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FE Analysis of a Modular Fireplace Fire with an Improperly Constructed Hearth Extension

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Abstract

A fire originated beneath a modular fireplace hearth in a newly constructed home, which then spread into the adjacent chase and attic spaces, resulting in the destruction of the residence. The fireplace was installed on a CMU block riser positioned on a wooden subfloor in violation of the manufacturer's installation instructions. Scene investigators concluded based on fire patterns and witness observations that the fire originated beneath the fireplace hearth and that the first fuel ignited was wood construction in proximity to the hearth. The author was contacted 3.5 years after the fire during ongoing litigation to review and analyze the available information and determine the cause of the fire. This paper examines the cause of the fire based on forensic engineering analysis and testing. Incorporation of analysis of previous similar cases and testing data as well as new testing data are utilized to reinforce the author's cause determination.

Keywords

Modular fireplace, hearth extension, wood burning, chimney, low-temperature ignition, smoldering, clearances, fire investigation, methodology, reconstruction, testing, chase, combustible concealed space, conduction, convection, radiant, heat transfer, NFPA 921, NFPA 211, UL 127, International Residential Code, forensic engineering

Background

The home in question was a newly constructed (less than 7 months old) two-story wood-framed structure of approximately 8,000 square feet containing two modular fireplaces. Identical in make and model, the fireplaces were installed on the first floor back-to-back to one another, utilizing a common fireplace and chimney chase enclosure. One of the fireplaces faced into the living room (living room fireplace); the second faced into a covered screened-in porch (porch fireplace). The chase enclosure was wood-framed, wood-sheathed with oriented strand board (OSB), and bisected the south exterior wall of the home. The OSB was covered with metal lathe, a mortar base (scratch) coating, and finally a stone veneer set in mortar. The chase formed a combustible vertical concealed space on the interior side that was sealed on the exterior (living room) side with masonry (mortar and stone veneer).

Sometime around 5 p.m. the evening prior to the incident, the homeowners built a fire in the living room fireplace and maintained an active fire (fuel continuously being added to and flaming) up until between 10 and 10:30 pm. When they retired to bed between 11 and 11:30 p.m., the fire had burned down to hot and simmering coals with no visible flames. The porch fireplace had not been used the evening prior to the incident. Monitored smoke alarms alerted the homeowners and the fire department to the house fire around 5:55 a.m. (6.5 to 7.0 hours after they went to bed). The homeowners opened their closed bedroom door and observed smoke inside the living room but no flames. They exited the home and observed flames at the junction between the roof and stone veneered chase. After verifying the fire department had been notified, they made multiple trips back into the home to save family photographs/property and never observed any flames inside the home. As they stood outside during firefighter operations, they observed the chase collapse into the structure as the compromised wood floor beneath gave way. No other sections of the home collapsed. As a result of the fire and structural damage, the home ultimately had to be demolished.

The living room fireplace was installed on top of a nominally 8-inch concrete masonry unit (CMU) block riser that was built on and supported by a wood-framed and decked floor. The installation method violated the

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manufacturer's installation instructions related to installing the fireplace on wooden floors and will be discussed in further detail later. Based on an examination of the scene, fire patterns, and subsequent chase collapse due to a compromised supporting floor (as observed by witnesses), scene investigators for the property insurer concluded that the area of fire origin was beneath the hearth of the fireplace. The investigators further concluded that the first fuel ignited was wood construction in proximity to the hearth.

Based on the thickness of the masonry riser materials provided, defendant parties were skeptical that sufficient heat would be transferred from the hearth through the baseplate and riser to ignite the wooden floor. After unsuccessful mediation attempts, the personal attorneys representing the homeowner assigned the author to review and analyze the available information and determine the cause of the fire.

Figures 1 and **2** depict views of the home and chase area on the south side of the home prior to and after the fire. **Figures 3** and **4** depict the living room and porch fireplaces prior to the fire.

Forensic Engineering Investigation and Findings

Based on a review of the initial discovery documents provided and the author's previous experience, the author concluded that it was unlikely that sufficient heat transfer occurred through the combined hearth, base plate of the fireplace, and CMU riser to ignite the wood floor. As discussed below, given the history and actual use conditions of the fireplace in combination with the hearth, base plate, and riser construction, it was unlikely sufficient heat would be transferred to ignite the floor — albeit such configuration still created a substantial fire hazard.

The homeowners (an older couple with no children living in the home) had moved into their new home in early spring and did not begin using the fireplaces until the first week in October. The incident fire that destroyed

Figure 1
A view of the south side of the home prior to the fire with the stone veneered chimney and fireplace chase bisecting the wall between the living room and covered porch. The first observed flames were at the juncture of the roof and chimney chase (circled in yellow but on the opposing side).

Figure 2
A view of the south side of the home after the fire with the remains of the stone veneered chimney and fireplace chase. The fire department utilized a track hoe during overhaul operations, making reconstruction more difficult.

Figure 3
A view of the finished living room fireplace and stone veneered chase enclosure prior to the fire.

Figure 4
A view of the porch fireplace and stone veneered chase enclosure prior to the fire.

the home occurred in the first week of December, providing a use period of approximately eight weeks. The homeowners testified that the living room fireplace had been used approximately five to 10 times — each time for a period of 5 to 6 hours (including the evening before the incident). The porch fireplace had also been used five to 10 times, although each time for a period of only 2 to 3 hours. Therefore, the fireplaces had each been used only once or twice a week for relatively short periods of time during each use.

Historical Testing and Results — Prior Cases #1 and #2

Approximately nine years prior to the author's involvement with the subject case, he constructed, instrumented, and tested a similar modular fireplace for another case (Prior Case #1). The fireplace was installed on an open back CMU riser with a hollow center. During that testing, the author thermocouple instrumented the interior top surface (floor) of the hearth as well as the exterior (bottom) surface of the base plate directly beneath the hearth thermocouple. These thermocouples were placed simply for the benefit of collecting the empirical data (for potential future use) and were unrelated to any question involved in the case. Testing with active burn times of 5 to 6 hours (substantially like the subject case of this paper) was performed. **Figure 5** depicts some of the data collected from the testing. While the temperature of the hearth surface interior reached and exceeded 1,100°F for an extended period, the exterior surface of the base plate directly beneath only reached approximately 276°F after 5 hours and 45 minutes. The temperature of the exterior surface of the base plate continued to very slowly climb when the testing was terminated.

The exterior surface of the base plate was open to the air and therefore subject to natural convective cooling as it was installed on an open back hollow CMU riser. The insulating effect of a wooden floor against the bottom of the base plate was not evaluated. However, in yet another separate case (Prior Case # 2) several years later involving a similar modular fireplace installed directly on a wooden floor with no CMU riser, the author contracted with a Fire Dynamics Simulator (FDS) modeler and professional fire protection engineer to construct a model and evaluate the heat transfer effect of the previously tested fireplace being installed on a wooden floor. The modeler utilized the empirical hearth interior surface temperature data obtained in the actual testing and used FDS to model the conduction heat transfer through the hearth refractory and base plate into the contacting wood flooring. **Figure 6** depicts the results of the modeling, which indicates a maximum temperature at the interface of the base plate and wood floor of approximately 300°F after approximately 5 hours and 45 minutes.

Past to Current Case Fireplace Construction Differences

A more substantial difference existed between the subject fireplace in this paper and the tested fireplace (Prior Case #1) and modeled fireplace (Prior Case #2). The tested and modeled fireplaces had a combined hearth refractory and base plate thickness of only approximately 5¼ inches. The combined hearth refractory, base plate, and solid-filled CMU riser thickness for the subject fireplace was much greater (at approximately 14¼ inches). An additional 9 inches of masonry was between the hearth surface and the wood floor — and would provide an increase in the overall thermal resistance to heat transfer. Therefore, it would produce even lower temperatures than the modeled 300ºF (Case #2) obtained in the absence of the riser over the same period of burn time.

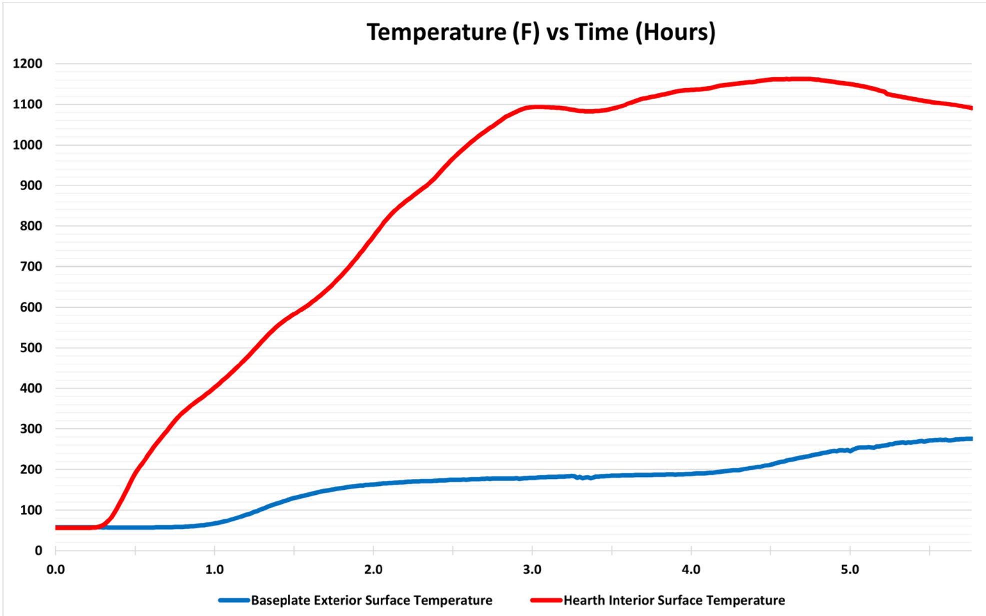

Figure 5
Prior Case#1 temperature results for the hearth interior surface temperature and the base plate exterior surface temperature for a burn test of approximately 5 hours and 45 minutes. Combined hearth refractory and base plate thickness of 5¼ inches. The exterior surface of the base plate was open to ambient air of 77ºF average temperature. The exterior base plate surface temperature reached approximately 276ºF after 5 hours and 45 minutes.

