Performance of Residential Buildings

Mitigation Assessment Team Summary Report and Recommendations
State of Hawai'i
Maui Wildfires

February 2025

FEMA

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1. Executive Summary

In early August 2023, a series of wildfires broke out in the State of Hawai'i. The island of Maui was particularly affected as multiple wind-driven fires prompted evacuations and caused widespread damage to Lahaina and Kula. The fires burned 6,721 acres resulting in the loss of 2,173 structures, with many more damaged.[1] The spread of the wildfires was attributed to dry, gusty conditions created by wind funneling between a strong high-pressure area north of Hawai'i and Hurricane Dora several hundred miles to the south.[2]

Following the fires, the Federal Emergency Management Agency's (FEMA) Building Science Disaster Support Program (BSDS), in conjunction with FEMA Region 9 and supported by the Strategic Alliance for Risk Reduction (STARR II), provided specialized architectural and engineering expertise through its Mitigation Assessment Team (MAT) to assess building performance; develop customized Recovery Advisories; provide tailored training and subject matter expertise; and document observations, conclusions, and recommendations. The outputs from these efforts resulted in the development of products and technical assistance that are meant to support the State of Hawai'i and Maui County in ongoing recovery from the August 2023 fires and to support preparedness for and resiliency in the face of future similar events.

The MAT worked with local agencies to assess damage to buildings and learn how buildings performed during the fires. After conclusion of the field investigation, the MAT analyzed the field data as well as other damage reports and studies conducted by others. The MAT prepared conclusions and developed recommendations based on these findings. This information is presented in two targeted summary reports:

- Codes, Standards, and Permitting
- Performance of Residential Buildings

This summary report focuses on the performance of one- and two-family residential buildings impacted by the August 2023 wildfires on Maui. The performance of residential buildings varied depending on their design, construction type and quality, geographic location, siting, development density, landscape vegetation, distance to other surrounding flammable materials, and maintenance history. Several homes sustained damage from wind as well as fire, including wind damage to roof coverings, windows, and doors.

The recommendations provided in this document and the referenced Recovery Advisories were created, in part, to assist the State of Hawai'i and Maui County in outlining a path forward for the repair and reconstruction of the large number of buildings damaged or destroyed by the August 2023 wildfires. The state and county can also use these recommendations to guide and better prepare communities, property owners, and other stakeholders for future hazard events through

[1] https://www.mauicounty.gov/2023-Wildfire-After-Action-Report

[2] mauicounty.gov/DocumentCenter/View/149693/FI23-0012446-Lahaina-Origin-and-Cause-Report_Plus-Appendix-A-B-C-Redacted

following pertinent recommendations. As Maui is subject to multiple hazards, including high winds, flooding, tsunami, and seismic events, a multi-hazard and holistic approach should be applied during recovery and rebuilding. Table 1 summarizes the detailed recommendations found in Section 4 and proposes leadership to facilitate and implement each recommended action.

Table 1: MAT Summary of Recommendations

#	Recommendation	Leader for Implementation
Structure and Building Envelope Hardening		
1a	The entire roof assembly should satisfy Class A requirements when tested in accordance with ASTM E108 or UL 790.	Property Owners
1b	The local residential building code should be amended to require a Class A roof assembly for all new residential construction.	Maui County
1c	International Wildland Urban Interface Code® (IWUIC) Section 507, Replacement or Repair of Roof Coverings should be incorporated into the local residential building code.	Maui County
1d	A noncombustible underlayment should be installed during roof installation.	Designers, Builders and Property Owners
2a	A newly designed residential roof should feature a consistent roof slope, with a limited number of joints, abrupt geometry changes and elevation changes.	Architects and Designers
2b	The roof structure of existing homes with complex, flat roofs should be hardened using noncombustible roof coverings and metal roof flashing to protect roof eaves and valleys.	Architects, Designers and Property Owners
3a	Ember and flame-resistant exterior vents should be specified.	Architects and Designers
3b	The Maui County Residential Code should be amended to require corrosion resistant, noncombustible exterior vents covered with 1/8-inch corrosion-resistant noncombustible mesh.	Maui County
3c	Limited eave overhangs, enclosed with noncombustible materials, are recommended for new construction. Regardless of size, enclosed eave overhangs should feature a corrosion-, flame- and ember-resistant soffit of 1/8-inch mesh.	Designers and Property Owners
4a	A study measuring the performance of mesh covered flood openings limited to 144-square inch size should be conducted.	FEMA
4b	Additional language should be integrated into the next IWUIC edition to provide additional language for 504.10 on flood opening requirements. Work with the flood openings industry to determine which opening types meet the 2024 IWUIC Section 504.10.1 standards.	U.S. Fire Administration (USFA) and FEMA
4c	Flood opening guidance should be included in the National Institute of Standards and Technology (NIST) Hazard Mitigation Methodology (HMM).	NIST

#	Recommendation	Leader for Implementation
5a	Language consistent with IWUIC 504.5 for Exterior Walls should be incorporated into the Maui County Residential Code to require exterior walls constructed with one of the following methods: 1) fire-resistance-rated materials with a minimum 1-hour fire rating, 2) noncombustible materials, 3) fire-retardant-treated wood rated for exterior use and meeting the requirements of International Building Code® (IBC) Section 2303.2, 4) ignition-resistant materials meeting the requirements of IWUIC 503.2.	Maui County
5b	Where existing combustible cladding is present, replace combustible exterior wall covering with noncombustible material for the bottom two feet from ground.	Designers and Property Owners
6a	Double paned windows, double paned with one layer tempered, wired glass, or fire rated glass for fire resistance are recommended for window replacement. Single pane and jalousie windows should be avoided.	Designers and Property Owners
6b	Windows with metal framing are recommended over wood or vinyl-framed windows.	Designers and Property Owners
6c	Noncombustible shutters (such as metal rolldown shutters) and noncombustible metal mesh screens are recommended to protect windows from windborne debris and firebrands.	Designers and Property Owners
7a	Exterior doors without glass that meet a minimum 20-minute fire-resistance rating with metal door jambs per NFPA 252 are recommended.	Designers and Property Owners
7b	Noncombustible (e.g., metal) garage doors without windows and metal flashing at the base that meet a minimum 20-minute fire-resistance rating per NFPA 252 are recommended.	Designers and Property Owners
7c	Wooden screen doors should be replaced with metal doors and frames. If a screen is present, it should be comprised of 1/16-inch (or smaller) metal corrosion-resistant mesh.	Designers and Property Owners
8a	Old plastic “bubble” skylights with wood or vinyl framing should be replaced with tempered glass pane skylights surrounded by non-flammable flashing sealed with noncombustible caulk.	Homeowners
8b	Skylights are not recommended for replacement roofs.	Architects, Designers and Property Owners
9a	Separation distances of 30 feet between accessory structures and homes and 15 feet from lot lines are recommended.	Property Owners
9b	Incorporation of setbacks in new construction site configuration is recommended to reduce the risk of structure-to-structure fire spread.	Maui County
9c	Replace small plastic or wood storage sheds with a metal shed. Position the shed so that the door does not face the main structure on the parcel. Design defensible space surrounding the shed and do not store flammable material within or next to accessory structures.	Homeowners

#	Recommendation	Leader for Implementation
9d	New or replacement carports should feature Class A roof assemblies and noncombustible floors, walls and ceilings with 1-hour fire-resistance ratings.	Architects, Designers and Property Owners
9e	Local building code requirements and enforcement mechanisms should be amended to ensure proper fire-rated separation walls designed/constructed between residences and carports. The fire rating for carports/houses should be increased to 15 feet from the neighboring property line or within 30 feet of an adjacent structure. Additionally, building codes and enforcement mechanisms should be amended to ensure that a proper fire-rated separation wall is designed and constructed between a house and a carport.	Maui County
10	Remove or replace existing combustible fencing with noncombustible fencing within five (5) feet of the house (also known as Zone 0) consistent with recommended defensible space requirements.	Homeowners
11a	When designing a new residence, a minimum 1-hour fire-resistance on the underside of the home is recommended. For existing structures, consider installing at least two layers of 5/8-inch Type X gypsum.	Architects, Designers and Builders
11b	The Maui County Ordinance 5603 should be revised to prohibit storage of combustibles under homes.	Maui County
11c	Where a home is elevated with skirting, noncombustible skirting with openings less than 1/8-inch is recommended.	Designers and Property Owners
12a	Flood, fire, wind, and seismic mitigation measures should be incorporated into residential repairs and renovations as indicated and practicable.	Architects, Designers and Property Owners
12b	The 2018 State of Hawai'i Residential Code Section R401.5 requires post and pier foundations for new construction designed with accepted engineering practice. Homes with this foundation type should be retrofitted with lateral support connections to resist flood, wind, and seismic forces consistent with building codes and standards.	Homeowners
13a	The 2027 IWUIC update should include a provision requiring the use of fire-resistant materials under elevated structures.	USFA
13b	A code change is recommended for the IWUIC Sections 504.5 and 504.6 to maintain consistency with floodplain management ordinance velocity hazard zone breakaway wall requirements.	FEMA
14a	Guidance should be added to Section 504.6 of 2021 IWUIC for elevated structures in flood-prone regions based on National Flood Insurance Program (NFIP) regulations and American Society of Civil Engineers (ASCE) 24 Standard requirements.	International Code Council (ICC)
14b	A section to explicitly reference fire safety in foundations should be added to the IWUIC.	ICC

#	Recommendation	Leader for Implementation
Defensible Space		
15a	Wildfire experts should be included in development of local ordinances, standards, and guidance documents for communal defensible space in overlapping defensible space zones.	Maui County
15b	Wildland fire safety concepts should be integrated throughout the regulatory life cycle from planning and zoning to design and permitting to construction to long-term maintenance and enforcement.	Maui County and Property Owners
16	On-site post-structure demolition erosion stabilization gravel can be incorporated into the landscape to create defensible space adjacent to and up to five (5) feet surrounding the residence.	Property Owners
17a	Current fire-resistant native plant recommendations should be updated to guide property owners by listing fire-resistant native plant options.	University of Hawai'i or Hawai'i Wildfire Management Organization (HWMO)
17b	Flammable, invasive and non-native vegetation within the defensible space of any buildings should be removed and replaced with native fire-resistant plants.	Property Owners
17c	Overgrown vegetation within 15 feet of structures should be pruned or removed.	Property Owners and Tenants
18a	Combustible items (e.g., barbeque grills, firewood, generators, gas-powered lawn equipment, furniture) or portable propane tanks should not be stored underneath or within five (5) feet of buildings, lanais, decks, carports, and open foundations.	Property Owners and Tenants
18b	Propane tanks should be placed a minimum of five (5) feet away from all combustibles.	Property Owners
18c	Large permanent propane tanks should either be (1) provided with 15 feet of separation, (2) behind a fire separation wall, or (3) buried to limit impact during a wildfire event and anchored to resist buoyancy during a flood.	Property Owners
19a	Adoption of current published editions of the International Residential Code® (IRC), International Fire Code® (IFC), and IBC that provide expanded protections for battery storage systems and solar arrays is recommended.	State of Hawai'i and Maui County
19b	A recognized testing laboratory should evaluate provisions in the International Codes that provide mandatory protection for energy storage systems; augment codes as appropriate to provide protection against damage and ignition of batteries.	National Fire Protection Association (NFPA), in cooperation with FEMA, USFA and ICC
Maintenance		
20a	An ordinance to require property owners' vegetation maintenance and enforcement mechanisms, supported by the Hawai'i Department of Natural Resources, should be adopted.	Maui County

#	Recommendation	Leader for Implementation
20b	Yard waste and roof debris should be removed from homes to reduce potential fire fuel. Debris should be removed from chimneys, roof valleys, and gutters.	Homeowners
21a	Proper disposal of vegetative debris and use of “green waste” bins for yard waste pickup should be communicated to residents.	Maui County
21b	Defensible space setbacks for properties adjacent to gulches, ravines and valleys should be required. Maui County should restrict dumping of yard waste into gulches and provide alternatives for proper yard waste disposal such as a green dump facility or woody materials utilization facility.	Maui County
22a	Adoption of vacant lot and weed abatement ordinances would improve maintenance of undeveloped lands, vacant lots, and absentee properties to reduce combustible vegetation.	State of Hawai’i and Maui County
22b	Property owners should be provided with recommendations on how to increase wildfire resiliency on their property if neighboring properties are non-compliant.	Maui County
23	Use of non-corrosive, metal noncombustible gutters, gutter covers and roof drip edge, or alternative water drainage is recommended to reduce roof fire vulnerability. Property owners and tenants should regularly remove debris from open gutters.	Property Owners and Tenants
24	Guidance should be distributed to property owners and tenants from StaySafe.org or similar organizations on safe storage in carport areas, highlighting use of appropriate metal cabinets with locks for hazardous or flammable materials.	Maui County

2. Acronyms and Abbreviations

ASCE	American Society of Civil Engineers
ASTM	ASTM International (formerly known as American Society for Testing and Materials)
BSDS	Building Science Disaster Support
CMU	Concrete masonry unit
ESS	Energy storage systems
FEMA	Federal Emergency Management Agency
HI-EMA	Hawai’i Emergency Management Agency
HMM	Hazard Mitigation Methodology
HWMO	Hawai’i Wildfire Management Organization
I-Codes	International Codes®
IBHS	Insurance Institute for Business & Home Safety
IBC	International Building Code®
ICC	International Code Council
IFC	International Fire Code®
IRC	International Residential Code®
IWUIC	International Wildland Urban Interface Code®
L-ion	Lithium-ion
MAT	Mitigation Assessment Team
MEMA	Maui County Emergency Management Agency
NFIP	National Flood Insurance Program
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NWCG	National Wildfire Coordinating Group

OSB	Oriented strand board
PV	Photovoltaic
SBCC	State Building Code Council
SFPE	Society of Fire Protection Engineers
STARR II	Strategic Alliance for Risk Reduction
UL	Underwriters Laboratories Standards & Engagement
USFA	U.S. Fire Administration
WUI	Wildland-Urban Interface

3. Event Overview and Study Purpose

3.1. Background

There are many terms that carry specific meaning in the context of wildfire which are important to understanding the contents of this report. Most of these definitions come from the National Wildfire Coordinating Group's (NWCG) online glossary[3], other nationally recognized fire organizations, and from existing FEMA terminology.

