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Forensic Engineering Analyses of a Home Fire

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Abstract

A fire had occurred in a single-family home where a family of four was living. The family was asleep when the daughter woke up, saw smoke in her bedroom, and screamed. The daughter and father exited by breaking through a bedroom window, but the other two family members were overcome by the fire before exiting (and were later found deceased by the fire department). None of the witnesses heard a smoke detector (activation), and brief searches by investigators did not find any evidence of either the detector bracket or other remains. Forensic engineering analyses of the preserved evidence were performed, and Fire Dynamics Simulator (FDS) software was used to analyze multiple fire origins, predicted smoke-detector activation, and egress times. Fire growth, thermally induced electrical failure (THIEF), glass breakage, smoke-detector activation, barrier failure, and tenability (CO, temperature and visibility) were calculated. The FDS analyses were performed using a combination of factual information, timelines, fuels derived from the Fire Burning Item Database (FireBID), analyses of photographs, and witness depositions, and were verified and validated. The analyses/methodologies were explained to the trier of the facts (jury), and the results were presented; namely, the most probable origin and cause (ignition) of the fire, smoke-detector-activation times, and egress times for the residents.

Keywords

Fire cause, fire origin, first fuel, ignition, Fire Dynamics Simulator (FDS), fires by electrical failures, smoke-detector activation, egress times, forensic engineering

Introduction

In the early morning hours of August 21, 2011, a disastrous fire occurred in a tenant-occupied detached single family home. The family was asleep when the daughter woke up, saw smoke in her bedroom (bedroom 3), and screamed. The father, mother, and son were sleeping in the master bedroom (bedroom 1), were awakened by the scream, and met the daughter in the hallway (**Figure 1**). Led by the father, they slowly moved to exit through the front entry door. When the family reached the end of the hallway, the fire and smoke intensity was too severe to exit through the front or kitchen. So they retracted to the daughter's bedroom and attempted to exit through the window. The window proved too difficult to open; therefore, they moved to the bedroom (bedroom 2) across the hallway. The father broke the window glass, slid out, and fell outside. He recovered in a few seconds, helped the daughter to get out, and carried her away from the burning house to the driveway. He returned to the window to rescue

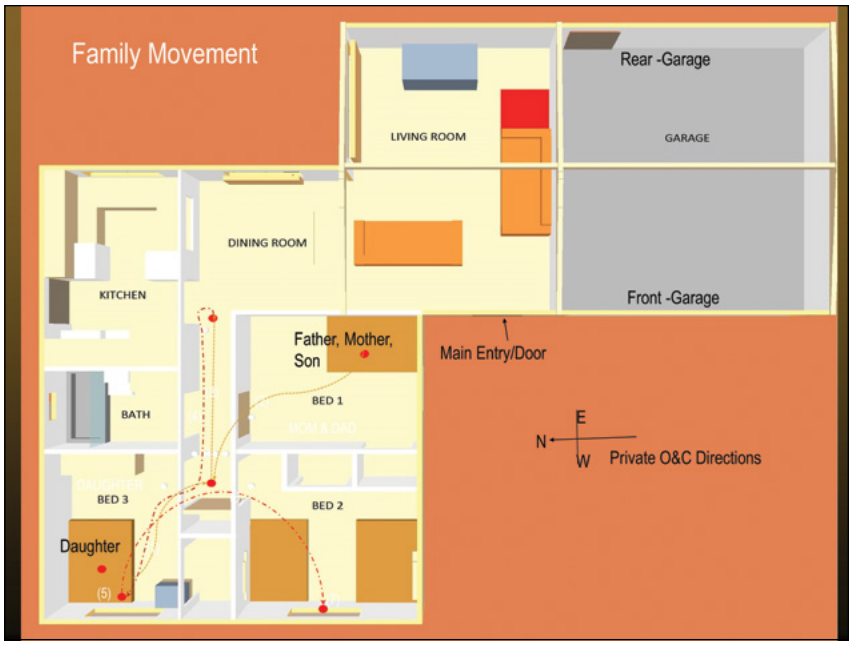

Figure 1
Family movement.

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the mother and son. The mother went to get the son and disappeared. Responding to a call by a neighbor, sheriff's officers arrived on the scene, found the father at the front door attempting to get in, and moved him away from the building for safety. One of the officers attempted to enter, but having determined that it was impossible to enter through the front door, he went to explore other possibilities. In the meantime, the fire department arrived and started extinguishing and rescue operations. The fire department found the bodies of the mother and son on the floor of bedroom 2.

Prior to the fire, the family had returned home around 9 p.m., stayed in the living room until approximately 10 p.m., and then retired to their bedrooms. The 911 call was made by the neighbor who heard screaming at 10:53:38 p.m.

Fire Scene Investigations

Sheriff and fire department investigators performed the origin and cause (O&C) investigation after the fire was controlled and suppressed. They observed the remains of a candle (**Figure 2** and **3**) in the northeast corner of the living room and then talked to the father in the hospital. When the father was asked whether candles were used the previous night, his answer was yes. Based on the fire department report, the origin of the fire was located in the northeast corner of the living room on the lower shelf of a metal & glass end table, and the candle(s) was listed as the cause of ignition.

A private fire O&C investigator, retained and shared by the gas utility and the landlord's insurance companies, performed an investigation the next morning (8/22/2011). The O&C investigator talked to sheriff's department investigators and learned about the candle. He opined that the origin was approximately half of the area comprising the east side of the living room (**Figure 4**). The electrical circuitry/wires and systems of the building were eliminated with the exception of the electrical/electronic components (namely, the remains of TV and stereo equipment) belonging to the tenant, which were found along the east wall of the living room. Though these components were within his origin area, the unattended candle was, in his opinion, the cause (ignition source) for the fire.

