Technological Advances in Smoke Alarms

Introduction
Smoke alarms are designed to detect a fire in its early stages and alert people so they have time to safely escape the dwelling unit or building. The smoke alarm industry has experienced substantial growth since the model codes began requiring their installation in one- and two-family dwellings in 1976. Since then, fire fatalities have decreased in all majority occupancy classifications.

Origin of Smoke Detection Requirements in Model Codes
The genesis of code requirements for smoke detection installation came from a 1968 Act signed by President Johnson to form a commission to assess the nation's fire problem and to find measures to reduce fire losses. In 1973, the commission delivered its report to President Nixon. The landmark report, *America Burning*, had 90 recommendations to reduce America's fire losses and also called for the formation of the U.S. Fire Administration (USFA). At that time, there were a hodgepodge of local, state, and federal agencies conducting research and issuing regulations, but there was no single entity coordinating all these activities. Also, local fire departments had no formal representation in the federal government.

The report urged Americans to install smoke alarms in their homes and recognized the need to promulgate regulations for the installation of smoke alarms. The next major step occurred in 1976 when NFPA 101, *The Life Safety Code ®*, added requirements for the installation of smoke alarms in one- and two-family dwellings. That was followed by the three regional code organizations requiring the installation of smoke alarms in one- and two-family dwellings in 1979. Since then, the number of U.S homes with smoke alarms has increased from 22% in 1977 to 96% in 2004.

Importance of Smoke Alarms
Numerous reports show that fire fatalities have decreased in all majority occupancy classifications. According to a 2011 NFPA report[1], home fatalities in the U.S. have decreased from 6,015 in 1978 to 2,644 in 2010, which represents an overall reduction of 44% in 32 years. NFPA classifies homes as one- and two-family dwellings, manufactured homes, or multi-family housing. According to another NFPA[2] study, non-home fire fatalities have decreased from 640 in 1977 to 120 in 2011. A 2012 NFPA report[3] concludes that fire fatalities in hotels and motels have declined from 62 in 1980 to 16 in 2010. During the same time period, the U.S. population increased by 97 million. Fatality reductions cannot be solely attributed to the use of smoke alarms, but many researchers agree that they have contributed to the substantial reductions.

Evolution of Smoke Alarms
Ionization smoke alarms were introduced in the U.S. in the mid 1950's and these early models required 240 volts AC for operation. Electronic advancements in the 1960's reduced the operating voltage to 9 and 24 volts. Smoke alarms utilizing photoelectric technology were introduced in the early 1960's.

- 1954: Cerberus achieves the first UL Listed Smoke Detector (the process took more than two years).
- 1964: First Alert develops a low-power (24 V) ionization smoke detector.
- 1965: Duane Pearsall of Statitrol develops a single-station photoelectric smoke detector powered by a battery which makes widespread installation highly feasible in residences.
- 1995: The first 10-year, lithium-battery-powered smoke alarm is introduced
- 1999: NFPA 72 requires residential smoke alarms be replaced every 10 years. The basis for the 10-year time frame was the result of a reliability study conducted in the mid 1970's

Single Technology Smoke Alarms

Ionization and photoelectric are the two smoke sensing technologies used in homes since the 1970's. The smoke chamber of an ionization sensor consists of two electrically charged plates and a small amount of radioactive material called americium. It should be noted the small amount of americium poses no threat to life or property when it is contained within the smoke alarm. The radioactive material ionizes the air and renders the air in the chamber to be conductive. Since the air is conductive, it permits current flow between two metal plates in the chamber. When smoke enters the chamber, the ions stick to the smoke particles and there is a reduction in current flow. The reduction in current can be equated to a given amount of smoke. The detector goes into alarm when the current falls below a predetermined level.

A photoelectric sensor consists of a chamber with an LED light source and a receiver known as a photodiode. Typically the LED pulses about every 5 to 20 seconds. The LED and photodiode are arranged so the light rays from the LED are not directed at the photodiode during clean air conditions. When smoke particles enter the chamber, some of the light's rays scatter from the particles and reflect at the photodiode. When the photodiode receives light, it generates an electrical current that causes the detector to operate.

Photoelectric Versus Ionization Technology

People frequently ask if one technology is better than the other: The first thing to remember is photoelectric and ionization sensors have to meet the same fire tests in the UL smoke detection product standards. Which technology is better depends on either the type of fire or the source of combustion, because every fire develops differently once a material is ignited.

