International Smoke Alarm Legislation & Technology in Residential Structures

A Review for Fire Protection Association Australia

An Interactive Qualifying Project Report
for the Melbourne Project Site
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WORCESTER POLYTECHNIC INSTITUTE
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Degree of Bachelor of Science
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Abstract

A comprehensive report on smoke alarm effectiveness was completed for Fire Protection Association (FPA) Australia to aid fire protection officials around the world in drafting legislation that more accurately reflects the international *de facto* standard. Research shows that photoelectric smoke alarms are more effective than ionization units in most residential fire situations. The current warning tone was shown to be ineffective and should be replaced with a 520 Hz square wave pattern. Analysis of a successful (70% return rate) international survey indicates current compliance monitoring and enforcement practices are insufficient in many regions. A database was developed for FPA Australia through compilation of the survey responses.

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Authorship

This report was created through the equal contributions of all group members: Timothy Manchester, John Meklenburg, Kemal Moise, and Brian Potts.

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Executive Summary

Smoke alarms have been one of the major contributors to improved home fire safety over the past 40 years. Nonetheless, residential fires remain a significant problem and cause approximately 3,000 deaths per year in the U.S. alone. Smoke alarms are designed to detect fires before they become dangerous and to provide sufficient warning to occupants so they can escape. Smoke alarms are essential to ensure the highest level of protection in a residence, but they must be used properly to guarantee maximum safety. As technology evolves and new research is conducted, smoke alarms need to be re-evaluated for effectiveness. The purpose of this project was to investigate international smoke alarm legislation and technology for residential structures and to provide a summary of the findings so that fire protection officials can become knowledgeable about the current state of smoke alarm technology and draft legislation that is more in line with the international *de facto* standard.

This report was prepared as part of a degree requirement for Worcester Polytechnic Institute (Worcester, MA, USA) in collaboration with Fire Protection Association (FPA) Australia (Box Hill, VIC, Australia). Over the course of the project, types of smoke alarms currently in use (ionization versus photoelectric), the effectiveness of smoke alarm warning tones on certain high-risk population sub-groups, international smoke alarm legislation, and socioeconomic factors that affect such legislation were all investigated. The goal was to review research on smoke alarms as well as the current state of global smoke alarm legislation, in order to compile data and identify possible gaps in international fire protection practices. The deliverables to FPA Australia include an international smoke alarm legislation database and a literature summary of smoke alarm technology and practices.

Three main methods were used to obtain these data: surveys, interviews, and a literature review. Data on international smoke alarm legislation were obtained through surveys distributed to fire protection experts worldwide. Representatives of 109 different countries, states, territories, and provinces were surveyed, including the United States, Australia, the United Kingdom, Canada, and New Zealand, as well as other countries in Europe, Asia, and Africa. Unstructured interviews were conducted with subject matter experts (SMEs) to provide us with a starting point for our research and literature review. The literature review was conducted, often based on information obtained through our SMEs, to supplement and support the information acquired through interviews and personal communications.

There are two main types of smoke alarms currently on the market throughout most of the world: ionization and photoelectric. Ionization detectors utilize a radiation source (Americium-214) and an electrical circuit to detect invisible particles of combustion ranging in size from 0.001 µm to 3 µm. Smoke enters the chamber and interferes with the measured current, causing the detector to trigger the alarm. Photoelectric detectors sense light from an internal source using photocells. They are sensitive to particles ranging in size from 0.3 µm to 10 µm. When smoke is present, light is refracted and redirected to the light-sensitive photocell, actuating the alarm. It is a commonly accepted fact that ionization alarms respond to flaming fires faster but photoelectric alarms respond earlier to smoldering fires.

There has been much debate in the fire protection community over which of these two types is more effective in reducing fatalities from residential fires. The controversy has been ongoing for years, but it has become increasingly politically charged over the past several months. The dispute stems from the fact that while ionization smoke alarms meet sensitivity and performance requirements, many experts believe that they provide insufficient protection in the case of a typical residential fire. A group of fire protection authorities across the world, including Boston's Deputy Fire Chief Joseph Fleming and New Zealand's Adrian Butler, are leading the push towards requiring photoelectric smoke alarms in all dwellings.

Studies have shown that photoelectric units are more effective at detecting the types of fires that are most likely to be fatal in homes: smoldering fires. One study reported that photoelectric smoke alarms respond more rapidly in three out of four likely residential fire situations: a smoldering fire with the alarm in the room of ignition, a smoldering fire with the alarm outside the room of ignition, and a flaming fire with the alarm outside the room of ignition. The only case in which the ionization alarm responded first was when the alarm was in the room of ignition of a flaming fire. Even then, the photoelectric alarm still provided the occupants with enough time to escape safely.

After a smoke alarm has detected a fire and sounded the alarm signal, the occupant must respond accordingly for the device to be of use. Recent research has shown that the current warning tone of standard smoke alarms is often insufficient to trigger the desired response from certain high-risk groups. Young children, the elderly, those with hearing impairment and/or high frequency hearing loss, and those who are alcohol impaired are at risk of sleeping through the standard tone.

The standard warning tone used in current smoke alarms is a sine wave with a frequency between 3000 Hz and 4000 Hz. It is easily distinguishable from background noise and therefore is a good notification of a dangerous situation for those who are awake. However, studies have shown that this signal is less than optimally effective for waking sleeping occupants. The most effective signal is a 520 Hz square wave, because of its additional energy at odd harmonics of the fundamental frequency. Unfortunately, size and power constraints prevent this technology from being utilized in standard smoke alarm units; future research will be necessary to make this signal useable in such a small device.

There are numerous factors and variables that influence the specific smoke alarm needs of a residence, especially the social and economic status of the region in which it is located. The prevailing lifestyle, heating fuel, and cooking methods, among other things, must be taken into consideration when recommending or requiring a specific type of smoke alarm for a residence. For example, in many developing countries people cook with coal, which is likely to trigger false alarms if a smoke alarm is present. This presents a problem because nuisance (false) alarms, which most often occur with ionization units, have been shown to be one of the primary reasons for homeowners to disable smoke alarms, rendering them useless. In addition, functionality is often less of a concern to the average buyer than affordability and cost, since most buyers are unaware of the different technologies available. In most cases, ionization alarms are less expensive than photoelectric, and are therefore the more popular of the two types.

The economic climate of a region is especially important when considering legislation requiring smoke alarms. It does no good to require smoke alarms in a country where nobody can afford them. The difference in smoke alarm affordability across the globe is enormous. It takes approximately a quarter-hour of work in the United States or Australia for an average citizen to be able to afford a smoke alarm, but over 75 hours of work in China. In nations where smoke alarms are an unobtainable luxury to most citizens, alternative methods of protection need to be considered.

Despite the variations in local circumstances, there is still a universal need for fire protection. Many regions around the world have legislation making smoke alarms compulsory in most or all dwellings. Of the 109 surveys addressing this question that we distributed, 76 responses were received. Only 29% of responding countries have enacted nationwide smoke alarm legislation. Of the eight Asian countries that responded, only one, Japan, has legislation. Europe, however, is relatively aggressive with smoke alarm legislation, with five out of the ten surveyed having legislation. Australia, the United States, and Canada do not have any nationwide legislation, but they have national provisions that can be adopted by individual states, territories, or provinces. There are very few regions that specify smoke alarm type, as only three of the 76 returned surveys stated that photoelectric units are required.

The most significant problem identified among regions with smoke alarm legislation is a lack of enforcement and compliance monitoring. Penalties for non-compliance should be stronger than they currently are, and inspections should be conducted on a more regular basis rather than only when an occupancy permit is issued or a home is sold.

Through our research, we have found that it is difficult, if not impossible, to make generalizations about the "ideal" smoke alarm arrangement for residences on a global level. For developed countries such as Australia and the U.S., the "ideal" smoke alarm is photoelectric, hard-wired with a battery backup, and interconnected. However, the number of factors and variables that can affect recommendations for type and proper use of smoke alarms are so great and vary so much for differing situations, it would be a gross oversimplification to make any blanket statements on the subject. Lifestyle differences like cooking methods, heating fuel, climate, housing style, and economic climate are only a few of the variables that must be considered.

Chapter 1: Introduction

Since the 1970s, smoke alarms have played a critical role in improving the state of residential fire safety. They provide an easy and relatively inexpensive way to deliver a level of protection that was not previously obtainable. Smoke alarms were one of the fastest growing methods of improving home safety *(Bukowski, 2001)*. As of 1970, very few American homes had smoke alarms installed. In the early 1970s, 17,000 mobile homes were manufactured with preinstalled smoke alarm units to serve as temporary housing after Hurricane Agnes. During this experimental period, the number of fires in these mobile homes remained constant, but the number of fatalities dropped to near zero. This was the first demonstration of the effectiveness of smoke alarms. By the 1980s, 75% of homes in the United States had smoke alarms installed *(Grant et al., 2006)*, and by 2004, this number had increased to 96% *(Ahrens, 2008)*.

Over the last four decades, fire protection officials have questioned whether or not current smoke alarms provide the highest level of protection possible. For example, one of the most controversial topics within the fire protection community has been the debate over the effectiveness of ionization versus photoelectric detectors. The debate has become heated over the last several years and is becoming an international issue as the world becomes more developed and connected. The effectiveness of currently used smoke alarm warning tones in successfully awakening sleeping occupants has also come into question, especially concerning young children, the elderly, the hearing impaired, and those who are alcohol impaired. To address these issues, socioeconomic as well as technical parameters must be taken into consideration, as affordability and lifestyle differences are factors.

Perhaps the most significant study for the fire community was conducted by the United States National Institute of Standards and Technology (NIST, formerly NBS, National Bureau of

Standards) in 1977 *(Bukowski, Waterman, & Christian, 1977)*. This study largely focused on types of smoke alarms (ionization versus photoelectric), and was one of the driving forces behind early smoke alarm legislation. More recent research deals with the effectiveness of warning tones, and strongly suggests that current smoke alarms are ineffective in waking young children *(Bruck, 1999)*. Currently, there is still debate on many of these concerns.

Although individual countries and in some cases states, provinces, or territories, have their own legislation, there has not yet been a centralized, coordinated effort to compile worldwide fire protection legislation data (such as detector type and placement) in conjunction with current research in the field. Even though different countries have a variety of backgrounds and needs, it would be useful to have these data available for reference. These data may be valuable to developing countries looking to improve the quality of their fire protection.

This project will focus on the types of smoke alarms currently in use (ionization versus photoelectric), the effectiveness of smoke alarm warning tones on certain high-risk population sub-groups, international smoke alarm legislation, and socioeconomic factors that affect such legislation. The goal of this project is to review research on smoke alarms as well as the current state of global smoke alarm legislation, in order to compile data and identify possible gaps in international fire protection practices. Fire Protection Association (FPA) Australia will make these data available to fire protection officials worldwide.

FPA Australia is located in Box Hill, Victoria, Australia. It is a non-profit organization that specializes in providing information regarding fire safety to experts as well as educating the general public to prepare for fire emergencies. Overall, as stated on FPA Australia's website, "FPA Australia provides a central source of information and services to promote the protection of life, assets, and the environment in Australia" *(Fire Protection Association Australia, 2009).*

FPA Australia also looks to work on an international level in order to improve fire safety standards throughout the world.

Chapter 2: Background

Between the years 1975 and 2000, the number of residential fire fatalities in the US decreased by approximately 50% *(Bukowski et al., 2007)*. Professionals in the field of fire protection would like this trend to continue. However, there is a great deal of debate within the fire safety community as to the best way to accomplish this. New technologies must be assessed in order to be utilized effectively. Shortcomings in current smoke alarms and their warning tones must be acknowledged and dealt with accordingly. Legislation must be reviewed and adapted to meet the needs of the people affected, and must take socioeconomic factors into consideration.

2.1 Smoke Alarm Technology

It is important to establish the difference between detectors and alarms. A smoke alarm includes both a detector and a signaling device combined into one unit; these were first introduced in 1965 *(Grant et al., 2006)*. Detectors are designed to sense smoke produced by a fire and send a signal that will then trigger an alarm. The introduction of battery-operated smoke alarms in 1970 was a key advancement in fire safety because it meant that a full early-warning system could be installed easily, especially in locations where hard-wiring (connecting the smoke alarm to the mains power) was not an option; for example, in mobile homes. There are currently two main types of smoke detection technology: ionization detectors and photoelectric detectors. Each will be discussed briefly in the next section.

2.1.1 Ionization Smoke Detection Technology

Ionization smoke detectors operate by comparing the current through two isolated circuits *(U.S. Environmental Protection Agency, 2009)*. Each circuit has a small gap in the wiring where a source, Americium-241, emits radiation that forms ions. These ions create a path that allows current to flow through the circuit. The detector has two chambers: one open to the surroundings and another that is closed *(O'Connor et al., 2008)*; each chamber has its own radiation source. This setup is shown in Figure 1. When smoke particulates enter the open chamber, they interfere with the ion path and lower the measured current. When this current drops significantly relative to that of the closed "reference" chamber, the detector activates. This type of detector is sensitive to small particles and is thus prone to nuisance (false) alarms due to cooking fumes, wood smoke, or any other particulate capable of interfering with the circuit.

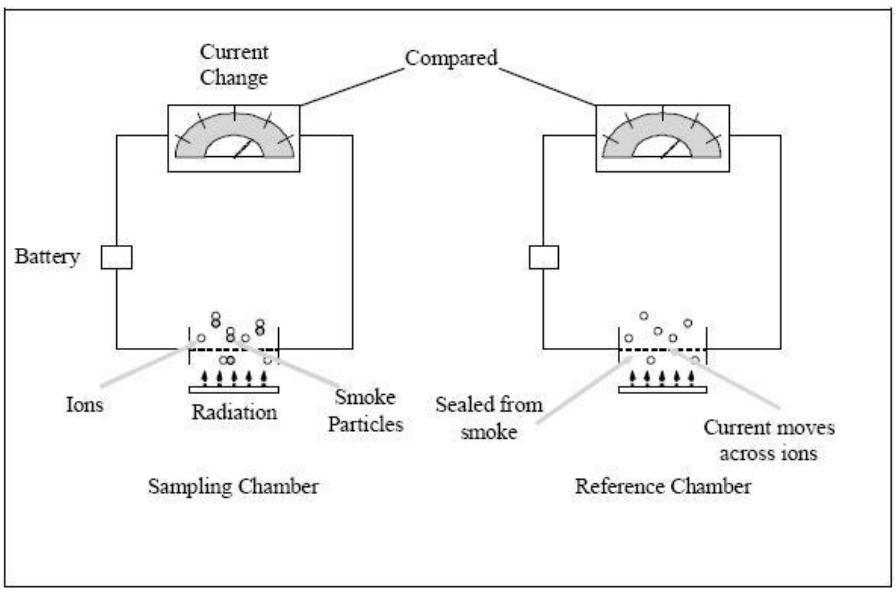

Figure 1: Representation of Ionization Smoke Detector *(O'Connor et al., 2008)*

2.1.2 Photoelectric Smoke Detection Technology

Photoelectric smoke detectors function by measuring the intensity of light through a chamber from an internal light source *(O'Connor et al., 2008)*. When there is no smoke, light does not reach the photoreceptor (which is not co-linear with the light source). This setup can be seen in Figure 2. Smoke particles refract light so that it is sensed by the receptor and the detector activates. Since the detector works by refracting light, it is sensitive to larger particulates in the air; however, it is insensitive to invisible particles and particles that absorb light.

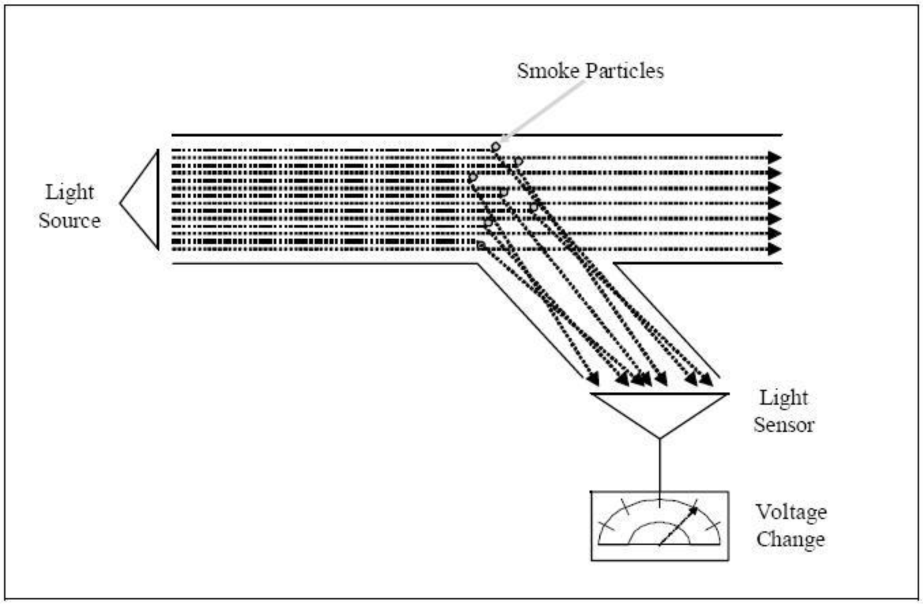

Figure 2: Representation of Photoelectric Smoke Detector *(O'Connor et al., 2008)*

2.1.3 Placement, Installation, and Power Supplies of Smoke Alarms

The effectiveness of smoke alarm units is also dependent upon where they are placed within a home. This consideration, along with the type of detector, was investigated in the Indiana Dunes Study in 1977 *(Bukowski et al., 1977)*. Problems can arise when the unit is in a different room than the fire. A fire in one room may not activate an alarm that can be heard by the occupant. This concern can be resolved by interconnecting the units so an alarm in one area of a household sounds the rest of the alarms *(Ed Comeau Interview, Appendix A)*. However, this is not always economically or physically possible, especially in older buildings. For this reason, units with wireless interconnectivity are now available at an added cost.

For a smoke alarm to be useful, it must also be operational. Battery-powered units became available in 1970 *(Grant et al., 2006)*. They allow for easier installation; however, batteries die and consumers often forget to replace them. Hard-wiring is an option, but this requires extensive installation. The 10-year battery was released in 1995, which combined a long-lasting power source with simple installation.