- **Conflagration** – Defined by the NFPA 101®, Life Safety Code Handbook as "A large destructive fire that can threaten human life, property, animal life, and health."
- **Wildfire** – An unplanned, unwanted fire burning in a natural area.
- **Wildland** – A natural environment that has not been significantly modified by human activity.
- **Wildland-Urban Interface (WUI)** – Defined by the NWCG online glossary as "the line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetation fuels."

Wildfires are a natural part of many of Earth's wildland ecosystems. Fundamentally, three ingredients are necessary for fires to occur (also known as "the fire triangle"): oxygen, which starts and sustains combustion; heat, which raises the fuel temperature or simply heats fuel to its ignition point; and fuel, which sustains and carries flames. Reducing the likelihood of initial ignition (heat) and limiting the available fuel after ignition are known to be effective strategies for controlling fire behavior.

Wildfires, however, are complex and challenging. The nature of the wildfire problem is a product of natural and man-made ignition sources, vegetative fuels, topography, weather, and characteristics of the built environment (e.g., building typologies, urban fuel loads, density). Understanding how these factors interact, along with fire history, fire ecology, climatology, and human interactions with these various facets, is central to developing appropriate and effective mitigation strategies. Each year only a small fraction of wildfires become large enough to produce significant property damage or casualties. A common misperception of the WUI is that it occurs only near forested areas; however, grasslands and shrublands can also be in the WUI. As environmental conditions continue to change the landscape and as human development continues to expand into vegetated areas near what has traditionally been deemed the WUI, the definition of "interface" may need to change.

Damaging fires can be attributed to a combination of environmental conditions favorable to wildfire, including limitations in adoption and/or implementation of WUI codes and standards, limited knowledge of wildfire hazards/risks, limited resources for retrofits, increasing construction in high wildfire areas, and availability of firefighting resources to effectively respond to fire incidents

[3] https://www.nwcg.gov/publications/pms205

(especially during the incipient stages of fire development). It should be noted, however, that wildfire occurrence, damages and injuries are increasing, attributable to changes in land use as well as climate change. Four major factors contributing to wildfire occurrence are:

- **Weather** – the most variable element of the wildland fire environment. Important components of weather that influence wildfire behavior are temperature, relative humidity, precipitation, and wind. All these elements have the potential to enhance or slow wildfire spread and intensity.

- **Vegetation** – the primary fuel source for wildfires and, along with weather, a key factor in determining the risk of wildfire hazards. In the WUI, both vegetation and urban fuels present a hazard. Locally, the abundance of non-native trees and shrubs used as landscaping vegetation and screening as well as unmaintained fallow agricultural lands have a negative effect on the wildland fire environment.

- **Urban Fuels** – urban sources of fuel such as combustible structures (e.g., houses, businesses, industrial facilities, outbuildings), combustible non-structural features (e.g., decks, fences, ornamental landscaping), vehicles, fuel tanks, etc., can contribute to the fire environment and significantly influence the fire behavior.

- **Topography** – the configuration of the earth's surface and the most stable of the elements in the fire environment. Topography significantly impacts wildfire behavior as it influences local winds by sheltering areas from prevailing winds or channeling winds through prominent canyons and drainages. Factors of topography that affect fire behavior include slope, aspect, terrain features, and elevation with the steepness of slope being the most influential.

Multi-Hazard Wildfire Interactions

Wildfire behavior is largely influenced by fuel, weather, and topography but other natural hazards can also influence wildfire behavior and severity. For example, lightning is a common ignition source for wildfire, especially in conditions of low relative humidity and abundant dry fuels. Extreme heat can work in tandem with drought to increase the volume of dry fuel available for ignition. High winds can increase the speed at which wildfires travel, help spread embers to ignite new fuel sources, and hinder fire suppression efforts. For the purposes of this report, wildfires that occur in combination with other natural hazards are considered "multi-hazard wildfire events."

In turn, wildfires can influence the severity and behavior of other natural hazards. In post-fire conditions, the significant loss of vegetative cover and erosion control can increase the risk of secondary natural hazards, such as floods, landslides, and debris-flows in and downslope of burned areas. These post-wildfire hazards often have cascading effects on the local natural and built environment, including incursions of invasive species and loss of watershed function, as well as impacts to critical infrastructure, buildings, and people.

3.2. Maui Wildfire History and Risk

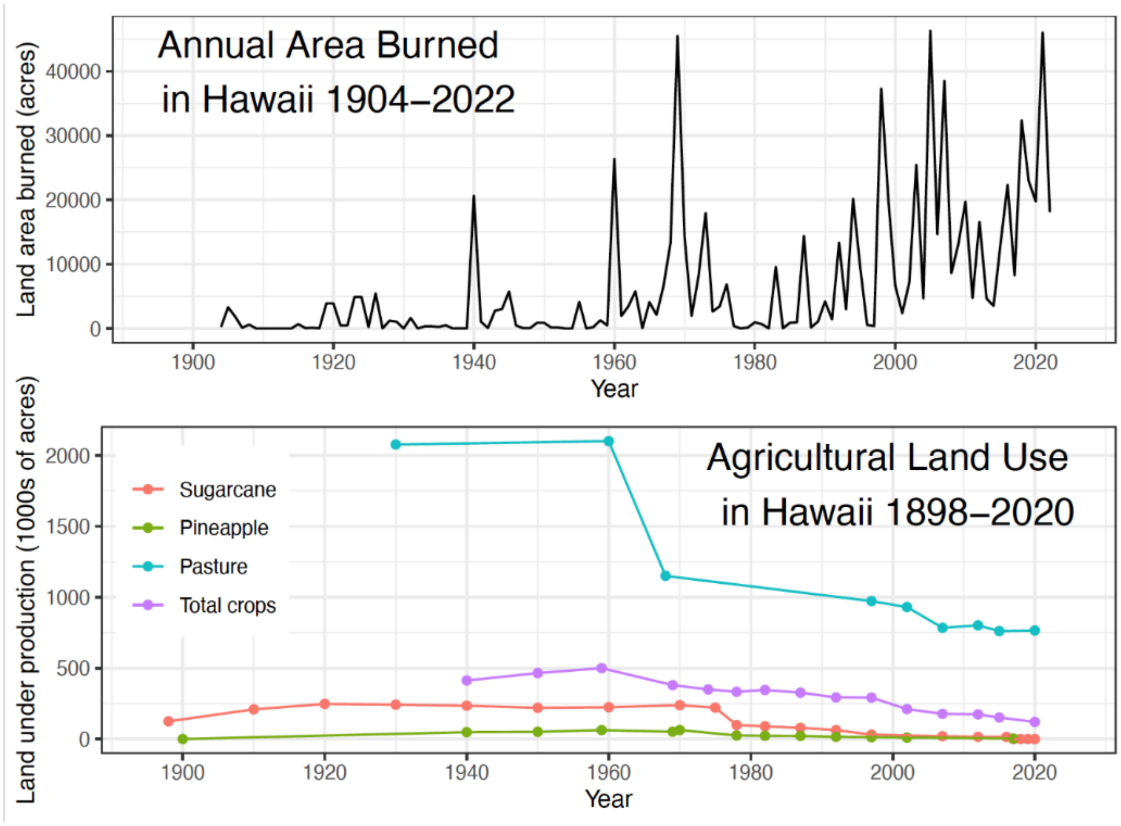
Maui's land use evolution is an important factor contributing to Maui's current wildfire risk levels. The *County of Maui Hazard Mitigation Plan Update* (2020) provides a helpful historical and cultural overview that illustrates the changing landscape of development and agriculture throughout the centuries:

> *The first inhabitants of the islands that make up Maui County arrived from the southern islands of Polynesia, approximately 800 to 1,000 years ago. These original inhabitants formed societies across the islands, but detailed prehistoric information is limited. European settlers arrived in the late 1700s. From that point onward, the islands of Maui County saw development that was similar but distinctive for each island. The towns of Hāna, Makawao, Wailuku, and Lahaina housed most of the native and arriving population in the early years after European contact.*
>
> *In 1848, Kamehameha III proclaimed the Great Māhele, or land division, establishing private ownership of lands in Hawaiʻi. Sugar planting and refining throughout Hawaiʻi was established between 1836 and 1861. In 1876, the Hawaiian Reciprocity Treaty with the United States allowed for duty-free admission of Hawaiian sugar to the U.S., resulting in a substantial increase of profits for island growers. With the massive growth of the sugar industry, the need for labor grew, resulting in the importation of workers from other countries. The pineapple industry began on Maui in 1890. By 1930, over 28 percent of Maui's cultivated lands were dedicated to pineapple.*
>
> *With a decline of the sugar and pineapple industries after World War II and bourgeoning economies on Oahu and the U.S. mainland, Maui lost 24 percent of its population between 1940 and 1960. In 1959, the Report of Land Use for the Island of Maui proposed that, to reverse the trend, Maui could work to capture a greater share of Hawaiʻi's tourist industry. The need for visitor facilities gave birth to the concept of the resort destination area, and in 1961 Kāʻanapali became the first of its kind in Hawaiʻi.*
>
> *As Maui's population grew, settlement patterns expanded rapidly, spreading out from existing population centers. Central, South, and West Maui have grown significantly in the subsequent decades with the birth of new subdivisions and visitor accommodations. Maui's rapidly expanding population eventually spread to the Upcountry area of the island, which experienced significant growth in the residential market beginning in the 1970s.*[4]

When agricultural operations relocated or left Maui between the 1970s to 1990s, the land became fallow, covered with extremely flammable buffelgrass and guinea grass (Figure 1). These changes

[4] https://www.mauicounty.gov/DocumentCenter/View/125977/2020-Maui-County-Hazard-Mitigation-Plan-Final

were a contributing factor for increased wildfire risk, occurrence, and acres burned on Maui in recent decades. Additionally, as residential areas developed on Maui, urban and suburban fuels increased.



Source: Pacific Fire Exchange[5]

Figure 1. Hawai'i Fire History and Agricultural Decline

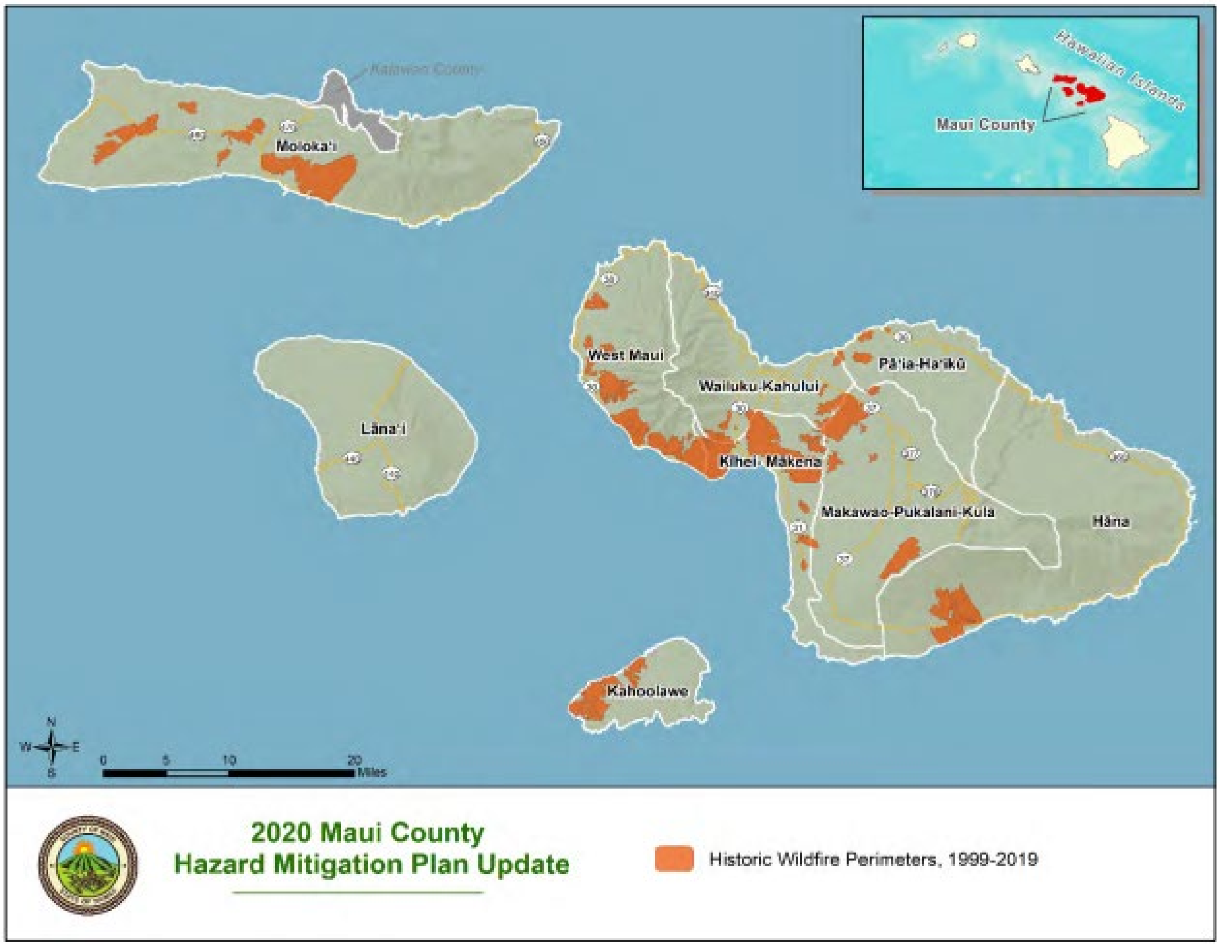
Maui's topographic features and land use history, coupled with extended drought, make the island more susceptible to wildfires. Weather conditions, especially unique island wind patterns due to Maui's topography, create challenges for monitoring and suppression of wildfire.

