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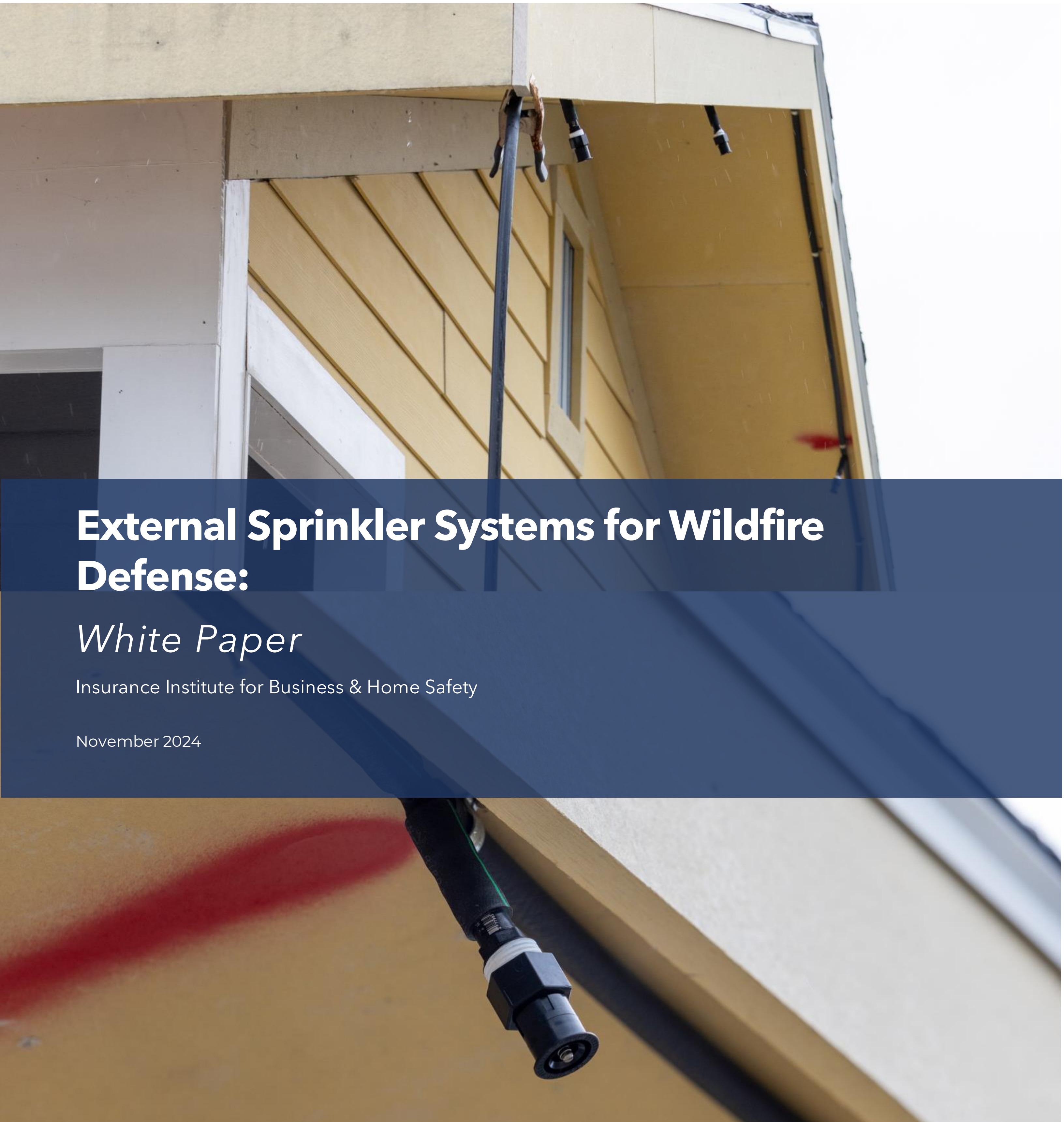

External Sprinkler Systems for Wildfire Defense:

White Paper

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Executive Summary

With the increasing frequency, intensity, and severity of wildfires leading to conflagration, there is a growing need to develop mitigation strategies for communities and homeowners to meaningfully reduce their risk profile. Extensive experimental testing and post-fire analyses have determined the vulnerability of a home from embers, radiant heat, and flames. While mitigation actions have been developed to reduce these vulnerabilities, new alternatives have entered the market employing existing technology for internal fire suppression to protect structures externally from wildfire. Sprinkler systems have been a topic of much debate for wildfire defense, yet limited methodical research exists on their real-world effectiveness. Before their adoption, many unknowns surrounding the external use of sprinkler systems as a defense against wildfire need to be addressed with research.

