CPSC Staff Statement on the Report
Evaluating the Need for a Consumer Focused Smoke Alarm Performance System,
December 17, 2015

The report, *Evaluating the Need for a Consumer Focused Smoke Alarm Performance System*, presents the findings of research conducted by Everett Baker, Tyler Bennett, Jimmy Mosteller, and John Williams (Worcester Polytechnic Institute). The students performed this research for their Interactive Qualifying Project ("IQP") at Worcester Polytechnic Institute ("WPI"). The 2015 WPI team examined the public benefits of performance information for smoke alarms. The team spent 6 weeks in the Washington D.C. area working at and with U.S. Consumer Product Safety Commission ("CPSC" or "Commission") staff at the National Product Testing and Evaluating Center in Rockville, MD. The IQP is not organized as a course, nor is it related to any particular major. Instead, the students work under the guidance of WPI faculty members to conduct research, using social science methods directed at a specific problem or need. Students deliver findings and recommendations through a formal report and oral presentation to project sponsors and a faculty advisor. The final report, as referenced above, contains their research and was submitted to the WPI advisors on December 17, 2015.

The attached WPI report is intended to keep stakeholders informed of technical research related to the CPSC's voluntary standard activities. The information and conclusion in the students' report express the views and opinions of the authors and do not necessarily reflect the positions or opinions of CPSC staff, the Commission, or WPI.

Evaluating the Need for a Consumer Focused Smoke Alarm Performance System

December 17th, 2015

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This project is submitted in partial fulfillment of the degree requirements of Worcester Polytechnic Institute. The views and opinions expressed herein are those of the authors and do not necessarily reflect the positions or options of the United States Consumer Product Safety Commission or Worcester Polytechnic Institute.

Abstract

Smoke Alarms play a key role in early detection of home structure fires. Annually there are 357,000 home fires in the United States. These fires result in an average of 2,470 civilian deaths, 12,890 civilian injuries, and $6.9 billion in direct property damage each year. Working in coordination with the Consumer Product Safety Commission (CPSC), we researched aspects of this problem with the focus of identifying whether a performance based rating system for smoke alarms would be beneficial to consumers in order to get better performing and safer smoke alarms into consumers' homes. We made recommendations to the CPSC on how to continue studying consumers, smoke alarms, and to look into a performance based rating system and a features list.

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Introduction

Every year, the United States invests time and money into the reparation of losses from home fires. According to the National Fire Protection Association (NFPA), from 2009 to 2013, there was an average of 357,000 home structure fires annually (Ahrens, 2015a). These fires resulted in an average of 2,470 civilian deaths, 12,890 civilian injuries, and $6.9 billion in direct property damage each year (Ahrens, 2015a).

Since the introduction of the smoke alarm to the U.S. consumer market in the mid-20th century, smoke alarms have played a key role in reducing the injury and loss of life caused by residential fires. In home fires between 2009 and 2013, the death rate per 100 reported fires in homes with working smoke alarms was 0.53, compared to 1.18 in homes with no working smoke alarms (Ahrens, 2015b).



Figure 1: Home Structure Fire
(Ahrens, 2015b)[1]

Recognizing the relationship between working smoke alarms and human mortality in home fires, the Consumer Product Safety Commission (CPSC) encourages consumers to install working smoke alarms and properly use smoke alarms. In its mission to protect the public from unreasonable risk of injury or death (CPSC, 2015), the CPSC aims to investigate new strategies to inform the public about the importance of appropriately working smoke alarms. In the past, the CPSC has done extensive work educating the public about fire hazards and fire prevention through the use of research reports, posters, and videos. While this information is helpful, there are some fires that can occur no matter what safety precautions the homeowner has taken. When unexpected fires occur, smoke alarms are a key precautionary element in homes to alert the occupants of the fire.

All smoke alarms currently sold in the U.S. meet the minimum voluntary standard performance requirements, as specified by Underwriter's Laboratories (UL). In addition, state and local jurisdictions often mandate stricter laws for the sale of smoke alarms. Smoke alarms are able to detect smoke particles in the air, and trigger an alarm before the fire spreads. The alarm alerts occupants to a fire, which gives them more time to safely escape the home. There are several steps that must occur to safely alert the occupants to a hazardous fire, and none of these steps can fail, otherwise the occupants may not have sufficient time to escape. The smoke must reach the alarm, the alarm must have a supply of power and be functional, it must be sensitive enough to the type of smoke that is reaching it, and finally it must sound an alarm that can be heard. The better the performance of the smoke alarm, the more likely the occupants will be alerted with enough time to escape.

Through innovation, smoke alarms have become not only more efficient, but also more diverse. Numerous additional features make the evaluation of smoke alarms difficult and may be a potential obstacle for consumers when trying to select the correct smoke alarm for their needs.

If consumers could easily distinguish between alarms in order to select the best smoke alarm for their own home, they could more effectively protect themselves from fires. One approach to improving consumer knowledge is to educate consumers during the purchasing process via a smoke alarm performance system. This project will investigate and develop a method for communicating smoke alarm performance to consumers and determine if this information will be beneficial to the public.

The United States Consumer Product Safety Commission

Mission to Keep the Public Safe

Since its formation in 1972, the United States Consumer Product Safety Commission (CPSC) has been vigilantly watching over consumer products. Created through the enactment of the Consumer Product Safety Act, it is an independent regulatory agency that is led by a chairman and up to four commissioners appointed by the President of the United States. The agency is "charged with protecting the public from unreasonable risks of injury or death associated with the use of the thousands of types of consumer products under the agency's jurisdiction" (CPSC, 2015). Acts such as the Poison Prevention Packaging Act, Flammable Fabrics Act, Virginia Graeme Baker Pool & Spa Safety Act, and the Consumer Product Safety Improvement Act provide a structure within which the CPSC can carry out its mission. Through the process of protecting consumers, the CPSC hopes to help lower the nation's spending on damages, injuries and deaths that result from consumer product incidents (CPSC, 2015).

Identifying Possible Hazardous Products

The commission staff is charged with monitoring safety concerns for all 15,000 consumer products in its jurisdiction (CPSC, 2015). To do this, the agency not only has its own epidemiologists that review adverse events related to product hazards, but also seeks help from the public to report potentially dangerous products. Hospitals report injuries and deaths caused by consumer products to the CPSC, in which the cause of injury to the patient is identified, and enter this information into the National Electronic Injury Surveillance System (NEISS). Consumers can also report products to SaferProducts.gov, and the public can call, email, fax, or mail a letter

to the Office of Compliance in Bethesda, Maryland.

National Product Testing and Evaluation Center

If a CPSC investigator is investing the safety of a particular product, the investigator will send the product to the CPSC lab for evaluation and testing. One of the main facilities in which the CPSC tests potentially unsafe products is the National Product Testing and Evaluation Center in Rockville, Maryland. Opened in 2011, this state-of-the-art building has 63,000 square feet of office and lab space that is equipped to handle a plethora of consumer products (CPSC, 2011). The Rockville site has electrical, chemical, carbon monoxide, pool safety, combustion, mechanical, recreational off-road vehicle, fireworks, and impact labs in which consumer products can be evaluated to determine if it presents a substantial hazard to consumers and the public.

Preventative Actions

When a product is determined to present a substantial hazard, the CPSC can negotiate with the manufacturer in recalling the product. The Commission can also develop a regulation to address a hazardous product(s) by issuing a Notice of Proposed Rulemaking (NPR). An NPR is a notice issued by law when one of the independent agencies of the United States government wishes to add, remove, or change a rule or regulation. An example of an NPR issued by the CPSC is the standard approved in 2006 stating that all manufacturers are required to place a warning label on portable generators Figure 2: Notice of Proposed Rulemaking for Portable Generators (CPSC, 2006) which includes images and statements warning consumers to never use the generators indoors (CPSC, 2006).

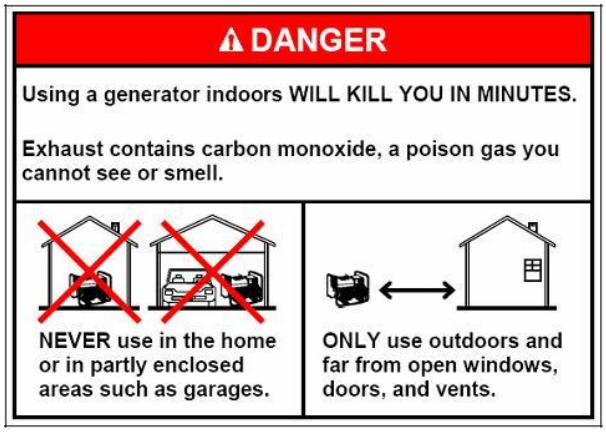


Figure 2: Notice of Proposed Rulemaking for Portable Generators (CPSC, 2006)

The CPSC staff may also initiate a recall with a smoke alarm if it is determined that it does not meet UL 217 voluntary standard for Smoke Alarms or presents a substantial product hazard. CPSC staff conducts research in-house and with the National Institute of Standards and Technology (NIST) to investigate the performance of smoke alarms. These tests can involve real fires to test the performance of smoke alarms currently on the market. Additionally, CPSC staff may investigate concerns that are not presently addressed by the standard. One such topic is the effects of aerosols on the carbon monoxide sensor in some smoke alarms.

Smoke Alarms

What a Smoke Alarm is... And is not

'Smoke detectors' are not the same as 'smoke alarms'. A smoke alarm includes the audible sounder in the same unit as the smoke sensor, while a smoke detector contains only the sensor and relies on external sounders (NFPA 72, 2013). Smoke *detectors* are often used in large buildings, whereas smoke *alarms* are usually found in private residences. Smoke detectors are often part of a fire alarm system that may include sprinklers, fire alarm pull stations, and a control panel. (Frank Quackenbush, personal communication, Sept. 2015). A fire alarm system is different from interconnected smoke alarms, which are described later. This project will focus on smoke alarms and not detectors. This is due to the fact that homeowners, the group we are focusing on in this project, will encounter smoke alarms most of the time in stores.

Heat alarms and carbon monoxide alarms are not considered smoke alarms, although these may be included in combination smoke and CO alarm units.

Types of Smoke Alarms

Current smoke alarms use two basic types of sensors to detect smoke: ionization and photoelectric. Both technologies have been around for many years and there are advantages and disadvantages associated with each type.

Ionization

Ionization smoke alarms use a small amount of radioactive material to ionize air between two electrical contacts in a small detection chamber (National Fire Protection Association, 2015). The ionized air allows electrical current to flow between the two contacts, completing a circuit. When smoke particles enter the detection chamber they break the circuit, which results in the alarm tripping.

The most common radioactive material used for ionization type smoke alarms, Americium-241, has a half-life of approximately 432 years, several times the recommended 10 year product life (Environmental Protection Agency 2015). Furthermore, the amount of Americium-241 present in the smoke alarm and its process of decay ensure that consumers are exposed to negligible amounts of radiation (World Nuclear Association 2014).

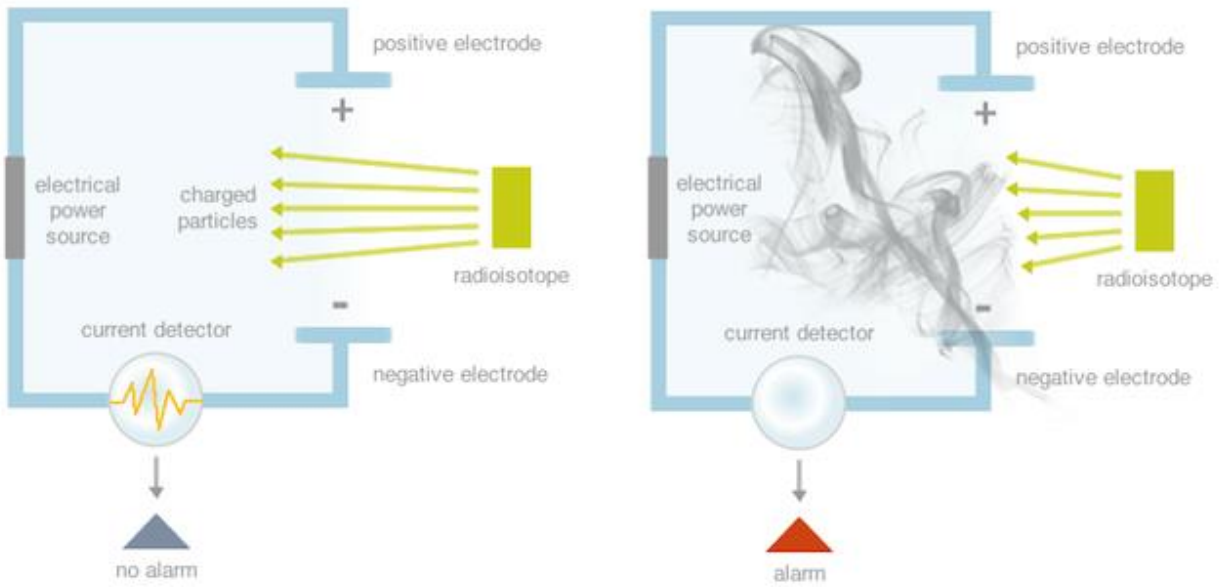


Figure 3: Ionization Smoke Alarm Diagram (Simplisafe.com)

Photoelectric

By contrast, photoelectric smoke alarms utilize a light source inside of the detection chamber that is aimed at an angle towards a photoelectric sensor. When smoke enters the detection chamber, smoke particles will interrupt the beam of light, causing some of that light to be scattered. This scattering of light results in the photoelectric sensor detecting a change in brightness within the chamber. Once this brightness passes a preset level, an alarm will sound.

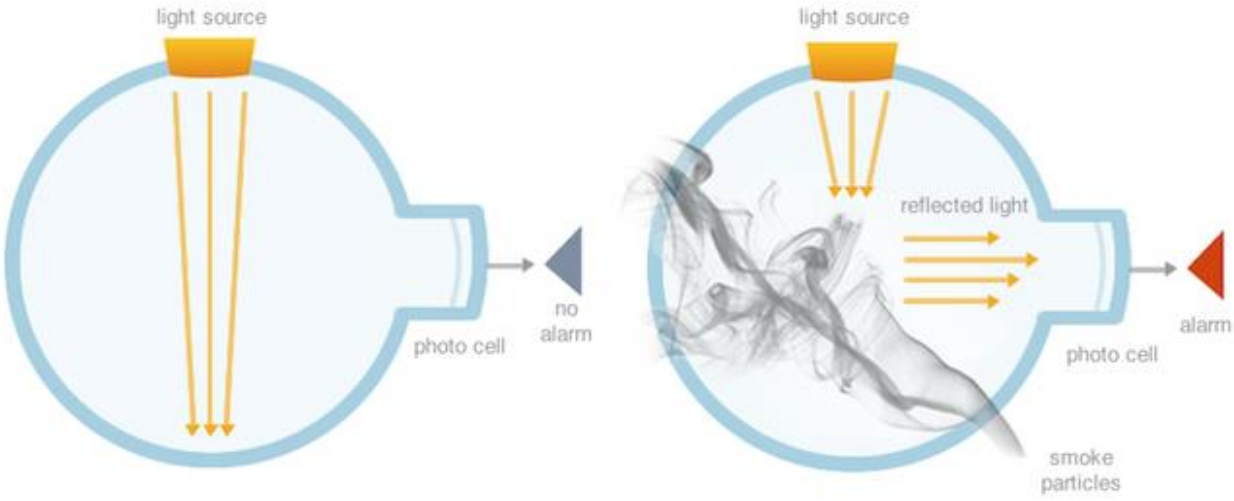


Figure 4: Photoelectric Smoke Alarm Diagram (Simplisafe.com)

Combination

In addition to ionization and photoelectric, there are several other types of smoke alarms. Some alarms combine both the photoelectric and ionization sensors into one unit. These smoke alarms provide the detection advantages of both types of standalone alarms, and some high end models include processor systems that reduce the occurrence of false alarms. Unfortunately, many combination alarms lack these advanced electronics and still suffer from nuisance alarms. It is for this reason that the International Association of Fire Fighters (IAFF) and some other organizations are no longer recommending combination alarms (Boston Fire Fighters Local 718, 2008). They suggest that the higher chance of nuisance alarms will lead to consumers disabling the alarm, as has been seen in some ionization alarm studies. Despite IAFF conclusions, some organizations still consider combination alarms a viable option, though there may be an increased risk of nuisance alarms over a purely photoelectric sensor. While combination alarms may be controversial, they are able to quickly respond to both flaming and smoldering fires.

