RESEARCH

Smoke Alarms in U.S. Home Fires

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Key Findings

Smoke alarms were present in three-quarters (74%) of reported home[i] fires in 2012-2016**.** Almost three out of five home fire deaths in 2012-2016 were caused by fires in properties with no smoke alarms (40%) or smoke alarms that failed to operate (17%).

The risk of dying in reported home structure fires is 54% lower in homes with working smoke alarms than in homes with no alarms or none that worked.

When smoke alarms were present in reported fires considered large enough to activate them, they operated in 88% of the fires, 71% of the deaths and 81% of the injuries.[ii]

People who were fatally injured in home fires with working smoke alarms were more likely to have been in the area of origin, involved in the ignition, to have fought the fire themselves, to have a disability or to be at least 75 years old. They were less likely to have been sleeping than were people who died in fires without working smoke alarms.

Hardwired smoke alarms (with or without battery backup) were found in 48% of reported home fires in properties with smoke alarms; smoke alarms powered by batteries only were found in 46% of such fires. Almost two-thirds (65%) of the deaths from fires in homes with smoke alarms were caused by fires in properties with battery-powered alarms.

In the 2011 *American Housing Survey* (AHS), three out of five (61%) respondents who reported having smoke alarms said their alarms were powered by batteries only. [1]

When present, hardwired smoke alarms operated in 94% of the fires considered large enough to trigger a smoke alarm. Battery-powered alarms operated 81% of the time. Power source issues, including missing or disconnected power batteries, dead batteries, or disconnection from or other AC power issues, were the most common factors when smoke alarms failed to operate.

Compared to reported home fires with no smoke alarms or automatic extinguishing systems (AES) at all, the death rate per 1,000 reported fires was

- 23% lower when battery-powered smoke alarms are present but AES are not;
- 42% lower when smoke alarms with any power source are present but AES are not;
- 63% lower when hardwired smoke alarms are present but AES are not; and
- 90% lower when hardwired smoke alarms and sprinklers are present.

[i] Homes include one- or two-family homes, including manufactured homes, and apartments or other multi-family housing.

[ii] Firefighter casualties are not included in this analysis.

Introduction

Smoke alarms have become such a common feature in U.S. homes that it is easy to take them for granted. These devices have alerted countless households to developing fires. This report provides the latest information about smoke alarms in home fires reported to local fire departments in the U.S. Most estimates in this report were derived from the U.S. Fire Administration's (USFA's) National Fire Incident Reporting System (NFIRS) and the NFPA's annual fire department experience survey. At present, 2016 is the most recent year of NFIRS data available.

While "smoke alarms" are not the same as "smoke detectors" in systems, NFIRS does not distinguish between the two. Except where specified, the term "smoke alarm" in this analysis is used inclusively for all fire detection equipment. Estimates of specific types of detection (smoke, heat, combination, etc.) are available in the supporting tables for this report.

Figure 1 shows that in 1977, less than one-quarter of all households had smoke alarms. Home smoke alarm usage increased rapidly in the late 1970s and 1980s. Telephone surveys since 2000 found that 96-97% of the surveyed U.S. households reported having at least one smoke alarm.[2] Based on these results, roughly five million households still have no smoke alarms.

A recent study by the National Institute of Standards and Technology noted that these surveys excluded those without phones and could include social desirability bias Such bias occurs when respondents report what they believe is the "proper" answer rather than the actual situation. Consequently, the author suggested that actual smoke alarm utilization is more likely to be 92%.[3]

Figure 2 shows that the number of reported fires fell sharply in the 1980s as home smoke alarms became more common.[4]