2.1.4 Ineffectiveness of Standard Smoke Alarm Warning Tones

A significant problem with smoke alarms that has recently become apparent is the ineffectiveness of the standard warning tones *(Thomas & Bruck, 2008)*. "Warning tones" are the audible signals emitted by smoke alarms upon the positive detection of particulates that signify the presence of smoke and/or fire. These sounds may not provide adequate protection for some high-risk population subgroups especially young children, the elderly, the hearing impaired (specifically those with high-frequency hearing loss), and alcohol impaired persons. Most young children do not have any problems hearing the alarm when awake, but the sound is often inadequate to wake them when sleeping. Older adults and those who are hard of hearing often have high frequency hearing loss that may prevent them from hearing the signal even when awake. Those who are under the influence of alcohol often have difficulty awakening to the standard smoke alarm sound as well.

This is a serious problem that must be resolved. Many studies have recently been conducted that examine the effectiveness of different types of warning tones in order to find out which is the most effective. In particular, Dorothy Bruck of Victoria University in Werribee, Victoria, Australia has conducted many such studies that have yielded promising results. However, technical restrictions are present with regards to the size, power requirements, and cost of more effective alarms *(Huey, Buckly, & Lerner, 1996)*. These studies and limitations need to be considered by manufacturers when designing new smoke alarms.

2.2 Socioeconomic Considerations for Fire Safety

Due to a large range of socioeconomic factors, a universal set of fire standards would not be a feasible solution to the problems concerning fire safety. What may be necessary for one group of people in one area may not be of concern to people in other states, territories or countries *(ISCAIP, 1999)*. Regulations based on smoke alarm type (photoelectric or ionization), power source (battery-operated or hard-wired), and housing characteristics (existing or new) differ throughout the world due to variations in lifestyles and annual family income. Overall, legislative bodies set different and specific standards in order to provide protection for citizens during a fire emergency.

Cooking styles vary worldwide based on cultural differences, which can result in nuisance alarms occurring under seemingly normal conditions when certain types of smoke alarms are used. For example, some households use coal or wood when cooking while others use gas; each situation will result in different responses from both ionization and photoelectric smoke alarms due to the differences between particulates generated by different types of fuel sources. While both types will sense cooking gases, ionization smoke alarms have been found to set off more nuisance alarms due to cooking compared to photoelectric *(O'Connor et al., 2008)*. The type of fuel used for cooking could be dependent on the economic and social characteristics of the area.

While smoke alarms are an affordable item for citizens of Australia, the United Kingdom and the United States, they are often too expensive to be mandated in many other countries *(Hendrie et al., 2004)*. In the aforementioned countries, many homes are required to have smoke alarms installed; this means that they need to be affordable for the average citizen, as they are an essential piece of safety equipment. In many nations, such as China, it is difficult to enforce legislation requiring smoke detectors because of their high cost. These differences present a new set of concerns that need to be dealt with, including whether or not nations have other types of fire protection measures enacted to ensure the safety of the population, and if not, if they are currently drafting any such legislation. It is also important to note whether or not there is a fire protection organization that is working towards more affordable smoke alarms, among other safety precautions

2.3 Smoke Alarm Legislation

According to the International Society of Child and Adolescent Injury Prevention, or ISCAIP, "Worldwide about 100,000 children die each year in fires, most of which occur in the home" *(ISCAIP, 1999)*. These tragedies may be reduced through the use of operating smoke alarm systems throughout residential homes. Due to the results of multiple studies performed throughout the world, many countries have adopted legislation which requires that homes be equipped with smoke alarm systems, while some nations are still in the process of passing these laws. Clearly, most countries, territories and states are taking fire safety very seriously.

In the 1960s, the U.S. Department of Housing and Urban Development (HUD) began experimenting with building safer, low-cost housing for the increasing urban population. One of HUD's primary concerns was fire safety in the new residential homes, as smoke alarms were found only in commercial establishments at that time due to their high price. The National Institute of Standards and Technology subsequently began working on creating smoke alarms and heat-sensing detectors for the general public at an affordable price *(Bukowski, 2001)*.

By the early 1970s, Richard Bright, a scientist for the NBS, and supervisor Irwin Benjamin began intensely monitoring smoke alarm units and experimenting with them to determine how they could best be used in residential settings *(Bukowski, 2001)*. Both scientists worked with different smoke alarm configurations and placements in test houses and produced multiple graphs and tables. The data indicated the times it took for each smoke alarm to react to a control fire from a specific source based on a selection of variables including air temperature, fire type, and distance of the alarm from the fire. The final outcome was published in 1977 as the Indiana Dunes Tests and due to the thorough results, many local governments began instating smoke alarm laws *(Bukowski et al., 1977)*.

In 1974, the National Fire Protection Association (NFPA) published the first set of residential fire alarm standards in the United States, known as NFPA 74 *(Bukowski, 2001)*. The regulations proposed four levels of protection based on affordability, requiring at least a smoke alarm unit outside of every bedroom and at the top of the basement stairs. The concept was universally opposed by members of the fire community, as they felt that nothing less than complete protection (a smoke alarm unit in every room) was sufficient.

Chapter 3: Methodology

In order to complete this project, a series of objectives had to be met by the group. These were accomplished through the use of three specific methods of data collection and analysis. These methods consisted of distributing surveys to fire protection officials worldwide and compiling and analyzing the results of these surveys; interviewing fire protection officials regarding current technology; and conducting a literature review using multiple fire protection and academic databases. Each of these three methods is explained in further detail in sections 3.1 through 3.3.

The following is a list of objectives that were necessary for successful completion of this project as well as the methods that correspond to each objective in parenthesis:

- Create a summary of residential smoke alarm legislation in the specific countries, territories, provinces, or states listed in Appendix B (by compiling surveys sent to fire protection officials and a literature review).
- Develop a detailed list of the advantages and disadvantages for ionization, photoelectric, and combination smoke alarms (using interviews with fire protection experts and a literature review).
- Consider how socioeconomic factors, specifically affordability, cooking style, and heating fuel, could affect a homeowner's choice of either ionization or photoelectric smoke alarms (using compiled survey data, and a literature review).
- Determine which smoke alarm warning tones are most effective at waking young children, the elderly, the hearing impaired, and the alcohol impaired (using interviews with fire protection experts and a literature review).

The completion of the project objectives resulted in two deliverables. The first is a database of international smoke alarm legislation. The second is a literature summary of the group's findings. Figure 3 gives a visual representation of the methodology used.

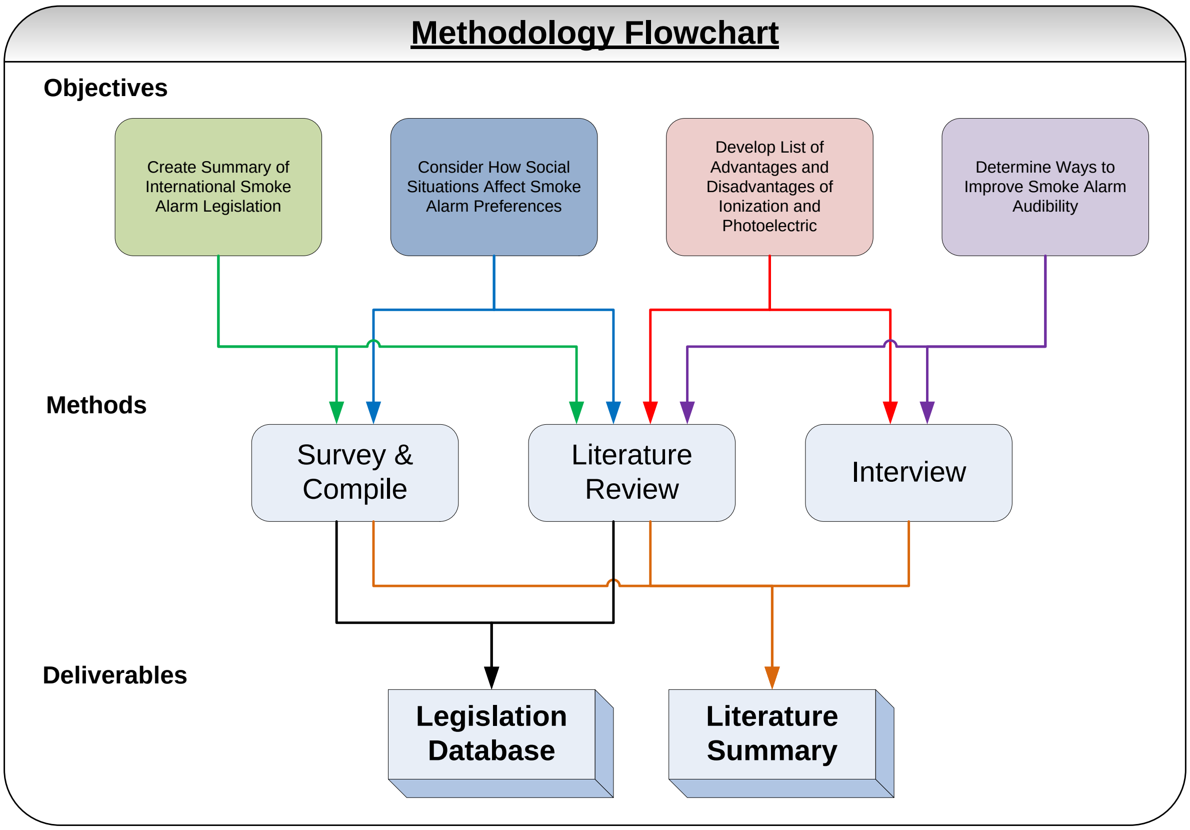

Figure 3: Methodology Flowchart

3.1 International Smoke Alarm Legislation Survey

To assure that the most current residential fire safety legislation data were utilized, it was necessary to obtain information through surveys that were sent to experts in the field from various locations around the world. The contact information for these experts was obtained through the Confederation of Fire Protection Associations International (CFPA-I) membership list for countries, fire marshal websites for U.S. states, the Council of Canadian Fire Marshals and Fire Commissioners (CCFM & FC) for Canadian provinces and territories, and the Australasian Fire and Emergency Services Authorities Council (AFAC) for the Australian states and territories. This strategy was chosen based on advice from the project sponsor.

Many studies have been conducted to determine the effectiveness of different methods of dispersing surveys which include mail (post), fax, and e-mail. One such study concluded that the greatest return would come from a survey sent by e-mail *(Cobanoglu, Warde, & Moreo, 2001)*. In their study, 100 surveys were sent out using each of the three methods. Of these 100, only 17 faxed and 26 mailed surveys were returned, while 42 e-mailed surveys were returned.

This study also measured the average number of days it took respondents to reply to each type of survey. It was found that the faxed surveys had the quickest return, averaging 4.0 days *(Cobanoglu et al., 2001)*. This means that if a survey is conducted by fax, a small number of people will respond quickly but if they do not respond immediately, they are unlikely to respond at all. The surveys conducted by mail took the longest to return at an average of 16.5 days; this would be expected as there is a great deal of travel time involved with this method. Respondents took slightly longer to return surveys by e-mail than by fax, at an average of 6.0 days. This statistic is somewhat misleading because even after the large influx of returned surveys by e-mail in the first few days, responses continued to come back several days after the faxes had ceased. At the end of each day during the study, more e-mail surveys had been collected overall than either of the other two returns.

Mail and fax surveys incur greater costs than e-mail surveys, especially in a case such as this project where data must be collected on an international level *(Cobanoglu et al., 2001)*. In addition, mail and fax surveys require more labor to implement. For these reasons, e-mail surveys have significant advantages over fax and mail surveys based on time and cost.

Another study analyzed whether or not sending out a letter before the survey is advantageous. It determined that response rates could be significantly increased by using this approach. The response rate of the surveys sent out with no initial notice was slightly over 20%. This number increased to approximately 30% when a notice was sent before the surveys *(Kaplowitz, Hadlock, & Levine, 2004)*. For this reason, an initial e-mail (Appendix C) with an attached letter (Appendix D) introducing our group and providing a brief explanation of the project was distributed to our contacts. Two days after sending the introductory e-mail, a second e-mail was sent that included the attached survey which was personalized for the specific location to which it was being sent. The e-mail that was sent with the initial survey can be seen in Appendix E. If a response was not received, a reminder was sent approximately two weeks later. Surveys were accepted over a period of six weeks and throughout this time, three follow-up e-mails had been sent if no response had been received. These follow-up e-mails are shown in Appendix F. Once surveys were returned, letters were sent to the respondents thanking them for their help; this letter is shown in Appendix G.

The survey consisted of fifteen questions regarding smoke alarm legislation, as seen in Appendix H. A large majority of these questions were open-ended. Open-ended questions allowed for the respondent to provide as much information as possible; however, these created a problem when compiling the final data and extracting necessary information. In order for the surveys to be useful, a sound method of compiling the data had to be established.

When survey results were received from the subjects, open-ended questions were analyzed for common themes. For example, a question along the lines of, “What are your smoke alarm legislative requirements for bedrooms?” is open-ended, but answers were similar from area to area. Although worded differently, results contained the same basic responses such as, "Smoke alarms must be located inside the bedroom," or "Smoke alarms are not required inside bedrooms but must be located directly outside the main doorway." Using this method, the subject was allowed to provide as much information as he or she felt was necessary and relevant data could easily be extracted. An example of a completed survey can be seen in Appendix I.

A database was constructed using the information obtained from the survey data and includes the responding location's name and answers to the survey questions. The surveys are not included as part of the report due to privacy reasons and restrictions from the Institutional Review Board form signed by the group; they will be held by FPA Australia for future reference. The database also includes information regarding the region's population, demographics, population density, and average income. This information was useful in providing possible links between smoke alarm legislation and socioeconomic factors.

Originally it was hoped that the database could be web based, but that was not possible due to intellectual property restrictions. Microsoft Access was also considered as a possible option; however, this application is not readily accessible to many people and is not commonly used. The next option considered was creating a spreadsheet in Microsoft Excel. This would have been a viable option but it was not capable of providing the desired user interface. It was then decided that the database would be created using Adobe Dreamweaver, a web development application that enables construction of the database using local HTML files. This allows for the most flexibility in design and ease of use. It also makes the database readily accessible since it can be viewed through any web browser. An example of a database page derived from the survey in Appendix I can be seen in Appendix J.

A skewed result was possible based on the number and distribution of countries that responded to the surveys. In order to make sure that the final analysis was valid, information was organized based on demographic information. For example, the survey results from thirty U.S. states could not be compared to results from two countries. Also, the data had to come from countries with a wide variety of per capita gross domestic products (GDP). Doing so ensured a representative distribution of data and enabled comparisons between locations with similar socioeconomic factors in order to identify common trends in smoke alarm legislation. Full analysis of the data is beyond the scope of the project; however, the data need to be organized and presented in a comprehensive way so that they can be analyzed with ease.

3.2 Interviews with Subject Matter Experts

Interviews with experts in the field of fire protection and fire safety were primary sources of information that were relied upon heavily throughout this project. These experts were identified by way of referrals from the project sponsor and from initial interviewees. This technique is known as snowball sampling *(Berg, 2007)*. A spreadsheet was used to keep track of all contacts and to sort through those which were most relevant based on their area of expertise.

One problem encountered was the large number of contacts acquired from interviewees, even in the early stages of the project. The most important contacts to interview had to be identified and contacted as soon as possible, as time constraints limited the number of interviews that could be realistically conducted. These contacts were identified with the help of people who were familiar with the names in the database, and could distinguish between those who would be useful and relevant to the project, and those who would not. Fire protection engineering consultant Jonathan Barnett and project liaison Robert Llewellyn were particularly helpful in this matter.

The interviews were conducted in person and were mostly unstructured and conversational in nature. Particular questions could not always be prepared ahead of time; the interviewee's specific area of expertise was often unknown. In this case, it was most effective to provide the interviewee with a brief description of the project and a few general questions, then allow him or her to steer the conversation toward his or her area of expertise.

The topics of discussion were not of a personal nature, so ethical concerns were minimal. The preferred method of gathering information during the interview was to use a voice recorder, so verbal permission to record the conversation had to be documented prior to the start of the interview. Several interviewees also requested permission to read the final report before publication; all such requests were respected.

The information gathered during interviews was very useful in dealing with the controversy over photoelectric vs. ionization type detectors. Expert opinions are valuable, and often provide information that cannot be obtained through a traditional literature review. However, experts differ in their interpretations of data and observations and their opinions were examined carefully to minimize bias in the final report.

3.3 Literature Review

The remainder of the information necessary to meet the project goals was obtained by conducting a literature review. The topics that were covered included smoke alarm types, warning tones, and socioeconomic information about the countries surveyed. The majority of the information came from scientific journals and past studies obtained through online databases.

Databases included in the literature review were found through NIST and NFPA. Since the databases are affiliated with these organizations, they are relevant and reliable as sources for the project. While some texts were referenced, many of them are dated and therefore, do not account for recent technical advancements. For example, the Indiana Dunes Tests performed in 1977 were groundbreaking for the field of fire protection and could not be omitted *(Bukowski et al., 1977)*. However, fire technology has advanced significantly since then and the study's conclusions may not be relevant. The databases are current and include papers and articles from within the last few years as well as older documents for reference.

Chapter 4: Smoke Alarm Technology

There are two main parts to any smoke alarm, the smoke sensor and the alarm sounding device. There are two main type of detectors, ionization and photoelectric, that sense different characteristics of a fire. After one of the detectors recognizes a fire, a signal is sent to the alarm component which is expected to alert any one present of a dangerous situation. If both components work properly, all residents should be warned early enough to escape and loss of life or injury should be minimized or avoided. However, there are still fatalities due to fire implying that there are still improvements to be made. This chapter will go into details about smoke alarm technology including ionization detectors, photoelectric detectors, and the effectiveness of warning tones.

4.1 Smoke Detection Technology

The subject of smoke detector types (ionization vs. photoelectric) has been controversial for the past few decades. In recent months, it has become even more politically charged. While ionization units have met the requirements for smoke alarm sensitivity, are readily available, and are more affordable than photoelectric units, numerous fire protection officials feel that photoelectric units are more effective, and are urging legislators to enact laws requiring photoelectric smoke alarms.

Many fire protection experts believe that ionization alarms are an insufficient form of protection. Some argue that current smoke alarms have not been tested thoroughly enough to substantiate the claim that they are effective *(Ian Thomas Interview, Appendix K)*. Many feel so strongly about this issue that they are willing to go to great lengths to make their message clear.