The *County of Maui Hazard Mitigation Plan Update* (2020) outlined historical wildfires on Maui between 1999 and 2019. During this 20-year period, 80 fires occurred within Maui County, including 28 in West Maui. Figure 2 illustrates the locations of historic wildfire perimeters during this period.

The *Western Maui Community Wildfire Protection Plan* (2014) noted that most of the Lahaina area was rated as extreme for overall wildfire risk.[6] The *Upcountry Maui Community Wildfire Protection Plan* (2016) mapped several areas in the Upcountry region with risk ratings varying from medium to high risk.[7] The *County of Maui Hazard Mitigation Plan Update (2020)* also rated wildfire risk across the county, labeling the West Maui area at high risk and the Upcountry area as low to medium risk.

[5] https://pacificfireexchange.org/resource/fire-data/
[6] https://www.hwmo.org/resource-library/western-maui-cwpp-2014
[7] https://www.hwmo.org/resource-library/upcountry-maui-cwpp-2016

This Plan also noted, “Maui County has experienced increased drought conditions over the last 30 years and is expected to experience increases in drought frequency and intensity as climate change brings warmer temperatures, decreased streamflows, and decreased precipitation. Drought conditions greatly increase the risk of wildfires. Further, as changing climate conditions make native species more vulnerable to competition from non-native species; continued increases in fire-prone non-native species could increase wildfire frequency and intensity in future.”

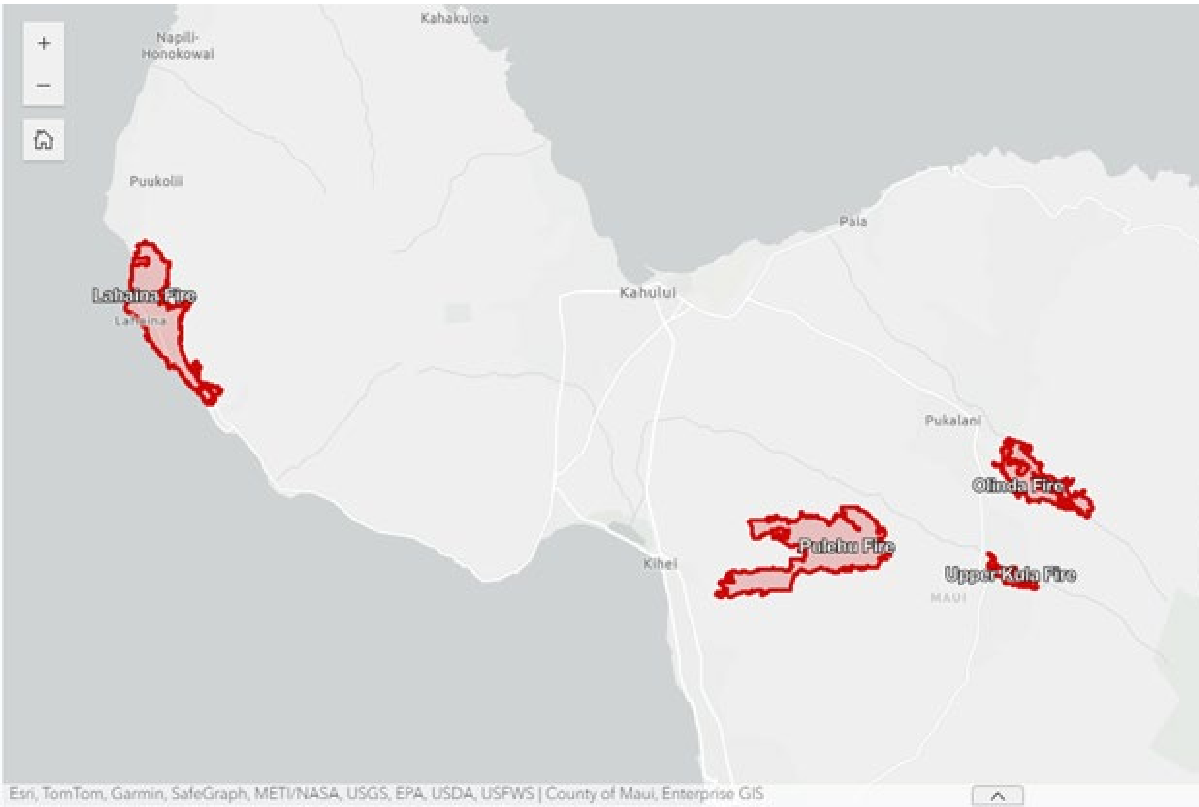


Source: 2020 County of Maui Hazard Mitigation Plan Update

Figure 2. Wildfires in Maui County, 1999-2019

3.3. August 2023 Event Overview

Throughout the day on August 8, 2023, four major fires erupted on the island of Maui: the Lahaina Fire, the Olinda Fire, the Upper Kula Fire, and the Pulehu Fire (see Figure 3). On August 9, 2023, the state government of Hawai’i issued a state of emergency for the entirety of the state followed by President Biden’s issuance of a federal major disaster declaration on August 10, 2023. The fires destroyed 2,173 structures across Maui. The MAT specifically focused field data collection and analysis on the areas impacted by the Lahaina and Upper Kula fires.



Source: mauirecovers.org

Figure 3. August 2023 Wildfire Extent Locations on Maui

The Lahaina fire burned 2,170 acres, including much of the downtown Lahaina Historic District, a designated National Historic Landmark. Lahaina was the capital of the Kingdom of Hawai'i for 35 years, and featured many important historic and cultural landmarks. The 3.4-square-mile area lost to the fire served as the commercial, residential, and cultural center of Lahaina. Ninety-six percent of burned structures were residential.

For more detailed information about the timeline and fire suppression efforts for the August 2023 fires on Maui, refer to the *Lahaina Fire Comprehensive Timeline Report* (Fire Safety Research Institute, 2024)[8] and the *2023 Wildfire-After-Action-Report* (County of Maui Department of Fire and Public Safety, 2023)[9].

[8] https://ag.hawaii.gov/wp-content/uploads/2024/04/FSRI-Lahaina-Fire-Timeline-Phase-1-Report-Press-Conference-240417.pdf
[9] https://www.mauicounty.gov/2023-Wildfire-After-Action-Report

Summary of the Lahaina Fire -- *Excerpt from Lahaina Fire Comprehensive Timeline Report*

In the days preceding August 8, 2023, Maui found itself in the crosshairs of potential disaster as Hurricane Dora approached from the south, passing approximately 500 miles offshore, it created a pressure gradient that meteorologists warned would bring damaging winds, low humidity, and an elevated risk of wildfires to the island. Recognizing the impending threat, several organizations including the National Weather Service (NWS), the Maui County Department of Fire and Public Safety, the Maui County Emergency Management Agency (MEMA), and the Hawai'i Emergency Management Agency (HI-EMA) issued numerous alerts about the possibility of high winds and extreme fire danger on August 8, 2023. In anticipation of hazardous conditions, MEMA partially activated the Emergency Operations Center (EOC) on the evening of August 7, 2023.

During the early morning of August 8, 2023, the predicted high winds arrived across central and western Maui. Trees toppled, utility poles fell, and power lines were downed, blocking critical roadways and making evacuation challenging.

Enabled by the dry fuels, sustained winds, and the dense urban landscape, a fire that began near Lahaina Intermediate School spread rapidly, overwhelming initial efforts to contain it. The origin of the Lahaina fire can be traced back to 06:35 (6:35 a.m.), when a fast-moving brush fire, later dubbed the "Lahaina AM fire" ignited near Ku'ialua Street and Ho'okahua Place. Intense winds, rocky terrain, a ravine, and utility poles with overhead electrical wires in the fire area would also complicate fire suppression efforts. Firefighters responded to the scene, employing private bulldozers and water tankers to construct perimeter lines and soak the fire area with water. They later reported that the fire was extinguished and returned to quarters at 14:17 (2:17 p.m.).

At 14:55 (2:55 p.m.) the "Lahaina PM fire" or "Ku'ialui fire" was reported at the same location as the earlier fire. This time, fueled by sustained high winds, the fire spread rapidly. Embers carried by the wind ignited unburned grassland areas downwind from the initial fire location and continued to spread, reaching homes and other structures. From there, the fire spread through direct flame contact, radiant heating, and flying embers. The high winds, funneling the fire into Lahaina Town and towards the Pacific Ocean, created a conflagration that overwhelmed the town's limited evacuation routes, some of which were blocked by downed utility poles and electrical lines. At times, people were forced to use the ocean for safe refuge.

Hawai'i Route 3000 (Lahaina Bypass), a primary evacuation route, was among the roadways impacted. Smoke, pushed low to the ground by the wind, made visibility difficult and soon overwhelmed the efforts of police and firefighters to evacuate the area. Many residents found themselves trapped, unable to escape the advancing flames and thick blinding smoke. On Lahainaluna Road, vehicles became stranded, and civilians were trapped by the rapidly encroaching fire. A similar scenario played out north on Kahua Street, where the fire's path of destruction would claim numerous lives. Responders and residents created several alternate evacuation routes by opening locked gates and clearing access to dirt roads in the area.

As the fire was moving quickly and roadways remained blocked, several crews of firefighters became trapped near Pauoa Street by the advancing fire and were overwhelmed by the flames. Fire apparatus became entangled by power lines or were unable to evacuate the area due to obstructions---and had to be abandoned, further hampering efforts to combat the growing blaze. One (1) firefighter rescued seven (7) colleagues, including an unconscious officer who required urgent medical attention. Numerous firefighters administered emergency care to the officer.

No longer just a wildfire, the fire had also become an urban conflagration, consuming more buildings than the firefighters were able to protect. Burning structures, vehicles, and vegetation all produced embers and became sources of radiant heat and flames. The fire quickly spread across Honoapi'ilani Highway (Hwy-30) and all the way to the ocean's edge.

As homes and other buildings burned, the water pipes failed, and water flowed unrestricted. Pressure in the water mains dropped to the point that there was no water coming from fire hydrants in some parts of Lahaina.

In the aftermath of this catastrophe, questions linger about the adequacy of warning systems, evacuation planning, and preparedness of communities for such extreme fire events. The tragedy serves as a sobering reminder that the threat of grassland fires, wildfires, and wildfire-initiated urban conflagrations, fueled by climate change and urban encroachment into wildland areas, is a reality that must be addressed with the utmost urgency and diligence--not just in Hawai'i, but around the globe.

While the physical scars of this disaster will take time to heal, the emotional toll on the people of Lahaina and the wider Maui community will be felt for generations to come. As the island and nation mourn the lives lost, the focus must also turn to learning from this tragedy, strengthening emergency response capabilities, and building more resilient communities that can withstand the increasing challenges posed by a changing climate and the ever-present threat of wildfires.

3.4. Purpose of the Study

Following the August 2023 fires, FEMA's BSDS Program, in conjunction with FEMA Region 9 and supported by STARR II, deployed a MAT to assess building performance and support resiliency to inform recovery. In September 2023, a pre-MAT was deployed to Maui to document damages and potential building successes in the Lahaina and Upper Kula Fires. The pre-MAT also assembled a list of key observations for further exploration during the full MAT deployment which would define the study parameters. In June 2024, the MAT deployed to Maui and worked with local agencies to assess damage to residential buildings. The MAT also studied the adequacy of current building codes and other relevant regulations based on observed post-disaster damages and undamaged properties. Upon conclusion of the field investigation, the MAT analyzed the field data, as well as other damage reports and studies by Federal, State and County government agencies. Finally, based on the analysis of data and reports, the MAT prepared conclusions and developed recommendations which are provided in Section 4 of this report and summarized in Table 1.

The purpose of the MAT study was to develop guidance and recommendations that can aid local officials and property owners to recover quickly and rebuild effectively to help mitigate future damage and losses from wildfires. Identifying building vulnerabilities and effective mitigation strategies to address wildfire can help focus recovery efforts to areas of most benefit. The recommendations resulting from this MAT summary report are intended to help the State of Hawai'i and Maui County outline a path forward for reconstruction that promotes resilient construction, repair, and alteration of buildings and the surrounding sites. The state and county also can use these recommendations to help guide and better prepare design professionals, contractors, and property owners for future hazard events through clear and wide-reaching communication.

4. Observations, Conclusions, and Recommendations

The MAT visited Maui in September 2023 and June 2024 and made observations related to residential buildings, including building envelope vulnerabilities, the importance of defensible space, and the need for regular, ongoing building and landscape maintenance. The conclusions and recommendations presented in this report are based on the MAT's observations in the areas studied and evaluation of relevant research *(see inset below on Limitations of Maui Fire MAT Observations).* The recommendations are intended to assist the property owners, builders, and State of Hawai'i as well as provide Maui County officials with resources for best practices that support recovery and help reduce future damage and impacts from wildfire. While other hazards exist, the recommendations in this document are focused on wildfire threats. Readers interested in additional resources are encouraged to review the extensive list contained within *Maui Wildfires MAT Recovery Advisory #1 (RA-1) Wildfire Recovery Resources for Maui.*[10]

Limitations of Maui Fire MAT Observations

The cornerstone of FEMA's MAT program is the concept of "observation, conclusion and recommendation," meaning that first-hand damage observations in the field by the MAT lead directly to supporting conclusions and recommendations. This concept has been effective for MATs historically addressing flood and wind hazard events such as Hurricane Katrina in 2005 (FEMA 549) and the 2008 Midwest Floods (FEMA P-765). However, it is less effective in wildfire MATs such as the 2021 Marshall Fire (FEMA P-2320) and the 2023 Maui Fire for the following reasons:

1) Limited degree of building damage. Unlike most flood and/or wind events where there are broad ranges of structural and non-structural damages, most fire events exhibit one of two extremes: minimal damage or complete destruction.