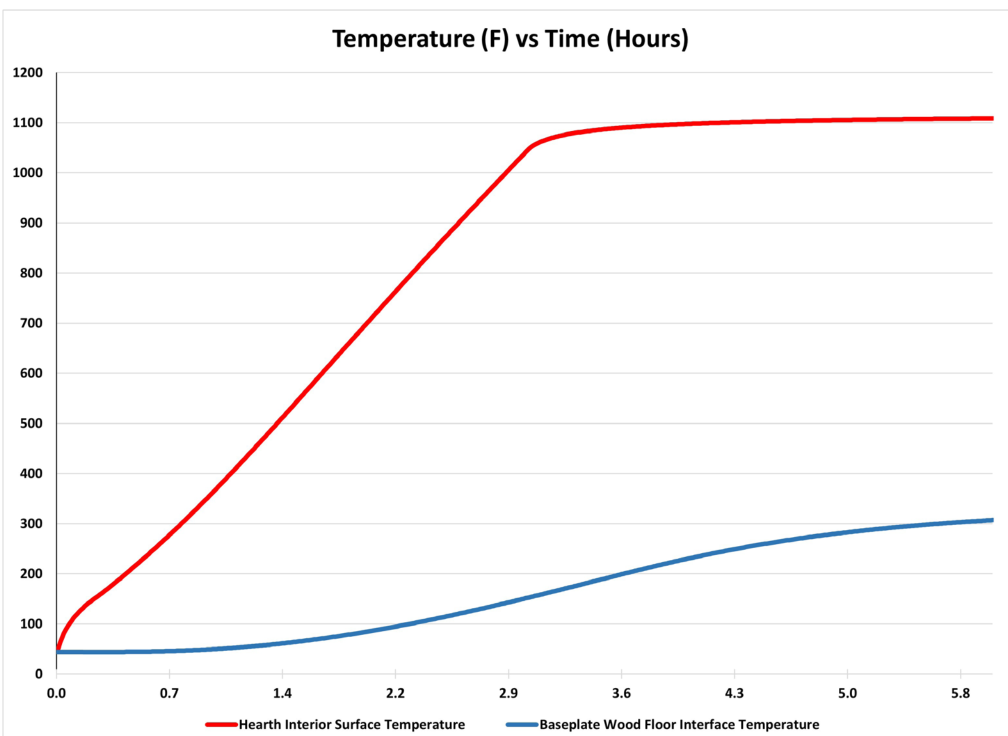

Figure 6
Prior Case #2 FDS modeled temperature results for the hearth interior surface temperature and the base plate exterior surface wood floor surface interface temperature for a burn test of approximately 5 hours and 45 minutes. A combined hearth refractory and base plate thickness of 5¼ inches. Models the exterior of fireplace and base plate sitting on a wood floor surface. The exterior base plate and wood floor interface temperature reached approximately 300ºF after 5 hours and 45 minutes.

Historical Testing and Results — Prior Case #3

Additional testing data was reviewed and considered for yet another prior case involving a similar modular fireplace that the author constructed, instrumented, and tested[1]. While no thermocouples were installed beneath the base plate, the rear wall exterior surface of the firebox where interfaced with contacting wood studs was instrumented. The rear wall of the firebox varied in combined refractory and modular block thickness ranging from 7¼ inch at the hearth surface level up to 11¼ inch (still 3 inches less than 14¼ inches) at the top of the firebox. Although the case only involved active burn testing of 3 to 4 hours, after the case concluded, the author performed active burn tests for approximately 12 hours for the benefit of data collection (again for potential future use). Temperatures at the 7¼-inch thickness at the hearth level and 11¼-inch thickness at the top of the firebox reached approximately 205°F and 182°F, respectively, after approximately 5 hours and 45 minutes. The temperature differences illustrate the reduction in temperatures achieved due to increased masonry thicknesses. It should be noted that the blocks utilized in the modular fireplace construction are proprietary blends of lightweight masonry containing air voids and volcanic pumice aggregate; therefore, they would have a lower thermal conductivity than the dense concrete blocks and (Type S) mortar fill that was used to construct the riser[2-8]. Nevertheless, there will be a substantial reduction in the heat transfer rate — and subsequently the wood floor temperature — due to the overall increase in masonry thickness (i.e., 5¼ inches versus to 14¼ inches).

Again, it should also be reiterated that as fuel continues to be added to the fireplace for extended burn times, the temperatures in the masonry will continue to rise, creating an imminent fire hazard to wood materials in contact or close proximity to the masonry riser surfaces. **Figure 7** depicts some data collected from the testing for a period of up to approximately 7 hours.

Initial Conclusions

Temperature ranges exceeding 170°F, the safe temperature limit of Underwriter's Laboratories (UL)[9,10],

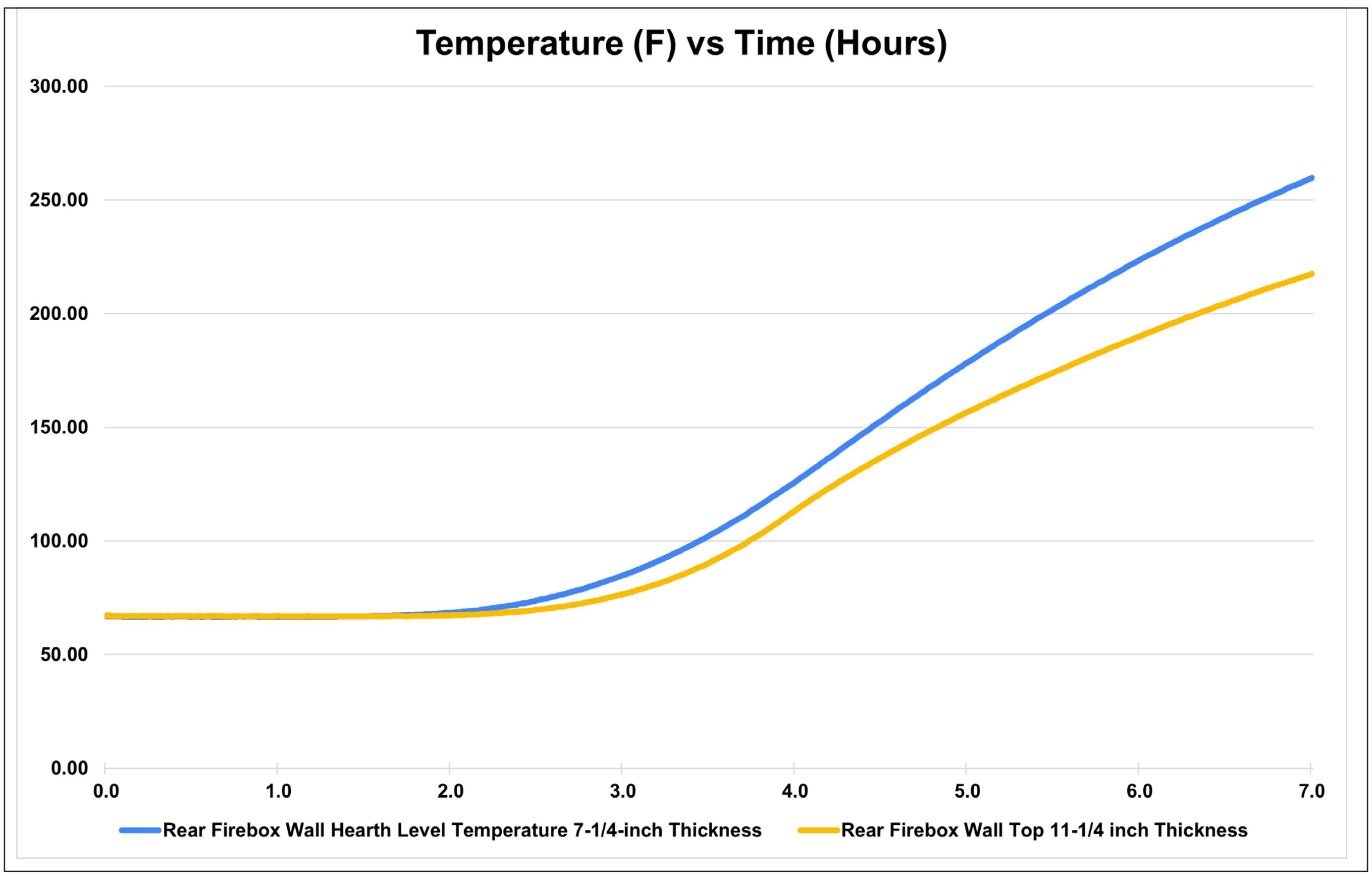

Figure 7
Prior Case #3 temperature results for the rear firebox wall and wood stud interface after approximately 7 hours of active burn testing. Note temperatures continue to climb as the fire is fed and the active burn time continues. Temperatures at the 7¼-inch thickness at the heart level and 11¼-inch thickness at the top of the firebox at the interfaces with the contacting wood studs reached approximately 205ºF and 182ºF, respectively after approximately 5 hours and 45 minutes.

represent a substantial fire hazard[11]; however, over a generally longer exposure time[9,11,12] than experienced in the subject case of five to 10 total burns at 5 to 6 hours each and temperatures considerably less than 300°F.

For the limited use history of the subject fireplace of this paper — and for the relatively short periods of time of each use — it was concluded there was insufficient heat transfer to ignite the wooden floor beneath the masonry riser. However, it should be noted that either a prolonged use (months or years of "short" burns) or extended use times (periods of longer burning) do represent a fire hazard as stated. This is further clarified by the fact that temperatures continue to climb in the masonry — and at the exterior surfaces of the masonry — as active burn times within the firebox continue. A fireplace should be able to operate continuously without the concern of igniting wood construction around the fireplace or chimney.

