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Smoke Alarm Presence and Performance in U.S. Home Fires

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1. Abstract

The vast majority of U.S. homes have at least one smoke alarm. For smoke alarms to be effective, they must have a functional power source, be close enough to the smoke to activate, they must be heard, and occupants must take appropriate action. In homes with smoke alarms and fires considered large enough, the alarms operated 83% of the time. Analyses of data from the U.S. Fire Administration's National Fire Incident Reporting System and the National Fire Protection Association's fire department survey showed that in 2003-2006, no smoke alarms were present in 31% of reported home fires and 40% of home fire deaths. Smoke alarms were present but failed to operate in 9% of the reported fires and 23% of the deaths. Thirty-seven percent of the deaths resulted from the 47% of fires with operating smoke alarms.

Circumstances of the fire, the detection equipment, and occupant characteristics must be considered when evaluating smoke alarm performance. Hardwired smoke alarms operated more often than alarms powered by batteries alone. Victims of fatal fires with working smoke alarms were more likely than victims of fires without working smoke alarms to have been in the area of origin when the fire began; fighting the fire; unable to act; or at least 65 years old; and less likely to have been sleeping. Findings from the Consumer Product Safety Commission's *2004-2005 Residential Fire Survey* provide background about smoke alarms in the general population and in unreported fires.

2. Introduction

The fire protection community is continually working to reduce the losses associated with fire by improving technology and strengthening fire codes. To determine the benefit of a proposed change, it is necessary to have an accurate understanding of the equipment currently in place and how well it performs in real-life situations. It costs money to install smoke alarms and even more to install hardwired, interconnected alarms. It is my contention that hardwired, interconnected alarms operate more reliably and are more likely to alert occupants to a developing fire. They are worth the cost. However, too many homes, including relatively new homes, lack this protection. Smoke alarms provide an early warning of a developing fire and precious time to act. By themselves, they cannot fight the fire or ensure that occupants escape. Data supporting these points are provided on the following pages.

Many factors influence the outcome of a fire. These include occupant characteristics, the nature and location of the fire, the proximity of the occupant to the fire, the type of fire protection present, and the extent of coverage. Fire detection's greatest success is not warning of a raging blaze. Rather, smoke alarms are most useful when they provide a warning of a very small fire or alert occupants to a situation, such as a burner left on or water that has boiled away, that could turn into a fire if corrective action is not promptly taken. Any fair examination of smoke alarm

performance must include fires that stayed small. The vast majority of household fires are handled without fire department assistance.

This paper will provide an overview of smoke alarm coverage in the U.S. population and how smoke alarms perform in fires handled without the fire department and in those to which fire departments responded. It will also compare the characteristics and circumstances of fire deaths resulting from fires in which smoke alarms operated, were present but failed to operate, and were not present at all. The death rate per 1000 reported fires for different combinations of fire protection is also discussed. More detailed information is available in the author's 2009 report, *Smoke Alarms in U.S. Home Fires.* [1]

3. Smoke Alarms in the General Population

In 2009, the U.S. Consumer Product Safety Commission (CPSC) released the findings of its 2004-2005 survey of households who experienced both reported and unreported fires.[2] They estimate that an average of 7.4 million home fires occur per year. Ninety-seven percent of these fires were not attended by the fire department (unreported fires). Although fire safety messages over the years have often focused on the importance of getting out quickly when a fire occurs, 78% of the fires were put out by someone in the household, 18% self-extinguished, the fire department put out 2%, and 2% were put out by someone else. (p. 159)

The CPSC compared households that had fires with those that did not. Because the number of households that experienced fires is such a small percentage of all households, percentages for all households and households without fires are generally within 0.1 percentage points of each other.

The vast majority of all households, with and without fires, had at least one smoke alarm. However, households that had unreported fires had somewhat less smoke alarm protection than households that had not experienced any fires at all. No smoke alarms at all were found in 7% of the households that had fires compared to 3% of households with no fires. Table 1 shows that 84% of households without fires had smoke alarms on every floor. This was true for 82% of households with fires. Thirty-one percent of households without fires had smoke alarms in all bedrooms; this was true for only 22% of households that had fires. Nineteen percent of households without fires had interconnected smoke alarms compared to 13% of the fire households.

The CPSC also identified demographic differences associated with the presence of smoke alarms in all bedrooms. Households with older adults, with smokers, and in non-urban areas were less likely to have this level of protection than were households without these characteristics. NFPA statistics show that in 2003-2007, people who were 65 or older had more than twice the risk of dying in a home fire as the overall population [3] and that smoking was the leading cause of home fire deaths. [4] NFPA also found that, in 2004-2008, the civilian fire rate per million population was highest in communities with fewer than 2,500 people. [5] CPSC found that only one of every five (21%) homes with someone who was at least 65 years old had smoke alarms in all bedrooms. Alarms were found in all bedrooms in one of every three (33%) homes when all of the occupants were under 65. One-quarter (26%) of the homes with at least one smoker had smoke alarms in all bedrooms. This increased to one-third (33%) when no smokers were

present. Likewise, only one-quarter (24%) of non-urban dwellers had smoke alarms in all bedrooms compared to one-third (32%) of urban households. [2]

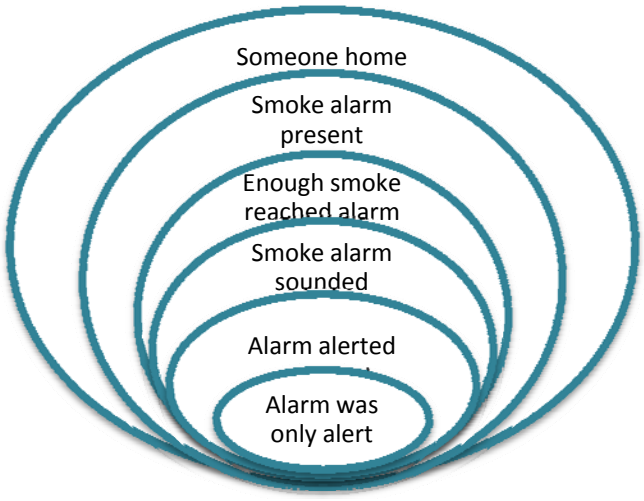
Homes in which someone was under 18 were actually more likely to have smoke alarms in all bedrooms. Thirty-five percent of households with someone under 18 had this level of protection compared to 27% of homes in which everyone was at least 18. NFPA statistics show that children under five years of age faced a risk home fire death that was 1.4 times the general population but the risk for older children and for the combined under 18 age group was lower than average. [3]

In the 2007 *American Housing Survey* (AHS), two-thirds (67%) of the respondents who reported having smoke alarms said their alarms were powered by batteries only, one-quarter (24%) said their alarms were powered by electricity and batteries, and 9% by electricity only. In more than one-third (37%) of homes that were less than five years old and had working smoke alarms in 2007, the alarms were powered by battery only.[6] The 1989 edition of NFPA 74, *Household Fire Warning Equipment,* required hardwired interconnected smoke alarms in new construction. These requirements were carried forward with NFPA 74 into NFPA 72, *National Fire Alarm Code.* Model codes must be adopted by government authorities before having the force of law. Often, states and local government regulations are not based on the most recent codes. Even when the codes are adopted, they must be enforced to be effective.

