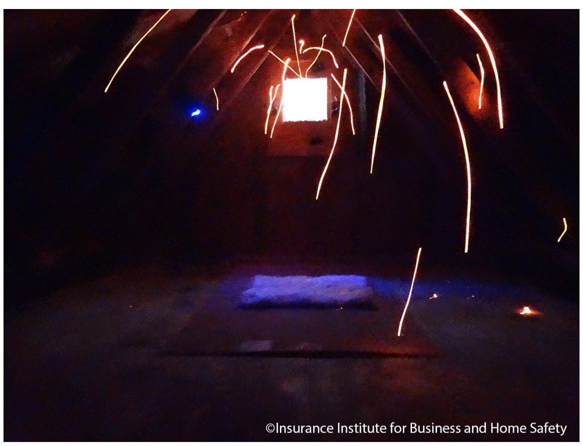

Figure 20. *The bright streaks are embers that entered the attic space through a gable end vent (left) and vents in open-eave blocking (right). They did not congregate in any concentrated area on the attic floor.*

Summary of Findings

1. There are two options for inlet vents, both located in the under-eave area. These include vents in the between-rafter blocking in open-eave construction and vents in the soffit material in soffited-eave construction. Vents located in soffited-eave construction were shown to limit ember entry and should therefore be the preferred construction type.

2. ¼-in. (6 mm) mesh screening should not be used to cover any vent. Finer mesh sizes of ⅛-in. (3 mm) or $^{1}/_{16}$-in. (1.5 mm) would be preferred. The finer $^{1}/_{16}$-in. mesh screen will require more cleaning-related maintenance to remove the debris that can accumulate on the screen surface.

3. The wildfire-resistant vents used in the gable end location performed better than the respective backing screen mesh alone.

4. Due to the relatively large size and vertical orientation of gable end vents, they should be avoided. If alternatives are not possible, a wildfire-resistant gable vent that has passed ASTM E2886 should be used.

5. Avoid using non-wildfire-resistant off-ridge and ridge vents. Of the ridge and off-ridge outlet vent options, the following performed well:
    - Miami-Dade wind-driven-rain-compliant ridge vent
    - Wildfire-resistant (steel wool fill) off-ridge vent
    - Turbine (off-ridge) vent

6. Wind-blown vegetative debris must be removed from the inlet of all ridge and off-ridge vents, paying particular attention to vents with plastic components. Plastic components are commonly used in ridge vents.

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