Additional Analysis — Construction Progress Photographs

After presenting these conclusions to the homeowner's attorneys, the author requested if any additional discovery, particularly pre-fire construction photographs, were available. Hundreds of pre-fire photographs were then provided to include daily construction progress photographs. After analyzing the photographs, multiple violations of the manufacturer's installation instructions and the (applicable) 2015 edition of the International Residential Code (IRC) clearances to combustibles and hearth extension construction requirements were discovered and evaluated for both the living room and the porch fireplaces. Discussion will be primarily (though not exclusively) limited to the living room fireplace because the porch fireplace was not in use at the time — and not the cause of the incident fire. However, the installation issues of the same model fireplace on the porch reflected a consistency in the lack of understanding of the proper installation requirements and a lack of an appreciation for the imminent fire hazards created by both. Therefore, some references will also be made to the porch fireplace installation and hearth extension construction.

IRC[13] Chapter 10 Sections *R1004 Factory-Built Fireplaces* and *R1005 Factory-Built Chimneys* provide that:

> ***R1004.1 General.*** *Factory-built fireplaces shall be listed and labeled and shall be installed in accordance with the conditions of the listing. Factory-built fireplaces shall be tested in accordance with UL 127.*
>
> ***R1005.1 Listing.*** *Factory-built chimneys shall be listed and labeled and shall be installed and terminated in accordance with the manufacturer's instructions.*

Prefabricated fireplaces and chimneys are required to be installed in accordance with the manufacturer's installation instructions. Subsequently, a violation of the manufacturer's installation instructions violates the building code. The manufacturer's installation instructions are an integral part of the fireplace listing and are used as a reference during examination and testing of factory-built fireplaces by testing laboratories[10,14]. Fireplace and chimney systems are assembled and constructed by testing laboratories using the manufacturer's installation instructions, including the manufacturer's specified minimum clearances to combustibles. The test assemblies are instrumented with thermocouples to verify maximum safe temperatures are not exceeded during operational testing.

Prefabricated masonry modular fireplaces that do not have factory-built and tested hearth extensions are required to comply with IRC Chapter 10 Section R1001.9, which provides [underlined emphasis added]:

> ***R1001.9 Hearth and hearth extension.*** *Masonry fireplace hearths and hearth extensions shall be <u>constructed of concrete or masonry, supported by noncombustible materials</u>, and reinforced to carry their own weight and all imposed loads. <u>Combustible material shall not remain against the underside of hearths and hearth extensions after construction</u>.*

The building code commentaries associated with hearth and hearth extensions provide additional insight:

> *The hearth includes both the floor of the firebox and the projection in front of it*[15].
>
> *Combustible forms and centers could ignite from exposure to heat from the adjacent fire place….these and other similar concealed, combustible components must be removed*[16].

Figure 8 is an annotated excerpt of IRC Figure R1001.1 that illustrates the proper construction of hearth and hearth extensions for masonry fireplaces. There should be no combustible materials, including wood framing or sheathing, within or beneath the hearth or hearth extension.

Industry standard NFPA 211, *Standard for Chimneys, Fireplaces, Vents, and Solid Fuel-Burning Appliances*, 2019 Chapter 11 Fireplaces[17], reflects similar provisions:

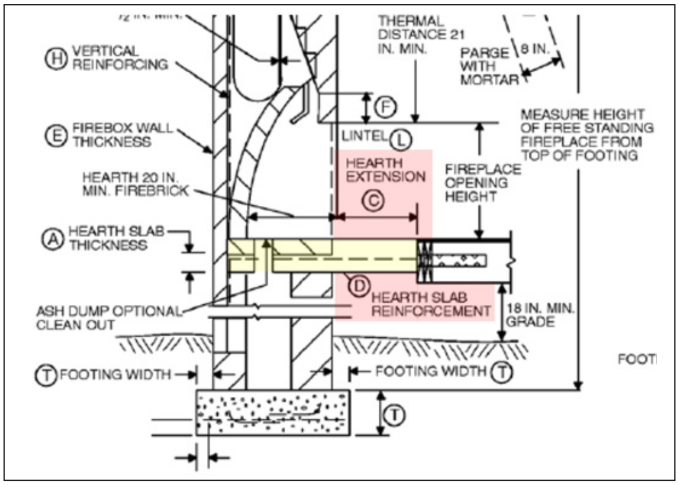

Figure 8
Annotated excerpt of IRC Figure R1001.1, illustrating the proper construction of hearth and hearth extensions for masonry fireplaces.

> *11.1 Factory-built fireplaces shall be listed and installed in accordance with the terms of the listing.*
>
> *11.2 Hearth extensions shall be provided in accordance with the manufacturer's instructions or be of masonry or noncombustible construction in accordance with Section 11.3.*
>
> *11.3 Hearth Extensions*
>
> *11.3.1 Masonry fireplaces shall have hearth extensions of brick, concrete, stone, tile, or other approved noncombustible material wholly supported by and integral with the chimney structure, and a minimum 4 in. (102 mm) clearance shall be maintained directly below the underside.*
>
> *11.3.1.1 Support for the hearth shall be provided by a structural slab or corbeled brickwork.*
>
> *11.3.1.2 Wooden forms used during the construction of the hearth and hearth extension shall be removed when the construction is completed.*

Finally, the provisions of the IRC and NFPA 211 regarding hearth and hearth extensions are also provided and illustrated in the manufacturer's installation instructions and will be referenced. **Figures 9** and **10** depict annotated pre-fire construction photographs of the living room fireplace prior to the enclosure and finishing of the chase.

The manufacturer's installation instructions provide for only one listed and tested system for the installation of the fireplace on a combustible floor that was not implemented

Figure 9
A view of the living room fireplace prior to chase enclosure. Notes: 1) wood floor; 2) CMU riser; 3) base plate; and 4) hearth refractory brick.

Figure 10
Another view of the living room fireplace with fiberglass batt insulation prior to chase enclosure. Notes: 1) wood floor; 2) CMU riser; 3) base plate; 4) hearth refractory brick; 5) radius throat front (RTF) block component; and 6) insulated air clearance spaces around the firebox (in blue font).

As a result, the installation violated the manufacturer's installation instructions and subsequently the building code. The fireplace was installed on an unlisted, untested, and unapproved solid-filled CMU riser supported by a wooden floor that was previously discussed in this paper.

The fireplace further incorporated a masonry block chimney system as opposed to a lightweight listed metal chimney system for installations to be performed on wooden floors. The fireplace, hearth extension, and chimney system were required by the installation instructions and code to be installed on a concrete slab supported by a CMU riser footing with no combustible materials within or beneath. **Figure 11** depicts an annotated excerpt from the manufacturer's installation instructions for installation of the fireplace where a crawl space with a combustible floor is involved (as in the subject case).

The installation manual further provides in reference to the concrete slab and drawing and in concert with the IRC and NFPA 211 that:

> *The fireplace must sit on a concrete pad or slab… This pad or slab should provide for the noncombustible hearth extension substrate needed to support the code required noncombustible hearth extension finish materials.*
>
> *Concrete Pad Supported by Masonry (CMU) Tower (Figure 4.2): Typically used when the fireplace is placed over a … crawl space. The noncombustible pad is best made from a 6" thick concrete slab with #4 rebar… poured on top of corrugated metal. Concrete pad must be supported by a full masonry tower with no combustible underpinnings… .*

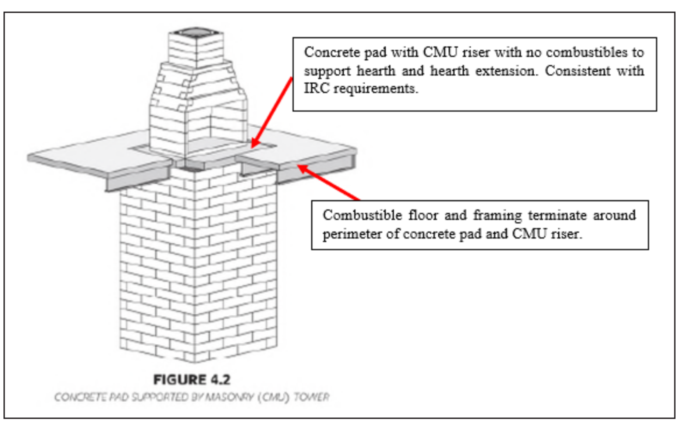

Figure 11
Concrete pad and foundation support structure drawing excerpted from the manufacturer's installation instructions where the fireplace is to be installed in a home with a combustible floor and with a crawl space.

Figure 12 incorporates side by side comparative photographs taken from nearly the same perspective and angle of the fireplace and chase enclosure with the OSB and then after/during the installation of the hearth extension, mortar and stone veneer. **Figure 13** is **Figure 12** again but with annotations to illustrate some of the features discussed.

The A and B lines approximately define the rectangular firebox opening and illustrate the very close proximity of the OSB to the opening edges. A/B (and other) ratios within the two photographs are equivalent. The light green dash-dot line across the windowsills provides a frame of reference to the top of the firebox. The Radius Throat Front (RTF) block (previously referenced in **Figure 10**) of the firebox begins at the top edge of the firebox opening and runs vertically up $9^{3}/_{16}$ inches toward the green dash-dot line. As seen in **Figure 10** and again in **Figure 14**, the RTF block forms a trapezoid shape (front face) with interlocking side blocks. The RTF block is clearly covered by the OSB depicted in **Figure 13**. OSB also extends over to the sides of the firebox near the opening edge. The area near the top of the hearth, extending down to the floor and running across the width of the firebox, is clearly

Figure 12
Photographs from near the same perspective/viewpoint and angle of the chase with OSB and then with the stone veneer and hearth extension in place. The stone finish in the right-side image defines the top edge of the firebox opening, which is consistent with the top edge of the OSB above the firebox opening in the left-side image.

Figure 13
Annotations added to the photographs of Figure 12.

covered by OSB in the left-side image and then the masonry hearth extension in the right-side image.