4. Smoke Alarm Performance in Unreported Fires

The same CPSC study also provided details on how fires were discovered in fires that were not attended by the fire service. (pp.150-180) Figure 1 provides a framework for the discovery process. Was someone home to discover the fire? If so, was a smoke alarm present? Did enough smoke reach the alarm so that it would be expected to sound? Did it sound? The questions up to this point could be answered with a yes or no. These questions help define the benefit of different levels of coverage.

Figure 1. Measuring Smoke Alarm Performance



Note: Not to scale

Interviewers also asked about what alerted someone to the fire. For this question, interviewers recorded all the responses mentioned, probed when necessary, but did not read a list. When someone is in the same room or near a fire, they may see, hear, or smell the fire before the alarm sounds. In some cases, a smoke alarm is heard at about the same time one of the other cues is noticed. Multiple cues may alert at once. Sometimes, a smoke alarm sounds, but the occupant may not wake or hear it. When a smoke alarm provided the only alert, it means that no other cues were noticed at the same time the alarm was heard. These fires may be smoke alarms' greatest successes, yet these situations are so common that they are barely noticed.

When calculating performance or effectiveness, percentages can be based on various combinations of conditions shown in Figure 1. Figure 1 illustrates the relationships only and is not to scale.

The statistics about smoke alarm performance in unreported fires shown in Tables 2 and 3 exclude fires in which no one was home from the calculations. Table 2 shows that when smoke alarms were present and someone was home, the alarms sounded in 35% of the unreported fires. In four of every ten (39%) fires with sounding alarms, the alarms alerted the occupants. This includes incidents in which other cues, such as the smell of smoke, were noticed at the same time the alarm was heard. In one-third (32%) of the fires with sounding smoke alarms, the smoke alarm provided the only alert to the fire prior to the fire's discovery.

CPSC's statistics about fire discovery were based on a shorter recall period than were their estimates of smoke alarm presence. Discovery statistics were based on fires, not households. While 93% of households with fires had smoke alarms, smoke alarms were present in only 87% of the fires. The authors noted that smoke alarms appeared slightly less likely to be found in households that had multiple fires. (p. 156)

The second row in Table 2 shows that when at least one smoke alarm was present but alarms were not present on all floors, smoke alarms operated in only 9% of the fires. The percentage increased to 38% when alarms were present on all floors, 37% when present in all bedrooms, and 53% when smoke alarms were interconnected. In question 44 of the survey, the 57% of respondents who reported that smoke alarms did not operate were asked "Do you think that enough smoke reached the smoke detector that it should have sounded?" Eighty-nine percent of these respondents said there was not enough smoke. (p. 158) With greater coverage, the probability that a smoke alarm will be close enough to the fire to activate is higher.

Limiting the scope to fires in which someone was home, smoke alarms were present, and enough smoke was said to reach the alarm, smoke alarms sounded in 83% of the fires.

The last row in Table 2 shows that, in total, when smoke alarms and occupants were present, the alarms alerted occupants to 14% of these unreported fires. It is important to remember that these fires tended to be very small and many of the smoke alarms were out of the range of the fire. In 61% of the unreported fires, no flame damage occurred at all. In 34%, flame damage was confined to the item first ignited. (p. 105). When smoke alarms were interconnected, they alerted the occupants in one-quarter (26%) of the fires. When the alarms were not interconnected, smoke alarms alerted occupants in only 12% of the fires. When smoke alarms were present but not present on all floors, they alerted occupants in only 4% of the fires.

Increased coverage increases the likelihood of a smoke alarm operating when the fire is in its earliest stages.

Different parts of the home tend to have different types of fires. Two-thirds (69%) of the unreported fires in CPSC's survey started in the kitchen, 7% began in the living room, and 7% started in the bedroom. (p. 101) Table 3 shows that when smoke alarms were present in the home, they sounded in 41% of the unreported kitchen fires, in one-quarter (25%) of the living room fires, and almost one-quarter (22%) of the bedroom fires. When smoke alarms sounded, they alerted someone in 40% of the kitchen fires, only 1% of the living room fires, and in two-thirds (69%) of the bedroom fires. Sounding smoke alarms provided the *only* alert in one-third (33%) of the kitchen fires, only 1% of the living room fires, and two-thirds (69%) of the bedroom fires. (p. 163)

CPSC found that cooking equipment was involved in 4.7 million unreported home fires per year. (p. ii) Table 3 shows that in unreported fires in which someone was home and smoke alarms were present, the alarms sounded in almost half (47%) of unreported fires involving stoves or ranges. This was a larger percentage than was seen in fires with other common heat sources. Smoke alarms sounded in almost one-third (30%) of the fires started by lighters, cigarettes, or matches; almost one-quarter (23%) of fires started by candles; almost one-quarter (23%) of fires started by heating or cooling equipment, and 8% of the lighting or wiring fires. When smoke alarms sounded, they provided the only alert in: 81% of the fires involving lighting or wiring; one-third (33%) of the stove or range fires; one-third (32%) of the candle fires; more than one-quarter (29%) of the lighter, cigarette, or match fires; and 3% of the heating or cooling fires. (pp. 170, 175)

Because people are usually up and about while cooking, it is easy to forget how important smoke alarms are in these situations. Smoke alarms provided the *only* alert in almost 600,000 unreported fires annually involving stoves, ranges or other cooking appliances. (p. 170) Without these alarms, many of these fires would likely have become far more serious.

5. Smoke Alarms in Reported Fires

5.1 Methodology

Estimates regarding the presence and operational status of smoke alarms in home fires reported to U.S. fire departments during 2003-2006 are projections derived from the detailed information collected in Version 5.0 of the U.S. Fire Administration's National Fire Incident Reporting System [7] (NFIRS 5.0) and NFPA's annual fire department survey. The analysis used the basic approach described by Hall and Harwood in their 1989 article in *Fire Technology* [8] with modifications to accommodate the changes introduced in NFIRS 5.0. Homes include one-and two-family homes, manufactured homes, and apartments, regardless of ownership type. The terminology used to describe the detection equipment and circumstances found in reported fires is based on the NFIRS 5.0 coding choices used by fire officers to complete their incident reports.

To make it easier for fire departments to document certain types of common minor fires, NFIRS 5.0 included a category of structure fires collectively referred to as "confined fires," identified by incident type 113-118. These include:

- cooking fires confined to the vessel of origin (incident type 113),
- confined chimney or flue fires (incident type 114),
- confined incinerator fires (incident type 115),
- confined fuel burner or boiler fires (incident type 116),
- confined commercial compactor fires (incident type 117), and
- trash fires in or on a structure that did not extend to other contents or the structure (incident type 118).

For these incidents, the only detection question required in NFIRS 5.0 asks simply if the detection equipment alerted or did not alert occupants. Information on the presence or operation of such equipment is not required. More detailed information is sometimes provided. However, non-required data elements have far more unknown data and are less representative than required data elements.