This private O&C investigator had collected several items as evidence (**Figure 5** and **Figure 6**). The alleged unattended candle was not saved/preserved by any of the scene investigators.

Figure 2
Origin area of FD.

Figure 3
Unattended candle remains within FD origin.

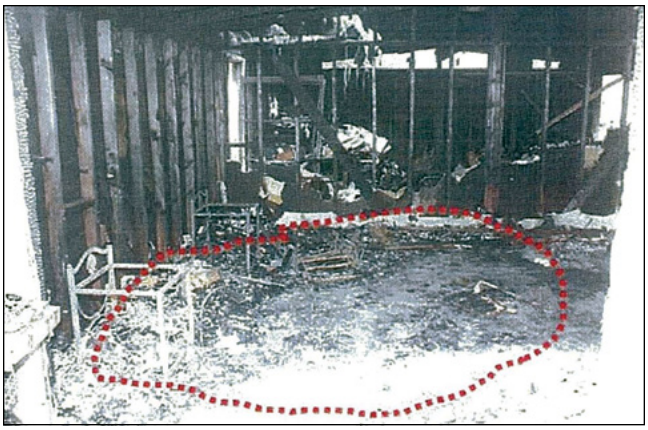


Figure 4
Origin area of private O&C.

Forensic Engineering Analyses

The attorneys representing the tenants (family) provided a brief background to the authors, including reports and photos by the sheriff's department, information collected from the various agencies, and the private O&C report. Later, numerous documents were supplied, including drawings of the home (**Figure 7**), applicable codes from the city/county/state, an invoice

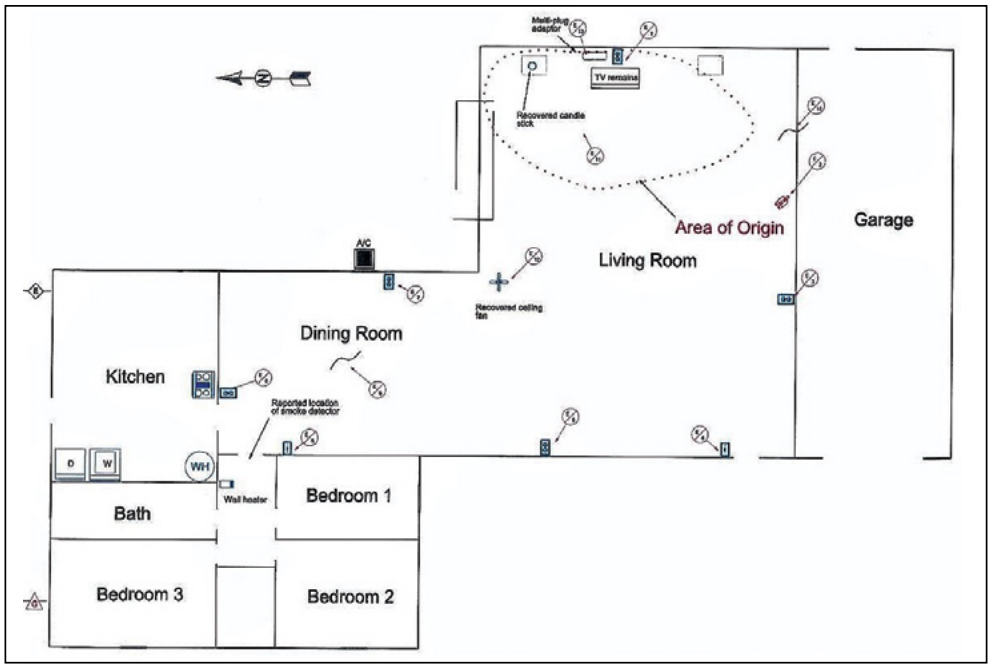


Figure 5
Evidence locations.

1	Outlet	Living Room-East Wall
2	Male Plug	Living Room floor-South Wall
3	Outlet	Living Room-South Wall
4	Switch	Living Room-West Wall
5	Outlet	Living Room-West Wall
6	Switch	Dining Room-West Wall
7	Outlet	Dining Room-East Wall
8	Outlet	Dining Room-North Wall
9	Wiring	Dining Room-Ceiling
10	Unknown Wiring	South Living Room Wall
11	Motor	Living Room Floor
12	Ceiling Fan	Floor of LR/Dining Room
13	Power Cords & Debris	LR Floor-East Wall

Figure 6
Evidence list.