The construction superintendent, who was present daily and took all photographs during the building of the home, had already been deposed; however, he was not questioned relative to the photographs contained in **Figure 12**. Furthermore, no subcontractors had been questioned relative to the photographs (they had simply been overlooked in the several years of discovery). Therefore, the author requested if testimony could be obtained from the superintendent regarding his observations of the placement of OSB around the opening of the firebox. As a result, affidavit testimony was obtained, and the supervisor testified that the OSB was installed no more than 1.5 inches from the opening edges of the firebox.

Figure 15 is an excerpt from installation instructions

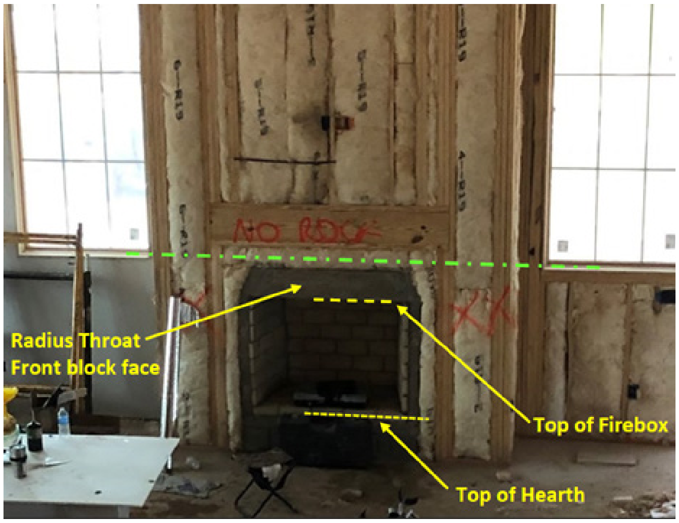

Figure 14
An annotated photograph of the living room fireplace prior to OSB and stone veneer enclosure.

This fireplace is designed to be installed so a 3" ledge is left on top of the radius throat front. This ledge allows space for a framing header to maintain the required 1" clearance and at the same time align flush with the room face of the firebox.

▲WARNING

Failure to maintain stated minimum clearance to combustibles on page 12 may result in a fire or explosion, causing property damage, personal injury, or loss of life.

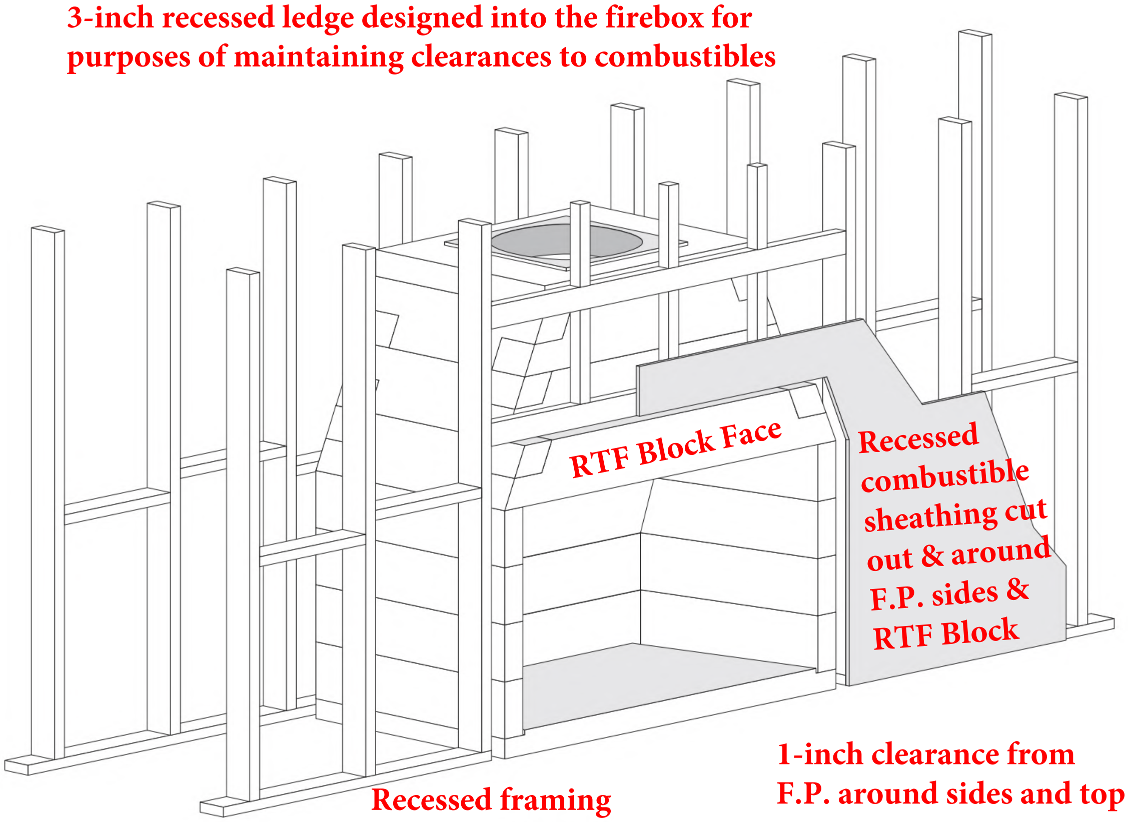

Figure 15
An excerpted and annotated view of an isometric drawing and the instructions above the drawing from the manufacturer's installation instructions.

illustrating and describing the fireplace design for framing and combustible sheathing installation around the firebox for the purposes of maintaining required clearances to combustibles. The fireplace is designed with a 3-inch ledge over the top of the RTF block to allow framing and combustible sheathing to be recessed and brought flush with the front vertical face of the firebox. For the case in question, OSB was installed across the face of the RTF block as well as the faces of the sides of the firebox and base plate. The OSB further projected beyond the vertical face of the firebox opening, creating a "trim" around the opening. **Figure 16** is another excerpted and annotated drawing from the manufacturer's installation instructions that depicts the proper construction around the firebox above the opening to maintain clearances to combustibles.

The OSB should not be in contact with any portion of the face of the RTF block (in this case, the OSB covers approximately 8 vertical inches of the face and runs across the entire width of the block). Instead, the OSB should be above the top of the RTF block with a minimum of 1-inch vertical clearance. Furthermore, the OSB should not project beyond the vertical face of the RTF block, as such projection creates a combustible trim above the face opening of the firebox. Based on the manufacturer's installation instructions, such trim projection would require a minimum

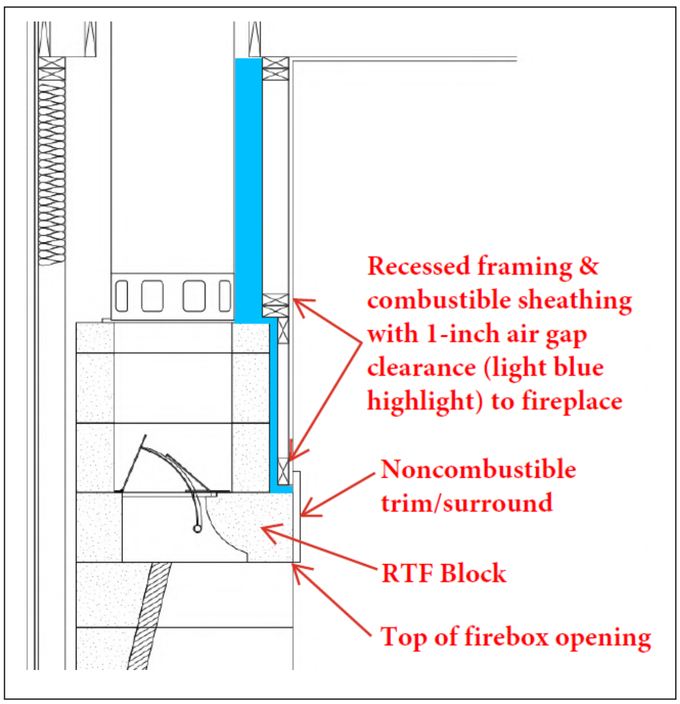

Figure 16
An excerpted and annotated profile drawing from the manufacturer's installation instructions pertaining to the combustible framing and sheathing around the top of the firebox. Note also the required cooling air spaces which are annotated in blue.

of 12 inches clearance. Covering such projecting trim with mortar and/or stone veneer does not render it noncombustible and does not prevent exposure to the substantial heat emanating from the top of the firebox opening; it merely conceals it, creating a hidden fire hazard.

The OSB on the sides is required to have 1-inch horizontal clearance to the sides of the firebox and is required to be recessed flush with the front vertical face. The OSB on the sides overlaps the vertical front face of the sides of the firebox and also projects beyond the vertical face, forming a "trim." No OSB or other combustible construction is permitted within or beneath the hearth and hearth extension. Yet, the OSB that was routed across the bottom opening of the firebox is sandwiched beneath and between the masonry joint formed by the hearth and hearth extension.

It should be noted also that a faulty or missing seal between the hearth and hearth extension could allow penetrating embers at that location to precipitate a fire. NFPA 211 Section 11.2.1.5 requires that joints be fully sealed. However, in this case: (1) the homeowners reported no cracking in or between the hearth or hearth extension; (2) the available photographs indicated no cracking in or between the (relatively new) hearth or hearth extension; and (3) the masons who constructed the unit stipulated all potential voids and joints were solid filled. Direct examination of the fireplace joints could not be made post-incident due to the level of destruction during collapse.

As previously observed in **Figures 10** and **14**, fiberglass batt insulation was installed in the air clearance spaces between the firebox and the wall framing in violation of the manufacturer's installation instructions. The instructions state that (in multiple locations of the manual) no insulation is to be placed in the air clearance spaces around the fireplace. Insulating air clearance spaces around the perimeter of the firebox will result in higher operating temperatures of those faces and, in particular, any combustibles in (improper) contact with or in close proximity to them.

