Smoke Alarms and the Modern Residence Fire:

Recent Studies and Research at UL

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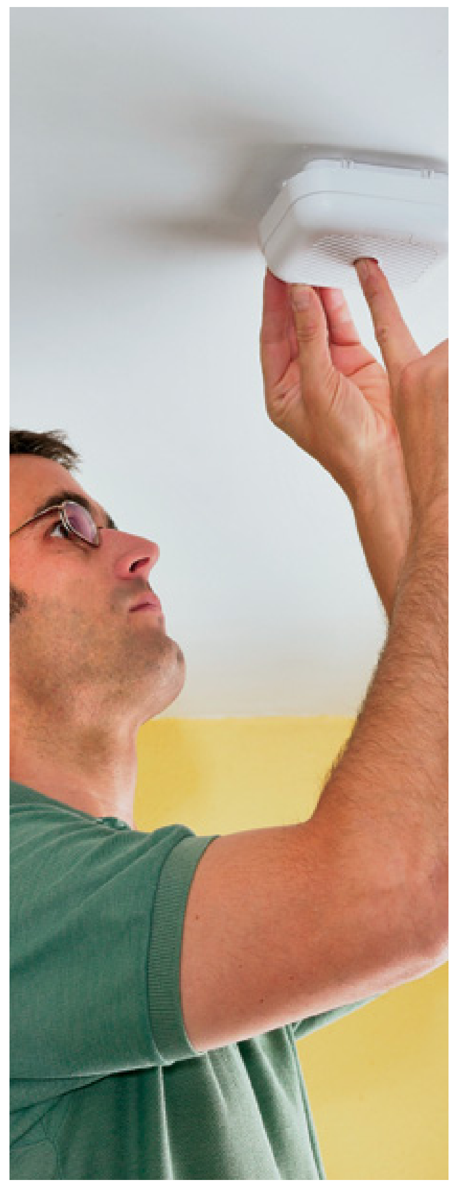
UL's Fire Experts Research Effectiveness of Smoke Alarm Technology

Recent research regarding the modern residence fire is providing new insights into the advantages and limitations of current smoke alarm technologies. This white paper summarizes recent and current research conducted at UL on the changing nature of residential fires and the effectiveness of smoke alarm technologies, and discusses the implications of this research for future standards development.



Home smoke alarms provide a critical first line of defense for occupants in residential settings should a fire occur. Their widespread use can be directly linked with the dramatic decline in deaths related to residential fires over the past 30+ years. During this same time period, residences have also changed. Homes have increased in size, the number and amount of furnishings and possessions have grown, and petroleum-based synthetic materials have supplanted natural materials in furnishings and home construction products.

The combination of these factors has changed the smoke and gas characteristics of residential fires and in some cases accelerated the speed of fire growth.

For the past several years, the changing nature of residential fires has been the focus of extensive research by scientists and engineers at UL and other institutions. The goal of this research is to increase the understanding of the range of expected conditions, e.g., smoke, temperature, gases in modern residential fires, and to ensure that smoke alarm technologies continue to provide individuals with the greatest possible protection in the event of a fire.

Smoke Alarms – A Proven History of Reducing Fire Deaths and Injuries

Commercially available residential smoke detectors and smoke alarms have been largely responsible for the dramatic decline in residential fire deaths and injuries in the past 30 years. According to research conducted by the National Fire Protection Association (NFPA) on data collected from the U.S. Fire

Administration's (USFA) National Fire Incident Reporting System (NFIRS) and the NFPA annual fire department experience survey, home fires accounted for 5865 deaths and more than 31000 injuries in 1977, when only 22% of homes were equipped with smoke alarms. [Karter 2004, Ahrens 2007]

By 2009, when more than 95% of homes were equipped with smoke alarms, the annual death rate from home fires had dropped to 2565, a 56% decline, and injuries dropped by more than 59% over a 32 year span. [Karter 2010, Ahrens 2010] While the entire reduction in deaths is not completely attributable to smoke alarm use adoption, it is a leading factor in the reduction of deaths over this period of time.