Figure 1. Growth in home smoke alarm usage 1977-2010

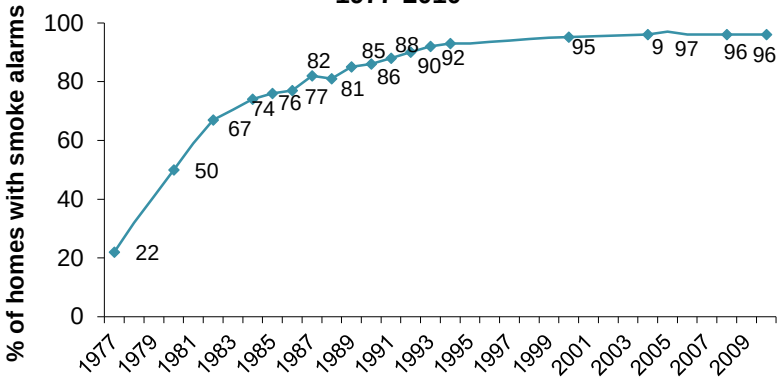


Figure 2. Reported home structure fires 1977-2017

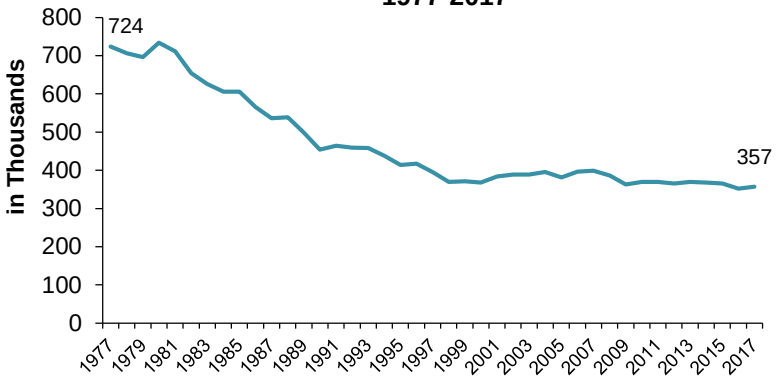
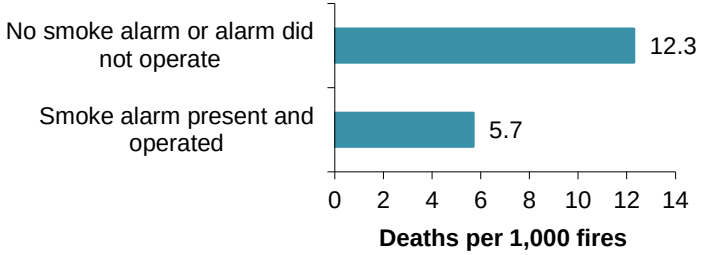


Figure 3 shows that the risk of dying in reported home structure fires is cut in half in homes with working smoke alarms. The death rate per 1,000 reported home fires in 2012-2016 was more than twice as high in homes that did not have any working smoke alarms, either because no smoke alarm was present or because an alarm was present but did not operate, as it was in homes with working smoke alarms.

Figure 3.
Death rate per 1,000 reported home fires by smoke alarm status: 2012-2016



Which fires are reported? What counts as a fire?

The 2012-2016 U.S. national estimates of smoke alarm performance in reported home fires, are, by definition, limited to fires reported to local fire departments. Two issues come into play here. Activations of monitored fire detection systems often result in a fire department response. This results in more minor fires being reported in properties with this protection. These systems are often found in public areas of apartments or other multi-family housing. Smoke alarms operated in 70% of reported fires in apartments or other multi-family housing compared to 45% of fires reported in one- or two-family homes. In many cases, the occupants have already handled the situation. Occupants of properties without monitored systems may not find it necessary to call the fire department for such minor fires.

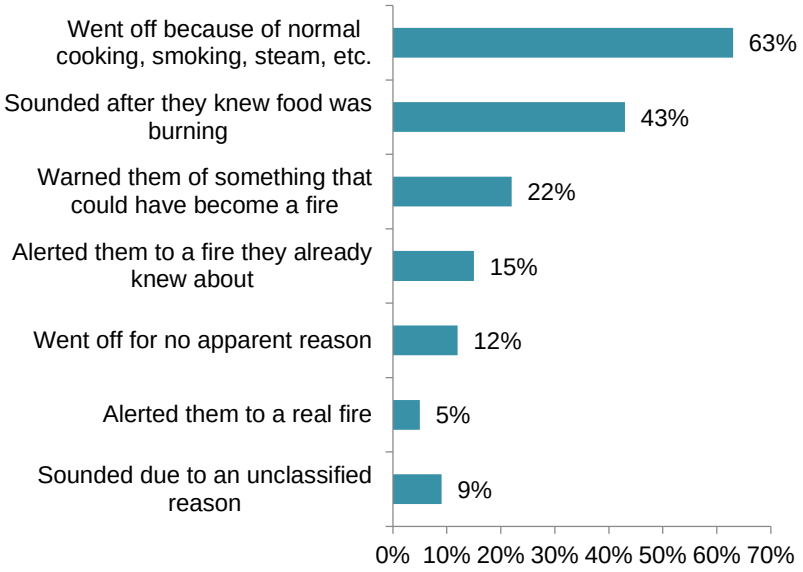
The Consumer Product Safety Commission (CPSC's) *2004-2005 National Sample Survey of Unreported Residential Fires* found that 97% of home fires were handled without fire department assistance.[5] The same study found that both reported and unreported fires decreased since their 1984 survey.

