Bringing Science to the Street: UL and Firefighter Safety Research

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According to data compiled by the U.S. Fire Administration, 1160 firefighters died as a result of injuries sustained in the line of duty during the period from 2001 through 2011.[1] Although the annual number of total firefighter deaths has declined in recent years, firefighter deaths that occur inside of structures are occurring at higher rates than those reported in the 1970s and 1980s, despite a decrease in the overall number of fires.[2] In addition, ongoing changes in construction methods, building materials, home designs and products used in home furnishings present new potential safety challenges under fire conditions. Ongoing research into the characteristics of the modern residential fire is therefore essential to reduce safety risks and to protect the lives of firefighters and occupants alike.

UL has long been in forefront of fire safety research to support efforts that prevent unnecessary fire-related deaths. Much of this research has been directed toward developing a better understanding of the characteristics of the modern residential fire, and providing members of the fire service with the information and knowledge needed to modify key firefighting tactics. While firefighting will never be without risk, UL research represents a vital contribution to overall efforts to reduce risks and to save lives.

Here is a summary of some of UL's recent and current fire safety research projects, and their implications for firefighter safety.

Structural Stability of Engineered Lumber in Fire Conditions [3]

Lightweight wood trusses and engineered lumber are increasingly replacing conventional solid joist construction in roof and floor designs in residential structures. But fire performance data on lightweight construction materials has been insufficient to assess whether the use of these materials pose an increased risk to firefighters. In collaboration with the Chicago Fire Department, Michigan State University and the International Association of Fire Chiefs, UL researchers compared the fire performance of conventional solid joist lumber with that of lightweight lumber. The study results demonstrated that, under controlled conditions, fire containment performance of an assembly supported by solid joist construction was significantly better than an assembly supported by an engineered I joist.

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Firefighter Exposure to Smoke Particulates [4]

In this study, 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 and from contact with contaminated personal protective equipment. The project included investigations on three fire scales: 1) fires in the Chicago metropolitan area; 2) residential room content and automobile fires; and 3) material-level fire tests. The study determined that the combustion of materials in a fire generates asphyxiants, irritants and airborne carcinogenic byproducts that can be debilitating to firefighters. These byproducts are also found in smoke during the suppression and overhaul phases of firefighting, and carcinogenic materials can be inhaled from the air or absorbed through the skin through contact with contaminated equipment.

Moreover, the 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.
- Long-term repeated exposure may accelerate cardiovascular mortality and the initiation and/or progression of atherosclerosis.

Firefighter Safety and Photovoltaic Systems [5]

Photovoltaic (PV) array systems used to generate solar energy pose unique electrical and fire hazards, but there has been limited data available about the risks to firefighters dealing with fires involving these systems. UL conducted testing on functional PV array fixtures at its Northbrook, IL facility and at the Delaware County Emergency Service

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Training Center to quantify the potential hazards associated with fire scenarios involving PV installations. Among other findings, this testing identified the hazards associated with the application of water to a PV array during firefighting suppression efforts, as well as effective PV array de-energizing practices. UL's research has also provided a basis for the development of updated firefighting operational practices in dealing with energized PV arrays.

Basement Fires and the Integrity of Engineered Floor Systems [6]

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The objective of this UL study was to increase knowledge on the response of residential flooring systems to fires originating in a basement area. Today's flooring system components and floor covering materials are designed to limit the flow of thermal energy. As a result, materials on the underside (i.e., basement side) of a floor can be on fire while exhibiting only modest temperature increases on the top side. Standard integrity assessments, such as sounding the floor, floor sag, gas temperatures on the floor above and thermal imaging, are imperfect indicators of the actual integrity of a floor over a burning fire. The study results identified a number of tactical issues for firefighters to consider when making a determination about dealing with residential basement fires. These tactical

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considerations include:

- Collapse times of all unprotected wood floor systems are within the operational time frame of the fire service regardless of response time.
- Size-up should include the location of the basement fire as well as the amount of ventilation. Collapse always originated above the fire and the more ventilation available the faster the time to floor collapse.
- When possible the floor should be inspected from below prior to operating on top of it. Signs of collapse vary by floor system; Dimensional lumber should be inspected for joist rupture or complete burn through, Engineered I-joists should be inspected for web burn through and separation from subflooring, Parallel Chord Trusses should be inspected for connection failure, and Metal C-joists should be inspected for deformation and subfloor connection failure.