Adrian Butler, head of the World Fire Safety Foundation, released a televised documentary in 2004 that aired in New Zealand, called "Stop the Children Burning" *(World Fire Safety Foundation, 2004)*. While his methods can be seen as extreme and sensationalist, there is some foundation to his claims that photoelectric detectors use more effective technology. He claims that ionization units are dangerous because they provide a false sense of security to homeowners, and that nothing less than complete protection is acceptable. In his documentary, Butler explains his position:

> There is one issue that really makes my blood boil, and that's when people make statements like "one or two smoke alarms are better than none at all." While this may sound reasonable, this kind of thinking totally lacks integrity and has resulted in thousands of fire deaths worldwide. Let me explain. A family is driving along in a car, mom and dad are in the front, the three children are in the back, and a policeman pulls the car over. He notices only one person has a seatbelt on. What would you think if the policeman said "hey that's okay, one seatbelt is better than none."

Clearly, smoke alarms cannot be compared to seatbelts. One properly placed smoke alarm will provide equal protection to everyone in a household. If only one passenger in a car wears a seatbelt, they are not providing equal protection to the rest of the passengers. This is the type of argument used throughout much of the documentary – emotions rather than facts are relied upon heavily in order to strengthen Butler's position.

Joseph Fleming, Deputy Fire Chief in Boston, Massachusetts, USA, is also of the belief that ionization alarms are grossly insufficient for applications in residential settings. In the last few decades, Fleming has become very knowledgeable on the subject of smoke alarms and is one of the most outspoken supporters of photoelectric alarms. His interest in smoke alarms began in the 1990s when he noticed that numerous fire fatalities occurred in homes where the smoke alarm was disabled specifically because of excess nuisance alarms *(Fleming, 2005)*. What began as in investigation of ways to reduce nuisance alarms continued into a crusade against ionization alarms. In a report published by the World Fire Safety Foundation in 2007, Fleming has been quoted as follows:

> I have often been cautioned that I should be quiet, "because we do not want the public to lose faith in smoke detectors." This statement implies that lives will be lost if we tell the American public the truth. I think the exact opposite is true … how many lives have been lost because the American public was not told the truth.

While it is important to educate the public about fire safety, it is also important to consider how that information is delivered so as not to discourage them from listening.

Naomi Brown is the Chief Executive Officer of AFAC and is also of the opinion that photoelectric detectors are better technology than ionization *(Naomi Brown Interview, Appendix L)*. In her interview, she stated that "the people who know a bit about it and have done their reading would pretty well come down on photoelectric." Thus the difficult task seems to be to convince governing bodies to move from requiring smoke alarms to requiring photoelectric smoke alarms. In Australia's case, that body is the Australian Building Code Board (ABCB), which creates and maintains the Building Code of Australia. The ABCB is currently doing more research on the effectiveness of the different technologies.

AFAC commissioned the Bushfire Cooperative Research Centre to do some of their own research *(Naomi Brown Interview, Appendix L)*. Some of those findings included the following:

> The literature review suggested that ionization alarms do not provide adequate egress time for smoldering fire in all circumstances. Photoelectric smoke alarms are better at detecting shouldering fires while still providing adequate egress time for flaming fires, and hence should be the preferred type recommended. Photoelectric smoke alarms provide better overall smoke detection performance than ionization smoke alarms.

These findings were used to inform the AFAC position statement.

Data have been collected by numerous national organizations concerning fire losses and damages throughout the world. A great deal of information is readily available for public use; however, it has its limitations with respect to this report. The data are often to general to be applied to arguments such as ionization versus photoelectric or flaming versus smoldering. An

NFPA report in the U.S. found one or more smoke alarms present in 96% of homes; it does not, however, record the types of these alarms *(Ahrens, 2007)*. This same report showed that smoke alarms were present but failed to operate in 22% of residential fire deaths. In 2002, Canada reported 53,589 fires with 304 fire deaths *(Council of Canadian Fire Marshals and Fire Commissioners, 2002)*. These numbers have not been classified by type of fire or cause of death. This lack of details makes it difficult to examine the effectiveness of each detector type and approach the debate in a scientific manner.

4.1.1 Shortcomings of Fire Data and Statistics

In the 1983 edition of United Kingdom Fire Statistics, fires were categorized into those that were discovered within five minutes of ignition and those that were discovered after 30 minutes *(Home Office, 1983)*. According to their data, there were 23,082 fires with four fatalities due to fires discovered in the first few minutes. There were only 5,870 fires discovered after 30 minutes however there were 20 fatalities. The study does not categorize the fires as smoldering, flaming, or transitioning; however, it is possible to conclude that the latter category (fires discovered after 30 minutes) consists of primarily smoldering fires since it is unlikely that a flaming fire will go unnoticed for such a long time.

A more recent publication from the UK recorded cause of death over the last 10 years (Figure 4) *(Communities and Local Government, 2008)*. Again, the data are not divided with respect to smoldering and flaming fires. Also, it is unclear how the distinction was made between deaths by a combination of burns and smoke and deaths by burns alone. It is possible that an occupant became incapacitated from smoke before the flames reached him or her. It is also possible that the occupant may have been disoriented by the smoke, making him or her unable to escape; this is more likely, but cannot be assumed. It is clear, however, that the overwhelming percentage of total deaths (40%) occurred due to smoke and gas alone. These data suggest that smoldering fires are in fact more deadly.

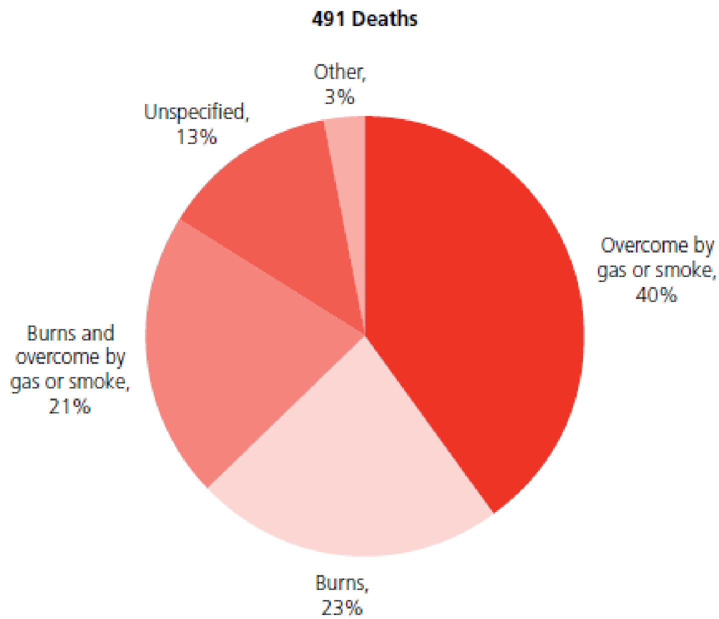

Figure 4: Causes of Fire Deaths in the United Kingdom *(Communities and Local Government, 2008)*

4.1.2 Response Times of Ionization and Photoelectric Detectors

During the tests discussed in NIST Technical Note 1455-1, the time from ignition to first alarm was recorded for each of 32 tests of different types of fires and alarms *(Bukowski et al., 2007)*. A summary of the results is shown in Table 1. On average, photoelectric alarms responded 30 min before ionization alarms for smoldering fires and less than one minute later for flaming fires. Also included in the table are columns for "Time to Untenable Conditions" and "Available Safe Egress Time" or ASET. Time to untenable conditions was measured from the start of the fire to when surroundings became unsafe. "Unsafe" is a subjective term that includes levels of poisonous gas, heat, and smoke obscuration in various locations. In this case, these levels were measured outside the room of origin at a height of five feet (1.5 m). The test does not specify whether the door between the fire and the detector was open or closed, which can greatly affect the results. Available safe egress time is the time between the first alarm and time to untenable conditions. The NIST study has been criticized for flaws in its test procedure and conclusions; however, the data still support three general statements agreed on by most fire officials: photoelectric units respond earlier for smoldering fires, ionization units respond earlier for flaming fires, and flaming fires cause untenable conditions faster than smoldering fires.

Table 1: Summary of Alarm Activation Times for Smoldering, Flaming, and Cooking Fires *(National Institute of Standards and Technology, 2008)*

Type of Fire	Time to First Alarm (in seconds)		Time to Untenable Conditions (in seconds)	Available Safe Egress Time (in seconds)	
	Photoelectric	Ionization		Photoelectric	Ionization
Smoldering Fires	2219 ± 1061	4010 ± 1120	4316 ± 1256	2136 ± 1011	276 ± 331
Flaming Fires	94 ± 33	47 ± 36	217 ± 67	129 ± 74	177 ± 69
Cooking Fires	738 ± 103	681 ± 475	1477 ± 249	739 ± 148	796 ± 241

Another study attempted to confirm the NIST conclusions. Oysten Meland and Lars Lonuik placed ionization and photoelectric units side by side and tested their response times to smoldering and flaming fires *(Lonuik & Meland, 1991)*. The study also controlled for location of the detector with respect to the fire by placing another set of detectors in the room next to the fire. This resulted in four tested fire scenarios: a flaming fire with the alarm in the room of ignition, a smoldering fire with the alarm in the room of ignition, a flaming fire with the alarm outside the room of ignition, and a smoldering fire with the alarm outside the room of ignition. Their results are summarized in Table 2.

Table 2: Summary of Alarm Activation Times by Alarm Location *(Lonuik & Meland, 1991)*

Detector Location	Smoldering Fire Response (In seconds)		Flaming Fire Response (In seconds)	
	Photoelectric	Ionization	Photoelectric	Ionization
In Room	2,500 – 3,000	5,000 – 5,500	60 – 100	30 – 60
Out of Room	7,000 – 8,000	N/A*	170 – 210	220 – 240

***Unit did not sound.**

In three out of the four possible fire scenarios, the photoelectric detector responded first *(Lonuik & Meland, 1991)*. In the situation where the ionization was faster (a flaming fire with the alarm in the room of ignition), it is possible to argue against the need for an alarm at all. Most flaming fires involve an open flame, which typically require human interaction. As such, any unit, regardless of type, would be superfluous at warning residents of a fire because they would already be aware of it.

The study also recorded when the critical limits for gases (CO and smoke visibility) were reached for the smoldering fire tests *(Lonuik & Meland, 1991)*. High concentrations of CO can cause unconsciousness and can potentially be fatal within 1-2 minutes in today's typical home with modern furnishings *(Craythorn, 2009)*. Smoldering fires can also produce toxic hydrogen cyanide and hydrogen chloride, which is a byproduct of the chemical composition change due to a fires effect on synthetic materials. These byproducts appeared between 5,000 (about 83 minutes) and 6,000 (100 minutes) seconds after ignition. Ionization units allow at most 1,000 seconds (about 17 minutes) of ASET when installed in the room of origin for smoldering fires

(Lonuik & Meland, 1991). The 30 minute delay between the responses of ionization and photoelectric units could arguably be enough to disorient the occupant (a side effect of exposure to smoke), lowering his or her chances of escape. Both units sounded after critical limits had been reached when out of the room of origin. No time was recorded for the ionization unit meaning that it did not go off before researchers concluded the test.

4.1.3 Combination Smoke Alarms

It is very difficult to predict when and where a fire will occur and there is little information available on how many fire fatalities are due to smoldering fires, flaming fires, or a combination of both *(Ed Comeau Interview, Appendix A)*. Combination units are commercially available that use both ionization and photoelectric principles. They offer full protection as they eliminate the need to guess the type of fire a resident is likely to have in a given location.

However, combination units also have their drawbacks. Detectors can be combined using either an "AND" gate or an "OR" gate *(Ian Thomas Interview, Appendix L)*. An OR gate will sound an alarm if the unit receives a signal from either one of the detectors. This means that the unit will sound at the earliest possible time, but also that the unit is susceptible to the most nuisance alarms due to the cumulative weaknesses of each detector. A unit designed with an AND gate will not sound until it receives a signal from both detectors. This lessens the chance of nuisance alarms but also means that the unit will not sound until the latest possible time. Manufacturers can adjust the sensitivity of each sensor independently, unknown to the consumer. This is usually done to desensitize the ionization detector, making the unit less prone to nuisance alarms, and in turn less likely to be deactivated by the consumer. However, this defeats the purpose of having both types of alarms in one unit.

4.1.4 Nuisance Alarms in Ionization and Photoelectric Smoke Alarms

A study conducted in Texas in the U.S. investigated the occurrence of nuisance alarms in residential settings *(Moore, 1980)*. Nuisance alarms may lead consumers to disable their alarms out of frustration, leaving them with no protection. In the study, alarms of both types were placed side by side and false alarms were recorded with respect to the type of detector and cause for the alarm. Out of 126 recorded nuisance alarms during the time frame, 115 were from ionization type alarms. Another study conducted by Beth Mueller also reported more nuisance alarms from ionization type units *(Alter, Grossman, Mueller, Perkins, & Sidman, 2008)*. Either an ionization alarm or a photoelectric alarm was installed approximately 3.50 m from the kitchen stove in 761 homes. When researchers returned (9 months after installation), 20% of ionization units were non-functional compared to 5% of photoelectric units. The causes of nuisance alarms, as reported by the occupants 15 months after installation, are summarized in Table 3.

Table 3: Summary of Causes for Nuisance Alarm *(Alter et al., 2008)*

Cause for Alarm	**Percent of Nuisance Alarms**	
	Ionization Alarm	Photoelectric Alarm
Cooking	93%	74%
Low battery	5%	22%
Fireplaces	2%	2%
Steam	1%	2%
Smoking	0%	1%
Incense	<1%	0%
Candles	1%	1%
Construction	<1%	2%
Heat from lights	2%	0%
	May not add to 100% due to rounding.	

4.1.5 Technological Comparisons of Ionization and Photoelectric Detectors

The difference in response for ionization and photoelectric detectors is a consequence of their differing technologies. Ionization detectors sense smaller particles of combustion, while photoelectric detectors respond to larger, visible smoke particles. Both kinds of particles are produced at different stages of a fire. For this reason each type of detector is better suited for specific fire situations. As time passes, smoke particles combine in a process referred to as smoke aging or smoke conglomeration, which occurs closer to the ignition source in the case of smoldering fires *(Cable & Sherman, 1986)*. For a given volume, it can be safely assumed that there is a constant mass of smoke. A larger average particle radius would imply a lower number of individual smoke particles *(Burry, 1982)*. Fewer particles enter the chamber, fewer ions are neutralized, and the ionization detector becomes less sensitive. Basically, the longer it takes smoke to reach the detector, the less sensitive the detector becomes. This is why ionization units outside of the room of origin report longer activation times and why distance from the fire should be considered *(Lonuik & Meland, 1991)*.

Figure 5 shows sensitivity of three types of smoke detectors as a function of particle size in microns *(Bukowski, 1979)*. "A" represents a photoelectric unit and "C" represents an ionization unit. ("B" represents a projected beam unit that is not discussed in this report. It is not common for residential structures but is shown in this graph for reference.) The sensitivity of ionization detectors drops (over this range) as the size of the smoke particles increases. Note that ionization units are less responsive to larger particles than photoelectric units but more responsive to smaller particles

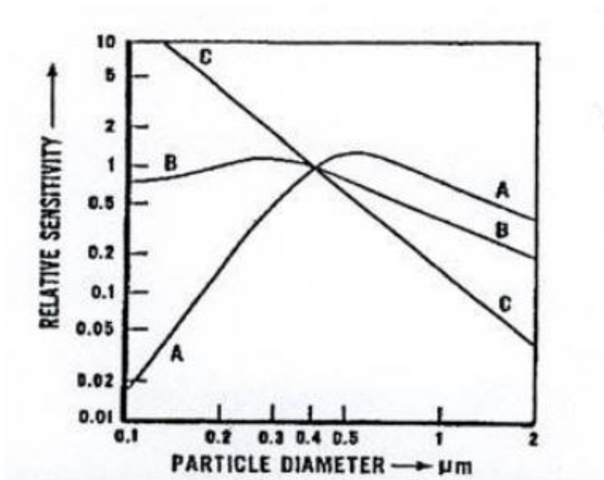

Figure 5: Relative Sensitivities of Detector Technologies vs. Particle Size *(Bukowski, 1979)*

Photoelectric detectors work by refracting light inside the chamber towards a photoreceptor as shown in Figure 2. Particles less that 0.1 μm in diameter are essentially invisible and do not interfere with the path of light *(Fleming, 2005)*. Photoelectric detectors cannot sense invisible smoke or any object that does not refract light. This includes black smoke which absorbs, rather than refracts, light. Figure 6 illustrates the sensitivity of smoke alarms with respect to color of the smoke *(Bertschinger, 1988)*. The color is an indication of the material that is burning as well as the size and concentration of smoke particulates in a given volume. The graph shows that ionization detectors respond before photoelectric detectors to invisible particles but also that both detector types are less sensitive to dark smoke. The responsiveness of photoelectric units spike as smoke becomes visible.

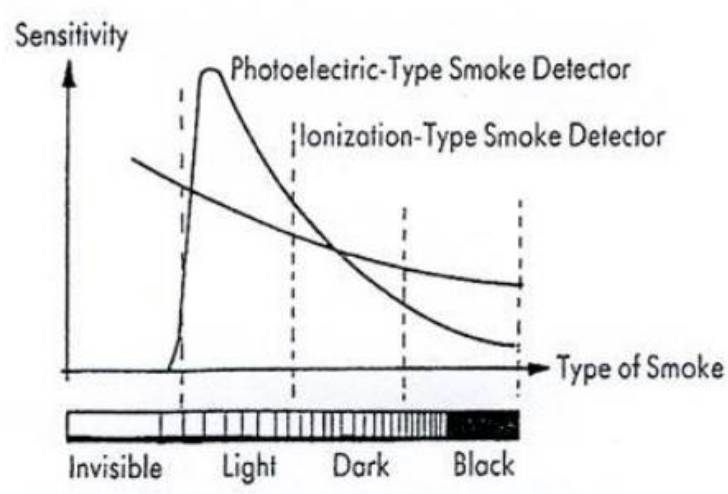

Figure 6: Response Sensitivity of Detectors vs. Smoke Color *(Bertschinger, 1988)*

4.1.6 Considerations for Choosing the Most Effective Smoke Alarm

Fire officials and legislators must consider their end goal when determining which type of smoke alarm is most appropriate for the widest range of fire situations. If the goal is to detect the greatest number of fires, then the most prominent type of fire (smoldering or flaming) must be statistically determined. This is difficult to do, since a fire may transition from smoldering to flaming over the course of combustion. Data from the time of ignition are often difficult to obtain since the firefighters (those who record fire data) are typically not present until the fire is noticed and reported, assuming it is reported at all.