2) Difficulty in determining the precise hazard(s) that caused the damage. Flood and wind hazard event damages are relatively easy to observe and catalog. However, fire hazard event damages can be caused by a range of issues (e.g., direct flame contact, convection, radiation, embers and firebrands) that can be much more difficult to observe or distinguish.

3) Dependence on weather and response conditions. Flood and wind events have hazard impacts that can be tied to a few measurable building and site-specific vulnerabilities (e.g., structure type, location in the floodplain, flood depth, event wind speed). However, wildfire impacts depend on a broad range of conditions, including the weather at the time of the event (e.g., temperature, wind conditions, humidity) and the location and magnitude of the fire response (e.g., location of firefighting resources deployed near vulnerable structures.) Additionally, some fire-related issues cannot be measured or even determined without thorough, site-specific research.

In addition to observations collected by the pre-MAT and full MAT, current published scientific and engineering research was used to provide additional support to observations.

[10] https://www.fema.gov/sites/default/files/documents/fema_maui-wildfires-mat-ra1-wildfire-recovery-resources.pdf

Maui County has not adopted and does not enforce the International Wildland Urban Interface Code (IWUIC) or similar codes or standards focused on wildfire hazards. Most homes and neighborhoods damaged or destroyed in Lahaina, or elsewhere in Maui County, were not required by local building and fire codes to provide structural hardening for wildfire.[11] Well-established and well-known wildfire safety provisions for structural hardening (e.g., roof classifications, boxed eaves, façade materials, vent protection, decking requirements) found in nationally recognized codes, such as the IWUIC, were not explicitly required or provided for most of the homes in the impacted areas. Additionally, many homes impacted by the Maui wildfires were built prior to inception of the IWUIC in 2003. While Maui has had a residential building code since the late 1970's, a robust code with hazard resistant provisions was not adopted until inception of the State Building Code Council (SBCC) in 2007 and adoption of the International Codes (I-Codes) in 2018 with local amendments (2012 International Residential Code (IRC) and International Building Code (IBC)) and the State Fire Code (NFPA 1) in 2010.

Each component of a building's exterior plays a significant role in limiting potential structure ignition and spread from wildfires. Structural hardening, coupled with defensible space, is critical to increasing a home's likelihood of surviving a wildfire. While not part of this study, community resilience and infrastructure hardening should also be considered to provide a holistic defense against future wildfires.

Section 4.1 of this report summarizes observations, conclusions and recommendations related to structure and building envelope vulnerabilities (from the top of a structure down) that are well-established and well-known points of weakness in a building or home's exterior envelope. *Maui Wildfires MAT Recovery Advisory #4 (RA-4): Fire-Resistant Materials and Assemblies*[12] provides detailed concepts and requirements for design professionals and builders to better understand the fundamental fire performance of common construction materials. It also provides additional details to achieve specific fire-resistance ratings and sources for major residential construction assemblies.

Section 4.2 of this report summarizes observations, conclusions, and recommendations related to defensible space. Defensible space is an area up to 100 feet from a building that has limited combustible fuels (e.g., vegetation, debris, fuel tanks). This distance helps slow or stop the progression of wildfire and reduces the chance that the building will catch fire during a wildfire event. Given the density of homes throughout Maui, and especially in Lahaina, defensible space recommendations may be difficult to achieve. For this reason, neighbors are encouraged to work together to achieve the highest level of defensible space possible. Defensible space combined with structural hardening provides the highest level of wildfire resilience.

Section 4.3 of this report summarizes observations, conclusions, and recommendations related to structure, site, and community maintenance. In many communities, maintenance considerations can

[11] See *Maui Wildfires MAT Summary Report 1: Codes, Standards and Permitting* for more information.
[12] https://www.fema.gov/sites/default/files/documents/RA-4_MauiMAT_FireResistantMaterialsandAssemblies_Final508.pdf

be overlooked, but this MAT, as well as numerous post-disaster investigations, have observed that maintenance practices can have significant consequences for community wildfire resilience.

Note that when planning and designing for wildfire resilience it is important to recognize the interdependent relationship between structural hardening (Section 4.1) and defensible space (Section 4.2). The National Institute for Standards and Technology (NIST) Technical Note 2205, *WUI Structure/Parcel/Community Fire Hazard Mitigation Methodology* was developed in partnership between NIST, the California Department of Forestry and Fire Protection, and the Insurance Institute for Business & Home Safety (IBHS). [13] NIST Technical Note 2205 recognizes the interdependence of structural hardening and defensible space for effective wildfire resilience, which is illustrated by a “sliding scale” shown in Figure 4 and is directly applicable to the Maui wildfires. When structures are densely packed on small lots with little allowance for defensible space, then structural hardening must be significantly increased to maintain effective wildfire resilience. By contrast, when structures are farther apart on larger lots, more emphasis can be placed on defensible space to support for effective wildfire resilience. The sliding scale concept demonstrates that it is commonly a combination of techniques working together to achieve wildfire hazard resilience.

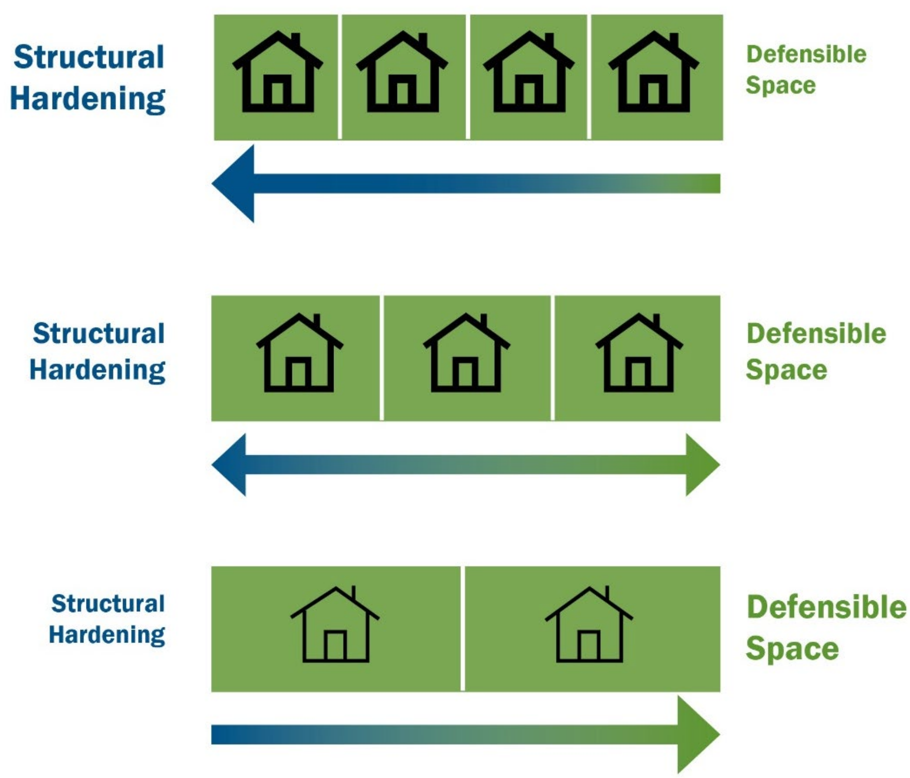


Figure 4. The “sliding scale” concept showing the interdependent relationship between structural hardening and defensible space for effective wildfire resilience.

[13] https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2205.pdf

Wildfire Resilience Through a Combination of Features

Shortly after the Maui wildfires, local and national news media outlets dubbed one house along the Lahaina coast as the "miracle house." The historic building survived the devastating Lahaina Fire, while its surrounding neighbors did not. While it cannot be determined precisely why this house survived when many others didn't, a combination of features likely contributed to its wildfire resilience (Figure 5). According to news articles from Honolulu Civil Beat and National Public Radio, the "miracle house" roof had undergone a detailed renovation that included replacement of the existing wood roof with a commercial grade metal roof.[14],[15] Metal roofs are more resistant to ember and firebrand penetration than a wood roof. Additionally, a 3-foot perimeter of wood mulch and other vegetation immediately surrounding the building was removed and replaced with river stones. Although the stone was intended to reduce the risk of termite damage and improve water drainage, it also helped provide defensible space (hardscaping) to resist fire spread toward the home. The news articles and the MAT concluded that the combination of structural hardening and defensible space, combined with a considerable amount of luck, allowed the "miracle house" to earn its name.

Source: Google Earth

Figure 5. Aerial image of the "miracle house" (left) and a street view of the house with a metal roof that provided structural hardening and minimal landscaping that provided defensible space (right).

4.1. Structure and Building Envelope Hardening

This section provides the Maui MAT observations, conclusions, and recommendations related to the following elements of the structure and building envelope vulnerabilities that require hardening to increase wildfire resistance:

- Roof Coverings and Assemblies (Section 4.1.1)

[14] https://www.civilbeat.org/2023/08/what-saved-the-miracle-house-in-lahaina/

[15] https://www.hawaiipublicradio.org/national-international/2024-09-17/these-houses-survived-one-of-the-countrys-worst-wildfires-heres-how

- Soffits and Vents (Section 4.1.2)
- Structural Framing and Exterior Wall Coverings (Section 4.1.3)
- Windows and Doors (Section 4.1.4)
- Accessory and Detached Structures (Section 4.1.5)
- Elevated Homes and Open Foundations (Section 4.1.6)

This section includes terminology to define the fire-resistance of materials and assemblies (see inset below). Refer to *Maui Wildfires MAT Recovery Advisory #4 (RA-4) Fire-Resistant Materials and Assemblies* for additional details.[16]

Fire-Resistance Terminology

- **Noncombustible** – A material that, as used and under the condition anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat.
- **Fire-resistant** – Fire-resistant materials possess characteristics that allow them to withstand fire and heat for an extended period. These materials are especially crucial for enhancing life-safety and property protection due to their ability to reduce the likelihood of ignition and slow the spread of a fire. Reducing the likelihood of ignition helps limit the size of a fire and loss potential. Slowing the spread of fire allows more time for evacuation, reduces life safety risks to the public and firefighters, and reduces damage to buildings and infrastructure. Fire-resistant building materials include asphalt shingles, treated fabrics, special coatings, etc.
- **Fire-resistance rating** – A technical term used to define the time, in minutes or hours, that an element, component, or assembly has withstood a standard fire exposure, as established in accordance with an approved test procedure appropriate for the structure, building material, or component under consideration (e.g., ASTM E119, ANSI/UL 263).
- **Assembly** – An assembly is any combination of materials or individual components constructed together to serve a purpose. For fire safety design, the purpose may include load bearing capacity, insulation, and integrity under fire conditions. A roof assembly, for example, is typically comprised of the roof deck, vapor barrier, insulation, roof covering, coatings, sealants, toppings, or any combination thereof. The details of the entire roof assembly determine its ability to achieve fire-resistance (e.g., 1-hour, 2-hour), not the fire performance characteristics of the individual materials or components that make up the assembly.

4.1.1. ROOF COVERINGS AND ASSEMBLIES

4.1.1.1 Observations

The MAT visited homes with roofs unaffected by the wildfire as well as those impacted by the wildfire, verified through post-fire aerial imagery. Most residential roofs in the impacted areas were

[16] https://www.fema.gov/sites/default/files/documents/RA-4_MauiMAT_FireResistantMaterialsandAssemblies_Final508.pdf

comprised of asphalt shingles or composite tile roof coverings attached to roof assemblies consisting of plywood or oriented strand board (OSB) sheathing supported by wood roof rafters or trusses. A few metal roofs, clay tile roofs, and wood shake roof coverings were also observed, but were less common. Most residential roof systems were low profile gable end or hip roofs with moderate to large overhangs. The roof lines were often complex with multiple levels, peaks, gables, and valleys due to additions or improvements to the structures over time. Studies of previous wildfires indicate that debris and embers can accumulate in these intersections and joints.

To help protect against fire, the entire roof assembly should satisfy the requirements for Class A when tested in accordance with ASTM E108 or UL 790. That is, the full roof assembly tested as an assembly should meet the requirements of Class A, not just the roof covering alone. Common roof coverings that achieve Class A ratings include most asphalt shingles, concrete-, brick-, or masonry-tiles, or metal panel/shingles.

Roof Covering Classifications

According to the *Society of Fire Protection Engineers (SFPE) WUI Handbook*, current building codes and standards identify the following three classifications of roof coverings for fire exposure:

Class A: The highest rating for roof coverings. Class A roof coverings are effective against severe fire exposure and tested per ASTM E108 or UL 790.

Class B: Roof coverings with this classification are effective against moderate fire test exposure.

Class C: Roof coverings with this classification are effective against light fire test exposures.