Structure fires without these incident types (incident types 110-123, excluding 113-118) are collectively referred to as "non-confined fires." Non-confined fires include:

- building fires (incident type 111),
- fire in a structure other than a building (incident type 112),
- unclassified or other structure fire (incident type 110, intended for use as a conversion-only code form earlier versions of NFIRS but used in 0.2% of the NFIRS 5.0 home fires),
- fire in a manufactured or mobile home when not in transit and used as a fixed residence (incident type 121),
- fire in a motor home, camper or recreational vehicle when not in transit and used as a structure for residential purposes (incident type 122),
- fire in a portable building when used at a fixed location (incident type 123), and
- fire in other or unclassified mobile property used as a structure (incident type 123).

Fires with unknown or unreported data were allocated proportionally in calculations of national estimates. This procedure relies on the assumption that if the unknown data were actually known, the distribution would resemble that of the known data. The confined fire incident types describe specific scenarios and would be expected to have different distributions of unknown data than the more general non-confined fire incident types. Consequently, confined and non-confined fires were analyzed separately because of the need to handle unknown or missing data. Smoke alarm presence or absence was reported (known) in 69% (304,481 raw incidents over the four-years) of non-confined fires, 61% (2,735 total) of associated deaths and 2% (8,369 total) of confined fires. Only one confined death fire was reported. In the tables, sums may not equal totals due to rounding errors.

5.2 Presence and operation in reported fires

Smoke alarms or system-based smoke detectors were the fire alarm type reported in 92% of the home fires in which the fire alarm type was identified. An additional 5% used a combination of smoke and heat detection. In 2%, more than one type of detection equipment was present. These percentages were based on raw data of 167,099 total non-confined fires and 6,048 confined fires in which detection equipment was coded as present and the type of equipment was known. (Table not shown.) Because home smoke alarms are so prevalent, the term "smoke alarm" is used as an all encompassing phrase throughout this analysis when describing early fire warning devices or systems in the home.

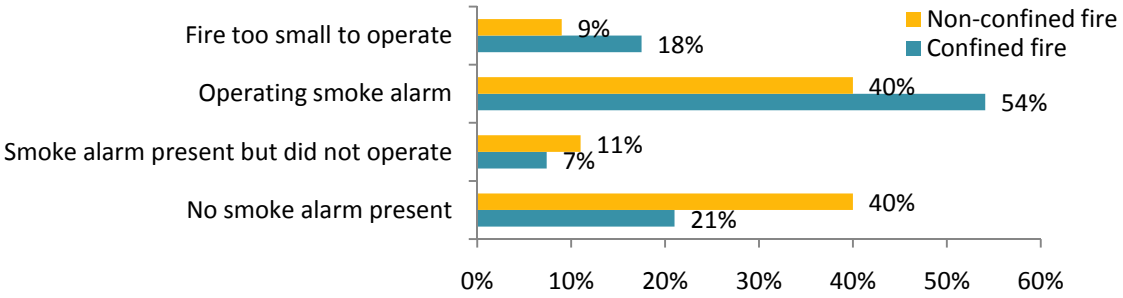
In 2003-2006, U.S. fire departments responded to an estimated average of 378,600 home fires per year, resulting in an annual average of 2,850 civilian deaths. Table 4 shows that 41% of the reported home fires during this period occurred in properties with either no smoke alarms at all (31% of total reported fires) or alarms that should have operated but failed to do so (9%).

Almost two-thirds of home fire deaths resulted from fires without the protection of a working smoke alarm. No smoke alarms were present at all in four of every ten (40%) of the home fire deaths. Alarms were present but did not operate in almost one-quarter (23%) of the fatalities. Operating smoke alarms were present in more than one-third (37%) of total home fire deaths. In 1% of the deaths, the fire was too small to trigger the smoke alarm.

Including fires without smoke alarms and fires that were too small to activate the alarm, smoke alarms were present and operated in almost half (47%) of total reported home fires.

Figure 2 shows that smoke alarms were more likely to be present and more likely to operate in confined fires than in non-confined fires. In the four-years of raw data, smoke alarm operation was known in a total of 147,947 non-confined fires and 981 associated deaths in which smoke alarms had been coded as present. Operation was also known in 6,025 confined fires and one associated death with smoke alarms present

Figure 2. Confined and Non-Confined Reported Home Structure Fires By Smoke Alarm Performance: 2003-2006



Source: NFIRS 5.0 and NFPA survey.

Excluding fires in which no smoke alarms were present or in which the fire was too small, smoke alarms operated 83% of the time. This is consistent with smoke alarm performance in CPSC's study of unreported fires. As noted above, 37% of all home fire deaths resulted from fires with operating smoke alarms. However, the percentage of deaths resulting from reported home fires with operating smoke alarms increases to 62% when based on a denominator of the sum of the estimated 1,040 deaths with operating smoke alarms and 640 deaths in which smoke alarms were present but failed to operate per year.

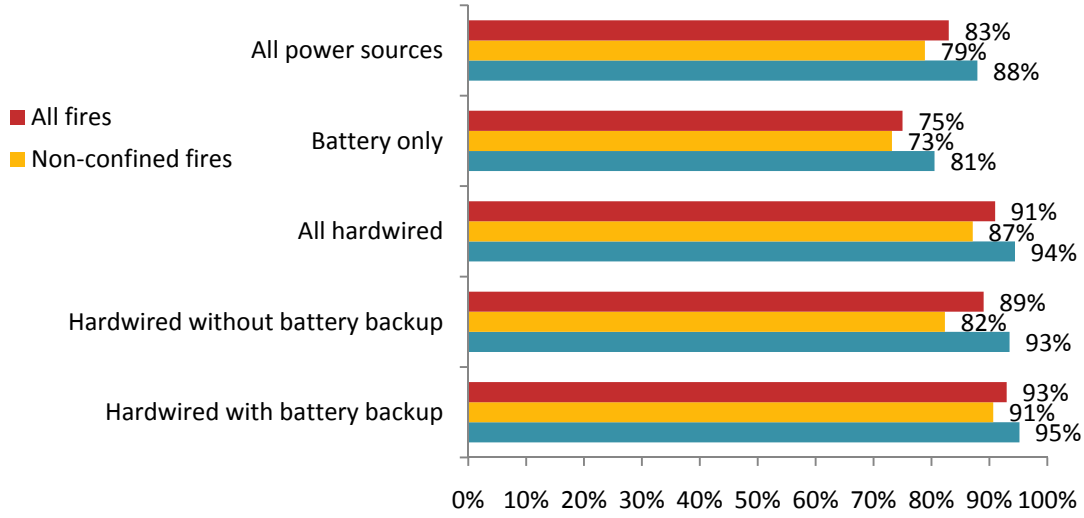
Table 5 shows that when smoke alarms were present in reported home fires, the alarms were

- battery-powered in 56% of the reported home fires and two-thirds (69%) of the home fire deaths.
- hardwired, with or without battery backup, in 39% of the reported home fires and 25% of the home fire deaths.

Sixty percent of the reported home fires with hardwired smoke alarms had confined fire incident types compared to only 46% of the fires with alarms powered by batteries only. (Calculations were not shown.) This suggests that minor fires may be more likely to be reported when hardwired smoke alarms are present or that the fires may be reported at an earlier stage with this type of protection.

