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TRAINING DIGEST

Applying Fire Research to Structural Firefighting

This training guide contains some of the most important firefighting research and analysis done in the past 50 years. Steve Kerber provides an insightful overview of the most significant research undertaken by Underwriters Laboratories, the National Institute of Standards and Technology, and several other agencies. Also included is application of this research to the complex and dangerous work of structural firefighting. This research can make firefighting more efficient and effective and show how tactics can affect fire behavior and survivability. This guide will enhance firefighters' abilities and decision-making capabilities by providing a greater array of options for conducting life-saving operations and property saving operations.

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Bringing Science to the Street: UL and Firefighter Safety Research

By **STEPHEN KERBER**

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.

Underwriters Laboratories (UL) has long been in forefront of fire safety research to support efforts that prevent unnecessary fire-related deaths and injuries. 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 poses an increased risk to firefighters. In collaboration with the Chicago (IL) 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.

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.

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, Illinois, facility and at the Delaware County Emergency Service 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 deenergizing 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]

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.

Impact of Horizontal Ventilation[7]

In this study, UL researchers examined fire service ventilation practices and the impact on ventilation because of 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 findings 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.

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 locations 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.

Governors Island Experiments with FDNY and NIST[9]

UL partnered with the National Institute of Standards and Technology (NIST), the Fire Department of New York, and the Governors Island Preservation and Education Corporation to use 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 because of 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 fires, and second-floor fires during 20 townhouse fire experiments.

Exterior Fire Spread and Attic Fires[10]

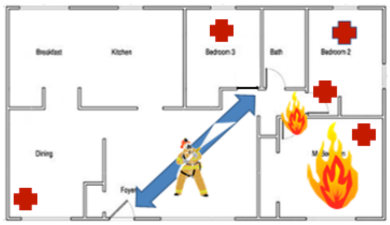
Underwriters Laboratories is currently leading a two-year study to examine fire service attic fire mitigation tactics and the hazards posed to firefighter safety by the changing modern residential fire environment and construction practices. The U.S. Fire Administration estimates 10,000 residential building 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 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.

Positive Pressure Ventilation (To be completed in 2016)[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.

Impact of Fire Attack Utilizing Interior and Exterior Streams on Firefighter Safety and Occupant Survival (To be completed in 2017)[12]

Recent fire service research has highlighted the importance of applying water to the fire as quickly as possible. This tactical consideration has highlighted a



knowledge gap and increased the interest in better understanding the impact of water applied as part of an interior attack or exterior attack. Many variables exist in fire attack that impact firefighter effectiveness and victim survivability, stream placement, the timing required to get water on the fire, stream type, stream movement, air entrainment, steam development, hot gas cooling and contraction and position of flow paths. Whether a fire attack crew chooses to apply water as part of an interior attack or as part of an exterior or transitional attack, they need to know what impact their stream is having on the fire environment ahead of them. This is difficult on the fireground because visibility is commonly limited and therefore all of their experience is from behind the nozzle. This results in beliefs about what is happening ahead of the nozzle and its impact on victim survivability, but knowledge of actual impact has not been researched.

The full reports on the above completed studies are available at the UL Firefighter Safety Research Institute Web site 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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CONTROLLING THE OPENINGS: IS THIS THE FUTURE OF VENTILATION?

BY **SEAN GRAY**

RECENTLY, A COHESIVE group of firefighters organized a Truck Company Operations course for our department. The basics were covered: ventilation, ground ladders, search, and forcible entry/exit. Cobb County (GA) Fire and Emergency Services does not traditionally operate with engine- or truck-specific assignments. We have 29 engines and only eight ladder trucks serving a diverse suburban community. To do efficient truck work, we would need to almost double the number of ladder trucks. In the past, we used the ladder truck mostly as an aerial master stream or increased staffing on the fireground. We do not have predetermined assignments for ladder trucks, and that's okay. Many suburban fire departments operate in a similar manner. However, the lack of focus on truck company operations, especially ventilation, was troubling to me and others, hence the creation of the Truck Academy.

Our department has no interest in becoming a large-city department. We have different buildings and different tactics than a big city. We strive to use the best tactics at the right time for the appropriate structure with the proper number of personnel. Safety is one of our primary department goals, and there is a detailed focus on tactics that may put our firefighters in danger. This is the reason roof ventilation has not been a popular choice within Cobb County. But after doing the research for the ventilation class, we learned that eight firefighters in the United States died while performing roof ventilation vs. 28 who died as a result of flashover within the past 15 years.

I began my career in Southern California, a place where roof ventilation is performed at almost every fire. So after relocating to Georgia, I started to notice that ventilation was not a priority within my department's fireground tactics. The most common ventilation practice was to place a fan at the front door to blow the smoke out during overhaul operations.

After attending two funerals for members of neighboring departments who had been killed by flashover in the line of duty, I became more focused on getting our department involved in ventilation practices. After a couple of years of meetings and planning sessions, I was given the opportunity to teach ventilation practices alongside the most respected firefighters within my department. I was honored, to say the least. The Truck Academy was a huge success. I was ecstatic about the results-until I attended the Underwriters Laboratories (UL) Ventilation Practices class presented by Steve Kerber.

UL VENTILATION FINDINGS

As Kerber broke down the science of ventilation into firefighter terms, I quickly started to realize that my department may have unintentionally been doing the right thing by not actively performing ventilation. What? It sounds crazy, doesn't it? Let's take a look at the firefighter's summarized notes of the UL information:

1. **The fire gets bigger if you provide a ventilation opening.** The easiest way to explain this is that if you give the fire air, the heat will increase at a faster rate and could cause a flashover, depending on the stage of the fire. The fire does not burn hotter; it gets hotter faster. It's all about the heat release rate (HRR). You cannot cut a hole in the roof big enough or make a large enough opening in a window to decrease the temperatures in a modern-day, ventilation-limited fire. The modern interior furnishings are the primary cause of the accelerated HRR. Venting without applying water first does not cool the fire.

2. **Ventilation must be coordinated with fire attack.** Gone are the days of taking out a window on your walk-around. If the fire has not already vented itself and you create an opening, you have approximately 100 seconds on average to get water on the fire before flashover could occur. When water is applied, the fire is controlled, and all the ventilation necessary can be done because conditions will now improve rapidly.

3. **The fire attack crew entrance is a ventilation opening.** This is simple: If you force the door, control it. If staffing allows, have a person to manage the hose

at the front door and keep the door closed as much as possible. Again, you have approximately 100 seconds on average to get water on the fire before flashover may occur.

4. **If the fire has self-vented out of a window, put water on it from the outside.** Soften the target, and then go interior to finish it off. This may prevent the fire from autoexposing to the attic or upper floors. We have also recently learned and all of the studies show that if you put water on the fire, interior temperatures will decrease, possibly making it survivable for any potential victims.