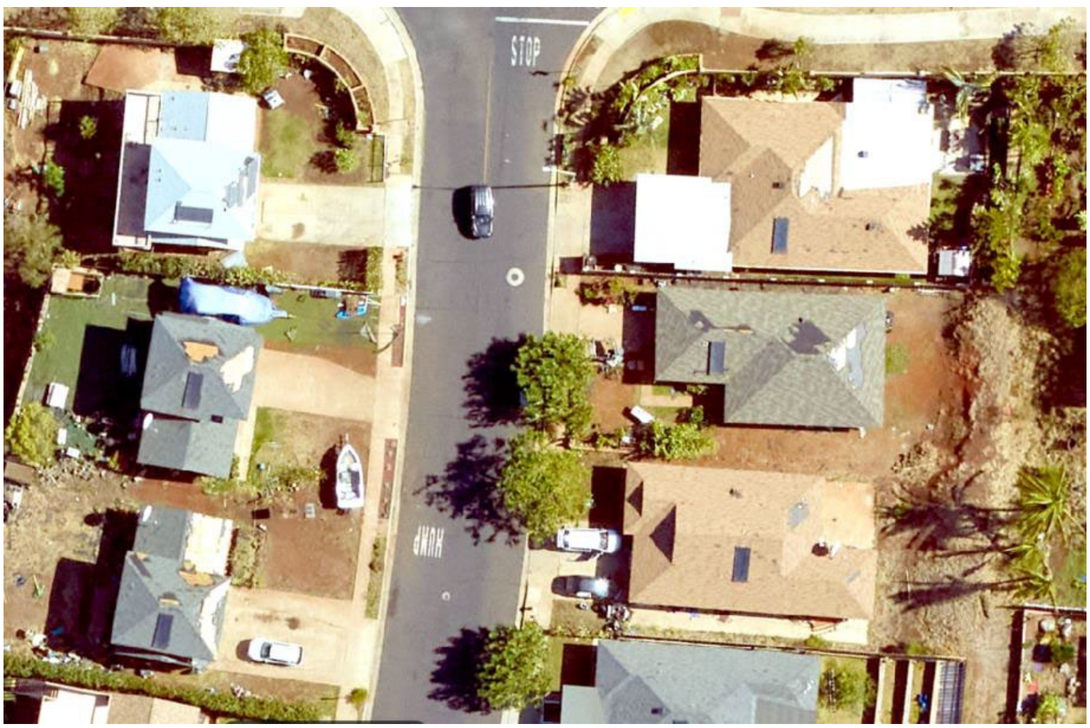
ASTM E108 Test Method: The intermittent flame exposure test provides steady airflow and a luminous gas flame applied intermittently at specific temperatures until all evidence of flame, glow and smoke has disappeared from the exposure surface or until failure occurs. Class A is exposed to 15 test cycles, Class B is exposed to eight test cycles, and Class C is exposed to three test cycles.

When designing a roof for new residential structures, important fire-resistant considerations include:

- Limiting the number of transitions, joints, abrupt geometry changes and elevation changes. Joints and elevation changes along with eaves and valleys in a roof can accumulate debris, increasing roof ignition vulnerability. Where possible, avoid a flat roof where debris accumulation is common.
- Using proper flashing at the joints between walls and porch roofs/lower roofs and roof edges; and
- Using noncombustible materials to construct roof expansion joints.

The MAT subject matter experts worked to understand the nature of roof damage caused by the Maui Fires. However, due to the complete destruction of more than 2,200 buildings in Lahaina and

Kula during the fires, it was difficult to determine if roofs were damaged by wind prior to ignition. It was uncertain how roofing systems contributed to structure-to-structure fire spread. However, in reviewing immediate post-damage aerial images, it appears that significant roof damage occurred due to wind (Figure 6) both inside and outside of the fire footprint. The wind damage to roofs included missing roof shingles as well as limited photovoltaic (PV) panel and limited structural damage. Specifically, the MAT observed that many asphalt shingle roofs lost shingles along the centers of the roof surface rather than along roof edges and ridges (Figure 7). The observed pattern of roof shingle damage differed from the loss of roof shingles along roof edges and ridge lines traditionally associated with high wind uplift pressures from hurricanes and severe storms. This could be evidence of localized wind turbulence produced by the fires, but additional research is necessary to verify this hypothesis. Removal of shingles revealed that many residential roofs were not protected by an underlayment, exposing combustible wood sheathing making the roof deck and other roof materials vulnerable to ignition as well as water damage from heavy rains. Coupled with the presence of complex roof shapes trapping embers against combustible roof decks and underlayments, the probability of roof ignition and interior water damage was high in Lahaina.



Source: Google Earth

Figure 6. Maui post-fire aerial image of roof cover damage to buildings.

Published research such as the IBHS Research Study *The 2023 Lahaina Conflagration* indicates that residential roofing systems are vulnerable to structure ignition due to radiant heat, embers, and direct flame contact (impingement).[17] When fires occur during high wind events, the roof covering

[17] https://ibhs.org/lahaina/

may become detached or dislodged, exposing combustible elements of the roof substructure (e.g., underlayment, wood roof deck, weather-resistant barriers, battens) as was seen in Lahaina. To limit potential wind-driven fire vulnerability, roof systems should be able to resist the uplift forces associated with design winds per the Maui Residential Building Code.

While research has attempted to understand the performance of asphalt shingles over the lifespan of a roof system, these studies have not typically considered the unique weather patterns of Maui. The consistent hot and humid environment, coupled with older roofs on the homes on Maui, may have contributed to the loss of asphalt shingles. Additionally, the increased wind speeds of August 2023 coupled with the wildfire may have created a turbulent wind environment. Roof systems are only tested for performance with straight-line winds, and it is unknown how the turbulent environment, coupled with the unique long-term aging of asphalt shingles on Maui, may have impacted their performance during the wildfire event.

Additional Wind Considerations

Maui is subject to multiple natural hazards. Observed roof framing at times lacked continuous load path construction and support for all gravity and wind loads corresponding to the site design, wind speed, roof height, exposure category, building location, and all required load combinations in accordance with the applicable building code.

Following the wildfires, the MAT attempted to identify wind damage to asphalt shingle roof coverings that potentially failed during the wildfires. The potential wind damage indicators included the following:

- The MAT observed many asphalt shingle roofs that appeared to be new, or in the process of being replaced, with new underlayment, in areas adjacent to buildings heavily damaged or destroyed by wildfire.
- The MAT observed many asphalt roof systems that had a tarp overlay in the post disaster aerial imagery, indicating likely roof cover loss.
- Discussion with local Lahaina residents indicated that roof pieces were detached and transported away from the home by the high winds.
- Many asphalt shingle roofs on residential buildings were found to have sections of shingles missing, and on other sites, loose shingles were found on the ground, where buildings remained intact (Figure 7).

Figure 7. Missing asphalt roof shingles were observed on an intact residential building in Lahaina (left). Asphalt shingles were scattered on the foreground adjacent to an intact multi-family residential building in Lahaina (right).

A few clay tile roof coverings on residential buildings were observed with missing or damaged tiles along roof edges and ridges (Figure 8), which suggests these roofs may have been damaged by high winds or windborne debris.

Figure 8. Missing clay roof tiles along roof ridge and edge of residential building in Lahaina.

The few metal roof coverings observed by the MAT appeared to perform well. The MAT also observed several single and multi-family residential buildings with wood shake roof coverings. These roof coverings were composed of two or more layers of 3/4- to 1-inch wood shakes and showed evidence that some top surface shakes were charred but not consumed by the fire (Figure 9). Although this could suggest positive performance on selected structures, most current fire research discourages the use of wood shake roof coverings in fire-prone areas.

Figure 9. Wood shake roof on a residential building in Lahaina, showing evidence of some surface shakes charred by fire.

Regardless of the type of roof covering used, residential roof assemblies on Maui observed by the MAT were constructed of plywood or OSB sheathing and supported by wood trusses or rafters. While some of these assemblies had an underlayment between the roof coverings and roof sheathing, many could not be observed in areas where the roof covering had been removed by the event. Flashing was observed on some building roofs. Where observed, metal gutters performed well provided they were properly attached to the roofline and well maintained, while vinyl gutters often melted (Figure 10). Most residential roof assemblies observed by the MAT had sufficient materials and connections within their load path, which withstood wind pressures and windborne debris from the Maui wildfires. While the shingles may not have remained intact during the wind event, the MAT did not observe any roof structural components damaged by wind. However, some roofs may have suffered isolated damage by wind or were damaged or destroyed due to inadequate fire protection of the roof covering and roof sheathing.

Figure 10. Melted vinyl gutters and melted window frame with lost glass pane on a residential building in Lahaina.

Many residential buildings on Maui featured rooftop PV panels, as well as solar water heaters. PV panels have become more popular throughout Hawai'i and are often a key component of charging stations for lithium ion batteries used in electric vehicles. Solar water heaters are required in new residential construction and are seen throughout Maui. The MAT observed that rooftop PV panels and solar water heaters generally performed well. However, there were a few instances where rooftop solar water heaters were damaged and rooftop PV panels were damaged in place or found destroyed on the ground (Figure 11). These PV panels or water heaters could have been damaged or dislodged from the building by windborne debris. The NFPA has conducted research on this issue. Refer to the *July 2023 NFPA Research Foundation Proceedings, Fire Safety and Photovoltaic Panels on Building Roofs Workshop* for details.[18]

Figure 11. Damaged solar water heaters observed on a residential building in Lahaina (left). PV panels found on the ground along a street lined with single-family residential buildings in Lahaina (right).

[18] https://www.nfpa.org/education-and-research/research/fire-protection-research-foundation/projects-and-reports/fire-safety-and-photovoltaic-panels-on-building-roofs-workshop

4.1.1.2 Conclusions and Recommendations

The lack of adequate roof coverings and assemblies contributed to roof damage, ignition and/or fire spread (see inset regarding roof covering classifications in Section 4.1.1.1). Ash, embers, sparks, and other burning material also may have lodged in unprotected roof penetrations, igniting a combustible roof deck or underlayment. The MAT provides the following conclusions and associated recommendations for roofing constructions and assemblies. For additional design and construction details to improve roof coverings and assemblies, refer to *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home*[19] and *Maui Wildfires MAT Recovery Advisory #3 (RA-3) Designing New Residential Structures to Decrease Wildfire Risk*[20].

Conclusion 1

Inadequate roof assemblies and/or combustible roof covers have contributed to ignition and/or fire spread.

Recommendation 1a:

Homeowners should install Class A roof assemblies. The entire roof assembly should satisfy the requirements for Class A when tested in accordance with ASTM E108 or UL 790. Thus, the full roof assembly tested as an assembly should meet the requirements of Class A, not just the roof covering. Common roof coverings that achieve Class A ratings include most asphalt shingles, concrete-, clay-, or masonry-tiles, or metal panel/shingles.

Recommendation 1b:

Maui County should amend the local residential building code to require a Class A roof assembly for all new residential construction. For additional design and construction details to improve roofing construction and assemblies, refer to *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home* and *Maui Wildfires MAT Recovery Advisory #3 (RA-3) Designing New Residential Structures to Decrease Wildfire Risk*. Maui County should consider amending the local building and residential code with the provisions in Table A, numbers 1-9, of the NIST Hazard Mitigation Methodology (HMM) guidance regarding roof systems.

Recommendation 1c:

Maui County should incorporate Section 507, Replacement or Repair of Roof Coverings, from the IWUIC into their local residential code. This requires that roof coverings on existing buildings that are replaced or have more than 25% of roof covering material replaced in any year meet the ignition-resistant construction requirements of the code.

[19] https://www.fema.gov/sites/default/files/documents/RA-2_MauiMAT_ReducingWildfireRiskToHome_Final508.pdf
[20] https://www.fema.gov/sites/default/files/documents/RA-3_MauiMAT_DesigningNewResStructures_Final508.pdf

Recommendation 1d:

Homeowners and designers should provide a noncombustible underlayment when replacing the roof or installing a new roof. When a roof profile provides for a gap between the roof covering and a combustible roof deck assembly shall include a 72-pound cap sheet that complies with ASTM D3909 (Asphalt Roll Roofing (Glass Felt) Surfaced with Mineral Granules). The cap sheet shall be rolled out over the entire roof deck. In lieu of the use of such a roll roofing product, fire-retardant treated plywood can be used. Such roof coverings shall also be blocked at eaves, ridges, and hips with a noncombustible material. Also, designers should specify the use of an approved penetration firestop system installed with a minimum positive pressure differential of 0.01 inch (2.49 Pascals) of water and tested in accordance with ASTM E 814 or UL 1479.

Conclusion 2

Roof structures with complex shapes and flat roofs can trap embers and increase the potential for ignition and fire spread.

Recommendation 2a:

When designing a new residential home roof, architects and designers should limit the number of joints, abrupt geometry changes and elevation changes, and maintain a roof slope. Joints and elevation changes in a roof, along with eaves and valleys, can accumulate debris and embers that increase roof ignition vulnerability.

Recommendation 2b:

For existing residential homes with complex or flat roofs, property owners, architects and designers should harden the roof structure using noncombustible roof coverings and metal roof flashing to protect roof eaves and valleys.

4.1.2. SOFFITS AND VENTS

4.1.2.1 Observations

The MAT observed that many residential buildings on Maui had large roof overhangs created by the extension of roof trusses and roof framing beyond the edge of the building. In continental U.S. residential buildings, the underside of these overhangs would typically be enclosed by soffits constructed of wood sheathing, metal, or vinyl panels that extend perpendicular from the top of the wall to the roof edge. Roof overhangs on Maui residential buildings observed by the MAT were typically larger than those observed in the continental U.S. Many roof overhangs on Maui were enclosed by soffit panels constructed of various materials (Figure 12, Left), but the underside of some residential roof overhangs on Maui were not enclosed by soffit panels. The MAT observed that roof overhangs protected by soffit panels constructed of ignition-resistant materials performed well, but vinyl soffit panels on Maui did not perform well when exposed to the wildfire. Additionally, the MAT observed some open roof overhangs without soffits. These roofs appeared to have performed well (Figure 12, Right), but wildfire mitigation guidance provided by FEMA and other agencies recommends roof overhangs in WUI fire areas be minimized or enclosed by a noncombustible soffit panel.

Figure 12. Typical closed Soffit on Maui residential building (left). Open soffits with small "birdhole" vents on residential units in Lahaina created by an extension of roof framing (right).

Vent openings covered by louvres were observed near the top of walls and along the gable ends of residential buildings (Figure 13), but fewer soffit or eave vents were observed. However, given the widespread destruction of buildings on Maui, the susceptibility of the vents trapping embers cannot be determined. Additionally, there were no indications that the louvred vents observed by the MAT were protected by noncombustible mesh to prevent ember intrusion.