As mentioned, when smoke alarms were present and the fire was large enough to trigger the device, smoke alarms, in total, operated in 83% of the fires. Figure 3 shows that battery-powered smoke alarms had the smallest percentage operating (75%), and hardwired alarms with battery backup (93%) the highest. Figure 3 also shows that higher percentages of smoke alarms operated in confined fires than in non-confined fires regardless of power source. When smoke alarms were coded as present in raw NFIRS 5.0, the power source and operation were both known in a four-year total of 130,051 fires and 850 associated deaths as well as 5,315 confined fires and one associated death.

Figure 3. Smoke Alarm Operation in Reported Home Fires Considered Large Enough to Activate Alarm by Power Source: 2003-2006



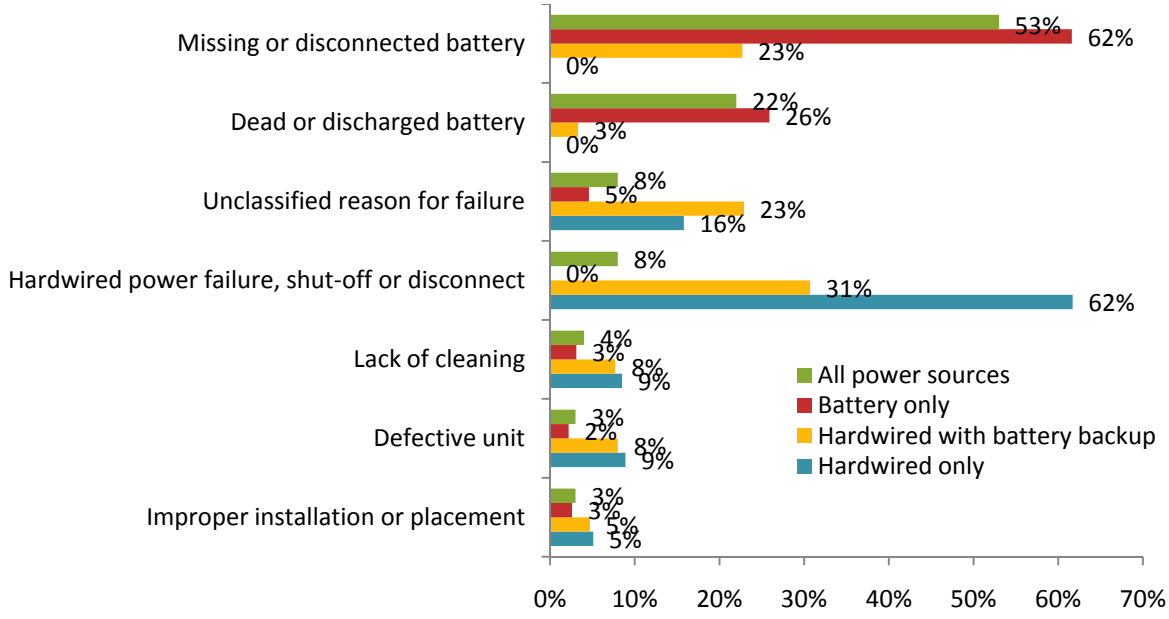
Source: NFIRS 5.0 and NFPA survey.

When smoke alarms did not sound in non-confined fires considered large enough to activate them, three-quarters (77%) of the smoke alarms used batteries only as a power source. Figure 4 shows power source issues were the leading reason smoke alarms failed to operate, with missing or disconnected batteries the leading problem. CPSC's 1992 *Smoke Detector Operability Survey* found that nuisance alarms were the most common reason for disconnecting or disabling smoke alarms. [9]

Figure 4 also shows that in 62% of the fires in which battery-powered smoke alarms failed to sound, the batteries were missing or disconnected. Dead or discharged batteries accounted for 26% of the battery-powered smoke alarm failures. When hardwired smoke alarms with no battery backup failed to operate, the power had failed, been shut off, or disconnected in 62% of the fires. This scenario can include both deliberate disabling of the smoke alarm as well as temporary power outages or power shutoffs to the home. When hardwired smoke alarms with battery backup failed

to operate, 31% of the failures were due to hardwired power failure, shut off, or disconnect; 23% were due to missing or disconnected batteries; and 3% were due to dead or discharged batteries.

Figure 4. Reason Smoke Alarm Failed to Operate In Reported Non-Confined Home Structure Fires: 2003-2006



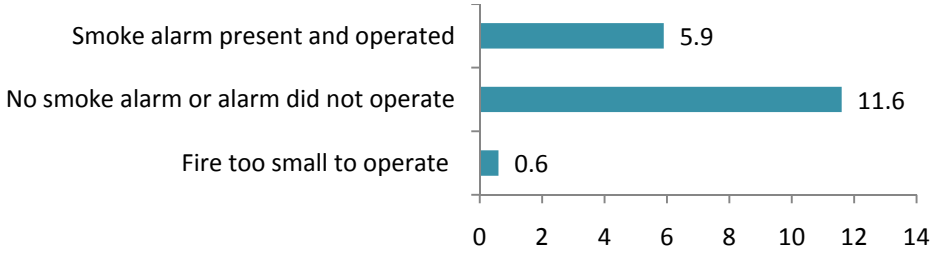
Source: NFIRS 5.0 and NFPA survey.

It appears that the fire service had a harder time identifying causes of failures in hardwired smoke alarms than in alarms powered by batteries. As noted in the methodology section, unknown data were allocated proportionally in the statistics presented. The reason for failure was originally undetermined for half of all hardwired alarms that did not operate (2,450 of 4,790 incidents from raw NFIRS 5.0), but only one-quarter of the battery-powered alarms (4,583 of 18,485 raw data) that failed. The percentage of unclassified reasons in Figure 4 was three to five times as high for hardwired smoke alarms as for battery-powered alarms.

5.3 Home fire deaths and smoke alarm performance

Figure 5 shows that in 2003-2006, the death rate per 1,000 reported home structure fires was twice as high when no working smoke alarm was present (that is, either no smoke alarm was present or an alarm was present but did not operate) compared to the rate with working smoke alarms (11.6 vs. 5.9). In other words, having a working smoke alarm is associated with a 49% reduction in the chance of dying in a reported fire.

Figure 5. Death Rate per 1,000 Reported Home Structure Fires By Smoke Alarm Status: 2003-2006



Source: NFIRS 5.0 and NFPA survey.

It is important to understand the circumstances and demographics of the 37% of victims killed by home fires in which smoke alarms operated. Table 4 showed that an average of 10 people died in confined fires per year and another 30 deaths per year resulted from fires that were too small to activate the alarm. These deaths are not included in the discussion that follows.

Table 6 shows that in more than three-quarters (79%) of the non-confined home fires with operating smoke alarms, the alarms alerted the occupants and the occupants responded. Roughly two-thirds (69%) percent of the deaths resulted from these incidents. The 3% of non-confined home fires in which smoke alarms sounded and occupants were alerted but failed to respond accounted for one of every five (21%) of the deaths caused by home fires with sounding smoke alarms. It is unclear whether the smoke alarm provided the first notification of the fire, whether there was a delay in alerting, whether the occupants were capable of responding, or whether some occupants responded while others did not. Also, another 9% of the home fire deaths resulted from 3% of fires in which smoke alarms operated but did not alert the occupants. It is possible that the individuals were intimately involved with ignition and already knew about the fire or that the individuals never heard the alarm. These estimates were based on 90,627 fires and 412 associated deaths in the raw NFIRS data which smoke alarms were reported to be present and operating and their effectiveness was known.