5. **During initial vent-enter-isolate-search (VEIS) operations, don't break the glass with the ladder**. VEIS is a valid tactic. Breaking out the window should be the last thing you do before entering the structure. Realizing the dangers of creating vent openings emphasizes the importance of isolate. Quickly find the interior door, and isolate yourself and the victims from the fire; then exit safely out the window.

COORDINATION

Controlling the door keeps the fire in a ventilation-limited state, and that is exactly where we want it until we are ready. Take control of the fire by coordinating ventilation and fire attack. Ideally, you should have your charged hoseline in place, the entry door unlocked/forced but controlled in the closed position. The ventilation crew should be in place and prepared to create an opening. When the incident commander (IC) makes the call, the fire attack crew should move quickly to extinguish the fire, and the ventilation crew should make the opening; they should be working together harmoniously. Again, once water is applied to the fire, it is no longer ventilation-limited; now, the structure can be opened and searched more quickly and safely.

To perform proper ventilation, ventilation must be coordinated. Take a look at your current staffing levels and consider if it's even possible to efficiently coordinate ventilation. Think outside the box: Consider using the pump operator to take a window as part of a coordinated horizontal ventilation tactic. Just remember it is important to use the approximate 100-second-on-average time frame from ventilation to extinguishment as a basic guideline. There will always be variables to this time frame. It is nearly impossible to figure an exact time because of the material burning and the size of the structure in which it is burning.

DOOR CONTROL

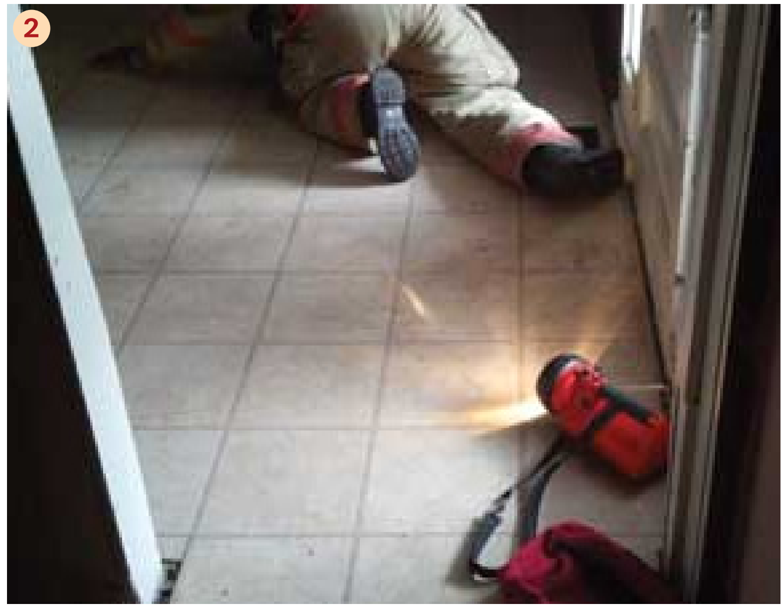
A pocket full of wedges is a staple in most firefighters' turnout gear. Chocking doors open has been a basic principle of firefighter safety for a long time. If door openings are now considered ventilation openings and we need to keep them closed, then how are we supposed to exit the building quickly and safely in an emergency? A designated firefighter to maintain door control at the primary entry/exit point is best. The next step is to do your own size-up for entry/exit points.

As an interior firefighter, it's a good idea to close doors as you progress toward the fire to reduce flow paths and fire spread. Don't give the fire a chance to trap you. Take away those opportunities by closing doors and visualizing the locations of windows and sliding glass doors as you make your way toward the fire.

Four firefighters in Sacramento were nearly killed when they entered the front door and opened windows for horizontal ventilation on the second floor, creating a flow path that almost killed them.(http://bit.ly/1p7Bvx7) Multiple firefighters have been injured or killed in wind-driven events where a window or a sliding glass door failed from fire on the outside (i.e., Arvada, Colorado, http://bit.ly/WyCsoI) or from the inside (i.e., Houston, Texas, http://bit.ly/1tuZyY8). Locating the seat of the fire during the initial size-up and maintaining situational awareness are crucial.

If staffing does not permit for a designated door control position at the entry/exit, the hoseline, in most circumstances, will keep the door from closing. It's best to have the door closed as much as possible; educating firefighters to recognize the door as a vent opening is of the utmost importance. Secondary crews or even a proactive pump operator could close the door from the outside to help reduce the chance of flashover.

Ideally, a firefighter (the door control firefighter) will be placed at the door to control the opening and to help feed hoseline to the interior crew (photo 1). This firefighter can be positioned on the interior or the exterior of the door. While



(1-4) Photos by Firefighter Chris Baines, Cobb County, Georgia.

training with this tactic, we found that the firefighter on the interior worked better to improve communications with the fire attack crew. You can also place a flashlight on the floor next to the entry point to help guide interior firefighters back to the entry point (photo 2). In most circumstances, the hoseline will keep the door from closing completely. You can prevent the door from closing also by using the dead bolt (photo 3) or a piece of rubber (photo 4), which can prevent the latch bolt from closing on doors without dead bolts.

As mentioned above, the ideal and safest option is to have a firefighter control the door. This firefighter can evaluate conditions and keep a hand on the hoseline to determine if water is flowing. If water is being placed on the fire, the door control firefighter should release the steam and smoke to increase visibility. It's essential that the door control firefighter be aware of the conditions and communicate with the firefighters on the hoseline to coordinate the ventilation opening.

SIZE UP FOR SAFETY

The thermal imaging camera (TIC) is a valuable tool when sizing up. You can see the thermal layer, and it can give you an idea of the location of the main body of fire during your walk-around. In addition, it can help you to identify rapidly increasing temperatures within a flow path, enhancing your chances of getting the nozzle to the fire as quickly and as efficiently as possible. Remember that flashover is reached at a much faster rate in today's fires.

In your size-up, be sure to evaluate the windows for safety reasons. As you approach the structure, recognize nearby windows or exit/entry points that can be used for emergency egress in their relation to the fire's location. Note that there is only one window on the B side of this house.

UL and National Institute of Standards and Technology engineers are not disregarding ventilation. They are providing us with the data to build a foundation of tactics. A UL credo is, "Know by test, and state the facts." Ventilation tactics do not need to change as long as water is being put on the fire. Unfortunately, many of us work for suburban or rural departments and don't have the staffing for coordinated and efficient roof operations. In these settings, it's easy for ventilation to become an afterthought.

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After being proud of the progression made in ventilation practices through our Truck Academy, the new UL ventilation information had crushed me. I was distraught and in disbelief. The firefighter inside me wanted to disregard all of this science mumbo jumbo and go back to performing roof ventilation. However, common sense prevailed, and I realized that I was wrong. It would be crazy for me to disregard this empirical evidence because of what I thought I knew all of these years.

