COORDINATED FIRE ATTACK

Dedicated to increasing firefighter knowledge to reduce injuries and deaths in the fire service and in the communities they serve.

UL FSRI advances fire research knowledge and develops cutting edge, practical fire service education aimed at helping firefighters stay safe while more effectively protecting people and property. Working in partnership with the fire service, research departments, and agencies, UL FSRI conducts fire dynamics research and makes the results widely available to the global fire community.

"The Study of Coordinated Fire Attack Utilizing Acquired Structures," a multi-year project that is funded by the Federal Emergency Management Agency's (FEMA) Assistance to Firefighters Grant Program, was designed to increase the understanding of suppression and ventilation tactics to improve firefighter safety and effectiveness. Importantly, occupant safety improves with increases in firefighting effectiveness.

This project extended previous UL Firefighter Safety Research Institute (FSRI)-led studies that examined the impact of specific fire service tactics on fire behavior in isolation and using purpose-built structures. This project specifically expanded upon three prior ventilation studies: "Impact of Ventilation on Fire Behavior in Legacy and Contemporary Residential Construction" [1]; "Effectiveness of Fire Service Vertical Ventilation and Suppression Tactics" [2]; and "Effectiveness of Positive Pressure Ventilation" [3]; a prior suppression study, "Study of the Impact of Fire Attack Utilizing Interior and Exterior Streams on Firefighter Safety and Occupant Survival" [4–6]; and a study on basement fires, "Understanding and Fighting Basement Fires" [7] by applying knowledge that was gained in the laboratory experiments to the streets.

Upon completion of these prior projects, our conversations with firefighters, project technical panel members and our advisory board often converged to a common theme: What happens when you combine these tactics and conduct experiments in real structures? To begin to answer that critical question, the UL FSRI team conducted 40 full-scale, live-fire experiments in residential and commercial acquired structures that included single-family homes, apartments within multi-family dwellings and units within a strip mall—all of which were slated for demolition. Our goal of this supplement is to provide insight into the key findings from the experiments, which are detailed in the following three technical reports (scan the QR code to view the reports online):

1. Analysis of the Coordination of Suppression and Ventilation in Single-Family Homes [8]
2. Analysis of the Coordination of Suppression and Ventilation in Multi-Family Dwellings [9]
3. Exploratory Analysis of the Impact of Ventilation on Strip Mall Fires [10]

To safely and successfully conduct these experiments in acquired structures, it was imperative to work with strong and supportive fire department partners. For the 20 single-family experiments, the team traveled to Ohio to work with the Sidney Fire Department and the Beavercreek Township Fire Department. The 13 multi-family experiments were conducted with the Cobb County Fire & Emergency Services in Marietta, GA. Finally, the team returned to Ohio to conduct the seven strip mall experiments with the Fairborn Fire Department. The UL FSRI team sincerely appreciates the men and women of these departments for their tireless effort, professionalism and hospitality during this experimental series.

The authors also wish to express our gratitude to the Shelby County Land Bank and Mary and Bob Nutter for the generous donation of the single-family structures that were used in these experiments. A special thank you goes to the Cobb County Department of Transportation for the generous donation of the apartment buildings that were utilized in the multi-family dwelling experiments. Finally, we thank the city of Fairborn for acquiring the strip mall.

Authored by UL FSRI Research Engineers:
- Craig Weinschenk, Jack Regan, Keith Stakes, Julie Bryant, Nick Dow

Single-Family Experiments

# of Structures:	**8**
# of Experiments:	**20**
Fire Location(s):	**First-Floor Kitchen, Second-Floor Bedroom**
Ventilation Tactics:	**Horizontal, Vertical, Door Control, PPV, Hydraulic**
Study Variables:	**– First-Floor/Second-Floor Fires – Interior/Exterior Suppression – Timing of Ventilation Relative to Suppression**

VENTILATION *and the Impact on* FIRE DYNAMICS

To understand the impact of ventilation on fire dynamics, let us first examine the impact of ventilation on the gas flows that are within a structure. The acquired structure experiments confirmed findings from the ventilation experiments in purpose-built structures on the importance of identifying and controlling flow paths that are within a structure (e.g., use of a hoseline, closed doors, fans, etc.). A flow path is the interior volume between a higher-pressure source and a lower-pressure space that's within the structure and/or atmospheric pressure exterior vent. Fresh air in-flow and smoke exhaust out-flow can be co-located at bidirectional vents or at independent locations via unidirectional vents. Gases that flow within the flow path are driven by pressure, which typically is generated from the production of expanding, high-temperature fire gases (i.e., smoke).

