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FE Analysis of Modular Woodburning Fireplace Fire with Gas Log Lighter in Determining Fire's Cause

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Abstract

A fire originated inside the chase[1] (a vertical enclosure, usually constructed of wood, that houses and conceals a chimney) surrounding a modular fireplace system of a new residence, ultimately spreading and destroying the home. A lawsuit by the homeowner's insurance company was later filed against the general contractor and framing subcontractor, alleging that improper clearances between the fireplace and chase framing caused the fire. The author was retained to perform a forensic engineering analysis of the origin and cause of the fire. An exemplar modular fireplace system and chase were constructed and instrumented, and more than 30 test burns were performed. Additional testing evaluated gas migration from the fireplace log lighter into flexible combustion make-up air ducting and the burning propensity of the ducting. The testing and analysis concluded that the cause of the fire was not improper clearances to the chase framing but improper installation of the combustion air kit facilitating a mediation of the case.

Keywords

Modular fireplace, log lighter, propane, gas migration, combustion air duct, wood burning, chimney, low temperature ignition, smoldering, clearances, fire investigation, methodology, reconstruction, testing, chase, NFPA 921, NFPA 211, UL 127, forensic engineering

Background

The home in question was a newly constructed, two-story, wood-framed structure of approximately 10,000 square feet containing a total of six fireplaces. The incident fireplace was located in the family room and installed in a common chase enclosure next to the exterior covered patio fireplace. **Figure 1** depicts a Google Earth image of the home prior to the fire and the locations of the family room, exterior covered patio, and associated modular fireplaces.

Figure 1
A pre-fire Google Earth image of the residence around the time it was first occupied in October of 2015.

The incident fireplace was identified as a solid woodburning listed masonry modular fireplace system. The firebox incorporated a make-up combustion air kit as well as a propane log lighter kit, which included a recessed pan style burner. Both the make-up combustion air kit and the log lighter kit were specified and approved for use with the fireplace. **Figure 2, Figure 3** (on page 34), and **Figure 4** (on page 34) are excerpts from the installation manual of the fireplace system depicting the style unit.

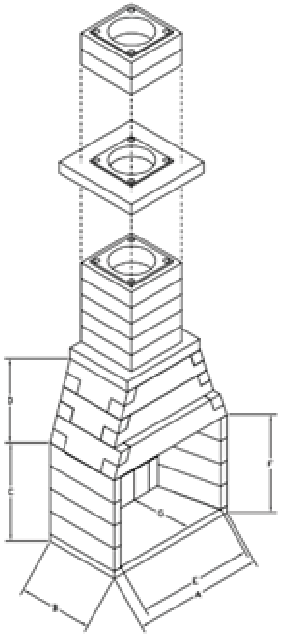

Figure 2
Either masonry or metal chimney kits are available for use with the fireplace system.

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Figure 5 is an excerpt of the installation instructions for the make-up combustion air kit. **Figure 6** is an image of an exemplar log lighter burner pan and cap that was installed in the incident fireplace.

The homeowner reported that the fireplace had been used approximately 30 times total since they had occupied the home. The homeowner cut, stacked, and seasoned his own firewood. The wood was seasoned for at least 18 months. The fireplace was used with a consistent frequency of once or twice a week during the heating season and used in a consistent manner each time. On the evenings when he would build a fire (around 7:30 p.m.), the homeowner would place three seasoned split oak logs of 3 inches in diameter and 20 to 21 inches long inside the fireplace. He placed newspaper beneath the logs, lit the paper with a grill lighter, and turned on the gas valve to the log lighter. After approximately 10 minutes the firewood would be burning well, and he would turn the log lighter gas valve off. After 60 to 90 minutes, he would add one or two more oak logs of the same size to the fire. At the time he and his wife would go to bed (around 10:30 p.m.), there would be nothing but coals and ashes in the fireplace.

Post-incident, the homeowner reported to the independent fire investigators for his insurance company that he had experienced two or three flash fires[2] with the fireplace

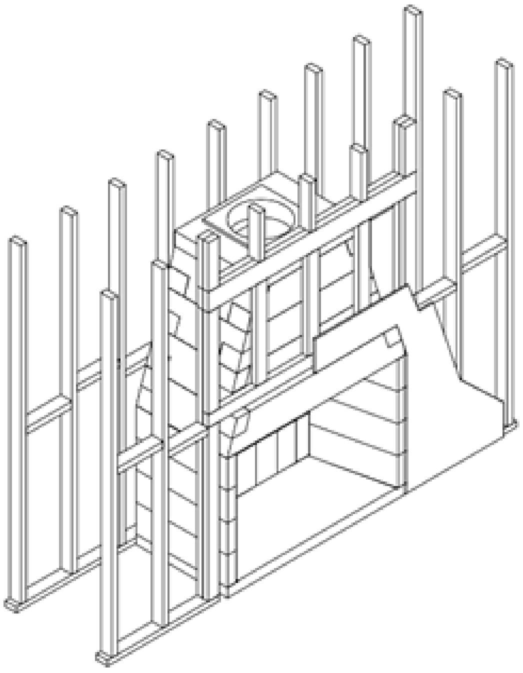
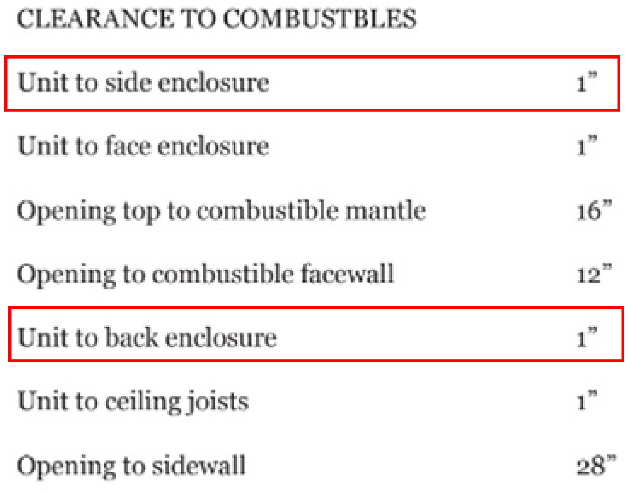


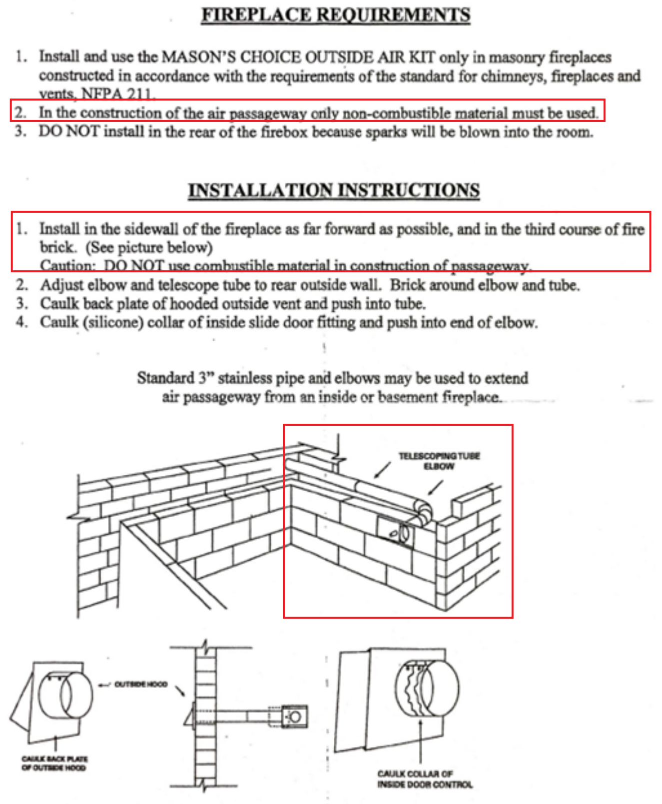
Figure 3
Clearances to combustibles, including wood-framing, are specified in the installation manual as well as on a permanent plate attached to the firebox.