During 2003-2007, roughly 1 of every 300 households reported a fire requiring intervention by the fire service. [Ahrens 2010] Of these 385000 fires per year, the 4% of households that do not have smoke alarms account for 31% of fires and 40% of deaths. [Ahrens 2010]

Furthermore, another 30% of deaths occur in households with installed, viable smoke alarms that were disabled or were otherwise not working. [Ahrens 2010] By providing occupants with advanced notice of the threat of a fire and additional time to escape, the presence of working smoke alarms is often the difference between escaping a home fire without injury and succumbing to it.

In the context of these statistics, it is understandable that significant public safety efforts are focused on ensuring that working smoke alarms are installed in 100% of homes. But at least one recent study by the National Institute of Standards and Technology (NIST) has shown that, even when working smoke alarms are present, the margin between available and safe egress times has shrunk over the past 30 years. [Bukowski 2004]

This trend suggests the presence of other emerging factors that have the potential to impact the effectiveness of smoke alarms in home fires. Most notably, it is the changing nature of the modern residence that is challenging the adequate egress time provided by smoke alarms.

The Changing Nature of the Modern Residence

In a never-ending effort to reduce production costs and improve product performance, manufacturers of home furnishings are turning away from materials like wood and natural fibers in favor of high-performance, lower-cost synthetic materials. For example, most upholstered furniture available today utilizes polyurethane foam for padding and synthetic fabric covers, replacing natural padding materials like cotton, down and feathers, and cover materials made of cotton, wool, linen or silk.

While these material changes can lead to products that are easier to clean and more resistant to normal wear and tear, they also react differently when exposed to an ignition source. Studies by UL researchers have found that synthetic materials typically ignite faster, burn more intensely, release their fire-enabled energy faster, and create greater amounts of smoke than natural materials. [Fabian 2007]

In addition, the type and quantity of smoke particles and gases generated when synthetic materials are ignited is characteristically different from that of natural materials.

The seemingly insignificant change from natural to synthetic materials in home furnishings has led to the faster development of residence fires and to the more rapid onset of untenable conditions. As such, the amount of time available for safe egress from a home fire is much shorter than in the past, placing a greater burden on smoke alarms to respond at the earliest possible stages of a fire.

Smoldering fires extend the time before lethal conditions are reached but also provide more time for smoke detection and warning to occupants. These fires are slow growing and may or may not transition to rapidly growing flaming fires. In a recent NIST study, initial smoldering phases lasted anywhere from 30 to 120 minutes before fire conditions became untenable. [Bukowski 2004]

While NFPA studies have determined that more than 25% of home fire deaths involve an extended initial smoldering phase, it is estimated that roughly 3% of the deaths involve fires that did not transition from smoldering to flaming. [Hall 2000]

Smoke Detection Technologies

Today's residential smoke alarms are largely based on one of two prevailing detection technologies: photoelectric or ionization. Ionization-based smoke alarms operate by monitoring a small current created by ionized air between electrically charged plates; smoke particles will reduce the current. A photoelectric-based smoke alarm, on the other hand, detects the scattering or obscuration of light caused by smoke particulates. In both cases, the units trigger when the signal crosses a set threshold value.

Research has shown that each smoke alarm technology has unique advantages under certain fire conditions. In controlled experiments, smoke alarms based on ionization technology tend to activate more quickly than those based on photoelectric technology in flaming fires, while photoelectric alarms tend to activate earlier than ionization alarms in smoldering fires. [IAFC 2008]

Additional research by UL on individual materials and items further clarifies these trends even for the same material. For example, when polyurethane foam (used in mattresses and upholstered furniture) was ignited with a cigarette lighter to flame, the ionization alarms activated earlier; when the same polyurethane foam was smoldered, such as from a cigarette, the photoelectric alarm activated earlier. [Fabian 2007]

Of course, the key challenge in selecting the appropriate smoke alarm technology is the inability to predict the type of home fire that is likely to occur. For that reason, nationally recognized fire safety organizations including NFPA, USFA, International Association of Fire Chiefs (IAFC), NIST, National Association of State Fire Marshals (NASFM) and UL all currently recommend the use of both photoelectric and ionization smoke alarms in residential settings, or the use of smoke alarms incorporating both types of these sensing technologies in a single device, in order to provide individuals with the earliest possible warning and the longest possible escape time, regardless of the type of fire encountered.