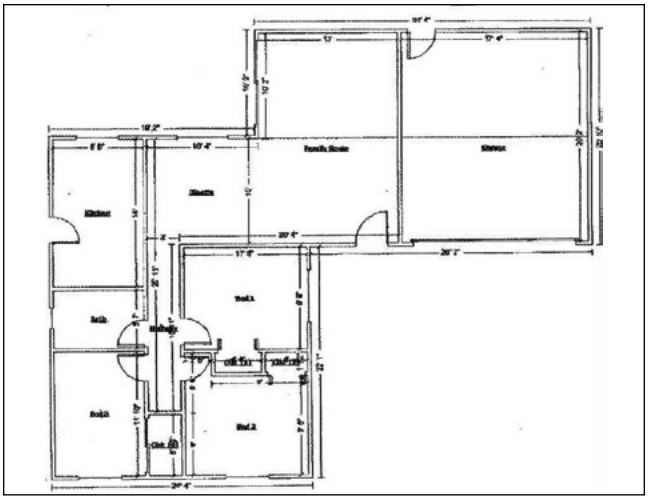


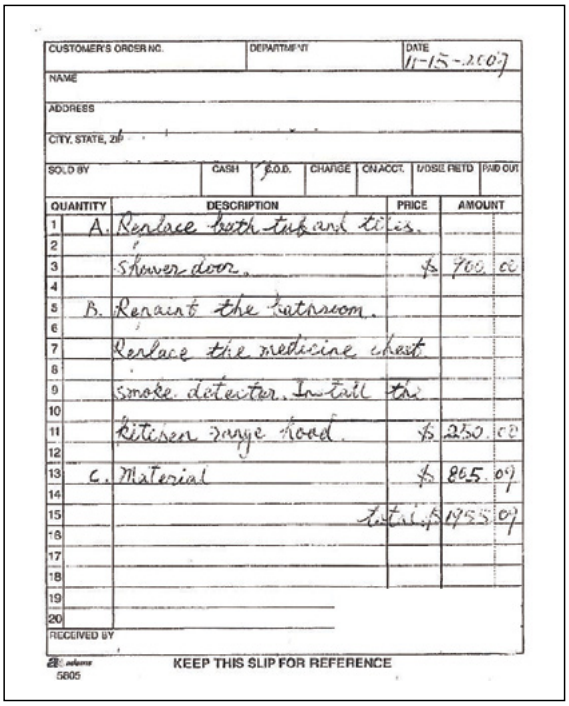
Figure 7
Home floor plan.

from a handyman (**Figure 8**), contents layout (**Figure 9**), pre-fire family photos, pre-fire water flood/loss data, depositions, and files of witnesses, investigators, and experts. Documents and information related to various topics, including physical and combustion properties of materials[1,2,3], flashover[2,4], electrical fires[5,6,7], fuel/material models[8,9], fire dynamics simulation[10,11,12,13], as well as structural elements, were reviewed.

Based upon the review of the information/documents, evidence examinations, and Fire Dynamics Simulator (FDS) modeling, a forensic engineering analysis was performed. The tasks, key observations, findings, and how this knowledge was used in performing the forensic engineering analysis are described in the subsequent sections of this paper.

Disputed Origins and Causes

Four O&C investigations were performed, and the investigators had different opinions (**Figure 10**). The fire department investigator (#1) opined that the origin was in the northeast corner of the living room, and the unattended candle was the cause (ignition source). As mentioned, the first O&C investigator of the landlord


CUSTOMER'S ORDER NO. DEPARTMENT DATE 11-15-2007
NAME
ADDRESS
CITY, STATE, ZIP
SOLD BY | CASH | C.O.D. | CHARGE | ON ACCT. | MDSE RETD | PAID OUT

QUANTITY	DESCRIPTION	PRICE	AMOUNT
1	A. Replace both tub and tile is.		
3	shower door.	$	700 00
5	B. Repaint the bathroom.		
7	Replace the medicine chest		
9	smoke detector. Install the		
11	kitchen range hood.	$	250 00
13	C. Material	$	805 04
15		Total $	1755 04

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KEEP THIS SLIP FOR REFERENCE
5805

Figure 8
Handyman invoice showing smoke detector purchase.

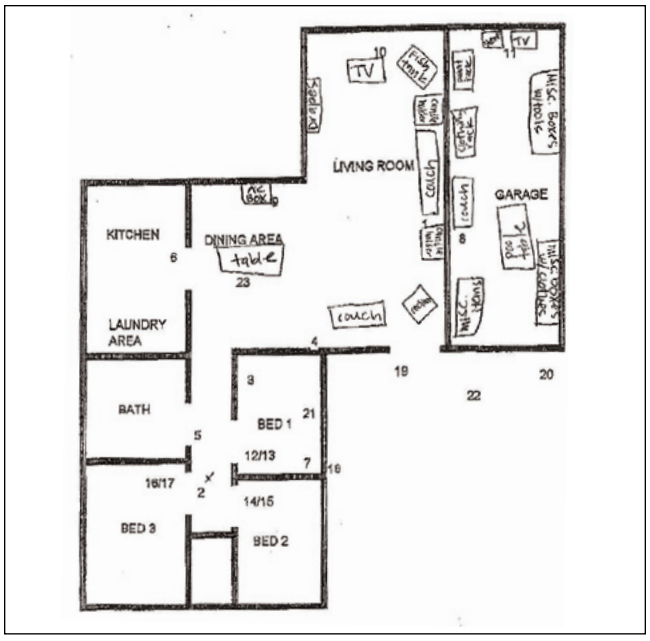


Figure 9
Pre-fire contents in home.

(#2) opined that the area of origin was approximately the east half of the living room, the building electrical system was eliminated, the tenant's electrical and electronic equipment could not be eliminated, and the unattended candle was the cause.

The O&C expert (#3) of the tenant (plaintiff) opined that the origin was in the south wall close to the east

Figure 10
Disputed origins within living room.

end of the couch. He further concluded that electrical failure/heating at the male-female plugs of the extension cords was the cause. The defendant (landlord) retained a second O&C expert (#4), who opined a flashover had occurred in the living room, the origin could not be determined, and the candle on the north wall of the living room above the couch was the cause. His origin was different than scene investigators (#1 and #2), and he stated that his opinions were based upon the review of the family photos and depositions (fire department, plaintiff experts, and family). He did not perform scene investigations nor examine the preserved evidence.