CLEARANCE TO COMBUSTBLES

Unit to side enclosure	1"
Unit to face enclosure	1"
Opening top to combustible mantle	16"
Opening to combustible facewall	12"
Unit to back enclosure	1"
Unit to ceiling joists	1"
Opening to sidewall	28"

Figure 4
Annotated clearances to combustibles table excerpt from the fireplace installation manual (also reflected on the permanent label on the firebox). Note the clearance requirement from the fireplace back and sides to combustibles, including chase enclosure wood wall framing, is 1 inch.



FIREPLACE REQUIREMENTS

1. Install and use the MASON'S CHOICE OUTSIDE AIR KIT only in masonry fireplaces constructed in accordance with the requirements of the standard for chimneys, fireplaces and vents, NFPA 211.
2. In the construction of the air passageway only non-combustible material must be used.
3. DO NOT install in the rear of the firebox because sparks will be blown into the room.

INSTALLATION INSTRUCTIONS

1. Install in the sidewall of the fireplace as far forward as possible, and in the third course of fire brick. (See picture below)
Caution: DO NOT use combustible material in construction of passageway.
2. Adjust elbow and telescope tube to rear outside wall. Brick around elbow and tube.
3. Caulk back plate of hooded outside vent and push into tube.
4. Caulk (silicone) collar of inside slide door fitting and push into end of elbow.

Standard 3" stainless pipe and elbows may be used to extend air passageway from an inside or basement fireplace.

Figure 5
An annotated excerpt from the combustion air kit manufacturer's installation instructions. A steel telescoping horizontal hard duct (tube) is provided with the kit. Note the requirement that the make-up combustion air discharge into the firebox be installed "as far forward as possible and in the third course of firebrick." Note also the multiple instructions not to use combustibles in the construction of the ducting.

Figure 6
An image of an exemplar log lighter burner pan of the style installed in the incident fireplace. The orifice can be removed and a solid plug inserted for purposes of leak checking the gas piping system.

during operation of the gas log lighter. The first flash fire occurred some weeks before the incident in question. The most recent flash fire occurred a few minutes before the home ignited and burned.

On a Sunday evening (approximately 24 hours prior to the home igniting and burning) around 7:30 p.m., the homeowner followed his normal routine of building and maintaining a fire in the fireplace. At the time he and his wife retired to bed at approximately 10:30 p.m., only coals and ashes remained in the firebox. On the following Monday morning, the homeowner went to work, and his wife remained at home all day. The fireplace was not used during the day, and there were no smells of smoke or anything unusual that day. On Monday evening, the homeowner arrived home from work around 6 p.m. He also did not smell any smoke or anything unusual. The homeowner and his wife had dinner in the dining room, which was immediately adjacent to and open to the family room, with the fireplace in clear view. They neither smelled smoke nor observed anything unusual. At around 7:30 p.m., he proceeded to construct his routine fire in the fireplace, except the ashes had not been cleaned out of the fireplace from the Sunday night fire. Shortly after he turned the gas on to light the log lighter, a flash fire occurred, and the resultant overpressure was sufficient to blow ashes out of the firebox and into the family room. According to the homeowner, the flash fire occurred on the left-hand side of the firebox.

After the flash fire dissipated, he continued to allow the log lighter to burn beneath the logs and sat down in the family room to read the newspaper. Approximately 3 to 4 minutes after the flash fire occurred, his wife reported smelling smoke. He then observed smoke, followed shortly thereafter by a fire burning a hole through the front thin wood paneled wall covering of the chase just to the left of (and above) the fireplace. See the annotated pre-fire photograph of the incident unit in **Figure 7**.

Upon discovery of the fire, the homeowner went outside and grabbed a garden hose, pulled it into the home, and began applying water into the wall where he observed the fire. At that time, he also turned off the gas to the log lighter at the log lighter valve. His wife called 911. The fire department arrived and applied water from one of their trucks; however, it ran out of water before the fire was extinguished. There were no nearby fire hydrants and no equipment to pull water from the adjacent lake; therefore, shuttling operations were initiated. The fire spread throughout the concealed spaces/attic, destroying the home.

Following the fire, the insurance company for the homeowner placed the general contractor and several subcontractors on notice of the loss and pending investigation. Two joint scene exams were conducted, artifacts were collected and removed from the scene, and the insurance company for the homeowner ultimately filed a lawsuit against the general contractor and several subcontractors, particularly alleging that the rear chase wall framing clearance to the back of the firebox was improper and caused the fire.

At the time the author became involved in the case, the

Figure 7
Pre-fire photograph of incident fireplace unit. The circle indicates the area where the witness first observed fire burning through the wall.

physical scene was no longer available for examination, other experts had already issued a report and offered opinions, no laboratory examination or testing of the artifacts had been conducted, and basic discovery was still ongoing. The author was retained to perform an engineering investigation and analysis of the incident, including a review of the available investigative documentation, expert reports, expert opinions, and ongoing discovery materials to determine the origin and cause of the fire.

The referenced materials were reviewed, and the author also contemporaneously prepared questions for ongoing discovery depositions of both fact and expert witnesses to obtain additional information concerning the circumstances of the incident and the scene investigation. In addition, the author called for and participated in a laboratory examination of artifacts that were recovered during the scene investigation.

Forensic Engineering Investigation and Findings

Based on a review of the available information, the author concluded that it might have been possible that the framing studs of the rear chase wall were installed with clearances less than the required 1 inch. After researching the subject, no temperature testing data was located for the fireplace being installed and operated with clearances less than 1 inch to wood studs. The plaintiff's experts provided no testing data for tests that either they conducted (or others had conducted); they provided no mathematical modeling or other calculations to estimate the temperatures the wall studs would reach under the conditions the fireplace was actually installed and operated.

Given the relatively large mass of the masonry modular fireplace (the firebox and refractory are approximately 2,000 pounds) and the consistent small, short, and infrequent nature of the fires built in the fireplace by the owner, it seemed unlikely sufficient temperatures would be achieved to either: (1) initiate a direct smoldering fire in the wall studs; or (2) gradually thermally degrade the wood wall studs such that they would be susceptible to the initiation of a smoldering fire via self-heating. The latter (sometimes referred to as long-term low temperature ignition of wood[3,4,5] or LTLTI) was inferred by the plaintiffs prior to expert depositions and then opined in expert deposition testimony. However, since the wall studs were possibly installed with less than the permissible clearance — and no comparable research or testing data was available for the situation — the author determined that testing would be necessary. Additional testing by the author evaluated gas migration from the fireplace log lighter into the flexible combustion make-up air ducting and the burning propensity of the ducting. **Figures 8(a)** through **8(r)** depict exemplars of the fireplace, combustion air kit, and log lighter during construction and testing.

The exterior chase wall behind the fireplace was constructed with manufactured faux stone veneer. During the

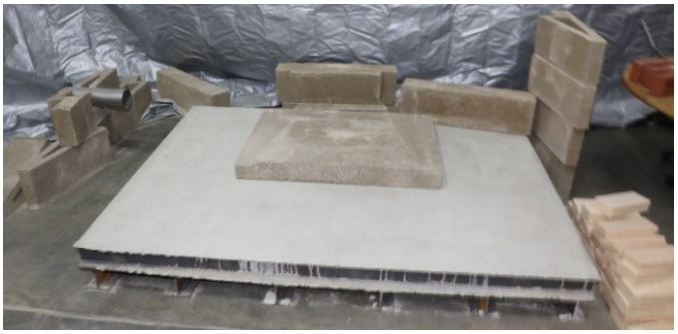


Figure 8a
"Portable" concrete floor assembly.

Figure 8b
Combustion air kit installation and
through hole for gas line to log lighter.

Figure 8c
Positioning of log lighter and combustion
air kits relative to hearth refractory.