> **A flow path is the interior volume between a higher-pressure source and a lower-pressure space within the structure and/or atmospheric pressure exterior vent. Fresh air in-flow and smoke exhaust out-flow can be co-located at bidirectional vents or at independent locations via unidirectional vents. Gases that flow within the flow path are driven by pressure, which typically is generated from the production of expanding, high-temperature fire gases (i.e., smoke).**

Consider the single-story structure that has a kitchen fire and two open kitchen windows that's shown in Figure 1 (Experiment 16 from the single-family home series). During the growth phase of the fire, bidirectional flows developed through the archways of the kitchen and dining room as higher-temperature, higher-pressure gases flowed toward areas of lower pressure. The area of lower pressure that was created by the increased velocity of the fire plume, combined with the higher-pressure smoke that pushed on the previously motionless gases, led to air flow toward the fire. Once the oxygen that was available for combustion in the air was consumed and smoke filled the dining room and living room, there was limited exchange of gases (predominately smoke), as shown by the small red arrows in Figure 1. At this point, the main source of air for combustion was the intake areas of the kitchen windows. The flow path (shaded in gray) was limited to the kitchen.

Once the front door was opened, the flow of gases through the dining room and living room portion of the flow path increased. An open door is an efficient vent (minimal sill, high lintel) for the exhaust of combustion gases and entrainment of air. Figure 2 shows the bidirectional flow at the doorway after it was opened and shows the changes to the flow of gases within the flow path, particularly between the higher-pressure supply (fire) and lower-pressure vent (open front door).

Figure 1. A photograph of an experiment from a kitchen fire in a single-story residential structure that has two open kitchen windows (single-family Experiment 16), and a representation of flows (intake and exhaust). After the rooms of the house open to the fire room have filled with smoke, the kitchen windows served as the only intake and exhaust vents of the flow path (shaded in gray).

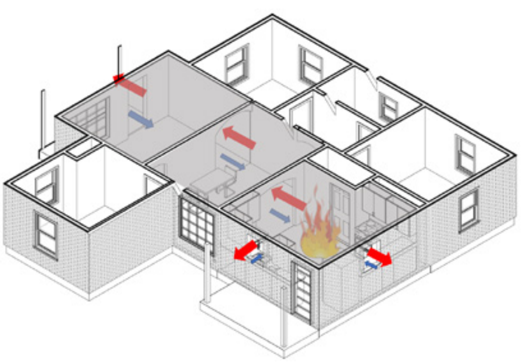


Figure 2. The suppression crew from a kitchen fire in a single-story residential structure that has two open kitchen windows after the front door was opened, and a schematic of the gas flow (intake and exhaust). The open front door added a new exterior vent to flow path (shaded in gray), which allowed for additional exchange of combustion gases and ambient air. This exchange provided increased oxygen to the ventilation-limited fire.

The increase in available oxygen led to an increase in the heat release of the fire. The fire response to changes in ventilation was common across prior laboratory experiments and in each of the acquired-structure experimental series. Therefore, the importance of identifying 1) the fire location, 2) existing intake and exhaust locations (i.e., where the air is coming from), and 3) points of firefighter entry relative to the fire location and open vents as part of a fireground size-up was a key element to tactical considerations that were emphasized in each of the three coordinated fire attack technical reports.

Let us now examine a two-story residential structure that has a second-floor bedroom fire (Experiment 3 from the single-family series). In this example, two bedroom windows were open and the front door was closed at the time of ignition (see Figure 3). Initially, the flow path included the fire compartment (bedroom), the open second-floor bedrooms, the second-floor hallway and open areas on the first floor. Bidirectional flow was established at both open bedroom windows and through the open fire room door. Similar to the living room and kitchen in the single-story experiment, as smoke filled the additional second-floor bedrooms, the magnitude of gas flows through the respective doorways progressively lessened, leaving the principle intake and exhaust flows between the open windows and the fire.

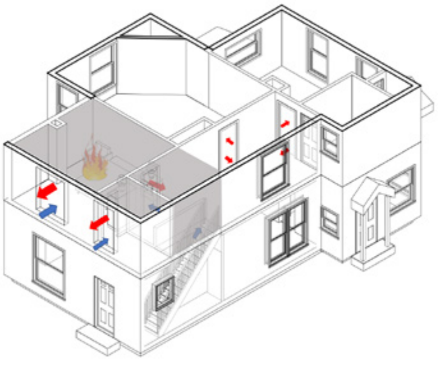


Figure 3. A representation of flow (intake and exhaust) from a bedroom fire within a two-story residential structure that has two open windows in the bedroom with the front door closed. After the two open bedrooms of the second floor filled with smoke, the fire room windows served as the primary intake and exhaust vents of the flow path (shaded in gray).

Smoke filled the open areas of the second floor but had not pushed down into the first floor. With no open vents on the first floor, limited air was able to be pulled up the stairwell. Once the front door was opened by the suppression crew (see Figure 4), the front door became a unidirectional intake vent, and the stairwell became the intake portion of the flow path. Knowledge of the fire location, fire development, open vents and flow path(s) can be leveraged by interior crews to take advantage of the air that's entrained through the open front door, which can improve conditions for potential occupants who are located in the inlet side of flow path. This benefit only is possible if the suppression crew quickly flows water to begin reducing the hazard of the fire. In