Years ago, we used to teach a cardinal rule to new firefighters: "Don't spray water on smoke; wait until you see fire." We taught that opening a nozzle on smoke was unprofessional; disturbed the thermal layer; and caused additional, unnecessary smoke and water damage. That rule is now dangerously outdated because we now know that smoke, or the fire gases in smoke, burn and will burn us if we cannot provide a ventilation opening to get them out of the building. If we cannot vent this fuel before it flashes over because of roof construction or a lack of staffing, then we will have to eliminate the heat leg of the fire triangle by directing a stream overhead. Forget "penciling!" Keep the nozzle flowing as you advance until its stream reaches the seat of the fire, which is producing the flammable smoke and gases.

We do not need to stop performing traditional ventilation practices and change all of our fireground tactics because of these studies. However, these studies are valid and may mold the future of the fire service. Be a student of the fire service; take time to review the recent studies. Make an informed decision, and continue to keep yourself and your crew safe.

Door control is vital to the success of interior firefighting operations if coordinated ventilation is not possible. You can control your own destiny by recognizing the conditions during size-up and controlling the structure's openings.

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COMBINED FIRE ATTACK

BY **ARTURO ARNALICH**

DURING THE 2014 International Fire Instructors Workshop (IFIW) in Olsztyn, Poland, I proposed and presented the discussion topic "Tools, Techniques, and Tactics (3T) in Combination for Firefighting," intending to introduce the concept of tactical combination for safer, more efficient, and more effective firefighting operations and to encourage a debate among my colleagues.

To illustrate the 3Ts in combination, I used the combined fire attack concept, a tactical combination developed in our fire department and found extremely useful in firefighting in our operational area. Later on, during the IFIW practical session, we had the opportunity to perform an evolution using combined fire attack.

Tactical combination is all about using the right tool, technique, and tactic in each situation during a firefighting operation. It requires teamwork, skilled incident command, and a dynamic size-up of the fire scene. Timing and coordination are key to a successful tactical combination.

COMBINED FIRE ATTACK

A combined fire attack is a coordinated and timed fire attack using transitional attack, gas-cooling techniques, and positive-pressure attack (PPA) tactics.

In today's fire environment, we often find underventilated fires (ventilation-controlled fires that have not yet gone through a flashover stage) with no clear stratification of the smoke and air layers, resulting in almost zero visibility and very slow operations in complex structures.

Recent studies by Underwriters Laboratories (UL) have shown and proven how rapidly modern fuel ventilation-controlled fires react to ventilation. As soon as

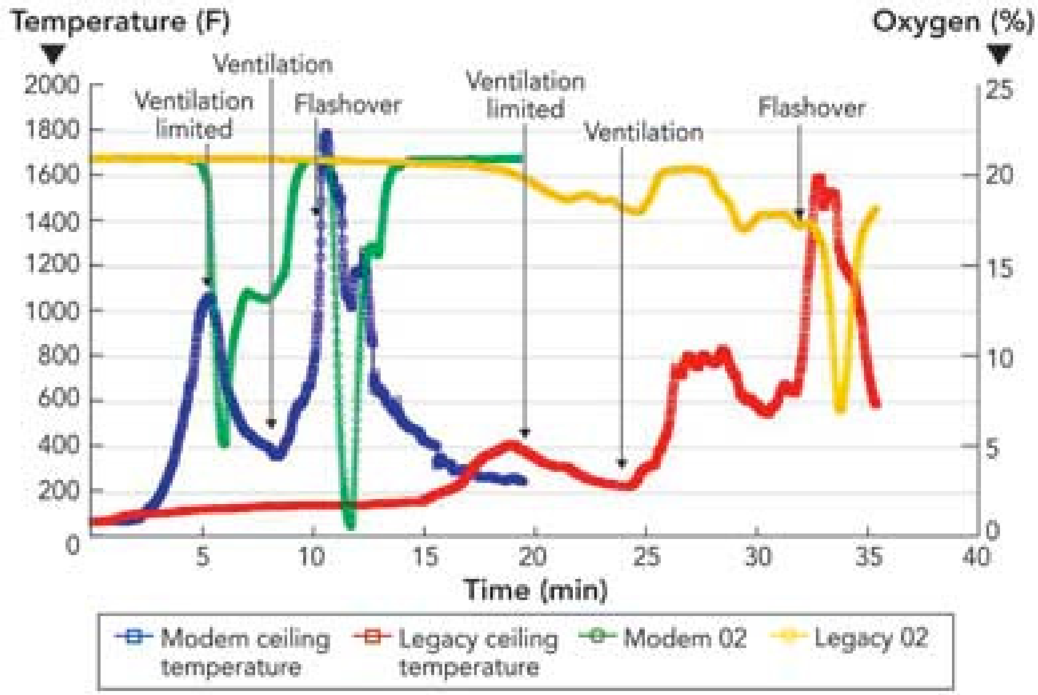

Figure 1. *Modern vs. Legacy Fires Response to Ventilation. A legacy fuel fire took more than eight minutes to reach flashover after a door was opened; a modern fuel fire took barely two minutes. Source: Underwriters Laboratories Fire Service Research Institute.*

ventilation occurs, there is a limited time frame-less than two minutes in most cases-during which to apply water on the fire before it evolves into a ventilation-induced flashover (Figure 1).

The idea behind combined fire attack is to apply water from a safe position into the fire compartment to reduce fire gases' temperature and flammability to a safe point, after which you can apply positive-pressure ventilation (PPV) with less concern about fire growth. PPV will improve interior conditions, increasing tenability for victim and faster interior team progress.

A firefighting operation is not only about fire suppression; it also involves search and rescue operations and making the egress path safe for any occupants inside the building. By using PPV for fire attack, you can clear smoke-filled areas and pressurize parts of the structure by opening and closing the appropriate windows at a given time. Thus, it combines easily with the complete range of defensive PPV, fire isolation, and flow-path control approaches.

COMBINED FIRE ATTACK EVOLUTION

1. Vent is opened. The vent closest to the seat of the fire is opened if it was closed. Shortly after, this will create a bidirectional flow through the window. Depending on the building, you can make vents using a pike pole from ground level, from a ladder, or from an aerial apparatus (Figure 2).

2. Transitional attack begins through the opened vent. A solid stream is directed to the ceiling of the structure, where it is deflected and broken down into smaller droplets. Although there is some direct attack on the fuel surfaces that the droplets hit, the main objective is to reduce the temperature of the hot gas layer.