NFPA commissioned Harris Poll survey questions in 2010 to learn more about smoke alarm activations. The 43% whose smoke alarms had sounded at least once were asked: **"**What do you think caused the smoke alarm to go off in the last year?" Cooking was cited as the reason by roughly three out of four (73%) respondents. Eight percent mentioned low battery chirps. None of the respondents said that a fire caused the activation. Only one answer was allowed.

Respondents were then asked to answer a series of questions about the last time the smoke alarm went off. These were phrased as "Did it?" questions to be answered either "yes" or "no." The results, shown in Figure 4, indicate several fire-type situations. More than one in five said the sounding alarm warned them of something that could have become a fire. Smoke alarms are traditionally considered tools for fire protection, not fire prevention, yet this response suggests that they frequently alert occupants to situations that might be called "almost-fires." With prompt occupant action, the situation is corrected and no recognizable fire occurs.

This suggests that smoke alarms have played a role in reducing the occurrence of unreported fires.

Figure 4. The last time a smoke alarm sounded, it...



Cooking is clearly a factor in unwanted activations. Beginning in 2020, manufacturers seeking UL listing for their smoke alarms and smoke detectors will be required to demonstrate that the devices are resistant to cooking and other nuisance alarm sources while activating within 3 minutes to burning polyurethane foam.[6] Studies to assess the impact of this new technology on unwanted alarms and on both reported and unreported fires will be needed.

Smoke Alarm Status in Reported Fires

Fire departments responded to an estimated average of 355,400 home structure fires per year during 2012-2016. Smoke alarms, including those in fires too small to activate them, operating smoke alarms, and those that failed to operate, were present in three-quarters (74%) of reported home fires. Figure 5 shows that smoke alarms were present and operated in more than half of these fires.

Almost three out of five home fire deaths resulted from fires in properties with no (40%) or no working (17%) smoke alarms.

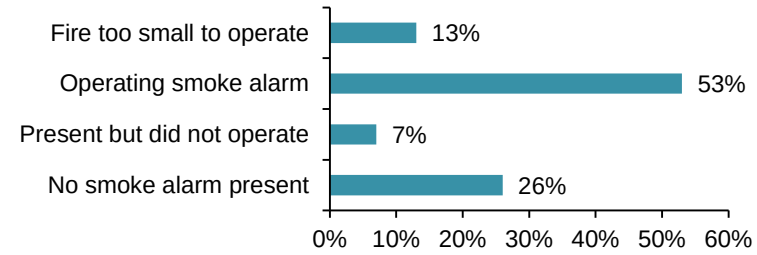
When smoke alarms were present in fires considered large enough to activate them, they operated in 88% of the reported fires, 71% of the deaths and 81% of the injuries.

Some examples of fatal fires without working alarms are shown below.

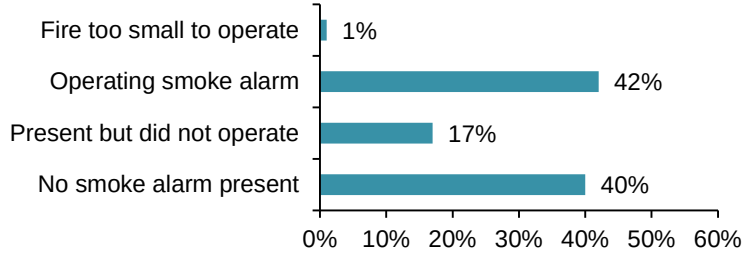
- A Louisiana man died of smoke inhalation after a cooking fire that began while he was sleeping. No smoke alarms were present in the single-family home.[7]
- Six people, including four children under six years of age died in a Georgia manufactured home fire caused by an improperly installed wood-burning heater. No smoke alarms were present.[8]
- The sole smoke alarm in the hallway a one-story Michigan house was missing its battery when a space heater ignited clothing that had been left to dry overnight in a sunroom. The room flashed over, and the fire spread to the dining area. Two residents were killed and three were injured.[9]

Figure 5.
Reported home structure fires and fire deaths by smoke alarm performance
2012-2016

A. Fires



B. Civcivilian deaths



Although slightly more homes with reported fires have hardwired smoke alarms (with or without battery backup), smoke alarms powered only by (or intended to be powered by) batteries were found in almost two-thirds of the fire deaths in home with smoke alarms. When present, hardwired smoke alarms operated in 94% of the fires considered large enough to trigger a smoke alarm. Battery-powered alarms operated 81% of the time.