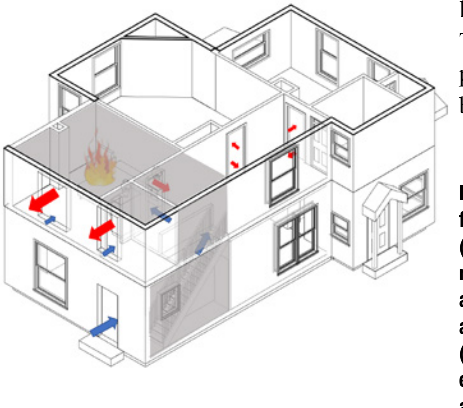
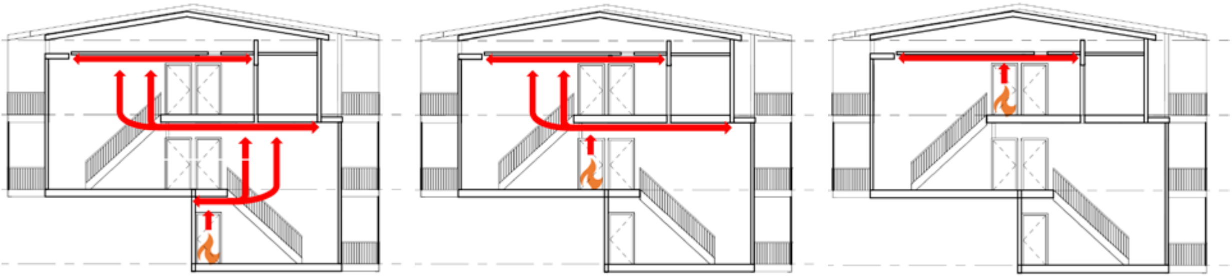


Figure 4. Fire conditions at the start of entry for a second-floor bedroom fire (single-family Experiment 3), and a representation of flows (intake and exhaust) at that time. The open front door created a unidirectional intake to the flow path (shaded in gray), which allowed for an exchange of combustion gases and ambient air.



Below-Grade Fires First-Floor Fires Second-Floor Fires

Figure 5. Smoke path of travel within the stairwell during below-grade, first-floor and second-floor fires of a multi-family dwelling that has a shared stairwell.

both the single-family and multi-family experiments, when the front door was opened (adding to existing ventilation), fire growth was observed, because a more efficient exchange of smoke and air was created.

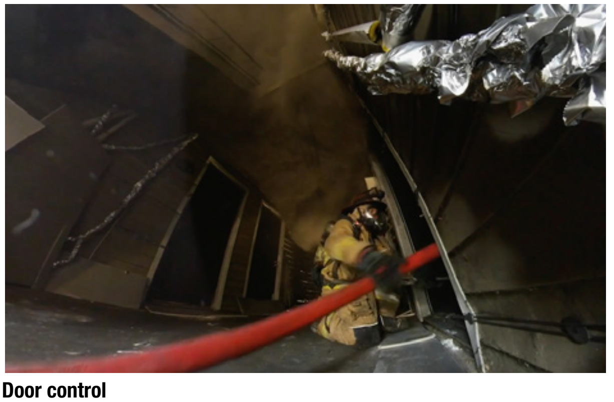
Just as it is important to recognize that opening vents can supply oxygen to the fire, firefighters also should understand the impact on path of travel for combustion products. This concept was of particular importance in the multi-family dwellings experiments, because it pertained to toxic gas exposures to potential occupants in the common enclosed stairwell. Figure 5 shows how smoke filled the stairwell and reduced visibility based on the level at which a fire might occur.

Opening the apartment door to gain access should be thought of as ventilation, in terms of its capability to exhaust from the fire compartment but also for its potential to cause fire growth as well as smoke movement into the stairwell (which could limit the egress for potential occupants in exposure units). Consideration should be given to employ suppression and ventilation tactics that may lessen the flow of combustion gases into shared common spaces whenever feasible. Although not an option for every fire, during both the single-family and multi-family experiments, exterior water application was shown to have a positive impact by lessening of the flow of high-temperature combustion gases out of the fire compartment. Additionally, ventilation tactics, such as door control, positive pressure (e.g., fan) and negative pressure (e.g., hydraulic), that were used either simultaneously with or sequentially post-suppression were shown to limit gas flows into common spaces. Figure 6 shows the conditions in the common stairwell following entry to the fire apartment during the multi-family experiments following different tactical approaches.

Similar fire behavior characterized the strip mall experiments. In each strip mall scenario that was examined,

Interior suppression

Initial exterior suppression



Door control

Positive pressure attack

Figure 6. Stairwell conditions following entry to the fire apartment for several different tactical options during the multi-family dwelling experiments.