Another common combination is a smoke alarm with a carbon monoxide alarm. At least 36 states have some requirement for carbon monoxide alarms in homes (National Conference of State Legislatures, 2015). Combination smoke and carbon monoxide alarms allow the consumer to reduce the hassle of maintaining two separate devices. Similarly, high end model smoke and CO alarms include processor systems that can reduce the occurrence of false alarms by using the CO sensor as an indicator of a true fire.

Since each smoke sensor has specific advantages depending on the type of fire, many fire safety experts recommend consumers use both ionization and photoelectric type smoke alarms in their homes. Manufacturers market the type of sensor to suggest the best location for a particular smoke alarm in the home. While standalone alarms respond quickly to either fast moving or smoldering fires, combination alarms are able to quickly respond to either type of fire. While Table 1 offers a general overview of smoke alarm advantages and disadvantages, the response of smoke alarms depends on many factors, such as location, type of fuel, home layout, heating and cooling system in the home, and position of doors and windows.

Type of Smoke Alarm	Advantages	Disadvantages
Ionization	Detects smaller smoke particles, responding more quickly to fast moving flaming fires.	Slower alert time for slow burning, smoldering fires. More sensitive to some common nuisance sources.
Photoelectric	Detects larger smoke particles, giving faster alert during smoldering fires.	Slower to alert to fast moving fires, giving occupants less time to escape.
Dual Sensor Combination	Able to react quickly to both smoldering and fast moving fires.	Generally higher cost per unit than stand-alone alarms.
Carbon Monoxide Combination	Combines CO alarm with smoke alarm, allowing consumer to maintain fewer total devices.	Generally more expensive than standard smoke alarms. May not make distinction between CO and fire alerts.

Table 1: Advantages and Disadvantages of Smoke Alarms

Performance

Sensitivity

The sensitivity of an alarm depends on the type of fire it is detecting. Fires can be generalized and classified as either flaming or smoldering. A flaming fire is faster moving and produces typically smaller smoke particles and density. A smoldering fire is slower and denser, typically producing larger smoke particles. Ionization alarms are known to be more sensitive to flaming fires, while photoelectric alarms are known to be more sensitive to smoldering fires.

Nuisance Resistance

Nuisance alarms occur when the smoke alarm is triggered by harmless sources, such as steam from a shower or kettle, or cooking aerosols. Nuisance alarms, as the name suggests, are irritating, but not necessarily dangerous. Nuisance alarms to cooking can also be considered precursors to an actual fire if the occupant doesn't address the source.

Nuisance alarms are based partly on product design, but also occur as a result of inappropriate smoke alarm placement. When a smoke alarm is in close proximity to nuisance particles such as steam or cooking aerosols from food, it is more likely to trip than a smoke alarm placed further from the source. Ionization smoke alarms are more sensitive to cooking particles because of the small particles emitted during cooking (National Fire Protection Agency, 2015). Since ionization alarms are more susceptible to nuisance alarms from cooking, their functional

capabilities may be best served in locations away from everyday cooking (i.e., not kitchens). Photoelectric smoke alarms are more susceptible to steam because of the large water droplet particles. Similarly, photoelectric smoke alarms should not be placed near bathrooms or similar locations that create steam. Even though location recommendations are already common on alarm packaging, nuisance alarms persist in homes due to inappropriate alarm placement. This situation is where nuisance alarms can turn dangerous. Frequent nuisance alarms may cause the owner to disconnect the alarm purposefully, creating a far more hazardous situation than if left connected.

Audibility

Audibility is a function of the tone's frequency, waveform, and amplitude. An alarm must be audible in the presence of background noise, through doors, to the young, the old, the hearing impaired, the intoxicated, and the sleeping (Ahrens, 2015b). Strobe lights and bed shakers connected to smoke alarms are also on the market for use by the hearing impaired. Interconnectability also affects the audibility of a smoke alarm, as is discussed in the next section.

Additional Features

Interconnectability

Some alarms can be interconnected with other alarms, such that when one alarm is triggered, they are all triggered as demonstrated in Figure 5: Interconnected Smoke Alarms (Consumer Product Safety Commission) Interconnected alarms are more than twice as likely to alert occupants as standalone alarms in the event of a house fire (Ahrens, 2015b). According to Marty Ahrens of the NFPA (2015b) "In homes that had interconnected smoke alarms, the alarms sounded in half (53%) of the fires and alerted people in one-quarter (26%) of the fires" (p. 5). In homes without interconnected alarms, smoke alarms only sounded in response to 27% of the fires, and alerted residents to 10% of the fires (Ahrens, 2015b).



Figure 5: Interconnected Smoke Alarms (Consumer Product Safety Commission)

Power Source

The power source of the smoke alarm is a vital part of the alarm. There are a variety of power options, each with their own advantages and disadvantages. The most commonly used power source is the replaceable battery (Ahrens 2015b). There are small, accessible

compartments in smoke alarms that house the battery. While this mode of power is relatively easy to set up, it is recommended that these batteries be changed every six months, requiring upkeep by the homeowner to ensure a functioning alarm (Kidde, 2012). National campaigns by different organizations and government agencies remind consumers to change the batteries in their smoke alarms in the fall and spring when the U.S. population changes their clock for day light savings. The user replaceable battery is generally the simplest and least expensive option.

Another smoke alarm power source is the 10 year battery. Ten years is the useful life of a smoke alarm, these batteries make upkeep a non-issue until the entire smoke alarm unit itself needs to be replaced. While typically being more expensive than replaceable batteries for the initial purchase, a 10 year sealed battery saves the homeowner the cost of ten to twenty replaceable batteries over the life of the smoke alarm, as well as the hassle that comes with the upkeep of the alarm and the possible hazards (i.e. falling) of changing the battery.

Smoke alarms can also be hardwired. This allows the smoke alarm to run off of the home's electrical wiring. Most hardwired smoke alarms also come with a backup battery, increasing the cost of the unit but also ensuring that the smoke alarm will function in the event of power failure in the home.

Hush Button

One feature that has been around for many years is the hush button. Smoke alarms installed near or in the kitchen are required to have a means to silence the alarm as specified in UL 217. When a smoke alarm is triggered, the button will silence the alarm for a short period of time, typically five to twenty minutes. The idea behind the button is that it will stop the practice of disconnecting the power source to disable the smoke alarm. Consumers with older model alarms that did not have an option to silence it would often remove the battery or disconnect the power source following a nuisance alarm. The problem with this practice was that often the consumer would not remember to reconnect the power source, leaving the owner unprotected in the event of a fire. The silencer button allows the alarm to automatically reset the sensitivity after the nuisance source has been dealt with; potentially saving many lives should a real fire occur in the home at a later time.

Voice Alarm

Some smoke alarms are equipped with voice alarms that will verbally alert the homeowners of a fire. Young children and the elderly may not recognize the UL 217 smoke alarm signal (temporary three beep pattern) going off as a fire. Occupants misinterpret the alarm as many other things, for instance the smoke alarm signal as a kitchen appliance alarming. Voice alarms are beneficial in these situations as they can announce the reason for the alarm in the home. When used in combination smoke and carbon monoxide alarms, some voice alarms can distinguish whether the alert is due to fire or carbon monoxide (NEST, 2015). Some voice alarms will even report the location of the alert within the home, allowing home owners to direct responding fire crews to the location of the fire (NEST, 2015).

Remote Controls

Some higher end smoke alarms include options to connect a remote control. Instead of having to reach the smoke alarm on the ceiling or high wall to silence the smoke alarm following a nuisance alarm from cooking, the user can simply walk within a few feet of the alarm and push a button on a remote control to temporarily suppress the audible alarm. In homes where the

smoke alarm is out of reach of the occupant, a remote control provides a very useful benefit to consumers needing to silence a nuisance alarm.

Some of the newest and most advanced alarms on the consumer market even include the option to use your smart phone as the remote. These alarms give the user the ability to silence and test the alarm via a Bluetooth or Wi-Fi signal, and can even call or text the homeowner should the alarm be triggered. These alarms protect not only the homeowners, but also their property by notifying the consumer of a fire even if no one is home at the time of a fire.

Standards

NFPA 72

The National Fire Protection Association (NFPA) 72 encompasses every practical feature and aspect of fire alarms and smoke alarm systems including the "application, installation, location, performance, inspection, testing, and maintenance," (National Fire Protection Association, 2013). The standard outlines design, use, and maintenance requirements. The performance of smoke alarms is covered in UL 217, Smoke Alarms.

Local and state regulations may adopt NFPA 72 as a whole or in part to satisfy their needs for smoke alarm installation. NFPA 72 specifies the need for a smoke alarm in every bedroom, and within 21 feet of each sleeping area, as well as at least one alarm per floor. These location requirements are often summarized in the smoke alarm packaging and in the smoke alarm sections of stores. To prevent nuisance alarms, NFPA 72 specifies that no smoke alarm must be within six feet of a cooking appliance, smoke alarms between six feet and 10 feet must be photoelectric type only, and smoke alarms between 10 and 20 feet must have a hush feature or be photoelectric. Smoke alarms may not be within 36 inches of a bathroom door, an air vent, or a ceiling fan blade.

New fire alarm systems that are manufactured and sold voluntarily comply with the accepted standard. Installation of smoke alarms is required on the state and local levels. Furthermore, information is provided to modify an existing system to improve its quality to the current standard level. The standards establish only a minimum of required performance levels (National Fire Protection Association, 2013). Smoke alarms can proceed to include additional features and performance measures above the voluntary standard. Smoke alarms that exceed the minimum standards can be several times more expensive than the basic models.

NFPA 72 also outlines proper placement of smoke alarms in homes. Figure 6: Smoke Alarm Placement Diagram
(Kidde 0910 Smoke Alarm User Manual, 2015) outlines the cases where smoke alarms are being installed in rooms with pitched and square ceilings. For pitched ceilings, the smoke alarm is to be placed within 4-12 inches of the ceiling. A smoke alarm that is on a normal square ceiling must be either 4-12 inches below the ceiling or 4 inches away from the wall on the ceiling (NFPA, 2013a).

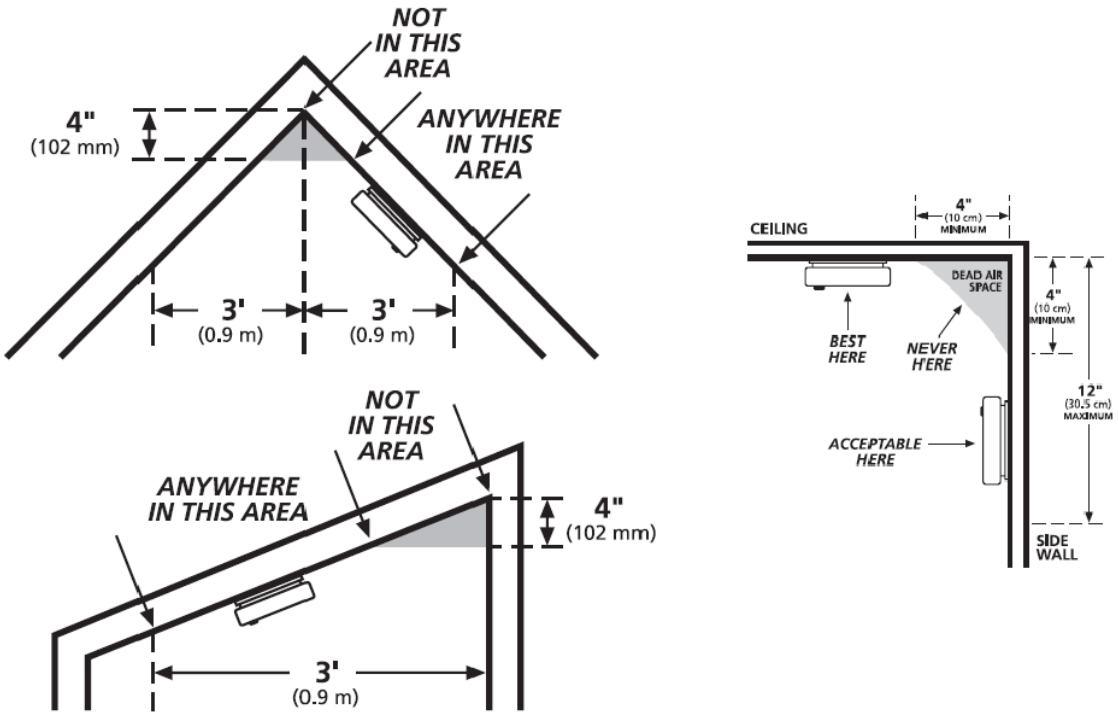


Figure 6: Smoke Alarm Placement Diagram
(Kidde 0910 Smoke Alarm User Manual, 2015)

Under certain conditions, both ionization and photoelectric smoke alarms may prove useful. For example, in kitchen areas smoke from cooking tends to contain a higher percentage of smaller size particles, leading to more nuisance alarms with an ionization type alarm. Therefore, the NFPA recommends not installing ionization type alarms within 10-20 feet of cooking appliances (Ahrens 2009). Since photoelectric alarms are less susceptible to nuisance alarms from cooking, they are suggested for use when kitchen size or shape requires a smoke alarm to be within a six foot radius of the cooking appliances.

UL 217

The UL 217 standard details in length the requirements for 'single station', or standalone smoke alarms and 'multiple station' smoke alarms, or interconnected alarms (Underwriter's Laboratories, 2015). These standards are meant for smoke alarms inside homes, or in recreational boats or vehicles. The standard does not cover heat detectors or smoke detectors, which are addressed in separate standards. UL 217 focuses on two main aspects of the alarm: construction and performance.

Construction Requirements

Most of the requirements in the construction category are concerned with physical aspects of the smoke alarm. First, the standard specifies the assembly of the alarm to ensure the safety and reliability of the physical structure. Examples include the sturdiness of the enclosure and sharp edges. The power supply or supplies are also regulated. For example, they must be below 30V RMS and 100W, and any battery terminals must be of specified types. There are also

specifications for field wiring (wiring during installation), such as what type of screw can secure a wire. The standard also covers internal wiring, specifying safety measures such as how wires should be secured and how exposed metal should be grounded. Specifications for electrical components include how current carrying parts should be mounted, and the requirement for a 'power-on' indicator light. Finally, the standard gives the minimum spacing between charged parts.

Performance Requirements

The requirements in the performance category are concerned with how well the smoke alarm performs in fires and external environmental influences. Requirements concerning performance generally require independent testing by an accredited lab to ensure that the standard has been met. The testing begins with a very basic 'normal operation test' which tests if the fundamentals of the alarm work, and if the alarm functions properly. The alarm to signal a fire must match a specific three-burst signal (temporal-three pattern) that is different from other warnings, such as low battery.

The standard contains a series of performance tests to ensure the smoke alarm's sensitivity does not drift under various environmental conditions. The sensitivity test uses aerosols (a suspension of tiny particles in air) to set off the smoke alarm, and the sensitivity must fall within a specified range. Sensitivity in this case is output amps divided by obscuration per distance. This main sensitivity test is used as the criterion for 'working' throughout the standard. In subsequent tests, this sensitivity must stay in this range for the following conditions: a change in photoelectric lamp, variations in temperature and humidity, aerosol speeds and directions, exposure to dust, jarring with a metal sphere, vibration, and corrosive atmospheres.