Figure 13. Examples of gable end louvred vents.

4.1.2.2 Conclusions and Recommendations

Vents for plumbing, crawl spaces, dryers, soffit vents, attics, and other openings without proper design and/or screening can allow ember intrusion, which can cause a home to ignite. In residential design, reduce the size and number of vents if possible. Alternatives such as replacing under-eave vents with a soffited eave or enclosed eave using noncombustible weather-resistant material should be considered.

Where flood openings (hydrostatic vents) are necessary, the design should be consistent with the NFIP, Maui Residential Building Code, and Maui Floodplain Management Ordinances and all applicable code and ordinance appendices. In the 2021 and previous editions of the IWUIC, Section 504.10 requires ventilation openings to not exceed 144 square inches covered with a corrosion resistant mesh; however, it is unclear how a flood opening would perform given this requirement. In the 2024 Edition of the IWUIC, a performance option requires vents, regardless of size, to meet specific criteria regarding temperature exposure and combustibility. It is unclear if any flood openings have been tested to the criteria outlined in this code. The prescriptive requirements remain such that vents should not exceed 144 square inches. Flood opening covers should be noncombustible and must open automatically when exposed to floodwaters. Engineered flood openings with a solid metal exterior flap are recommended to reduce the chance of debris accumulation, which could ignite upon contact with embers or flames.

The MAT provides the following conclusions and associated recommendation for soffits and vents. Refer to *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home* for additional details on protecting soffits, eaves, and vents from wildfire damage.[21]

Conclusion 3

Vents and open eaves with exposed soffits may have contributed to fire spread/ignition.

Recommendation 3a:

Where exterior vents are required, designers should specify the use of ember- and flame-resistant vents. While not required by the Maui County Fire Code, the California Building Code Chapter 7A provides a list of vents that have been tested by the California State Fire Marshal or meet the requirements of *ASTM E2886, Standard Test Method for Evaluating the Ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement*. Specific recommendation per vent type:

- **Gable:** Where possible, homes should be designed without a gable vent. If a gable vent is present, ensure that the vent is ember and flame resistant.
- **Eave:** Design home with a soffited eave or enclosed eave using noncombustible material. Where undereave vents are present, replace with an ember and flame-resistant vent and add fire caulking around blocking.
- **Crawl Space:** Where possible and if compatible with design, design home with an unvented crawl space. Where an unvented crawl space is not possible, provide crawl space vents that are ember and flame resistant.
- **Dryer Vent:** Provide a metal flapper that remains closed.

Recommendation 3b:

Maui County should amend the Maui County Residential Code to require that all exterior vents be corrosion resistant and noncombustible. The designer should specify covering the vent with 1/8-inch stainless steel (choose stainless steel, when available, or corrosion resistant steel, when

[21] https://www.fema.gov/sites/default/files/documents/RA-2_MauiMAT_ReducingWildfireRiskToHome_Final508.pdf

stainless is not available) mesh. Dryer vents should include a metal flapper that remains closed when not in use.

Recommendation 3c:

Homeowners and designers should consider a design with limited eave overhangs for new construction. Regardless of size, eave overhangs should be enclosed by soffits composed of noncombustible materials to create an enclosed soffit, and any soffit vents covered by 1/8-inch mesh that is corrosion-resistant and noncombustible as well as ember- and flame-resistant.

Conclusion 4

Section 504.10, Vents, of the 2021 IWUIC requires ventilation openings to not exceed 144 square inches covered with a corrosion resistant, noncombustible mesh; however, it is unclear how a flood opening (hydrostatic vent) would perform with a mesh covering and whether current products meet the need.

Recommendation 4a:

FEMA should sponsor a study measuring the performance of flood openings with 144-square inch size limitation and covered with mesh.

Recommendation 4b:

The U.S. Fire Administration (USFA) should sponsor a code change proposal to the next edition of the IWUIC which provides additional language for 504.10 where flood openings are provided. FEMA should work with the flood openings industry to determine which flood openings can meet the performance criteria in the 2024 IWUIC Section 504.10.1.

Recommendation 4c:

NIST should consider specifically including guidance in the NIST HMM for flood openings.

4.1.3. STRUCTURAL FRAMING AND EXTERIOR WALL COVERINGS

4.1.3.1 Observations

Most buildings observed by the MAT were one-, two- and three-story single-family homes or multi-family residential structures constructed of wood structural framing with exterior walls sheathed in wood or fiber-cement siding or masonry framed buildings with exterior walls finished with paint or stucco (Figure 14).

Buildings constructed with noncombustible structural framing materials (e.g. masonry framing, concrete framing, stone exterior walls) performed better than wood-framed structures. The MAT observed a few multi-family residential buildings with metal studs destroyed by fire.

Figure 14. Wood-framed single-family residence with fiber cement siding in Lahaina (left) and painted masonry-framed single-family residence in Lahaina (right).

Buildings constructed with noncombustible structural framing materials (e.g. masonry framing, concrete framing, stone exterior walls) performed better than wood-framed structures. The MAT observed a few multi-family residential buildings with metal studs destroyed by fire.

Buildings that had exterior walls covered with noncombustible exterior siding performed better than buildings sheathed with combustible wood or vinyl siding (Figure 15). This was especially critical in Lahaina, where many residential buildings were spaced closely together. The MAT observed combustible exterior cladding present throughout residential neighborhoods on Maui.

Figure 15. Comparison of residential buildings with noncombustible exterior siding (left) vs combustible exterior siding (right).

4.1.3.2 Conclusions and Recommendations

Houses on Maui, and especially in Lahaina, were observed to be spaced closely together, increasing the potential for fire to spread from one structure to another (see Section 4.2.1). On all exterior walls, at least a 1-hour fire-resistant exterior assembly tested in accordance with ASTM E119 should be provided. For structures within 15 feet of an adjacent structure (such as a shed or a neighbor's home), stored combustible items, or unmanaged vegetation, designers should consider providing a 2-hour fire-resistance rated exterior wall. Additionally, designers should choose products that meet or exceed the 10-minute direct flame exposure test in ASTM E2707 or provide materials with a flame spread index less than 25 per UL723 or ASTM E2768. Designers should specify the use of noncombustible insulation inside wall cavities and seal exterior wall openings with fire-resistant caulk.

While ASTM E119 considers heat penetration through the wall, it does not address fire spread on the surface. The use of combustible exterior cladding, such as wood or vinyl siding, should be avoided even when wood cladding is noted to be fire retardant, due to the uncertainty on the long-term performance of fire-retardant treated exterior wood products in hot humid climates. Additionally, care should be taken when specifying the use of a metal siding material, as it may warp when exposed to heat. Noncombustible exterior wall covering, such as concrete masonry unit (CMU) blocks, cement board, brick, or three coat stucco is recommended. Note that the use of a noncombustible or ignition-resistant exterior wall covering does not supersede the need for a fire-resistant rated exterior wall assembly where there is potential for radiant heat and direct flame exposure. Limiting the number of aesthetic or architectural features that may trap embers or debris is recommended. In neighborhoods with small lots where homes are in proximity, the home should be designed so that window, door, and other openings are minimized on sides adjacent to other structures.

The MAT provides the following conclusion and associated recommendations for structural framing and exterior wall coverings. For additional design and construction details to improve structural framing and exterior wall coverings, refer to *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home*[22] and *Maui Wildfires MAT Recovery Advisory #3 (RA-3) Designing New Residential Structures to Decrease Wildfire Risk*[23].

Conclusion 5

The use of combustible exterior wall materials may make a residential structure more susceptible to ignition and fire spread.

Recommendation 5a:

Maui County should adopt language consistent with IWUIC 504.5 for Exterior Walls in the Maui County Residential Code, which requires exterior walls be constructed using one of the following methods: 1) fire-resistance-rated materials with a minimum 1-hour fire rating, 2) noncombustible materials, 3) fire-retardant-treated wood rated for exterior use and meeting the requirements of IBC Section 2303.2, 4) ignition-resistant materials meeting the requirements of IWUIC 503.2.

Recommendation 5b:

Where existing combustible cladding is present, replace combustible exterior wall covering with noncombustible material for the bottom two feet form ground. Add metal flashing to protect

[22] https://www.fema.gov/sites/default/files/documents/RA-2_MauiMAT_ReducingWildfireRiskToHome_Final508.pdf
[23] https://www.fema.gov/sites/default/files/documents/RA-3_MauiMAT_DesigningNewResStructures_Final508.pdf

bottom edge of sheathing.

4.1.4. WINDOWS AND DOORS

4.1.4.1 Observations

The MAT observed a wide range of doors and windows on Maui residential buildings. Homes in the area featured both single- and multi-pane windows. Windows can break due to radiant heat, direct flame impingement, high wind pressure, and windborne debris. Residential buildings with jalousie and single pane windows were observed to have higher rates of breakage from the fire event (Figure 16), but the precise cause of the window damage could not be determined. Based on research conducted by NFPA and other agencies, *Maui Wildfires MAT Recovery Advisory #3 (RA-3) Designing New Residential Structures to Decrease Wildfire Risk* indicates that jalousie and single pane windows are at substantial risk of breakage from fire. The MAT also observed a few large windows that may have been broken by high wind pressures or windborne debris (Figure 17). Most windows were not protected by shutters, but some were covered by mesh screens.

Figure 16. Examples of residential window damages from the Maui wildfires in Lahaina.

Figure 17. Large broken windows covered by plywood sheathing on residences in Lahaina (left) and Kula (right).

Combustible doors and non-fire rated glass windows and doors posed a risk for ignition and glass breakage. Due to the extent of the Maui wildfire destruction, the MAT observed few instances of entry door or garage door damage in buildings that survived the fires.

The MAT observed skylights in some residential buildings. Of the damaged skylights that were observed, it is unclear if they were properly designed to limit ember intrusion, if they may have been operable and left open, or if the frames failed and caused the skylight to fall out. A few older plastic skylights appear to have been damaged, but it is unclear if the damage was caused by radiant heat, windborne debris, or firebrands (Figure 18).

Figure 18. Older plastic skylight on a residential building in Kula damaged by wildfire.

4.1.4.2 Conclusions and Recommendations

Design decisions made regarding windows and doors can affect the performance of buildings during a fire or wind event. Designers should review whether the home is sited in a windborne debris region which may require additional window protection. Windows and doors should meet the design requirements for windborne debris regions. The MAT provides the following conclusions and associated recommendations for windows and doors. For additional design and construction details to improve doors and windows, refer to *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home*[24] and *Maui Wildfires MAT Recovery Advisory #3 (RA-3) Designing New Residential Structures to Decrease Wildfire Risk*[25].

24 https://www.fema.gov/sites/default/files/documents/RA-2_MauiMAT_ReducingWildfireRiskToHome_Final508.pdf
25 https://www.fema.gov/sites/default/files/documents/RA-3_MauiMAT_DesigningNewResStructures_Final508.pdf

Conclusion 6

Single pane and jalousie windows frequently fail due to fire exposure and debris impact.

Recommendation 6a:

Double paned windows, double paned with one layer tempered, wired glass, or fire-rated glass for fire resistance are recommended for window replacement. Single pane and jalousie windows should be avoided.

Recommendation 6b:

Homeowners and designers should select windows with metal framing. Avoid windows with wood or vinyl frames.

Recommendation 6c:

Homeowners should install noncombustible shutters, such as metal rolldown shutters, and noncombustible metal mesh screens to protect windows from windborne debris or firebrands.

Conclusion 7

Entry doors and garage doors are susceptible to damage from fire, high wind or debris impact.

Recommendation 7a:

Homeowners and designers should choose exterior doors without glass that meet a minimum 20-minute fire-resistance rating with metal door jambs. Where fire-resistance rating information is not available, choose a steel or solid wood core door that is at least 1-3/4 inch thick. Ensure that the door frame is also noncombustible.

Recommendation 7b:

Homeowners and designers should choose a noncombustible (e.g., metal) garage door without windows that meets a minimum 20-minute fire-resistance rating with metal flashing at the base. Consider purchasing a new garage door or reinforcing existing garage doors with girts and strengthening the wheel tracks to resist high winds in accordance with ASTM E330, ANSI/DASMA 108, or Florida Building Code TAS 202.

Recommendation 7c:

Property owners should replace wooden screen doors with metal doors and frames. If a screen is present, ensure the screen is at least 1/16-inch metal corrosion-resistant mesh.

Conclusion 8

Skylights are susceptible to breakage from radiant heat, direct flame impingement, or impact by windborne debris or firebrands.

Recommendation 8a:

Homeowners should remove old plastic "bubble" skylights with wood or vinyl framing and replace them with tempered glass pane skylights surrounded by non-flammable flashing with no exposed wood and sealed with noncombustible caulk. Operable skylights that can be opened should specify a stainless-steel screen with a 1/8-inch mesh opening on the inside.

Recommendation 8b:

Homeowners, architects and designers should consider a roof design without skylights when replacing an existing roof. This is especially important on steep slope roofs (i.e. roofs with a slope greater than 4:12 or 18 degree) where skylights are more susceptible to radiant heat or direct flame impingement.

4.1.5. ACCESSORY AND DETACHED STRUCTURES

4.1.5.1 Observations

Many single-family homes observed by the MAT had accessory structures, such as storage sheds or accessory dwelling units (locally known as ‘ohanas). The 2018 State of Hawai’i Building Code allows for an ’ohana on residential lots of 10,000 square feet or greater. However, in 2019, Maui County adopted Ordinance 4936, which amended the Maui County building code to allow for one ’ohana on residential and other selected zoning parcels up to 7,500 square feet and two ’ohanas on parcels exceeding 7,500 square feet. Storage sheds constructed of vinyl were often melted by the fire, while other accessory structures composed of the same materials as the main residence experienced the same or somewhat greater fire and wind damage than the main residence (Figure 19).

Figure 19. Accessory dwelling unit (‘ohana) behind main residence in Lahaina damaged by high winds during wildfire.