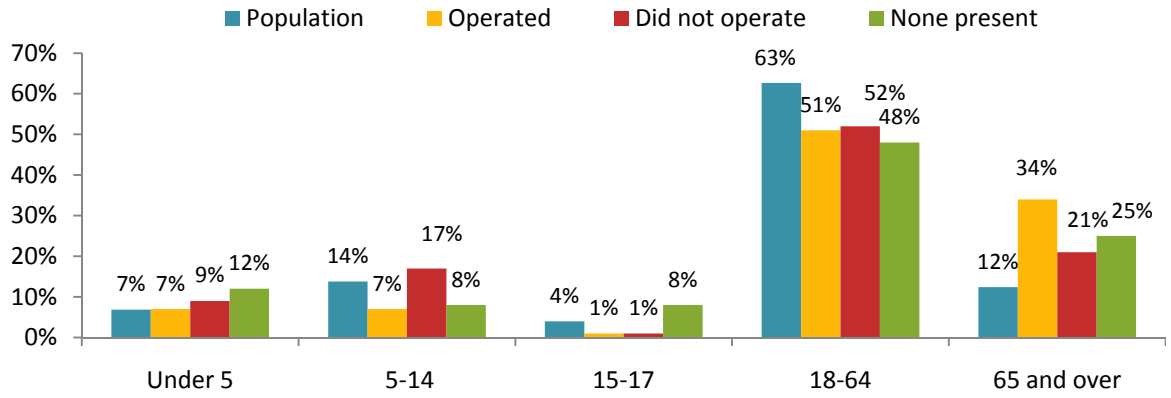
Section 29.4.1 of the 2010 edition of NFPA 72, *National Fire Alarm and Signaling Code,* states that the requirements of the household fire alarm system chapter assume that "occupants are not intimate with the ignition and are capable of self-rescue." Table 7 shows that in fatal fires in which smoke alarms operated, almost half (47%) of the victims were involved in ignition and in the area of origin at the time of the incident. An additional 16% of the victims with operating smoke alarms were in the area of origin but not involved. It is likely that many of the victims who were in the area of origin could be considered intimate with ignition. When no working smoke alarms were present, the percentage of victims in the area of origin was lower. Only 30% of the victims in which smoke alarms were present but did not operate, and 35% in which no smoke alarms were present, were in the area of origin and involved in ignition.

Only 38% of the victims of fires with operating smoke alarms were outside the area of origin when the fire began. Fifty-six percent of the victims of fires in which smoke alarms were present but failed to operate, and 49% of the victims with no smoke alarms at all were outside the area of origin. When people are a greater distance away from the fire origin, a sounding smoke alarm gives them more time to react. These estimates are based on raw NFIRS 5.0 deaths for which the victim's location at ignition was known and a) smoke alarms were reported to be present and to have operated (364), b) to have been present but not operated (214), and c) to not have been present at all (498).

Intuitively, one would expect little difference between situations in which no smoke alarms were present at all and situations in which smoke alarms were present, should have operated, but did not. Households that had installed smoke alarms but either disabled or did not maintain them may have different characteristics than households that had no smoke alarms at all. Also, the numbers of home fires and associated deaths in which smoke alarms were present but failed to operate are much smaller than the numbers seen when no smoke alarms were present at all. More fluctuation is likely with smaller numbers.

According to U.S. Census data, only 12% of the resident population was at least 65 years of age in 2003-2006. Although older adults face the highest risk of dying in fires, regardless of smoke alarm performance, the percentage of victims who were 65 or older was higher in fatal fires with operating smoke alarms than in fires with no working alarms. Figure 6 shows that 34% of the victims of fatal home fires with working smoke alarms were 65 years of age or older, compared to only 21% of the victims in fires in which the alarms did not operate and 25% in which no smoke alarms were present. These estimates are based on raw NFIRS 5.0 deaths for which the victim's age was known and a) smoke alarms were reported to be present and to have operated (593), b) to have been present but not operated (370), and c) to not have been present at all (1,088).

Figure 6. Fatal Home Fire Victims by Age and Smoke Alarm Status, 2003-2006



Source: NFIRS 5.0 and NFPA survey and U.S Census data.

Table 8 shows that when smoke alarms were present and operating, the victims were more likely to be engaged in fire control (6%) or unable to take action to save themselves (14%) and less likely to be sleeping (30%) than were victims of fires in which no smoke alarms were present or in which they were present and failed to operate,. When no alarms were present, only 2% of the victims were fighting the fire, 8% were unable to act, and 41% were sleeping. When smoke alarms were present but did not operate, 3% of the victims were trying to fight the fire, 8% were unable to act, and 45% were sleeping. These estimates are based on raw NFIRS 5.0 deaths for which the victim's activity at injury was known and a) smoke alarms were reported to be present and to have operated (271), b) to have been present but not operated (173), and c) to not have been present at all (390).

Human factors that contributed to home fire deaths are discussed in more detail in the full report. [1] Physical disability contributed to the fatal fire injury in 17% of the deaths resulting from fires in which smoke alarms operated. Such a disability was a factor in only 10% of the deaths when no smoke alarms were present and 9% of the fatalities when smoke alarms were present but failed to operate. These percentages were based on raw NFIRS 5.0 total deaths with valid human factors contributing to injury and: a) smoke alarms were reported to be present and to have operated (461), b) to have been present but not operated (301), and c) to not have been present at all (709).

When physical disability was a factor contributing to the fatal injury, smoke alarms operated in fires associated with 54% of the deaths. [10] A physical disability can make it difficult or even impossible for an individual to escape without assistance.

Different sensors respond faster to different types of fires. NFIRS 5.0 does not differentiate between photoelectric and ionization smoke alarms. Nor does it specifically differentiate fires that started with a smoldering period from those that were flaming at the outset. Some differences in fire development could be expected based on the item first ignited. Table 9 shows the leading items first ignited in non-confined home fire deaths by smoke alarm status.

Upholstered furniture and mattresses and bedding were the leading items first ignited in home fire deaths with and without working smoke alarms. However, the percentage of deaths resulting from fires starting with items likely to be very close to the victims, such as mattresses or bedding, and clothing, tended to be higher when smoke alarms operated than when no alarms were present. The majority of upholstered furniture fire victims were also injured in the room of origin. During 2002-2005 two-thirds (66%) of the victims of home fires in which smoking materials ignited upholstered furniture and 55% of the victims of all home fires that began with upholstered furniture, were in the area of fire origin when fatally injured. [11] During the same period, 86% of the victims of home mattress and bedding fires started by smoking materials and 75% of all victims of home fires beginning with mattresses and bedding were in the area of origin. [12] Victims who are very close to where the fire started will have less time to escape and may be injured before fire protection can operate. The proximity of the victim must be considered when evaluating alarm performance.

The home fire death estimates and rates shown in Table 9 were based on four-year raw NFIRS totals in which the item first ignited was known and: a smoke alarm operated (81,066 non-confined fires and 356 deaths); the smoke alarm did not operate (21,911 non-confined fires and 239 deaths); and no smoke alarm was present (75,882 non-confined fires and 564 deaths).