At the same time, ongoing studies are providing researchers with a more advanced understanding of the characteristics of various types of fires, along with their smoke and gas byproducts, leading to the development of more complex and detailed fire profiles that can be integrated into current fire detection technologies.

Innovations in Smoke Alarm Technologies

In addition to the ionization and photoelectric smoke detection technologies that have been available for many years, a new generation of smoke detection technologies are being developed in industry. The goal of these efforts is to produce a smoke alarm that reacts more effectively to fires in the modern home.

In an effort to promote innovation of new smoke detection technologies, the UL 217 smoke alarm standard does not restrict the types of smoke detection technologies that can be employed in smoke alarms, provided they can meet the performance tests specified in the standard. Similarly, the NFPA 72 National Fire Alarm Code does not place restrictions on the smoke detection technologies that can be used.

Research by UL

Researchers at UL have been actively engaged in ongoing investigations regarding the changing nature of modern fires and the effectiveness of current smoke detection technologies.

UL currently recommends the use of both photoelectric and ionization smoke alarms in residential settings, or the use of smoke alarms incorporating both types of these sensing technologies in a single device, in order to provide individuals with the earliest possible warning and the longest possible escape time, regardless of the type of fire encountered.

This research has led to some important findings that will guide future UL Standards development activities involving smoke alarms.

The following sections summarize some of UL's research regarding smoke alarms and modern residence fires, details the key recommendations produced by the studies that have been completed, and outlines future steps for those studies still in progress.

Smoke Characterization Project [Fabian 2007]

In 2006 in conjunction with the Fire Protection Research Foundation (FPRF) of the NFPA, and as a follow up to a 2004 NIST study, UL initiated a Smoke Characterization Project. In that earlier NIST study, researchers observed a reduction in available safe egress times, attributed to significantly faster fire growth caused by the types of materials used in modern furnishings.

The purpose of the UL-FPRF Smoke Characterization Project was to more fully characterize the products of both flaming and non-flaming combustion on a variety of products and materials typically found in residential settings. This study used smoke particle and gas effluent characterization technology that had not been previously available for commercial testing purposes.

Testing scenarios included the standard UL 217 smoke alarm fire test protocols, including a burning coffee maker, a toaster with a bypassed shutoff, and flaming and smoldering upholstered furniture components.

The Smoke Characterization Project study produced the following key findings:

- Synthetic materials ignite faster, burn more intensely and create greater amounts of smoke and other types of gases than natural materials.
- The response time of photoelectric and ionization smoke alarms was influenced by different smoke particle sizes and counts due to changes in the combustion mode (flaming versus non-flaming).
- Commercially available ionization smoke alarms triggered earlier than commercially available photoelectric smoke alarms for flaming and high energy non-flaming (toaster) fires.
- Photoelectric alarms triggered earlier for lower energy non-flaming fires.
- Smoke from low energy non-flaming fires was found to stratify with time.

The full report of the Smoke Characterization Project is publicly available at http://www.nfpa.org/assets/files//PDF/Research/SmokeCharacterization.pdf.

Firefighter Exposure to Smoke Particulates [Fabian 2010]

One of the key observations noted in the UL-FPRF Smoke Characterization Project was the predominance of sub-micron sized smoke particles generated by combustion. Other studies have shown that such particles penetrate the human cardiovascular system, and can be subsequently absorbed into the body. Throughout their professional careers, firefighters are exposed to intense heat, smoke particulate and fire gas effluents. Firefighters also have a history of greater cardiovascular risks and certain types of cancers than the general population.