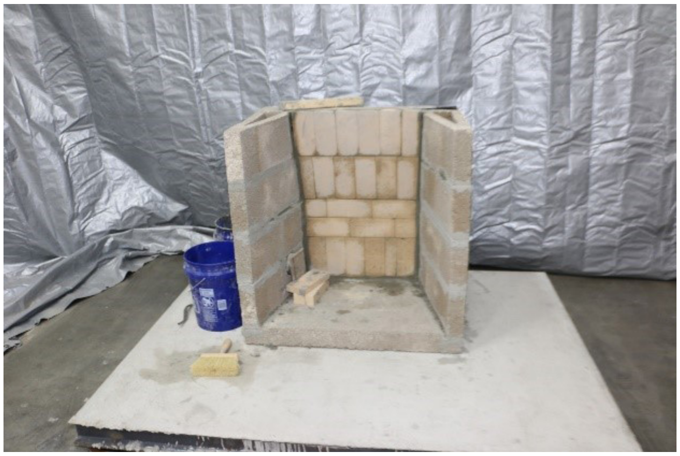


Figure 8d
Firebox construction and wall lining refractory installation.

Figure 8e
Dry-fit hearth refractory and log lighter kit.
Combustion air kit ducting (circled).

Figure 8f
Constructed to match incident installation.
Combustion air kit discharge register door (circled)
near rear of the firebox and flush with the hearth.

Figure 8g
Smoke dome, damper, and masonry
chimney construction in progress.

Figure 8h
Chase walls, hearth extension, and surround construction.

Figure 8i
Chase walls, hearth extension, surround and mantel construction.

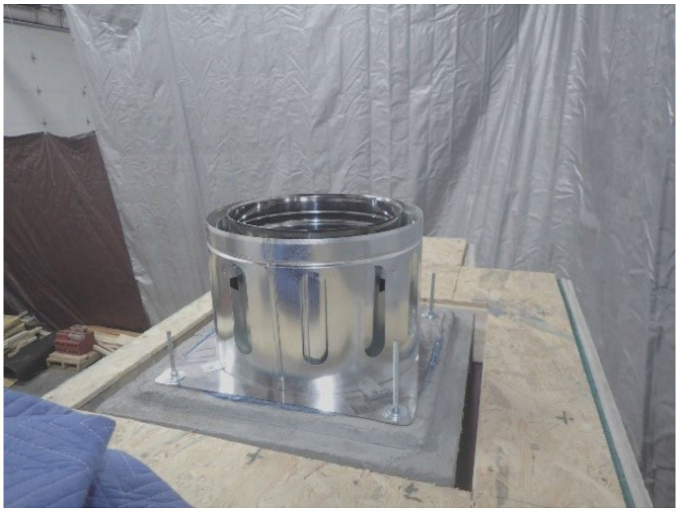


Figure 8j
Transition to metal chimney above the top of the chase enclosure.

Figure 8l
Left side of chase with observation windows. Flexible ducting from combustion air kit routed vertically up to elevated exterior intake.

Figure 8k
Completed exemplar construction and thermocouple instrumentation.

Figure 8m
Thermocouple instrumentation of lower rear chase wall studs. Note the inserted wood wedges to eliminate any clearances.

Figure 8n
Thermocouple instrumentation of upper rear chase wall studs. The smoke dome slopes away from the studs.

Figure 8o
Rear chase wall insulated.

Figure 8p
Rear chase wall covered.

Figure 8q
Log lighter test burn.

Figure 8r
Test burn view. All fires were built against the rear wall of the firebox.

fire incident, the upper portions of the wall, roof, and attic burned and collapsed. The collapse partially displaced the lower portion of the wall relative to the firebox. The fire scene investigators failed to document or even photograph the location of the exterior wall floor plate that was anchored to the slab relative to the back of the firebox. They also failed to document (in detail) the remains of the vertical wall studs behind the firebox (where they contend the fire originated). They failed to reconstruct (see NFPA 921[2] Sections 3.3.76 and 7.8.5.1) the wall and measure the actual clearances that would have been present pre-fire. Determining the location of the exterior wall floor plate (and documenting it) — and the repositioning of exemplar vertical wall studs — would have provided valuable reconstruction information regarding the actual pre-fire clearances between the back of the firebox and the wood studs.

Furthermore, reconstruction would have revealed that the studs could not have been in continuous direct contact with the back of the firebox without the wall being substantially out-of-plumb. During the laboratory assembly of the exemplar fireplace system and chase, it was discovered that the design of the firebox contained a projecting lip of approximately ¼ inch at the juncture between the firebox and the smoke dome installed on top of the firebox. The ¼-inch projecting lip prevented the erection of wood wall studs directly in continuous contact with the rear wall of the firebox without substantially placing the wall studs out of plumb. A plumb wall immediately adjacent to the firebox would have resulted in a minimum of a ¼-inch continuous gap clearance between the back of the firebox and the wood studs. Scene photographs were reviewed, and it was observed that the same (approximately ¼-inch) lip projection existed on the incident fireplace as the one constructed in the lab. Proper scene reconstruction would have identified the projection and corresponding necessary wall off-set. It is extremely unlikely that the wall of the multi-million-dollar home in question was ¾-inch out-of-plumb.

To be conservative, the wall studs in the lab were placed against the bottom of the firebox, creating a wall that was ¾ inches out of plumb and only contacting the firebox at the base plate and the ¼-inch lip. To be ultra conservative, wooden wedges (see **Figures 8 (m)** and **8 (n)**) were installed in the residual clearances between the studs and the back of the firebox where thermocouples were positioned.

The exemplar exterior rear chase wall was insulated with unfaced R-13 fiberglass batt insulation as postulated by the plaintiff experts. The incident exterior chase wall was most probably insulated; however, scene investigators failed to properly document the existence of any insulation in the wall. Their documentation failure resulted in a substantial amount of time-consuming fruitless discovery and deposition questions. The lower portion of the wall near the firebox was intact. Fiberglass batt insulation most often remains at the base of a wall on top of the horizontal floor plate; in this case, an area that was also not properly documented. Furthermore, such insulation acts very effectively to protect the floor plate from the fire.

The incident fireplace was installed immediately adjacent and to the left of another fireplace (patio fireplace). The incident chase was therefore open, except for a second chimney on the right-hand side. To be conservative, the exemplar right-hand chase wall was constructed with a double layer of cement board with fiberglass batt insulation sandwiched between from floor to ceiling. The purpose of the insulated full wall on the right-hand side was to reduce heat transfer through the wall and was conservative relative to the actual installation. A masonry chimney was constructed from the top of the smoke dome up to the top of the 9-foot chase. The top of the chase was capped with plywood leaving a 1-inch clearance gap around the chimney. The actual incident chase was larger in total volume and was open to the concealed attic cavity (overlapping roofs).

A detailed review of the scene investigation photographs provided indicated the remains of a steel wire coil still inside the chase footprint on the left-hand side of the fireplace. The steel wire coil remains resembled the coil remaining after flexible ductwork jacketing is burned away, as can be commonly observed, for example, on dryer vent ducts after a structural fire. No air intake register for the combustion air kit was observed on the remaining lower portion of the exterior wall behind the fireplace. The upper portion of the wall was destroyed. As a result, the author interviewed an additional witness and discovered that the intake register had been installed in the exterior wall near the soffit level approximately 12 feet above grade for aesthetic reasons. As such, the combustion air intake register for the combustion air kit was installed substantially elevated above the air discharge register located within the fireplace. The author's interview also revealed that a "fire-resistant" but combustible, flexible aluminized foil duct (the same type as that used on dryers and sold at local hardware stores) had been installed instead of the rigid metal ducting that came with the approved combustion air kit.

Based on the available specification sheets and purchase receipts used during the construction of the home, the author obtained an exemplar combustion air kit. The kit came with an air intake register, an air discharge register with a sliding door assembly, and a horizontal rigid steel telescoping duct section. In reviewing the installation manual as well as the scene photographs of the actual installation, two primary installation violations were noted as follows:

1. The manufacturer's instructions depicted in **Figure 5** required that only non-combustible materials be used in the construction of the combustion air duct work. The horizontal rigid steel ducting provided by the manufacturer had been replaced with a long vertical run of "fire-resistant" flexible aluminized foil ductwork.