While the installation violations of the OSB across the top and sides of the firebox are clear fire hazards, the scene investigators concluded that the origin of the fire was beneath the firebox hearth due to the extensive fire damage to the floor and floor system beneath. The floor system beneath the firebox and hearth extension was consumed and compromised during the fire event, resulting in the collapse of the chase enclosure. Floor systems beneath masonry are often protected[18] from fire exposure and remain in good condition after extinguishment when a fire originates elsewhere.

The hearth, hearth extension, and the joint between the two are subject to substantial radiant heat transfer from the fireplace opening and subsequently substantially elevated temperatures. *Kirk's Fire Investigation*[19] notes that radiant heat fluxes of 20KW/m^2, producing equilibrium surface temperatures of approximately 500°F can be experienced at the face of the fireplace; and radiant heat fluxes of up to 30KW/m^2, producing equilibrium surface temperatures of up to approximately 800°F can be experienced in the interior of the fireplace.

As previously noted, the author has instrumented the top surface of the hearth floor of a modular wood-burning fireplace and recorded operational temperatures. Temperatures in excess of 1,100ºF are established and maintained on the floor due to the continuous accumulation of hot and burning embers. The accumulated burning embers on the surface result in conduction and convection heat transfer processes directly impinging on and heating the hearth floor. The hearth extension is as the name indicates: an extension of the hearth. Hot and burning embers and ash commonly accumulate not just on the hearth floor but also up to and including the joint between the hearth and hearth extension (and sometimes beyond). **Figure 17** depicts a summary of the features of the as-built fireplace and the discussed concealed fire hazards. **Figure 18** depicts the subject fireplace in operation.

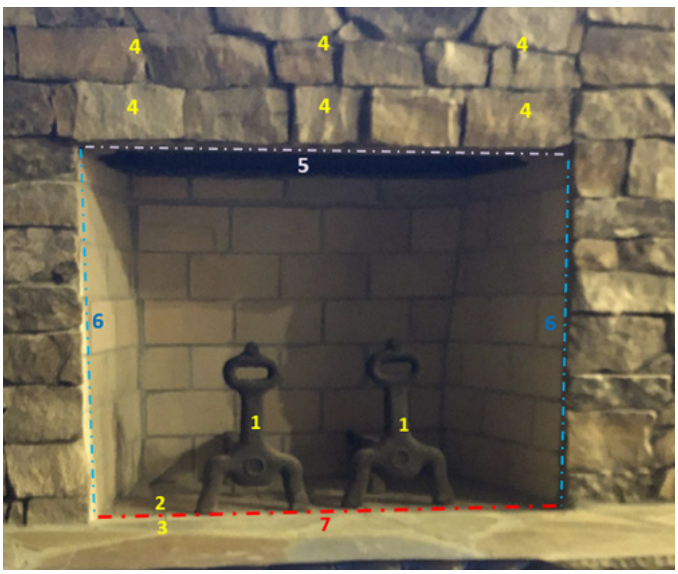

Figure 17
A view of the finished fireplace opening and hearth extension in front of the fireplace. Notes: 1) andirons (used to support logs during fireplace use); 2) fireplace hearth (note proximity of mortar joint 7, red dash-dot line); 3) fireplace (flush) hearth extension; 4) stone/mortar covering OSB running across and in direct contact with the face of the RTF block and with air/clearance spaces above the RTF block packed with fiberglass insulation; 5) mortar joint covering the edge of the OSB sheathing projecting beyond and around the perimeter face of the fireplace opening (trim projection); and sandwiched between the stone veneer and the RTF block face along the top of the firebox. Purple dash-dot line at top of firebox opening; 6) mortar joint covering the edge of the OSB sheathing projecting beyond and around the perimeter face of the fireplace opening on the sides (trim projection) and sandwiched between the stone veneer and firebox side faces. Blue dash-dot line. The OSB is also in direct contact with the vertical front face of the firebox sidewall; and 7) mortar joint covering the edge of the OSB sheathing projecting beyond and around the perimeter face of the fireplace opening and sandwiched between the hearth and hearth extension. Red dash-dot line. Subject to intense radiant, conduction and convection heat transfer processes during operation of the fireplace.

During operation — and for an extended period after operation of the fireplace — conduction heat transfer will occur from the vertical front face of the hearth refractory brick and base plate into the OSB in direct contact with the base plate. Heat will also directly transfer via conduction from the top of the mortar joint above and into the OSB. Heat will further be transferred via conduction into the vertical face of the OSB from the hearth extension side.

Analysis Pursuant to Past Testing & Investigations

As part of his investigation, the author continued reviewing past case file materials as well as testing and data

Figure 18
A view of the subject fireplace in use (on a different occasion) sometime prior to the incident. Note the spark screen forms a trapezoid projection (yellow outline) out into the hearth extension. Also note the hot burning coals and ash accumulating beneath the burning logs and andirons on the hearth surface.

involving incidents where modular masonry fireplace installation defects caused structural fires. In addition, the author performed laboratory supplemental new testing utilizing a modular fireplace that he had constructed for another case years before of the same make and by the same manufacturer. The new testing will be discussed in a later section.

Prior Case #4 involved a modular masonry fireplace that was enclosed in a wood-framed and wood-sheathed chase and finished on the exterior with masonry stucco. The fireplace was installed on a concrete block (CMU) riser set on a concrete slab foundation. The fireplace incorporated an adjacent wood framed and sheathed hearth extension covered with metal lathe and then stucco. The stucco covering created a hearth extension flush with the fireplace hearth. Fire investigators examined and reconstructed the scene and concluded that the fire originated within the wood-framed and sheathed hearth extension, spread into the connected chase enclosure, and then spread vertically up the interior of the chase and into the rest of the home. As a result, the home was destroyed.

The fireplace was part of a rental beach residence used for short-term vacations. The complete history of the fireplace is unknown — though it was thought to be infrequent because of the transient nature of the property. On the date of the incident, the home was being rented for a wedding. Around 4:30 p.m., a fire was built in the fireplace, and the fireplace was operated up until around 9:30 or 10 p.m. (5 to 5.5 hours), at which time there were only hot embers and ashes remaining on the hearth. Guests left the fireplace/patio area around 11:30 p.m. Sometime after 5 a.m. (approximately 7 hours after active burning in the fireplace ceased), a guest woke up to use the bathroom, smelled smoke, and searched for/discovered a fire at the wall common to the fireplace chase enclosure. The 911 call occurred at 5:36 a.m.

Figure 19
Prior Case #4. A view of the fireplace during excavation and reconstruction at the fire scene.

Based on the scene and reconstruction data obtained by the fire investigators, an exemplar modular fireplace, chase, and hearth extension were constructed, instrumented with thermocouples, and tested. Testing was conducted with the hearth extension wood framing against the base plate of the firebox and approximately 1.5 inches below the hearth surface and mortar covering the hearth extension surface. Based on the testing, temperatures obtained (up to approximately 650°F) were more than sufficient to initiate thermal decomposition, charring, and smoldering ignition of the wood substrate of the hearth extension[11,18,20].

It should be noted that the engineer performing the testing on multiple occasions pushed embers and ash away from the masonry joint between the hearth and the hearth extension toward the back of the firebox. Variations in temperature would (and did) occur, depending upon where hot ashes and embers accumulated relative to the joint — and particularly where they accumulate relative to the thermocouples that were imbedded beneath the joint. The temperatures measured were not necessarily the hottest points along the joint. **Figures 19** through **21** depict

Figure 20
Prior Case #4. A view of the fireplace, chase, and hearth extension during laboratory reconstruction (per data from the fire investigators scene exam) and instrumentation prior to covering the hearth extension and surround with masonry. Notes: 1) wood framed hearth extension covered with plywood, felt paper and metal lathe prior to covering with masonry mortar; 2) hearth refractory; and 3) joint between hearth and hearth extension.

Figure 21
Prior Case #4. Joint between the hearth and hearth extension (fitted with new wood after a prior test run) prior to thermocouple instrumentation, filling and covering with masonry. The wood framing is beneath the hearth refractory brick surface (approximately 1.5 inches) and in contact with the base plate. The joint as well as the surface of the hearth extension were filled and covered with masonry to make it flush with the hearth.

the fireplace at the scene and reconstructed fireplace for testing purposes. **Figure 22** depicts a data plot from the testing.

Prior Case # 5 involved a modular fireplace and chase enclosure built into the exterior wall of a home. The fireplace was installed on a double layer of concrete CMU blocks resting on a concrete slab. The fireplace incorporated a wood-framed and wood-sheathed chase enclosure with brick veneer finish. OSB wrapped the entire face perimeter of the fireplace (substantially similar to the subject fireplace of this paper). OSB was sandwiched/embedded between the base plate of the firebox and the masonry hearth extension (also substantially similar to the subject fireplace of this paper).

Fire investigators and engineers (including the author) examined the scene and delayered the fireplace brick veneer. It was concluded that the fire originated within the OSB sandwiched between the fireplace base plate (beneath the hearth) and the masonry hearth extension. The OSB was ignited via smoldering ignition. Once sufficient degradation occurred to the embedded OSB structure and sufficient oxygen pathways were available, the smoldering fire transitioned to flaming combustion and spread into the chase enclosure, vertically up the interior of the chase, and then into the rest of the home. As a result, the home was completely destroyed.