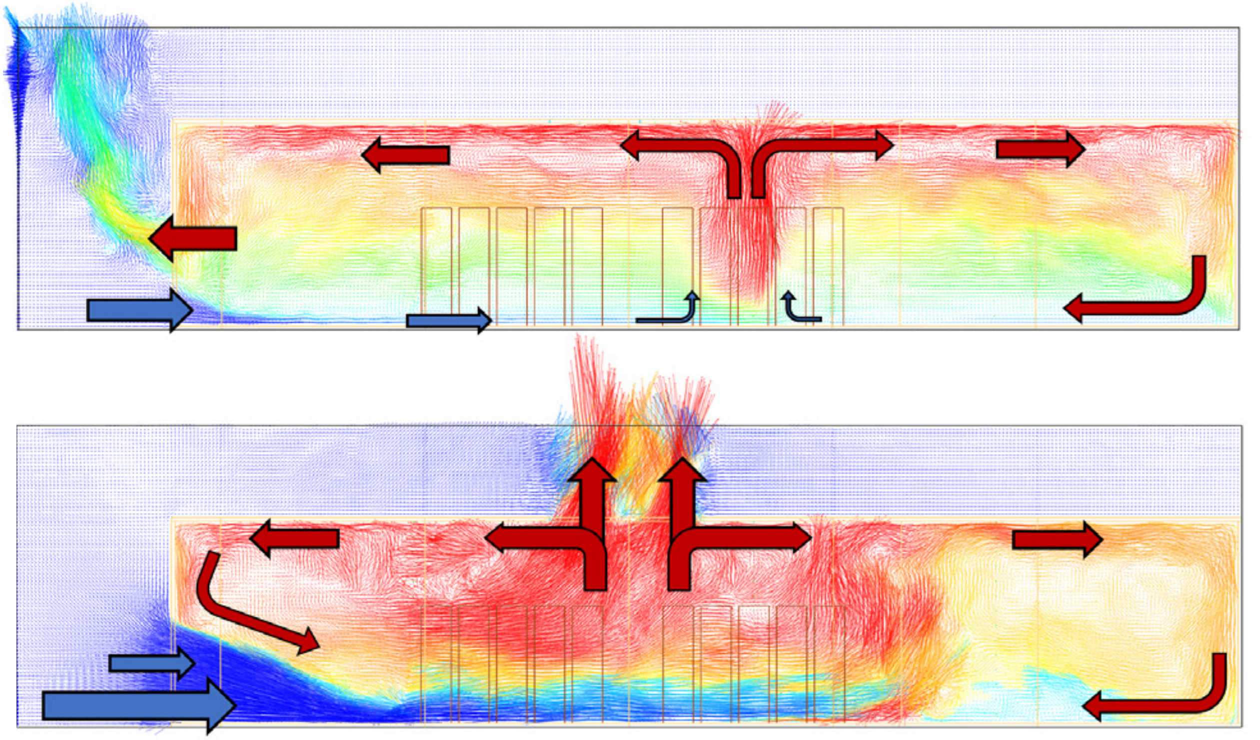


Figure 7. A representation of flows (intake and exhaust) within the strip mall unit following horizontal ventilation (top) and after vertical ventilation (bottom), generated using a computational fire model [11].

32 square feet of vertical ventilation

64 square feet of vertical ventilation

Figure 8. Visible flames following the opening of 32 square feet of vertical ventilation area (left) and 64 square feet of vertical ventilation area (right) for an experiment with suppression delayed until after the completion of ventilation.

when the additional ventilation area (vertical or horizontal) increased the exhaust of combustion products, it also caused additional air to enter the unit. The additional air added oxygen to a ventilation-limited fire, and the temperatures that were inside of the structure increased. For the experiments that excluded vertical ventilation, a flow path was established between the open front door and the seat of the fire. The flow path began and ended at the front door, with the bottom of the door as the intake and the top of the door as the exhaust. Intake flows circulated as far back as the remaining fuel near the ignition location. Consider Figure 7, which depicts a cutaway of the unit that was generated from a computational fire model [11] with representative flows that developed as a result of the open front door. The addition of the vertical vents transitioned the front of the structure from a bidirectional flow to a unidirectional intake as the vertical vents were unidirectional exhausts. Note the decreasing magnitude of intake with elevation.

Following vertical ventilation, flames were visible at the open vertical vents in two experiments in which suppression was delayed by approximately 90 seconds. However, this was not an indication that all of the heat was being exhausted. In fact, it was an indication that the heat that was within the structure increased, and additional unburned fuels were generated to burn outside of the structure (see Figure 8).

WATER USAGE *and* DISTRIBUTION

The water usage discussion focuses on the single-family and multi-family experiments due to the various suppression tactics studied during those series.

In 31 of the 33 residential experiments, a single 1¾-inch hoseline was utilized for initial knockdown and suppression, with either a combination nozzle flowing 150 gpm at 50 psi or a 7/8-inch smooth bore nozzle flowing 160 gpm at 50 psi. For these 31 experiments, the total water that was used during primary suppression of these room and contents fires for both interior suppression and exterior fire control was on average 145 gallons ± 51 gallons that ranged between 73 gallons and 256 gallons. Although this water flow data doesn't include the water that was used during overhaul and mop-up operations, the primary suppression streams that were used in both single and multiple rooms of fire employing either interior suppression or an exterior fire control technique required total flow that could be attained with fewer than the 300 gallons minimum booster tank capacity on fire apparatus [12]. This does not devalue the need to secure a water supply for your primary suppression apparatus as quickly as possible but highlights that a lot of good can be done with a relatively small amount of water. The two experiments that were outliers include multi-family Experiment 1A, in which the pressurized water extinguisher used less than 5 gallons, and multi-family Experiment 5, where the multi-apartment fire required multiple lines for control and suppression.