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- Sounding the floor for stability is not reliable and therefore should be combined with other tactics to increase safety.
- Thermal imagers may help indicate there is a basement fire but can't be used to assess structural integrity from above.
- Attacking a basement fire from a stairway places firefighters in a high risk location due to being in the flow path of hot gases flowing up the stairs and working over the fire on a flooring system which has the potential to collapse due to fire exposure.
- It has been thought that if a firefighter quickly descended the stairs cooler temperatures would be found at the bottom of the basement stairs. The experiments in this study showed that temperatures at the bottom of the basement stairs where often worse than the temperatures at the top of the stairs.
- Coordinating ventilation is extremely important. Ventilating the basement created a flow path up the stairs and out through the front door of the structure, almost doubling the speed of the hot gases and increasing temperatures of the gases to levels that could cause injury or death to a fully protected firefighter.

- Floor sag is a poor indicator of floor collapse, as it may be very difficult to determine the amount of deflection while moving through a structure.
- Gas temperatures in the room above the fire can be a poor indicator of both the fire conditions below and the structural integrity of the flooring system.
- Charged hose lines should be available when opening up void spaces to expose wood floor systems.

Impact of Horizontal Ventilation [7]

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In this study, UL researchers examined fire service ventilation practices and the impact on ventilation due to changes in modern house designs. A total of 15 experiments were conducted on two houses constructed expressly for this study, in which the ventilation locations and the number of ventilation openings were altered. One of the most important finding of this study is the critical importance of coordinating increased ventilation with the application of water or another type of fire suppressant in achieving a successful firefighting outcome. The study also affirmed that the simple act of closing a door between a firefighter and a fire can provide tenable temperature and oxygen concentrations behind the closed door, increasing the chances of survival.

The tactical considerations in this study include:

• Stages of fire development : The stages of fire development change when a fire becomes ventilation limited. It is common with today's fire environment to have a decay period prior to flashover which emphasizes th e importance of ventilation.

• Forcing the front door is ventilation : Forcing entry has to be thought of as ventilation as well. While forcing entry is necessary to fight the fire it must also trigger the thought that air is being fed to the fire and the clock is ticking before either the fire gets extinguished or it grows until an untenable condition exists jeopardizing the safety of everyone in the structure.

• No smoke showing: A common event during the experiment s was that once the fire became ventilation limited the smoke being forced out of the gaps of the houses greatly diminished or stopped all together. No some showing during size-up should increase awareness of the potential conditions inside.

• Coordination: If you add air to the fire and don't apply water in the appropriate time frame the fire gets larger and safety decreases. Examining the times to untenability gives the best case scenario of how coordinate d the attack needs to be. Taking the average time for every experiment from the time of ventilation to the time of the onset of firefighter untenability 4 conditions yields 100 seconds for the one-story house and 200 seconds for the two-story house. In many of the experiments from the onset of firefighter untenability until flashover was less than 10 seconds. These times should be treated as being very conservative. If a vent location already exists because the homeowner left a window or door open then the fire is going to respond faster to additional ventilation opening because the temperatures in the house are going to be higher. Coordination of fire attack crew is essential for a positive outcome in today's fire environment.

• Smoke tunneling and rapid air movement through the front door: Once the front door is opened attention should be given to the flow through the front door. A rapid in rush of air or a tunneling effect could indicate a ventilation limited fire.

• Vent Enter Search (VES): During a VES operation, primary importance should be given to closing the door to the room. This eliminates the impact of the open vent and increases tenability for potential occupants and firefighters while the smoke ventilates from the now isolated room.

• Flow paths: Every new ventilation opening provides a new flow path to the fire and vice versa. This could create very dangerous conditions when there is a ventilation limited fire.