The new home had been completed in May of 2010 and occupied by the owners around that time. The fireplace had only been used approximately six to seven times

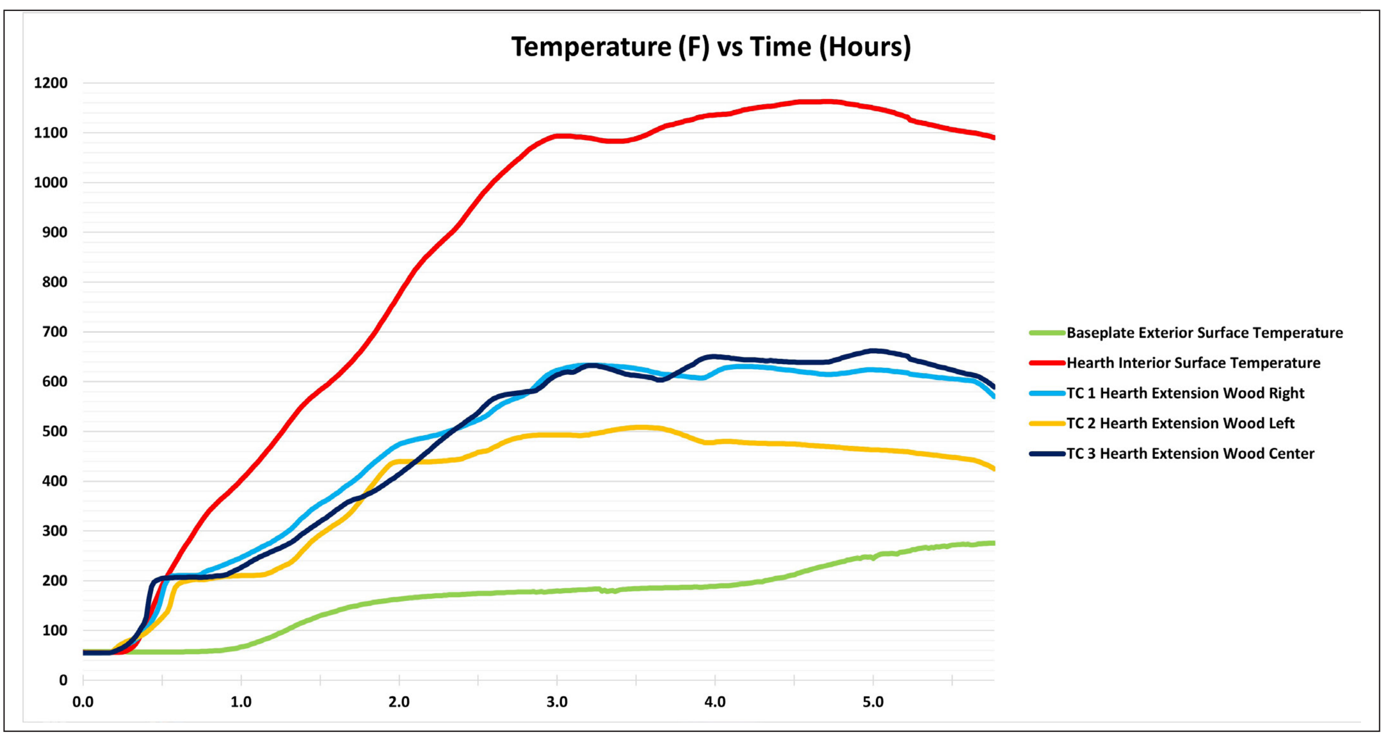

Figure 22
Prior Case #4. Data plot of thermocouple temperatures on the wood approximately 1.5 inches below the mortar joint between the hearth and the hearth extension. Also included are the hearth interior surface temperature and the exterior bottom surface of the base plate.

prior to the incident fire. On the date of the incident in early October of 2010, a fire was built in the fireplace around 10:15 a.m. and maintained up until around 6:45 p.m. (approximately 8.5 hours into the fireplace operation), at which time the wife discovered smoke in the home. Looking from a window, the homeowners saw smoke coming from around the flashing of the chimney. **Figures 23** through **26** depict the delayering of the brick veneer and origin of the fire.

Supplemental New Testing for the Subject Case

In addition to the past case file testing and material reviews, the author performed demonstrative (supplemental new) testing to illustrate the nature of the fire hazard created by installing wood within the hearth and hearth extension structure. Testing data was already available for wood located 1.5 inches beneath the surface of the hearth. It should be noted that the superintendent for the subject case of this paper testified the OSB was within 1.5 inches of the opening of the firebox. To expand upon the available existing data, the new testing for the subject case fireplace doubled the distance to the OSB to a depth of 3 inches. In addition, OSB at a depth of 2.5 inches was included in the same testing to illustrate/contrast differential heat transfer under the same conditions. A small to modest active fire was maintained in the fireplace over the approximate same period of time for the subject case.

The testing results were generally consistent with what would be expected to occur based on the fireplace

Figure 23
Prior Case #5. A view of the modular fireplace during delayering of the brick veneer.

Figure 24
Prior Case #5. Another view of the fireplace during progressive delayering. Fire spread from near the base of the fireplace and up the wall and into the attic.

Figure 25
Prior Case #5. A view with the hearth extension masonry removed, exposing the joint between the hearth and the hearth extension. The yellow arrows indicate the OSB remains and burned-away portions of the OSB that was sandwiched between the hearth and the hearth extension. The fire spread until reaching the left side of the fireplace where the interior side of the OSB ran vertically up the chase.

Figure 26
Prior Case #5. The OSB had been installed approximately 1.5 inches below the surface of the hearth.

face radiant heat exposure data previously referenced in *Kirk's Fire Investigatio*n (i.e., up to around 500°F). It should be noted, however, that radiant heat transfer is not the only heat transfer process taking place, particularly at the hearth floor surface as previously discussed.

Convection and conduction heat transfer processes are operative on the hearth surface due to the accumulation of burning embers, log fragments, and hot ashes on that surface over the course of the active/flaming fire — and then even well after the active/flaming fire is out (i.e., smoldering embers beneath insulative ash cover). Depending on how/where the hot embers and burning collapsing logs fall as fuel consumption takes place will substantially impact temperatures on, near and within the masonry joint between the hearth and hearth extension. In general, the test fires were monitored to keep any burning logs or large burning embers that collapsed directly off of the joint, although such a scenario is certainly foreseeable and even likely.

As noted, the tests involved a maintained small to modest fire in the fireplace. It is also certainly foreseeable that a larger fire could be built and maintained that would more rapidly elevate the observed temperatures both in rate and magnitude within the joint and subsequently the wood. So, variability in fire size — as well as different distributions of natural falls of burning logs and embers from the andirons within the fireplace — can result in temperatures even more elevated than those obtained in the present tests. Nevertheless, the temperatures that were obtained in the testing were much more than sufficient to ignite the embedded wood. In any case, as discussed, the codes and standards prohibit any wood in the structures of a hearth and hearth extension because it is well understood that given sufficient foreseeable conditions and time, ignition of that wood will occur.

The previously constructed lab fireplace[1] utilized was installed on a raised concrete slab and has a full masonry hearth extension. The joint between the hearth and the hearth extension was sawn out with a masonry saw. One-half-inch OSB sheathing board was step cut and instrumented with thermocouples and installed in the joint against the base plate below and along the full opening of the fireplace. Thermocouples were placed on the top horizontal edge of the OSB at intervals of approximately every 2 inches. Half of the OSB strip was installed 2.5 inches below the hearth surface. The other half of the OSB strip was stepped down and installed 3 inches below the hearth surface. The joint cavity balance was backfilled with Type S mortar.

Two similar operational tests were performed, each with active burns over a period of approximately 4.5 and 5.25 hours. A small to moderate fire was maintained in the fireplace by periodically adding wood as the logs in the fireplace were consumed. Temperatures obtained during the first test for the 2.5-inch and 3-inch depths below the hearth extension reached a range of approximately 360°F in approximately 3.5 and 4.5 hours. Temperatures continued steadily rising thereafter for another approximately 3.5 hours to peak temperatures of nearly 500°F and 460°F (well after active/fuel fed burning had ceased). Temperatures did not drop below 360°F for another approximately 4 hours after peak or approximately 6.5 hours after the fire in the fireplace was down to glowing embers. The temperatures obtained were much more than sufficient[11,18,20] to thermally decompose, char, and ignite the OSB to self-sustained smoldering combustion, which is further discussed later.

Figures 27 through **30** generally depict the fireplace setup and burn testing. **Figures 31** and **32** depict the data plots of testing results from the first test. The results are similar for the second test, which are depicted in **Figures 33** and **34**. Note that the data logger was shut off approximately 7 hours after active burning ceased in the second test. The data logger was allowed to run longer after test one, and the data reflects the long period of time that it takes the masonry to cool back down to ambient temperatures. **Figure 35** depicts hot glowing embers that were hidden by ash and uncovered approximately 7 hours after the active fire ceased in the fireplace during the second test.

Analysis and Discussion

Although analysis of the area of origin was not within the scope of the author's assignment, the data he reviewed in this case was consistent with the area of origin being beneath the living room fireplace, specifically beneath the hearth and hearth extension masonry joint. The area of most extensive damage occurred to the enclosed chase structure. The homeowners reported there was no visible fire in the living spaces of the home (including the living room), as they made multiple trips into and out of the home while attempting to save family photographs. The chase structure also collapsed during the incident as observed by the homeowners consistent with structural compromise of the floor while the remainder of the house structure remained standing.

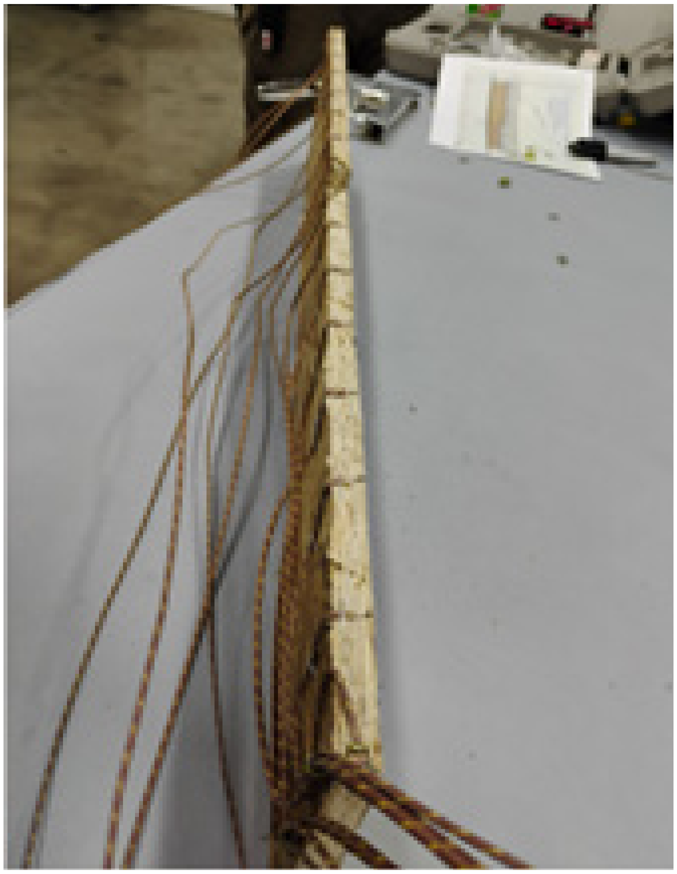

Figure 27
A view of the thermocouple instrumented stepped OSB sheathing installed in the joint between the hearth and hearth extension.