2. The instructions also required that the discharge register be installed as far forward (near the fireplace opening face) as possible and in the third course of fire (refractory) brick (up from the hearth floor). The discharge register was actually installed close to the rear of the fireplace and flush with the hearth floor.

The instructions reference NFPA 211, *Standard for Chimneys, Fireplaces, Vents, and Solid Fuel-Burning Appliances*[6]. Provisions of NFPA 211 reflect the instruction requirements that the ducting be constructed of noncombustible materials. Furthermore, the improper installation of the combustion air kit violated the 2012 *International Residential Code*[7] (IRC), adopted at the time of the construction of the home. Regarding the location of the combustion air intake, the IRC provides, in part:

> *R1006.2 Exterior Intake*
>
> *…The exterior air intake shall not be located … nor shall the air intake be located at an elevation higher than the firebox ….*

The *2012 IRC Code Commentary*[8] on this provision provides the following justification:

> *…The air intake must be lower than the firebox so that the firebox will properly draw in combustion air. Where combustion air openings are located inside the firebox, the air intake opening on the outside of the dwelling cannot be located higher than the firebox. Such an installation could create a chimney effect, drawing the products of combustion up through the combustion air ducts. These ducts are not generally constructed of materials which can withstand the heat and sparks that could be drawn through them….*

For the case in question, the installation configuration did in fact result in the *IRC Code Commentary* described chimney effect within the combustion air ducting in every laboratory test performed regardless of the position of the sliding door on the air discharge register located in the fireplace (there is no seal on the loosely fitting discharge register door).

Fire scene investigators failed to collect the remnants of the steel wire ducting coil or the intake and discharge registers. The steel wire ducting coil remains could have been measured and the length of the flexible ducting determined. A measurement of the length of the flexible ducting that was used could have provided information as to how much of the ducting was coiled inside the bottom of the chase, which, in turn, would provide fuel loading information. The flexible ducting came in 10-foot and 20-foot lengths. Therefore, either all of a 20-foot section was used, or it was cut to some length. In addition, fragments of jacketing remaining on the wire coiling could have been analyzed to determine and verify the type of material (including polymeric materials) and the burning properties of the material.

Laboratory testing of the fireplace assembly and individual testing of the flexible ducting indicated that conducted heat, hot gases, sparks, or momentary flames impinging on the polymeric lining material cause melting, degradation, and delamination (separation, shrinkage and curling of the polymer material) from the aluminized jacket. As the polymer lining melts, degrades, separates, and curls, it would increase the exposed surface area (both sides of the curled and degraded polymer material) that would be subject to the next insult and subsequently increase the potential for sustained ignition and continuous burning.

In addition, the scene investigators failed to consider all reasonable fire cause scenarios involving an improper installation. For example, one plausible fire-cause scenario could be a flash fire initiating in the firebox that then propagates into the improperly installed combustible flexible ducting — igniting the ducting. A second plausible fire-cause scenario could involve the migration of gas into the ducting (due to delayed ignition of the log lighter) that is subsequently ignited and, in turn, ignites the ducting. A third potential fire scenario could involve flames or hot gases from the fire inside the firebox rolling off the bottom of logs, entering the discharge register, and flowing up the vertical run of ducting (chimney effect). Laboratory testing of the incident configuration resulted in flame deflection off the bottom of the logs directly into the opening of the combustion air discharge register. Finally, the flush position of the door opening with the hearth would allow ash, embers, and incompletely burned firewood residual to fall into, or be inadvertently swept (during cleaning) into, the opening, creating a fuel load inside the ducting. Therefore, the combustion air discharge register opening would function as an ash pit.

The wall studs of the chase and combustion air ducting were instrumented as depicted in **Figure 8(m), Figure 8(n), Figure 9** and **Figure 10**. A Keysight Technologies model 34980A Multifunction Switch/Measure Unit data logger[9] was utilized to record temperatures at 1-minute intervals for each thermocouple throughout the duration of each test, including cool down periods after the fire burned completely out. The laboratory ambient temperature was also recorded. Igor Pro 8 scientific graphic and data analysis software by WaveMetrics[10] was used to generate temperature time curves for all thermocouples and for each test. The software can be set up to filter out data curves below a specified set temperature. For example, any thermocouples with maximum temperatures below 150°F can be automatically filtered out of the displayed curves reducing busyness and improving clarity of the graphs. After initially setting up the program for the first test, the software automatically generates time temperature curves for each subsequent test based on the filters set. Thermal imaging was also performed periodically to depict the overall chase temperatures as well as the combustion air intake register temperatures.

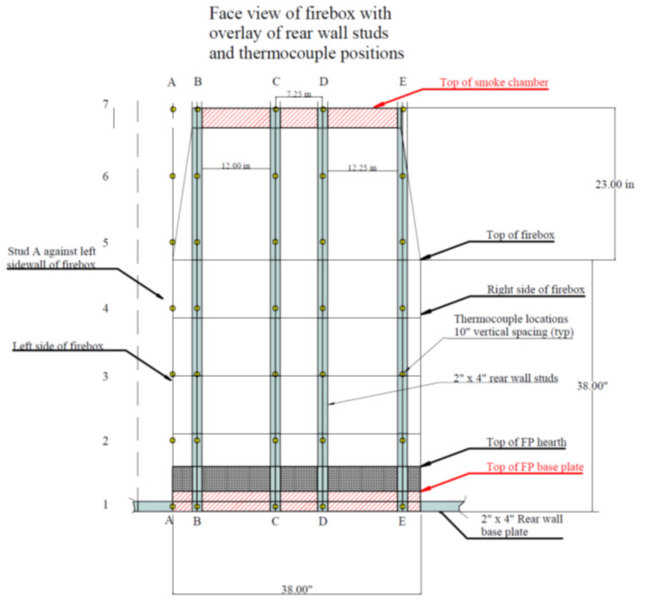


Figure 9
Thermocouple locations on the rear chase wall and interior left side jog wall extension stud. The view is from the front of the firebox looking at the studs behind the firebox. The horizontal lines represent the joints in the masonry firebox and smoke dome construction.

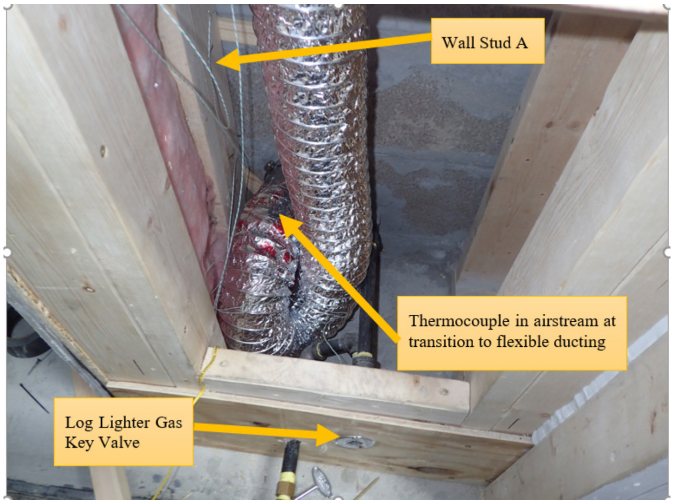


Figure 10
A view into the chase cavity on the left-hand side of the firebox. The rear wall jogged or recessed inward into the chase on the left-hand side. The wall stud, identified as "A," also in **Figure 9**, was placed in direct contact with the firebox and wood wedges inserted in the gaps where thermocouples were located.

Propane fuel-gas was provided to the home via a two-staged regulator system from a 1,000-gallon underground tank. Gas supply pressure into the home was 11-inches water column. Prior to the laboratory evidence examination, the author procured two exemplar log lighters. The log lighters used a rectangular flush pan-style and cap designed to be recessed and embedded in the hearth refractory. A brass elbow, which screwed into the base of a rectangular steel log lighter pan, contained internal threads into which a steel plug with a number 30 drilled orifice (0.1285-inch diameter opening) was screwed. The exemplar log lighters came from the manufacturer with the steel plug orifices already installed. At 11-inches water column, a number 30 orifice delivers 115,343 Btu/hr.