At one extreme, smoldering fires from natural materials like cotton upholstery and wood furniture generally produce measureable levels of carbon monoxide and larger particles of combustion in the 0.3 to 10.0 micron size range, which photoelectric sensors are better at detecting. However, a smoldering fire may never generate enough heat to lift the particles of combustion to the smoke alarm.

At the other extreme, flaming fires from synthetic materials used in modern interior furnishings produce small particles of combustion in the 0.01 to 0.3 micron size rang and generate high temperatures very quickly with a minimal amount of carbon monoxide. Ionization sensors are generally better at detecting these types of fires. It's impossible to know what type of fire will occur because most buildings have materials that will produce small and/or large particles of combustion. If the type of fire is unknown, then you can't know what type of sensor to install.

Unwanted Alarms

Unwanted alarms, also referred to as nuisance alarms, are the leading cause of occupants disabling their smoke alarms: roughly 20% of all smoke alarms installed in U.S. homes have been disabled. That percentage may be higher in high-risk areas, such as inner cities and rural communities. Normal cooking activities like pan frying, baking, and sautéing are the leading cause of unwanted alarms. While both ionization and photoelectric alarms are subject to alarms from normal cooking activities, ionization alarms are more likely to generate unwanted alarms when installed too close to a cooking appliance.

For the 2010 edition of NFPA 72, *The National Fire Alarm and Signaling Code*, new placement requirements were added to reduce the occurrence of unwanted alarms from smoke detection devices installed near fixed cooking appliances. Smoke alarms are prohibited from being installed within 10 feet of a fixed cooking appliance, unless listed for installation in close proximity to cooking appliances. It should be noted that at this time there is no product listing for smoke alarms installed near cooking appliances. Smoke alarms installed between 10 feet and 20 feet of a fixed cooking appliance are required to be equipped with an alarm-silencing means or use photoelectric detection. Even though the requirement does not specifically call out ionization technology, ionization alarms are only permitted to be installed between 10 and 20 feet of a cooking appliance if they have an alarm silencing means (more commonly referred to as a hush button).

An unwanted alarm does not mean the smoke detection device is not operating properly; an unwanted alarm may be an early warning of a potential developing hazard not imminently threatening to life or property, such as normal cooking activities. Even though the smoke alarm is activating to a non-hazardous source, it is actually detecting particles of combustion that may be invisible to the occupant. Despite this fact, occupants who are inconvenienced or annoyed by these alarms often disconnect the power source and therefore leave the residence partially or completely unprotected.

Multi-Criteria Fire Detection:
Today's single-technology smoke alarms have been on the market for over 30 years and they have performed very well during that time. However, they have reached their limit in terms of faster detection and rejecting unwanted alarms. The development of a multi-criteria technology is the result of manufacturers designing a smoke alarm that successfully addresses the two major issues that affect the overall well-being of the consumer:

1. Improving detection performance by detecting both smoldering and flaming fires sooner, to provide the occupant the maximum amount of time to react in potentially life threatening situations.
2. Improving resistance to unwanted alarms without sacrificing the detection performance.

A multi-criteria smoke alarm is best described as follows:

> A device that either contains multiple sensors that separately respond to physical stimuli such as heat, smoke, and fire gases, or employs more than one sensor to sense the same stimuli. The smoke alarm is capable of generating only one alarm signal from the various sensors employed in the design, either independently or in combination. The smoke alarm output signal is mathematically evaluated to determine when an alarm signal is warranted. The smoke alarm has a single listing that establishes the primary function of the unit.

How does a multi-criteria smoke alarm differ from a traditional single-technology smoke alarm?

Multi-Criteria Smoke Alarm:

- The alarm has multiple sensors. Several examples are photoelectric, ionization, heat, gas, or flame
- Each sensor output is mathematically evaluated by a microprocessor to determine if a fire is valid and the microprocessor uses filters to eliminate common causes of unwanted alarms The detector has one listing and generates a single alarm signal

Single Technology Alarm:

- The alarm has a single sensor, either photoelectric or ionization
- The alarm has one listing and generates a single alarm signal

A multi-criteria smoke alarm will contain a combination of sensors listed below but probably not all:

- Photoelectric smoke sensor
- Ionization smoke sensor
- Fixed temperature heat sensor
- Rate-of-rise heat sensor
- Carbon monoxide sensor
- Non-carbon monoxide sensor for toxic gases
- Infra-Red sensor

All multi-criteria smoke alarms contain a microprocessor that manages and processes the individual sensor outputs with prescribed algorithms. This process allows all inputs to provide information to the processor, which uses multiple outputs to determine whether there is actual smoke, heat, gases, or flames produced from a true fire. This process takes a few seconds to either provide occupants with maximum early warning of a true fire or to conclude that the sensor inputs do not correlate to an actual fire (no alarm is actuated in this case, thus eliminating an unwanted alarm).