If the goal is to reduce injuries and loss of life, data are needed that shows the percentage of fire deaths and injuries that are caused by each type of fire. These are not always easy to determine, since a death that appears to be due to severe burns (indicating a flaming fire) may have been caused by smoke inhalation (indicating a smoldering fire) prior to the flames reaching the occupant. Studies like those mentioned in United Kingdom Fire Statistics in 1983 *(Home Office, 1983)* and in Summary of Fire Statistics 2006 *(Communities and Local Government, 2008)*, along with similar records from other countries, would be beneficial to the fire community in this regard. If the goal is to increase the available evacuation time overall, then photoelectric alarms are more effective since, on average, the time they save when detecting smoldering fires is much greater than the time lost when detecting flaming fires.

Ionization alarms are better suited to provide earlier warning in the case of a flaming fire. Flaming fires spread quickly and are arguably more dangerous because they allow less time to escape before surroundings become untenable. It is possible for occupants to survive in smoldering conditions for an extended period of time, but a few seconds in a flaming fire could prove fatal. Flaming fires tend to occur when the residents are "aware" and directly involved with ignition; for example, while cooking or if a candle is accidentally knocked over *(Ed Comeau Interview, Appendix A)*. In this case, the occupant may be able to respond appropriately before any alarm sounds or before conditions become untenable. Smoldering fires are likely to occur while occupants are asleep and go unnoticed for an extended period of time; for example, if a cigarette ember is dropped in a sofa, it can smolder for hours before becoming dangerous.

4.1.7 Recommendations of National Fire Authorities

Smoke alarm systems need to be implemented appropriately in order for them to be effective. Installing units incorrectly or inadequately could limit their ability to sufficiently warn occupants of a fire. Figure 7 from the NFPA 101 Life Safety Code Handbook illustrates an example of misused units *(Coté & Harrington, 2009)*. Installing the units too close to walls and overhangs allows for smoke to collect significantly before detection. Having too few units is unsafe because a fire in one room may not activate an alarm further away from the room of ignition until conditions are already unsafe in the room of origin. NFPA recommends that all units have two independent power sources to ensure fire protection in the event that one of the sources is unavailable. All the arguments regarding reasons for interconnection and dual power supplies (Section 2.1.3) still apply.

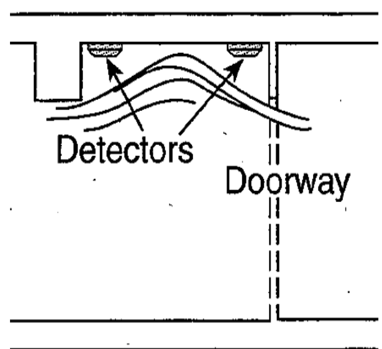

Figure 7: Example of Misplaced Smoke Alarm *(Coté & Harrington, 2009)*

NFPA 74, Standard for the Installation, Maintenance, and Use of Household Fire Warning Equipment, proposed different levels of protection for homes *(Bukowski, 2001)*. The minimum recommendation called for a unit outside each group of bedrooms and at the top of the basement stairs (or an entrance from a garage). The next level added a unit in the living room. The third level added units in every bedroom. The final level of protection recommended a unit in every room of the house. Some fire officials believed that nothing less than the best protection was sufficient, however requiring a smoke alarm in every room would not be economical and a compromise had to be reached.

Current standards in the United States for placement, installation, and power supplies are given in NFPA 72 National Fire Alarm Code *(Technical Committees on Fundamentals of Fire Alarm Systems, 2007).* The first edition combined information from previous releases of NFPA 74 and other NFPA documents. The NFPA only provides recommendations; it is up to the governing body to decide whether or not they should adopt legislation based on its recommendations. For residential areas, NFPA 72 recommends smoke alarms "in all sleeping rooms and guest rooms; outside of each separate sleeping area within 6.4 m of any door to a sleeping room, and on every level of a dwelling unit". The code also recommends all units to be within 9.1 m of each other (travel distance) or one unit per 46.5 m^2 of floor space. NFPA 72 does not distinguish between detector types in its codes; however, NFPA's official stance is that both detector types should be used in order to ensure complete protection *(National Fire Protection Association, 2009)*. It only recommends that a photoelectric unit or and ionization unit with a "hush feature" be used if the alarm is located within 6.10 meters of any appliance used for cooking. (A hush feature temporarily disables an alarm.)

Figure 8 represents possible unit configurations based on NIST recommendations *(National Institute of Standards and Technology, 1995)*. All units should be interconnected and have two independent power supplies, usually hard-wired with a battery back-up capable of maintaining the system for a given amount of time.

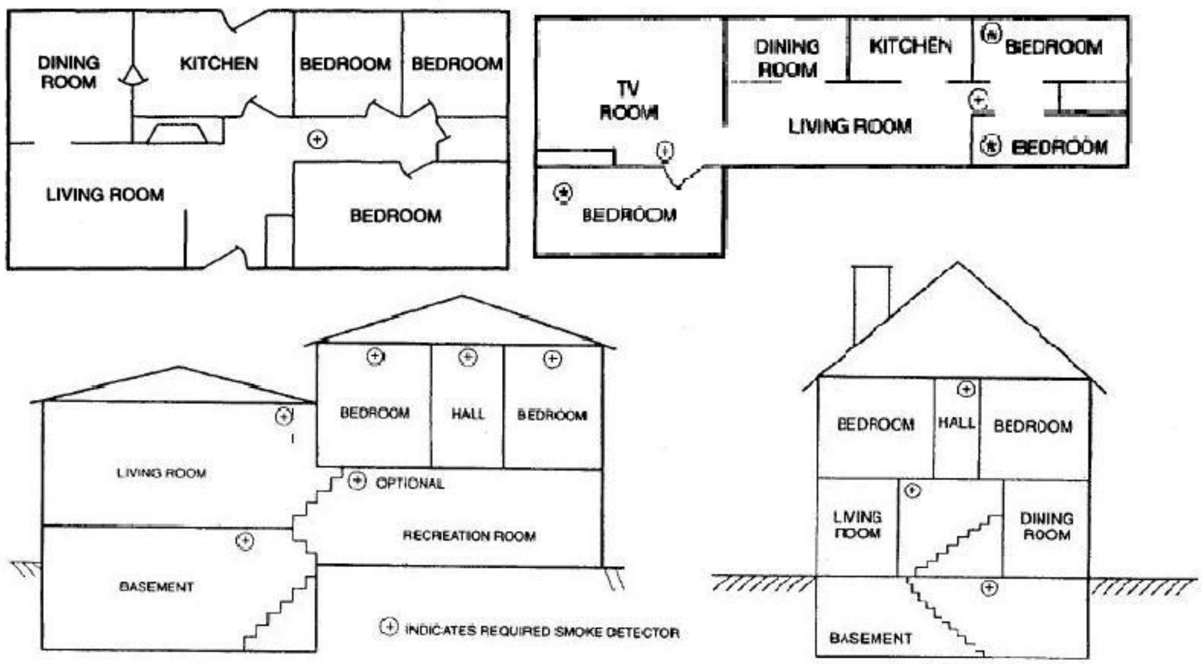

Figure 8: Possible Configurations for Residential Smoke Alarms *(National Institute of Standards and Technology, 1995)*

AFAC's official position on residential smoke alarms is similar to that of NFPA *(Australasian Fire Authorities Council, 2006)*. All smoke alarm units should be interconnected and have two power supplies: a permanent source (hard-wired or a non-removable long-life battery) and a battery back-up. Units should be located in all sleeping areas and all paths of travel between sleeping areas, exits, and floors. In addition, the units should not be placed where temperature control devices may interfere with performance (for example, smoke may never reach a unit placed behind a ceiling fan) and, if possible, away from kitchens and bathrooms. AFAC cites kitchens and bathrooms as sources for nuisance alarms. It also notes that nuisance alarms are the primary reason for disabled smoke alarms and that photoelectric units are less prone to be triggered by cooking fumes.

AFAC differs from NFPA in that they specifically recommend photoelectric units as the primary means of smoke detection *(Australasian Fire Authorities Council, 2006)*. It does, however, allow ionization units to be used to supplement the photoelectric alarms to ensure complete protection. The Council also reports that combination alarms are acceptable, but warns that they are more prone to nuisance alarms and only provide marginal benefits. AFAC's rational is that photoelectric units are "generally more effective than ionization alarms across the broader range of fire experienced in homes" and that ionization units "may not operate in time to alert occupants early enough to escape from smoldering fires." The goal of organizations such as AFAC is to combine maximum protection with minimum costs; however, as more research is done it has become clear that compromises need to be made.

4.1.8 Conclusion

To provide earliest warning for all fires regardless of type, combination detectors (of the OR gate principle) are, ideally speaking, most effective. This assumes that they are fully operational, and do not have reduced or otherwise altered sensitivities *(Ed Comeau Interview, Appendix A)*. It must also be noted that, due to the frequency of nuisance alarms from current ionization technologies, combination detectors are likely to be disabled by a consumer, rendering them useless to warn occupants of any fire.

For residential settings, photoelectric smoke alarms are more likely to provide early warning in a fire situation. While it is impossible to predict a fire, they perform better than ionization alarms in three out of four potential fire scenarios (Table 2). Those three scenarios are arguably more likely to occur when a resident would need to be alerted to a fire. They also reduce the occurrence of nuisance alarms, the most common reason for disabled detectors. Ionization alarms do not always respond early enough for smoldering fires, and when they do respond, occupants may already have inhaled large amounts of smoke or paths of egress may be blocked. Consumers may be uncomfortable with radioactive material in their homes, even in very small amounts, which are present in ionization units. Both alarms lose sensitivity to black smoke; however, an occupant should ideally be alerted before this stage of a fire. Table 4 summarizes our findings with respect to the difference smoke alarm technologies.

Table 4: Advantages and Disadvantages of Ionization, Photoelectric, and Combination Smoke Alarms

	Advantages	**Disadvantages**
Ionization	Detects small invisible particles (0.01 µm – 3 µm) Usually cheaper to purchase and manufacture Respond faster to flaming fires when in the room of origin	Respond slower to fires outside the room of origin due to smoke aging Contain radioactive elements (which do not pose a strong health risk) More frequent nuisance alarms from steam and cooking fumes May not provide enough warning for smoldering fires
Photoelectric	Detects larger particles (0.3 µm – 10 µm) Respond faster to smoldering fires Respond faster to flaming fires outside the room of origin	Usually more expensive (than ionization) to purchase and manufacture Sensitive to dust
Combination	OR gates respond quickly Respond to both types of fire	Usually most expensive to purchase and manufacture OR gates have more frequent nuisance alarms AND gates respond slowly Sensitivities can be altered independently by manufacturers Contain radioactive elements

4.2 Smoke Alarm Warning Tones

Studies show that being asleep significantly increases the risk for residential fire death *(Bruck & Ball, 2007)*. Anywhere from 46% to 86% of fire victims were sleeping at the onset of the fire. Even though most fires occur during the day, the death rate from fires that occur between 1:00 AM and 7:00 AM is up to three times greater. Thus, it is critically important that smoke alarms emit tones that are most effective at awakening sleeping occupants, even in the deepest stages of sleep.

Most adults with normal hearing will awake to the sound of a standard smoke alarm without a problem. In fact, studies have shown that many will be aroused even without the sounding smoke alarm *(Bruck & Brennan, 2001)*. Sensory cues that are often associated with the presence of fire, such as crackling and shuffling sounds, flickering lights, and smoke odor, are often enough to wake most adults without the intervention of a smoke alarm. In an early test conducted by Dorothy Bruck of Victoria University, 33 subjects between the ages of 25 and 55 were tested using the auditory and visual cues, and it was found that 91% and 83% awoke to the cracking and shuffling sounds, respectively. Forty-nine percent awoke to the flickering light. In another test performed in a sleep laboratory on 17 subjects, it was found that 59% successfully awoke to the smoke odor.

Tests conducted in the early 1980s by Nober et al. *(Nober, Peirce, & Well, 1983)* also suggest that the standard smoke alarm warning tone is sufficient to successfully awaken sleeping adults without hearing impairments. They investigated responses to standard signals in college-age adults. The main findings of this study concluded that the subjects had no problem waking to the standard signal, and that reaction time decreased as alarm volume increased and background noise decreased. While these data are reassuring for a large proportion of the general population, there are significant high-risk groups that do not respond nearly as well, even in the presence of a standard smoke alarm.

Most audible residential smoke alarms have warning tones with peak signal energy in the region of 4000 Hz *(Huey et al., 1996)*. The Underwriters Laboratory has set a standard (UL 217) for warning tone intensity, which states that the signal must be at a level of 85 decibels (dB) three meters from the source. There is no set standard for warning tone frequency, but most alarms emit similar high-frequency sounds for purely physical reasons. This fact creates a technological barrier to progress in the area, even though studies indicate that lower frequency warning tones would be more effective.

While residential fire codes generally do not specify a standard frequency for smoke alarm warning tones, the International Standards Organization (ISO) defines the T-3 (temporal-3) pattern as the standard tone pattern to signal the necessity of immediate evacuation *(Bruck, Thomas, & Kritikos, 2006)*. The temporal-3 pattern turns the signal on and off in the following pattern: on (0.5 s), off (0.5 s), on (0.5 s), off (0.5 s), on (0.5 s), off (1.5 s). Smoke alarms using the temporal-3 pattern are now being sold in many countries, including the U.S. and Australia. It is believed that using this pattern will increase the recognition that the signal means immediate evacuation is necessary.

High-frequency warning tones have both advantages and disadvantages. They are easily differentiated from other sounds common in the average person's everyday environment *(Bruck & Ball, 2007)*. Thus, they serve as a good signal for an urgent emergency situation. However, high-frequency sounds are significantly attenuated by structures such as walls and doors that lie in the path of the signal. For this reason, many countries (such as Australia, the U.S., and the U.K.) have regulations that specify a threshold "at the pillow" of 75 dB. Studies have shown that there is a 12 dB loss in signal intensity from a hallway to a room with the door open, and a 27 dB loss with the door closed. These are certainly not negligible losses. It has been shown that the signal propagation and transmission characteristics are much more favorable for lower frequency signals in the range of 500 Hz.

There are alternative smoke alarms for those who are significantly hearing impaired such that they will not be able to hear any type of audible smoke alarm. These include vibrating bed shakers, pillow shakers, and flashing strobe lights. The effectiveness of these devices is also discussed in this section.

Many studies have been conducted over the past several years that examine the effectiveness of different smoke alarm signals for different population subgroups. At the forefront of this work are researchers at Victoria University. They have published several papers investigating the responsiveness to smoke alarm sounds in children, older adults, those who are hearing impaired, and even those who are under the influence of alcohol. Their work, as well as those of various other studies (which largely corroborate their findings), are summarized in the sections below.

4.2.1 Effectiveness of Warning Tones for Young Children

The first study to investigate the effectiveness of the current standard smoke alarm signal was conducted in 1999 at Victoria University by Bruck. It was necessitated by the results of a study conducted on young adults (ages 18-24) in 1995 *(Bruck & Horasan, 1995)*. While previous studies *(Nober et al., 1983)* had shown that typical adults usually do not have a problem awakening to the standard smoke alarm warning tone, Bruck's 1995 study on young adults found that 20% of the participants did not awaken to a 60 dB, high frequency signal *(Bruck & Horasan,* *1995).* This suggested that younger age groups may have more difficulty awakening to the standard warning tone than was previously thought.

According to Bruck, an increasing number of newly constructed homes are being built with children's bedrooms farther away from the master bedroom, making the issue of smoke alarm audibility even more pressing *(Bruck & Horasan, 1995).* Since most homes only have smoke alarm units in the hallways and not in the bedrooms themselves, the situation becomes especially dangerous should a fire break out between the master bedroom and the children's bedrooms.

Twenty children (ages 6-17) participated in the 1999 study *(Bruck, 1999)*. Subjects were fitted with an actigraph, a device worn on the wrist that monitors movement to determine the wake/sleep status of the subject. Each test was conducted in the subject's own home. The alarm was positioned such that the sound level at the pillow was around 60 dB. The report does not provide specifics on the signal being tested with regards to the frequency or pattern; it is only implied that it is a standard high-frequency smoke alarm warning tone. Seventeen of the 20 children slept through the alarm during one or both tests. The parents of the children were also tested; they had no problem awakening to the alarm. This study was very basic and did not take the type of warning tone into consideration, but it was important in identifying the problem and provided a baseline and an impetus for future research in the field.

In 2004, Bruck et al. released another report on child subjects (ages 6-10), this time taking signal type into consideration *(Bruck, Reid, Kouzma, & Ball, 2004)*. Four different warning tones were tested across three different studies: the child's mother's voice, a female actor's voice, a mixed-pitch T-3 signal, and a standard smoke alarm signal. The mixed-pitch T-3 signal is used by Bruck often, and is a complex signal that contains many frequencies but has a fundamental frequency centered around 520 Hz. These studies also used actigraphy as a means of measuring wakefulness.

The results of this study *(Bruck et al., 2004)* were definitive, with the voice alarms and the mixed-pitched T-3 alarm proving to be much more reliable at awakening young children than the standard smoke alarm tone. Both voice alarms were designed to convey a sense of urgency and emotion; the mother's voice used the child's name often and the actor's voice used the words "danger" and "fire" repeatedly. All of the children awoke to the sound of the mother's voice. The response to the actor's voice was almost as effective, as all but one child (94.4%) awoke to it. The same was true for the mixed-pitched T-3 alarm (96.4% awoke); however, only 16 children (57.1%) awoke to the standard warning tone. Note that the above percentages vary due to differing sample sizes across the studies. Bruck's data from the 2007 study can be seen in more detail in Table 5.