The main performance tests are the fire tests. The fire tests examine the performance of the smoke alarm in actual fires. The fire tests expose the alarm to a variety of common burning materials, such as wood and paper. The standard was just revised to include a common material in homes, polyurethane (PU) foam. The PU foam test evaluates smoke alarm performance to both flaming and smoldering PU foam. For each material, the alarm must sound within a certain amount of time. The stability test subjects the alarm to 90 days of smoke free scenarios to test for false alarms. This time can be sped up with the alternate accelerated aging test.

After one year, the battery must not fail without triggering the battery trouble signal (replacement signal). The battery must have enough power to produce the trouble signal for seven days and three minutes of alarm. Any fault introduced to the circuitry must also trigger a trouble signal, and not an alarm.

Another series of tests subject the alarm to abnormal voltage and current situations. These include the overload test, transient tests, dielectric withstand test, abnormal operation test, overvoltage and under voltage tests, static discharge test, polarity reversal test. The alarm must operate over the rated voltage and current in the overload test. Similarly, it must operate after being subjected to specified transients and surges (including proximity to a Jacob's ladder or cell phones). The leakage current from the inside to the outside must not exceed a certain amount after the humidity test.

UL 217 Section 67, Audibility Test states that, " the alarm sounding appliance, either integral with the smoke alarm or intended to be connected separately, shall be capable of providing for at least 4 minutes, a sound output ... of at least 85 decibels (dB) at 10 feet (3.05 m)"

(Underwriters Laboratories, 2006). Comparatively, 85 dB is roughly the same level of loudness as city traffic, and at a sustained 90-95 dB, hearing loss may occur. This level of noise is meant to be loud enough to wake the occupants and allow sufficient time to escape.

UL 217 mentions that the smoke alarms must comply with NFPA 70, National Electrical Code. NFPA 70 is a standard for all electrical practices for public and private venues, offices, stores, shops, homes, vehicles, floating buildings, covering the installation of the electrical equipment and system (National Fire Protection Association, 2014).

State Specific Fire Marshall Requirements

Each state has its own requirements on top of the UL 217 standard. These requirements are outlined in detail in Appendix H: State-by-State Guide to Smoke Alarm Requirements.

National Institute of Standards and Technology

NIST Testing of Smoke Alarms

Established in 1901, the National Institute of Standards and Technology (NIST) is part of the US Department of Commerce. Congress originally established the agency to help keep the United States industrially competitive with economic rivals like Germany and the United Kingdom. At the time, the infrastructure in place for measurements was a major handicap to scientists and industry in the US, so NIST was founded to be the domestic authority on standards and measurements. Current NIST standards support everything from nanoscale devices to skyscrapers and jetliners.

NIST released a study called *Performance of Home Smoke Alarms: Analysis of the Response of Several Available Technologies in Residential Fire Settings,* in which smoke alarms were evaluated based on 'time to escape' and nuisance sensitivity (Bukowski et al., 2008, 12). The results are not used as or presented as a rating system for the consumer, but the study gives insight on the performance differences of smoke alarms on the market. The testing was based on the original Indiana Dunes tests of 1975-1976 (Bukowski et al., 2008, 12). Escape times were determined for a variety of situations, including an upholstered furniture fire, a cooking fire, and a mattress fire. For each situation, times were determined for each location in the test house. For other tests, NIST used a 'fire emulator/detector evaluator' (FE/DE), an apparatus used to create any type of smoke at any flow rate and temperature. To test for nuisances, a variety of foods were prepared, and candles and cigarettes were lit. One group of smoke alarms was modified such that instead of alarming when a threshold was passed, they output a raw analog signal. This way, sensitivities could be compared directly, independently from the thresholds. Since there are so many factors to consider in 'time to escape', this provides only a benchmark value based on averages and used for comparison. Time to alarm versus time to untenable conditions was tabulated in spreadsheets for every alarm tested, but codenames were given instead of brands and models. Figure 7: NIST Average Egress Times (National Institute of Standards and Technology) gives the average egress time of four alarm types (Photoelectric, Ionization, Dual Photoelectric and Ionization, and Aspirated) in each fire situation listed.

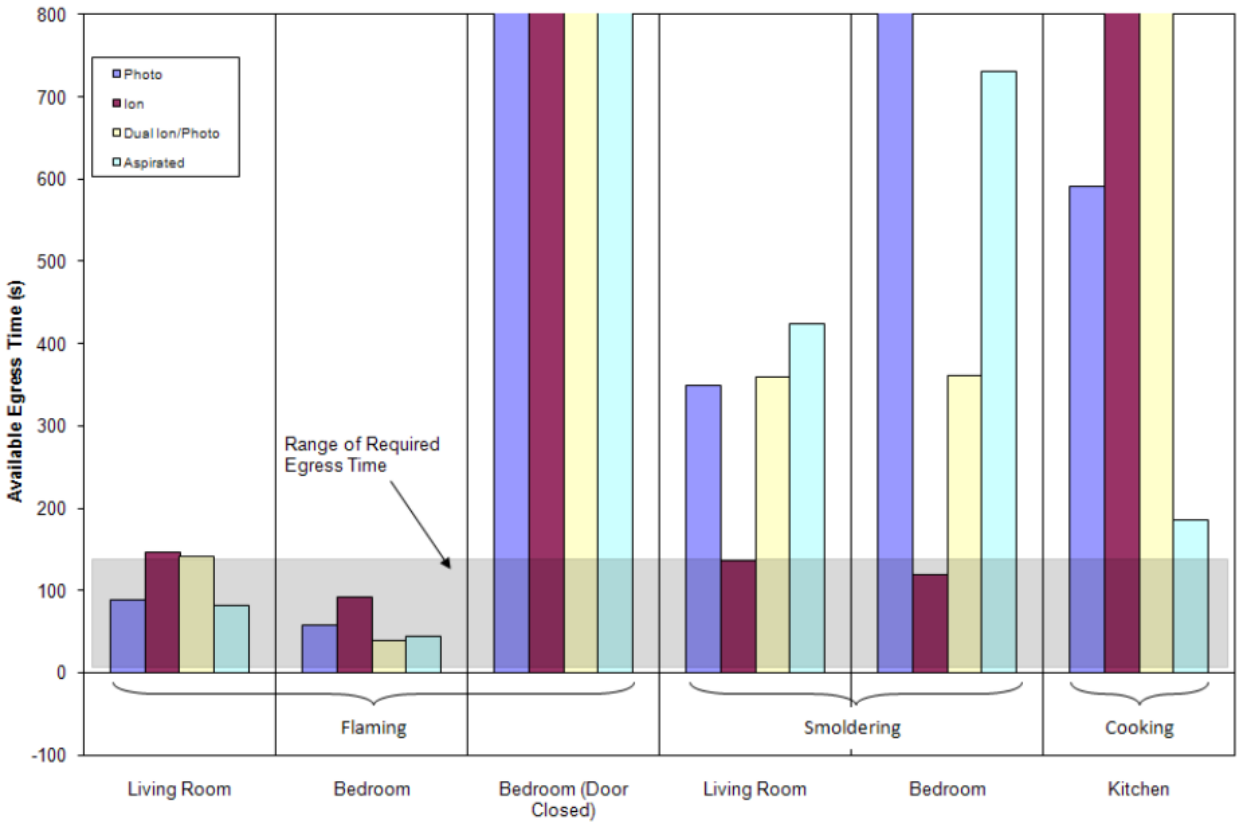


Figure 7: NIST Average Egress Times
(National Institute of Standards and Technology)

Performance Rating Systems

Performance rating systems often judge different traits of the object in question. These traits can be determined through observations and patterns (Wright, 1982, p. 1). From these patterns, lines can be drawn that create categories into which items and variables can be placed. Performance rating systems are intended to elicit "unambiguous, ordinal indications" (Linacre, 1999, p. 104) of the location of the variables being observed. Categories within the system can be observed as steps in a decision process. With these steps, it is possible to see what performance level the item in question has reached within the rating system (Wright, 1982, p. 3). The steps within a rating system should be mutually exclusive (Linacre, 1999, p. 104). If created using a methodical process based on observations of patterns, performance rating systems can be a powerful tool for comparing traits within objects.

5 Star Crash Test Rating

Performance rating systems are presently used on a variety of products to rate certain safety aspects associated with the product. A great example of this is the five star crash test safety rating system used to rate the crashworthiness of cars. This system calculates the "stars" through an algorithm that is fed numbers related to the force of the crash test. When the algorithm outputs a number, it is placed in the rating scale. If that number is lower than 0.10, the car is rewarded five stars for that certain crash trait. During the crash tests, the speeds and impact locations were modeled after the "conditions in a large portion of actual … crashes that result in

fatalities or serious injuries" (Hackney & Kahane, 1995, p. 1). Through the use of crash patterns, the creators of the system were able to develop a "simplified nonnumeric format which could provide consumers with easily understandable vehicle performance information" (Hackney & Kahane, 1995, p. 1).

Consumer Reports

Consumer Reports, an independent, nonprofit, product rating website, evaluates a wide range of consumer products, including smoke alarms. Consumer Reports uses its familiar rating system of red and black dots where a full red dot means a high or excellent performance and a full black dot means a low or poor performance. The performance rating system consists of a smoldering test score, a flaming test score, and an overall score. The smoldering test uses a smoky wood fire, and the flaming test uses a paper fire. The outcomes of these tests are recorded as either excellent or poor. As seen in Figure 8: Consumer Reports Alarm Ratings (Consumer Reports), all of the alarms listed received the same grade for the smoldering and flaming tests. Figure 9: Consumer Reports Smoke Alarm Convenience Features (Consumer Reports) shows the features and specifications section of the ratings, which lists the alarm's ability to connect to other alarms, type of power source, presence of a hush button, and price. The overall score is subjective and includes the features as well as the test results. Combination alarms tended to have the highest ratings, and photoelectric alarms had ratings similar to ionization alarms, but with higher performance rating for smoldering fires and lower performance rating for flaming fires. Nuisance resistance is not considered, although this is a major factor in performance. While these ratings may offer some notable benefits, they are not immediately accessible to the consumer because the ratings are offered as part of a service that users subscribe for a monthly fee to access the website.

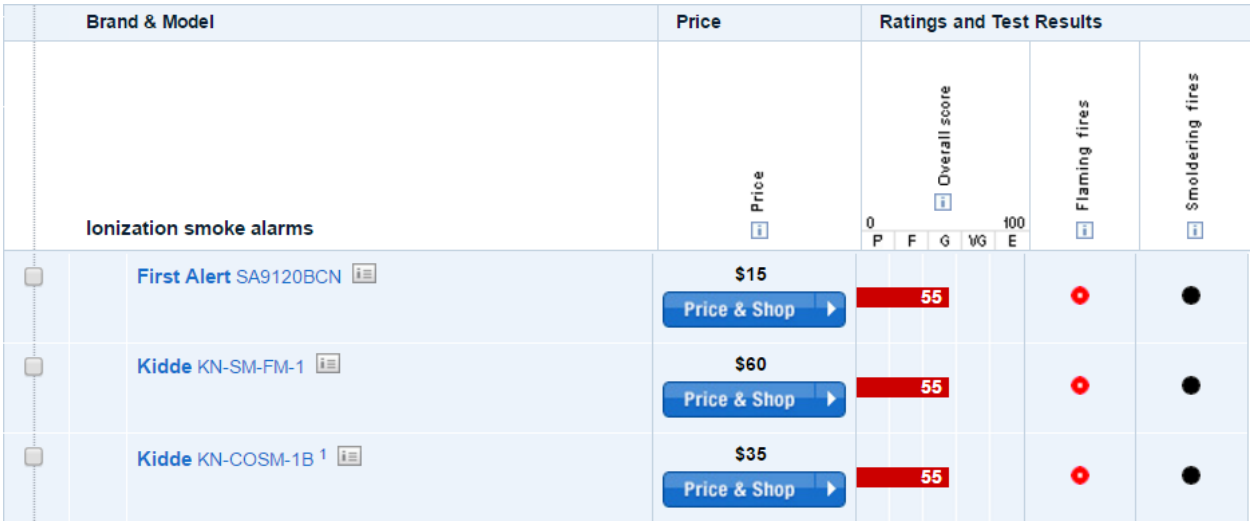
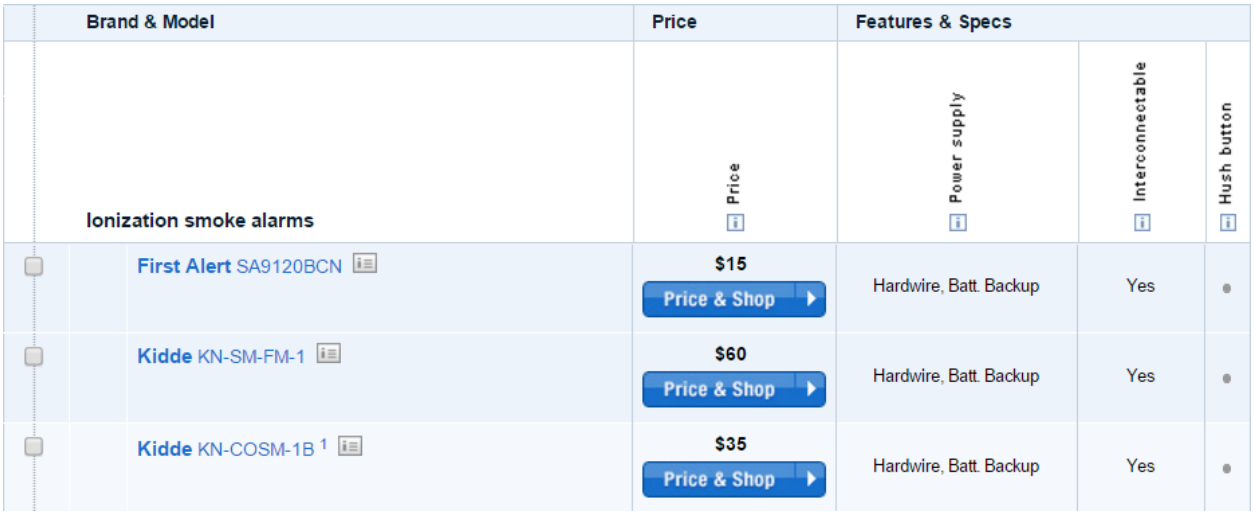


Figure 8: Consumer Reports Alarm Ratings (Consumer Reports)



Brand & Model	Price	Features & Specs		
Ionization smoke alarms	Price	Power supply	Interconnectable	Hush button
First Alert SA9120BCN	$15 Price & Shop	Hardwire, Batt. Backup	Yes	•
Kidde KN-SM-FM-1	$60 Price & Shop	Hardwire, Batt. Backup	Yes	•
Kidde KN-COSM-1B [1]	$35 Price & Shop	Hardwire, Batt. Backup	Yes	•

Figure 9: Consumer Reports Smoke Alarm Convenience Features (Consumer Reports)

Smoke Alarm Consumers

Types of Consumers

Contractors

Market research by IBIS World claims that "most safety alarms and detectors are installed during construction of a new residential or commercial building" (IBIS World, 2015). However, builders mainly buy smoke detectors, not smoke alarms. This research is primarily interested in household smoke alarms for consumers.

In-Store vs. Online

Household smoke alarm consumers can be further subdivided into two main purchasing mediums: purchase from a retail store or through the Internet. Online shopping present's information in a very different way, and the group that shops online may have different behaviors. Online shopping will not be focused on in this project.

Income & Gender

Consumers may also behave differently based on their income. Data indicates that although households that make less than $15,000 per year make up only 23% of households with smoke alarms, they constitute 33% of homes without any working smoke alarms (Smith, 1994). Gender is another variable that could affect purchasing traits, especially if one gender is more likely to be buying the smoke detector (Bakshi, 2012).