Most homes still have smoke alarms powered by batteries only. In the 2011 *American Housing Survey* (AHS), three out of five (61%) respondents who reported having smoke alarms said their alarms were powered by batteries only, one-third (33%) said their alarms were powered by electricity and batteries, and 7% had alarms powered by electricity only.[10]

For many years, NFPA 101®, *Life Safety Code*®, and other codes have required smoke alarms in new construction to be hardwired with battery backup. Yet the AHS found that in 30% of homes that were less than five years old and had smoke alarms, the alarms were powered by battery only.

In 2012-2016, the death rate per 1,000 reported fires was more than twice as high in fires with smoke alarms powered by batteries (8.4) as it was in fires with hardwired smoke alarms (3.6).

Causes of Smoke Alarm Failure

During 2012-2016, local fire departments responded to an estimated average of 25,700 home fires per year in which smoke alarms should have operated but failed to do so. These fires caused an average of 440 deaths and 1,440 injuries annually.

When smoke alarms failed to operate, it was typically because of disconnected or non-working power sources. Battery problems were most common. See Figure 6. It appears that the fire service had a harder time identifying causes of non-operation in hardwired smoke alarms. NFPA routinely allocates unknown data in our national estimates.

The reason for failure was originally undetermined for half of all hardwired alarms, but less than one-third of the battery-powered alarms. The percentage of unclassified reasons was roughly four times as high for hardwired smoke alarms as for battery-powered alarms.

Smoke alarms powered by lithium batteries do not require annual battery changes. These batteries are sometimes referred to as "10-year batteries." Two studies show that installation programs should follow up more frequently to ensure smoke alarm protection where these alarms were installed.

A follow-up study of lithium battery-powered smoke alarms installed in 1998-2001 in five states investigated whether these alarms were present and operational eight to ten years later. *At least one* of the installed alarms was still present and functional in only 38% of the homes visited. Slightly more than one-third (37%) of the installed alarms were missing, one-third (33%) were present and operational, and slightly less than one-third (30%) were present but not operational.[11]

Most of the alarms used in the program had battery chambers that permitted replacment. Although all of the alarms started with lithium batteries, more than two-thirds had non-lithium batteries eight to ten years later. Three-quarters (78%) of the smoke alarms that still had lithium batteries were still functional at the time of the evaluation. Smoke alarms that had been installed in the kitchen were less likely to be functional.

Rental properties and properties that had changed occupants were more likely than owner-occupied properties and properties with the same occupants to be missing at least one program-installed smoke alarm at the time of the evaluation.

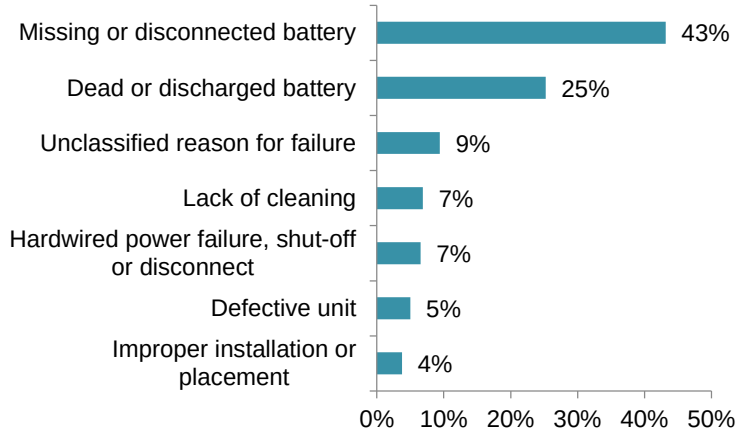
From December 2011 through October 2012, members of the Dallas Fire-Rescue Department (DFRD) conducted follow-up home visits to homes in which smoke alarms with lithium batteries that had been installed from 2001-2010 to monitor how these smoke alarms functioned over time.[12]

- In the second year group, 88% of the smoke alarms were present and 84% were working.
- In the fourth year group, 75% were present and 55% were working.
- In the sixth year group, 71% were present and 27% were working.
- In the eighth-year group, 63% were installed and 20% were working.
- In the tenth-year group, 55% were installed and 22% were still working.

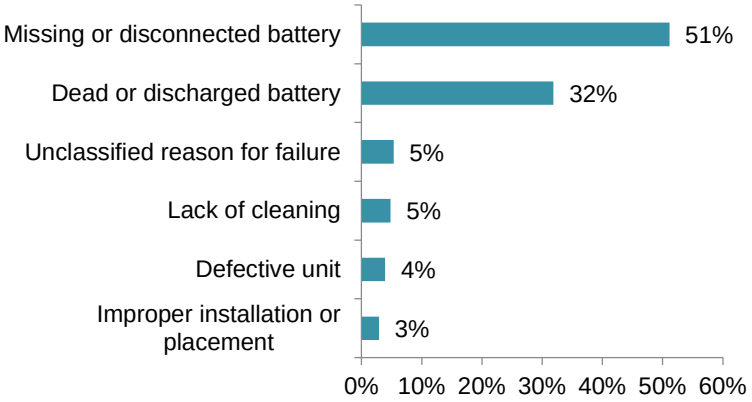
Reminders to change the smoke alarm battery when changing the clock can cause some people to replace a lithium battery with a conventional battery with a shorter lifespan. New technology can complicate messaging. While it is discouraging that smoke alarms were sometimes removed from rental housing when tenants moved, it is encouraging that relocating tenants apparently saw the smoke alarms as valuable enough to take with them.