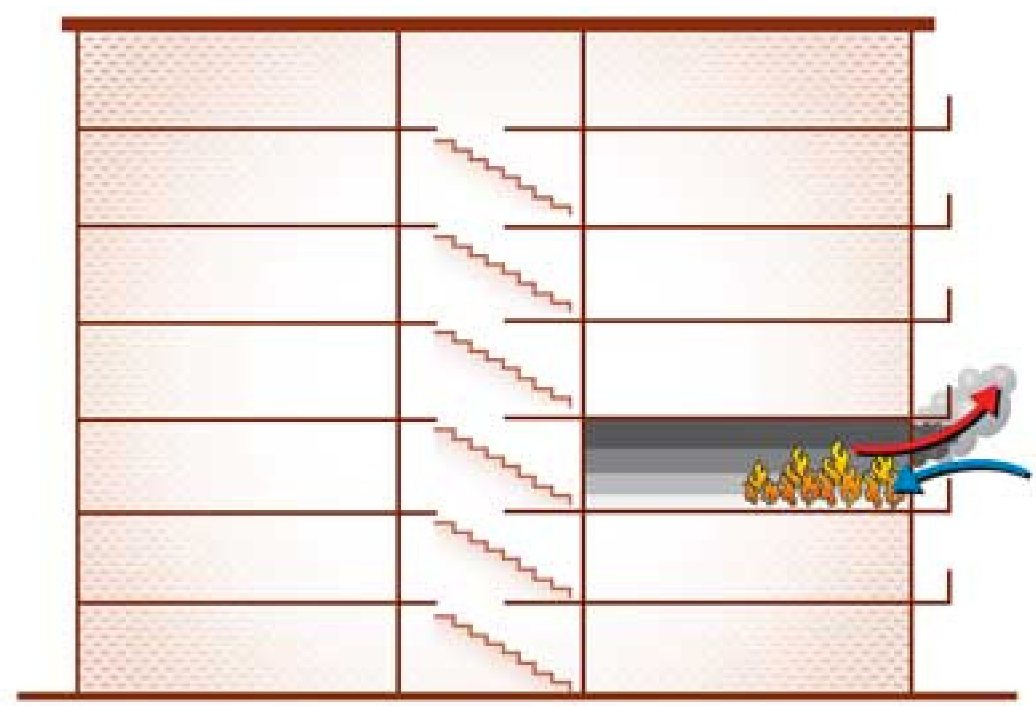

Figure 2. *Fire After Opening the Vent*

You use a solid stream to minimize the interference of the air and smoke flows through the window. A fog nozzle pattern would surely be more effective for cooling gases, but it would require a larger area to entrain. The exhaust could be obstructed, preventing steam from exiting the structure. Fire gases would be displaced somewhere else, and the flow path would be altered.

You can perform transitional attack from the ground level or from an aerial apparatus. It should start as soon as a clear outward flow of ignitable hot fire gases is identified. This does not necessarily mean visible flames. It should continue based on fire conditions, keeping in mind that the goal is to "reset the fire" and not to flood the fire room.

Ten-second water applications at 200 liters per minute (lpm) followed by a waiting period to gain thermal stratification can be enough to "soften the target," as some like to call this tactic.

Moving the solid stream while applying water may block the structure and will hit a larger ceiling area, resulting in more steam without significantly improving the result.

3. Gas cooling from the entrance door. As soon as the attack team reaches the entrance door, it applies a fog pattern stream from the outside. The door remains open just for the short time the nozzleman needs to apply water. Short pulsing has proven to have a limited reach. In underventilated fire conditions with no clear layer at the bottom, disrupting the thermal balance should not be an issue; therefore, a narrower cone, deeper reach, and longer and oscillating pulsing would be more effective (Figure 3).

4. PPA on the softened fire. Once the flammability of the fire gases and the interior temperature have been reduced, a PPA can begin. A flow path is created from the entrance door to the window at which the transitional attack was performed. Excess smoke and steam will be removed rapidly. Fire reaction to ventilation will be milder because of the "softened" conditions prior to PPV (Figure 4).

The attack team should remain outside at the entrance door until interior conditions and visibility improve. This will take a short time, after which the team can make fast interior progress. Use gas cooling to reduce the flammability of the fire gases and the entrained fresh air mixture.

After the interior team reaches the seat of the fire and performs a direct attack, the fire is under control. During this stage, crews performing interior attack will feel fresh air blowing on their backs and there will be little or no steam because