Forensic Engineering Analysis of the Evidence

Thirteen electrical items from the subject home were examined (**Figure 5** and **Figure 6**). For each item, the failure/damage hypothesis was synthesized, and postulates were generated/tested to determine whether an item had an internal failure and produced (or was capable of producing) heat for the ignition of the coterminous fuel.

Each item was photographed and documented, and in some cases macro and microscopic photography was performed. The fire scene photographs were reviewed to assess the fuels, condition, state, and severity of the fire in the locations. Key observations and findings are summarized in **Figure 11**.

Analyses of the microscopic photos of evidence item #10 (**Figure 12** and **13**) and X-rays of evidence item #13 (**Figure 14**), combined with observed failure modes of these items, supported the hypothesis that there were no internal electrical failures within the items (causative of ignition) but that these items were damaged by external exposure to fire. Evidence item

Evidence	Description	Evidence Location	Observation/Findings
1	Remains of a Wall Outlet	LR-East Wall	Plastic box, No ground screw, Old Romex 2-cond/12AWG. All Slots - Open. "Eagle" imprinted on Ground yoke
2	Remains of Male Plug	LR floor-South Wall	Remains of male prong and female slots, evidence of localized damage and fused prong within slot. Conduductor connected to prongs were ~16AWG
3	Remains of Wall Outlet	LR-South Wall	Outlet box was damaged and broken one ground yoke, male prong and a 2-conductor Romex remained ~12AWG
4	Remains of Wall Switch	LR-West Wall	Switch box. Plastic box with metal bracket 4-4AWG, 3 crimped connections pigtails. No parts of a switch
5	Remains of Wall Outlet	LR-West Wall	Plastic box with metal bracket. Two Romexes, 14AWG both
6	Remains of Wall Switch	Dining Room-West Wall	Stranded wires inside box poss dimmer. Resolidified metal. Two sets of conductors all 14AWG
7	Remains of Wall Outlet	Dining Room-East Wall	Remains of wall receptacle two sets of conductors both 12 AWG
8	Remains of Wall Outlet	Dining Room-North Wall	Remains of wall receptacle two sets of conductors both 12 AWG, ground yoke marked "LEVITON"
9	Remains of Electrical Wiring	Dining Room-Ceiling	Remains of wiring in ceiling all 14AWG
10	Remains of building Wiring	South Living Room Wall	Building wiring 14AWG ~2' in length with metal beads on conductors.
11	Remains of Electric Motor	LR Floor	Remains of electric motor with 6 conductors connected to motor
12	Remains of Ceiling Fan	Floor of LR/Dining Room	Remains of ceiling fan motor. No hotspot
13	Remains of Power Cords & Debris	LR Floor-East Wall	Remains of a power tap, metal body and 10 outlets-X-ray no localized damaged.

Figure 11
Summary of evidence examinations.

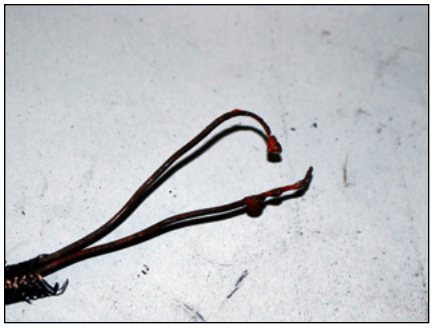


Figure 12
Evidence item #10 melted conductors.

Figure 13
Microscopic view of evidence #10.

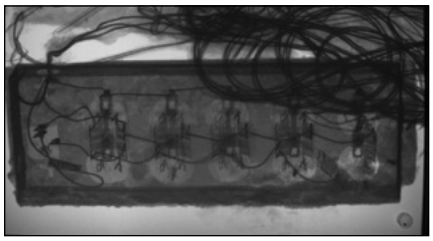


Figure 14
X-Ray evidence item #13 Power-Tap.

Figure 15
Evidence #2 male-female plug remains in the living room.

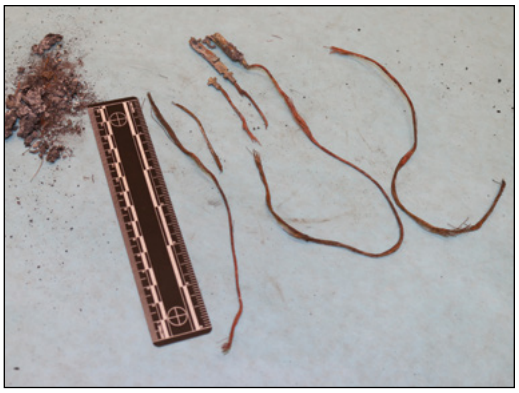


Figure 16
View of male-female plug remains collected.

#2, identified as a male plug from the south wall of the living room (**Figure 15** to **16**), had evidence of localized re-solidified and fused/bonded metal. The examinations determined that these were parts of male and female plugs of extension cords.

The two extension cords were daisy-chained, the failure-mode was localized, and internal melting of the prongs/blades was consistent with electrical resistance heating and faults/arcs (**Figure 17** and **18**). Evidence item #3 shows the remains of the outlet behind the couch in the south wall of the living room (**Figure 19**).

Figure 17
Closer view of male-female prongs.

Figure 18
Microscopic views of male-female prongs.

Figure 19
Evidence #3 outlet from the south wall of living room.