Figure 9. Example of improved water dispersion by leveraging exterior water directed off of a window frame.

Previous research into water application as a part of the fire attack study [4, 6] highlighted the importance of water dispersion within a compartment, regardless of the position of the line relative to the structure (i.e., inte-

Multi-Family Experiments

# of Buildings:	4
# of Experiments:	13
Room(s) of Origin:	Bedroom, Kitchen, Living Room
Floor of Origin:	Below Grade, First Floor, Second Floor
Ventilation Tactics:	Horizontal, Door Control, PPA, PPV, Hydraulic
Study Variables:	– Protection of Common Stairwell – Interior/Exterior Suppression – Interior/Exterior Exposures – Timing of Ventilation Relative to Suppression – Limited Access

"The UL FSRI research is vitally important to the fire service. As a member of the technical panel, I have seen first-hand the positive results of these studies as they provide actionable intelligence (research) for the fire service. For the FDNY, this has both validated long-standing procedures and has resulted in adjustments to others. Importantly, it has also added to the understanding of why we perform certain tactics on the fireground. A deeper understanding of the why adds operational flexibility and enables our firefighters to operate more effectively in the 'gray areas.' These are the areas that are not as well defined in our written procedures. A firefighter who understands the why is better equipped to size up, react and adjust tactics in real time on the fireground. A thinking firefighter is one of our greatest assets, and the research combined with our experiences greatly deepens the thinking firefighters' understanding and knowledge base."

- Frank Leeb, Deputy Assistant Chief, Fire Department of the City of New York (FDNY)

Figure 10. Example of improved water dispersion by leveraging interior water directed off of a door frame.

rior or exterior). In these experiments, alternative means for creating a broken stream improved water distribution within a compartment. A traditional exterior application of water into a fire compartment used a straight stream at a steep angle from a fixed position. This approach maximizes surface/fuel cooling in the compartment and, as a result, is successful generally at reducing the heat release rate of a fire.

However, because of the momentum of the water, the majority of the water is dispersed around the perimeter of the compartment. Depending on the layout of the fuel within the compartment, the lack of water onto the center of the floor of the compartment can increase the likelihood of regrowth during the transition time for the crew(s) to move to the interior of the structure to complete suppression.

A method for breaking up the hose stream on the upper edge of a window frame in a way that deflects the water spray into the fire room was used as part of the exterior fire control tactic in both the single-family and multi-family components of this experimental series (Figure 9). Applying a broken hose stream into a fire room dropped temperatures throughout the fire compartment and reduced the regrowth potential. In a related manner, an interior suppression crew might be able to get water into a fire compartment much earlier than arriving at the threshold of the fire room door (a hose stream generally should be considered a line-of-sight tool) by using similar principles to the window frame hit (Figure 10). If the nozzle operator is able to determine the location of the door frame, water can be deflected into the fire compartment by manipulating the nozzle up and down along the frame. This causes the stream to break apart, sending some component of the water into the fire compartment and cooling surfaces even before the hose team reaches the room for entry.

"The Coordinated Fire Attack study has strengthened Metro Fire's commitment to a fast-water, fast-search culture. Over the past decade, Metro Fire has had a large turnover of our membership in all ranks. The information from UL FSRI has aided the development of our training curriculum that has led to better decisions being made on the fireground. Taking the lab to the streets in acquired structures has validated many of the tactical considerations from earlier studies, and I encourage everyone to take a look back at the prior studies to compare their personal experience with what was found in the research. Looking ahead to the UL FSRI study on Search and Size-Up, we are anticipating a better understanding of victim removal that may result in better outcomes for victims as well as how to improve our size-up capabilities."

- Russell Gardner, Captain, Sacramento Metro Fire Department

Coordination of FIREGROUND TACTICS

One second before start of ventilation

One second after start of ventilation

Across these experiments, a common theme emerged with respect to fireground coordination. When ventilation was provided by opening the front door for access or by conducting horizontal or vertical ventilation and the suppression was delayed, the ventilation led to an increase in the oxygen that was available for combustion. Additional oxygen provided to a vent-limited fire resulted in an increase in the heat release rate of the fire. As the time difference between ventilation and suppression lengthened, there was an increase in severity of the thermal and toxic hazard that was within the structure.

√ Ventilation pre-suppression should be limited, potentially to the fire compartment only, and closely timed with the beginning of suppression. Ventilation post-suppression should be focused on the areas of greatest hazard for potentially trapped occupants' continued exposure to fire gases.

20 seconds after start of ventilation

Figure 11. Examples of coordinated suppression. The suppression crew was in place outside of the apartment door (in the enclosed stairwell), made entry to unit and began flowing water within seven seconds of the start of window ventilation.