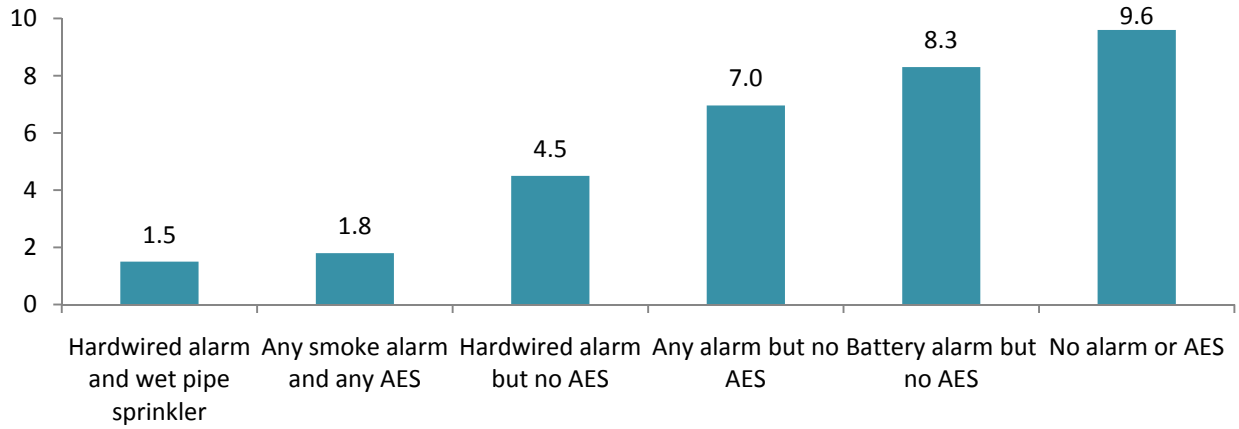
The death rate per 100 reported non-confined home fires for these items by smoke alarm status is also shown in Table 9. While the death rates for some items, particularly cooking materials and rubbish, would be much lower if confined fires were included, one point stands out. When upholstered furniture was the item first ignited, the death rate was 7.6 per 100 non-confined fires when smoke alarms operated and 9.1 when no smoke alarms were present at all and 12.8 per 100 fires when smoke alarms were present but failed to operate. Rates were calculated after scaling ratios were applied and unknown data were allocated.

6. Increasing levels of fire protection

CPSC's *Residential Fire Survey* showed that interconnected smoke alarms were more likely to alert occupants to an unreported fire than were smoke alarms that were not interconnected. NFIRS does not indicate whether smoke alarms are interconnected or provide data on extent of coverage. It does provide information about power source. As mentioned earlier, in 56% of the reported home fires in 2003-2006 and 69% of the associated deaths, smoke alarms were powered by batteries only. Figure 7 shows that the death rate per 1,000 reported fires steadily declines with greater levels of fire protection. The death rate is lowest in homes with wet pipe sprinklers and hardwired smoke alarms. These rates are based only on the presence of the equipment in

fires that are reported to the fire department and were calculated from the estimates after scaling ratios were applied and unknown data allocated. The equipment's operation was not considered. Figure 3 showed that hardwired smoke alarms were more likely to operate than were battery-powered smoke alarms.

Figure 7. Fire Death Rate per 1,000 Reported Home Structure Fires by Presence of Smoke Alarms and Automatic Extinguishing Systems (AES) 2003-2006



Source: NFIRS 5.0 and NFPA survey

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

- 14% lower when battery-powered smoke alarms are present but AES are not;
- 27% lower when smoke alarms with any power source are present but AES are not;
- 53% lower when hardwired smoke alarms are present but AES are not;
- 81% lower when smoke alarms with any power source and any AES are present; and
- 84% lower when hardwired smoke alarms and wet pipe sprinklers are present.

It is possible that a systemic bias exists that causes more minor fires to be reported when alarms are hardwired. CPSC's *Residential Fire Survey* found that 14% of households had two or more smoke alarms connected to a home security system. (p. 84) Home security systems would generally be hardwired. Monitored systems may increase the likelihood that very small fires will be reported to the fire department. This could decrease the death rate per 1000 fires for hardwired alarms, and in comparison, make battery-powered alarms look less effective. CPSC noted that household members themselves actually put out the fire in 24% of home fires attended by the fire department. In 12% of the attended fires, the fire self-extinguished. (p.159) Unfortunately, the method of fire department notification was not discussed in the CPSC study.

As mentioned earlier, confined fires accounted for 60% of reported home fires with hardwired smoke alarms but only 46% of the reported fires with battery-powered alarms only. The AHS found that two-thirds of households had smoke alarms powered by batteries only, a substantially larger share than was seen among reported fires.

Discussion

When smoke alarms operated in fires reported to the fire department, the death rate per 1,000 fires was half the rate of fires in which smoke alarms failed to operate or were not present at all. Operating smoke alarms were present in 37% of all fire deaths and 62% of the deaths from fires with smoke alarms and enough smoke. When evaluating the effectiveness of existing technologies and codes or considering the benefits of possible refinements, it is necessary to have an accurate understanding of how existing technology is actually used and what it can reasonably be expected to accomplish. Often the technology that is in place lags considerably behind the current model code requirements. Although model codes have required hardwired smoke alarms in new construction for years, more than one-third of the homes that were under five years old in the American Housing Survey had smoke alarms powered by batteries only. This suggests that this requirement is not universally in place or enforced.

CPSC's *Residential Fire Survey* found that a number of high-risk groups, including older adults and households with smokers were somewhat less likely than average to have smoke alarms in all bedrooms. Households that had fires had less smoke alarm protection than other households. Even so, the vast majority of high-risk households and households with fires did have at least some smoke alarm protection. Only 31% of the reported home fires occurred in properties with no smoke alarms at all.

The 2007 edition of NFPA 72 required interconnected smoke alarms in all homes, including existing ones, and the installation of smoke alarms in all bedrooms. Although CPSC's survey was conducted before these provisions took effect, with only 19% of all households having interconnected smoke alarms at that time, and the two-thirds of households in the 2007 AHS with smoke alarms powered by batteries only, it is clear that most homes do not yet have the benefit of interconnected smoke alarms. In their analysis of unreported fires, CPSC found that interconnected smoke alarms were more likely to sound and to alert occupants.

Hardwired smoke alarms operated more reliably in reported fires than alarms powered by batteries only. Figure 3 showed that hardwired smoke alarms (including those with or without battery backup) operated in 91% of fires considered large enough to activate the alarm while smoke alarms powered by batteries only operated in just 75% of the fires. When battery-powered alarms failed to operate, the batteries were missing or disconnected in 62% of the incidents. The batteries were dead in roughly one-quarter of the failures. It is possible that installers of hardwired smoke alarms are more knowledgeable about where smoke alarms should be installed. Investigators in CPSC's 1992 Smoke Detector Operability Survey found that cooking was the most common cause of nuisance activations that led to nuisance alarms. They discovered that one-third of the alarms collected because of nuisance alarms had been located within five feet of a smoke, steam or moisture source such as a stove or bathroom. [9] When the smoke alarm installation requirements in NFPA 72 are followed, nuisance alarms are less likely.