Purchase Decision Process

In order to achieve certain purposes or accomplish goals, consumers make purchasing decisions based on prior beliefs or experience. Consumers have the greatest interest in obtaining information about high-cost products (Transportation Research Board, 1996, p. 77). Smoke alarms, however, fit the characteristics of a low involvement purchase. A low involvement purchase is one that the consumer puts little thought into and has little interest in. A consumer is likely to have low involvement if they are replacing a product, if the prices are

low, or if they perceive low risk (Marketing Principles, 2012). Zaichkowsky (1986) correlates low involvement with minimal information-seeking, little comparison of attributes, perception of similarity among products, and impulsive decisions. A survey conducted by the Kidde smoke alarm company found that almost half of consumers spend 15 minutes or less choosing a smoke alarm (Kidde, 2015). Consumers were measured to spend more time choosing a microwave (Kidde, 2015).

Consumer Knowledge of Smoke Alarms

Research indicates that many consumers are not conversant in smoke alarm basics. One study found that "nearly five times as many Americans know the shelf life of a Twinkie snack cake (45 days) than know the operating life of a smoke alarm (10 years)" (Kidde, 2015). A survey of 1,018 homeowners with battery powered alarms in 10+ year old homes found that one in four homeowners never replaced their home's smoke alarms (Kidde, 2015). Also, 74% of homeowners could not correctly describe where smoke alarms should be placed within the household (Kidde, 2012). Three in five homeowners did not realize that smoke alarm batteries should be replaced every six months (excluding 10 year battery). According to a report by Marty Ahrens (2015a), consumers do not know the difference between ionization and photoelectric alarms. As such, listing the type of the alarm on the packaging is not helpful. Even an explanation of the difference is not likely to be read thoroughly. A performance system would facilitate safer choices, make the selection process easier, and also provide an incentive for companies to improve their products.

Consumer Response to Performance Systems

While a smoke alarm performance system may be helpful to consumers, the manner in which it is crafted determines how effective it will be. The two main factors involved when creating a performance system are the information included, as well as how the information is displayed visually. When performance systems include information that is clearly and simply presented, it is more likely to be meaningful to consumers. The information should include both summaries as well as a comparative aspect, so that consumers are able to put product-specific information in context. Once the information can be put it in context, consumers will perceive it to be more relevant to their circumstances (Transportation Research Board, 1996, p. 80). The design is equally as important. The message must be distinct, must be devoid of competing information, and have the appropriate artistic approach (Transportation Research Board, 1996, p. 77). If the design of the information can "be limited to a few critical items, help simplify comparisons among alternatives, and convey some sense of the certainty and validity of the underlying data," then it will have the most impact on consumers (Transportation Research Board, 1996, p. 80). Crafting a performance system based on these criteria will not only create a larger potential for the use of the performance system, but also allow consumers to consider safety as an important decision criterion when purchasing a smoke alarm.

Crafting a Performance System

Questions to Address

In order to achieve our project goal, we developed and addressed these five main questions:

- What do consumers know about smoke alarms?

- What are the factors that consumers look for when buying a smoke alarm?
- What metrics should make up the performance system?
- How can packaging better inform consumers of the performance of the product?
- Is a smoke alarm performance system beneficial to consumers?

From these questions, we were able to derive methods, which provided a structure through which we could obtain results.

Inspector and Manufacturer Interviews

In order to gain insight on how the industry would receive this project, we decided to reach out to people within the smoke alarm industry. A list of contacts from the standards technical panel for UL 217 was used as a starting point for contacting reaction to this project. We drafted three sets of interview questions, one for each of these three groups. These questions can be found in the Appendix F: Manufacturer, Inspector, and Standards Questions. We contacted individuals on the list who we thought were relevant to the project. Of the 20 people we attempted to contact, only four individuals agreed to be interviewed.

Manufacturer Interviews

One group that would be impacted by the implementation of a smoke alarm performance system is smoke alarm manufacturers. Out of the seven manufacturers contacted, two were able to set up interviews.

One of the manufacturers said that the time between model updates is a year to 18 months. They revealed that the main reason for changes was not to appeal to consumers but to comply with changes in standards and building codes.

Both of the manufacturers said their company would probably not use a rating system if optional. One's reason was that UL's new polyurethane fire tests will enforce a higher level of performance, even without the help of a rating system. The other's reason was that they would need to make room on their existing packaging.

From these results it seems that some manufacturers may be reluctant to adopt a rating system. In order for a rating system to be widely used and accepted, such a system would either have to be mandatory, involve an incentive, or be proven to attract more customers.

Inspector Interviews

Of those interviewed, two were inspectors. When asked whether consumers would benefit from a performance system, one said that consumers never read and wouldn't pay attention to it, and the other said that the electricians who install them need education materials more than the consumers. One inspector explained that poor placement by consumers is not an issue because the builders or electricians usually determine the placement. The overall consensus was that the electricians are an important piece of the puzzle that should not be overlooked.

1st Round of Data Collection

Our next step was to determine what the average consumer currently knows and wants when purchasing a smoke alarm. In order to gather this information we planned to conduct interviews with consumers at hardware stores in the Washington, D.C. and Rockville, MD areas,

as listed in Appendix D: Store List. Appendix A: Letter to Store Owner/Manager is the letter presented to the store owners, detailing the problem of home fires and the goals that our project is working towards. In addition to the letter, we included a copy of the short survey and list of questions we had prepared for the consumers, as listed in Appendix B: Consumer Smoke Alarm Survey and Appendix C: Consumer Interview Questions. Store owners were also informed that for agreeing to participate we would acknowledge their store in the final report and send them a copy. We also created an online version of our in-store survey that was sent out to various groups of consumers with the intent to gather data from a wider range of consumers. Once we collected all of our first round data, we hoped to discern consumer perspective of performance when purchasing smoke alarms.

In-Store Interviews and Surveys

We visited eleven different stores in the area, and met with a manager at each store. Nine of the managers we met with informed us that they would have to talk to their superiors before we could get permission, and promised to contact us by email or phone. Of the other two stores, one manager of an Ace Hardware informed us that he would like to help with our project, but we would be limited to standing outside the store entrance due to the small size of the store. The other manager said that she had no choice in the matter, and we would have to talk with Home Depot's corporate office for permission. Upon emailing Home Depot we were given a form letter reply stating that any attempt to talk with customers in the store met the company's definition of solicitation and would not be given any consideration. Calling the phone number the store manager had provided was met with a similar response.

Several days after our visit, Brad Smith, the manager of 5th Street Ace Hardware in Washington, D.C., informed us that he would be happy to help. We scheduled a few hours on a Saturday when the manager informed us that the store would likely be the busiest. During our in store interviews we attempted to talk with customers that were entering and exiting the store, but many stated that they were too busy. The most successful method was to approach customers in line during check out, and interview or survey them while they waited to pay.

Once they agreed to help, customers were asked the series of questions listed in Appendix C: Consumer Interview Questions and all answers were recorded. In order to make the consumers feel more comfortable being open and honest in their answers, the interviewer attempted to turn the interview into a conversation as opposed to simply a series of questions. Many questions and answers led to side discussions, giving much more honest answers than could be obtained by a simple list of questions. Consumers were much more willing to talk, and more likely to say more, when the interviews had a more friendly and personable feeling.

Following the interview, the customers were asked if they had another moment to answer a short survey, and those that agreed were given the survey listed in Appendix B: Consumer Smoke Alarm Survey. Those customers that did not have time for the full interview were also asked if they would complete the survey.

Products Sold at Ace Hardware

While at Ace Hardware conducting consumer interviews, the type of sensor and power source of the smoke alarms sold were noted and recorded in Table 2.

Type of Alarm	Percentage on Shelf
Ionization	37.5%
Photoelectric	37.5%
Combination	25%

Table 2: Ace Hardware Smoke Alarm Distribution

In addition to the types of alarm available for purchase, Ace Hardware employees were able to provide sales information for some of the alarms. A selection of alarms with varying features and power sources was chosen to be representative of all alarms offered. Sales data listed in Table 3 are for the previous month as of December 12, 2015. The sales data shows that the most popular models tended to be the simplest and least expensive, however the top two still represent less than half of the alarms sold. Due to the small sample size, it is suggested that future study of consumer buying choices use data from multiple stores over a longer timeframe.

Characteristics	Retail Price	Qty Sold (1 month)
Ionization, only a 3 year warranty	$5.99	6
Ionization, mute button	$9.99	4
Photoelectric, 10 year battery, carbon monoxide	$49.99	2
Photoelectric, advertises nuisance resistance	$16.99	2
Photoelectric, carbon monoxide	$39.99	2
Ionization, long battery life	$16.99	2
Ionization, Hardwired with battery backup	$19.99	2
dual sensor, mute button	$26.99	2
Photoelectric, 10 year battery	$25.99	1

Table 3: Sales Information of Smoke Alarms at the 5th Street Ace Hardware

Online Surveys

In addition to the interviews and surveys done in person at Ace Hardware, an online version of the survey listed in Appendix B: Consumer Smoke Alarm Survey was distributed. Emails containing the link to the survey were sent out to friends and family, who then distributed it to their coworkers and friends. The most effective of these emails was sent to WPI Professor Fred Looft for him to forward to the WPI faculty, which resulted in over one hundred responses coming in within two hours of his distribution.

Analysis of the 1st Round of Data Collection

Surveys

Once the survey responses had been collected, the data was entered into an Excel spreadsheet for analysis. At the time the data was compiled, there were a total of 18 written

responses collected at Ace Hardware and 207 responses to the online survey. Each survey that was completed was assigned a number for tracking of the data. The responses for the performance factor questions were used to calculate a mean response value for each feature or factor. Standard deviations were also calculated for each question in order to determine the variability between answers, with a lower standard deviation indicating a general consensus among consumers, and a higher standard deviation indicating a wider range of answers.

The percentage values from the first part of the survey were used to determine how many consumers have and maintain smoke alarms in their home. This information was used to ensure that the data collected represents a wide range of consumers, including those that have and maintain smoke alarms, as well as those that don't.

The mean values calculated based on the survey data provided insight into what consumers might consider when looking to purchase smoke alarms. The mean values indicate the importance of a given feature or performance factor to an average consumer. The higher the mean value, the more important the feature or factor is to consumers when looking to purchase a smoke alarm. This information was used in the creation of a test rating system by allowing the rating system to focus on the factors that are most important to consumers, therefore making the rating system more appealing.

The standard deviation values were used to determine the variability among responses. The higher the standard deviation value for a given feature or performance factor, the greater the average difference between each answer and the calculated mean value. A lower standard deviation value, combined with a higher mean value, indicates that in addition to thinking the given feature or performance factor is important, consumers are more likely to give that category the same rating. This information is important in determining the categories that consumers are more likely to agree upon.

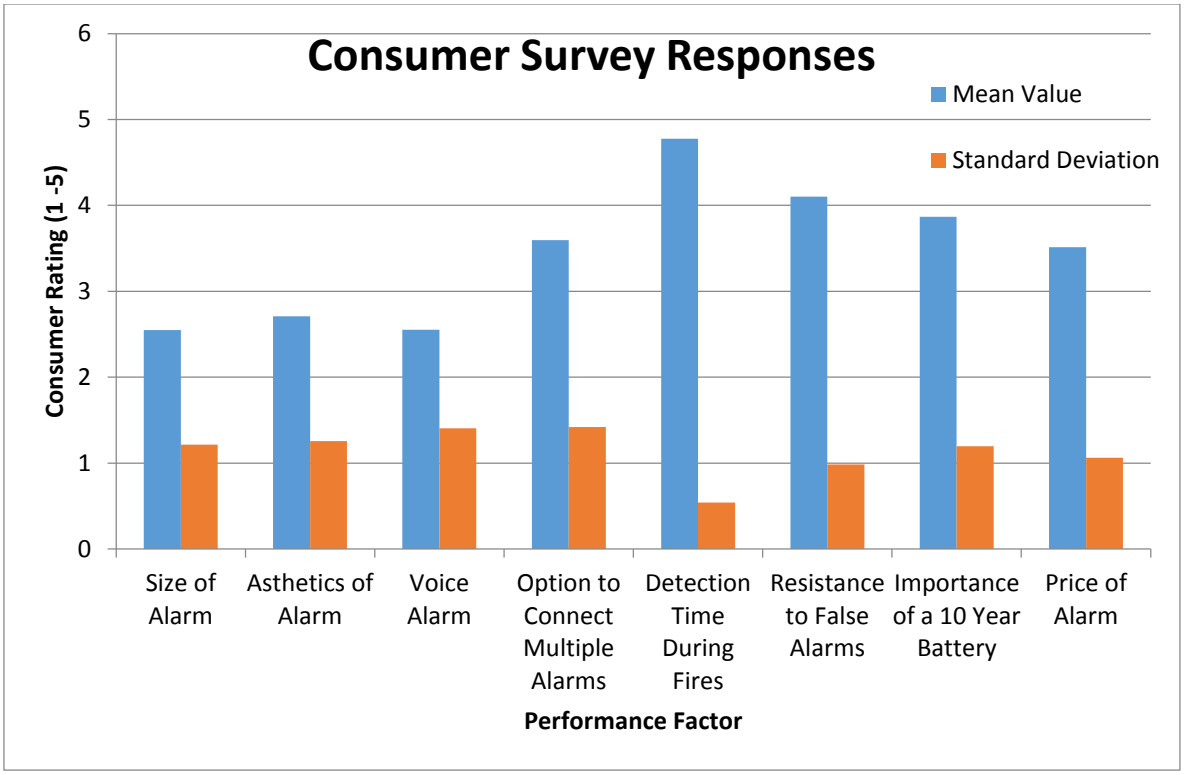


Figure 10: Consumer Survey Responses

Interviews

A total of 45 people were interviewed. Of those, 29 were random Ace Hardware customers, four were Purdue University faculty, and the remaining 12 were personal acquaintances.

Question	Percent Yes
Do you have a smoke alarm in your home?	95.56%
Have you ever purchased a smoke alarm?	44.44%
Were you aware that some smoke alarms respond faster to certain fires?	14.44%
Are you aware of the locations in your home where smoke alarms should be installed?	56.67%
Do you have a smoke alarm inside or near your kitchen that goes off often?	60%
Would a smoke alarm performance rating system, much like that of the 5 star crash test safety rating system for cars, influence your decision on which smoke alarm you would purchase?	93.33%

Table 4: Answers to Yes or No Questions

As expected, the vast majority had at least one smoke alarm. Less than half of our respondents had bought a smoke alarm. In agreement with the Marty Ahrens 2015, very few respondents were aware of ionization and photoelectric alarms. Of those who had bought an alarm before, nearly double (27.50%) knew this. In answering the question on smoke alarm placement, many people tried to remember where the alarms were currently in their home and repeat that. Often people are replacing rather than installing for the first time, and they are not responsible for the location. Also, we may have been too accepting of some responses that were not entirely correct. Sixty percent of respondents had an alarm in or near the Kitchen that sounded often. This explains why nuisance resistance was a popular answer for question 3: consumers had experience with the problem. The vast majority said a performance system influence their decision.

What Consumers Look for in a Smoke Alarm

One interview question asked, “What do you look for when purchasing a smoke alarm?” Respondents were encouraged to list as many criteria as they could. Responses were categorized so that they could be quantified. Similar answers were given the same name. For example, “steam resistant” and “no false alarms” would both be classified as nuisance resistance. This method allowed the occurrences of a particular response to be grouped or categorized. The results are shown in Figure 11: What Consumers Look for in a Smoke Alarm Chart. Seven of the 45 respondents were unable to list anything for this question. Of these, some said they would need to research, others drew a blank, and others thought that smoke alarms were all the same.