Figure 28
A view of the thermocouple instrumented joint between the hearth and the hearth extension after installation of the OSB.

Figure 29
A view of the equipment and fireplace setup.

Figure 30
A view of the small to modest fire maintained in the fireplace during testing.

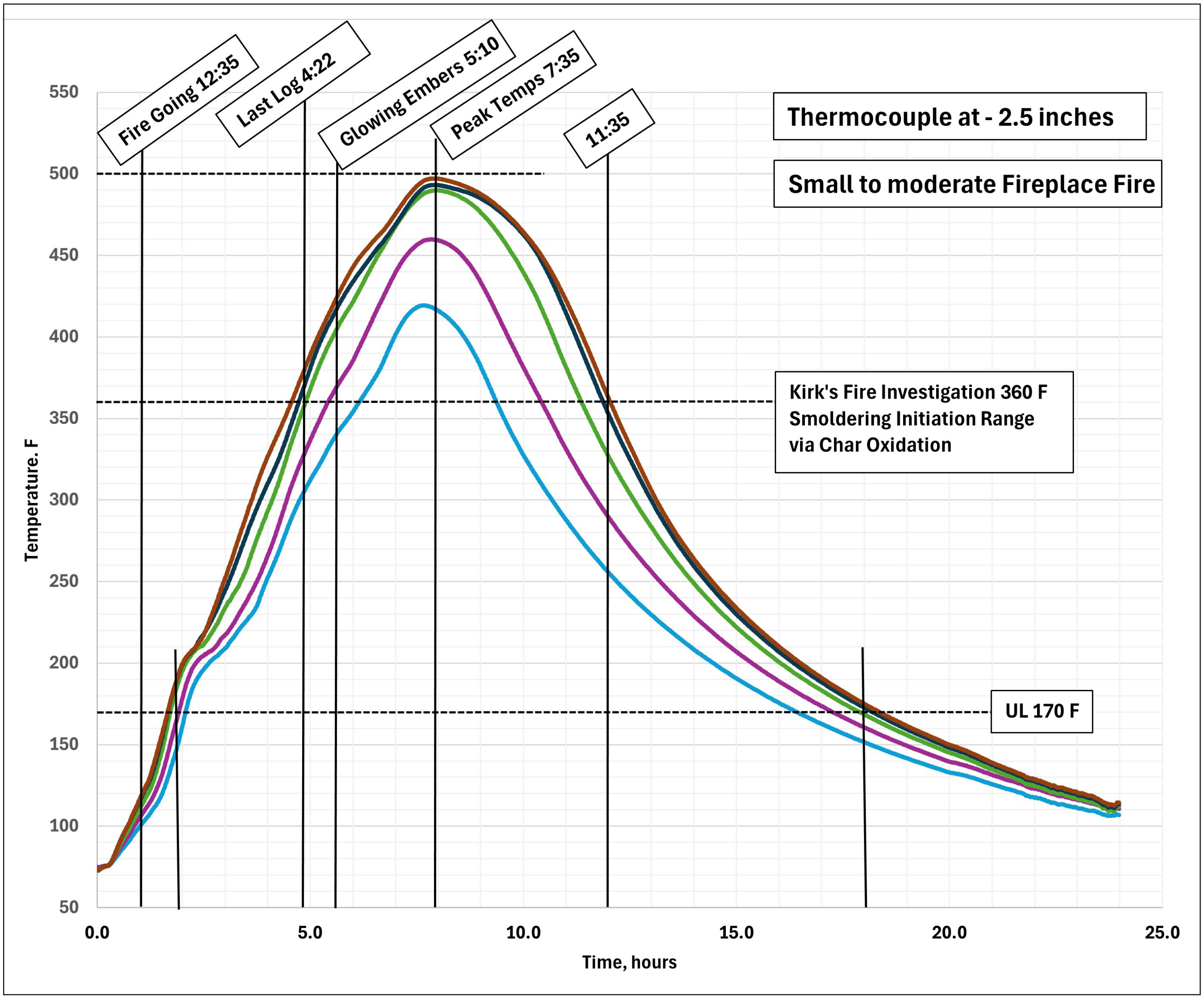

Figure 31
A view of thermocouple data at 2.5 inches depth from Test 1.

The chase was of combustible construction on the interior with masonry and stone on the exterior, creating a substantially sealed/isolated combustible concealed space through which a smoldering fire could initiate, transition to flaming, become well developed, and spread before ultimate discovery. The OSB sandwiched between the hearth and hearth extension masonry joint was in very close proximity to the hottest part of the fireplace: the hearth floor. The hearth floor is the hottest part of the fireplace and remains the hottest part the longest due to: (1) high operational temperatures transmitting energy via radiation, conduction and convection into the hearth and hearth extension masonry; and (2) the accumulation of sustained glowing/ slow smoldering embers protected by ash cover. Just as the insulative hearth ashes contained glowing embers some 7 hours after cessation of flaming fire in the fireplace, thermally damaged, charred, and smoldering OSB sandwiched within the hot masonry joint would also be sustained. Once the OSB was sufficiently thermally and physically degraded and oxygen channels opened up, the smoldering fire transitioned to flaming and spread through the chase interior and then into the remainder of the home.

Temperatures in the demonstration testing reached 460°F/500°F (3 inch / 2.5 inch) in test one and 475°F/508°F (3 inch / 2.5 inch) in test two. Temperatures at 1.5-in depths would therefore be even higher for the testing undertaken utilizing a small to moderate fire and controlling large ember and log collapse migration onto the joint. The temperatures obtained reached and exceeded common

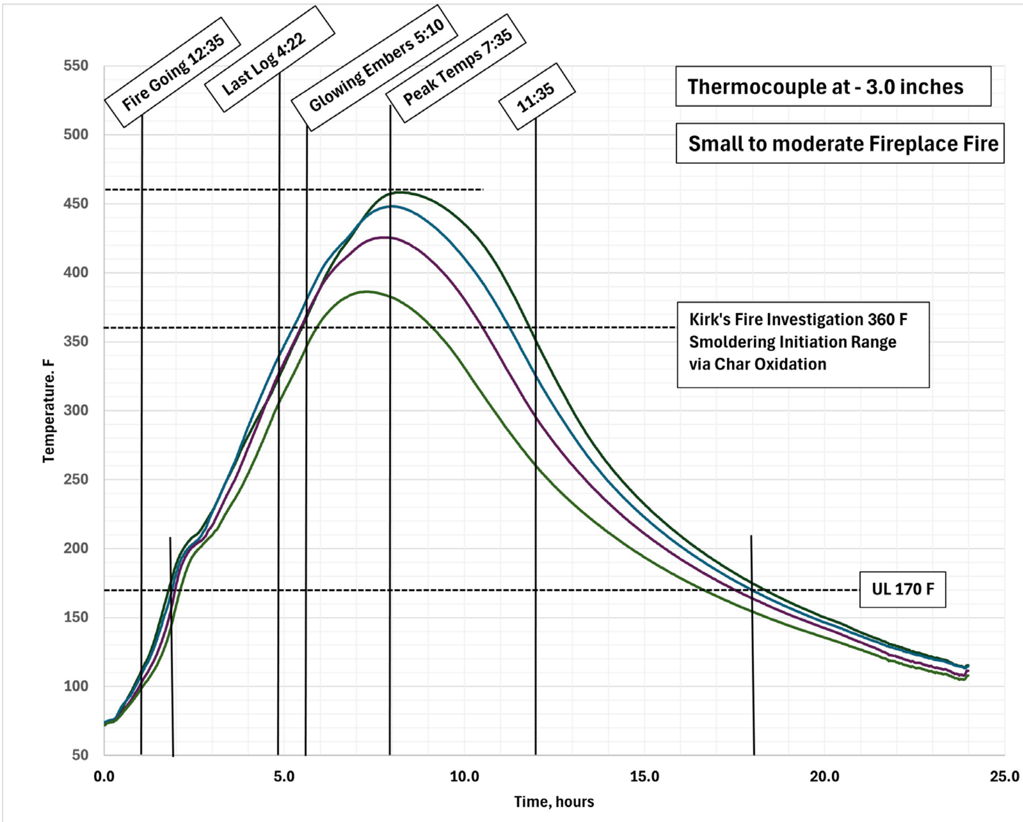

Figure 32
A view of thermocouple data at 3.0 inches depth from Test 1.