Key Takeaways

- Passive wildfire mitigation strategies (e.g., Class A roof, noncombustible siding, 0–5-foot noncombustible zone around the house, etc.) for community and parcel level mitigation should never be replaced by active strategies (e.g., external sprinklers).
- Standard performance criteria for external sprinkler systems must be developed for real-world, high-intensity wildfire conditions rather than simply extending the use-case of internal or landscape irrigation sprinkler systems.
- Significant questions remain unanswered about the efficacy of external sprinkler systems during high-intensity wildfire conditions, particularly the effects of strong wind on the level of coverage and evaporation rates.

To be fully effective, sprinklers depend on critical infrastructure (i.e., water, electrical) to function, and this infrastructure may be unavailable or overtaxed at the time of need.

Background

Wildfire mitigation strategies for buildings can be broadly categorized into two types: passive and active. Passive strategies are implemented when there is no immediate wildfire threat and focus on long-term benefits, primarily involving the use of fire-resistant materials, landscape designs that limit fire pathways, designed fuel breaks, and proper management of connective fuels around structures. While some passive mitigation elements require periodic maintenance to ensure effectiveness, these strategies are always in place and do not require immediate human actions during a wildfire. In contrast, active strategies require action when exposure is expected. Some active strategies are deployed shortly before wildfire exposure (i.e., embers, radiant heat, and flames), and have a limited effective service life. Other active strategies need to be implemented when there is no immediate wildfire threat but will require additional actions, infrastructure support (i.e., electrical power, water supply, etc.), and systems to provide the defense. These strategies utilize two main principles to protect the substrate material: (1) shielding from heat, such as thermal blankets and intumescent paints, and (2) pre-wetting agents, including fire protective gels and external sprinklers (Kadel, Hedayati et al. 2021).

Sprinkler Systems in a Wildfire Environment

The need to protect life and property from internal fires using fire sprinklers dates to the early 1800s. Since the installation of the first modern sprinkler system, the effectiveness of internal fire sprinklers in detecting fire, slowing fire spread for life safety protection, and maximizing fire suppression response has been extensively studied and proven. As wildfires increasingly impact the built environment, external application of these systems is being considered for external wildfire defense of structures in lieu of or as an additional level of protection to passive systems.

Figure 1. Example of an external sprinkler system for wildfire defense installed on a rooftop. Image courtesy of Steve Quarles.

Currently, there appears to be a scarcity of published research focusing on external sprinkler systems. Determining the effectiveness of a sprinkler system is easier within a controlled environment inside a building as opposed to an external system subjected to the chaotic outdoor environment. Most evolving technologies like these systems outpace the development of standardized test methods to evaluate their performance and establish a minimum performance threshold for product approvals. As a result, the technical guidance available for designing such systems relies heavily on anecdotal evidence, knowledge from related fields (e.g., farm irrigation, internal sprinklers), and engineering judgment (Green 2019). Only in recent years have researchers begun to explore the efficacy of sprinklers when used outdoors in a wildfire environment, as these systems came to market as a means to combat conflagration.

In the United States, there are currently no standardized test methods for assessing the effectiveness of external sprinkler systems nor is there a minimum performance requirement for these systems. Since 2012, Australia has provided guidance on water spray systems in AS 5414-2012. Many of the commercially available systems in the United States utilize landscape irrigation sprinkler heads and piping, which can include plastic components and be prone to heat-induced failures. Additionally, these systems often include moving parts, contrary to the guidelines outlined in AS 5414-2012 which requires the exclusion of moving parts to minimize the risk of malfunction (Green 2019). Nevertheless, the demand for additional protection has prompted both the market and homeowners in wildfire-prone regions to adopt external sprinkler systems. These sprinklers are commonly installed on the roof, under eaves, and covered areas to pre-wet the roof, siding, and the area immediately surrounding the home. In some cases, sprinklers are also installed at greater distances from the structure, particularly on larger properties.

Post-event investigations have revealed that embers play a crucial role in the spread of fires (Maranghides, Link et al. 2021, Quarles, Standohar-Alfano et al. 2023). External sprinkler systems primarily focus on mitigating this risk of ember exposure to a building. In optimal conditions, external sprinkler systems pre-wet the surroundings of homes and quench embers when they land within the footprint of the system. These systems may also be able to suppress small, low intensity spot fires if sufficient water reaches them. However, nothing replaces the combined benefit of creating defensible space around a structure to reduce the exposure and implementing retrofits to a structure to increase the resilience of the external building materials. For external sprinklers to be considered as an additional level of protection, the design criteria for these systems needs to be established and tested under realistic wildfire conditions including at a large scale. The current unknowns surrounding the effectiveness of these systems are listed below.

Engineered System:

An external sprinkler system needs to be designed, installed, and maintained to a standard with known performance criteria to be effective in defending a building from exposure to a high-intensity wildfire. The established performance criteria need to account for realistic high wind conditions. The engineered system for external use during wildfire exposure should have a standard like the NFPA 13D Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes for internal sprinkler systems.