Table 5: Number of Children Who Awakened by Time Period and Signal Type *(Bruck & Ball, 2007)*

	0-30 s	31-60 s	60-180 s	Did Not Wake	% Total Awake
Mother's voice	15	4	0	0	100
Mixed T-3	14	7	0	1	96.4
Female voice	12	5	0	1	94.4
High-pitched alarm	10	1	4	12	57.1

A report by Smith et al. *(Smith, Splaingard, Hayes, & Xiang, 2006)* corroborates Bruck's findings. The authors of this report are critical of Bruck's study, specifically citing the differing subjects across studies and the lack of sleep stage monitoring through electroencephalography (EEG) as major problems. However, their results proved to be nearly identical to Bruck's. Of the 24 children (ages 6-12), 23 (96%) awoke to the voice alarm, but only 14 (58%) awoke to the standard warning tone. The study also recorded whether or not the child was able to successfully escape from the room after the sounding of the alarm. More details about the data gathered by Smith et al. can be seen in Table 6.

Table 6: Percentage of Children Who Awakened and Escaped vs. Alarm Type *(Smith et al., 2006)*

		Percent Awakened		Percent Escaped	
Child Age	**N**	**Tone n (%)**	**Voice n (%)**	**Tone n (%)**	**Voice n (%)**
6	5	1 (20)	4 (80)	0 (0)	3 (60)
7	2	1 (50)	2 (100)	0 (0)	2 (100)
8	3	0 (0)	3 (100)	0 (0)	2 (67)
9	5	4 (80)	5 (100)	1 (20)	4 (80)
10	3	2 (100)	2 (100)	2 (100)	2 (100)
11	4	3 (75)	4 (100)	3 (75)	4 (100)
12	3	3 (100)	3 (100)	3 (100)	3 (100)

These studies clearly show that children have great difficulty awakening to the standard smoke alarm signal, and that alternatives should be considered. In general, lower frequency signals (voice alarms and mixed-pitch T-3) performed significantly better than the standard high-pitched smoke alarm signal.

4.2.2 Effectiveness of Warning Tones for the Elderly

Bruck et al. conducted another study in 2006 which investigated the response of older adults to a variety of different signal types to determine which is the most effective *(Bruck et al., 2006)*. Forty-two older adults (ages 65-82) participated in the experiment. The signals tested include a mixed-pitch T-3 signal, a male voice ("Danger! Fire! Wake up!"), a 500 Hz pure tone (in a T-3 pattern), and the standard smoke alarm warning tone (high-pitched T-3). The male voice contained frequencies in the range of 500 Hz to 2500 Hz. The high-pitched T-3 is complex, but has a fundamental frequency of around 3000 Hz. The test was designed such that the auditory threshold, that is, the sound level at which a given signal is capable of awakening the subject, could be determined.

The test was conducted in each participant's own home on two different nights. Two signals were tested per night. The sounding device was placed in the same room as the subject. EEG was used to monitor the sleep stage of the participant. The alarm was presented shortly after the subject entered slow-wave sleep (the deepest stage of sleep). This was to add a measure of consistency to the test and removes variables that could be present between subjects with regards to their sleep schedule and quality. Alarms were initially sounded at 35 dB and increased by 5 dB every 30 seconds until the subject was awakened, allowing the researchers to determine each participant's audibility threshold. After awakening, the subject was instructed to perform both a "physical task" (getting out of bed and walking 15 meters), and a "simple cognitive task" (dialing a phone number and recording a message). The time it took to complete these tasks showed how quickly one responded in a fire situation, and can be seen in Table 7.

Table 7: Auditory Arousal Threshold and Behavioral Response Time in Older Adults for Auditory Signals *(Bruck et al., 2006)*

	Mixed-Pitch T-3	Male Voice	High T-3	500 Hz T-3
Mean Auditory Arousal Threshold (dB)	48.0	55.9	63.7	52.6
% slept through 75 dB	4.6%	14.0%	18.3%	15.5%
% slept through 85 dB	2.3%	9.3%	4.6%	6.6%
% slept through 95 dB	0%	7.0%	2.3%	2.3%
Mean behavioral response time (s)	93.3	153.9	192.1	124.5

The results of this investigation *(Bruck et al., 2006)* showed the mixed-pitch T-3 to be the most effective for waking sleeping people. At 50 dB, less than 25% had awoken to the high-pitched T-3, whereas over 70% had awoken to the mixed-pitch. The difference between signal responses was especially significant across the mid-range of volume (40 dB to 70 dB). The data gathered in this study can be found in Table 7 and Figure 9. It is interesting and important to note that a few participants with English as their second language did not awaken to the male voice; therefore, English voice alarms are not suitable for non-English speaking persons or those with English as their second language.

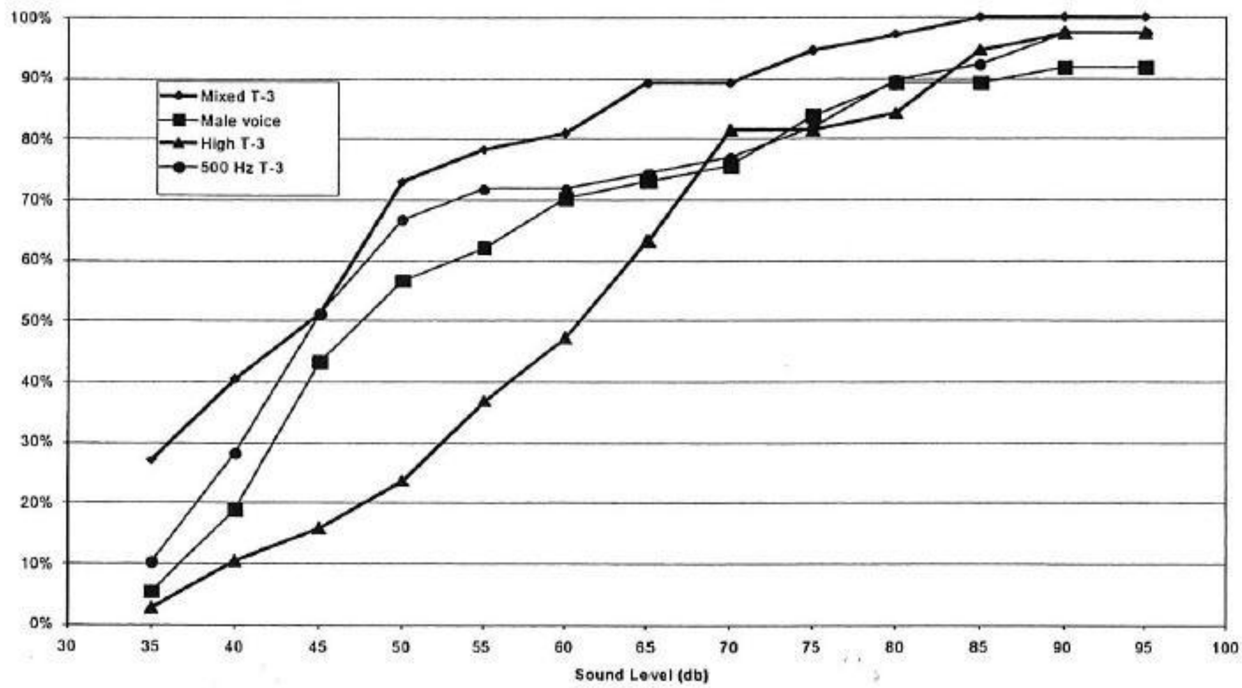

Figure 9: Percentage of Subjects who were Successfully Awakened by Signal Type and Sound Level *(Bruck et al., 2006)*

4.2.3 Effectiveness of Warning Tones for the Hearing Impaired

The Victoria University scientists have also conducted experiments to investigate the effectiveness of alternative smoke alarm signaling devices, such as bed shakers, pillow shakers, and strobe lights on hard of hearing subjects *(Bruck & Thomas, 2007)*. The responses to these devices were compared to responses to auditory signals. The auditory signals tested include two mixed-pitch T-3 signals with fundamental frequencies centered at 400 Hz and 520 Hz, as well as a 3100 Hz pure tone to represent the current standard for smoke alarm signals. These fundamental frequencies were selected based on an auditory threshold test conducted while the subjects were awake to determine the best two signals out of eight that were tested. The tactile alarms were also presented in a T-3 pattern.

Thirty-eight people participated in the study *(Bruck & Thomas, 2007)*, although not everyone completed a test of each of the signals, so the sample sizes of the final results vary. Each participant suffered from hearing loss of between 25 dB and 70 dB in both ears. The tests were conducted in the participant's own home. The auditory signals were delivered at a sound level of 75 dB, and the tactile alarms were delivered at the default level when purchased. These levels are considered to be the "benchmark" for comparison between the different signals.

It is interesting to note that even among hard of hearing individuals, the mixed-pitch auditory signals were still more effective than the tactile alarms. The 520 Hz mixed-pitch tone was the most successful, followed closely by the 400 Hz mixed-pitch. The pillow shaker was the most effective among the tactile alarms, followed by the bed shaker. The pure tone only managed to awaken approximately 50% of the participants. The least effective signal for awakening hard of hearing individuals was the strobe light. More detailed results can be seen in Table 8.

Table 8: Percentage of Hearing Impaired Subjects Who Awakened at or Below the Benchmark Signal Intensity *(Bruck & Thomas, 2007)*

	Percentage to awaken at or below benchmark
520 Hz mixed-pitch T-3	91.7%
Bed shaker	90.0%
400 Hz mixed-pitch T-3	86.5%
Pillow shaker	83.4%
3100 Hz pure tone	56.3%
Strobe light	27.0%

4.2.4 Effectiveness of Warning Tones for the Alcohol Impaired

It has been reported that alcohol intoxication is among the most significant risk factors for fire death *(Focus on fire safety: Alcohol and fire, 2009).* In fact, studies have shown that alcohol is a factor in over half of all fire fatalities *(Bruck, Thomas, & Ball, 2007).* Victoria University has conducted an extensive study dealing with this very issue.

Thirty-two young adults (ages 18-26) participated in the study. Seven signals were tested for their waking effectiveness when the subjects had a blood-alcohol content (BAC) of 0.05. The signals tested included two mixed-pitch signals (with fundamental frequencies of 400 Hz and 520 Hz), a 500 Hz pure tone, a 3100 Hz pure tone, a bed shaker, a pillow shaker, and a strobe light. All signals were presented in the usual T-3 pattern. Each signal was sounded for 30 seconds. After a pause, the signal would sound again at an incrementally higher decibel level until the participant awakened. As in other studies, sleep stage was monitored, and the signals were delivered when the subject entered slow-wave sleep. The test was conducted in essentially the same manner as the test discussed in the previous section. The results from this test are very similar to those of previous tests, and are shown in Table 9.

Table 9: Percentage of Alcohol Impaired Subjects Who Awakened at or Below the Benchmark Signal Intensity *(Bruck et al., 2007)*

	Percentage to awaken at or below benchmark
520 Hz mixed-pitch T-3	100.0%
400 Hz mixed-pitch T-3	93.0%
500 Hz pure tone	86.0%
Bed shaker	64.5%
3100 Hz pure tone	61.0%
Pillow shaker	58.0%
Strobe light	24.0%

It is important to note that this test dealt only with alcohol impaired subjects; thus, no comparisons in responsiveness could be drawn between sober and impaired subjects. However, a preliminary test was done by Bruck and Ball in 2004 that compares responsiveness in sober subjects, and those with BACs of both .05 and .08 *(Bruck & Ball, 2004)*. The average threshold is much higher for those who are alcohol impaired, even with a BAC as low as .05. The results of this test are shown in Figure 10 below.

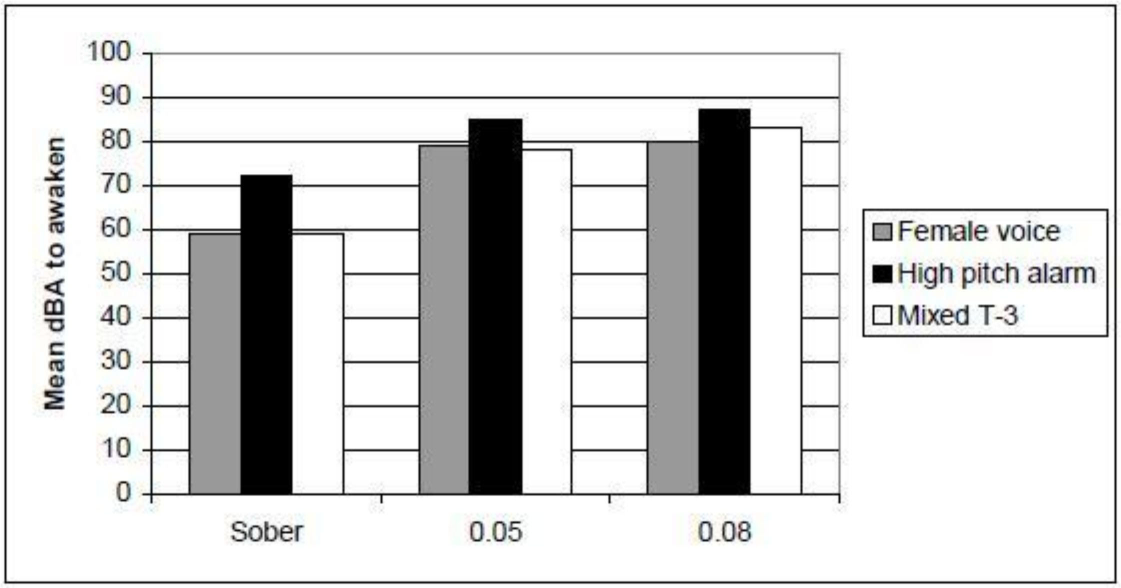

Figure 10: Mean Sound Level for Auditory Signals Required to Awaken Young Adults by Blood Alcohol Content *(Bruck et al., 2007)*

4.2.5 Conclusion

From these studies, it is clear that the 520 Hz mixed-pitch T-3 signal is by far the most effective at awakening the widest range of high-risk groups. It is almost as effective as the mother's voice in young children, and the most effective in older adults. It is also the single most effective signal (among both audible and tactile signals) for awakening those who are hearing impaired. It is the only signal that was able to awaken 100% of alcohol impaired participants.

The reason this warning tone is so effective lies in the nature of the signal itself. The 520 Hz mixed-pitch signal is emitted in a square wave pattern *(Dorothy Bruck Interview, Appendix M)*. Square waves contain the majority of their energy at their fundamental frequency (in this case 520 Hz), but also contain energy at all odd harmonics of that frequency. For example, the frequency spectrum of a 520 Hz square wave contains a peak at 520 Hz, and subsequently smaller peaks at 1560 Hz, 2600 Hz, etc. The energy at these harmonic frequencies stimulates other parts of the basilar membrane in the inner ear that would not be stimulated by a 520 Hz sinusoidal waveform. A 75 dB 520 Hz square wave will sound louder than a 75 dB 520 Hz sinusoidal wave, while giving the same decibel reading on a sound meter.

This added stimulation of the basilar membrane by the additional harmonics of the square wave allow for superior awakening characteristics when compared to pure tone signals. Not only does the square wave signal successfully awaken all of the subgroups under investigation (young children, elderly, hearing impaired, and alcohol impaired), but it leads to faster awakening as disclosed by the subject's EEG *(Bruck et al., 2007)*. The most telling example of the true effectiveness of the square wave signal is that it was significantly more effective than the tactile and visual alarms at awakening hard of hearing subjects.

The results of the tests on hard of hearing subjects are surprising *(Bruck & Thomas, 2007)*. The tactile and visual alarms proved to be very ineffective. Individuals with mild to moderate hearing loss should not be relying on these devices for awakening. The strobe light alarm was especially ineffective, a problem which is exaggerated by the fact that the lowest intensity level tested was above the level recommended by NFPA 72. However, a previous study conducted in 1991 by Underwriters Laboratory on legally deaf participants showed a much higher rate of awakening (92%) with strobe lights *(Report of research on emergency signaling devices for use by the hearing impaired, 1991).* This could be due to the fact that those who are deaf often have much sharper visual and tactile sensory responses. It has yet to be determined whether or not there is a difference in response among those who are deaf from birth and those with acquired deafness *(Dorothy Bruck Interview, Appendix M).*

The subgroup with the most significant improvement in awakening due to the 520 Hz square wave was young children. In a summarizing report by Bruck and Thomas *(Bruck & Thomas, 2009)*, the ratio of the number of people who slept through the current smoke alarm signal to the number of people who slept through the 520 Hz square wave was calculated. The ratio for young children was 12:1. The ratio for the other subgroups was also significant, but not as high as that of the youngest age group. The rest of the ratios are shown in Table 10.

Table 10: Ratio of the Number of People Who Slept Through the Current Smoke Alarm Warning Tone to the Number of People Who Slept Through the 520 Hz Square Wave *(Bruck & Thomas, 2009)*

Subgroup	Ratio of # who slept through current alarm to # who slept through 520 Hz alarm
Children 6-10 years old	12:1
Deep sleeping young adults	6:1
Adults over 65 years old	4:1
Hearing impaired adults	7:1
Young adults with .05 BAC	*
Sober young adults	*
* means that a ratio could not be calculated due to the fact that 0 slept through the 520 Hz signal	

The results of these tests all point to one seemingly obvious conclusion: replace the current smoke alarm warning tone with a 520 Hz square wave signal. However, this task is not quite as simple as it sounds. The engineering challenge lies in the physics of how the tones are generated *(Huey et al., 1996)*. The resonant frequency of the piezoelectric devices used to generate the sound are typically in the 4000 Hz range. It would be very difficult to output lower frequencies in such a small, inexpensive, battery-powered device like a smoke alarm. Lowering the frequency would require an output device with a larger surface area capable of resonating at lower frequencies, and would require more power. The power problem could easily be solved by the switch to hard-wired systems, but size and cost constraints still exist.

Lifetone Technology (http://www.lifetonesafety.com) has recently introduced a device similar to a standard smoke alarm unit that emits a 520 Hz square wave warning tone, and includes a tactile alarm in the form of a bed shaker. The device represents a step in the right direction, but it has its shortcomings. It does not contain a detection device; it is only an alarm. The device (a unit similar to a clock-radio that sits on a night stand) monitors the current smoke alarm signal and sounds the 520 Hz signal when it “hears” the existing smoke alarm sounding, so it requires standard smoke alarm units to already be installed. As discussed earlier, it is larger than an average smoke alarm unit, and uses more power (the backup battery only lasts four days). The device is not yet on the market and no price has been posted, making cost comparisons impossible.