• Can you vent enough?: In the experiments where multiple ventilation locations were made it was not possible to create fuel limited fires. The fire responded to all the additional air provided. That means that even with a ventilation location open the fire is still ventilation limited and will respond just as fast or faster to any additional air. It is more likely that the fire will respond faster because the already open ventilation location is allowing the fire to maintain a higher temperature than if everything was closed. In these cases rapid fire progression if highly probable and coordination of fire attack with ventilation is paramount.

• Impact of shut door on occupant tenability and firefighter tenability: Conditions in every experiment for the closed bedroom remained tenable for temperature and oxygen concentration thresholds. This means that the act of closing a door between the occupant and the fire or a firefighter and the fire can increase the chance of survivability. During firefighter operations if a fire fighter is searching ahead of a hoseline or becomes separated from his crew and conditions deteriorate then a good choice of actions would be to get in a room with a closed door until the fire is knocked down or escape out of the room's window with more time provided by the closed door.

• Potential impact of open vent already on flashover time: All of these experiments were designed to examine the first ventilation actions by an arriving crew when there are no ventilation openings. It is possible that the fire will fail a window prior to fire department arrival or that a door or window was left open by the occupant while exiting. It is important to understand that an already open ventilation location is providing air to the fire, allowing it to sustain or grow.

• Pushing fire: There were no temperature spikes in any of the rooms, especially the rooms adjacent to the fire room when water was applied from the outside. It appears that in most cases the fire was slowed down by the water application and that external water application 5 had no negative impacts to occupant survivability. While the fog stream "pushed" steam along the flow path there was no fire "pushed".

• No damage to surrounding rooms: Just as the fire triangle depicts, fire needs oxygen to burn. A condition that existed in every experiment was that the fire (living room or family room) grew until oxygen was reduced below levels to sustain it. This means that it decreased the oxygen in the entire house by lowering the oxygen in surrounding rooms and the more remote bedrooms until combustion was not possible. In most cases surrounding rooms such as the dining room and kitchen had no fire in them even when the fire room was fully involved in flames and was ventilating out of the structure.

On the website of UL FSRI one can find a training module related to the findings of this research.

Impact of Vertical Ventilation [8]

Building on its horizontal ventilation research, UL examined the impact of vertical ventilation (i.e., through the roof) on the growth behavior of fires in residential structures. This two year research project developed empirical data on multiple vertical ventilation location of the hole in relation to the fire and the impact of hole size. Vertical ventilation is especially important because it requires being positioned above the fire and can have a fast impact on interior fire conditions. This research study developed experimental fire data to demonstrate fire behavior resulting from varied ignition locations and ventilation opening locations in legacy residential structures compared to modern residential structures. This data will be disseminated to provide education and guidance to the fire service in proper use of ventilation as a firefighting tactic that will result in reduction of the risk of firefighter injury and death associated with improper use of ventilation and to better understand the relationship between ventilation and suppression operations.

There has been a steady change in the residential fire environment over the past several decades. These changes include larger homes, more open floor plans and volumes, and increased synthetic fuel loads. UL conducted a series of 17 full-scale residential structure fires to examine this change in fire behavior and the impact of firefighter ventilation and suppression tactics. This fire research project developed the experimental data that is needed to quantify the fire behavior associated with these scenarios, and result in the immediate development of the necessary firefighting ventilation practices to reduce firefighter death and injury.

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The fuel loads acquired for these experiments produced approximately 9 MW to 10 MW, which was enough energy to create the necessary ventilation-limited conditions in both houses. The bedrooms and living rooms were loaded to between 2 lb/ft 2 and 4 lb/ft 2 and the kitchens were loaded to between 4 lb/ft 2 and 5 lb/ft 2 . These could be considered low compared to actual homes, which have more clutter. Despite this, ventilation-limited conditions were created, and additional loading would just allow the fire to burn longer. Additionally, the heat release rate and total heat released from the living room fuel load is within 10% of that of the fuel load used in the previous study on horizontal ventilation, such that the experiments can be compared for various horizontal and vertical ventilation scenarios. Doubling the volume of the fire room by raising the ceiling height while maintaining the same amount of ventilation does not significantly slow down the time to flashover due to the rapid increase in heat release rate that occurs prior to flashover. Each room fire experiment transitioned to flashover in 5:00 to 5:30 after ignition.