Figure 6.
Reason smoke alarms did not operate in home structure fires considered large enough to activate, by smoke alarm power source
2012-2016

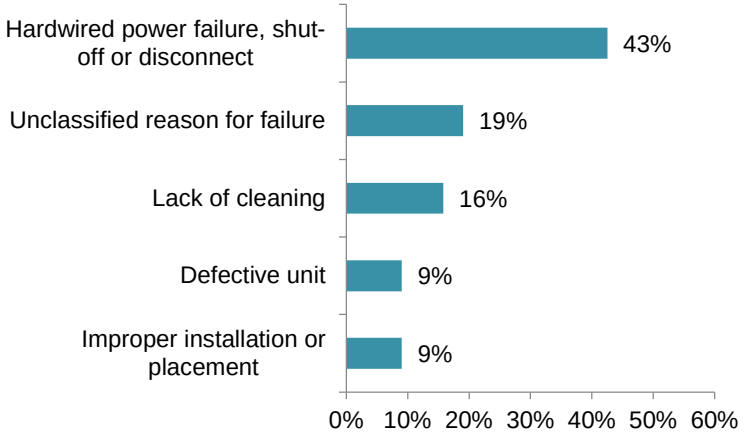
A. All power sources



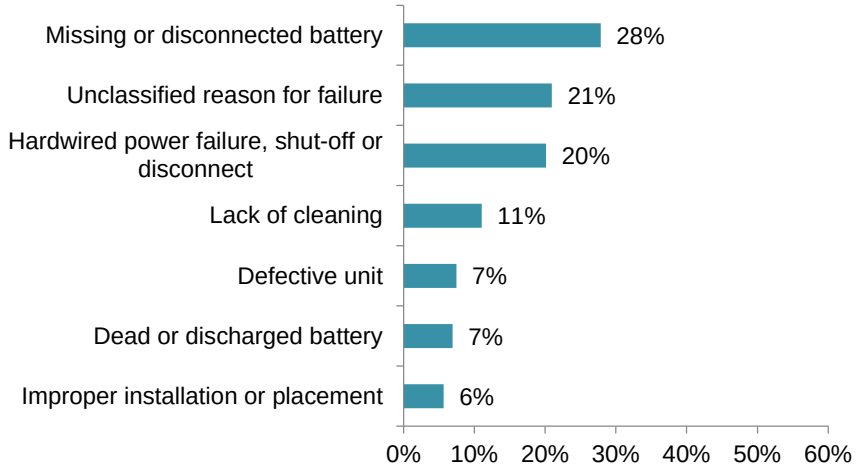
B. Battery only



C. Hardwired only



D. Hardwired with battery backup



Power sources are often disabled because of unwanted alarms. Causes of unwanted alarms were discussed earlier. The low-battery chirp is sometimes considered an unwanted alarm. While the fire-safety community understands the message, members of the public may not. In practice, even people committed to fire safety may disable an alarm that starts chirping in the middle of the night. Replacing conventional batteries in battery-powered and hardwired alarms with battery backup annually reduces the likelihood of inconvenient chirping and subsequent disabling of alarms.