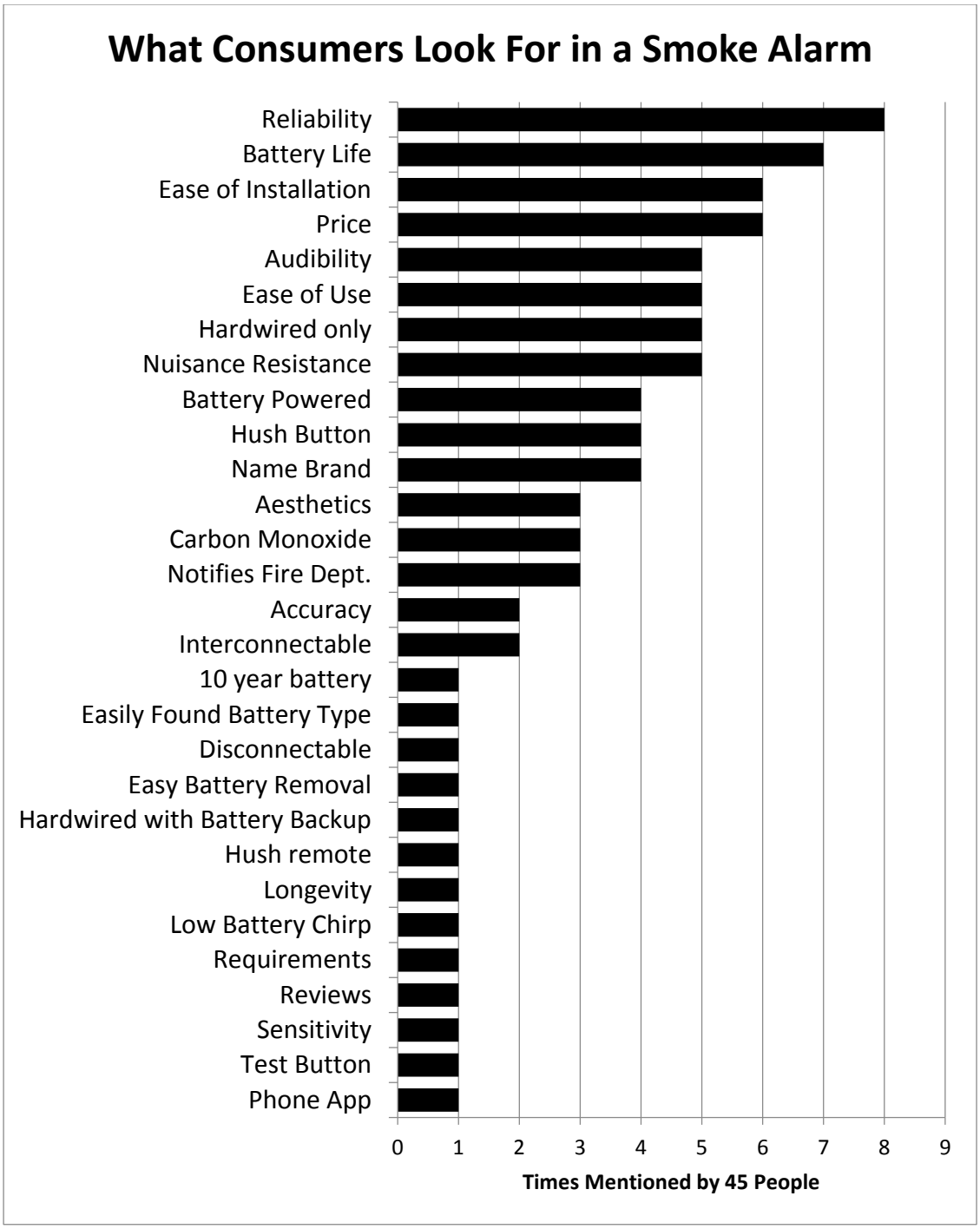


Figure 11: What Consumers Look for in a Smoke Alarm Chart

High on the list

Reliability was mentioned most often. It is an ambiguous word that could encompass many things such as the performance, durability, power source, and even the consumer's perception of the brand. It is difficult to define, measure, and communicate an alarm's overall reliability in an objective way.

Battery life was another common factor. Battery life depends on not only the type of

battery but the alarm itself, and would have to be measured for each individual alarm. Although a long battery life would cause the smoke alarm to chirp less often, consumers are encouraged to change the battery every six months regardless of the type.

We saw no simple way to quantify ease of installation, ease of use, or any other factor relating to ease. Hardwired alarms are more difficult to install than battery powered if no wiring exists, and this may have been on people's minds when they said ease of installation.

Audibility was another popular topic. Audibility is regulated by the UL 217 standard to be 85 dB from 10 feet, which is already loud enough to cause hearing loss (NIDCD). A louder alarm is not necessary. Perhaps people do not know this is standardized. We have seen many smoke alarms that advertise 85 dB as if it sets them apart from the rest.

Low on the list

Interconnectability was surprisingly low on the list, with only 2 out of 45 people mentioning it. This feature deserves to be higher on the list as it doubles the chances of a homeowner being alerted by the alarm (Ahrens 2015). When interviewing people and explaining our project to others, we found that most did not know what the term interconnectability meant, or were not aware that one alarm could trigger others.

The 10 year battery was only mentioned once, even though battery life was so popular. Sensitivity, which is fundamental to the function of the alarm, was also mentioned only once.

Categorizing Responses

Next the answers were counted in even broader categories: features, detection, other performance, ease/convenience, power supply, and miscellaneous. The composition of these categories is tabulated in Appendix I: Categories of What Consumers Look For in a Smoke Alarm.

Figure 12: What Consumers Look For in a Smoke Alarm (Categorized)shows that detection is only a small selection of responses, even though it is central to the function of the alarm. Nuisance resistance was the most popular factor in this category, possibly because consumers have the most experience with it. This can be seen in our interview results, with 60% of consumers responding that they have a kitchen alarm that goes off often. The results show that consumers are more likely to base their decisions on features or power supply than on detection. Features are displayed on the package more often than detection.

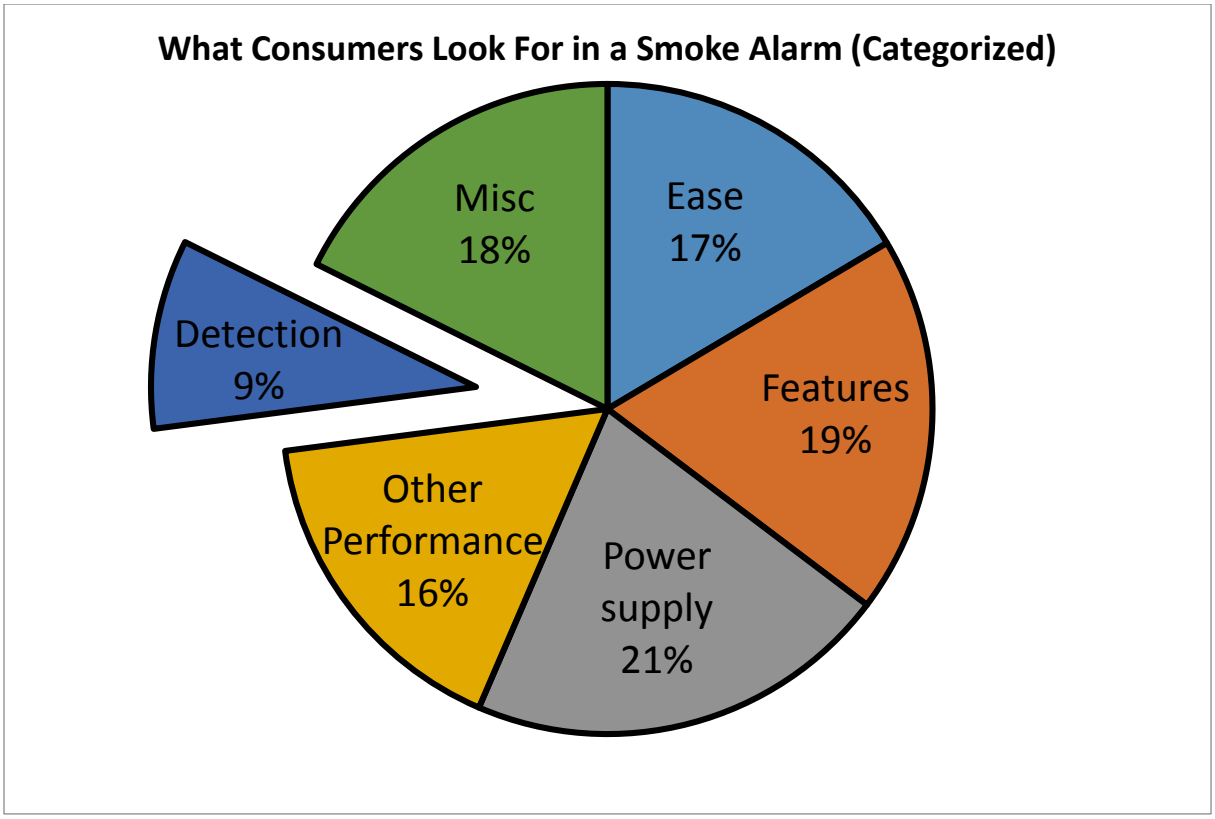


Figure 12: What Consumers Look For in a Smoke Alarm (Categorized)

Preferred Power Source

Power source options were listed for consumers to choose from, and each person had to choose only one. When the 10-year battery option was mentioned to them, many consumers were surprised to know this was an option. The most popular answer was hardwired with battery backup. These answers are in a different order from the power sources mentioned in the question, "What do you look for in a smoke alarm?" In that question, hardwired only and battery only were the most common results. When given options to pick from, consumers were able to consider power supplies they were not familiar with, giving drastically different results. It is important to note that these results are biased to reflect the power source of the alarm being replaced.

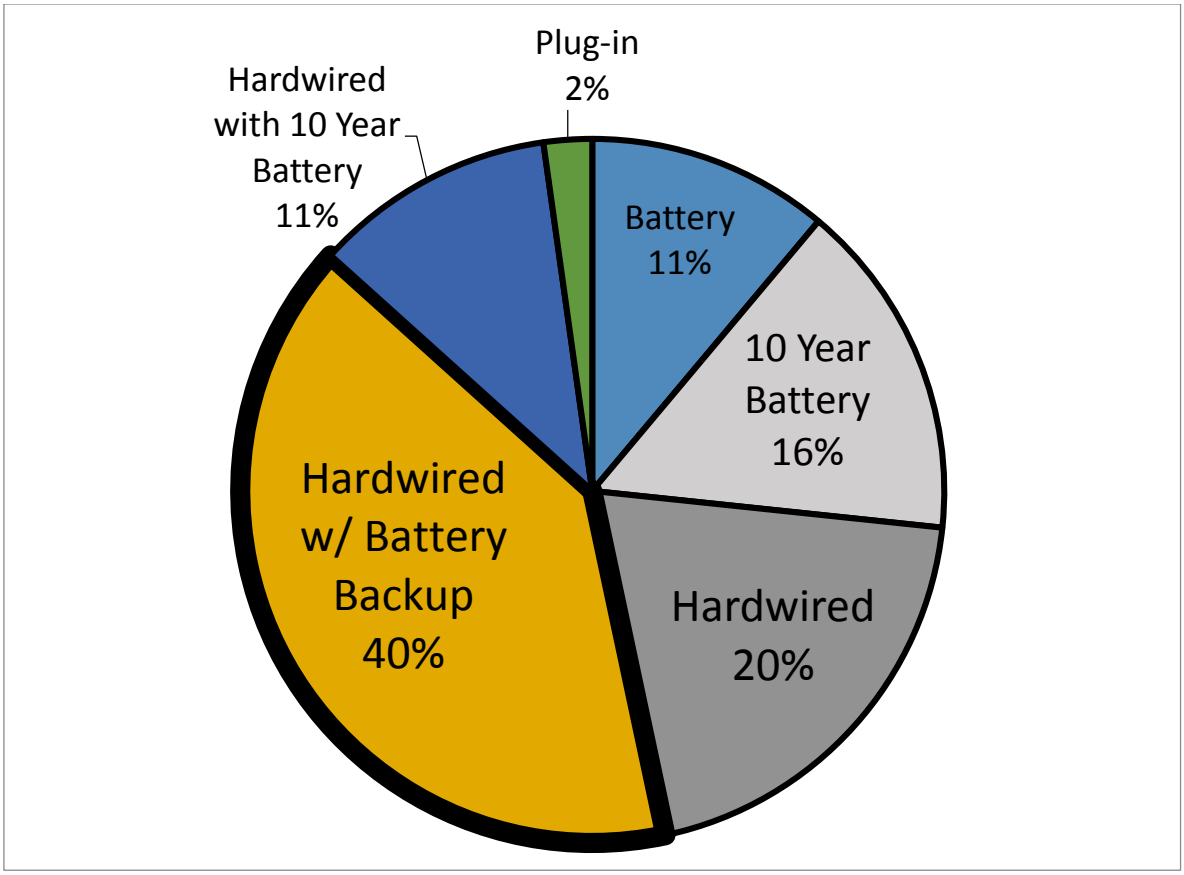


Figure 13: Preferred Power Source Pie Chart

Rationale for a Standardized List of Features

A standardized list of features is an alternate way of communicating a smoke alarms characteristics. It could be used instead of or in addition to a rating system.

According to our interviews, many of the things consumers look for in a smoke alarm, such as features or power supply, are not measurable performance quantities, and would not be communicated by a rating system. A features list was constructed based on the features listed by the consumers.

Packages already list features. However, they are listed in different formats that may be hard to compare. Also, they often omit characteristics that are not as popular. For example, we observed that smoke alarms are more likely to display their type if they are photoelectric. Sometimes ionization has to be inferred from a small radioactivity warning on the back. Also, alarms with only replaceable batteries usually did not display their power source, whereas alarms with other power sources did.

What is missing on the list is as important as what is checked. If a smoke alarm is missing a safety enhancing feature that the consumers are unaware of, such as a 10 year battery or interconnectability, they will not be deterred. Unchecked items on a standardized list would alert uninformed consumers and educate them about their options.

Unlike the rating system, a features list does not conflict with UL 217 because it makes no performance claims. Since manufacturers may feel limited by a list, we provided a section at the bottom where they can list additional features outside the scope of the standardized list.

A standardized features list would not only simplify comparison shopping, but also point out what is missing and inform the consumer about what to look for.

2nd Round of Data Collection

Designing the rating system graphics

Content

A performance system was created to include the following three measures: sensitivity to flaming fires, sensitivity to smoldering fires, and nuisance resistance. These are the factors that we concluded would best show the differences in alarm detection. We chose to keep these factors separate instead of consolidating them into one rating because this allows the consumer to determine what is important, or whether a location is appropriate.

Representation

Multiple representations of the information were considered, such as stars, bars, numbers. We decided to use stars because they are widespread in existing rating systems, and therefore are easily recognized by consumers.

It was decided that the most obvious icons for flaming and smoldering sensitivity were flames and smoke. The nuisance resistance icon required more thought. When we spoke to consumers in various locations, often the topic of nuisance alarms came up when cooking was involved. Building on this consumer experience, we created a cooking pan with smoke for our nuisance resistance icon. We later added a red no symbol over the pan to clarify that more stars meant more resistant, not more sensitive. We were unsure if consumers would understand these icons, a text version with the same rating categories was prepared as an alternative.



Figure 14: Icon Based Performance System Used in Survey



Figure 15: Text Based Performance System Used in Survey

Packaging

In order to simulate real shopping decisions, we prepared images of side by side packages with price tags. Starting with an image of an existing package in a store, Photoshop and CorelDraw software were used to remove all information from the package. A variety of other information was then added to the blank package to compare consumer responses. Figure 16: Photoshop Packaging Creation is an example of multiple packages with different methods of communicating information. The original package was not used in the consumer survey.



Figure 16: Photoshop Packaging Creation

Methods for Packaging Survey

Once an experimental rating system had been created, images of a smoke alarm package were modified in order to test the rating system with consumers. Multiple images were then created with a variety of information and ratings, depending on what was to be tested in the consumer packaging survey. An online version of the survey received 100 responses and a second in store interview at 5th Street Ace Hardware in Washington, D.C. resulted in 22 additional responses.