It is important to recognize that as the distance between the fire and the vent location decreased, the response time of the fire to changes in the flow path also decreased. This time can be impacted by other factors, including but not limited to fuel composition, fuel orientation, structure compartmentalization (e.g., closed or open doors) and external wind, among others. Therefore, when creating a new vent in a structure, an appropriate size-up should be conducted with consideration given to the location of the fire and location of the vent.

If water is applied immediately following an opening being made, the removal of heat prior to the renewed source of oxygen reaching the combus-

Figure 12: Exterior conditions through the open vertical vent and at the front door following initial suppression.

tibles that still are pyrolyzing can rapidly reduce the temperatures within the structure. Consider an example from the multi-family experiments (Experiment 1C). In this experiment, all vents to the apartment were closed at the time of ignition. Firefighter operations began by venting the fire room (bedroom) window (see Figure 11). Within seven seconds, the suppression crew made entry to the fire apartment and began flowing water. Figure 11 shows the conditions 20 seconds after ventilation. Immediately following ventilation, there was an increase in fire room temperatures and visible burning from the bedroom window ventilation. However, as a result of short lag time between ventilation and suppression, there was no noticeable increase in temperatures in any compartment of the apartment or common stairwell that was outside of the fire room. It is important to consider that, whenever possible, ventilation pre-suppression should be limited, potentially to the fire compartment only, and closely timed with the beginning of suppression.

Coordination should be thought of as the systematic approach to the implementation of suppression and ventilation tactics. These tactics can occur sequentially or simultaneously with proper communication and coordination to minimize the time lag that's between them.

Similarly, in the strip mall experiments, when suppression occurred simultaneously with additional ventilation (Experiment 5), temperatures throughout the compartment and through the ventilation openings decreased upon the start of water flow. Figure 12 shows the visible smoke through the open vertical vent as the crew flowed water at the doorway to the unit. Note the difference compared with Figure 8, where suppression actions lagged the creation of vertical vents.

Ventilation actions that occurred after the onset of suppression (within 30 seconds) limited additional fire growth in any of the experiments that were conducted as part of this series. In general, the effectiveness of post-suppression ventilation varied substantially between structures, but the experiments in which toxic gas concentrations remained highest for the longest were those in which no timely ventilation actions were performed close to the occupant location. Ventilation post-suppression should be focused on the areas of greatest exposure hazard for potentially trapped occupants.

Strip Mall Experiments

# of Units:	**4**
# of Experiments:	**7**
Ventilation Tactics:	**Horizontal, Vertical**
Study Variables:	**– Commercial Fuel Loads – Commercial Construction – Large-Volume Fire Rooms – Increasing Horizontal & Vertical Ventilation**

Technical panel members Greg Hubbard, Ray McCormack and Russell Gardner (front row) talk through the scenario of a single-family experiment with Jason Truesdale of the Sidney Fire Department (back row) prior to ignition in Sidney, OH.

WHAT'S NEXT

The wide range of variables on the fireground makes it difficult to make definitive statements on the exact time window within which crews must perform suppression and ventilation tactics. However, this project has led to further understanding of the coordinated fireground. Coordination should be thought of as the systematic approach to the implementation of suppression and ventilation tactics. These tactics can occur sequentially or simultaneously with proper communication and coordination to minimize the time lag that's between them. Firefighting tactics research still is far from complete. Future research should include additional experiments in large-volume structures/fire compartments and improved understanding of thermal and chemical exposures to firefighters. A common research need that was identified in all three phases of the project was additional research into firefighter search and rescue. The coupling of suppression and ventilation tactics for size-up and search and rescue on the residential fireground currently is an area of active research for UL FSRI.

Additional Project Information

The authors of the three technical reports (Craig Weinschenk, Jack Regan, Julie Bryant, Keith Stakes, Nick Dow and Robin Zevotek) thank the entire UL FSRI team for their hard work over the duration of this project. This project required tremendous effort from structure acquisition through instrumentation, experiment execution and data analysis. The authors also thank team member Joshua Crandall for his work capturing many of the photographs that appear throughout this supplement.

For the duration of the project, the UL FSRI team collaborated with the project technical panel (see page A14) to maximize the impact of each specific experiment for the purposes of improving firefighter safety and firefighter engagement with research. They provided invaluable expertise during the development and planning phase of this project and contributed valuable feedback regarding the project results and conclusions.

"The fire service is filled with 'We believe what we have experienced, and from our experience we know what is right on the fireground.' Some of this comes from our training ground and some of it is just how we operate in the fire service. Each technical panel member has increased their knowledge during the course of each project. What we thought we knew or what we experienced isn't always what is going on inside the fire building. The research accomplished by UL FSRI over the past five years with Fire Attack Study and Coordinated Attack Study have proven many of these beliefs and/or tactics to be right or wrong. Regardless, it has given the fire service a better understanding of what is actually going on during a structure fire. It has helped the fire service change or adjust tactics to meet the recommendations from each study. In Coordinated Attack, we had the ability to take the data from the lab experiments in Fire Attack to the streets of acquired structures around the country. Truth be told, the Coordinated Attack study was more challenging to complete due to the different interior layouts and construction features based on what UL FSRI could get their hands on to run the tests. Then to see the fire dynamics did not change was even more reassuring, that the science doesn't change from a structure built in a lab or structure built on the street. The things that do change are outside influences like wind, rain, or snow and UL FSRI did a great job in working around those outside influences. Getting out of the lab, we felt we would be able to test out other theories or beliefs, since we were using real structures. No matter what we came up with, UL FSRI accepted the challenge and did what they could to test our theories. The end results support that fire dynamics are fire dynamics regardless whether you put the building on the street or in a lab."