Limiting the air supply to the fire was found to be an important consideration for the ventilation- limited fires in this series of experiments. The experiments where the door was opened to allow access and then closed the width of a hoseline slowed the growth of the fire, which maintained lower interior temperatures and better gas concentrations than if the door were opened completely. This allows for fire department intervention while keeping the fire at a lower heat release rate, which makes it easier to extinguish.

There was not a ventilation hole size used (4 ft. by 4 ft. or 4 ft. by 8 ft.) in these experiments that slowed the growth of the fire. All vertical ventilation holes created flashover and fully developed fire conditions more quickly. Once water was applied to the fire, however, the larger the hole was, and the closer it was to the fire , allowed more products of combustion to exhaust out of the structure, causing temperatures to decrease and visibility to improve. Ventilating over the fire is the best choice if your fire attack is coordinated. If a ventilation-limited fire receives air, it will increase in size. Additionally, the closer the source of the air to the seat of the fire, the quicker it will increase in size. If you ventilate in coordination with fire attack (the hose stream is removing more energy than is being created) , it does not matter where you ventilate, but the closer to the seat of the fire, the more efficient the vent will be in removing heat and smoke, which will improve conditions for the remainder of the operations taking place on the fire ground.

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Ventilating remote from the fire can be effective under some circumstances. If the fire is in a room that is connected to the rest of the house by a door way, ventilating the roof outside of that room could allow for smoke to be cleared from the rest of the house. However, as air is entrained to the room, the fire will increase in size, while visibility may improve in the flow path leading from the air inlet to the fire room. The reason the fire does not grow uncontrolled is because the doorway becomes the limiting factor in keeping the fire contained. Once fuel outside of that doorway ignites, such as a bedroom fire extending to living room furniture, the heat release rate can increase quickly and overcome the temporary benefit of the remote vertical ventilation hole. Vertical ventilation remote from the fire can provide a visibility benefit but the fire and temperatures in the area of the fire are increasing.

Flow paths and timing are very important to understanding fire dynamics and the impact of firefighter tactics on the fire ground. The closer the air is provided to the seat of the fire, the faster it can intensify. Several experiments showed that fire showing does not mean that the fire is vented; it means it is venting and still remains ventilation-limited. In every experiment, the fire was burning outside of the window or roof ventilation hole because there is no air available inside to burn. It is not possible to make statements about the effectiveness of ventilation unless you include timing while understanding that the longe r the fresh air has to travel, the slower the fire will react to it. However the larger the flow path to catch firefighters in between where the fire is receiving fresh air and where the fire is exhausting to the low pressure behind them the greater chance that a rapid change can result in a negative outcome.

The fire service's workplace has changed and one of several significant factors is home furnishings. As home furnishings have evolved over decades to be made of synthetic materials, the heat release rates generated by home furnishings have increased significantly. This change speeds up the stages of fire development, creating an increased potential for ventilation-limited fire conditions prior to fire department arrival. In these experiments, it took 5 minutes for the modern fuel to transition the one-story house to ventilation-limited conditions while the legacy fuel took approximately 18 minutes . Earlier ventilation-limited conditions make the ventilation tactics of the fire service of utmost importance. Most importantly, the time between ventilation and flashover are 2 minutes for the modern fire and over 8 minutes in the legacy fire. The legacy fire could be described as forgiving as it pertains to ventilation. Poorly timed ventilation or an uncoordinated attack can be made up for prior to flashover because there is 8 minutes to adapt. The time to recover in the modern fire was 2 minutes, or 25% of the legacy time.