The plug orifice had been removed from the incident log lighter, likely for leak testing the gas system piping during original construction. The plug orifice, however, was not reinstalled in the incident log lighter (leaving a

0.6670-inch diameter opening). As such, there was no gas flow limiting orifice in the log lighter, creating conditions favorable for large amounts of gas to be released in a short period of time (dependent upon the exact position of the log lighter key valve). See **Figures 11(a)** and **11(b)**, which depict the incident log lighter and the orifice installed in an exemplar log lighter.

As will be discussed later in the paper, ash migration into the perimeter cap openings of the log lighter results in blockage of gas discharge ports and subsequently asymmetric discharge of gas out of the log lighter and therefore an increased likelihood of delayed ignition and a flash fire. So, in addition to the potential for over-firing the fireplace (no orifice), conditions are also favorable for a delayed ignition of gas producing a substantial flash fire and potentially an explosion.

Both the combustion air discharge register and gas log lighter are flush with the hearth and approximately 8 inches apart (see **Figure 8(f)** again); therefore, the potential for propane gas migration into the discharge register is substantial. While the position of the register door at the time of the incident is not clear, the loose-fitting door is not hermetically sealed, and gas will migrate through the door into the ducting (as verified by laboratory testing) when it is either fully closed or fully open or at any position between. Obviously, the more open the door is, the higher the propensity for gas or flames to enter.

Figure 11a
Incident log lighter with no orifice (0.6670-inch opening).

Figure 11b
Exemplar log lighter brass elbow connection
with number 30 (0.1285-inch opening) steel plug orifice.

There were ashes in the base of the firebox from the Sunday evening fire and likely previous fires. The author made several observations concerning ashes and gas log lighters based on studies made in this case as well as studies and testing made in a similar separate case.

1. Ash completely covers the log lighter after a short period of time of operation. One fire in the fireplace will result in the log lighter in this case becoming completely covered.

2. Ash tends to enter and block off portions around the perimeter of the pan style log lighter cap plate where gas would otherwise normally escape and then burn. As a result of this blockage, sometimes no gas discharges around large sections of the perimeter top cap plate while the unblocked portions of the cap plate discharge the full amount of gas (asymmetric discharge of propane gas). See **Figure 8(q)** for symmetric discharge and burning of gas from the log lighter.

3. As an example, no gas may be discharged on the right-hand side of the log lighter (fully blocked) top cap plate gas discharge ports. Therefore, all the gas is discharged on the left-hand side of the top cap plate discharge ports (unblocked). If a piece of paper is lit and placed under the logs on the right-hand side — and the gas is then turned on — there is a delayed ignition resulting in a large flash fire in the firebox. In other words, until the gas discharging on the left-hand side of the firebox migrates and reaches the right-hand side (where the ignition source is), it will accumulate on the left-hand side and inside the immediately adjacent combustion air ducting. Once the gas reaches the ignition source, a substantial flash fire results. See **Figures 12(a)** through **12(j)**, on pages 44 to 45, depicting such a scenario generated during laboratory testing in this case. **Figure 12(c)**

Figure 12a
Ignition of paper on the right-hand side of the fire box. Gas is off.

Figure 12b
After paper ignition gas is ready to be turned on.

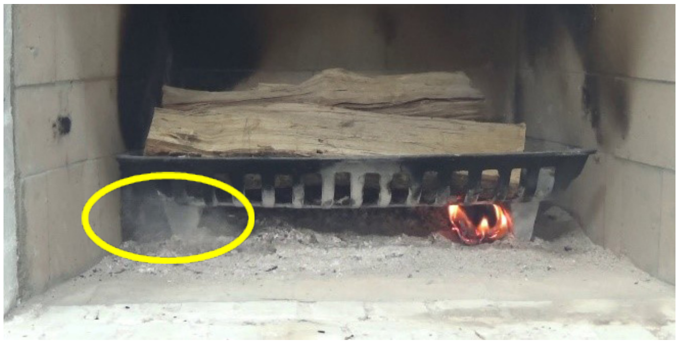


Figure 12c
Ash cloud forms on the left-hand side when the gas valve is opened. Note proximity to the register door.

Figure 12d
Flash fire ignites on the right-hand-side and propagates rapidly to the left beneath the firewood.

Figure 12e
Continued flash fire propagation right to left toward register door. Door, circled, partially open.

Figure 12f
Flash fire impingement on the left-hand side of the firebox and door when accumulated gas is ignited.

Figure 12g
Gas accumulated on the left-hand side of the firebox continues burning.

Figure 12h
Asymmetric flames from the log lighter and horizontal deflection to the left side of the firebox and onto the register door. Near flash fire end.

Figure 12i
After the flash fire, flames from the discharging gas impinge on the logs above and toward the left-hand side of the firebox and onto/into the combustion air discharge register door and doorway.

Figure 12j
Ash cleaned out of the log lighter ports to create a more even distribution of gas and flames.

depicts the relatively close proximity of the gas discharging and accumulating at the combustion air kit discharge register prior to being ignited.

3. Ash blockage of the log lighter top cap plate discharge ports can also result in a substantially larger continuous flame on one side of the firebox. Since logs are placed over the log lighter, the natural result is that the large one-sided flame will be substantially deflected horizontally. And in the incident case, the combustion air kit discharge register door is located also below the logs (flush with the hearth and the inlet of the doorway) and is subjected to substantial flame impingement or intrusion when flames are deflected. It should be noted that even without ash blockage, horizontal flame deflection onto and into the doorway occurs because the doorway was not located in accordance with the installation instructions. The condition is exacerbated when ash blockage of the log lighter cap plate occurs.

4. The ash/ember/wood residual cover (depending on the depth, density, and degree of blockage of the log lighter) can facilitate the lateral spread of gas beneath the ash and into the ductwork (similar to the lateral movement of gas in an underground gas leak). The horizontal blockage of the firewood on the grate above also facilitates gas migration toward the combustion air discharge register door.

5. Ash may also form uneven contours as it falls onto the hearth during the operation of the fireplace. As a result, the ash can form "dams" or "trenches" on the hearth that functions to facilitate the lateral spread of "pooling" propane into the combustion air kit discharge register doorway and therefore into the ducting prior to ignition.

For case testing purposes, more than 30 test fires within the exemplar fireplace system were conducted. The fireplace grate was positioned directly against the rear wall of the firebox for all tests to maximize heat and flame impingement on the back wall of the firebox. The combustion air kit inlet door of the firebox was positioned in multiple positions: closed, various states of partial opening, fully open, open/closed during the same test, etc. Although the homeowner indicated he only used oak firewood, well-seasoned (more than 18 months) oak and hickory firewood were utilized in the laboratory testing. In general, hickory is a slightly better firewood[11] than oak (having a greater density and heating value).

Exemplars of the flexible ducting used in the installation of the combustion air kit were obtained, and a simple burn test was performed to evaluate the propensity of the material to burn. A fuel load consisting of a single sheet of loosely balled-up (fist-size) craft paper (approximately 12 inches by 12 inches) was placed into the inlet of the ductwork and ignited via a match. In a horizontal position, the flexible ductwork was resistant to ignition — and did not sustain burning and flame propagation. After the paper was consumed, the fire self-extinguished.

As might be anticipated, the burning characteristics were different in the vertical orientation. A 7- to 8-foot section of ductwork was suspended in a vertical orientation, and the paper fuel load was placed in the base of the ductwork and ignited via match. In the vertical orientation, the flexible ducting easily ignites, burns readily, and propagates flame rapidly. See **Figures 13(a)** through **13(f)**, on page 46, depicting some of the burn testing. Several types of available "fire-resistant" flexible ducting were tested with the same results.

The "fire-resistant" ducting is clearly combustible and will easily sustain burning. In the incident case, the ducting was installed in a vertical orientation in the chase on the left-hand side of the firebox. The soffit where the ducting terminated is 12 feet above the finished floor. As noted earlier, the ductwork comes packaged in 10- or 20-foot sections. Therefore, a 10-foot section would be too short for the installation in question (requiring a 20-foot section be used). Depending on how much (if any) of the 20-foot section the installer cut off would determine how much of the ducting was coiled up at the base of the chase and what fuel load it represented.