Effects of Elevated Wind Speeds on Level of Coverage:

High winds during wildfires can significantly affect the dispersion of water droplets from external sprinklers. As droplets fall, wind causes droplets to break up, producing a broad drop size distribution. As wind speeds increase, droplets break up even more leading to smaller and smaller droplets that are more easily carried away by the wind. Since wildfires are usually accompanied by elevated wind speeds, the effectiveness of external sprinklers during a fire relative to their intended design coverage comes into question. Consequently, the intended footprint of the external sprinkler system can be highly variable and dependent on the wind flow characteristics. Patches of over-wetted areas may form, while other areas may not receive any moisture at all. These coverage issues are further exacerbated by the effects of rapid evaporation in hot, dry, and windy conditions typical of a high-intensity wildfire. Numerical simulations—supported by experimental findings—indicate that wind can cause as much as 40% of the sprayed water to drift downwind of the building and up to 20% of the water evaporating (Green and Cooper 2022).

The same strong winds that affect water droplet dispersion also effectively transport embers. Wind direction and speed becomes more complex and less uniform across a community as topographic features, vegetation, the built environment, and other variables impact the wind flow down to a sub-parcel level. Consequently, embers can attack the components of the home from all directions and angles. Embers with enough thermal energy can land on a vulnerable exposed material or pass through vents and land on a vulnerable interior material leading to ignition. It is unknown if the current systems on the market are engineered to protect against the entry of embers through vents of all types and locations on a building.

Effectiveness in Compact Communities:

The primary advantages of external sprinklers are to pre-wet the area around a home and external surfaces and to even extinguish small spot fires near a home. However, the movement of water droplets after impacting surfaces—particularly on vertical surfaces—remains poorly understood. After hitting vertical surfaces, some fraction of water droplets is absorbed by the surface while others splash or run off. In densely built communities, as strong winds accelerate through open spaces between buildings and water splashes onto vertical surfaces in small droplets, it is likely that a significant portion of the water disperses. Where droplets do reach the structure, there is a lack of understanding of the potential thermal shock from rapid cooling of glass and siding. A nearby structure engulfed in flames poses an additional challenge to the effectiveness of an external sprinkler system as the ability of the currently available systems to reduce thermal exposure from a neighboring burning structure remains highly questionable.

System Operation and Infrastructure Needs:

Some external sprinkler systems feature automated activation mechanisms, which are often user adjustable. As wildfires approach, homeowners who have invested in such systems can manually activate the system hours before the wildfire reaches their home. Additionally, users can modify the duration of operation. Extrapolating from existing social science research on actions during extreme events, it would seem plausible that most homeowners would run the system continuously as a perceived way to lower the risk to their property as much as possible. When considering the mass use of these systems, without rigorous test methods to ensure efficient water usage, the demand on the water supply could have devastating impacts for first responders. There have been several recent examples of municipal water supply systems ceasing to function during conflagrations including in the town of Paradise, CA during the Camp Fire and in Lahaina, HI during the Lahaina Fire. Loss of the municipal water supply impacts the ability of first responders to protect the community at large and would render the external sprinkler system ineffective if it is solely reliant on municipal water. Therefore, each external sprinkler system should have its own stand-alone water supply.

When the water source is pool or well water, external sprinklers need a pump to pump the water to the system. The pump needs an electrical power supply to activate, operate, and maintain the optimal flow of water for the duration of need. However, during conflagrations, the fire itself almost always impacts the electrical power supply to a community, and de-energization often occurs to protect the life safety of citizens and first responders operating within the fire impacted area. Thus, the system needs a standalone generator or battery to provide the electrical power and a dedicated pump to provide the optimal flow of water, each of which could become a hazard itself. Furthermore, there remains a lack of understanding regarding the level of protection needed to keep generators, piping, and pumps operating under high-intensity wildfire conditions.

Due to the design of the system—including water flow and coverage area requirements—and water supply limitations, it is often not feasible for the entire system to operate at the same time. To account for these limitations, external sprinkler systems are designed to function in a series of zones. When one zone is in operation, the other zones in the system are not running which is similar to the function of a landscape irrigation system. While a zone is off, the effect of water evaporation from the hot, dry, and windy conditions is further exacerbated.

Conclusion

Like all rapidly evolving technologies which are attempting to meet an immediate market need, it is imperative to develop testing standards that keep pace. It is these standards that set the design criteria and minimum performance requirements. This document intends to raise awareness of these concerns and offer guidance for future research, prior to use of such systems without adequate standards in place. The first steps toward integrating these systems as a tool should be to develop a standard for installation of external sprinkler systems and to determine the minimum flow rate required to maintain a defined wetting footprint under realistic strong wind and high-intensity wildfire conditions. These steps will not only set a performance requirement but will also ensure that adequate infrastructure is in place to support the large-scale deployment of exterior sprinkler systems without hindering the activities, effectiveness, and safety of first responders. Consequently, active wildfire mitigation strategies (e.g., external sprinklers) should never be used in lieu of passive mitigation strategies (e.g., Class A roof, noncombustible siding, 0–5-foot noncombustible zone around the house, etc.) to defend homes and communities from wildfire.

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