- Chad Christensen, Fire Captain, Los Angeles County Fire Department

COORDINATED FIRE ATTACK BY THE NUMBERS

WHAT IT TOOK TO CONDUCT FULL-SCALE ACQUIRED STRUCTURE EXPERIMENTS

20 Single family residential experiments
Partnering with City of Sidney Fire Department and Beavercreek Township Fire Department

7 Strip mall experiments
Partnering with Fairborn Fire Department

13 Multi-family residential experiments
Partnering with Cobb County Fire and Emergency Services

More than **4,100** miles traveled

58 days spent conducting experiments for a total of **879** staff and technical panel days

More than **8,000** unique temperature, pressure, heat flux, gas concentration, and velocity measurements made

17 miles of measurement cable run

7.5 TB of data, video, and pictures recorded

Total pages across three reports: **981**

Total tables: **93**

Total graphs: **738**

ULfirefightersafety.org

Partial group photo of project technical panel from Fairborn, OH, during strip mall experiments.

Coordinated Fire Attack Technical Panel

Christopher Byrne, Colorado Springs Fire Department
Tony Carroll, District of Columbia Fire and EMS Department
Chad Christensen, Los Angeles County Fire Department
Shea Chwialkowski, Richfield Fire Department
Danny Doyle, Pittsburgh Fire Department
Brad French, Dayton Fire Department
Russell Gardner, Sacramento Metropolitan Fire Department
Scott Gray, Seattle Fire Department
David Guercio, Baltimore City Fire Department
Greg Hubbard, Orange County Fire Rescue
Curt Isakson, Escambia County Fire Rescue
Cody Johnson, Homer Volunteer Fire Department
Frank Leeb, Fire Department of the City of New York (FDNY)
Dennis LeGear, Oakland Fire Department
Stephan Lopez, Dallas Fire-Rescue
Ray McCormack, Fire Department of the City of New York (FDNY)
James Mendoza, San Jose Fire Department
Nicholas Papa, City of New Britain Fire Department
Joe Pronesti, Elyria Fire Department
Richard Riley, Kentland Volunteer Fire Department
Andrew Ruiz, Los Angeles Fire Department
Terrence Sheppard, Chicago Fire Department
Eric Staggs, City of Spokane Fire Department
Chris Stewart, Phoenix Fire Department

The authors also thank the research team from the Illinois Fire Service Institute (IFSI Research) for their assistance throughout the experimental series. Particularly, their expertise in laser diagnostics and skin burn assessments improved the measurement capability of the experiments.

References

[1] S. Kerber. Impact of Ventilation on Fire Behavior in Legacy and Contemporary Residential Construction. Technical report, Underwriters Laboratories, Northbrook, IL, December 2010.

[2] S. Kerber. Study of the Effectiveness of Fire Service Vertical Ventilation and Suppression Tactics in Single Family Homes. UL Firefighter Safety Research Institute, Northbrook, IL, June 2013.

[3] R. Zevotek and S. Kerber. Study of the Effectiveness of Fire Service Positive Pressure Ventilation During Fire Attack in Single Family Homes Incorporating Modern Construction Practices. UL Firefighter Safety Research Institute, Columbia, MD, May 2016.

[4] C. Weinschenk, K. Stakes, and R. Zevotek. Impact of Fire Attack Utilizing Interior and Exterior Streams on Firefighter Safety and Occupant Survival: Water Mapping. UL Firefighter Safety Research Institute, Columbia, MD, December 2017.

[5] C. Weinschenk, K. Stakes, and R. Zevotek. Impact of Fire Attack Utilizing Interior and Exterior Streams on Firefighter Safety and Occupant Survival: Air Entrainment. UL Firefighter Safety Research Institute, Columbia, MD, December 2017.

[6] R. Zevotek, K. Stakes, and J. Willi. Impact of Fire Attack Utilizing Interior and Exterior Streams on Firefighter Safety and Occupant Survival: Full-Scale Experiments. UL Firefighter Safety Research Institute, Columbia, MD, January 2018.

[7] D. Madrzykowski and C. Weinschenk. Understanding and Fighting Basement Fires. UL Firefighter Safety Research Institute, Columbia, MD, March 2018.

[8] J. Regan, J. Bryant, and C. Weinschenk. Analysis of the Coordination of Suppression and Ventilation in Single-Family Homes. UL Firefighter Safety Research Institute, Columbia, MD, March 2020.