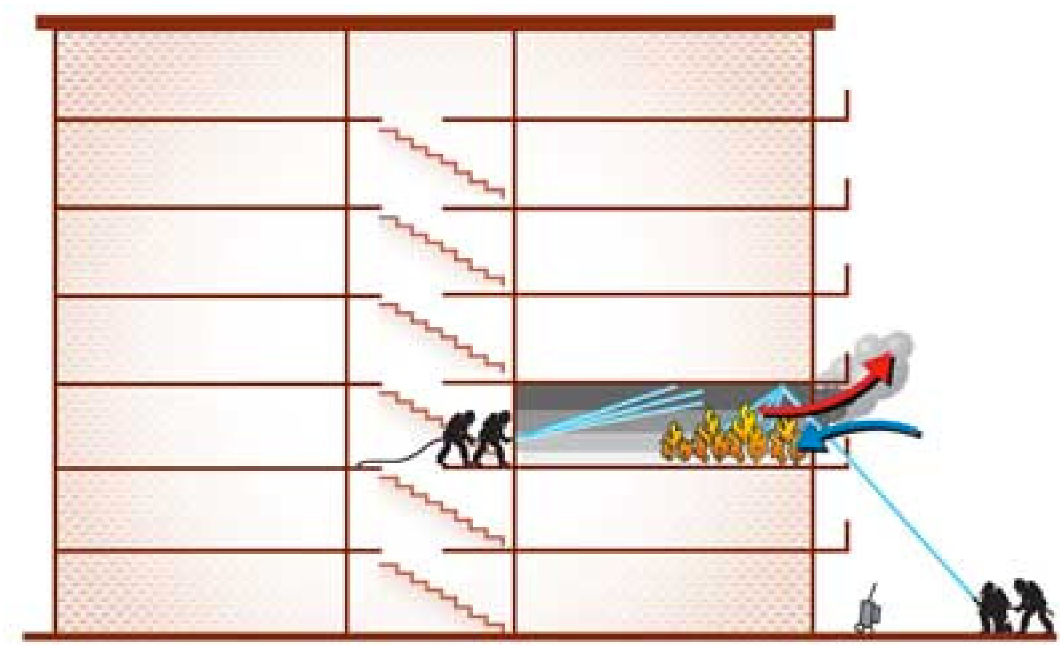

Figure 3. *Gas Cooling and Transitional Attack*

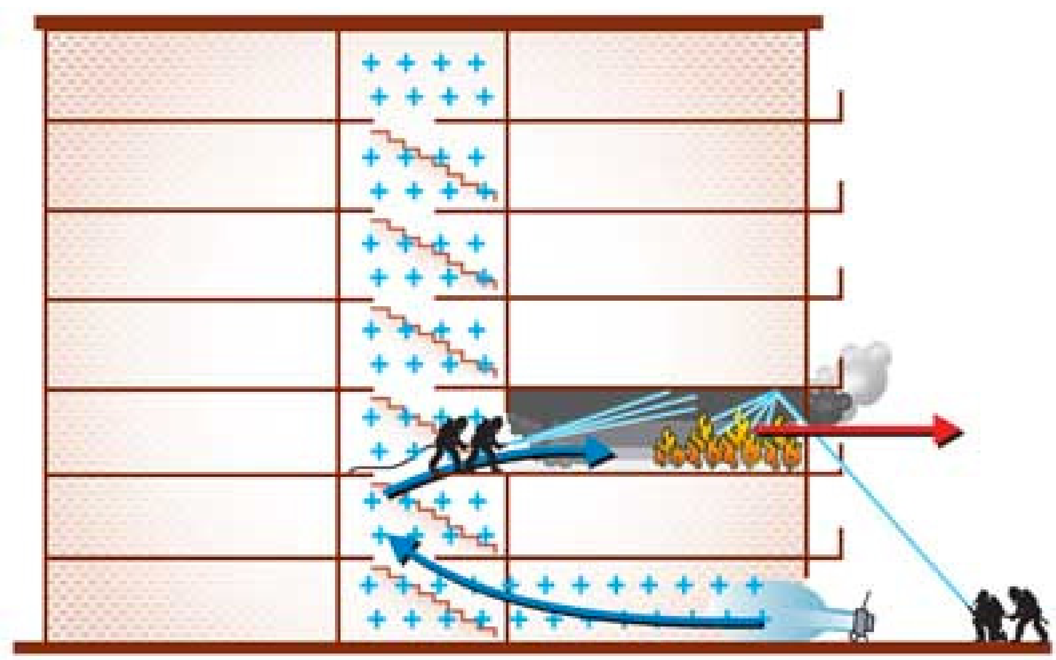

Figure 4. *Positive Pressure Attack on the Softened Fire*

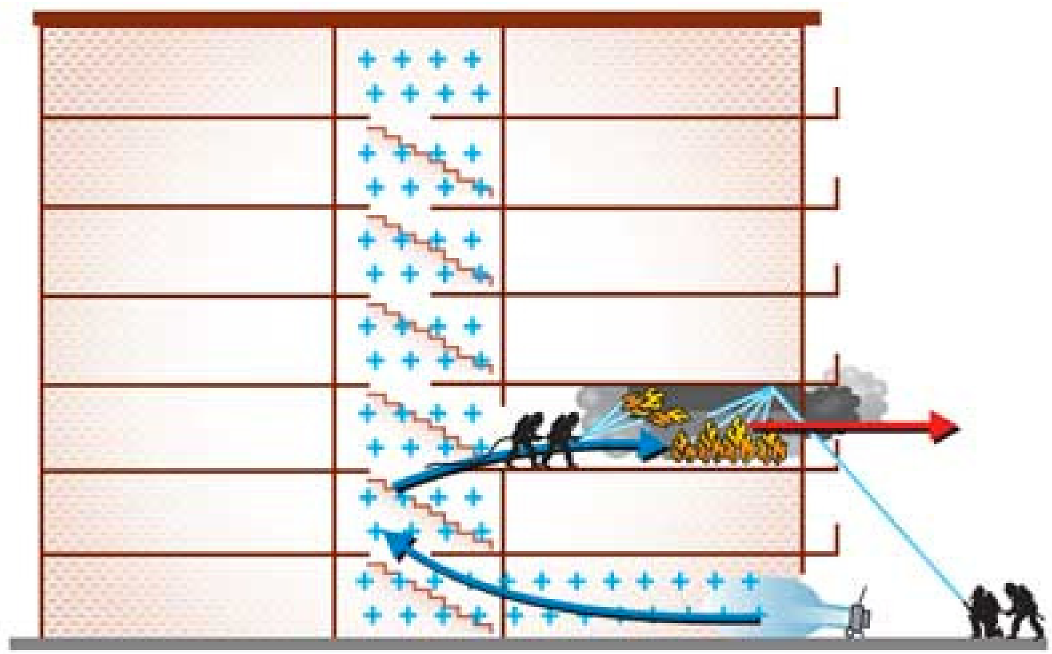

Figure 5. *More Gas Cooling and Transitional Attack*

a PPV fan is reinforcing the flow path, redirecting the excess steam downstream (Figure 5).

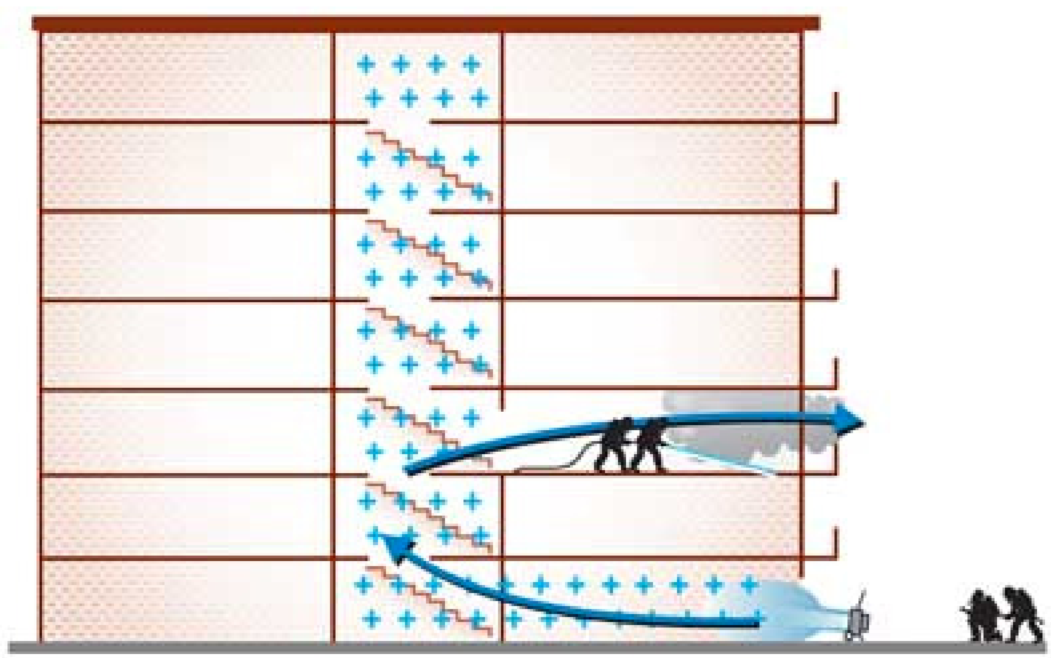

Figure 6. *Direct Attack on the Seat of the Fire*

After the fire is under control, search and rescue operations begin. Nevertheless, shortly after PPV starts, tenability for victims is improved as a fresh layer of cold breathable air spreads throughout the structure from the bottom (Figure 6).

USING TECHNIQUES ALONE VS. IN COMBINATION

Gas cooling. Gas cooling has been used widely throughout Europe, Australia, and some Asian countries. It has proven to be a reliable and effective way to reduce fire gases' ignition risk as crews make interior progress. The pulses of water fog cool and dilute the upper hot gas fire layer. Water fog expands into steam at a lower rate than the fire gas layer contracts. Hence, it preserves the thermal balance and is the best way to maintain visibility in the lower area (Figure 7).