Closer examinations found the witness mark of an arc within the line-side slot of the receptacle (**Figure 20**). This suggested that there was a plug in that receptacle, and a parting arc had occurred when the energized blade was pulled/separated from the receptacle during the fire spread.

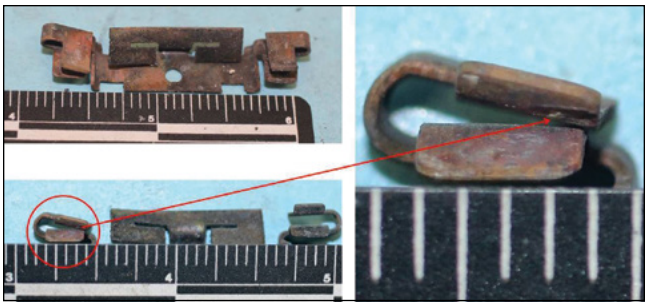


Figure 20
Witness mark of parting arc within evidence #3.

The scene photographs of evidence items #2 and #3 indicated that the male-female plugs were located on the left (east) side of the couch. The wires of the male plug went through the wall toward the garage (**Figure 15**). The wires of the female plug came into the living room and were severed approximately 6 inches from the female blade/slots. The severed wires of the cord went along the floor toward the wall outlet (closest) that was behind the couch. The residents (father and daughter) indicated that there was an extension cord plugged into the outlet that ran on the floor along the wall. The extension cord disappeared into a hole in the wall located next to the satellite TV cable box.

The scene photos of the south wall of the living room and the corresponding areas of the garage were reviewed. The review found a fire damaged orange-colored extension cord in the garage. The cord ran from the garage side of the male-female plugs up to the bottom cord of the main roof beam (north to south; **Figure 21**). The cord wires continued to a damaged junction box that was located approximately in the middle of the roof beam near the garage door opener (GDO). Fire damaged and hanging wires were found downstream of the junction box of the receptacle ("receptacle box") and the remains of the GDO, as shown in **Figure 21** (viewer in living room looking toward garage; north to south) and **Figure 22** (view from front to rear of garage; west to east). The father stated that, on occasion, he had used a stick to push a fallen down extension cord onto nails in the beam. Two nails were found in the main beam in the supplied scene photos.

Engineering analyses determined that the male plug of the short extension cord (A) was plugged into the receptacle (Evidence item #3) behind the couch. The male plug of another extension cord (B) was plugged into the female plug of extension cord (A). The daisy-chained cords went through the wall into the garage, up to the bottom of the roof beam, and ran (north to south)

Figure 21
Trace of extension cords from living room to garage.

Figure 22
View of the trace of cords in garage.

along the side of the beam (supported by nails) and into the receptacle box, where the power cord of the GDO was plugged (**Figure 22**).

The GDO and the daisy chained extension cords were installed around the year 2000 by a person retained by the landlord. The garage was used for storage by the tenants. Various items, such as a pool table, stereo, an old TV, and other items were stored in the garage. There was no pedestrian door between the house and the garage, and the GDO was used for access.

The electrical wires within the wall cavity (upstream of item #3, exposed after the fire origination) and the other collected evidence had no traces of electrical fault(s). The TV and stereo equipment (upstream of item #3 and the same circuit) did not contain any evidence of an internal electrical failure. The evidence of electrical fault/arc was found only at items #3 and #2 (furthest downstream site of arcing).

Information learned from the family indicated there were materials present or stored along the south wall between the couch and the east wall, including an aquarium tank and stand, electrical wires, cables (including the TV/satellite dish cables), plastic junction box of the TV cables, and other items. Analyses of the wall studs by the O&C investigator (#3) determined that there was a "V" pattern (**Figure 21**) on the wall studs, and the apex of the V was at the location where the male-female plugs (evidence item #2) of the extension cords (A to B daisy chain) were found. These and other observations indicated electrical resistance heating had occurred and served as a source of ignition heat for the fire.

Tracing the remains of the electrical circuit wires of the building in the wall cavity found that the circuit originated in the breaker panel of the building and ran along the west wall — and then continued to the outlet on the south wall (last on the circuit). There was also a branch in the south wall upstream of the receptacle that went up approximately 7 feet above the floor and ran to a junction box within the garage. Based upon the review of the photos and the information learned from the tenant, it was concluded that there was a circuit wire for the pull chain-operated light fixture in the garage.

Analyses of the photos of the meter and the breaker panel found that there was no main breaker for the electrical system (**Figure 23**). Furthermore, it was noted that most of the breakers were of the "pushmatic" type, implying that they were 1960s vintage electrical breakers with associated installation. The trace indicated a ganged-pair of circuit breakers were utilized

Figure 23
Meter and circuit-breaker panel for the home.

for the window AC (air conditioning) unit that was located in the dining room area. Scene examinations found that the electrical system of the home was not grounded. The receptacles were of the 3-prong type (ground), but there was no ground conductor wired to the receptacles.

Based upon the examination of the evidence and review of the scene photos, it was determined that the GDO did not have a dedicated circuit — and that it was plugged into the duplex receptacle via two daisy-chained extension cords, which passed through a hole in the south wall of the living room. Further, the specifications of the garage door opener were compared to the measured gauge size of the conductors of the extension cord, and the extension cord conductors were under sized. These and other observations indicated that the garage door opener installation did not meet the National Electrical Code and the International Fire Prevention Code (which prohibit the use of extension-cords as permanent wiring), and the electrical system was inherently unsafe.