The NFPA has proposed changes to NFPA 72, the National Fire Alarm Code, based in part on the research done at Victoria University. If the changes are accepted, NFPA will be recommending 520 Hz square wave alarms for those with mild to moderate hearing loss *(NFPA Technical Committee, 2009)*. This type of signal will also be recommended for those with profound hearing loss, as long as it is used in conjunction with a tactile device. These changes will be discussed at NFPA’s 2009 annual conference in Chicago, Illinois.

Chapter 5: Socioeconomic Considerations for Fire Safety

Social and economic situations can greatly affect the kind of smoke alarm a person will purchase. Unfortunately, the average consumer is unaware of the advantages and disadvantages with regards to smoke alarm type, power source, and interconnectivity. Manufacturers need to be aware of this lack of public education and must take into account the safety of those who buy and use their products while at the same time, minimize the number of false alarms people will experience.

For people who are aware of the various differences among smoke alarms, many factors can be associated with whether they will buy an ionization smoke alarm over a photoelectric smoke alarm or vice versa, as the specific alarm's functionality is highly dependent on the living situation of the family. This is also true for differences in the unit interconnectivity and power source. Four characteristics of smoke alarms (affordability, availability, ease of disposal, and frequency of nuisance alarms) are discussed further in the upcoming sections to establish connections between these factors, differing smoke alarm technologies and current international legislation.

5.1 Affordability of Smoke Alarms

When it comes to choosing a smoke alarm, one of the more visible concerns to the average homeowner is its price. According to Berger and Kuklinski in their article, "When Smoke Alarms Are a Nuisance," a lack of consumer education exists regarding smoke alarm types *(Berger & Kuklinski, 2001)*. This lack of education creates the attitude in the general population that all smoke alarms are technologically the same. Such a hypothesis results in the average customer buying the least expensive smoke alarm possible, which may not be appropriate for their particular housing situation.

In most instances, ionization smoke alarms cost less to manufacture and are less expensive for homeowners to purchase compared to photoelectric smoke alarms. However, with the recent regulations implemented in parts of the world that require photoelectric alarms, the price of these units has dropped slightly *(Craythorn, 2009)*. Even though ionization smoke alarms are more affordable to the average family, the fire protection community has become increasingly critical of these alarms because they do not provide adequate protection or adequate response time for the occupants to evacuate if a fire were to occur.

According to Berger and Kuklinski, "…we [the fire protection community] believe there is already sufficient justification for promoting photoelectric detectors in family dwellings" *(Berger & Kuklinski, 2001)*. Simply stated, the majority of the members of the fire protection community believe photoelectric smoke alarms are superior to ionization smoke alarms when it comes to saving lives. Unfortunately, cost becomes a problem that often overshadows the technological differences between the two types.

An article written for *Injury Prevention* in 2004 by D. Hendrie et al., researched both the availability and cost of multiple safety devices in 18 nations with differing average wages *(Hendrie et al., 2004)*. Information regarding each country's typical working wage and cost for a smoke alarm was obtained and the number of hours needed to afford the device was tabulated using these data.

In the study, factory worker wages were used due to their ease of accessibility and because they were thought to be the best representation of those who would normally purchase smoke alarms. In both high-income and low-income nations, factory wages are often quite different than average income; in high-income nations, factory worker wages are just slightly above the national average while in low-income nations, this gap is even greater, with factory workers exceeding the national income average by a large amount. These workers are more likely to purchase a smoke alarm compared to people making less than the national average income, especially in nations where smoke alarms are not required. The data collected from the study were compiled and analyzed to make comparisons (see Table 11).

Table 11: Prices of Smoke Alarms in US Dollars (2002), Hourly Wages for Factory Workers (2000) and Factory Hours of Work Needed to Pay for a Smoke Alarm in 13 Countries *(Hendrie et al., 2004)*

Country	Cost of smoke alarm (2002 – USD)	Hourly Wage (Factory – USD - 2000)	Hours of Work Needed to pay for Smoke Alarm
China	169	2.26	75
Albania	13	0.59	22
Philippines	28	1.90	15
Japan	50	22.00	2.3
South Africa	10	5.64	1.8
Israel	17	12.88	1.3
New Zealand	9	8.13	1.1
Austria	21	19.46	1.1
Canada	10	10.16	0.98
Germany	14	22.99	0.61
United Kingdom	6	15.88	0.38
Australia	4	14.15	0.28
United States	5	19.86	0.25

Table 11 provides information about 13 of the 18 countries analyzed in the 2002 study. Nations such as the United Kingdom, Australia and the United States offer smoke alarms for less than US$10 and due to the fairly high wages of factory workers, residents can buy a smoke alarm after a half hour of work. In nations like China and Albania, citizens are required to work anywhere from 20 to 75 hours before they can afford a smoke alarm.

The majority of the nations with high relative smoke alarm prices do not require that homes have them and are considered to be a "luxury," while the nations with low prices normally require that they be installed *(Hendrie et al., 2004).* There are a few exceptions to this statement, however. Some nations do not manufacture their own smoke alarms and therefore rely on devices imported from other countries. Shipping the alarms outside national borders can raise the selling prices of the devices, thus making them more expensive for the consumer. On the other end of the spectrum, countries such as Albania, New Zealand and South Africa produce smoke alarms to export to other countries, making them much less expensive within national borders.

While hypotheses can be proposed for the causes of differences in price of the same smoke alarm from one country to another, Hendrie et al. state the following:

> The price differentials observed are extremely wide considering that a large market potentially exists for these devices in some lower income countries. A major study weakness is the inability to explain these differentials fully. Without data relating to factors such as number of personal vehicles on the road, local device production, domestic device sales, and country of production of safety devices, it was difficult to disentangle the many possible reasons underlying price differentials.

Only a few certain conclusions can be made on this topic. If national or local legislation in low-income countries require a home to be equipped with smoke alarms, the device's price should naturally lessen. As noted previously, smoke alarms need to be imported into some low-income countries and the cost to package and transport them further raises the purchase price. The fact that these imports do not have local competitors in the low-income nations does little to help the price differential. Lack of competition creates a monopoly in the smoke alarm market in that specific region, allowing the solitary supplier to raise prices.

Interconnecting smoke alarms throughout a residential setting is also essential when maximum safety and protection for the occupants is desired *(Craythorn, 2009).* Interconnectivity of smoke alarms can be achieved through either wired or wireless communication. With respect to the affordability of interconnected units, neither type has an overall advantage over the other. Wireless interconnected smoke alarms are expensive, but are easy and quick to install. Wired units are more than four times less expensive than a wireless interconnected device, but the cost of installation must be considered.

In single-story homes, installation of wired interconnected smoke alarms is relatively simple. An electrician can be hired to mount multiple smoke alarms on the ceilings of different rooms and, with access to the attic, can connect the units to the power mains and to each other with relative ease. Wires will run on the floor of the attic and will not be visible from the main floor; therefore, the installation would be fairly straightforward for the installer and the cost for the combined smoke alarms and installation could potentially be less than that of the cost of the wireless interconnected smoke alarms. In this situation, wired interconnected smoke alarms would be more affordable and equally as efficient.

In homes with multiple floors, wireless interconnected smoke alarms could be more cost effective. The cost to have an electrician interconnect wired smoke alarms throughout multiple floors could eventually add up to or exceed the cost of wirelessly interconnected devices. These extra costs would come from running wires through the walls of the house and the removal and replacement of carpet and/or flooring on upper floors in order to mount the smoke alarms for the floor below. Ultimately, comparisons of wired and wireless interconnected smoke alarm systems with respect to affordability must be established based on a variety of factors beyond the price of the smoke alarms themselves.

When carefully considered, the cost issue is not as clear-cut as most people would assume. An inexpensive purchase at the store will not necessarily save money in the end, especially for those who have not been educated in different smoke alarm options. Deciding what is best for one's own situation is the task of the consumer, but fire protection officials and smoke alarm manufacturers should take responsibility in educating the public about the different types of devices so that they will make the appropriate decision. Additionally, manufacturers should ensure that the best smoke alarms are available for purchase for a wide variety of living situations in order to assure the safety of everyone.

5.2 Availability of Smoke Alarms in Differing Economic Circumstances

While price differences can create shifts in sales of ionization versus photoelectric smoke alarms, the availability of certain types in a specific country greatly affects which alarm people will buy. Simply stated, the availability of smoke alarms to the general public varies worldwide *(Hendrie et al., 2004)*. Nations containing a large amount of people with high incomes, such as Germany, the United States and the United Kingdom, have many different types (including power source) of smoke alarms on the market.

On the other hand, low-income nations such as China, Albania, the Philippines and Vietnam consider smoke alarms to be "luxuries" which are only sold in stores aimed towards high-income families. In addition, neither China nor Vietnam requires homes to be equipped with smoke alarms, which also affect what stores keep in stock. Japan does not sell economy-level smoke alarms; only high-end models are available, which explains the high cost of alarms in the country.

Out of the 18 nations studied in the report by Hendrie et al., four were listed as "N/A" under the cost of a smoke alarm meaning that these countries did not have smoke alarms readily available for residential homes. Three of these countries, Thailand, Brazil and South Korea, didn't sell smoke alarms at all to the general public, as legislation does not require that homes be equipped with them. Venezuela provided smoke alarms for industrial and commercial use only.

The availability of smoke alarms is highly dependent on the legislation of the country in question. Not surprisingly, nations with high fatality rates due to fire typically have very little fire legislation in effect. According to Hendrie et al. in a report published in 2004:

> Smoke alarms had a very limited availability in lower and some middle income countries. Despite the high rate of fire deaths in these countries, smoke alarms may not have the broad residential applicability. They do not work in settings where open flames or wood/coal cook stoves give off smoke. Nevertheless, smoke alarms generally would cut the fire risks of the middle and upper classes, especially for the burgeoning urban apartment dwellers in many lower and middle income countries. They should be more available.

This statement brings out the important point that the lack of smoke alarm availability in many low-income nations is related to the high number of fatalities due to fire. Although not all situations are ideal for a smoke alarm to be used, the advantages outweigh the disadvantages in most cases. Unfortunately, this study (as well as many others) tends to test and report on population groups in the middle to upper economic classes, leading Hendrie et al. to the conclusion that "they should be more available," while almost disregarding those in the lower class.

Affordability and availability are two very obvious and important concerns of the average homeowner when choosing a smoke alarm but there are many factors that are often not considered. Cost and availability are influential; the satisfaction received from buying a unit that is both affordable and readily available is often stronger than any other considerations such as smoke alarm type, functionality, or disposal method. In the case of smoke alarms, all three of these should be taken into account.

5.3 Smoke Alarm Disposal and Associated Risks

One problem often overlooked is the proper disposal of old or unused smoke alarms. This becomes especially problematic when disposing of ionization units. According to the Position Statement released by AFAC, "In Australia, for ionization alarms … amounts of ten or less smoke alarms can be disposed of in domestic waste. Quantities of more than ten need to be treated as radioactive waste" *(Australasian Fire Authorities Council, 2006)*. This regulation is in accordance to recommendations by the Australian Radiation Protection and Nuclear Safety Agency.

While it is true that ionization alarms do contain trace amounts of radioactive material, the amount is so miniscule that it is of little concern to the general public. Even though Americium-241 is highly radioactive *(World Nuclear Association, 2009),* a typical ionization smoke alarm contains less than 1/3,000 of a gram of the element, which in most cases is insignificant to a person's health. To paraphrase a quote by Michael Craythorn of Brooks, a major manufacturer of smoke alarms in Australia, "if you were to fill a wheelbarrow with ionization smoke alarms and then fill a second wheelbarrow with dirt from the ground, the wheelbarrow containing the dirt would more than likely be more radioactive than the smoke alarms" *(Craythorn, 2009)*. Although it has become less of a concern, the issue of radioactive material in the ionization vs. photoelectric debate still confers a small advantage on photoelectric units.

5.4 Lifestyle Effects on Nuisance Alarms

Smoke alarms have been proven to be immensely effective in reducing casualties in residential fires; however, loss of life still occurs. One of the main reasons for this tragedy is the large number of smoke alarms that have been disabled due to frequent nuisance alarms. By definition, a nuisance alarm occurs when a smoke alarm is activated when there is not a fire safety risk. Common nuisance alarm activators include cooking smoke, insects, dust, moisture from showers or bathrooms, candles, and cigarette/cigar smoke *(O'Connor et al., 2008)*. Repeated nuisance alarms cause home owners to disable their smoke alarms, which creates an unsafe living environment. According to the Task Force Group at the NFPA, about 20% of smoke alarms installed in the United States are currently inoperable, either because they have non-functioning batteries or because they are disconnected at the owner's discretion due to constant nuisance alarms. Furthermore, Berger quoted John Hall of the NFPA who said, "…one-third of homes with smoke detectors that have reported fires have no smoke detectors that work" *(Berger & Kuklinski, 2001)*.

The prevalence of disabled smoke alarms in a multitude of studies has shown that nuisance alarms have been a significant problem in the fire protection field; Berger and Kuklinski mention some of these studies in their report. One such study from the U.S. involved two Native American communities, one in North Dakota and one in Arizona. Data from North Dakota showed that 48% of smoke alarms did not work; in 86% of these cases, they had been disconnected by the owner because of nuisance alarms. In the Arizona tribe, 50% of alarms didn't work and 64% of these were disconnected by the owner.

In another study, four small towns in Alaska were surveyed. The results showed that 92% of homeowners with ionization smoke alarms reported nuisance alarms within six months of initial installation and that 19% of these were disconnected at some point during that time. A smoke alarm installation program that began in Oklahoma, Minnesota and North Carolina was also analyzed. Homes were fitted with smoke alarms and an update was performed in each home three to four years later. The report found that 27% of the smoke alarms were inoperable due to dead batteries or disconnection of the unit by the owner. Twenty-one percent claimed to have removed the batteries due to nuisance alarms. The final study analyzed in the paper was performed in 15 U.S. cities and showed that 59% of smoke alarms in homes that reported fires did not work and of these, 35% were disabled because they were prone to nuisance alarms.

The main cause of nuisance alarms in homes stems from cooking *(Berger & Kuklinski, 2001)*. In order to eliminate these false warnings, smoke alarm manufacturers have been installing "hush buttons" into the devices to silence them if activated. Although well-intentioned, hush buttons are doing little to promote fire safety. Hush buttons are of limited value, as they can be inaccessible for the average person, especially those who are alcohol impaired (it was found that 85% of victims from cooking fires are alcohol impaired). These problems will still lead to the removal of the battery if too many nuisance alarms occur, negating any use of the smoke alarm.

The type of smoke alarm installed has also been linked to prevalence of nuisance alarms *(Berger & Kuklinski, 2001)*. In an Alaskan study that was analyzed by Berger et al., ionization alarms triggered eight times as many nuisance alarms as photoelectric alarms; however, ionization alarms were much more widespread in homes (approximately 90% of homes in the U.S. had ionization alarms in 1995).

One final area of interest concerning activators of nuisance alarms is heating fuel. In a study performed by Mueller et al., a total of 750 participants had a smoke alarm installed in their homes: 366 were given ionization alarms and 384 were given photoelectric *(Mueller, Sidman, Alter, Perkins, & Grossman, 2008).* Before the test began, a list of characteristics was created indicating, among other things, each home's heating type. Categories included electric, natural gas, oil, wood and other. Alongside these data, presence of a wood stove or fireplace and its frequency of use was recorded. Unfortunately, even though the study was completed successfully, the results section dealing with home heating types was not released in the report. More research needs to be performed in this area in order to determine whether or not there is a correlation between nuisance alarms and heating type.

5.5 Conclusion

Both affordability and availability are important to the average consumer. The cost of a device can deter a person from purchasing one type over another. However, while cost can be a significant deciding factor, it should not be the only aspect of the device in mind. It is also widely accepted in the fire protection community that ionization smoke alarms are much more common in households, leading one to believe that these specific devices are more available to the consumer. Type of detector is rarely considered by homeowners, making ease of disposal hardly a concern to them; luckily, this aspect is of the least importance in relation to all other factors described in this section.

Many of the studies regarding nuisance alarms show that there is a lack of consumer education about fire safety. The average homeowner is unfamiliar with the different types of smoke alarms on the market, never mind the advantages and disadvantages of each or which will cause nuisance alarms in certain situations. This leads to homeowners purchasing the least expensive smoke alarm, which may or may not be appropriate for them. This lack of education needs to be dealt with by the fire protection community and brought to the attention of the general public to promote fire safety in the future. Modifications to legislation can also bring forward changes in rates of fire fatalities.

While many studies have been performed about nuisance alarms, very few have primarily dealt with families of lower classes and their problems with nuisance alarms. For example, a middle-class family may cook on an electric range while a lower-class family may use a gas stove or coal/wood-fueled cooking stove; both have different characteristics which may trigger nuisance alarms. In the end, it is impossible to specify a certain set of smoke alarm rules for people of every social class in every location to follow.

Chapter 6: Residential Smoke Alarm Legislation

Throughout the world, residential smoke alarm legislation varies significantly. Some countries are specific and thorough with their smoke alarm requirements, while others do not have any at all. When evaluating smoke alarm legislation, there are several important factors that must be considered. These factors include but are by no means limited to the detector type, placement, power source, interconnectivity, enforcement, and compliance monitoring.

In order to gather this information, surveys were e-mailed to the 109 locations listed in Appendix B. This yielded 76 survey respondents, giving us a high return rate of 70%. Surveys were returned from 24 countries, eight Australian states and territories, eight Canadian provinces and territories, three U.K. countries, and 33 U.S. states. Of the 24 countries, two were from North America, ten were from Europe, eight were from Asia, two were from Africa, and two were from Oceania. A chart summarizing international legislation can be seen in Appendix N. This table is based on information presented by the ISCAIP which has been updated based on the information received from the survey responses *(ISCAIP, 1999)*.

Only 29% of the responding countries have nationwide legislation. There does not seem to be any correlation between the locations that have smoke alarm legislation and the nation's gross domestic product or average annual income. One notable observation is that of the eight Asian countries that responded, only one had legislation: Japan. Most of the countries with nationwide smoke alarm legislation are located in Europe.

It is important to note that in Australia, Canada, and the United States there is no nationwide legislation. All three of these countries have recommendations which can be adopted by the states, provinces, and territories as they choose. In Australia these recommendations are located in the Building Code of Australia which is adopted by the individual states/territories unless a variation is accepted by Australia. Canada uses the National Building Code of Canada which can be adopted by the territories/provinces as they see fit. In the United States the recommendations come from NFPA 72 National Fire Alarm Code which can be adopted or modified by individual states. In some U.S. states, legislation is governed on a more local basis, and even varies from county to county.