Figure 7. *Traditional European Gas Cooling*

However, as it was said before, most underventilated fires don't stratify clearly, and the neutral plane descends nearly to the floor. Gas cooling is effective in terms of reducing flammability, but it will not create a clear bottom layer unless a fresh supply of air is introduced and a flow path is created.

Making interior progress in zero visibility takes a significant amount of time. Crews are exposed to high temperatures for longer, and there is a significant risk of not finding the correct path to the seat of the fire in complex structures.

The combined use of transitional attack will reduce interior temperature for easier interior progress while PPA will rapidly improve visibility.

Transitional attack. UL's studies have proven that transitional attack reduces temperature throughout the whole structure, not just in the fire room. Most concerns about this tactic involve excess steam inside and on the interior crew making progress. Inappropriate water application (cone pattern stream or moving solid stream) could also possibly prevent the exit of fire gases and steam from the compartment (Figure 8).

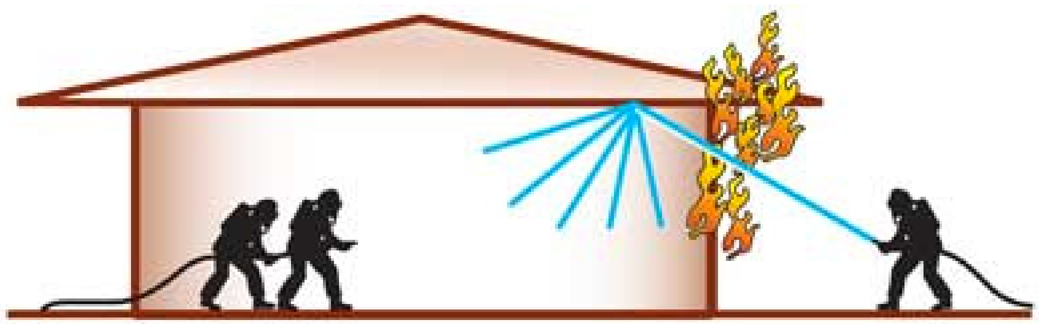

Figure 8. *Transitional Attack Concerns*

Using a PPV fan to create and ensure a flow path will, in most cases, avoid exposing interior crews to steam as they progress along with the fresh air stream. Inappropriate water flow rates or application will have less impact as excess steam is directed toward the exhaust opening and it is harder to block the window with the exterior water application.

PPA. Although PPA improves interior conditions for fire attack, a delay in water application or inappropriate inlet and exhaust sizes may disturb the fire gas mix and result in fire growth or even a ventilation-induced flashover scenario. Modern fuel fires respond to ventilation more violently and reduce the time frames to reach the fire seat before growth.

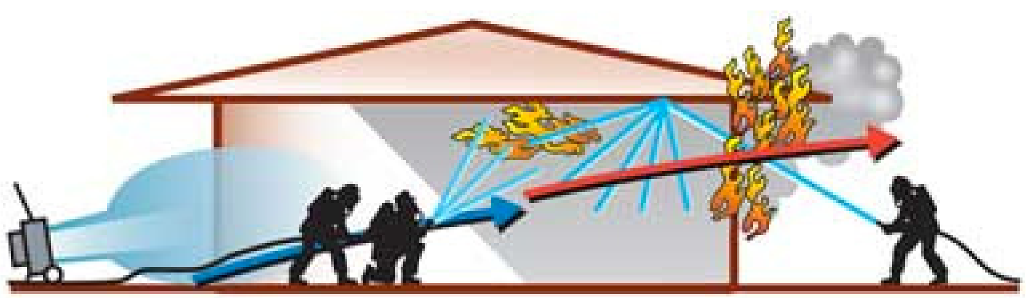

Figure 9. *Transitional, Positive-Pressure Attack, and Gas Cooling*

Transitional attack combined with gas cooling from the entrance door will reduce the interior temperature and, therefore, increase the time needed for fire growth, allowing for a safer and more effective PPA (Figure 9).

•••

A combination of gas cooling, transitional attack, and PPA can result in a safer, more efficient, and more effective firefighting operation vs. employing each tactic alone. Fire scenario assessment, timing, and coordination are essential for success.

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VENTILATION-LIMITED FIRES IN RESIDENTIAL BUILDINGS

By **ERICH J. RODEN**

FIREFIGHTERS USED TO breathe a sigh of relief when they found fire showing from a window or two on arrival: Visible fire meant you knew the fire's location, and a simple check by the first-arriving truck officer would define the fire area. Locating the fire has always been the top priority for the incident commander (IC), and all other fireground strategy and decision making are based on this priority's results. A located and defined fire area allows the IC to size up the fire's possible effects on trapped civilians or on firefighters advancing hoselines and conducting searches. In other words, the sooner you find the fire, the sooner those searches get underway and the sooner you can stretch hoselines to the correct floor, apartment, room, or area.

Once the engine had the first hoseline stretched, flaked, charged, and ready to advance, the truck would often begin taking windows to begin clearing the smoke from the fire floor. This was routinely performed by those operating on the exterior or fire escapes to allow those on the interior to see below the smoke layer to check for any visible fire. Moreover, this is further accomplished by those on the interior conducting searches as well: the "vent as you go" procedure to lift the smoke to find and provide relief for incapacitated occupants, too. And regardless of the interior contents' vintage, heavy smoke of any color always obscures the fire's location and search operations. This makes ventilation an initial priority for the truck, as visible fire is what we still need to find first, and the engine and searching firefighters always enjoy seeing things more clearly before the nozzle is opened. But the simple act of ventilating multiple windows to assist in finding fire and occupants, respectively, has changed.

Recent fire behavioral research from Underwriters Laboratories (UL), specifically its *Impact on Ventilation and Fire Behavior in Contemporary and Legacy Residential Construction* study, is discovering flaws in our incumbent horizontal ventilation

(1) Firefighters operating on fire escapes often ventilate windows by starting with the "off" window adjacent to the fire escape balcony and continue ventilating their way back to the stairs (egress). Although this is the proper method of ventilating from a fire escape, this could cause untenable fire conditions in the fire apartment if not properly coordinated with those searching for the fire's location on the interior. Clear communications between inside and outside teams help to ensure ventilation-limited fires are managed properly. (Photo by Lloyd Mitchell.)

procedures and describes the false sense of security visible fire from the exterior instills: that increased horizontal ventilation actually creates more untenable fire conditions for eager engine and truck companies.[1] (For the remainder of this article, I will refer to this study as the "UL study.")

Ventilation is still a priority; however, many departments are reconsidering its immediate incorporation into the tactic of locating the fire area. It appears that contemporary science seems to be making visible fire less attractive these days. Nonetheless, we still have to find the fire we so desperately don't want to see any more if the IC is to determine appropriate strategy, resource deployment, and risk-especially if the IC plans on putting people above the fire floor.