Based upon these observations and analysis, it was concluded that electrical resistance heating occurred in the male-female plugs (A-B) of the extension cords, which, over time, progressively damaged the plastic material of the plugs and caused electrical faulting/arcing. This electrical resistance heating and subsequent electrical faulting/arcing was the cause of ignition of the adjacent fuel-material (plastic box, wires, cables, table, wood) which, in turn, spread to the combustible materials in the room as well as into the wall space. This was the most probable ignition and fire origination scenario consistent with the evidence (fire scene and collected evidence items).

The supplied invoice from a handyman (**Figure 8**) listed "smoke detector" as a part for the work, but the handyman couldn't provide any information/details in his deposition. The witnesses stated that there was no annunciation/sound from the smoke detectors. The search by the fire department and the private O&C investigators did not find any remains nor marks (bracket) of the smoke detector. The code requires a smoke detector in all sleeping quarters, hallways, and high-point(s) of the living space. As a part of the forensic engineering analysis of the fire, analyses were performed to determine the egress times for the residents with and without smoke detectors using the Fire Dynamics Simulator.

Fire Dynamics Simulation

Based upon the supplied and reviewed information, a 3D model of the subject single-family home was developed. The building geometry and layout were derived from the supplied drawings and photographs. After the 3D model was developed in the Fire Dynamics Simulator (FDS) program[10,13], it was verified to match the subject building. The combustible materials (fuels), such as the sofas, mattresses, dining table, TV, wood ceiling beams, drywall, and other items, were approximated and placed within the building. The positions of the items and type of items were based upon information and photographs supplied by the tenants. The combustible materials (fuels) placed within the building were mathematically represented based upon the various tests and published data. The electrical wires and the male-female plug were represented using the thermally induced electrical failure (THIEF) cable model within FDS[8].

FDS software includes the two most common residential smoke detector types: ionization and photoelectric detectors. Both smoke detector types were placed in two ceiling locations in the hallway and in each bedroom (**Figure 24**). The sliding door and window glass panes were instrumented in the model with an array of temperature and heat-flux detectors to break the glass at the appropriate conditions. The drywall was instrumented in the model to cause failure of the wall to allow the fire to spread from the living room to the garage. The carbon monoxide (CO), temperature, heat flux, and smoke levels were monitored throughout the interior of the building at various locations.

Figure 24
Hypothetical smoke detector locations.

The mathematical models/representation of the fuels in the FDS were checked, validated, and verified. As needed, fuel models were constructed/synthesized, and the published data were simulated to validate the fuel models. The simulation results were validated by information from witnesses, the timeline, O&C investigators, scene photographs, and physical evidence.

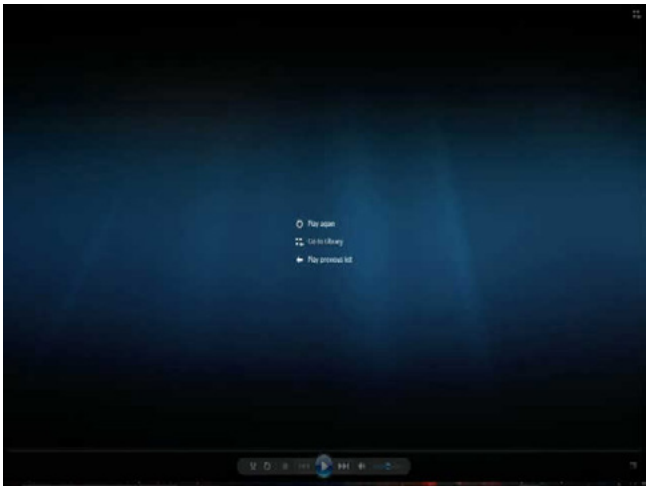
Parametric analyses of the mesh, dynamics of combustion, the door/vent status, and timeline were performed. Based upon these parametric analyses, the optimum grid size, fire dynamics and the timeline were developed.

Three potential origins were analyzed: (1) northeast corner of the living room near the sliding glass door (fire department); (2) origin on top of the sofa (defendant); and (3) origin near the floor level on the side of the couch (plaintiff). For all three analysis scenarios, slow and fast fires (T^2 heat-release rate profiles) were implemented, and the smoke detector activation times, glass breakage times, and severity of the fire (temperature, carbon-monoxide, visibility, and heat-flux levels) were monitored. Seven of the simulations are summarized in **Figure 25**.

Eight different simulations of the fires on top of the sofa (candle fire) and side of the sofa at floor level (male-female plug) with the cords are summarized in **Figure 26**.

Using photographs, fire damage patterns, timeline(s), and witness information, the simulation labeled as Q5 was the best fit and most probable simulation for the subject fire (origin at the south wall of the living room near the east edge of the sofa) per #3 plaintiff investigator. The smoke level, CO (ppm at 2-meter elevation) and temperatures for the smoke detector activation time of 45 seconds are shown in **Figures 27, 28,** and **29**, respectively. The temperature, carbon monoxide and visibility levels, smoke detector activation, and egress times are presented, and the computed values for selected times (slices/snap-shots) are illustrated in **Figures 30** to **32**.

The video of the Q5 FDS simulation for 210 seconds (actual time) is in the attached multi-media file (Q5 Real Time.avi). This video-simulation includes freeze-frame snapshots of parameters for illustration (total run time ~5 min 30 sec).