Additionally, many older single-family homes observed by the MAT had moderate to large carports. Many were attached to the home, but a few were detached. Although some carports experienced little damage from the wildfires, several of them featured elements that made them less structurally sound and more vulnerable to fire and wind damage than the rest of the home. These vulnerabilities include large roof overhangs with minimal support, lower quality building materials (e.g., particle board, single-pane windows), and hazardous/flammable materials stored out in the open (Figure 20).

Maui County allows carports to have zero separation between carport and adjacent properties. This allows for the carport to be directly adjacent to a neighbor's fence or structure, thereby reducing the spacing between buildings. The *Lahaina Incident Fire Analysis Report (Phase 2 Report)* released by the Hawai'i Attorney General in September 2024 noted that the density of buildings in Lahaina contributed to rapid fire spread, which is consistent with the MAT fire observations in Lahaina.[26]

Figure 20. House with attached carport in Lahaina, with carport side support wall constructed or repaired using leftover door panels.

Many buildings on Maui were separated by property fences constructed of one or more materials including wood, vinyl, metal, masonry, or stone. Some fences extended back to the main structure, while others were separated from the structure. Fences constructed of wood were highly vulnerable to fire damage and vinyl fences were prone to melting or warping during the wind-driven wildfires (Figure 21). In some cases where the fence was very close to or attached to the structure (within five feet), the burning fence may have led to ignition of the structure. Although not directly observed, findings regarding wood fence vulnerabilities and observed vinyl fence damage were consistent with the findings of NIST Technical Note 2228, *Wind-Driven Fire Spread to a Structure from Fences and Mulch,* published in August 2022.[27] By contrast, fences constructed of metal (chain link), masonry or mortared stone were often undamaged; in some cases masonry or stone fences may have limited structure-to-structure fire spread (Figure 22).

[26] https://ag.hawaii.gov/wp-content/uploads/2024/09/Maui-Phase-2-Report-Press-Conference-Final-20240913.pdf

[27] https://www.nist.gov/publications/wind-driven-fire-spread-structure-fences-and-mulch

Figure 21. Residential buildings with vinyl property fences melted or warped by wind-driven wildfire.

Figure 22. Homes with stone or masonry property fences that appeared to resist wildfire damage.

4.1.5.2 Conclusions and Recommendations

The MAT provides the following conclusions and associated recommendations for accessory and detached structures. For additional design and construction details to improve accessory and detached structures, refer to *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home*[28] and *Maui Wildfires MAT Recovery Advisory #3 (RA-3) Designing New Residential Structures to Decrease Wildfire Risk*[29].

Conclusion 9

Accessory or secondary structures create a potential source of ignition. Lack of adequate separation increases the risk of fire spread between structures. Residential design guidance to reduce wildfire damages should also apply to detached structures, such as an ‘ohana. Accessory structures, such as sheds and accessory dwelling units (‘ohanas), should be sited at least 15 feet from the home or

[28] https://www.fema.gov/sites/default/files/documents/RA-2_MauiMAT_ReducingWildfireRiskToHome_Final508.pdf
[29] https://www.fema.gov/sites/default/files/documents/RA-3_MauiMAT_DesigningNewResStructures_Final508.pdf

other combustible structures, storage areas or combustible materials like fences. If siting further than 15 feet is not feasible, design of the accessory structure should follow the recommendations in *Maui Wildfires MAT Recovery Advisory #3 (RA-3) Designing New Residential Structures to Decrease Wildfire Risk*. It is recommended that accessory dwellings be protected to the same level as the main residence. Carports must be open on at least two sides, but otherwise must meet the same design considerations for garages.

Recommendation 9a:

Property owners should allow for 30 feet separation between accessory structures and homes and 15 feet from lot lines. Maui County should consider providing guidance to homeowners where unpermitted buildings/structures exist for adequate setbacks.

Recommendation 9b:

Maui County should provide guidance on setbacks for planning and fire department response to reduce the risk of structure-to-structure fire spread. The Maui County Planning and/or building department should coordinate to enforce setback in new and existing construction.

Recommendation 9c:

Homeowners should replace small plastic or wood storage sheds with a metal shed. Position the shed so that the door does not face the main structure on the parcel. Design defensible space surrounding the shed and do not store flammable material within or next to accessory structures.

Recommendation 9d:

When designers and architects construct a new carport or replace an existing carport, the roof should be provided with a Class A roof assembly, the floor should be noncombustible, and the carport ceiling and walls should also be designed with noncombustible materials with 1-hour fire-resistance ratings.

Recommendation 9e:

Maui County building code requirements and enforcement mechanisms should be amended to ensure proper fire-rated separation walls designed/constructed between residences and carports. The fire rating for carports/houses should be increased to 15 feet of the neighboring property line or within 30 feet of an adjacent structure. Additionally, building codes and enforcement mechanisms should be amended to ensure that a proper fire-rated separation wall is designed and constructed between a house and a carport.

Conclusion 10

Combustible fencing was located close to residential buildings, increasing ignition vulnerability.

Recommendation 10:

Property owners should install combustible fencing that follows the same defensible space requirements as other vegetation and landscaping elements located within five (5) feet of the house (also known as Zone 0, as described in *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home*). Ideally, all fencing should be removed to at least five (5) feet from the home so it is located outside defensible space Zone 0, and any combustible fencing beyond five (5) feet from the home should be replaced with noncombustible fencing in accordance with *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home.* Where removal of fencing within 5 feet of the home or replacement of combustible space beyond five (5) feet is not possible, replace combustible fencing within five (5) feet of the home with noncombustible fencing to minimally improve defensible space.

4.1.6. ELEVATED HOMES AND OPEN FOUNDATIONS

4.1.6.1 Observations

Although many wood-frame and masonry homes on Maui were constructed with slab-on-grade or crawlspace foundations, the MAT also observed many elevated homes constructed on open foundations. Elevated homes with open foundations are commonly built in Lahaina for flood protection and in Kula for siting on slopes or to enhance views. Open foundations used to elevate the homes were typically masonry piers and timber pilings or columns. Though not currently in effect in Hawai'i, Section 504.6 of the IWUIC requires that elevated buildings or structures enclose the area between the floor deck and the ground with exterior walls in accordance with Section 504.5. There is currently insufficient guidance on flood considerations for foundations in the IWUIC.

The MAT also observed several homes elevated with post and pier foundations consisting of timber posts resting on a foundation block at grade without connectors or fasteners between posts and the foundation block or between the foundation block and the ground other than the weight of the supported structure. These post and pier foundations were traditionally used to support old plantation-style modest dwellings throughout Hawai'i, but many remain on Maui and have been adapted over the years to support single-family homes (Figure 23). While post and pier foundations can resist gravity (dead and live) loads and small lateral and uplift forces, the lack of lateral support connections in these foundations make them highly vulnerable to damage or collapse during flood, high wind, or seismic events.

Figure 23. Maui residential building supported by post and pier foundation.

The MAT observed that elevated homes on open foundations were more vulnerable to ignition in the wildfires:

- Elevated homes expose more of a structure's underside, which includes flammable wood framing and wood floor decking surfaces.
- Elevated foundations are more vulnerable to fire damage than slab-on-grade or crawlspace foundations and may act as ladders to carry fire from the ground to the elevated structure (Figure 24).
- Residents frequently use the underside of elevated homes for storage, including combustible materials (Figure 25). Maui County Ordinance Number 5603 allows for the storage of vehicle and other goods at the underside of an elevated home; however, combustibles stored underneath residential buildings increase the risk of structure ignition.

Figure 24. Home in Lahaina consumed by fire was elevated on masonry piers.

Figure 25. Elevated foundation homes with items stored underneath.

4.1.6.2 Conclusions and Recommendations

The MAT provides the following conclusions and associated recommendations for elevated homes and open foundations. For additional design and construction details to improve elevated and open foundations, refer to *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home*[30] and *Maui Wildfires MAT Recovery Advisory #3 (RA-3) Designing New Residential Structures to Decrease Wildfire Risk*[31].

Conclusion 11

The lack of fire resistance of the underside of elevated homes increases the likelihood of fire spread from the exterior to the interior of the home. Storage of combustibles impact fire spread and ignition potential. Maui County Ordinance Number 5603 does not support fire safety.

Recommendation 11a:

When designing a new, elevated home, architects, designers, and builders should add a minimum of 1-hour fire-resistance on the underside of the home. Installation of at least two layers of 5/8-inch Type X gypsum can add fire resistance to the underside of existing elevated homes. All spaces should be sealed with fire-resistant caulk. Fire-resistant, rated floor separation and other provisions should be considered for elevated structures. The substructure should be constructed of fire-resistant materials (e.g., reinforced concrete, masonry).

Recommendation 11b:

Maui County should revise County Ordinance 5603 to address fire resistance. Specifically, Maui County should adopt a local ordinance to prohibit storage of combustibles under homes.

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30 https://www.fema.gov/sites/default/files/documents/RA-2_MauiMAT_ReducingWildfireRiskToHome_Final508.pdf

31 https://www.fema.gov/sites/default/files/documents/RA-3_MauiMAT_DesigningNewResStructures_Final508.pdf

Recommendation 11c:

Where a home is elevated and skirting is provided, the skirting should be noncombustible. The noncombustible skirting should have an opening less than 1/8-inch to decrease the chance of ember intrusion under the home.

Conclusion 12

Homes spared from the Maui wildfires may be susceptible to multiple types of hazard events. The MAT observed many homes that experienced little to no structural damage but remain vulnerable to the effects of wind, fire, flood, and seismic forces. In some cases, the connections between the structural members represent weak links in the wind load path vulnerable to failure. Post and pier foundations do not provide adequate load path connection and can fail during multiple hazard event types including wildfire.

Recommendation 12a:

Homeowners should evaluate and retrofit existing homes for flood, fire, wind, and seismic vulnerabilities. Homeowners should hire design professionals to evaluate the existing structure to determine if it can carry at least 75 percent of the design load per the 2018 International Existing Building Code. If it cannot, wind retrofits with continuous load path systems in accordance with FEMA P-804, *Wind Retrofit Guide for Residential Building*s (FEMA, 2010) can be installed. Homeowners can also consider wind retrofit techniques set forth for varying protection levels of FEMA P-804 to holistically improve the hazard resistance of homes. Similarly, homeowners can review flood retrofit techniques from FEMA 499, *Home Builder's Guide to Coastal Construction* (FEMA, 2010) and seismic retrofit techniques from FEMA P-50-1 *Seismic Retrofit Guidelines for Detached, Single-Family, Wood-Frame Dwelling*s (FEMA, 2012).

Recommendation 12b:

The 2018 State of Hawai'i Residential Code Section R401.5 requires post and pier foundations for new construction designed in accordance with accepted engineering practice. Homes with this foundation type should be retrofitted with lateral support connections to resist flood, wind, and seismic forces in accordance with building codes and standards.

Conclusion 13

Section 504.6 of the IWUIC requires that buildings or structures have underfloor areas enclosed to the ground with exterior walls in accordance with Section 504.5. The area under the elevated home is often used for storage or as a carport. The code does not provide a requirement for fire resistance of the underside of these homes.

Recommendation 13a:

USFA should propose a code change to the 2027 IWUIC which would require fire resistance of the underside of an elevated structure.

***Recommendation 13b*:**

Inconsistency exists in Section 504.6 of the IWUIC which requires elevated structures to have exterior walls that meet the requirement of 504.5. The IWUIC does not include floodplain management and building code breakaway wall requirements for velocity flood zones. FEMA should submit a code change proposal to the IWUIC which would address the fire safety of elevated homes with breakaway walls or provide guidance on how to meet the criteria of IWUIC Section 504.5 with breakaway walls.

Conclusion 14

There are gaps and conflicting guidance in the IWUIC. Current IWUIC guidance for underfloor areas may cause confusion in areas where breakaway walls may be required by the NFIP. There is a lack of direct guidance where homes are elevated due to flood risks and are required to have breakaway walls.

Recommendation 14a:

The International Code Council (ICC) should provide guidance in the IWUIC (Section 504.6 of 2021 IWUIC) for elevated structures in flood-prone regions based on NFIP regulations and the American Society of Civil Engineers (ASCE) 24 Standard requirements.

Recommendation 14b:

ICC should add a section to reference fire safety in foundations in IWUIC.

4.2. Defensible Space

Defensible space is an area up to 100 feet from a building that has limited combustibles to help slow or stop the progression of wildfire and reduce the chance that it will catch fire during a wildfire event. Defensible space, coupled with structural hardening, is critical to increasing a building's likelihood of surviving a wildfire.

4.2.1. OBSERVATIONS

Most residential building parcels throughout the Lahaina and Kula fire areas had a range of defensible space deficiencies. Common deficiencies observed in the field included:

- Lack of adequate defensible space
- Overgrown or unmanaged vegetation
- Hazardous and non-native plants
- Storage of combustible materials
- Lithium-ion (Li-ion) batteries

Small parcel sizes observed throughout the impacted and unimpacted neighborhoods of Lahaina and Kula limited homeowners from incorporating defensible space best practices on their own property. This resulted in residences proximate (e.g., within five to 30 feet) to their property line or their neighbor's home with insufficient defensible space, compounded by a lack of fuel treatments or other forms of defensible space on the adjacent neighbor's property (Figure 26). Many of the neighborhoods impacted by the Lahaina fire featured densely spaced buildings with limited fire separation distances (i.e., less than 10 feet of separation) (Figure 27). At the time of the fire, local planning, building and fire codes did not incorporate wildfire hazard and risk assessments as part of the planning or development process. *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home* provides guidance and best practices for defensible space considerations on Maui.[32]

Source: Google Earth

Figure 26. Aerial imagery showing limited distances between residential buildings in Lahaina.

[32] https://www.fema.gov/sites/default/files/documents/RA-2_MauiMAT_ReducingWildfireRiskToHome_Final508.pdf

Figure 27. Examples of limited separation distances between residential buildings in Lahaina.