Tenability was exceeded in the fire room of ever y experiment prior to fire department arrival except for the legacy experiment in the one-story house. Behind a closed door is the most likely place to find a victim that can be rescued. Every experiment included one closed bedroom next to an open bedroom. In every experiment, a victim in the closed bedroom was tenable and able to function throughout every experiment and well after fire department arrival. In the open bedroom, there would be a very different story. Most victims would be unconscious, if not deceased, prior to fire department arrival or as a result of fire ventilation actions. The average time to untenability in the open bedroom was 7:30 taking into account temperature and carbon monoxide concentrations, while the closed bedroom did not exceed either of these criteria until well after fire department intervention.

Water was applied to the fire from the exterior during every experiment, in some experiments through the doorway and some through the window. Water was flowed for approximately 15 seconds, delivering 25 gallons of water into the structures. Comparing temperatures just before water application to temperatures 60 seconds after flow was stopped resulted in an average of a 40% decrease in fire room temperatures and a 22% decrease in the temperatures of surrounding rooms. In almost all of the experiments, tenability was improved everywhere in both structures with the application of water into the structure, even in locations downstream of the fire in the flow path. The data demonstrated the potential benefits of softening the target prior to making entry into the structure; the inability to push fire, as fire was never close to being forced from one room to another with a hose stream; and the benefits of applying water to the seat of the fire in a large open volume.

The fire dynamics of home fires are complex and challenging for the fire service. Ventilation is paramount to understand for safe and effective execution of the mission of the fire service to protect life and property.

On the website of UL FSRI one can find a training module related to the findings of this research.

Governors Island Experiments with FDNY and NIST [9]

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UL partnered with the National Institute of Standards and Technology (NIST), the New York City Fire Department, and the Governors Island Preservation and Education Corporation to utilize rigorous scientific methods to advance firefighter safety. The collaborative research team worked together for months to design the experiments that were conducted over six days in July on Governors Island in New York City and consisted of a series of live burn experiments that replicated conditions in modern homes. The live burn tests were aimed at quantifying emerging theories about how fires are different today, largely due to new building construction and the composition of home furnishings and products that in the past were mainly composed of natural materials, such as wood and cotton, but now contain large quantities of petroleum-based product and synthetics that burn faster and hotter. Ventilation and suppression procedures were analyzed during basement fires, first floor and second floor fires during 20 townhouse fire experiments. On the website of UL FSRI one can find a training module related to the findings of this research.

Exterior Fire Spread and Attic Fires (ongoing) [10]

Underwriters Laboratories is currently leading a 2-year study to examine fire service attic fire mitigation tactics and the hazards posed to firefighter safety by the changing modern residential fire environment and construction practices. The US Fire Administration estimates 10,000 residential building attic fires are reported to U.S. fire departments each year and cause an estimated 30 civilian deaths, 125 civilian injuries and $477 million in property loss. These attic fires are a very challenging for the fire service to mitigate and have led to numerous line of duty deaths and injuries. Further complicating attic fires, current building practices include new products to achieve better energy performance to meet newer code requirements with little understanding of fire performance or the impact on firefighter safety. The purpose of this study is to increase firefighter safety by providing the fire service with scientific knowledge on the dynamics of attic and exterior fires and the influence of coordinated fire mitigation tactics from full-scale fire testing in realistic residential structures.

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Positive Pressure Ventilation (ongoing) [11]

The purpose of this study is to increase firefighter safety by providing the fire service with credible scientific information, developed from full-scale fire testing in representative modern single family homes, on the usage of positive pressure ventilation fans during fire attack. The changing dynamics of residential fires as a result of the changes in home construction materials, contents, size and geometry over the past 30 years compounds our lack of understanding of the effects of ventilation on fire behavior. Positive Pressure Ventilation (PPV) fans were introduced as a technology to increase firefighter safety by controlling the ventilation. However, adequate scientific data is not available for PPV to be used without increasing the risk to firefighters.

The full reports on the above completed studies are available at the UL Firefighter Safety Research Institute website at www.ULfirefightersafety.com.

As the above research demonstrates, UL has made significant contributions to the understanding of the characteristics of the modern residential fire, and has provided the fire service with important tactical guidance that can reduce risk and increase firefighter safety. However, there is still much more to learn, and UL FSRI will continue to contribute information vital to firefighter safety with future research efforts.

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