Only three of the returned surveys stated that they require a specific type of alarm (Iowa – combination, Quebec – photoelectric, Vermont – photoelectric). Several responses said that they recommend the use of photoelectric alarms. Very few places require the use of smoke alarms on every floor or the home. Most regions consider it sufficient to have smoke alarms placed either inside or outside of bedrooms. A few specified that smoke alarms should be located on the entry level or in passageways/hallways.

The most common problem stated on the survey responses was that legislation is not strictly enforced. In the opinion of these respondents, there are not a sufficient number of inspections conducted, and when violations are found, penalty fines are not high enough to encourage compliance. Fire protection officials want to see a stronger enforcement policy worked into the legislation. Other common recommendations that were mentioned are to require hard-wiring and interconnectivity of smoke alarms wherever it is not already required.

Chapter 7: Conclusion and Recommendations

Smoke alarms are essential in ensuring the highest level of protection in a residence; however, they must be used properly to guarantee maximum safety. As technology evolves and new research is conducted, smoke alarms need to be re-evaluated for effectiveness. A smoke alarm's ability to detect fires and alert occupants is paramount to its successful implementation. The primary goal of this project was to provide Fire Protection Association Australia with a starting point for centralization of smoke alarm legislation information and a summary of smoke alarm research.

This project had a wide and varied scope, and although all the main goals were met and deliverables completed, there is still work to be done. Although we received an exceptionally high survey return rate, the information contained in the surveys was not as complete and clear as we had hoped. We were limited in the time we had to prepare these surveys since they had to be sent out before we arrived in Melbourne. Only by conducting and assessing the survey did we learn how we should have implemented the survey in the first place.

There were several factors of which we were not aware when the surveys were sent. For example, legislation often differs for existing and new structures, a fact that was not reflected in the surveys. Some survey questions were often misunderstood or misinterpreted by the respondents, and therefore provided irrelevant or incomplete information. For example, some respondents answered the question, "Which year and month was your legislation enacted?" with the date smoke alarm legislation was initially created in the area, while some responded with the date on which it was last updated. The question, "When the legislation was first phased in, what criteria were used regarding the following topics?" also caused confusion. Furthermore, there were additional useful questions (e.g. specifically regarding power source and interconnectivity) that we lacked adequate knowledge to ask at the time the surveys were distributed. Any information contained in the database on those subjects was gleaned from exceptionally thorough answers to other questions.

It also appeared to be unclear to some respondents whether we wanted information about national recommendations or requirements. Many countries such as Australia, the United States, and Canada, have national codes that are typically adopted by states, territories, or provinces, but are not required by federal legislation. Thus, the database pages for these countries specify that there is no smoke alarm legislation, when in fact most states (or territories/provinces), if not all areas in the country, do have legislation. Future work in this area should include conducting a more thorough survey with more clear and quantifiable questions and less open-ended questions.

We were still able to identify some trends in global legislation. The most glaring problem in regions with smoke alarm legislation is very weak enforcement practices and compliance monitoring. Penalties for non-compliance should be stronger than they currently are, and inspections should be conducted on a more regular basis. Typically, inspections are only conducted prior to issuance of an occupancy permit for new constructions or after a major renovation, or sale of the home. A more proactive and preventative approach may prove successful in reducing loss of life.

Based on our research, we can conclude that the “ideal” smoke alarm for most residences in developed countries like the U.S. and Australia is photoelectric, interconnected, hard-wired with a battery backup, and uses a 520 Hz square wave warning tone. Unfortunately, this “ideal” smoke alarm does not yet exist, since a low-frequency signal cannot be generated by a device small enough to fit inside a standard smoke alarm. Hopefully, technological advancements will make this possible in the coming years. It should also be noted that most studies done on smoke alarms are from developed countries, and often overlook circumstances in underdeveloped countries. For example, interconnectivity is generally an important feature to citizens of Australian and U.S. who tend to have larger homes, but to citizens of less developed countries, it is irrelevant since they may not even have basic smoke alarms.

Through our research, we have found that it is difficult, if not impossible, to make generalizations about the "ideal" smoke alarm arrangement for residences on a global level. The number of factors and variables that can affect recommendations for type and proper use of smoke alarms are so great and vary so much for differing situations, it would be a gross oversimplification to make any blanket statements on the subject. Lifestyle differences such as cooking methods, heating fuel, climate, housing style, and economic climate are only a few of the variables that must be considered.

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Appendix A: Excerpts from Ed Comeau Interview

Date: February 9, 2009
Time: 1:30 PM
Attendees: John Meklenburg, Kemal Moise, Brian Potts, Ed Comeau
Location: Belchertown, MA, USA

Background: Ed Comeau is "the principal writer of writer-tech.com. His career in emergency services has spanned over twenty-five years, and he brings together a unique blend of experience in the fields of fire fighting, emergency medical services, engineering, training and technical writing. He is widely published and has presented at numerous conferences and programs around the globe."[1] Comeau also has connections to International Association of Fire Chiefs, The Nation Fire Protection Association (USA), and the Society of Fire Protection Engineers. It was recommended to us that we speak with him early on by our project liaison Rob Llewellyn. During the interview we discussed smoke alarm technologies with respect to the ionization versus photoelectric debate as well as other professionals we should consider contacting. Below are sections used to support text in the report.

Excerpts: "A few years ago I had been looking at photoelectric and ionization combination smoke alarms as kind of like the magic bullet. I said okay, we got the best of both worlds. But what I discovered is that they can slide the sensitivities of both sensors in there and still stay within the UL listing. So they can desensitize ionization and ramp up the photoelectric or vice versa. So you're defeating the purpose, why have it?"

"We issued a position paper several years ago. I helped write it but I don't agree with it because it says, "In your house you should use both types of technology." Well, that means you're predicting what kind of fire is going to break out in what location. Should my living room have an ionization or photoelectric?"

"This is an older house so the smoke alarms weren't hard wired so I'm using wireless technology to get the coverage. It's perfect for an application just like mine. I don't have wires running from basement to ceiling. At night, if I have a fire in my basement, I'm never going to hear it upstairs. But now I've got interconnected throughout the house."

"If you look at the stats, if I recall right, most fires are cooking related fires in the home. Generally people are alert and can react to them. So that's why if you look at what's the largest cause of fatal fires, smoking materials is the ignition source, and with smoking materials it's going to be smoldering and it's not going to be open flaming fires. I do a lot of campus safety stuff and a common scenario is a fire breaks out on a Thursday night after a party, in a couch. They we're having a party, someone was smoking a cigarette, went down in the couch, everyone goes to bed, hours later…."

[1] http://www.writer-tech.com/pages/background.htm

Appendix B: List of Survey Recipients

- Australia
  - Australian Capital Territory
  - New South Wales
  - Northern Territory
  - Queensland
  - South Australia
  - Tasmania
  - Victoria
  - Western Australia
- Austria
- Belgium
- Canada
  - Alberta
  - British Columbia
  - Manitoba
  - New Brunswick
  - Newfoundland and Labrador
  - Northwest Territories
  - Nova Scotia
  - Nunavut
  - Ontario
  - Prince Edward Island
  - Quebec
  - Saskatchewan
  - Yukon
- China
- Cyprus
- Denmark
- Egypt
- Finland
- France
- Germany
- Hong Kong
- India
- Indonesia
- Ireland
- Italy
- Japan
- Malaysia
- Netherlands
- New Zealand
- Norway
- Pakistan
- Serbia
- Singapore
- Slovenia
- South Africa
- South Korea
- Spain
- Sweden
- Switzerland
- Thailand
- United Kingdom
  - England
  - Northern Ireland
  - Scotland
  - Wales
- USA
  - Alabama
  - Alaska
  - Arizona
  - Arkansas
  - California
  - Colorado
  - Connecticut
  - Delaware
  - DC
  - Florida
  - Georgia
  - Hawaii
  - Idaho
  - Illinois
  - Indiana
  - Iowa
  - Kansas
  - Kentucky
  - Louisiana
  - Maine
  - Maryland
  - Massachusetts
  - Michigan
  - Minnesota
  - Mississippi
  - Missouri
  - Montana
  - Nebraska
  - Nevada
  - New Hampshire
  - New Jersey
  - New Mexico
  - New York
  - North Carolina
  - North Dakota
  - Ohio
  - Oklahoma
  - Oregon
  - Pennsylvania
  - Rhode Island
  - South Carolina
  - South Dakota
  - Tennessee
  - Texas
  - Utah
  - Vermont
  - Virginia
  - Washington
  - West Virginia
  - Wisconsin
  - Wyoming

Appendix C: Introduction E-mail for Survey

Dear [Name],

Please see the attached letter of introduction regarding a collaborative research project between students at Worcester Polytechnic Institute (Worcester, MA, USA), and the Fire Protection Association of Australia. Your cooperation is essential to the success of the project.

If you have any questions, feel free to contact us at survey-fpa@wpi.edu.
If you feel you are not the intended recipient of this letter, or you know of someone who is more knowledgeable on the topic of fire protection legislation in your [country], please respond to us with updated contact information.

Thank you,

Timothy Manchester
John Meklenburg
Kemal Moise
Brian Potts

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609 USA

Appendix D: Letter of Introduction Sent Prior to Survey

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609 USA

February 23, 2009

Dear Sir or Madam,

We are a group of undergraduate students at Worcester Polytechnic Institute in Worcester, Massachusetts, USA, currently working on a project to complete a degree requirement. Our group consists of Timothy Manchester (Mechanical Engineering and Civil Engineering), John Meklenburg (Biomedical Engineering and Electrical & Computer Engineering), Brian Potts (Electrical & Computer Engineering), and Kemal Moise (Mechanical Engineering). We are all third year students at WPI, and can be contacted via e-mail at **survey-fpa@wpi.edu**.

We will be travelling to Melbourne, Australia to work with Robert Llewellyn at the Fire Protection Association of Australia, who is aiding us in our project, which consists of two parts. The first involves analyzing the effectiveness of smoke detectors, including the somewhat controversial debate about ionization vs. photoelectric type detectors. The second part involves compiling a database of current international smoke detector legislation. We are asking for your help with the latter part of the project.

Within the next few days, you will be receiving a survey via e-mail. The information you provide in this survey will be used to compile an international database which will be then used to identify possible gaps in current legislation. Furthermore, developing countries will be able to access these data to help structure any new legislation. The ultimate goal of this database is to improve fire protection on an international level.

We would greatly appreciate your prompt and complete response to this survey. The success of the project depends heavily on your cooperation, and will be of great benefit to the international fire community.

Best Regards,

Timothy Manchester
John Meklenburg
Kemal Moise
Brian Potts

Worcester Polytechnic Institute
FPA-D09 IQP Group

Appendix E: Initial Survey E-mail

Dear [name],

We are the group of students from Worcester Polytechnic Institute (Worcester, MA, USA) working on the collaborative research project with the Fire Protection Association of Australia regarding smoke detector legislation. Attached is the survey that we mentioned in our previous e-mail. Please return this survey as soon as possible. We really appreciate your cooperation, and your participation is essential to the success of this project.

Thank you,

Timothy Manchester
John Meklenburg
Kemal Moise
Brian Potts

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609 USA

Appendix F: Survey Follow-up E-mails

Follow-up E-mail 1

Dear [Name],

We are the group of students from Worcester Polytechnic Institute (Worcester, MA, USA) working on the collaborative research project with the Fire Protection Association of Australia regarding smoke detector legislation. We contacted you a few weeks ago regarding the completion of a survey about smoke detector legislation and we have yet to receive a response. This e-mail is meant to be a follow-up in case you have forgotten.

If you feel that you are not the most qualified person to complete this survey or if you know of someone more knowledgeable than yourself on the topic of smoke detector legislation in your [country], we ask that you either forward this e-mail to him or her, or reply to us with his or her contact information.

Attached is the survey that we sent in our previous e-mail. We ask that you complete and return it at your earliest convenience. We appreciate your cooperation, and your participation is essential to the success of this project.

Thank you,

Timothy Manchester
John Meklenburg
Kemal Moise
Brian Potts

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609 USA

Follow-up E-mail 2

Dear [Name],

We are the group of students from Worcester Polytechnic Institute (Worcester, MA, USA) working on the collaborative research project with the Fire Protection Association of Australia regarding smoke detector legislation. We contacted you a few weeks ago regarding the completion of a survey about smoke detector legislation and we have yet to receive a response. This e-mail is meant to be a follow-up in case you have forgotten. This is the second reminder, and we are eager to include your area's information in our database.

If you feel that you are not the most qualified person to complete this survey or if you know of someone more knowledgeable than yourself on the topic of smoke detector legislation in your [country], we ask that you either forward this e-mail to him or her, or reply to us with his or her contact information.

Attached is the survey that we sent in our previous e-mail. We ask that you complete and return it at your earliest convenience. We appreciate your cooperation, and your participation is essential to the success of this project.

Thank you,

Timothy Manchester
John Meklenburg
Kemal Moise
Brian Potts

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609 USA

Follow-up E-mail Final

Dear [Name],

We are the group of students from Worcester Polytechnic Institute (Worcester, MA, USA) working on the collaborative research project with the Fire Protection Association of Australia regarding smoke alarm legislation. We contacted you a few weeks ago regarding the completion of a survey about smoke alarm legislation and we have yet to receive a response. This e-mail is meant to be the final follow-up in case you have forgotten. We are eager to include your area's information in our database and therefore, we would like to extend one last opportunity to complete the attached survey. We request that completed surveys be returned no later than April 8th. Also, if your area does not have smoke alarm legislation or it is mandated on a local level and therefore the survey would not apply to you, please reply to this e-mail informing us of this.

If you feel that you are not the most qualified person to complete this survey or if you know of someone more knowledgeable than yourself on the topic of smoke alarm legislation in your area, we ask that you either forward this e-mail to him or her, or reply to us with his or her contact information.

Attached is the survey that we sent in our previous e-mail. We ask that you complete and return it at your earliest convenience. We appreciate your cooperation, and your participation is essential to the success of this project.

Thank you,

Timothy Manchester
John Meklenburg
Kemal Moise
Brian Potts

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609 USA

Appendix G: Survey "Thank You" E-mail

Dear [Name],

Thank you for taking the time to complete our survey. Your responses will help greatly in providing the desired outcome of an international smoke detector legislation database. If you have any further questions or requests, feel free to contact us at survey-fpa@wpi.edu.

Regards,

Timothy Manchester
John Meklenburg
Kemal Moise
Brian Potts

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609 USA

Appendix H: Survey

International Fire Protection Legislation Database

A collaborative research project between students at Worcester Polytechnic Institute and the Fire Protection Association of Australia.

Location:	

Name:		Title:	

1. **Does your country have smoke alarm legislation for residential facilities, including houses, apartments and mobile/transportable homes (caravans)?**

2. **Please provide a link to your smoke alarm legislation if available.**

3. **Which year & month was your legislation enacted?**

4. **What are your smoke alarm legislative requirements for the following locations?**
   a. **Bedrooms:**

   b. **Passageways/Corridors:**

   c. **Living Rooms:**

   d. **Any Other Regulations:**

5. **What are your smoke alarm legislative requirements for the following types of alarms?**
   a. **Ionization:**

   b. **Photoelectric:**

   c. **Combination:**

    d. **Other:**

6. **If your country is governed on a state/territory basis, do the requirements differ from location to location? If yes, please provide details.**

7. **When the legislation was first phased in, what criteria were used regarding the following topics?**
    a. **Smoke alarms installed in new residences:**

    b. **Smoke alarms installed in all 'major' house renovations (renovations requiring a building permit):**

    c. **Smoke alarms installed in private rental accommodations:**

    d. **Smoke alarms installed in mobile/transportable homes (caravans):**

    e. **Smoke alarms must be installed within   months of change of ownership.**

8. **What compliance arrangements were established?**

9. **Which agency is responsible for compliance arrangements?**

10. **What has compliance monitoring found?**

11. **What issues/problems have been found with the legislation? Are the requirements adequate?**

12. **With the benefit of hindsight, what changes (if any) to your legislation would you recommend?**

13. **Are there any measureable outcomes that the legislation may have influenced? For example, has there been a decrease in the number of fatalities and/or injuries responded to by your agency per 100,000 homes? How big of an impact has there been?**

14. **Please reference any surveys and/or evaluations of compliance and/or effectiveness of smoke alarms in your location.**

15. **If your country does not have any smoke alarm legislative requirements for residential properties, are there recommended practices from the Fire Department(s), Fire Protection Authorities, etc.? Please provide links if possible.**

Appendix I: Example of Completed Survey

International Fire Protection Legislation Database

A collaborative research project between students at Worcester Polytechnic Institute and the Fire Protection Association of Australia.

Location:	**Washington**

Name:	**[removed]**	**Title:**	**[removed]**

1. **Does your state have smoke alarm legislation for residential facilities, including houses, apartments and mobile/transportable homes (caravans)?**

   Yes - in addition to the requirements listed in the adopted fire and buidling codes (2006 edition of the IFC/IBC) we have state specific laws that require smoke alarms in all dwelling units.

2. **Please provide a link to your smoke alarm legislation if available.**

   www.leg.wa.gov (please use the search engine on the site to search for "smoke alarms" - the site is not always easy to navigate so I believe this may be the easiest way to find things of interest.)

3. **Which year & month was your legislation enacted?**

   In the early 1980's.

4. **What are your smoke alarm legislative requirements for the following locations?**
   a. **Bedrooms:**

      No specific legislation to address where located - this is outlined in the IFC/IBC.

      New construction, required in all sleeping rooms. Existing buildings must have alarms in the room or outside of the room.

   b. **Passageways/Corridors:**

      No specific legislation to address where located - this is outlined in the IFC/IBC.

      Required in all hallways corridors.

   c. **Living Rooms:**

      Not required.

d. **Any Other Regulations:**

N/A

5. **What are your smoke alarm legislative requirements for the following types of alarms?**
   a. **Ionization:**

   No - the code does not specify an alarm type, only that they be listed with a testing laboratory.

   b. **Photoelectric:**

   Same as above.

   c. **Combination:**

   Same as above.

   d. **Other:**

   Must be hardwired with battery backup.