In 2007 to further investigate the causal relationship between sub-micron smoke particles and the risk of cardiovascular problems, UL partnered with the Chicago Fire Department and the University of Cincinnati College of Medicine to collect data on the smoke and gas effluents to which firefighters are exposed during routine firefighting operations, as well as contact exposure from contaminated personal protective equipment. This research was funded by a grant from U.S. Department of Homeland Security (DHS).

As a component of this study, the combustibility, smoke and gas characteristics of 42 different residential construction and furnishing materials were characterized using the methodology developed in the UL-FPRF Smoke Characterization Project. This increased the number of measured smoke signatures from the 18 materials, originally completed in the UL-FPRF Smoke Characterization Project, to the 60 smoke signatures now currently identified.

The Firefighter Exposure to Smoke Project study produced the following key findings:

- Concentrations of combustion products were found to vary tremendously from fire to fire, depending on the size, the chemistry of materials involved, and the ventilation conditions of the fire.
- The type and quantity of smoke particles and gases generated depended on the chemistry and physical form of the materials being burned. However, synthetic materials produced more smoke than natural materials.
- Combustion of the materials generated asphyxiants, irritants, and airborne carcinogenic byproducts that could be potentially debilitating.
- Multiple asphyxiants, irritants and carcinogenic materials were found in smoke during both suppression and overhaul phases. Carcinogenic chemicals may act topically, following inhalation, or following dermal absorption, including from contaminated equipment.
- Long-term repeated exposure may accelerate cardiovascular mortality and the initiation and/or progression of atherosclerosis.

The full report of this research is publicly available on the project's webpage at UL's website (www.ul.com/fireservice).

Smoke Alarm Fire Tests

In the UL-FPRF Smoke Characterization Project discussed above, researchers determined that flaming and non-flaming polyurethane foam produces smoke with characteristics that are different from those used to evaluate smoke alarms under UL 217.

Accordingly, in 2008, UL formed a Task Group under the UL 217 Standards Technical Panel (STP), to develop appropriate tests for flaming and non-flaming polyurethane foam. The objective of the Task Group is to expand the number of smoke signatures to which smoke alarms are evaluated under the standard.

To date, the Task Group has established target performance criteria for the new fire tests that will not inadvertently cause an increase in nuisance alarm frequency. UL has also investigated the smoke produced by samples of commercially available foams used in mattresses and upholstered furniture, covering a range of densities.

In addition, the Task Group has investigated how sample size, geometry, density, mode of combustion, and mode of heating impacts smoke particle size, count distribution and smoke concentration build-up rates.

In the final stages of its work, the Task Group is using the results of its work to select the test foam material and the flaming and smoldering test protocols to be proposed to the UL 217 STP. Test material specifications and test consistency limits are now being formulated for the selected test protocols generated by the Task Group.

One unanticipated issue in the development of material specifications and test consistency limits has been the discovery that the cell size of polyurethane foam (independent of the foam density) significantly impacts the smoke build-up rate, particularly for the slower smoldering fire test protocol. To address this issue, the Task Group is currently pursuing two approaches:

1) Develop test material specifications and test consistency limits for a range of commercially available foams meeting the test material property targets
2) Develop a standard reference for polyurethane foam

Once the material properties (chemistry, density, indentation load density, cell size, etc.) have been established, the proposed test protocols will be repeated 30 times to establish the test consistency limits, and the Task Group will submit the developed test protocols (including test sample specifications) to the UL 217 STP for review and consideration.

Comparison of Modern and Legacy Home Furnishings [Kerber 2010]

Funded through an Assistance to Firefighters Grant from the U.S. Department of Homeland Security, UL researchers recently completed an investigation on impact of fire service ventilation practices on fire growth in modern and legacy residences.

As a part of this study the fire growth behavior in modern and legacy furnished living rooms was examined in side-by-side fires. Each living room measured 12 ft. by 12 ft., with an 8 ft. ceiling and an 8 ft. wide by 7 ft. tall opening on the front wall.