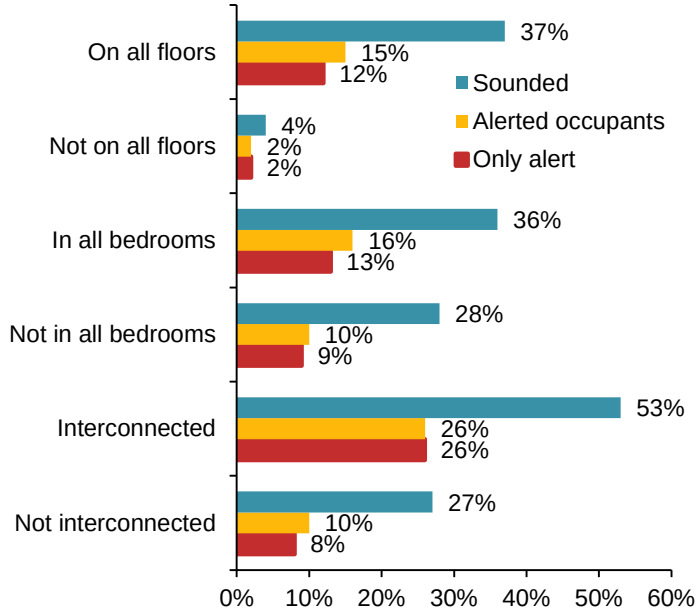
If a smoke alarm in the kitchen is sounding too often, the problem could be solved by moving the smoke alarm. NFPA 72®, *National Fire Alarm and Signaling Code*® states that unless designed specifically for the area, all smoke alarms should be at least 10 feet away from cooking appliances. If space constraints make it necessary to have a smoke alarm within 10-20 feet of the kitchen stove, either a photoelectric alarm or an alarm with a hush feature that can be temporarily silenced without disabling the alarm should be used. The UL requirements for resistance to cooking nuisance alarms (discussed earlier) are also expected to address this issue.

Fire Discovery

NFIRS data does not capture the extent of smoke alarm coverage or whether the alarms were interconnected. NFIRS data also do not have information on incidents that were not reported to the fire department.

While people often notice a fire before hearing a smoke alarm, CPSC's survey of households with fires found that interconnected smoke alarms were both more likely to have operated and more likely to have provided the only alert.[13] See Figure 7. In CPSC's study, when smoke alarms did not operate, it was generally because the smoke never reached the alarm.

Figure 7.
Smoke alarm performance and effectiveness in CPSC's 2004-2005 survey of unreported residential fires



Fire statistics from England provide additional insights. In 2013-2018, home smoke alarms were present, operated, and raised the alarm in 38-43% of dwelling fires reported in England. Smoke alarms operated but did not raise the alarm in 11-12% of the fires.[14]

- In three out of five (59-60%) such fires, a person raised the alarm before the system operated (Someone in the same room may notice a fire immediately.);
- In one-fifth (19-20%), no one was in hearing distance of the alarm; and
- The occupants failed to respond in 13% of the fires.[15]

To be effective, a smoke alarm's warning must be heard or received. Another CPSC study found that a closed lightweight door reduced the volume of a smoke alarm signal from another room by 10 to 20 decibels. The signal was weakened by roughly 20 decibels each level it traveled.[16]

In her literature review on sleep and waking to fire alarms,[17] Dorothy Bruck concluded that louder signals are needed when significant background noise is present. She also found that arousal thresholds vary significantly. Sleep deprived adults are less likely to be wakened by a smoke alarm, as are young children and people under the influence of alcohol, marijuana or sleep inducing medication. The higher frequency hearing loss that often accompanies aging reduces the probability that older adults will wake to a smoke alarm.

Moinuddin, Bruck and Long found that the sound level decreased substantially from room to room even when doors were open. They tested the volume of smoke alarms with different sensors, different sound wave frequencies and shapes (105 dBA and 85 dBA and 520 Hz square wave) placed in different locations and different configurations.[18] A 75 dBA waking threshold sound level was recommended for reliable notification and waking. Only the 105 dBA alarm with doors open throughout the home consistently exceeded the 75 dBA threshold in rooms other than the room of sound origin. Sound from the 520 Hz square wave signal was transmitted slightly more effectively. Tests with closed doors ended after initial tests showed that so little smoke escaped that none was detected by smoke alarms in hallways or adjacent rooms. The authors concluded that "…to achieve early detection and adequate notification, smoke alarms are required in every room and should be interconnected."

While Moinuddin, Bruck and Long found that audibility decreased as signals travelled, NIST's Thomas Cleary found that larger spaces and distance diluted the smoke and delayed smoke alarm activation.[19] Full-scale experimental test burns that began with the ignition of a chair mock-up were done in the bedroom and living room of a small home mock-up with the door open or closed. The materials in the chair and the ignition mode both influenced the time required to activate smoke alarms. Due to the effects of smoke transport and dilution, the average time to alarm increased when smoldering fire tests were performed in the living room rather than the bedroom. Time to alarm was higher when the bedroom door was open in both smoldering and flaming conditions. Smoke dilution and transport effects delayed the activation of smoke alarms in the bedroom. Signal volume was not captured in this study.

Researchers in British Columbia, Canada found that working smoke alarms reduced the probability that residential fires attended by the Surry Fire Services would spread beyond the room of origin regardless of response time. In properties with no working smoke alarms, the probability that a fire would

spread beyond the room of origin increased 17% for each one minute increase in time needed for an effective fire department attack force to assemble. When working smoke alarms were present, the probability that a fire would spread beyond the room of origin was reduced by 71% regardless of response time.[20] Fire department performance metrics of fires that spread beyond the room of origin should include the presence or absence of working smoke alarms.