Survey Question 1

The first question in the survey asked the consumer to select which of three smoke alarm packages they would be most likely to buy. Figure 16: Photoshop Packaging Creation was a baseline with minimal information on the alarm the package contained. The second image used the same package from the first image, but added a rating system with three stars for all categories. The last image contained a list of possible convenience features smoke alarms may or may not have, with some of the features checked off. All three alarms were priced the same at $24.99. Consumer responses to this question were used to indicate whether or not consumers would be more likely to purchase smoke alarms that had a rating system or a standardized list of features.

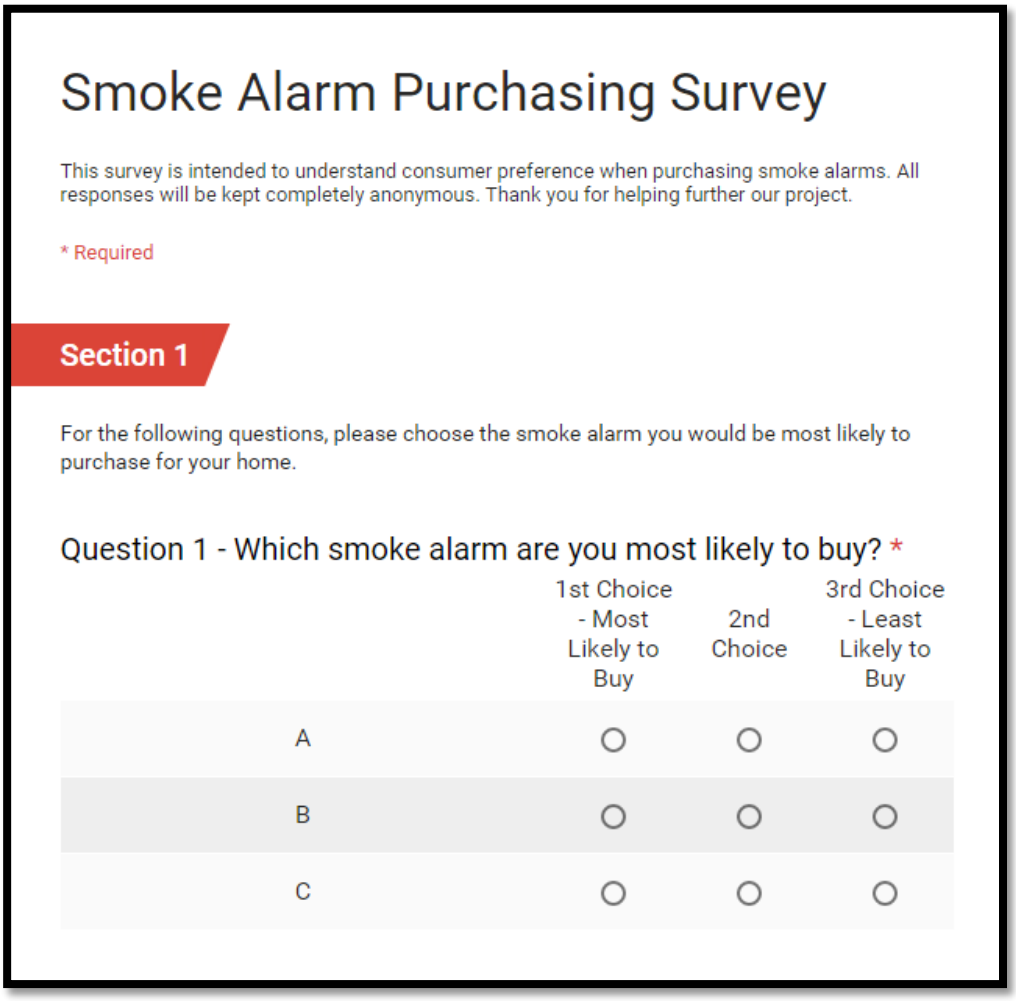


Figure 17: Question 1 of the Consumer Packaging Survey

The results of the first question strongly indicated that consumers prefer to have more information on smoke alarm packages. When asked to rank the three images from most to least likely to buy, only 20% of the consumers indicated that they would purchase the package without

the rating system or standardized list of features. Between a rating system and list of included features consumers showed a tendency to prefer the features list, with 45% of those surveyed indicating that they would be most likely to purchase the features list, versus 35% who would prefer the rating system. When asked the reasoning behind their choices, several consumers noted that the rating system shown "only had three stars," and that they didn't choose it because they wanted a higher rated alarm. It is possible that more consumers would have preferred the performance rating system to the other options, but avoided that choice due to the perception of it being a low or average scoring of smoke alarm performance. Further testing will need to be done to more accurately judge consumer preferences of a rating system versus the tested features list.

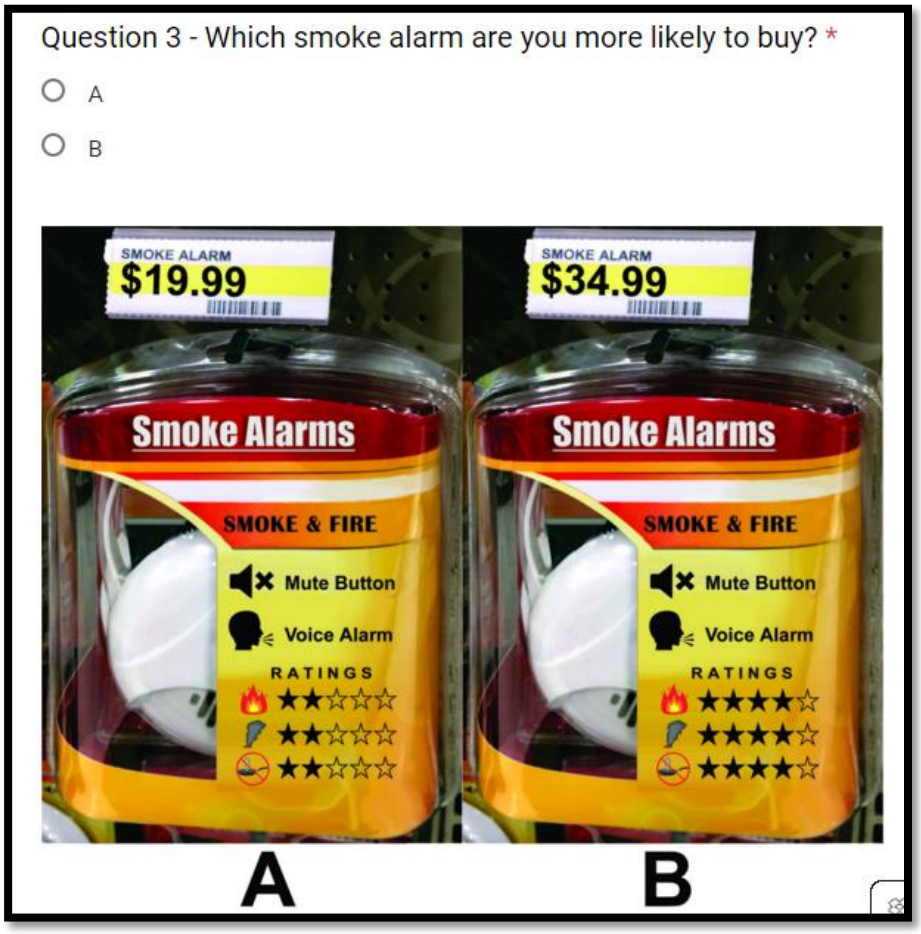


Figure 18: Question 3 of the Consumer Packaging Survey

Survey Question 2 & 3

The second and third survey questions aimed to examine whether consumers are willing to pay more for a better performing smoke alarm. The second question showed the basic package from question one, with option A priced at $19.99 and option B priced at $34.99. The third question then added a rating system to both packages, with option A having two stars for all categories and option B having four stars. The pairing of these questions allowed question two to serve as a baseline, evaluating if, when given no obvious packaging differences, consumers will

be more or less likely to purchase the less expensive option. Question three then adds a rating for each alarm in order to determine a percentage of consumers that are willing to pay a higher cost for an alarm that has better performance.

The results of question two indicate that given two similar products, consumers favor the less expensive option. 94% of those surveyed said that given no clear distinction between the products, they would purchase the $19.99 alarm over the $34.99 alarm. Of those that selected the higher priced alarm, many stated that they did so because of the assumed quality improvements in the higher priced alarm, an indication that consumers look for quality or performance over cost. This idea is further supported by the results from question three, where 82% of those surveyed selected the higher rated alarm over the lower cost option. The fact that over three quarters of surveyed consumers changed their selection indicates that a performance based rating on smoke alarm packages would likely help consumers to purchase better smoke alarms.

Of those that selected the lower rated alarm in question three, many indicated that their choice was not solely based on price, but the fact that they had no information on the ratings shown. One response noted that there was no mention of what organization had assigned the ratings and that "Unless the ratings are from some independent organization that I trust, the stars are meaningless." This and other similar responses show that some consumers are skeptical of marketing claims of manufacturers. If a rating system is to be implemented for smoke alarms, testing must be done by a publically recognized and independent organization in order to gain consumer trust.

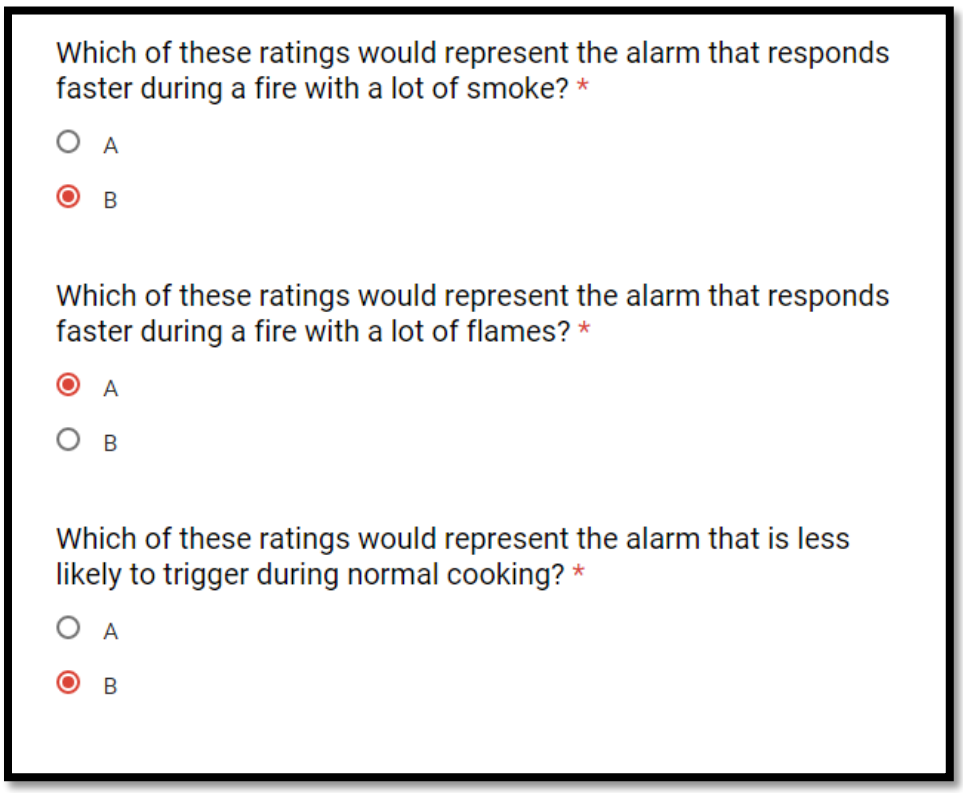


Figure 19: Comprehension Questions from the Packaging Survey

Performance System Comprehension Testing

After evaluating the usefulness of a rating system in section one, the online survey contained two sections intended to test consumer understanding of a potential rating system. Section two evaluated consumer comprehension of an image based rating system, while section three evaluated comprehension of the text based system. Each section had two rating systems side by side, with identical format but a different rating for each of the three categories: flaming fires, smoldering fires, and nuisance resistance. Consumers were asked to select which rating represented the alarm that would respond more quickly during a fast moving fire, which would respond more quickly during a fire with a lot of smoke, and which would be less likely to be triggered during normal cooking.

The results of sections two and three strongly indicate that consumers understand the rating systems with regards to detection times. 98% and 97% of consumers were able to determine the correct answer for the icon based ratings of flaming and smoldering fires, respectively. Similarly, the text based system resulted in correct answers for 96% and 95% responses to flaming and smoldering fire detection times, respectively. When looking at resistance to nuisance alarms, the majority of consumers understood the ratings, however the correct response percentages were noticeably below the fire detection time percentages. For nuisance resistance, the image based system gave a 68% correct response rate and the text based system yielded a 75% correct response rate. While these values suggest that at least two thirds of consumers understood the nuisance resistance ratings, the values are far from the near perfect response rates seen in the flaming and smoldering fire responses. The results of sections two and three in the online consumer survey indicate that if a rating system is to be implemented for smoke alarms, further research needs to be done with regards to consumer understanding of the nuisance resistance category.

Conclusions & Recommendations

Conclusions

The first conclusion to be drawn from the data collection is that consumers care about the performance of a smoke alarm in a fire, but it is not at the front of their minds when they are actually purchasing a smoke alarm. This can be seen in the differences in responses between the interviews and surveys from our first round of data collection. When given a predetermined list of features to choose from, consumers valued detection time as the most important factor to them on the most consistent basis. However, when asked during our interviews "What features would you look for when purchasing a smoke alarm?" consumers generally listed detection time less often than optional features and qualities of the smoke alarm. What is important to note is the fact that the answers we received during the interview were completely derived from the thoughts that first came to mind, which are generally considered as the ones most important or prevalent to them. Finally, when asked during the interview "Were you aware that some smoke alarms respond faster to certain types of fire?" 85 percent of consumers did not know that there was a difference. Some consumers even went as far as to ask: "There is a difference between smoke alarms?"

The juxtaposition of the survey findings and the answers to these particular interview questions is telling about the process by which consumers choose a smoke alarm. It shows that while consumers care about detection, when it comes time to actually purchase a smoke alarm, they bypass performance. This could be for two reasons: 1.) being unaware of the variation in smoke alarm detection capabilities; and 2.) performance differences are not presented on packaging. It is because of these reasons that consumers are more likely to focus on other features of the alarm when deciding on which smoke alarm to purchase.

The next conclusion drawn from the data is that consumers want information on performance and will use it when it is given. This idea is supported by the data collected during the second consumer survey. When shown 3 separate smoke alarm packages and told to select the smoke alarm they would be most likely to purchase, 80% of those surveyed indicated that their first choice would be a smoke alarm with a rating system or list of features included. The survey results provide insight into how the consumer values additional information on smoke alarms. Many consumers stated that their choice was based on wanting more information.

Another conclusion to make is that consumers will chose performance over price. This is supported by the findings in Survey Question 2 & 3, where 82% of those surveyed selected the higher rated alarm over the lower cost option. The information provided by this question shows that consumers are aware of the importance of the performance of a smoke alarm, and believe that it is worth the extra money to purchase a better rated smoke alarm.

Sections 2 and 3 of the Consumer Packaging Survey indicate that consumers mostly understand the tested rating systems, but there are still improvements that could be made. Over 90% of consumers understood both the icon and text based rating systems used, however that proportion dropped significantly in the nuisance resistance category.

Recommendations

Test Placement and Format

A large factor in the creation of a performance system is the visual component. While we

tested some aspects of the format of the performance system, others still need to be investigated. First, more work needs to be done determining if the placement of the performance system on the packaging affects consumer behavior. Determining an optimal position on the package would be beneficial to the success of the performance system. Also, alternatives to stars representing metrics need to be explored. Other options, such as the ones seen in Appendix G: Rating System Preference Survey, should be looked at to determine the most ideal way to display performance.