Waking Effectiveness of Smoke Alarms

While smoke alarms provide life-saving value when occupants are awake, their greatest benefit may be when the occupants are asleep. This is illustrated in a 2010 U.S. Fire Administration study[4], which reports that 50% of fire fatalities in residential buildings occur between the hours of 10:00 p.m. and 6:00 a.m. when most people are sleeping. A 2008 study performed by Dr. Dorothy Bruck[5] concludes most unimpaired adults wake up quickly to the "standard" 2 kHz – 4 kHz audible fire alarm signal, even at levels well below 75 dBA. However, 13% of fire fatalities in residential buildings involve children less than 10 years old, and 44% of fire fatalities are adults between the ages of 40 and 69. Also, according to another Dr. Bruck study[6] there are more than 34.5 million people in the US who are hearing impaired.

The integral sounder used in nearly all smoke alarms produces a 3 kHz audible alarm signal. By contrast, the low frequency audible alarm signal has a fundamental frequency of 520 Hz. Researchers have been testing the effectiveness of various alarm signals and frequencies in waking at-risk sub-groups of the population. Much of this research has been conducted by Dr. Dorothy Bruck and her colleague, Ian Thomas, at Victoria University in Australia. The findings conclude that "most unimpaired adults will normally awaken quickly to 3 kHz audible alarm signal and the low frequency signal is most effective at waking up high risk segments of the population such as people with hearing loss, the elderly, school age children, and the alcohol impaired."

A series of tests were conducted with different groups of subjects. Variables in the tests included sound intensity (in dB) and frequency (in Hz) of the alarm signal, and other stimuli including voice, strobe lights, and bed and pillow shakers. Each test was constructed differently, so the findings are not directly comparable between them, but the findings were consistent over multiple studies. They showed the waking effectiveness of the 520 Hz signal with appropriate harmonics was superior to the "standard" alarm signal, as follows:

- Six to ten times more effective at waking children.
- Six to ten times more effective at waking young adults, both sober and with .05 blood alcohol level
- Six times more effective at waking adults with hearing loss

More recent research by Dr. Bruck with colleagues Chris Lykiardopoulos and Michelle Ball, confirms similar results with "hypnotics" (i.e., sleep-inducing drugs). This work was not published at the time this white paper was published.

In response to this research, new requirements have been incorporated into most of the applicable U.S. consensus codes and standards. Section 29.3.8 of NFPA 72 requires a low frequency audible alarm signal in sleeping rooms and guest rooms only for those with mild to severe hearing loss or where required by a local law or code. The effect of 29.3.8 is that when smoke alarms are installed in sleeping rooms, the low frequency audible alarm signal is only required when the person with the mild to severe hearing loss chooses it.

Notification appliances that produce the low frequency audible signal draw more current than the traditional 2 kHz and 4 kHz audible signal. The higher current draw of the low frequency signal has caused considerable challenges for smoke alarm manufacturers. Consequently, at this time there are no smoke alarms and carbon monoxide alarms with an integral sounder producing the low frequency audible signal. However, there are listed alarm accessory devices that provide the low frequency audible fire alarm signal.

Conclusion

Home fire fatilities have declined from 6,016 in 1978 to 2,644 in 2010, due in large part to the model codes requiring smoke alarm installation in one- and two-family dwellings. Many researchers estimate that over 90,000 lives have been saved since the late 1970's. Even though there have been significant reductions in fire fatalities, challenges remain: Unwanted alarms are still the leading cause of unprotected homes because of occupants disconnecting their smoke alarms, and the standard 3 kHz audible fire alarm signal may be ineffective at waking high-risk groups (the hearing impaired, school-age children, and the elderly). Manufacturers continue to make advancements in technology designed to reduce fire fatalities. Multi-criteria technology improves smoke alarm performance by detecting both smoldering and flaming fires and by improving resistance to unwanted alarms, without sacrificing the detection performance. Research has shown that the low frequency audible alarm signal is more effective than the "standard" alarm signal at waking children, young adults, those over 65 years old, and adults with mild to moderately severe hearing loss. New smoke alarm placement requirements have been made to national consensus codes and standards to reduce unwanted alarms.

Sources

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4. *USFA, Civilian Fire Fatalities in Residential Buildings 2008-2010 Report*
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