6. **If your state is governed on a more local basis, do the requirements differ from location to location? If yes, please provide details.**

   No - we have a state minimum code.

7. **When the legislation was first phased in, what criteria were used regarding the following topics?**
   a. **Smoke alarms installed in new residences:**

   Required as indicated in the code in effect at the time of construction.

   b. **Smoke alarms installed in all 'major' house renovations (renovations requiring a building permit):**

   Yes, per the code requirements in effect at the time of the renovation.

   c. **Smoke alarms installed in private rental accommodations:**

   Yes.

   d. **Smoke alarms installed in mobile/transportable homes (caravans):**

   Required in all mobile homes, not codes exist for vehicles used as a residence in the state.

   e. **Smoke alarms must be installed within** N/A **months of change of ownership.**

8. **What compliance arrangements were established?**

   Unsure of what is being asked here.

9. Which agency is responsible for compliance arrangements?

Local authority having jurisdiction.

10. What has compliance monitoring found?

Unsure of finding in residential occupancies as they are not typically inspected.

11. What issues/problems have been found with the legislation? Are the requirements adequate?

Yes. We believe the current codes address the requirements adequately.

12. With the benefit of hindsight, what changes (if any) to your legislation would you recommend?

Sprinkler requirements for multi unit housing and high density housing areas.

13. Are there any measureable outcomes that the legislation may have influenced? For example, has there been a decrease in the number of fatalities and/or injuries responded to by your agency per 100,000 homes? How big of an impact has there been?

Unsure of the data as the law has been in effect since the early 1990s. We have seen a decrease in fire deaths in the state the past 5 years but can not attribute it to this law.

One point of interest is that although alarms are required, 85% of the fire deaths in our state indicate that the alarm was disabled, not working, or not installed at all.

14. Please reference any surveys and/or evaluations of compliance and/or effectiveness of smoke alarms in your location.

15. If your state does not have any smoke alarm legislative requirements for residential properties, are there recommended practices from the Fire Department(s), Fire Protection Authorities, etc.? Please provide links if possible.

Appendix J: Example of Completed Database Page

<table>
<tr><td colspan="2" align="center">Washington</td></tr>
<tr><td rowspan="5">
</td><td>Population (2005) - 6,287,759</td></tr>
<tr><td>Population Density - Persons per sq.mi (2000) - 88.6</td></tr>
<tr><td>Average Annual Income - USD (1999) - $22,973</td></tr>
<tr><td>Median Annual Income - USD (2003) - $48,185</td></tr>
<tr><td>State GDP - USD (in billions) (2006) - $311.200</td></tr>
</table>

Above information obtained and derived from: http://www.infoplease.com/us/census/data; http://www.nam.org/TradeData/StateData.aspx

Above graphic obtained from: http://encarta.msn.com/encnet/features/mapcenter/map.aspx

This state has smoke alarm legislation for residential settings: Yes
State smoke alarm legislation URL or source: www.leg.wa.gov
Smoke alarm legislation enacted in: **Month**: No data **Year**: Early 1980's
State requires smoke alarms:

On every floor: No **In basement:** No **In attic:** No **On entry level:** No **Inside each bedroom:** Yes, in new construction **Outside each bedroom:** Yes, in existing homes (inside room also acceptable) **In hallways:** Yes **In living areas:** No
State requirements for smoke alarms: **Legislation specifies type:** No ***If yes:*** **Ionization:** **Photoelectric:** **Combination:** **Legislation specifies power source:** Yes ***If yes:*** **Hard-wired:** No **Hard-wired w/ battery back-up:** Yes **Battery-powered:** No **Legistion requires interconnectivity:** No data
Smoke alarm legislation is governed on a more local basis: No

Compliance information: Local authorities are reponsible for compliance although it is not typically inspected.
Inadequacies of or recommendations to current smoke alarm legislation: It is believed that the legislation is adequate. One recomendation that was made is for sprinkler systems in multi unit housing and high density housing areas.
Additional comments: There has been a decrease in fire deaths over the last five years in Washington; however, this cannot be directly attributed to their smoke alarm legislation. Fire death statistics in Washington show that 85% of fire deaths occur where the smoke alarms are disabled, not working, or not installed at all.

Above information obtained from: Washington Survey

Appendix K: Excerpts from Ian Thomas Interview

Date: March 20, 2009
Time: 1:00 PM
Attendees: Timothy Manchester, John Meklenburg, Kemal Moise, Brian Potts, Ian Thomas, Dorothy Bruck
Location: Victoria University, Werribee Campus, VIC, Australia

Background: Ian Thomas, a fire engineer, is a professor at Victoria University in Werribee, Victoria, Australia and is the director of their "Centre for Environmental Safety and Risk Engineering." He works closely with Dr. Dorothy Bruck and joined us for our interview. Together they research effectiveness of smoke alarm warning tones on different populations as well as other aspects of fire protection. Below are sections used to support text in the report.

Excerpts: "You need to think about the actual effectiveness of smoke alarms."

"There are claims made by various people about how effective smoke alarms are in terms of reducing the number of fatalities from fire. If smoke alarms were a pharmaceutical product they wouldn't be allowed to be used because they haven't been tested properly. Well, if you think about it, if you want to put out a tablet for something, what you have to do is you first of all have to test it in an appropriate way. And the appropriate way is to do a double blind test where neither the tester, nor the person who's taking the tablet, knows whether they've got the real thing or not. And it's when you do a double blind test that you can really tell whether something works or not."

"The really important thing about it is, just because it's in the stats, [it] doesn't say that its smoke alarms that cause that difference. There might be other reasons why there's a difference in fatality rates."

"People are currently looking at dual detectors. If you put in a photoelectric detector and an ionization detector you can do it in two ways. If you put in an ionization detector as it is sold separately, then it'll detect the fire that it would've detected when it was sold simply as an ionization detector. If you then put in a photoelectric detector as well, then what you've achieved by doing that is you actually get it to sound when the first of those would have detected something, and that's an OR gate. And that does two things it gets it to sound as early as the first one would've sounded but it makes it less reliable because you get the false alarms from either of them. The alternative to that is that you put in an AND gate instead, so you require both of them to go off. That's likely to make them more reliable but it's also likely to make it significantly later because you wait for the last one to be triggered. The alternative that the manufacturers can do is to tweak the sensitivity of both of them, that way you can get something that's different from either the AND gate or the OR gate with the original sensitivities."

Appendix L: Excerpts from Naomi Brown Interview

Date: April 2, 2009
Time: 9:00 AM
Attendees: Timothy Manchester, John Meklenburg, Kemal Moise, Brian Potts, Naomi Brown
Location: Vic Def Building, Melbourne, VIC, Australia

Background: Naomi Brown is the CEO of the Australasian Fire and Emergency Services Council (AFAC) located in Melbourne Victoria. AFAC is comprised of members from all Australian states and territories, New Zealand, and the Pacific. AFAC aims to strengthen fire and emergency services through sharing, collaboration and innovation.[2]

Excerpts: "AFAC published a position on smoke alarms in June 2006. The position expressed AFAC's position on a number of issues related to domestic smoke alarms installed in residential accommodation or those buildings defined by the Building Code of Australia as Class 1 buildings and sole occupancy units in Class 2, 3 & 4 buildings."

"AFAC in fact commissioned the Bushfire Cooperative Research Centre to undertake a review of the literature, and data analysis and potential testing program, to determine the most effective means for the early detection of fire or smoke in the Australasian residential environment"

"The aim of the project was to inform AFAC on the efficacy of the position. The Bushfire CRC outsourced both the literature review and data analysis to the Centre for Environmental Safety and Risk Engineering, Victoria University."

"We received an early draft of the literature review and had discussions with Victoria University prior to releasing our June 2006 Position. The literature review suggested that ionization alarms do not provide adequate egress time for smoldering fire in all circumstances. Photoelectric smoke alarms are better at detecting shouldering fires while still providing adequate egress time for flaming fires, and hence should be the preferred type recommended. Photoelectric smoke alarms provide better overall smoke detection performance than ionization smoke alarms. Limited conclusions could be drawn from the data owing to its poor quality."

"I think nearly every state now has legislation whereby if you're building a new house or you're renovating an old house, you must install hard-wired smoke alarms so it's now coming to legislation but we can't get the legislators to say that it must be photoelectric and the link into that is a thing called the Australian Building Code and the people who run that are the Australian Building Code Board."

[2] http://www.afac.com.au/who_we_are

Appendix M: Excerpts from Dorothy Bruck Interview

Date: March 20, 2009
Time: 1:00 PM
Attendees: Timothy Manchester, John Meklenburg, Kemal Moise, Brian Potts, Dorothy Bruck, Ian Thomas
Location: Victoria University, Werribee Campus, VIC, Australia

Background: Dr. Dorothy Bruck is a professor and researcher at Victoria University in Werribee, Victoria, Australia and specializes in psychobiology and health psychology. Her research interests include sleep pathology and human responses to fire emergencies.[3] She works closely with Professor Ian Thomas, director of the "Centre for Environmental Safety and Risk Engineering. Together they research effectiveness of smoke alarm warning tones on different populations as well as other aspects of fire protection. Below are sections used to support text in the report.

Excerpts: "…one of the other more interesting things is most recently I've been talking to people from the Hearing Loss of America Association, and they're very interested to know whether the responsiveness to strobe will vary if you've got acquired deafness or if you've been deaf from birth, with the idea that people who have been deaf from birth may have developed a much stronger sensitivity to visual cues than those that have got acquired deafness."

"The other thing that you might find interesting that is in our later papers but not in the human factors paper is the theoretical reason why a square wave might be quite good. You all know what a square wave is don't you? It's got the fundamental frequency and at each alternate harmonic it's got peaks, so it's a very complex wave. What seems to happen is that each one of these peaks stimulates a different part of the basilar membrane in our inner ear. This makes it seem louder. Apparently they use that fact in some advertisements. You know how sometimes advertisements on TV come up a lot louder? Apparently some of them use the complex wave, the square wave pattern, in the material that they use because it makes everything sound louder even though if you're measuring it on a sound meter it comes up at the same level."

[3] http://www.staff.vu.edu.au/PsychDept/staff%20profiles/Bruck.html

Appendix N: Summary of International Smoke Alarm Legislation

Country (State/Province/Territory)	Effective Date	Dwellings Affected	Alarm	Responsibility/Enforcement
Australia	None			
Australia (ACT)	1994	New Buildings and Major Alterations	Hard-wired w/ battery in new Smoke Alarms in Major Renovations	ACT Planning and Land Authority
Australia (New South Wales)	New: 1996 Exist: 2006	Houses, Flats, and Units	Hard-wired w/ battery in new Smoke Alarms in existing residences	Local Government / Max A$550
Australia (Northern Territory)	2005	New	Hard-wired w/ battery	Building Certifier
Australia (Queensland)	New: 1997 Exist: 2007	All	Hard-wired w/ battery in homes built after July 1997 Smoke Alarms in homes built before July 1997	Fire Officers and Queensland Land Registry / Max A$375
Australia (South Australia)	All: 1993 New: 1995 Change of Ownership: 1998	All	Smoke Alarms in all Hard-wired w/ battery in new Hard-wired w/ battery or 10-Year in change of ownership after February 1998	Local council / A$750
Australia (Tasmania)	1994	New	Hard-wired w/ battery	Local council
Australia (Victoria)	New: 1997 Exist: 1997	All	Hard-wired w/ battery in new Smoke Alarms in existing	Municipal Building Surveyor
Australia (Western Australia)	New: 1997 Exist: New Legislation Proposed	New Buildings and Major Alterations	Hard-wired w/ battery in new New Legislation Proposed to require hard-wired in existing	Local Government
Austria [3]	None			
Belgium	None			
Canada	None			
Canada (Alberta)	1970s	All	Hard-wired	Owner
Canada (British Columbia)	1977	New	Hard-wired, Interconnected	Local Building Official
Canada (Manitoba) [3]	New: 1981 Exist: 1987	All	Hard-wired in new Any Type and Power in existing	No data
Canada (New Brunswick)	1982	All	Any Alarm	Office of the Fire Marshal
Canada (Northwest Territories)	1990	All	Hard-wired, Interconnected	Office of the Fire Marshal
Canada (Nova Scotia)	1987	New Buildings and Major Alterations	Any Type [1,2]	Building Officials and Fire Inspectors
Canada (Ontario)	2007	All	Any Type [1,2]	Owner
Canada (Prince Edward Island)	No data	All	Hard-wired w/ battery, Interconnected	No data
Canada (Quebec)	2008	Residential buildings more than 2 stories and 8 units	Photoelectric [1,2]	No data
China	None			
Denmark	2004	All	Hard-wired w/ battery	Owner
Egypt	None			
England	1992	New	Hard-wired, Interconnected	Building Inspectors
Finland	2002	All	Any Type and Power [2]	Owner
France	None		*No Ionization*	
Hong Kong	None			
Indonesia	None			

Italy	None			
Japan	2006	All	Any Type [1,2]	Owner
Malaysia	None			
Netherlands [3]	Delayed	New	Hard-wired, Interconnected	Local Authority
Northern Ireland [3]	1994	New Buildings and Major Alterations	Hard-wired	Building Inspectors
New Zealand	2003	New Buildings and Major Alterations	Any Alarm	Local Government
Norway	1990	All	Any Type [1,2]	Owner
Pakistan	None			
Scotland	1994	New	Hard-wired w/ battery, Interconnected	Owner
Singapore	None			
South Africa	None			
South Korea	None			
Spain	None			
Sweden	2004	All	Any Alarm	Local Building Authority
Switzerland	None		*No Ionization*	
United Kingdom	No data	All	Hard-wired w/ battery [2]	Owner
United States	None			
USA (Alabama)	No data	All	Any Type [1,2]	Local Code Enforcement Authority
USA (Alaska) [3]	1975	All	Per State Marshal	Owner and State Fire Marshall
USA (Arizona) [3]	1983	New Buildings and Major Alterations	Any Alarm	Builder or Owner
USA (Arkansas)	2008	All	Hard-wired w/ battery, Interconnected	No data
USA (California) [3]	New: 1987 Major Alt: 1986 Sold: 1985	New Buildings, Major Alterations, and Sold Homes	Battery	Owner
USA (Colorado)	None			
USA (Connecticut)	1976	All	Hard-wired w/ battery [2]	No data
USA (Delaware)	1993	All	Hard-wired, Interconnected in new Battery in existing	County Building Official
USA (District of Columbia) [3]	1978	All	Any Alarm	Owner / $100-300
USA (Florida)	2008	All	Any Type [1,2]	Local Fire and Building Official
USA (Georgia)	2001	All	Any Type [1,2]	No Specific Authority
USA (Hawaii) [3]	None			
USA (Idaho) [3]	1994	All	Battery	Owner
USA (Illinois) [3]	1987	All	Any Alarm	Owner
USA (Indiana) [3]	1982	All	Any Alarm	Owner
USA (Iowa)	1970s	New	Combination, Hard-wired w/ battery, Interconnected	Owner
USA (Kansas)	1999	New	Hard-wired [2]	Local and State Fire Marshal
USA (Kentucky) [3]	None			
USA (Louisiana) [3]	1991	New 1 and 2 family		
USA (Maine)	1985	All	Any Alarm	Code Official
USA (Maryland)	1984	New	Hard-wired w/ battery, Interconnected	Local and State Fire Marshal
USA (Massachusetts)	1980	All	Hard-wired w/ battery, Interconnected for apartments Any Alarm for other	Fire Departments
USA (Michigan) [3]	1974	Mobile Homes (new or newly sold)		Owner / Misdemeanor

USA (Minnesota)	1977	All	Battery in homes built prior to 1989 Hard-wired, Interconnected in homes built prior to 2006 Hard-wired w/ battery, Interconnected in homes built after 2006	Inspecting agency / Written warning then Misdemeanor
USA (Mississippi)	None			
USA (Missouri)	None			
USA (Montana)	None			
USA (Nebraska) [3]	1981	All	Any Alarm	Owner or agent / Misdemeanor
USA (Nevada)	None			
USA (New Hampshire)	1986	All	Interconnected [1]	State Fire Marshal or Local Fire Official
USA (New Jersey)	1983	New	Interconnected	Commissioner for the Department of Community Affairs
USA (New Mexico) [3]	None			
USA (New York)	1995	All	Any Type [1,2]	Department of State
USA (North Carolina)	2008	All	Hard-wired w/ battery, Interconnected	Local Building Inspection Departments
USA (North Dakota)	1995	Motel & Rental Property	Battery [2]	Health Department or Lessee / Infraction then Misdemeanor
USA (Ohio)	None			
USA (Oklahoma)	1997	New	Any Type [1,2]	State Fire Marshal's Office
USA (Oregon) [3]	1997	All	Long-life battery or hard-wired	State Fire Marshal
USA (Pennsylvania)	None			
USA (Rhode Island)	2004	All	Any Type [1,2]	State Fire Marshal's Office
USA (South Carolina)	No data	All	Battery in some existing Hard-wired in new	Local Fire Official / Misdemeanor consisting of fines or even imprisonment
USA (South Dakota)	None			
USA (Tennessee)	2006	All	Battery in some existing [2] Hard-wired in new [2]	Department of Commerce and Insurance
USA (Texas)	2006	All	Hard-wired w /battery, Interconnected	Local Authority Having Jurisdiction
USA (Utah) [3]	None			
USA (Vermont)	2008	All	Photoelectric, Hard-wired w/ battery	Department of Public Safety
USA (Virginia) [3]	None			
USA (Washington)	Early 1980s	All	Hard-wired w/ battery [2]	Local Authorities
USA (West Virginia) [3]	1991	1 and 2 family	Any Alarm	Owner / $50-100
USA (Wisconsin) [3]	1978	1 and 2 family, mobile homes	Any Alarm	Owner / $25-500
USA (Wyoming)	None			
Wales	1992	New	Hard-wired, Interconnected	Building Inspectors

[1] No data on survey regarding power source
[2] No data on survey regarding interconnectivity
[3] ISCAIP. (1999). International smoke detector legislation--ISCAIP smoke detector legislation collaborators. *Injury Prevention : Journal of the International Society for Child and Adolescent Injury Prevention, 5*(4), 254-255.

NOTE: Updates or corrections to information in this table can be sent to FPA Australia via e-mail at database@fpaa.com.au. Please include "WPI Smoke Alarm Database Update" in the subject line of the e-mail.