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FLASH PLAYER MUST BE INSTALLED TO RUN THE VIDEOS.
IT CAN BE DOWNLOADED AT: HTTPS://GET.ADOBE.COM/FLASHPLAYER/

The model for the Q5 simulation (most probable) was modified and updated to determine whether the subject house fire produced fire, flux, and temperatures sufficient to melt the copper conductors of evidence items #2 and #10 and spread/propagate to the garage through the common wall. The modifications included the use of verified THIEF models of cables/wires[8]. FDS

	Wire 1	Wire 2	Wire 3	Wire 4	Wire 5	Wire 6	Wire 7	Wire 8
Model-size	Full	small	small	small	small	small	small	small
Upper wall material	wood	wood	wood	gypsum	gypsum	gypsum	gypsum	gypsum
Fire location	side of couch	on couch	on couch	on couch	on couch	on couch	on couch	on couch-hot surface only
Screen	no	yes	yes	yes	yes	yes	no-replaced w/ wall	yes
screen free area	n/a	0.4	0.1	0.2	0.05	0.2	0.2	0.15
Wire location	S-E corner	L-side of couch	L-side of couch	L-side of couch	L-side of couch	L-side of couch	L-side of couch	L-side of couch
Wire temp (*C)	1040	953	53.6	668	75	756	802	767 at 357sec
Hole in wall at wire	no	no	yes	yes	yes	yes	yes	yes
Vent in upper wall	no	no	yes-wood	yes-gypsum	yes-gypsum	yes-gypsum	yes-gypsum	yes-gypsum
Vent opening time	n/a	n/a	178	364	not open yet	181	282	330
Vent criteria	n/a	n/a	900*C & 60kW/m^2	1100*C & 130kW/m^2	1100*C & 130kW/m^3	900*C & 130kW/m^2	1100*C & 130kW/m^2	1100*C & 130kW/m^4
Slider opening time	163	66	85.8	86.4	not open yet	86.8	85.2	200
Slider criteria	4-dvcs	4-dvcs	4-dvcs	4-dvcs	6-dvcs	4-dvcs	4-dvcs	6-dvcs
Fire Size - HRR (MW	30+	14.5	5.9	14.3	4.3	14.1	16.5	15
Total Time - sec	250	322	184	378	210	400	400	
				crashed	crashed-O2 Constrained			

Figure 25
Summary of wire model features and results.

	Time (s)						
	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Smoke Detector (East end of Hallway)	N/A	N/A	N/A	33.9	34	79.2	42.4
Smoke Detector Heskestad Ionization (West end of Hallway	42.0	42.0	36.6	41.7	41.5	86.4	45.6
Smoke Detector Cleary Ionization I1 (West end of Hallway)	42.6	42.6	37.8	41.7	41.8	87.6	46.4
Smoke Detector Cleary Ionization I2 (West end of Hallway)	43.2	43.2	37.8	42.6	42.5	87.6	46.4
moke Detector Cleary Photoelectric P1 (West end of Hallwa	43.8	43.8	38.4	42.6	42.5	88.2	47.2
moke Detector Cleary Photoelectric P2 (West end of Hallwa	45	45.0	40.2	44.1	44.3	88.8	48.8
Smoke Detector (Bed 2)	N/A	N/A	N/A	56.4	56.3	113.4	57.6
Smoke Detector (Bed 3)	N/A	N/A	N/A	57	56.8	112.2	56.8
Smoke Detector (Bed 1)	N/A	N/A	N/A	200.7	156.3	216	
Slider Breaks	162	162.6	112.8	162.9	163.3	293.4	
Dining Room Window Breaks	186	181.8	256.2	184.5			
CO in Entry Reaches 5000+ ppm	148	150.0	268.2	145	147.8		
Temperature in Entry Reaches 200+ F	100	100.0	85.2	105	105.3		
CO in Kitchen Reaches 5000+ ppm	N/A	158.0	159	155.1	156.3		
Temperature in Kitchen Reaches 200+ F	145	128.0	95.4	125.7	124.8		
CO in Hallway Reaches 5000+ ppm	200	222.0	279.6	177.3			
Temperature in Hallway Reaches 200+ F	145.8	145.8	285	160.8	151		
CO in Bed 1 Reaches 5000+ ppm	188.4	192.0	274.2	213.3			
Temperature in Bed 1 Reaches 200+ F	190.2	195.0	281.4	212.1			
CO in Bed 2 Reaches 5000+ ppm	188.4	190.2	330.6	182.1			
Temperature in Bed 2 Reaches 200+ F	175	156.0	324	162	164		
CO in Bed 3 Reaches 5000+ ppm	193	180.6	N/A	182.1			
Temperature in Bed 3 Reaches 200+ F	223	154.2	324	159.3	162		

Q1 - preliminary FDS model with origin near couch long runtime
Q2 - preliminary FDS model with origin near couch and more output files
Q3 - FDS model with origin near drapes of sliding glass window
Q4 - FDS model with origin near couch with more devices and updated timeline
Q5 - FDS model with origin near couch with updated timeline after depo review
Q6 - Same model as Q5 but changed to slow growth T-squared fire
Q7 - Same as Q3 but changed to slow growth T-squared fire and updated timeline

Figure 26
Summary of results of simulations.

analyses showed that simulation temperatures at item #2 were significantly below the melting temperature of copper, the temperatures at item #10 exceeded this threshold (**Figure 33**), and the fire would burn through the drywall into the garage. These were consistent with the evidence and damage.