As depicted in **Figures 13(a)** through **13(f)**, very little of the ducting was coiled up at the base in the laboratory exemplar testing; however, sustained burning continues even after the vertical section is consumed, drips, melts and falls to the base. The front interior chase wall from the floor to the ceiling was constructed with thin wood paneling nailed to studs installed in a vertical orientation. The thin wood paneling would be in proximity to (inches from, or directly in contact with) the flexible ducting and would likely be readily ignited by the burning ducting.

During laboratory testing of the full exemplar assembly, elevated air temperatures (briefly exceeding 450°F) inside the flexible ductwork were produced during an

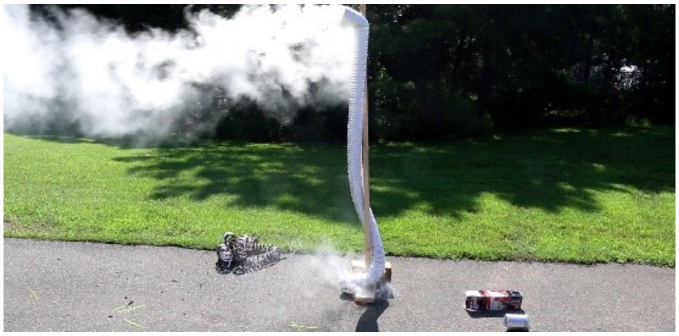


Figure 13a
Immediately after ignition of balled paper in the base.

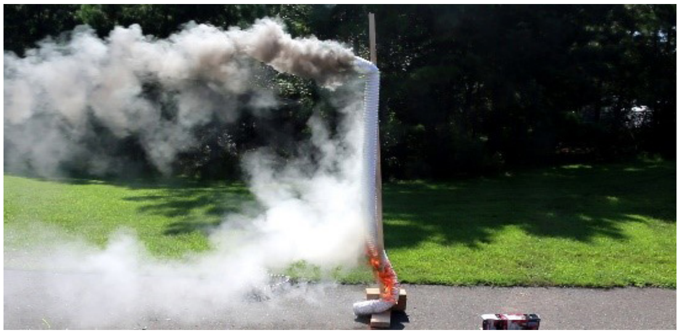


Figure 13b
Seconds after ignition of balled paper in the
base flames burn through and spread rapidly upward.

Figure 13c
Rapid upward flame spread.

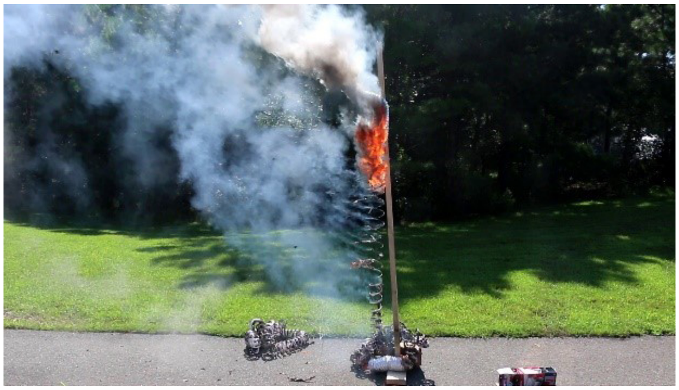


Figure 13d
Rapid upward flame spread.

Figure 13e
Sustained burning at the base.

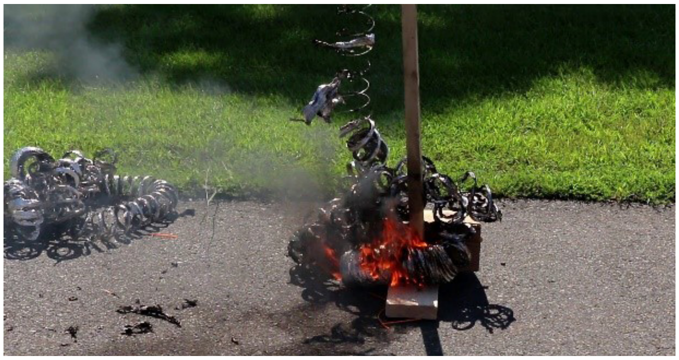


Figure 13f
Sustained burning at the base.

intentionally generated flash fire event (**Figures 12(a)** through **12(k)**). The elevated temperatures caused concern for potentially igniting the ductwork and the chase assembly in the lab due to flame deflection off the firewood, sparks migrating, and the general chimney effect. Therefore, careful monitoring of the hearth area around the air discharge register was implemented during further testing to intentionally prevent accidental ignition (e.g. coals and ashes were moved, firewood was shifted, etc., to prevent constant exposure to the door and doorway of the discharge register). A dimensional mockup assembly of the firebox, log lighter, and combustion air discharge register was constructed with cement board bounds to observe the effects of gas migration and flash fires generated in the firebox.

For safety reasons, the exemplar log lighter was equipped with the manufacturer's number 30 orifice, and the gas supply was controlled via a flow meter and regulator assembly connected to a 20-pound propane cylinder also equipped with an excess flow valve. Safety candles were positioned in proximity around the assembly and lit to limit the maximum amount of propane that could potentially accumulate prior to ignition. A combustible gas detector was also used to determine the extent of gas migration, particularly into the rigid metal duct stub out. Various positions of the combustion air discharge register door were tested. Flash fires were ignited that propagated into and through the rigid ductwork stub when the door was as little as ½-inch in the open position. Gas migrated through the door in all cases, even in the fully closed position. Removing the orifice and increasing the gas flow into the log lighter would increase gas migration and accumulation prior to ignition. Variations in ash configuration, contouring, damming, and blockages in the ports of the log lighter would likely further enhance gas migration and accumulation prior to ignition.

Figures 14(a) through **14(l)** depict a flash fire generated when gases, ignited on the right-hand side of the fire box, propagated to the left-hand side and then through and out of the rigid steel ducting stub where the flexible ducting would have been attached. Note that the gas flame plume continues to burn [**Figure 14(l)**] after the flash fire subsides on the right-hand side of the firebox due to the blocked ports of the log lighter.

Figure 14a
Test video 6 image capture.

Figure 14b
Ash cloud produced
when gas valve turned on.

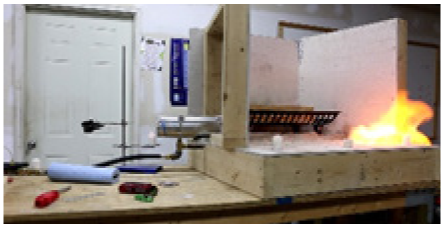


Figure 14c
Flash fire initiated at
right-hand side safety candle.

Figure 14d
Flash fire propagates into the firebox.

Figure 14e
Flash fire propagation into the firebox.

Figure 14f
Flash fire propagation right to left.

Figure 14g
Flash fire propagation right to left.

Figure 14h
Pressure wave ahead of the flame front
distorts the candle flame (circled).

Figure 14i
Flash fire propagation through
and out rigid duct work.

Figure 14j
Flash fire continuing out rigid duct work
where flexible ducting would be connected.

Figure 14k
Burning continues on the right-hand side
after flash fire nears completion.

Figure 14l
Asymmetric burning on the right-hand side
continues due to blocked log lighter ports.

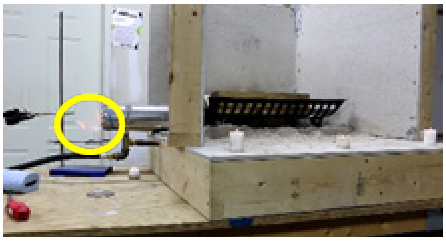


Figure 15a
Test video 15 image capture.
Flash fire ignition.

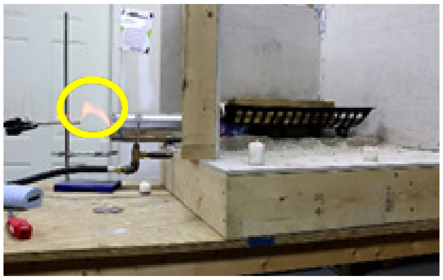


Figure 15b
Flash fire ignition.