Nuisance Resistance Confusion

The comprehension of the nuisance resistance metric appeared to be an issue with consumers during the consumer packaging survey. Although nuisance resistance was a desired trait in the interviews, it was apparent that both the icon and text representation of the metric confused consumers. Alternative visual representations need to be looked into in order to more effectively communicate the nuisance metric to the consumer. This could entail changing both the icon of the smoking pan and the "nuisance resistance" text. Another topic that could be addressed is the word nuisance itself. Work needs to be done to see if consumers understand the word in the context of smoke alarms, and if not, what words would be more appropriate.

Consumers Unsure of the Performance System

Many consumers were reluctant to choose certain options during testing because they were unsure of what went into giving a smoke alarm a certain rating. This appeared to be due to a few reasons that consumers brought up:

- Who authorized the rating system?
- What are the tests to determine the ratings?
- What is the scale of the system? What does one star mean? What does three stars mean? What does five stars mean?

All of these concerns should be addressed through packaging, a brochure, and/or an in-store display. An in-store display would be a great option because it can be eye-catching, there is plenty of room to display information, and does not need to be actively searched for. Consumers will not use the performance system if they do not understand or trust it.

Changes to UL217

There is a section in the UL 217 Standard that deals with smoke alarm packaging. It states that:

> The material shipped with the alarm, including the package, instructions, or user's manual, shall not include information other than that specified in 101.1, such as manufacturer's claims on the operation of the alarm which have not been substantiated by the performance tests included in this standard, or that are not covered in Household Fire Warning Equipment provisions of NFPA 72, or other applicable NFPA standards of the National Fire Protection Association. The package shall also include the end-of-life information described in 101.1(f). (Underwriter's Laboratories, 2015)

In other words, no unverified performance claims can appear on a package. This presents an issue for a performance system. In order for the system to be implemented, there needs to

either be changes to this section of UL or it needs to be verified by the appropriate organizations.

Features List

There are a multitude of features and additions to smoke alarms that manufactures may incorporate into their products. During development of a performance system for smoke alarms, the idea of a standardized list of features on alarm packaging was suggested. The inclusion of a features list in the first question of the consumer packaging survey allowed the incorporation of more of the features suggested in the consumer interviews than could be included in the rating system. The feature list was the most popular option to consumers in the packaging survey. This finding could be used as an incentive for manufacturers to use the features list.

Current smoke alarm packaging distributes features over the front and back of the package, in varying fonts and sizes. A standardized features list would allow consumers to clearly and concisely view a list of the features the alarm has, as well as those features that are not included. This list would allow consumers to quickly identify which smoke alarm has the features that they want. In addition to these benefits, a features list would not violate the performance packaging restrictions in UL 217. Testing of a standardized features list was minimal in this project, so further study should be done to fully understand if such a list would be useful to consumers.

Electricians & Manufacturers

A full implementation of a performance system should also consider the pieces of the puzzle other than just the consumer. During our talks with manufacturers and inspectors, it seemed apparent that electricians play a big role in the installation of smoke alarms in the home and should be looked into. Manufacturers will be affected by the implementation of a performance system and how to obtain their cooperation should be investigated.

Further steps to be taken

Following the conclusion of this project, we hope to continue promoting consumer fire safety. Our project has been accepted for presentation at the NFPA Suppression/Detection Conference in March of 2016. We are currently working with the Consumer Product Safety Commission to attend the conference where we hope to share our findings and promote a performance based system for smoke alarms.

Reflections

Everett Baker

My experience in Washington, D.C. was extremely rewarding and enjoyable. When applying to project centers I wanted to find a project that could truly make a difference in the world, and I feel that working to save lives with the CPSC has done so. Several years ago I lost a family friend in a house fire due to non-functioning smoke alarms, so this project had tremendous personal meaning to me. Being able to say that I am working toward saving lives means more than being able to go to a beach after work or saying I traveled to another country for IQP. In addition to the project, Washington, D.C. was a great city to spend the term. I was able to visit Arlington National Cemetery on Veterans Day, see the National Christmas Tree the night it was lit, and see museums such as the Smithsonian Air and Space and National Firearms Museums. I would highly recommend the Washington, D.C. project center for those that want to enjoy a great city as well as work on a useful and meaningful project.

Tyler Bennett

IQP has been one of the most important parts of my college career so far. Through my experiences working on this 14 week project, I have found out what I am made of. This project was both strenuous and time consuming, but worth every second. It has a chance to have a large effect on consumers across the United States. I am very proud of what my team and I have accomplished- we set goals for our project and met them. This experience has helped me mature as well. Traversing the metro every day as well as managing my time and money over the course of two months has shown me I can be resourceful and adapt to different situations. IQP is something that cannot be replicated in any other form and I am very glad that I got to be a part of it. I can't wait to see the impact of our findings.

James Mosteller

My IQP experience was one of the best of my life so far as I was able to grow as a student, as a young adult, and as a friend to others. Doing our project with the CPSC was incredible, as the facility and everyone we interacted with made for a helpful and informative journey. Through our project, I was able to practice and improve my communications skills, within our group and with consumers, as well as research a multitude of aspects of smoke alarms and consumers. Living in Washington, D.C. for two months was another amazing aspect to the experience, as there was always something to do, within a walk or metro ride of our hotel. I was also able to make new friends with our entire IQP group, where I had not interacted with most of the students before this project. One thing that I would suggest to improve upon, is the communication between group, advisors, and sponsors, as that will provide a smoother ride for all parties. I will highly recommend that other students apply for and go off-campus to do their IQP, as it is truly a once in a lifetime opportunity to learn, live, and grow in another part of our beautiful planet.

John Williams

This has been my first group project at WPI. What a way to start! I gained experience with how unpredictable the purchase decision-making process can be. The Interviewing component of the project made me more comfortable with talking to random people. I got to be close friends with my group members outside of the project. I also learned to deal with their different personalities and working styles. I loved the experience of walking around DC, with its wide

streets, architecture, and museums. I was fascinated by the Rockville testing facility and NIST burn labs. I was able to see how engineers work for the government and to wonder if this would be interesting to me. I was proud that to be part of an impactful project that could potentially save lives. If I ever buy a smoke alarm I will be sure to choose the right one!

More Information

If you would like more information on any of the topics discussed in the paper or if you have any questions, please contact Brigitte Servatius or Arthur Lee.

Bibliography

718, B. F. L. (2008). Smoke Alarm Information. Retrieved from http://bostonfirelocal718.org/?zone=/unionactive/view_page.cfm&page=SMOKE20DETECTOR20INFOMATION

Administration, U. S. F. (2015, 17 Aug 2015). Statistical Report on the U.S. Fire Problem. Retrieved from http://www.usfa.fema.gov/data/statistics/reports.html

Ahrens, M. (2009). Factors in Smoke Alarm Performance: National Fire Protection Association Fire Analysis and Research Division.

Ahrens, M. (2013). *Home Fires Involving Cooking Equipment*.

Ahrens, M. (2014). *Item First Ignited in Home Structure Fires in which Upholstered Furniture Contributed to Flame Spread Beyond the Object of Origin*.

Ahrens, M. (2015a). Home Structure Fires. Retrieved from http://www.nfpa.org/research/reports-and-statistics/fires-by-property-type/residential/home-structure-fires

Ahrens, M. (2015b). *Smoke Alarms in US Home Fires*. Retrieved from http://www.nfpa.org/research/reports-and-statistics/fire-safety-equipment/smoke-alarms-in-us-home-fires.

Association, N. F. P. (2015). About NFPA. Retrieved from http://www.nfpa.org/about-nfpa

Association, U. S. F. (2015). Residential Building Fires (2011-2013). *Topical Fire Report Series, 16*(1). Retrieved from http://www.usfa.fema.gov/downloads/pdf/statistics/v16i1.pdf

Bakshi, S. (2012). IMPACT OF GENDER ON CONSUMER PURCHASE BEHAVIOUR (Vol. 1).

California State Fire Marshall. (2015). Information Bulletin 14-006 *Updated Smoke Alarm Requirements* (pp. 2).

Ching Biu Tse, A. Factors affecting consumer perceptions on product safety. *<journal-title xmlns:mml="http://www.w3.org/1998/Math/MathML" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">European Journal of Marketing</journal-title>, 33*(9/10), 911-925.

Commission, C. P. S. (2011). CPSC Announces Grand Opening of New State-of-the-Art National Product Testing and Evaluation Center.

Consumer Product Safety Commission. Smoke Alarms - Why, Where, and Which CPSC Pub. 559 (pp. 9). Consumer Product Safety Commission.

Council, T. R. (1996). *Shopping for Safety: Providing Consumer Automotive Safety Information*.

CPSC. About CPSC. Retrieved from http://www.cpsc.gov/en/About-CPSC/

Galen Carol Audio. (2007). Decibel (Loudness) Comparison Chart. Retrieved from http://www.gcaudio.com/resources/howtos/loudness.html

Giaimo, C. (2013). Smoke Detector Alarms Save Lives—Which One Is Right For You? Retrieved from http://simplisafe.com/blog/smoke-detector-alarms-guide

Guest, G., Bunce, A, and Johnson, L. (2006). How Many Interviews Are Enough? An Experiment with Data Saturation and Variability. *Field Methods, 18*(1), 59-82.

Hackney, J., & Kahane, C. (1995). *The New Car Assessment Program: Five Star Rating System and Vehicle Safety Performance Characteristics*.

Haefele, S., & Westkämper, E. (2014). Identification of product safety-relevant tasks for global automotive manufacturers (Vol. 17, pp. 326-331). Procedia CIRP.

Hall, J., Jr. (2013). *Home Fires Involving Heating Equipment*. Retrieved from http://www.nfpa.org/research/reports-and-statistics/fire-causes/appliances-and-equipment/heating-equipment

Kidde Survey: Consumers Know More about Snack Cakes Than Smoke Alarms. (2014). *Professional Services Close-Up*. Retrieved from *Business Insights: Essentials* website: http://bi.galegroup.com/essentials/article/GALE%7CA386450066?u=mlin_c_worpoly&sid=summon&userGroup=mlin_c_worpoly

Laboratories, U. (2015). Standard for Safety - Smoke Alarms *101.3* (Vol. 217).

Linacre, J. (1999). Investigating rating scale category utility. *Journal of outcome measurement, 3*(2), 103-122.

Market Analysis of Smoke Detection and Applications. Worcester Polytechnic Institute. Retrieved from https://www.wpi.edu/Pubs/E-project/Available/E-project-042507-154514/unrestricted/VS_IQP_FINAL.pdf

Meet NEST Protect. Retrieved from https://nest.com/smoke-co-alarm/meet-nest-protect/

Meet NEST Protect. Retrieved from https://nest.com/smoke-co-alarm/meet-nest-protect/

Murray, K. B. (1991). A Test of Services Marketing Theory: Consumer Information Acquisition Activities. *Journal of Marketing, 55*(1), 10-25. doi:10.2307/1252200

National Conference of State Legislatures. Carbon Monoxide Detector Requirements, Laws, and Regulations: National Conference of State Legislatures.

National Fire Protection Association. (2013a). NFPA 72: National Fire Alarm and Signaling Code.

National Fire Protection Association. (2013b). *U.S. Home Structure Fires Fact Sheet*.

National Fire Protection Association. (2014). NFPA 70 National Electrical Code (pp. 910).

National Fire Protection Association. (2015, February 26, 2014). Ionization vs Photoelectric. Retrieved from http://www.nfpa.org/safety-information/for-consumers/fire-and-safety-equipment/smoke-alarms/ionization-vs-photoelectric

Nayeem, T. C., Riza. (2015). Australian consumers' decision-making styles for everyday products. *Australasian Marketing Journal, 23*(1). Retrieved from sciencedirect.com website:

Performance of Home Smoke Alarms
Analysis of the Response of Several Available

Technologies in Residential Fire Settings. (2008). Retrieved from http://www.nist.gov/el/fire_protection/buildings/upload/NIST_TN_1455-1_Feb2008.pdf.

Quackenbush, F. (2015) *Smoke Alarms in Building Construction/Interviewer: J. Williams*.

Smith, G. (2015). Fire and Smoke Alarm Manufacturing in the US Industry Market Research Report from IBISWorld Has Been Updated. *PRweb*. Retrieved fromhttp://www.prweb.com/releases/2015/02/prweb12532597.htm

Tanner, J., & Raymond, M. A. Low-Involvement Versus High-Involvement Buying Decisions and the Consumer's Decision-Making Process, *Marketing Principles*.

The United States Fire Administration. (2010). State-by-State Residential Smoke Alarm Requirements: Federal Emergency Management Agency.

Underwriters Laboratories. (2014). Single- and Multiple-station Smoke Alarms. Retrieved from http://database.ul.com/cgi-bin/XYV/template/LISEXT/1FRAME/showpage.html?&name=UTGT.GuideInfo&ccnshorttitle=Single-+and+Multiple-station+Smoke+Alarms&objid=1074303606&cfgid=1073741824&version=versionless&parent_id=1073994256&sequence=1

Underwriters Laboratories Inc. (2006). UL Standard for Safety for Single and Multiple Station Smoke Alarms, UL 217.

United Nations Scientific Committee on the Effects of Atomic Radiation. (2008). Sources and Effects of Ionizing Radiation (Vol. I): United Nations.

United States Environmental Protection Agency. (2015, June 29, 2015). Smoke Detectors & Raditation. Retrieved from http://www.epa.gov/radiation/sources/smoke_alarm.html

United States Fire Administration. (2015, August 17, 2015). U.S. Fire Statistics. Retrieved from http://www.usfa.fema.gov/data/statistics/

United States of America Consumer Product Safety Commission. (2015). *Fiscal Year 2016 Performance Budget Request*.

Warmack, R. J. B., Wise, M., & Wolf, D. (2012). Home Smoke Alarms *A Technology Roadmap* (pp. 32).

World Nuclear Association. (July 2014). Smoke Detectors and Americium. Retrieved from http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Radioisotopes/Smoke-Detectors-and-Americium/

Wright, B., & Masters, G. (1982). *Rating Scale Analysis*. Chicago: Mesa Press.

Yang, J., Peek-Asa, C., Jones, M. P., Nordstrom, D. L., Taylor, C., Young, T. L., & Zwerling, C. (2008). Smoke Alarms by Type and Battery Life in Rural Households: A Randomized Controlled Trial.*American Journal of Preventive Medicine, 35*(1), 20-24. doi:http://dx.doi.org/10.1016/j.amepre.2008.03.020

Zaichkowsky, J. L. (1986). Conceptualizing involvement (pp. 4-34).

Appendix A: Letter to Store Owner/Manager

WORCESTER POLYTECHNIC INSTITUTE
WORCESTER, MASSACHUSETTS 01609

U.S. CONSUMER PRODUCT SAFETY COMMISSION
ROCKVILLE, MARYLAND 20850

November 5, 2015

Dear Store Owner or Manager,

We are students from Worcester Polytechnic Institute working with the U.S. Consumer Product Safety Commission to gather information about consumer knowledge and preference of smoke alarms.

Each year, home fires result in 2,470 deaths, 12,890 injuries, and $6.9 billion in property damage. In 21% of these deaths, a smoke alarm was present but failed to operate. We are gathering information to help improve the usage, selection, and information on smoke alarms for consumers. Hopefully, this information will allow customers to make better selections on the type of smoke alarms that may best suit their needs and thus, reduce the number of fire deaths.

With your permission, we would like to spend a few hours at your store interviewing customers the attached questionnaire. The questionnaire will only take 5 minutes of a customer's time, but provide us with valuable information.

Our end goal is to use this valuable information to create an information rating system that would be used on the packaging of smoke alarms to better inform the consumers and your customers the important safety information in selecting a smoke alarm.