Locating the fire these days means first understanding where contemporary fire science research seems to be headed with regard to horizontal ventilation. The UL study does not recommend prohibiting the truck from conducting horizontal ventilation; to the contrary: UL warns of the consequences of random and *multiple* ventilation openings, especially if fire *is* visible on arrival and the fire area is not yet defined. This includes the cumulative effect on interior conditions once personnel force and chock open the door. The UL study's executive summary states the following with regard to increasing horizontal ventilation openings (referenced in this article as ventilation to locate fire):

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 is highly probable, and coordination of fire attack with ventilation is paramount. (1)

UL further states:
It is important to understand that an already open ventilation location is providing air to the fire, allowing it to sustain or grow. (1)

Although this may seem like common sense to most firefighters, the conventional thinking held by many that horizontal ventilation would speed up the process of simultaneously locating the fire in conjunction with the engine's timely advance still holds true; however, the rapid time to flashover of the interior for operating companies may possibly outweigh the need to locate the fire because it could be everywhere if poor ventilation practices are initiated-especially if any water problems are encountered. The consequences will be abandoned searches and engines backing out. This becomes the current impetus for reexamining how much glass or how many doors to take out before locating the fire. But empirical data and procedural changes notwithstanding, the fire we so desperately don't want to see any more still has to be found at every fire.

So how can we continue to safely size up and determine the fire's location prior to initiating interior operations while limiting ventilation to maintain tenable fire areas? Easy: You can start by relying on your own experience and your knowledge of the buildings within which you fight fires and correlating them with what you also see and hear.

LOCATING THE BUILDING

Although it has been ingrained into firefighters to always conduct a personal size-up, how many of you actually consider attempting to locate the fire before leaving the firehouse? This is where your experience and your knowledge of your buildings and their common construction types help. The late Fire Department of New York Battalion Chief Orio Palmer wrote a very impressive article in the 4th/2002 issue of With *New York Firefighters* regarding principles of locating the fire geographically. He described a way to locate the fire by simply listening to what address the dispatcher relayed or reading what the response ticket said and correlating this with what the caller was reporting. This information was referenced to the varying geographical address nomenclature in a given borough in New York City and provided personnel with a systematic method to approach locating fires.[2] Although this article's geographical designations were exclusive to New York City, you can and should apply its principles to any city.

Consider the reported fire building address: What side of the street is it on? In Milwaukee, even numbered addresses are on the north and east sides of the street; odd numbered addresses are on the south and west sides. What is the actual building address number? Is the building residential or commercial? Is the building compartmentalized or does it have open areas? Is a letter used after the address number? This can indicate if the building is a duplex or a rear cottage (carriage house). Is the address on the corner, in the middle, or at the end of the block?

Locating the fire building is just as important as finding the fire inside it, as this is a clue to many other size-up considerations such as hydrant locations. For example, in Milwaukee, hydrants are typically on every northeast corner and "middle-of-the-block" locations. So a reported fire on 2901 N. 30th Street suggests that the fire building is the first address on the west side of the block and a hydrant should be right across the street, on the corner.

Apartment locations in the building are equally important. Knowing what Apartment H means, where its location may be in conjunction with the stairwell, or what floor or wing it may be on gives you a tactical advantage as to how long it may take the truck to investigate and locate the fire, the length of your hoseline stretch, smoke travel to upper floors, and so on.

Once you know the building's location, take a look at what the dispatcher types on the alarm printout. Is there any specific information from the caller listed? This information may key responding companies into determining the likely location of the fire before they even arrive. Information such as *kitchen fire* is an easy tip-off to where the fire may be if it's not showing itself on arrival or if there is only light

(2) Here is a cut-and-dried operation for the first-arriving engine and truck company: The fire's location is known and defined on arrival because of an open window in the fire room, and the engine has begun stretching the first hoseline to make quick work of this room-and-contents fire. Although a window is open, exposing the fire's location, it is still allowing air to enter the fire area, creating a ventilation-limited fire. More ventilation is not necessary until the engine has started water on the fire area. (Photo by Lou Minutoli.)

smoke showing. If the fire building is an apartment building, a kitchen fire will likely mean that the fire is probably right behind the apartment door, off the public hallway. Most apartments open into the kitchen area, so the first-due engine and truck can assume they will be met with fire at the door once they gain entry. Additionally, if the dispatcher reports over the radio that occupants have fled the apartment, then the fire in the kitchen is probably entering the public hallway, too.

If the kitchen fire is reported in a private dwelling, the kitchen is almost always at the rear of the residence. Companies should expect to find smoke and heat behind the front entrance door and the initial fire area at the rear of the first floor. The benefit of anticipating the fire's location-based on address and dispatch information-should ease some of our concerns about having to limit horizontal ventilation and that limiting the number of windows we ventilate is not necessarily going to hinder our ability to locate the fire as much as we may think. What's more, we will also have an idea as to *which* windows we will most likely be ventilating once the engine has water and is ready to advance into the occupancy because of our experience and knowledge of buildings in our area.

LOCATING THE FIRE

If there is no available information from the dispatch or the caller-and no occupants or bystanders around when we arrive-then we still must locate the fire before making any strategic decisions. Regardless of this inherent responsibility, locating fire is not as easy as it used to be. Energy-efficient windows and doors,

(3) *The initial ventilation point at this private-dwelling fire is the front door, which is rarely calculated into the number of ventilation openings that, collectively, impact ventilation-limited fires' tenability. Although the likely location of the fire is the first floor, always check the basement prior to operating above. The presence of board-ups on the basement windows emphasizes this point, as they often conceal fire and smoke conditions. (Photo by Dennis Walus.)*

board-ups, and fabricated property security systems have sealed up today's buildings more than ever before. As a result, delayed alarms are always possible, particularly at night. People often report a "smell of smoke in the area" when calling the fire department; they don't necessarily see or look for fire in the house behind them, across the alley, or down the block, but they certainly know a fire when they smell one. And sometimes, all the dispatcher can give responding companies to investigate, at best, is an intersection or the caller's address. Delayed alarms mean fires get a head start, and companies should anticipate a lot of smoke and fire inside the building once they finally find the address. If the address is known, however, it is best to start with what you see, as there are many indicators that tip us off to a fire's location in residential buildings.

Visual indicators of a fire's location from the exterior are based on the type of building and its construction features. Fires in private dwellings are much easier to locate based on the size of the building and the relatively small, adjacent

(4) Many cities' truck companies have a roof firefighter position. The roof position allows the IC to get a topside view of the entire fire building through radio reports and can locate any fire showing in the rear and closed shafts much faster than interior companies can. Moreover, this position is able to control ventilation of the interior stairs through the bulkhead door by coordinating this operation with the IC to prevent untenable conditions for those searching for fire inside. (Photo by Tim Olk.)

rooms. These compartmentalized rooms are always near the open stairwell, and smoke will rapidly fill the entire dwelling. This is one of the main reasons we consider private dwellings one fire area: the limited separations betweens floors and rooms.