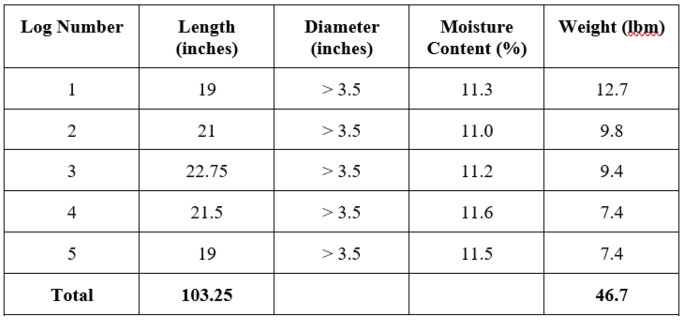
Figure 15c
Propagation through ductwork
and into the firebox (left to right).

Figures 15(a) through **15(c)** depict an initiating flash fire generated when "trenched" ashes allowed gas to migrate into the rigid ducting and reach the lower flammability limit (LFL) at the point the flexible ducting would have been connected. The combustion air discharge register door was open only approximately ½ inch.

Analysis and Discussion

For all tests performed in the exemplar fireplace and chase system, the weight, diameter, length, and moisture content of each piece of wood was measured, recorded, and tabulated. **Figure 16** provides the data for laboratory test number 4, which was the largest mass of wood burned during a single test (46.7 pounds).

The owner burned (at most) five logs total during each fireplace use measuring 3 inches in diameter and (at most) 21 inches long. Therefore, the maximum cumulative length of wood he burned was 105 inches. Since many normal pieces of firewood are shorter than 21 inches in length, more than five total pieces of wood were burned in some tests to attain a cumulative length closer to 105 inches. In all cases, the minimum diameter of the wood exceeded 3 inches, many times exceeded greater than 3½ inches — and in some cases, were much greater than 3½ inches. Considering five pieces of wood (each 21 inches long and approximately 3 inches minimum in diameter), a baseline test (test number 6) was performed by the author to establish the closest approximation for the incident fireplace use conditions. The baseline test was also used to establish the minimal amount of wood (31.8 pounds) to burn for all subsequent testing. The data for test number 6 is depicted in **Figure 17**. Note that the amount of wood used in test number 4 was approximately 150% of the mass of the amount of wood used in test number 6.



Log Number	Length (inches)	Diameter (inches)	Moisture Content (%)	Weight (lbm)
1	19	> 3.5	11.3	12.7
2	21	> 3.5	11.0	9.8
3	22.75	> 3.5	11.2	9.4
4	21.5	> 3.5	11.6	7.4
5	19	> 3.5	11.5	7.4
Total	**103.25**			**46.7**

Figure 16
Wood burned during laboratory test number 4.
Largest amount burned during a single test.

The moisture content for all firewood in all tests was substantially uniform (approximately 10% to 12%). Therefore, as expected, the total weight of wood burned for each test fire was the driving factor for temperatures achieved in the firebox walls. **Figures 18** and **19** depict the time-temperature curves for tests 4 and 6, respectively.

The maximum temperature reached during test 4 on the exterior wall of the firebox in contact with the wood was approximately 193°F, occurring 6 hours after the initiation of the test. The software was set to depict the graphs of all thermocouple points that exceeded 150°F. Temperatures briefly exceeded 450°F in the combustion air ducting during the flash fire illustrated in **Figure 12**; however, the temperature point was removed to maintain graph scale and clarity. For the most part, flames and embers were intentionally kept away from the combustion air door, but occasionally burning wood fell near the door and temperatures in the duct work elevated.

The combustion air door was opened further in test 6 and resulted in substantial temperature fluctuations in the ducting throughout the firewood burning, depending on where hot coals, or burning wood landed as they fell. In most cases, the test attendee tried to keep coals, sparks, and flames from becoming diverted into the duct opening or onto the door to prevent accidental ignition of the flexible ducting. Care was also taken not to inadvertently sweep ashes and unburned charred pieces of wood into the doorway when the fireplace was cleaned out, although such occurrences would be realistic. Maximum observed temperatures in the exterior firebox wall in contact with the wood studs remained below 160°F throughout the test. The temperatures of test 6 most likely conservatively reflect the temperatures experienced during the actual use conditions of the fireplace. Air temperatures in the flexible ducting were substantially higher than those of the exterior wall of the firebox.

Log Number	Length (inches)	Diameter (inches)	Moisture Content (%)	Weight (lbm)
1	17.5	> 3.0	10.9	5.2
2	18	> 3.0	10.6	5.0
3	18.5	> 3.0	11.5	6.1
4	18	> 3.0	11.3	5.2
5	17.5	> 3.0	9.0	3.8
6	20.375	> 3.0	10.9	6.5
Total	**109.875**			**31.8**

Figure 17
Wood burned during laboratory test number 6.
Smallest amount burned during a single test.

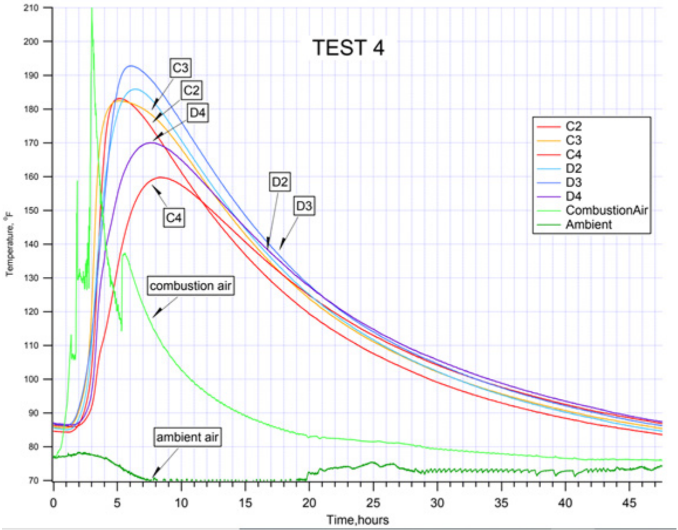


Figure 18
Time-temperature curves for test 4. The combustion air duct door was partially open during the testing.

During all laboratory tests, the combustion air ducting operated in reverse, allowing hot gases to flow into the ducting. Substantially elevated temperatures within the ducting occurred: (1) during a generated flash fire event; (2) during normal operation of the fireplace when hot embers dropped and piled against the doorway when the door was closed or in the doorway when it was open; or (3) when flames rolled off of the bottom of the logs and onto the door (when closed) or into the doorway (when open).

The incident fireplace was only utilized once or twice a week. During testing, it was observed that 24 hours after the initiation of the fire that the masonry firebox mass (exterior wall) was still at approximately 105°F to 110°F.

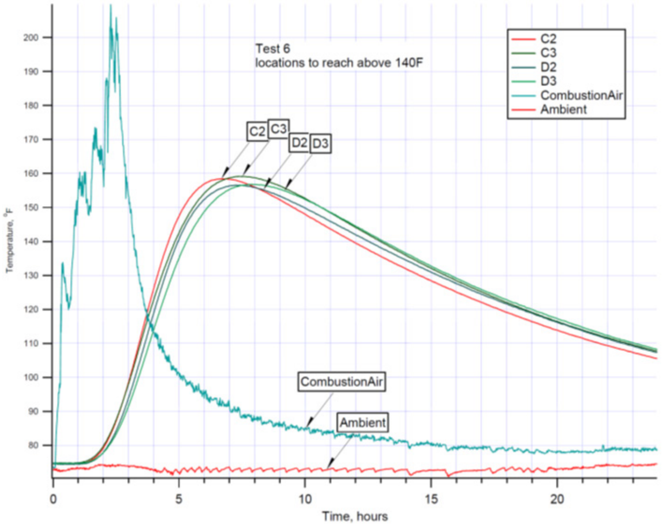


Figure 19
Time-temperature curves for test 6, baseline test most approximating use conditions of the fireplace. The combustion air duct door was partially open during testing. Maximum temperatures of the firebox wall remained below 160°F.