Our current plan is to have a completed information rating system by the beginning of December. At that point in time, we hope to return, with your permission, to evaluate customers' preference on the information rating system for smoke alarms.

Once we are finished collecting data, we will be accumulating our results into a report. We can place your store in the acknowledgements section as well as share our final report with you and your company or if you prefer to have your participation undisclosed, we can reference your store with a designated random letter. To schedule a date for us to conduct interviews at your store, or if you have any other questions or concerns, we can be reached at dc15-cpsc@wpi.edu or 703-577-0565. Thank you very much for your help.

With gratitude,
The WPI Smoke Alarm Team
Everett Baker
Tyler Bennett
James Mosteller
John Williams

Appendix B: Consumer Smoke Alarm Survey

This survey is intended to help us understand current consumer smoke alarm preferences. All responses will be kept completely anonymous. Thank you for helping to improve fire safety.

Please choose all that apply:

- ☐ I am here today to look at or buy a smoke alarm.
- ☐ I have never bought a smoke alarm before.
- ☐ I currently have one or more smoke alarms in my home.
- ☐ I actively maintain the smoke alarm or alarms in my home.

Rate each factor on a scale of 1 to 5, with 1 being not important and 5 being very important.

Features:

Size of the alarm:	1	2	3	4	5	Aesthetics of the alarm:	1	2	3	4	5
Voice alarm:	1	2	3	4	5	Option to connect alarms:	1	2	3	4	5

Performance:

Detection time:	1	2	3	4	5	Resistance to false alarms:	1	2	3	4	5
Importance of 10 year battery:	1	2	3	4	5	Price of the alarm:	1	2	3	4	5

Optional Information: ☐ Male ☐ Female Age: ☐ Under 25 ☐ 25-40 ☐ 41-60 ☐ 60+

This survey is intended to help us understand current consumer smoke alarm preferences. All responses will be kept completely anonymous. Thank you for helping to improve fire safety.

Please choose all that apply:

- ☐ I am here today to look at or buy a smoke alarm.
- ☐ I have never bought a smoke alarm before.
- ☐ I currently have one or more smoke alarms in my home.
- ☐ I actively maintain the smoke alarm or alarms in my home.

Rate each factor on a scale of 1 to 5, with 1 being not important and 5 being very important.

Features:

Size of the alarm:	1	2	3	4	5	Aesthetics of the alarm:	1	2	3	4	5
Voice alarm:	1	2	3	4	5	Option to connect alarms:	1	2	3	4	5

Performance:

Detection time:	1	2	3	4	5	Resistance to false alarms:	1	2	3	4	5
Importance of 10 year battery:	1	2	3	4	5	Price of the alarm:	1	2	3	4	5

Optional Information: ☐ Male ☐ Female Age: ☐ Under 25 ☐ 25-40 ☐ 41-60 ☐ 60+

Appendix C: Consumer Interview Questions

INTERVIEW QUESTIONS

1. Do you have a smoke alarm in your home?
2. Have you ever purchased a smoke alarm?
3. What features would you look for when purchasing a smoke alarm? (freelist)
4. Were you aware that some smoke alarms respond faster to certain fires?
    a. If yes, what are the different types of smoke alarms?
    b. Which type of alarm detects which type of fires?
5. Are you aware of the locations in your home where smoke alarms should be installed?
6. Do you have a smoke alarm inside or near your kitchen?
    a. Does your alarm go off often?
7. Would a smoke alarm performance rating system, much like that of the 5 star crash test safety rating system for cars, influence your decision on which smoke alarm you would purchase?
8. ~~Which one of these rating system types do you like?~~
    a. ~~Have images to show them to think about and choose from.~~
9. What is your preferred power source?
    a. After they answer, mention the following types
        i. Replaceable Battery
        ii. 10 year Battery
        iii. Hard-wired (with battery backup)
10. Do you have any other thoughts or questions?

Appendix D: Store List

Store		Address	Dist.	Time
Home Depot	1	15740 Shady Grove Rd, Gaithersburg, MD 20877	1.2	5
	2	7111 Westlake Terrace, Bethesda, MD 20817	8.1	11
	3	21010 Frederick Rd, Milestone Center, Germantown, MD 20876	9.2	12
	4	14000 Georgia Ave, Aspen Hill, MD 20906	7.5	17
	5	901 Rhode Island Ave NE, Washington, DC 20018	Metro	25
Lowes	1	40 Market St, Gaithersburg, MD 20878	3.7	11
Walmart	1	20910 Frederick Rd, Germantown, MD 20876	9.3	13
Ace	1	19600 N Frederick Rd, Germantown, MD 20876	7.5	11
	3	1734 14th St NW, Washington, DC 20009	Walk 1	20
	4	**1055 5th St NW, City Vista, Washington, DC 20001**	**Metro**	**21**
Target	1	Washingtonian Center, 25 Grand Corner Ave, Gaithersburg 20878	2	7

Appendix E: Project Timeline

WPI IQP Timeline 2015

Week 1: October 26th – October 30th

- Revise interview questions.
- Brainstorm about interviewing manufacturers. (questions; which manufacturers)
- Create something to say to store owners, think about our setup @ stores.

Week 2: November 2nd – November 6th

- Finalize plan of how we will talk with consumers.
- Finalize where we will go.
- Go to the stores and ask for their permission.
- Revise our introduction, background, and methods section.

DUE: Thursday, November 5th: Introduction & Background both fully revised and updated; Methods draft.

Week 3: November 9th – November 13th

- Go to the stores.
- Set up and conduct interviews with manufacturers.
- Further revise our introduction, background, and methods.

DUE: Thursday, November 12th: Introduction, Background, & Methods fully revised and updated.

Week 4: November 16th – November 20th

- Finish up store interviews.
- Finish up manufacturer interviews.
- Analyze the results, start creating the rating system.
- Finish revising our methods.
- Outline our results section.

DUE: Thursday, November 19th: Methods (polished), Results outline.

Week 5: November 23rd – November 25th

- Finish up rating system.
- Begin creating graphics.

Students are to work on results, data analysis, etc.

Week 6: November 30th – December 4th

- Finish up graphics.
- Test and analyze rating system by going back to stores with graphics.
- Type up our results section.

DUE: Wednesday, December 2nd: Introduction, Background, Methods, Results draft.

Week 7: December 7th – December 11th

- Keep adding to our final report.
- Finish our final presentation slides.

DUE: Thursday, December 10th: Final Presentation Slides.

Weekend (12th & 13th): Practice final presentations and revise slides.

Week 8: December 14th – December 17th

- Finish our final report.

DUE: Monday, December 14th – Report final draft

Wednesday, December 16th – Final Reports ready for submission

Thursday, December 17th – Final Reports submitted

Appendix F: Manufacturer, Inspector, and Standards Questions

Manufacturers:

What does your job entail?

Do you record what percentage of your smoke alarms are sold to contractors, versus stores or internet retailers?

(If not) Do you have any suggestions of where this information might be available?

What models are the most popular?

Which are more popular…Ionization or Photoelectric? Strictly smoke alarms or combination alarms? High cost models or lower cost models?

What type of power source is the most popular?

What is the profit margin of a low cost and high cost smoke alarm?

How often do you update a model or add features in a new model?

Why do you make these changes?

When changing products or making a new model, how do you appeal to consumers?

Do you have any examples of marketing a product to consumers?

Do you think a performance based rating system for smoke alarms would be beneficial to consumers?

Would a rating system change the way you design or market your products?

If such a rating system was optional, would your company consider using it on your packaging?

Inspectors:

What does your job entail? (What under what circumstances are you called upon to inspect buildings?)

Do people understand where to install smoke alarms?

If a building's smoke alarms do not follow standards, what kind of advice do you give them to reach the standards?

Do you think a performance based rating system would be beneficial to consumers?

Are there certain types of alarm that you encounter most frequently?

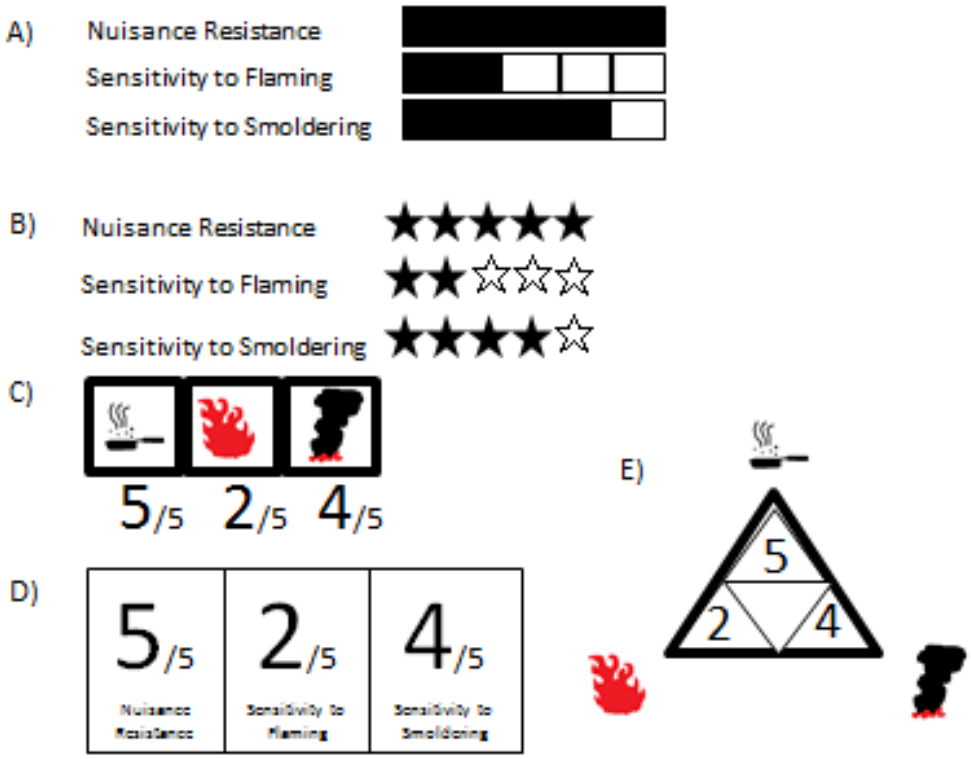
UL Standards:

Do you think a performance based rating system would be beneficial to consumers?

I don't mean to make you speak for the whole company, but do you think UL might take part in a rating system?

Would it be feasible for UL to record performance values for a rating system during testing?

Appendix G: Rating System Preference Survey



Appendix H: State-by-State Guide to Smoke Alarm Requirements

2013 State-by-State Guide to Smoke Alarm Requirements				
State	**Upgrade on Permit**	**Hardwiring**	**Interconnection**	**10-Year Battery Backup**
AL	**Requirements are based on 2003 NFPA codes. The primary power for all smoke alarms in newly built homes shall be from the building's electrical system. Battery-powered smoke alarms are recognized in existing dwellings.**			
AK	**X**	**X**	**X**	
AZ		**X**	**X**	**X**
AR		**X**	**X**	
CA	**X**			**X**
CO	**There are no statewide regulations; check with the local jurisdiction.**			
CT	**An affidavit of smoke alarms present is required on a property transfer; new rules are pending.**			
DE		**X**	**X**	
DC		**X**	**X**	**X**
FL				**X**
GA	**NFPA 72 codes apply; contact county fire office for connection requirements.**			
HI		**X**	**X**	
ID		**X**	**X**	**X**
IL		**X**	**X**	
IN	**State law requires all newly installed smoke detectors to be dual-sensor type, with photoelectric and ionization technologies.**			
IA		**X**		**X**
KS		**X**	**X**	**X**
KY		**X**	**X**	**X**
LA				**X**
ME	**State law requires the purchaser of a property to install approved smoke alarms within 30 day of closing.**			
MD	**X**	**X**	**X**	**X**
MA	**State law requires installation of approved smoke alarms by the seller on the transfer of a property. Newer homes must have hardwired, interconnected alarms with sealed a 10-year battery backup.**			
MI	**X**	**X**	**X**	**X**
MN	**X**	**X**	**X**	**X**
MS		**X**	**X**	
MO	**There is no statewide fire code; jurisdictions are encouraged by the state to observe current NFPA 72 standards.**			
MT	**Smoke detectors are required for the sale of a property.**			

NE		**X**	**X**	
NV	**Standards are set by local jurisdictions.**			
NH	**Smoke alarms are required in every residence built after 1982.**			
NJ	**X**	**X**	**X**	**X**
NM	**There are no state requirements.**			
NY	**Interconnected smoke alarms are required. They may be hardwired or wireless, and 10-year backup batteries encouraged. The state can levy fines of not more than $1,000 a day where violations are found through inspection, but enforcement of local requirements (which may be more or less stringent) is left to the local AHJ.**			
NC		**X**		
ND		**X**	**X**	**X**
OH	**For new construction, follow the 2006 Residential Code of Ohio. There is no retroactive requirement for smoke alarms in older homes.**			
OK	**There are no smoke alarm requirements for existing single-family residences unless they're rented. New construction and remodeling projects are subject to NFPA 72 standards and enforced by the permitting process of the local AHJ.**			
OR	**Technical requirements for smoke alarms are governed by ORS 479.297. Installation requirements are governed by OAR 837-045-0050. Dwellings may not be sold or transferred without the required smoke alarms installed in accordance with the state building code in force at the time of construction and the rules of the state fire marshal.**			
PA	**New homes are subject to smoke alarm requirements found in IRC 2006, Section 313, requiring hardwiring, interconnection and battery backup. The remodeling of existing homes requires at least non-interconnected smoke alarms at prescribed locations per the code. The local AHJ may enforce standards other than those required by the state.**			
RI	**X**	**X**	**X**	**X**
SC	**Smoke alarms are required for all homes. Guidelines have been issued for the placement and installation of hardwired and battery-powered units. No enforcement mechanism is articulated in the available information.**			
SD	**No statewide legislation addresses smoke alarm requirements for single-family homes.**			
TN	**There are no state requirements for smoke detectors in single-family homes. For new construction and remodeling, apply the local building code per the jurisdiction.**			
TX	**X**	**The standards for the location, installation and power source for smoke alarms are set and enforced by local AHJ.**		
UT	**State law requires smoke alarms to be installed outside sleeping areas and on all levels of a home.**			

VT	**Homes constructed after 1994 are required to have hardwired smoke alarms with a battery backup.**			
VA	**X**	**X**	**X**	**X**
WA	**Smoke detectors are required in all dwellings built after 1980 and in dwellings not occupied by the owner. Seattle requires hardwiring, interconnection and battery backup. Other jurisdictions are encouraged to adopt the current version of NFPA 72.**			
WV	**Smoke detectors are required in all one- and two-family dwellings installed in accordance with the current NFPA 72 requirements. A fine of up to $250 can be levied if an inspection shows that compliant smoke alarms are not present, with a fine of up to $2,000 on the second offense.**			
WI	**Dwellings permitted after April 1, 1992 are required to have hardwired, interconnected smoke detectors with a battery backup on each level and within 6 feet of all sleeping quarters.**			
WY	**State regulations are not currently available. However, the state fire marshal refers residents to IBC 2006, which stipulates standards for hardwiring, interconnection and battery backup.**			

Source: FEMA

Appendix I: Categories of What Consumers Look For in a Smoke Alarm

Categories of What Consumers Look For in a Smoke Alarm

Detection:
- Nuisance Resistance
- Accuracy
- Sensitivity

Ease:
- Ease of Installation
- Ease of Use
- Disconnectable
- Ease of Battery Removal
- Easily found battery type

Features:
- Hush Button
- Carbon Monoxide
- Call in Emergency
- Interconnectable
- Phone App
- Hush remote
- Low battery chirp
- Test button

Misc.:
- Price
- Brand
- Aesthetics
- Requirements
- Reviews

Other Performance:
- Reliability
- Audibility
- Longevity
- Battery Life

Power Supply:
- Hardwired only
- Battery Powered
- Hardwired with Battery Backup
- 10 year battery