Smoke Alarms in Context

Individual characteristics, locations and activities also influence the outcome. People who died in fires with working smoke alarms often had characteristics or circumstances that made escape more difficult. Compared to deaths resulting from fires in which no smoke alarms were present or alarms were present but did not operate, victims of fatal fires with working smoke alarms were

- More likely to have been in the room or area of origin and even more likely to have been in the area of origin and involved in ignition;
- More likely to have had a physical disability;
- More likely to have been fighting the fire themselves;
- More likely to have been at least 75 years old; and
- Less likely to have been sleeping when fatally injured.

Two examples illustrate these points.

- Although operational smoke alarms were present in a Michigan house fire started when woodstove ashes ignited their cardboard container in the basement, an elderly man's poor health prevented his escape from the ground floor. He was found in the home's doorway.[21]
- Responding firefighters heard the sound of smoke alarms at a West Virginia house fire that began when bedding was ignited by a cigarette in the ashtray on the bed. Medical oxygen was a contributing factor in the fire's development. The elderly female victim, who had routinely used a walker, was found on the floor by the bed.[22]

Smoke alarms are an important part of home fire protection, but they are not the only part. The risk of fire death per 1,000 reported home fires steadily declines as levels of fire protection increase.

Figure 8 shows that the death rate is lowest in homes with sprinklers and hardwired smoke alarms. These rates are based on presence in reported fires only. Operation is not considered.

While fires in which partial sprinkler systems were present or in which sprinklers were outside the fire area and did not operate were excluded from the calculations, the data did not permit us to exclude fires that did not have enough smoke alarms or in which the smoke alarms were not audible to the occupants.

As discussed earlier, a closed bedroom door is likely to delay operation of a single-station alarm in response to fire on the other side of the door. Similarly, a single-station alarm sounding on a different floor or behind a closed door may not be loud enough to alert someone in another part of the home.

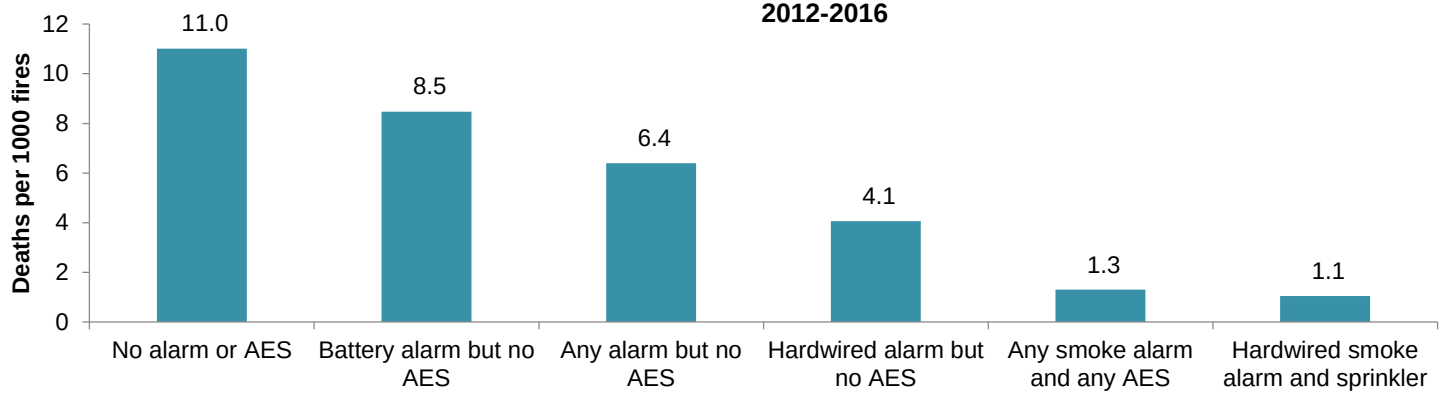
Hardwired smoke alarms are more likely to be interconnected, although battery-powered wireless interconnected alarms are available. New homes should have hardwired smoke alarms.

Any program to ensure adequate protection must include smoke alarm maintenance.

In the 2010 Harris poll, only one in five respondents reported testing their smoke alarms at least once a month.

It is easy to forget that a smoke alarm's sole function is to sound the warning. People also need to develop and practice escape plans so that if the alarm sounds, they can get out quickly. Because smoke alarms alert occupants to fires that are still relatively small, some people try to fight these fires themselves. Unfortunately, some of these attempts are unsuccessful due to either rapid fire spread or inappropriate methods of fire control. Meanwhile, precious escape time is lost.