Therefore, to develop conservative results, multiple series of tests were run “back-to-back” (i.e., assuming a fire of similar size and duration was burned in the fireplace consecutively every 24 hours) — sometimes two to three days in a row. **Figure 20** depicts testing results from one set of back-to-back testing over a three-day period. Even with the back-to-back testing, maximum temperatures did not exceed 222°F. In these tests, it was observed that the heat transfer to other portions within the large masonry fireplace mass begin to increase (i.e., more thermocouple points begin to appear on the graphs) as the heat is more uniformly distributed within the firebox masonry.

Figure 21 provides the summary data for the wood burned in the consecutive testing depicted in **Figure 20**.

After a total of 32 burn tests were performed, the rear chase wall was opened, and the wood studs and wood wedges examined. There was no discoloration of the studs or wedges, no charring, no cracking or other detectable physical changes to the wood.

As previously noted, the firebox and refractory are of substantial masonry mass (approximately 2,000 pounds), and, as such, would have a large thermal capacity available. Small fires of relatively short duration combined with the large thermal capacity of the firebox and refractory, the normal expected system heat losses to the environment, and relatively new condition of the unit brings into question the likelihood of sufficient heat transfer occurring into the studs to either significantly thermally deteriorate them or otherwise directly ignite them. The observed temperatures and exposure times were insufficient to generate any substantial or even detectable thermal degradation of the wood leading to LTLTI much less direct smoldering ignition. As noted in *Kirk’s Fire Investigation*[4], 8th Edition page 260 [underlined emphasis added]:

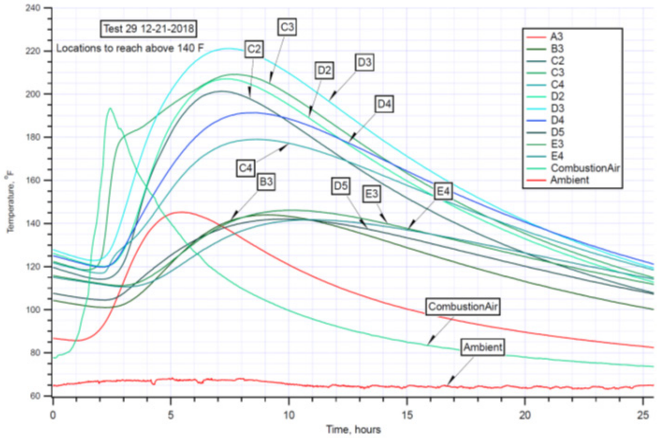


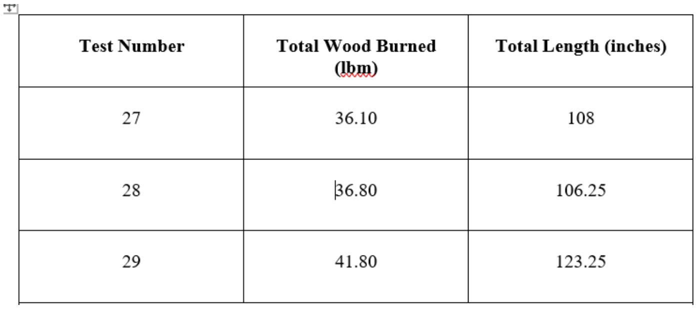
Figure 20
Results of back-to-back testing over three consecutive days. Note that the incident fireplace was only used once or twice each week (the home had five other fireplaces).

> *…the investigator must be careful of blaming “pyrophoric carbon” for any fire in the vicinity of a flue or hot water pipe merely because no other cause can be identified….*
>
> *…The <u>time has to be long enough</u> (weeks, months, or years, <u>depending on the intensity of the applied heat)</u>; …..*
>
> *…Because of the time required for the production of charcoal, low-temperature ignition of wood <u>can generally be eliminated as a cause of fires in very new buildings</u>.*

The maximum exposure temperatures achieved during testing for the extreme conditions considered in the subject case were 222°F. The baseline testing temperatures did not exceed 160°F. While temperatures during some of the testing did exceed the Underwriter’s Laboratories (UL) 127[4,12] threshold of approximately 170°F for relatively short periods of time, both the temperature and exposure times (including cumulative times) were comparatively substantially small when considering LTLTI. For example, empirical data from well documented restaurant fires combined with engineering laboratory testing and analysis of those fires provides[3]:

> *…. it was concluded for the conditions studied that ignition of wood occurred under <u>exposure temperatures</u> of as low as 256 °F when exposed to <u>12 to 16 hours per day</u> in as little as 623 days or approximately 21 months….*

In other words, it took nearly two years of daily temperatures of 256°F or greater with exposure times of 12 to



Test Number	Total Wood Burned (lbm)	Total Length (inches)
27	36.10	108
28	36.80	106.25
29	41.80	123.25

Figure 21
Summary data for wood burned in consecutive testing depicted in **Figure 20**.

16 hours per day to initiate an LTLTI fire in the wood studs. In addition, for the referenced study, there were metal fasteners exposed to a heat source that penetrated the wood. There were no such fasteners in the present case. Finally, the temperatures achieved in the present case are substantially insufficient to cause direct smoldering ignition.

Following is a summary of opinions that were offered by the author along with the supportive testing and research data summarized in this paper. The forensic engineering analysis facilitated the mediation of the case.

1. The origin of the fire was inside the base of the flexible combustion air ducting on the left-hand side of the firebox, not in the wood studs of the chase framing behind the firebox.

2. The flexible combustion air ducting was combustible and in a vertical orientation ignites, burns readily, and propagates flames rapidly.

3. The combustible flexible ducting installation violated the manufacturer's installation instructions, the *International Residential Code* (IRC) and NFPA 211.

4. Hot gases, sparks, ash, embers, and/or flames flowing via a chimney effect from the fire inside the firebox into the flexible ducting during normal operation of the fireplace would act to melt, thermally degrade, and delaminate the plastic polymer lining inside the ducting making it susceptible to ignition during further insult.

5. The flush mounted discharge register door opening of the combustion air ducting was only inches from the propane gas log lighter and subject to gas migrating and accumulation inside the ducting during delayed ignition incidents. Contoured ash accumulations and ash blockage of the log lighter ports would facilitate gas migration and asymmetric burning inside the fireplace.

6. The missing stainless-steel plug orifice created conditions favorable for quick relatively large releases of propane gas increasing the likelihood of gas migration and flash fires or explosions during delayed ignitions.

7. The most likely source of ignition of the thermally degraded combustible flexible ducting was heat from the flash fire or heat from flames diverted horizontally into the ducting due to blocked log lighter ports.

8. The most likely cause of the fire was the improper material selection and installation of the combustion air kit and combustible flexible ductwork.

9. Assuming there was zero clearance between the stud wall and back of the firebox (which is unlikely) there was insufficient time and temperature exposure to the wood stud walls to generate a smoldering fire either via direct ignition or self-heating via LTLTI.

10. Wood wall studs installed less than the specified clearances of the manufacturer do however present a fire hazard via smoldering ignition or LTLTI under the right conditions.

Conclusions

Determining the correct cause of a fire and contributing factors to the cause of the fire is critical to the prevention of future fires. To that end, investigators and forensic engineers must employ proper procedures and reliable methodologies in their analysis. If no, or insufficient, research and testing data exists for the scenario being considered, engineering testing or modeling should be performed to fully evaluate the scenario. One of the purposes of publishing this paper is to make some such testing data readily available for use in the fire investigative and forensic engineering industry.

In this paper forensic engineering research, testing, and analysis were implemented to evaluate the true cause of the fire. The presence of a possible or real fire code violation (e.g., clearances to combustibles) should not be automatically assumed to be the cause of the fire without complete and proper analysis. The conditions under which systems (e.g., fireplaces) are used and operated are important to understand as part of the analysis. In addition, the identification and comprehensive evaluation of all fire code violations and installation errors are critical to performing a competent investigation that will allow an accurate determination of the cause of the fire.

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