While hardwired smoke alarms are not necessarily interconnected, hardwired alarms are much more likely to be interconnected than are those powered only by batteries. To be effective in providing a warning, the smoke alarm's signal must be noticed. CPSC's *Residential Fire Survey* found that in unreported fires, smoke alarms were more likely to have sounded and to have alerted occupants when the alarms were interconnected.

In a 2005 study, Arthur Lee concluded that a single-station smoke alarm in a home with two or three floors or larger square footage may not be adequate to alert unimpaired adults in all parts of the home. Closed doors, turns, and narrow hallways also reduced the volume of the signal. [13] Dorothy Bruck and her colleagues found that several factors influence the effectiveness of smoke alarms in waking people. These include the nature of the smoke alarm signal, individual arousal thresholds, the presence of background noise, sleep deprivation, hearing loss, childhood or youth, alcohol, medication and drugs. [14, 15, 16, 17, 18, and 19]

Several differences were seen when smoke alarm performance was compared in fires that resulted in death. Compared to victims of fires with no working smoke alarms, victims of fires with working smoke alarms were less likely to be sleeping and more likely to have been fighting the fire, at least 65 years old, or unable to act when fatally injured. Physical disability was more likely to be a factor when smoke alarms operated. Victims with operating smoke alarms were also 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 than victims without working alarms. The requirements of NFPA 72 assume that the occupants are not intimate with ignition and can act to save themselves. In cases of civilian firefighting or return to the fire, individuals can be alerted by the smoke alarm but take actions that increase their risk of harm.

Figure 7 showed that the lowest death rates per 1,000 reported fires were found in fires with wet pipe sprinklers and hard-wired smoke alarms. A few limitations should be noted. The rates shown in Figure 7 are based solely on data from fires reported to local fire departments. These fires tend to be more severe than those handled without fire department assistance. All of these rates would be much lower if the fires included unreported fires. It is quite possible that people who are more concerned about safety have installed more complete fire protection or that homes with the best fire protection are owned by healthier and lower risk individuals. Also, operation is not considered. As mentioned, in fires with enough smoke, hardwired alarms were more likely to operate than were those powered by batteries only. Battery-powered smoke alarms are also more likely to be stand-alone. Most interconnected smoke alarms are hardwired, as are systems that are monitored. The warning from an interconnected smoke alarm is more likely to be heard throughout the home. Small fires in homes with hardwired monitored systems may be more likely to be reported to the fire department. While it is impossible to state that all of the differences in fire death experience are due to the presence or absence of different types of fire protection, it does appear that that the equipment plays a major role.

Through the years, fire safety education has typically encouraged people to leave the home should a fire occur. In practice, the overwhelming majority of home fires are handled without fire department assistance and cause little, if any, flame damage. Smoke alarms play an important role in these successful outcomes. Although people are typically up and about while cooking, they sometimes do not pay adequate attention. CPSC found that smoke alarms provided the only alert in almost 600,000 unreported fires per year involving stoves, ranges or other cooking appliances.

Smoke alarms are an important fire protection feature even when sprinklers are present. NIST researchers compared the performance of sprinkler actuating elements with other detection technologies in their 21st century study of home smoke alarm performance. [20] Sprinklers activated after the smoke alarms in all the scenarios tested.

Hardwired smoke alarms are more reliable than battery-powered units. Model codes have required hardwired smoke alarms in new construction for years. Interconnected smoke alarms increase the likelihood that the alarm will register with the occupants. NFPA 72 now requires interconnected smoke alarms on all levels and in all bedrooms. For smoke alarms to be effective, they must have a functional power source, a sensor must be close enough to detect the smoke, and the signal must be strong enough to alert the occupants. The highest level of home fire safety can be obtained when this protection is combined with residential fire sprinklers. Even with the best protection possible, the abilities and actions of the occupants will influence the outcome.

Additional information may be found in the author's full report, *Smoke Alarms in U.S. Home Fires,* published by NFPA in 2009.

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Table 1.
Smoke Alarm Coverage and Power Source in Homes with and without Fires
In CPSC's 2004/2005 Residential Fire Survey

Coverage and Power Source	Households with fires	Households without fires	All Households
No alarm	7%	3%	3%
Alarms on all floors	82%	84%	84%
In all bedrooms	22%	31%	31%
Interconnected alarms	13%	19%	19%
Battery-powered	72%	70%	70%
Hardwired	10%	13%	13%
Hardwired with battery backup	18%	17%	17%

Source: Greene and Andres, 2009.

Table 2.
Smoke Alarm Coverage and Performance in Unreported Fires when Someone Was Home
In CPSC's 2004/2005 Residential Fire Survey

Performance	All Unreported Fires	Inter-Connected	Not Inter-Connected	All Bedrooms	Not All Bedrooms	All Floors	Not All Floors
Were present	89%	100%	87%	99%	85%	100%	48%
Alarm sounded, based on those present	35%	53%	32%	37%	34%	38%	9%
Alarms that alerted, based on those sounded	39%	49%	37%	45%	37%	39%	46%
Alarms provided the only alert, based on those sounded	32%	49%	28%	35%	31%	32%	46%
Alerted occupants based on those present	14%	26%	12%	16%	13%	15%	4%

Source: Greene and Andres, 2009.

Table 3.
Smoke Alarm Performance in Unreported Fires when Someone Was Home
In CPSC's 2004/2005 Residential Fire Survey, by Fire Area and Cause

Performance	Kitchen	Living Room	Bedroom	Stove or Range	Lighting or Wiring	Heating or Cooling	Candle	Lighter, Cigarette, or Match
Were present	90%	99%	87%	87%	84%	98%	100%	96%
Alarm sounded, based on those present	41%	25%	22%	47%	8%	23%	23%	30%
Alarms that alerted, based on those sounded	40%	1%	69%	38%	81%	23%	35%	29%
Alarms provided the only alert, based on those sounded	33%	1%	69%	33%	81%	3%	32%	29%

Source: Greene and Andres, 2009.

Table 4.
Home Structure Fires by Smoke Alarm Performance
2003-2006 Annual Averages

Detection Performance	Fires		Civilian Deaths	
TOTAL	**378,600**	**(100%)**	**2,850**	**(100%)**
Smoke Alarm Present	**260,100**	**(69%)**	**1,710**	**(60%)**
Fire too small to operate alarm	*48,500*	*(13%)*	*30*	*(1%)*
Fire too small to operate in non-confined fire	18,600	(5%)	30	(1%)
Fire too small to operate in confined fire	29,900	(8%)	0	(0%)
Smoke alarm present and fire large enough to operate alarm	**211,600**	**(56%)**	**1,670**	**(59%)**
Smoke alarm operated	*176,400*	*(47%)*	*1,040*	*(37%)*
Smoke alarm operated in non-confined fire	84,200	(22%)	1,030	(36%)
Smoke alarm operated in confined fire	92,200	(24%)	10	(0%)
Smoke alarm present but did not operate	*35,200*	*(9%)*	*640*	*(23%)*
Smoke alarm present but did not operate in non-confined fire	22,600	(6%)	640	(23%)
Smoke alarm present but did not operate in confined fire	12,600	(3%)	0	(0%)
No Smoke Alarm	**118,500**	**(31%)**	**1,140**	**(40%)**
No smoke alarm present in non-confined fire	82,600	(22%)	1,140	(40%)
No smoke alarm present in confined fire	35,800	(9%)	0	(0%)
No working smoke alarm(Sum of no smoke alarms and alarms that were present but did not operate)	***153,700***	***(41%)***	***1,780***	***(62%)***

Note: Sums may not equal totals due to rounding errors.
Source: NFIRS 5.0 and NFPA survey.