Figure 8. Average fire death rate per 1,000 reported home structure fires by presence of smoke alarms and automatic extinguishing systems (AES) 2012-2016



Additional Information

See *Smoke Alarms in U.S. Home Fires: Supporting Tables* by Marty Ahrens, January, 2019, for more detailed information about the material presented in this report.

For consumer information about smoke alarms, visit nfpa.org/smokealarms.

Methodology

The statistics in this analysis are estimates derived from the U.S. Fire Administration's (USFA's) National Fire Incident Reporting System (NFIRS) and the National Fire Protection Association's (NFPA's) annual survey of U.S. fire departments. Fires reported to federal or state fire departments or industrial fire brigades are not included in these estimates. Only civilian (non-firefighter) casualties are discussed in this analysis.

NFPA's fire department experience survey provides estimates of the big picture. NFIRS is a voluntary system through which participating fire departments report detailed factors about the fires to which they respond. To compensate for fires reported to local fire departments but not captured in NFIRS, scaling ratios are calculated and then applied to the NFIRS database using the formula below.

$$\frac{\text{NFPA's fire experience survey projections}}{\text{NFIRS totals}}$$

NFPA also allocates unknown data proportionally to compensate for fires that are reported but data were undetermined or not reported.

"Smoke alarms" are not the same as "smoke detectors." Most homes have what we now call "smoke alarms." These units detect the presence of smoke and sound the alarm. Some properties, particularly some multi-family complexes and newer single-family homes, have smoke detectors that are components of an alarm system with a panel. The detection unit itself does not necessarily sound the alarm. Instead, the signal is transmitted to a control unit that then sounds the alarm throughout the premises. Older studies of smoke detectors usually studied devices that would now be called smoke alarms. NFIRS does not distinguish between smoke detectors and smoke alarms. Except where specified, the term "smoke alarm" in this analysis is used inclusively for all fire detection equipment. Estimates of specific types of detection are available in the supporting tables for this report.

Some spaces in a home, such as garages, exterior parts of the structure, concealed spaces, and unoccupied attics, are not expected or required to have smoke alarms. No adjustments were made for these spaces.

Detection in apartments or other multi-family housing also poses coding challenges. A smoke alarm may be missing from or disabled in the unit of origin, but the detection system in the common areas or a smoke alarm in an adjacent unit may have operated and sounded the alarm. It is unclear whether detection would be considered present and operating in such a fire.

"Confined" structure fires in NFIRS include confined cooking fires, confined chimney or flue fires, confined trash fires, confined fuel burner or boiler fires, confined commercial compactor fires, and confined incinerator fires (NFIRS incident type 113-118). Losses are generally minimal in these fires, which by definition, are assumed to have been limited to

the object of origin. Although detailed data about detection is not required for these fires, it is sometimes present. Raw NFIRS data 2012-2016 contained a total of 33,215 (6%)"confined" structure fires in which detection was present and 27,004 (93%) confined fires in which detection was present and its operation was known.

Raw NFIRS data for the five years of 2012-2016 contained a total of 434,293 "non-confined" structure fires (NFIRS incident type 110-123 excluding incident types 113-118) in which detection presence was known (coded as either present or not present). A total of 4,215 civilian deaths, 22,371 civilian injuries, and $13.3 billion in direct property damage was associated with these fires. Detector (or smoke alarm) presence was known for 68% of the non-confined fires, 59% of the deaths, 77% of the injuries and 64% of the direct property damage.

When detection was present in "non-confined" structure fires, detection operation was known (coded fire too small to operate, operated, or failed to operated) in a five-year raw total of 219,551 fires associated with 1,665 deaths, 12,687 injuries, and $7.4 billion in direct property damage. Detector (or smoke alarm) operation when present was known for 83% of the non-confined fires, 65% of the deaths, 83% of the injuries and 76% of the direct property damage.

For more information on the methodology used for this report see, *How NFPA's National Estimates Are Calculated for Home Structure Fires.*

Acknowledgements

The National Fire Protection Association thanks all the fire departments and state fire authorities who participate in the National Fire Incident Reporting System (NFIRS) and the annual NFPA fire experience survey. These firefighters are the original sources of the detailed data that make this analysis possible. Their contributions allow us to estimate the size of the fire problem.

We are also grateful to the U.S. Fire Administration for its work in developing, coordinating, and maintaining NFIRS.

To learn more about research at NFPA visit www.nfpa.org/research.
E-mail: research@nfpa.org.

NFPA No. USS04

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