The modern room was lined with a layer of ½ inch painted gypsum board and the floor was covered with carpet and padding. The furnishings included a microfiber covered polyurethane foam filled sectional sofa, engineered wood coffee table, end table, television stand and book case. The sofa had a polyester throw placed on its right side. The end table had a lamp with polyester shade on top of it and a wicker basket inside it. The coffee table had six color magazines, a television remote and a synthetic plant on it. The television stand had a color magazine and a 37 inch flat panel television. The book case had two small plastic bins, two picture frames and two glass vases on it. The right rear corner of the room had a plastic toy bin, a plastic toy tub and four stuffed toys. The rear wall had polyester curtains hanging from a metal rod and the side walls had wood framed pictures hung on them.

The legacy room was lined with a layer of ½ inch painted cement board and the floor was covered with unfinished hardwood flooring. The furnishings included a cotton-covered/cotton-batting filled sectional sofa, a solid wood coffee table, two end tables and a traditional television stand. A cotton throw was placed on the right side of the sofa. Both end tables had a lamp with polyester shade on top. Two paperback books were placed near the lamp on the left side of sofa and a wicker basket was located on the floor to the right of the sofa at the floor level. The coffee table had three hard-covered books, a television remote and a plant made of synthetic materials. The television stand had a 27 inch tube television. The right front corner of the room had a wood toy bin, and multiple wood toys. The rear wall had cotton curtains hanging from a metal rod and the side walls had wood framed pictures hung on them.

Both rooms were ignited by placing a lit stick candle on the right side of the sofa. The fires were allowed to grow until flashover. The legacy room transitioned to flashover in 29 minutes and 30 seconds whereas the modern room transitioned in just 3 minutes and 30 seconds.

The full report of this research, *Impact of Ventilation on Fire Behavior in Legacy and Contemporary Residential Construction*, and the video showing the two burning rooms are publicly available on the ventilation project webpage at UL's website (www.ul.com/fireservice).

Smoke Alarm Response Project

This study is intended to characterize smoke and gas conditions in various locations throughout a modern, two-story open floor plan residence to evaluate the response rate of different smoke detection technologies and assess the benefits of having alarms in multiple locations. The various scenarios investigated in this project include cooking in the kitchen, e.g., making toast, frying bacon, a cooking oil fire, smoldering and flaming upholstered furniture fires in the two-story family room, smoldering and flaming upholstered furniture fires in a den, and mattress fires in the bedrooms. The standard test protocols found in UL 217 to evaluate smoke alarms were also conducted in the living room.

UL is currently analyzing the recorded data, including smoke particle size and count distribution, effluent gas composition, reference obscuration and ionization signals, analog photoelectric and ionization detector signals, and temperature. A final report summarizing the research from this project is expected to be released in the near future, and will be publicly available through UL's website (www.ul.com/fireservice).

Implications

National and local building codes and regulations have been responsible for the almost universal installation of smoke alarms in residential structures over the past decade. These codes are continually revised to reflect the knowledge gained through ongoing research and product development. Because of these ongoing efforts, smoke alarms installed in today's residences are more effective and reliable than ever.

The studies and research efforts discussed in this white paper illustrate the extent to which UL researchers are actively engaged in better understanding the changing nature of residence fires, and the ramifications for smoke detection systems and smoke alarm technologies.

As the results of this research are made available, further changes to UL 217 smoke alarm standard and model codes can be expected. Although the transition of enhanced safety requirements from product safety standards to codes and regulations often proceeds in a seemingly non-linear fashion, such enhancements are also critical in ensuring that codes and regulations provide the highest possible level of safety.

The ultimate goal of UL's smoke alarm research is to provide the technological data that can help eliminate fire deaths in residential dwelling units. This can lead to advancements in product safety standards, model codes and regulations. Achieving that goal also depends on having working smoke alarms installed in every home, and on continuing programs that effectively educate consumers about the dangers of residence fires, and the actions that they can take to ensure their safety. Taken together, these steps will lead to safer homes and fewer injuries and lives lost to fire.

For more information about Smoke Alarms and the Modern Residence Fire, please contact Tom Fabian, Ph.D., research manager for Fire Hazard, UL, and Pravin Gandhi, Ph.D., director of Global Corporate Research, UL.

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