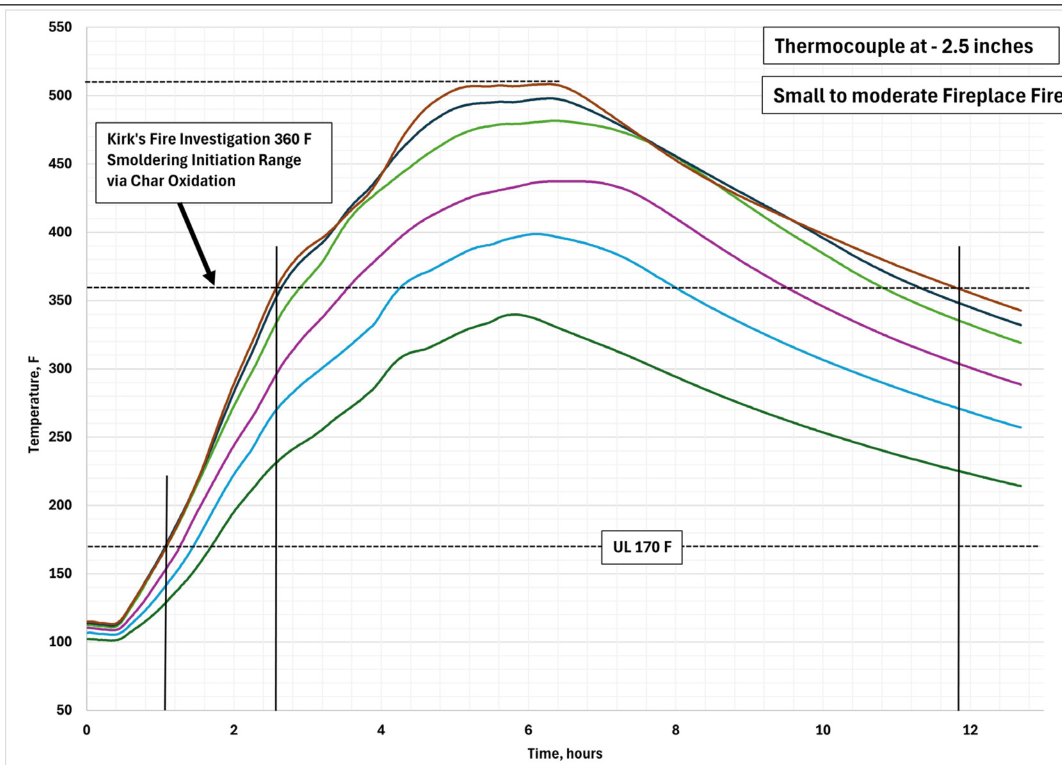

Figure 33
A view of thermocouple data at 2.5 inches depth from Test 2.

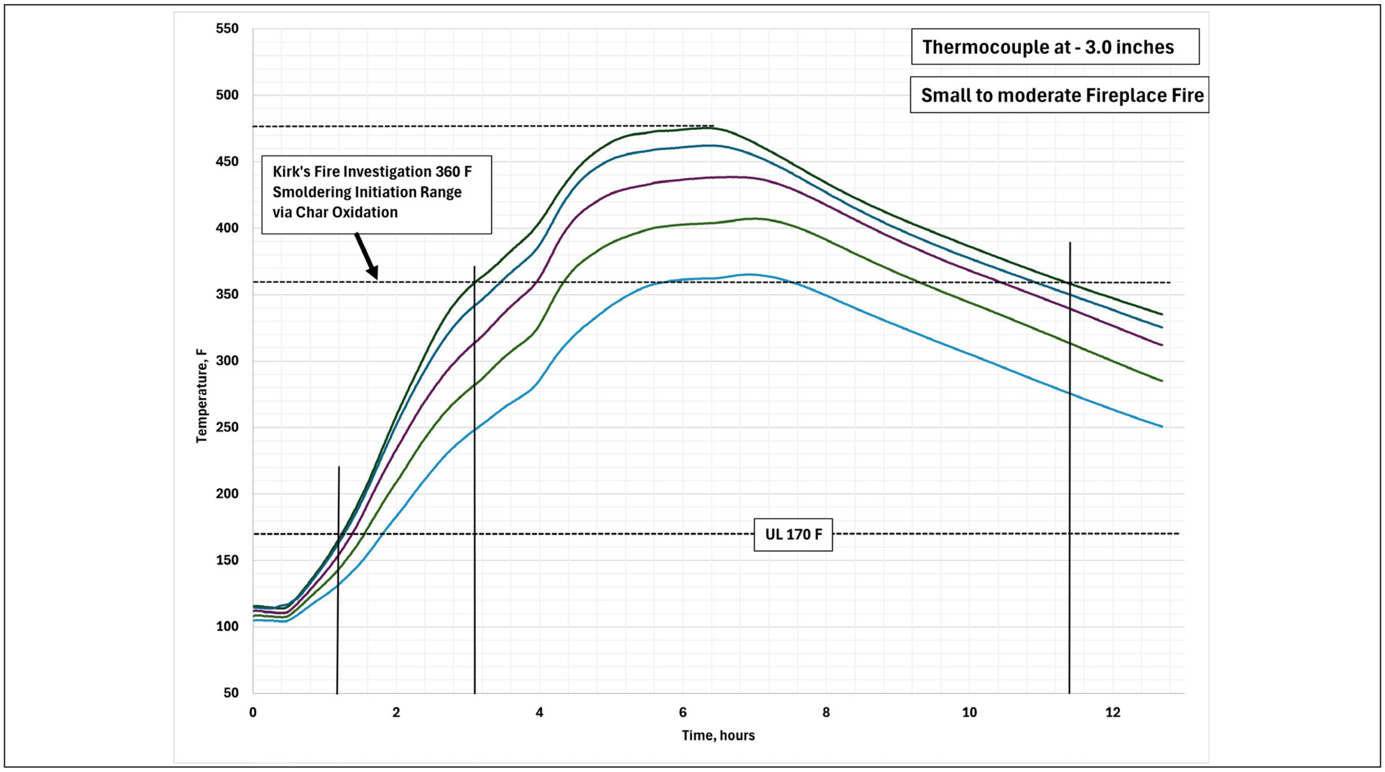

Figure 34
A view of thermocouple data at 3.0 inches depth from Test 2.

temperature ranges associated with the ignition of wood (392°F to 480°F)[18,20].

Of additional interest in this case is that temperatures exceeding 360°F are also attained and maintained for extended periods of time. The OSB is embedded in hot masonry, concealed, and therefore in an oxygen limited and insulated environment. As a result, the installation configuration also represents a substantial smoldering ignition fire hazard. *Kirk's Fire Investigation 8th Edition* notes in discussing smoldering ignition:

> *At temperatures above 180°C (360°F), the pyrolysis of all three major constituents (i.e. cellulose, hemicellulose, and lignin) reaches its maximum rate, leaving a smaller percentage (10 to 20 percent by weight) as char. If the heat being accumulated by the char is retained, and there is an adequate supply of oxygen, the temperature of the mass can rise to the point at which combustion can take place….The retention of heat depends on the amount of thermal insulation available and the amount of heat that is being lost to convective and conductive processes. If there is too much insulation, the supply of oxygen becomes inadequate to sustain*

Figure 35
A view of hot glowing embers hidden in the ash and uncovered 7 hours after active burning ceased in the fireplace.

> *combustion, although smoldering combustion can take place at very low oxygen levels….*

The OSB embedded in the masonry joint would be subject to substantial pyrolysis, char formation, and smoldering ignition with sustained combustion likely every time the fireplace was used. In uses of the fireplace prior to the night of the incident, insufficient oxygen (due to the embedded nature) and eventual heat dissipation (after the masonry mass cooled down) would cause the charred and smoldering OSB to self-extinguish until the next use of the fireplace when the process of pyrolysis, char formation, and smoldering ignition with sustained combustion would repeat itself. Once the OSB underwent sufficient thermal and physical degradation and sufficient oxygen channels and pathways opened up along and within the OSB, the smoldering combustion could then transition into flaming combustion.

A smoldering fire in the masonry embedded OSB may initiate at any time during operation of the fireplace and continue to smolder for an extended period of time (many hours), well after the active fire in the fireplace has ceased. For example, approximately 7 hours after active (flaming) fire had ceased in the second burn test, ashes within the firebox were stirred, and substantial glowing/smoldering embers were still present (**Figure 34**) though not visible or otherwise detected until the ash was moved around. Ash covering the embers had functioned to insulate and sustain slow smoldering combustion (with a low heat release rate) without the production of any detectable smoke. In like manner, charred and smoldering wood embedded within the hot masonry joint would continue to smolder in a manner even less detectable due to the masonry embedded concealed nature. Not until the smoldering combustion transitioned into flaming combustion (not a predictable event[18]) within the chase would the fire likely become detectable. *Kirk's Fire Investigation 8th Edition* [pp. 258] notes:

> *… Due to the low heat release rate (HRR) and slow combustion and the insulative properties of ashes and the charred wood, the embers are undetected when removed. …Wood or charcoal embers, insulated by ashes, can continue to smolder for 3 or 4 days under the right conditions and can result in ignition after being removed.*

Kirk's Fire Investigation 8th Edition [pp 79-80] also notes that:

> *Investigators tend to associate the time of discovery with the time of first ignition. This assumption may introduce serious errors into the fire analysis. Due to its slow output of heat and smoke, smoldering may proceed for an extended period of time without being noticed. When the combustion transitions to flame, it is almost certain to be discovered quickly.*

The cause of the fire was the defective installation of the living room fireplace by integrating wood OSB into the structure of the required non-combustible hearth and hearth extension in violation of the manufacturer's installation instructions, the IRC, and nationally recognized standard NFPA 211.

The porch fireplace contained similar multiple violations related to clearances to combustibles — two of which are mentioned here. The porch fireplace was installed directly on top of the wood floor with no CMU riser. The porch fireplace was installed with a wood-framed and sheathed hearth extension in direct contact with the base plate of the firebox. The relatively infrequent use (five to 10 times) and much less operational times (2 to 3 hours) with each use is the likely reason a structural fire had not yet resulted from using the porch fireplace.

The installation of the living room fireplace as well as the porch fireplace included multiple violations of the manufacturer's installation instructions as well as the IRC and NFPA 211, which created conditions that would result in an imminent fire.

Conclusions

In this paper, the use of testing and analysis from prior similar cases was used to evaluate and support the fire cause in the present case. Additional testing and analysis was implemented to illustrate to (and enhance the understanding of) various involved parties as it relates to heat transfer into masonry hearth and hearth extensions and how fires may smolder undetected for extended periods of time before transitioning to flaming combustion.

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