Table 5.
Smoke Alarms in Reported Home Structure Fires by Smoke Alarm Power Source
2003-2006 Annual Averages

Power Source	Fires		Civilian Deaths	
Battery only	145,900	(56%)	1,180	(69%)
Non-confined fire	*79,100*	*(30%)*	*1,170*	*(69%)*
Confined fire	*66,800*	*(26%)*	*10*	*(1%)*
Hardwired (with or without battery back-up	102,100	(39%)	420	(25%)
Non-confined fire	*41,300*	*(16%)*	*420*	*(25%)*
Confined fire	*60,800*	*(23%)*	*0*	*(0%)*
All other, including multiple detection devices and power sources	12,100	(5%)	110	(6%)
Non-confined fire	*5,000*	*(2%)*	*110*	*(6%)*
Confined fire	*7,100*	*(3%)*	*0*	*(0%)*
Total	260100	(100%)	1,710	(100%)
Non-confined fire	*125,400*	*(48%)*	*1,700*	*(99%)*
Confined fire	*134,700*	*(52%)*	*10*	*(1%)*

Table 6.
Effectiveness of Operating Smoke Alarms In Non-Confined Home Structure Fires
2003-2006 Annual Averages

Effectiveness	Fires		Civilian Deaths		Civilian Injuries		Direct Property Damage (in Millions)	
Alerted occupants and occupants responded	66,800	(79%)	710	(69%)	5,150	(87%)	$2,492	(70%)
Alerted occupants but occupants failed to respond	2,500	(3%)	220	(21%)	340	(6%)	$113	(3%)
No occupants were present	12,600	(15%)	0	(0%)	160	(3%)	$770	(22%)
Failed to alert occupants	2,400	(3%)	100	(9%)	270	(5%)	$200	(6%)
Total	84,200	(100%)	1,030	(100%)	5,910	(100%)	$3,575	(100%)

Source: NFIRS 5.0 and NFPA survey.

Table 7.
Victim's General Location at Time of Incident by Smoke Alarm Presence and Operation
In Non-Confined Home Structure Fire Deaths
2003-2006 Annual Averages

Victim's Location	Present and Operated		Present but Did Not Operate		None Present	
In area of origin and involved	480	(47%)	190	(30%)	400	(35%)
In area of origin and not involved	160	(16%)	80	(13%)	170	(15%)
Subtotal --In area of origin	*640*	*(62%)*	*280*	*(43%)*	*560*	*(49%)*
Not in area of origin and not involved	160	(16%)	170	(27%)	280	(24%)
Not in area of origin but involved	220	(22%)	190	(29%)	290	(25%)
Subtotal –Not in area of origin	*380*	*(38%)*	*360*	*(56%)*	*570*	*(49%)*
Unclassified	0	(0%)	0	(0%)	10	(1%)
Total	1,030	(100%)	640	(100%)	1,140	(100%)

Note: Fire deaths resulting from fires too small to activate the smoke alarm are not included in these tables. Sums may not equal totals due to rounding errors.

Source: NFIRS 5.0 and NFPA survey.

Table 8.
Activity at Time of Victim's Fatal Injury by Smoke Alarm Presence and Operation in Non-Confined Home Structure Fire Deaths
Excluding Fires Too Small to Activate the Smoke Alarm
2003-2006 Annual Averages

Activity	Present and Operated		Present but Did Not Operate		None Present	
Escaping	310	(30%)	200	(31%)	420	(37%)
Sleeping	310	(30%)	290	(45%)	460	(41%)
Unable to act	150	(14%)	50	(8%)	90	(8%)
Unclassified activity	70	(7%)	30	(5%)	40	(4%)
Fire control	70	(6%)	20	(3%)	20	(2%)
Returning to vicinity of fire before control	50	(5%)	10	(2%)	30	(3%)
Irrational act	50	(5%)	20	(4%)	30	(2%)
Rescue attempt	20	(2%)	20	(3%)	40	(3%)
Total	1,030	(100%)	640	(100%)	1,140	(100%)

Note: Fire deaths resulting from fires too small to activate the smoke alarm are not included in this table. Sums may not equal totals due to rounding errors.

Source: NFIRS 5.0 and NFPA survey.

Table 9.
Non-Confined Home Structure Fire Deaths
By Leading Items First Ignited and Smoke Alarm Status
2003-2006 Annual Averages

	Present and Operated			Present but Did Not Operate			None Present		
Item First Ignited	**Civilian Deaths**		**Deaths per 100 Fires**	**Deaths**		**Deaths per 100 Fires**	**Deaths**		**Deaths per 100 Fires**
Upholstered furniture	220	(22%)	7.6	110	(18%)	12.8	310	(28%)	9.1
Mattress or bedding	180	(18%)	3.5	100	(16%)	6.4	150	(13%)	3.1
Flammable or combustible liquid or gas, or pipe, hose, duct or filter	90	(9%)	2.8	40	(6%)	5.6	60	(6%)	1.7
Clothing	80	(8%)	2.2	40	(6%)	3.3	40	(3%)	1.3
Unclassified furniture or utensil	60	(5%)	2.1	30	(5%)	4.7	80	(7%)	3.4
Structural member or framing	50	(4%)	0.7	40	(6%)	1.8	50	(4%)	0.6
Cooking material, including food	40	(4%)	0.3	30	(5%)	1.0	30	(3%)	0.5
Multiple items first ignited	30	(3%)	2.4	20	(3%)	4.8	40	(4%)	1.9
Electrical wire or cable insulation	30	(3%)	0.5	10	(2%)	0.6	50	(4%)	0.9
Floor covering rug, carpet, or mat	30	(3%)	1.4	50	(8%)	9.1	50	(4%)	1.7
Cabinetry	30	(2%)	0.9	10	(2%)	1.9	20	(2%)	1.1
Interior wall covering. excluding drapes	20	(2%)	0.7	20	(3%)	2.6	60	(6%)	1.6
Rubbish, trash, or waste	20	(2%)	1.0	20	(3%)	3.3	20	(1%)	0.6
Unclassified structural component or finish	20	(2%)	1.0	20	(3%)	3.2	50	(4%)	1.4
Magazine, newspaper or writing paper	20	(2%)	1.3	10	(1%)	2.0	20	(1%)	1.1
Unclassified soft goods or wearing apparel	20	(2%)	1.0	10	(2%)	2.3	30	(2%)	1.7

Note: Percentages were calculated from the number of deaths with each smoke alarm status. Confined fires, which tend to be minor, were excluded from the calculations of deaths per 100 reported fires.

Source: NFIRS 5.0 and NFPA survey.