If the fire is in the basement, look for heavy smoke with no visible flame on the first floor. Basement windows rarely show smoke or fire conditions as the heavy smoke obscures visible fire, whereas heat and smoke rapidly vent up the basement stairs to the first floor. It is also wise to take a peek at the chimney, if present. In older private dwellings, a basement fire will fill the stove, burner, or incinerator with smoke, allowing smoke to exit the chimney. In fact, a dead giveaway of a basement fire during warmer months is any smoke exiting the chimney.

The greatest private dwelling challenge to locating the original fire area is the presence of balloon-frame construction. Fire originating in the basement may show smoke on the upper floors, too, including the attic, through the inherent continuous stud bays with absent sill plates. Regardless of the private dwelling's construction, always check the basement prior to operating above it-period. In addition, haphazardly ventilating basement windows to aid those peeking around the basement could prove disastrous, especially if they lose their orientation to the basement stairs. It takes only a few seconds to check the basement, and it takes only a few more seconds for it to light up on unsuspecting firefighters.

For upper floors and attic fires, on the other hand, look for smoke-stained windows or smoke pushing from window frames, partially broken windows;

eaves; roof and soffit vents; and roof boards and shingles. Consider the entire fire building the fire area. Spend the proper time determining where the fire is and where it possibly is going. First, conduct a 360° walk around the dwelling and get everyone into position, ready to advance inside the structure. It is tempting to begin taking out windows or chocking the entrance door open to initiate the search (this does the engine a large favor), but without water coming right behind you, you may get chased out.

When arriving chief officers see firefighters getting chased out of the dwelling, they usually "call it" and prematurely move to defensive operations. When this happens before the fire is located and defined, everyone loses. Professionals take the time to make the time. This is another reason the IC should micromanage horizontal ventilation until the fire is located and the engine has good water in the line.

Multiple dwellings require a little more work than private dwellings when it comes to visually determining the fire's location. Because of the size of these residential buildings, and if no visible fire is present, the first-arriving companies must enter the fire building to find the fire and report the location to incoming units. This is where limiting horizontal ventilation from the exterior, particularly fire escapes, is paramount to maintaining a tenable fire apartment or floor. The truck officer is usually responsible for determining the correct fire apartment and the easiest path to get there. The engine officer must further ensure that the path to the fire apartment is unobstructed and should act to verify the correct location and definition of the fire area.

Many fire departments split their truck company personnel to cover the entire fire building, including the roof at multiple dwelling fires. The primary reason for this split-crew deployment is to rapidly assist in locating the fire, extension, and any trapped occupants. Moreover, these personnel become the eyes for the IC to allow for continued size-up and a 360° view of the incident. When these exterior positions communicate with those looking for the fire on the interior, the fire becomes easier to define. For example, if the truck officer states that there is heavy smoke showing around the door to apartment 5C, those on the exterior could relay reports back such as, "There's heavy fire out two of the windows at the rear of the fifth floor." The truck officer on the interior will then have located and defined the fire as involving a great portion of the apartment. Obvious extension is to the apartment above, so other companies can rapidly deploy to cover this area and floor.

The firefighters assigned to the roof play a significant role at multiple-dwelling fires. They can perform an immediate survey or aerial view of the entire building-on all sides. They can readily observe any smoke or fire coming from windows below, even at night. There are many other roof observations that could point those on the interior right to the fire. For instance, many utility chases pierce the roof membrane, including soil pipes. Taking off a glove and feeling the base of the soil pipe could indicate fire in the cockloft. If the soil pipe is hot, then check the pipe chase that it runs through. If the soil pipe is extremely hot to the touch, then you must check for fire in the pipe chase and cockloft. The roof firefighters can also check the returns or draft stops in skylights and inside scuttle hatches by punching inspection holes to look for fire in the cockloft. If the building has a bulkhead, forcing the door and quickly checking the interior stairs for victims and fire conditions could reveal extension. The roof firefighters should make the IC aware that they are forcing open the bulkhead, because of the UL study's increased horizontal ventilation concerns.

Once you force the bulkhead door, it may not close all the way, particularly if you damage it while forcing it open. Consider using the cinderblock that always seems to be present near the door or anything else to butt against the door to help keep it closed until the hoseline has entered the fire apartment and the IC gives permission to reopen it to assist with controlled ventilation.

From the ground, the IC should always be alert for what companies are reporting. Talk to the roof position firefighter, truck officer, and engine officer. Are the engine and truck officers reporting knockdown or trouble darkening the fire? This may indicate the fire area may be in an adjacent room or knee wall and they are simply putting water on the smoke lighting up after exiting the actual fire area that no one can get to. Is the door to the fire apartment burning off? No IC wants to listen to endless chatter on the radio, but until the fire is located, defined, and being extinguished, every little thing is important. Correlate all reports as to where the fire may be going; ventilation operations may take longer until the hoseline is placed or the stream gets into the right area.

Regardless of the type of residential building, horizontal ventilation is not necessarily the most rapid means of locating fire. Although its usefulness is under scientific scrutiny, it is still necessary once the fire is located and the engine begins applying water to the fire area. Complete searches require the fire area to be ventilated, and UL's research findings are entirely based on the "precontrol" concerns observed during the study, including removing as much smoke as possible and determining any minor extension that may not have been discovered prior to the engine opening the nozzle.

Always remember that any visual, anticipated, or reported location of the fire could be wrong. The benefit to systematically locating the fire, with preincident knowledge, experience, visual cues, and reports from those looking for it, will objectively validate any firefighting strategy. Fire departments should interpret helpful fire behavioral research data as a means to incorporate more survival strategy into saving lives. This includes adapting research findings into conventional tactics to allow fire departments to do better what they have already been doing well. Knowing where the fire is has always been the foundation of fireground risk management, and it is still the IC's priority. Once the IC locates the fire, he can properly determine strategy, and everyone can realize safer and more productive fireground operations.

ENDNOTES

1. Underwriters Laboratories. Impact on Ventilation and Fire Behavior in Contemporary and Legacy Residential Construction. Ed. Steve Kerber. Underwriters Laboratories, 2010. Document. <http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/ventilation/DHS%202008%20Grant%20Report%20Final.pdf>;.
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Company Description:

UL's Firefighter Safety Research Institute is dedicated to increasing firefighter knowledge to reduce injuries and deaths in the fire service and in the communities they serve. Working in partnership with the fire service, research departments and agencies, FSRI executes cutting-edge firefighter research and makes the results widely available to the global fire community. With a team of pioneering experts and access to UL's leading infrastructure, equipment and vast knowledge and insights, FSRI conducts and disseminates research and training programs that focus on the changing dynamics of residential, commercial and industrial fires, and the impact they have on the fire service tactics and strategies.

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