Adequate separation to allow defensible space was not observed for most secondary or accessory structures in the fire-affected areas. Separation distance or setbacks did not appear to be required or enforced for accessory structures or new construction.

Observed overgrown vegetation between residential structures increases the risk of spot fire ignition from embers (Figure 28). This circumstance may lead to structure ignition and structure-to-structure fire spread. Non-native and invasive plants are prevalent in Maui County. During MAT interviews, it was noted that there is a lack of specific resources (and knowledge of existing resources) regarding fire-resistant plants recommended for use in Hawai'i.

Figure 28. Examples of homes in Lahaina with overgrown vegetation directly adjacent to the building.

The MAT noted that many homes stored combustible materials, including fixed and portable propane

tanks, close to dwellings (Figure 29). Open foundation areas under the floor and open carports were commonly used storage areas for household items (Figure 30). Storage or placement of potentially combustible outdoor furniture was common in yards, patios, and against the sides of homes (Figure 31).

Figure 29. Propane tanks are commonly used in and around residential buildings.

Figure 30. Examples of open storage of household items in carports and underneath floors.

Figure 31. Examples of homes with outdoor furniture or other potentially combustible material stored on patios and in yards.

Lithium-ion (Li-ion) batteries were noted, including PV energy battery storage units and electric vehicles parked near buildings. Both commercial and residential codes and standards provide fire safety provisions for energy storage systems (ESS) but do not explicitly address the risk of wildfire. Within the fire safety standards for ESS, protections for Li-ion battery ESS are more limited. ESS provisions are new additions to the model building codes, first appearing in the 2018 IRC and significantly expanded in the 2021 IRC. NFPA 855 also provides fire safety protections for residential ESS in parallel with the 2021 IRC, including unit spacing, unit capacity limitations, fire detection, and location. These codes were not in effect during 2023, and limited or no protections were codified or enforced when most buildings in the fire footprint areas were constructed.

During the June 2024 MAT field visit, residential site debris removal operations were in progress to remove fire and ash debris from damaged and destroyed structures and objects. The MAT observed that gravel was spread on the residential building footprint area for erosion control following debris clearance. Gravel and other hardscape materials, such as concrete pavers, can be used to provide a non-flammable ground cover to serve as defensible space within five (5) feet of the house (Zone 0). However, field interviews with property owners indicate that there is a lack of awareness of how gravel can be incorporated into the landscape post-reconstruction to serve as defensible space. These field interviews also identified property owner concerns about the cost to remove the gravel. Property owners did not consider the use of the gravel remaining after demolition to support the development of defensible space during reconstruction. Figure 32 and Figure 33 provide observed uses of gravel and hardscaping materials used.

Figure 32. House with gravel acting as a non-flammable ground cover.

Figure 33. Concrete and stone hardscape creates a non-flammable ground cover around the perimeter of the home.

4.2.2. CONCLUSIONS AND RECOMMENDATIONS

The MAT provides the following conclusions and associated recommendations for defensible space. For additional design and construction details to improve defensible space, refer to *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home*[33] and *Maui Wildfires MAT Recovery Advisory #3 (RA-3) Designing New Residential Structures to Decrease Wildfire Risk*[34].

Conclusion 15

Parcel sizes in densely spaced neighborhoods may limit property owners' abilities to satisfy defensible space best practices. Because lot sizes generally are fixed and cannot be changed, defensible space needs to be established at the neighborhood or community level where possible.

Recommendation 15a:

Maui County planning and zoning departments should consult wildfire experts to develop local ordinances, standards, and guidance documents for communal defensible space in overlapping defensible space zones. Guidance documents should include audiences such as homeowners' associations and individual property owners.

Recommendation 15b:

Maui County should integrate wildland fire safety concepts throughout the regulatory process from planning and zoning to design and permitting to construction to long-term maintenance and enforcement. This may include wildfire protection planning, environmental impact reports that include wildfire risks, zoning, codes and standards, general plans, landscaping codes, and safety elements. This may also include increasing structure separation distances in residential zoning ordinances in high wildfire risk areas.

Conclusion 16

Gravel placed on properties to backfill foundations following post-fire debris removal provides an opportunity for cost-effective defensible space improvements, especially within five (5) feet of the home, if property owners are educated about this option.

Recommendation 16:

Homeowners should consider using gravel remaining after demolition to create defensible space in the 0-5 feet area surrounding the house. This may include use in walkways and next to the home instead of wood or other combustible mulch.

[33] https://www.fema.gov/sites/default/files/documents/RA-2_MauiMAT_ReducingWildfireRiskToHome_Final508.pdf
[34] https://www.fema.gov/sites/default/files/documents/RA-3_MauiMAT_DesigningNewResStructures_Final508.pdf

Conclusion 17

The presence of overgrown vegetation, including hazardous/invasive plants, near buildings increases fire risk.

Recommendation 17a:

The University of Hawai’i or Hawai’i Wildfire Management Organization (HWMO) should review existing resource materials on fire-resistant native plants from sites such as Plant Pono[35] and educate property owners on best choices for fire-resistant native plants and landscaping in the State of Hawai’i.

Recommendation 17b:

Property owners should remove hazardous, invasive and non-native vegetation within the defensible space of any buildings. Only native fire-resistant plants should be planted.

Recommendation 17c:

Owners should regularly check their properties to trim and remove overgrown vegetation surrounding their homes. Particular attention should be focused on overgrown and overhanging tree limbs located within five (5) feet of the home in accordance with *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home*.

Conclusion 18

The presence of combustible materials, such as propane tanks, adjacent to and within buildings potentially contributed to fire spread and growth.

Recommendation 18a:

Property owners and tenants should not store combustible items (e.g., barbeque grills, firewood, generators, gas-powered yard equipment, furniture) or portable propane tanks around or underneath the home, including lanais, decks, carports, and open foundations.

Recommendation 18b:

Homeowners should place propane tanks a minimum of five (5) feet away from all combustibles. The location of portable propane tanks should be evaluated in defensible space in accordance with *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home*. Additional detailed language regarding size and location of tanks can be found in NFPA 1140, *Standard for Wildland Fire Protection* (2022).

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[35] https://plantpono.org/top-10-fire-resistant-plants-hawaii/

Recommendation 18c:

Large permanent propane tanks should either be (1) provided with 15 feet of separation, (2) behind a fire separation wall, or (3) buried to limit impact during a wildfire event and anchored to resist buoyancy during a flood event (if located in the regulatory floodplain).

Conclusion 19

PV energy systems, solar hot water heaters, electric vehicles, and other systems that store energy in Li-ion batteries pose an environmental and fire hazard if ignited. Though NFPA 855 and the 2021 International codes provide fire separation standards for some Li-ion battery systems, Hawai'i and Maui County have not yet adopted these standards. Additional protections against wildfire may be needed as this technology becomes more prevalent.

Recommendation 19a:

The State of Hawai'i and Maui County should adopt the latest published editions of the IRC, IFC, and IBC that provide expanded protections for battery storage systems and solar arrays.

Recommendation 19b:

The NFPA, in coordination with FEMA, USFA and ICC, should collaborate with a recognized fire testing laboratory (e.g., Underwriters Laboratories Standards & Engagement (UL), Southwest Research Institute, Intertek) to evaluate provisions in the International Codes that provide mandatory protection for energy storage systems and augment as appropriate to provide protection against damage and ignition of these systems resulting from wildfire.

4.3. Maintenance

This section describes the MAT's observations related to maintenance of buildings and surrounding property. Home and property maintenance are important for reducing risk to wildfire.

4.3.1. OBSERVATIONS

Owners often neglect building and property maintenance. Maintenance may be neglected because the owner is busy and/or has limited financial resources for maintenance or is unaware of the maintenance needs (particularly in the case of homes used by the owner as rental properties). Neglect of maintenance can also occur on a community level, especially in the case of large unoccupied parcels where maintenance responsibilities can be unclear. Lack of attention to maintenance can increase wildfire impacts and damages.

Due to the large number of buildings destroyed by the Maui wildfires, the MAT was unable to observe all maintenance issues. Based on a review of available information, there were several key maintenance issues that increased the risk of damage in the Maui wildfires to homes and the community, including:

- Deferred home maintenance increased the risk of fire exposure. This included loose or missing roof shingles or tiles that were not repaired or replaced to help prevent embers from getting trapped, and gutters filled with vegetative debris (due to a lack of gutter covers) that may have ignited by embers and spread to the structure. Homes with complex roof shapes (Figure 34) or upcountry homes with chimneys can be particularly vulnerable to debris or ember accumulation.

Figure 34. Example of Maui home with complex roof shape subject to debris or ember accumulation.

- Storage of items outside homes, including flammable materials, increased the risk of home ignition and structure-to-structure fire spread. Storage in open carports or on narrow side lots near adjacent buildings increased the potential for fire spread for slab-on-grade homes, while those with open foundations featured storage on the underside of the house (see Section 4.2.1).

- Homes lacked management of vegetation (Figure 35). Some roofs had vegetative debris accumulation or overhanging tree limbs, and other property owners appeared to have dumped yard waste into gulches (see Section 4.2.1).

- Unmanaged vegetation in large open space and wildland space (Figure 36), discussed in Section 3.1.1, combined with a lack of local ordinance or guidance on vegetation management on vacant lots can contribute to an increased community-wide risk of fire ignition and fire.

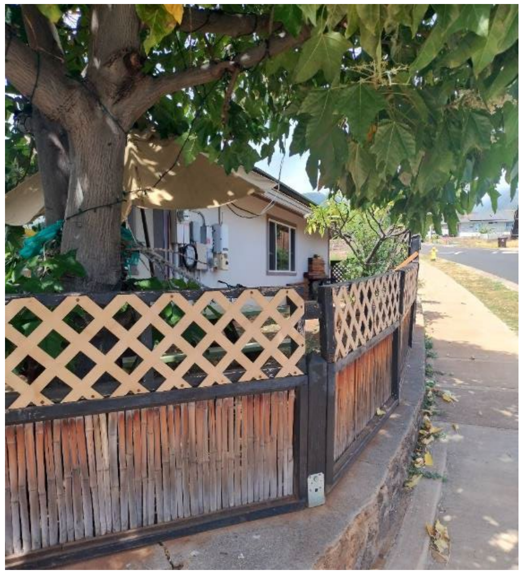

Figure 35. Maui home with lack of vegetation management from overhanging trees.

Figure 36. Examples of large parcels of unmanaged vegetation.

4.3.2. CONCLUSIONS AND RECOMMENDATIONS

The MAT provides the following conclusions and associated recommendations to address maintenance issues. For additional suggestions to improve maintenance, refer to *Maui Wildfires MAT Recovery Advisory #2 (RA-2) Reducing Wildfire Risk to Your Home*[36] and *Maui Wildfires MAT Recovery Advisory #3 (RA-3) Designing New Residential Structures to Decrease Wildfire Risk*[37]*.*

[36] https://www.fema.gov/sites/default/files/documents/RA-2_MauiMAT_ReducingWildfireRiskToHome_Final508.pdf

[37] https://www.fema.gov/sites/default/files/documents/RA-3_MauiMAT_DesigningNewResStructures_Final508.pdf

Conclusion 20

Increased vegetation of non-native grasses may have influenced fire spread. Lack of maintenance of trees, shrubs and other vegetative debris around buildings presents a fire risk, particularly on roofs, chimneys and gutters.

Recommendation 20a:

Maui County should adopt an ordinance to ensure maintenance of vegetation by the property owner. The Hawai'i Department of Natural Resources should support Maui County to develop vegetative management regulations. Multiple stakeholders including the Maui County Fire Department should facilitate development of vegetation maintenance requirements and enforcement protocols.

Recommendation 20b:

Homeowners should remove yard waste and roof debris to reduce flammable fuels. Chimneys, roof valleys, and gutters should be maintained to avoid debris accumulation.

Conclusion 21

Vegetative debris increased the vulnerability of the community and homes to wildfire.

Recommendation 21a:

Maui County should improve public education for proper disposal of vegetative debris and encourage residents to use "green waste" bins for yard waste pickup.

Recommendation 21b:

Maui County should require defensible space setbacks for properties adjacent to gulches. Maui County should restrict dumping of yard waste into gulches and provide alternatives for the public to properly dispose of yard waste, such as a green dump facility or woody materials utilization facility.

Conclusion 22

Large unmaintained properties led to increased risk of ignition and fire spread hazards outside and into communities, increasing the risk of structure/property loss and damage.

Recommendation 22a:

The State of Hawai'i and Maui County should adopt vacant lot and weed abatement ordinances for public and private landowners to increase maintenance of undeveloped lands, vacant parcels, and absentee properties. This could include various disincentives, such as automatic fines on property taxes (refer to Napa County and Ventura County Fire in California for precedence). Maui County departments including Planning, Fire, and Parks and Recreation need to be involved to integrate across county departments.

Recommendation 22b:

Maui County should provide property owners with guidance on how to increase resilience of their own property if neighboring properties are non-compliant. Provide allowances for defensible space easements and consider providing tax relief to property owners who donate property to community gardens, native vegetation nurseries, or other well-maintained purposes.

Conclusion 23

Debris in gutters may increase fire spread/ignition via roof edge.

Recommendation 23:

Homeowners should install non-corrosive, metal noncombustible gutters, gutter covers and roof drip edge, or consider alternative water drainage. Homeowners with open gutters should keep them clear and regularly remove debris.

Conclusion 24

Storage in open carports may increase ignition potential and fire spread to the home and to adjacent properties. Storage of hazardous/flammable materials may have contributed to fire spread and/or ignition.

Recommendation 24:

Property owners and tenants should be provided guidance from StaySafe.org or similar organizations about safe storage of items in carport/garage areas, such as the use of appropriate metal cabinets with locks for hazardous or flammable materials.