[9] K. Stakes, J. Bryant, N. Dow, J. Regan, and C. Weinschenk. Analysis of the Coordination of Suppression and Ventilation in Multi-Family Dwellings. UL Firefighter Safety Research Institute, Columbia, MD, May 2020.

[10] C. Weinschenk and R. Zevotek. Exploratory Analysis of the Impact of Ventilation on Strip Mall Fires. UL Firefighter Safety Research Institute, Columbia, MD, April 2020.

[11] K. McGrattan, S. Hostikka, J. Floyd, R. McDermott, and M. Vanella. "Fire Dynamics Simulator, Users Guide." National Institute of Standards and Technology, Gaithersburg, MD, USA, and VTT Technical Research Centre of Finland, Espoo, Finland, sixth edition, September 2019.

[12] *NFPA 1901: Standard for Automotive Fire Apparatus*. National Fire Protection Association, Quincy, MA, 2016.

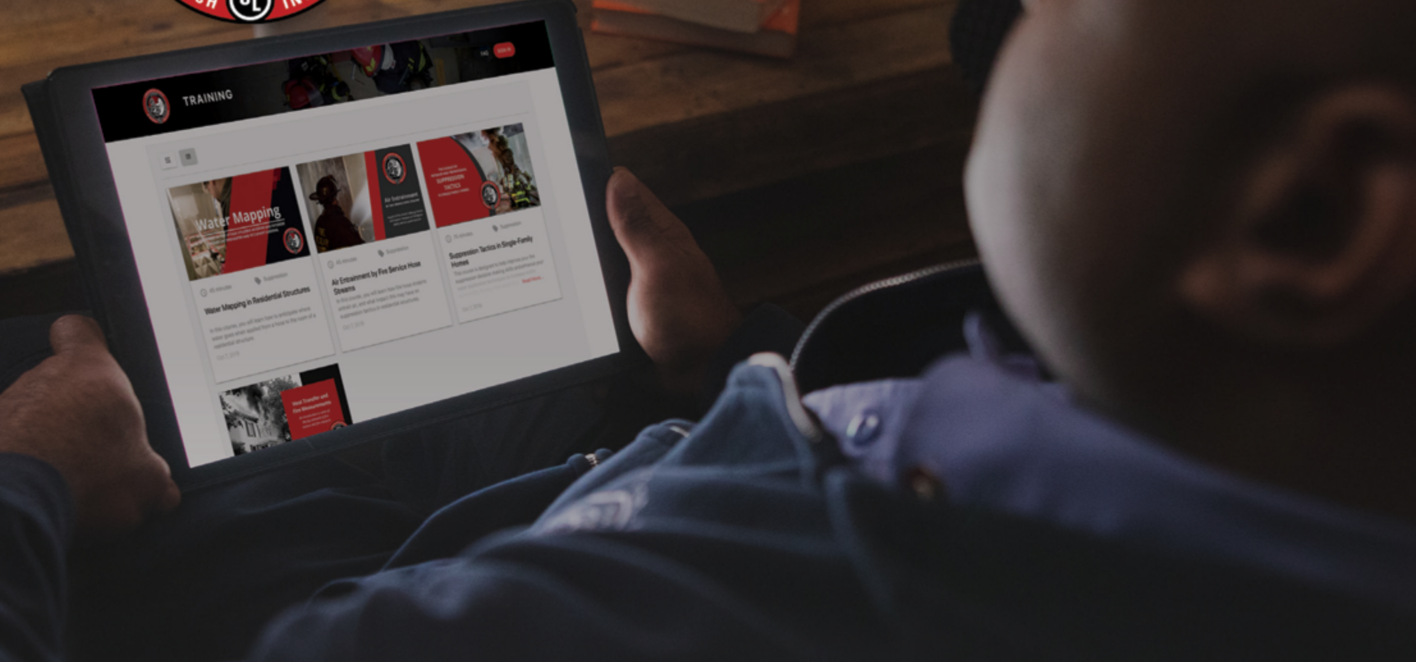
Want the latest updates on UL FSRI research and training sent directly to your inbox?

Scan this QR code to sign-up for the UL FSRI Newsletter.

Stay informed by following UL FSRI on social media:

- ulfirefightersafety.org
- @ulfirefightersafety
- @UL_FSRI
- @ulfsri
- @ulfirefightersafety
- @ulfsri

FIRE SAFETY ACADEMY



Translating science into strategy

The UL FSRI Fire Safety Academy online platform makes it easy to stay updated on the latest in science-based information.

The courses found in the FSA translate UL FSRI research findings into tactical considerations, increasing your knowledge and helping you and your department make more efficient, safe and informed decisions on the fireground.

"Operationalizing the detailed research conducted by the UL FSRI team can be a challenge, especially for larger fire departments. The UL FSRI Fire Safety Academy provides a fantastic foundation for the science and allows a department training and operations divisions to create the expectations and training for the decision making and action on the fireground."

– Chris Stewart,
Deputy Chief, Phoenix Fire Department

Visit **training.ulfirefightersafety.org** for future training courses related to the findings of the Coordinated Fire Attack in Acquired Structures project.