Opinions

The electrical wiring system was inherently unsafe, and the electrical circuitry of the garage door opener did not comply with the prevailing electrical and fire codes and standards. In addition, the operation of the garage door opener caused currents greater than the nominal capacity of the wires, and the cyclic electrical resistance heating at the weak link (male plug and female receptacle slot of the extension cords) led to overheating and arcing (catastrophic failure). This internal electrical resistance heating (and the subsequent arcing) was the competent and viable ignition source for the adjacent materials (plastic box, wires, cables, table, wood) and hence the cause of the fire.

FDS analysis showed that the most probable origin and the ignition source/scenario was the male-female plugs of the extension cords of the garage door opener, producing electrical resistance heating, arcing, ignition, and fire.

The results of the FDS analyses were consistent with the physical evidence, including the temperatures at item #2 and at item #10. The analyses also showed fire propagation through the common wall to the garage.

Based upon the most probable simulation, a smoke detector in the hallway would have annunciated between 34 and 45 seconds after ignition-flame/fire originated, depending upon the detector location, and provided approximately 1 minute for egress through the kitchen and front entry doors. The annunciation would have provided approximately 2 minutes for safe egress through the bedroom windows.

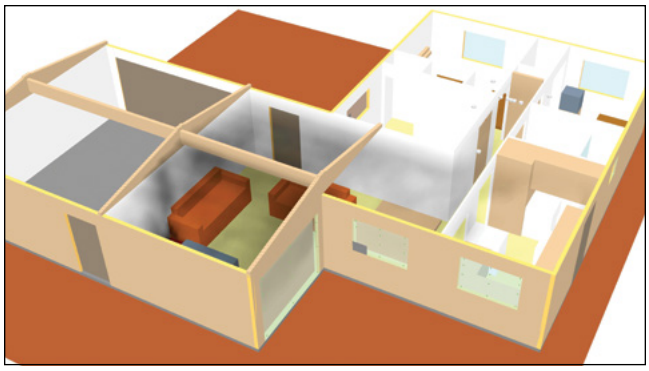

Figure 27
Smoke @ 45 sec.

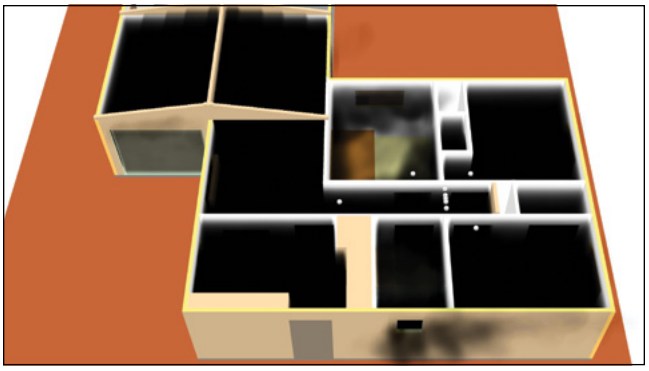

Figure 30
Smoke @ 160 sec.

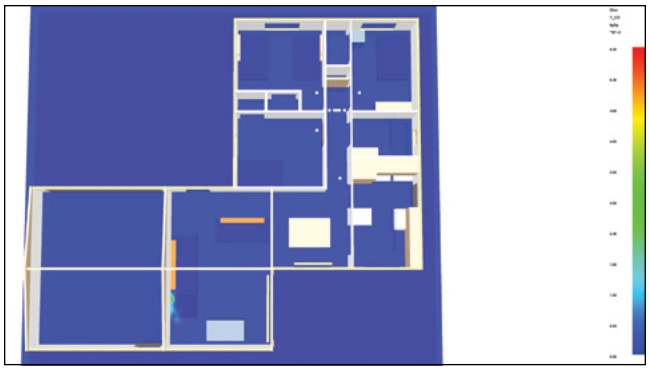

Figure 28
CO @ 45 sec.

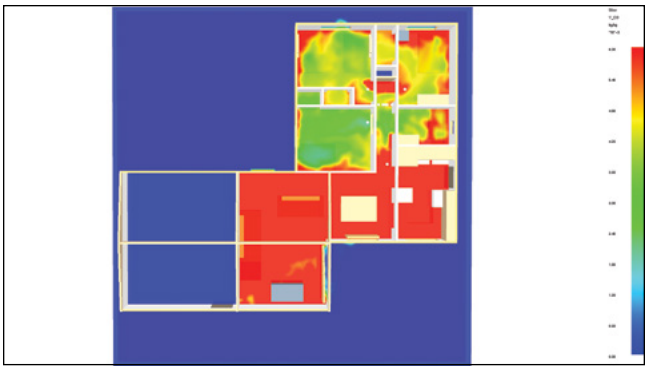

Figure 31
CO @ 182 sec.

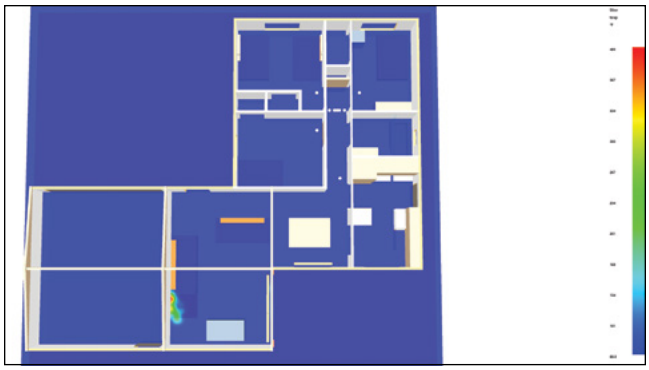

Figure 29
Temps @ 45 sec.

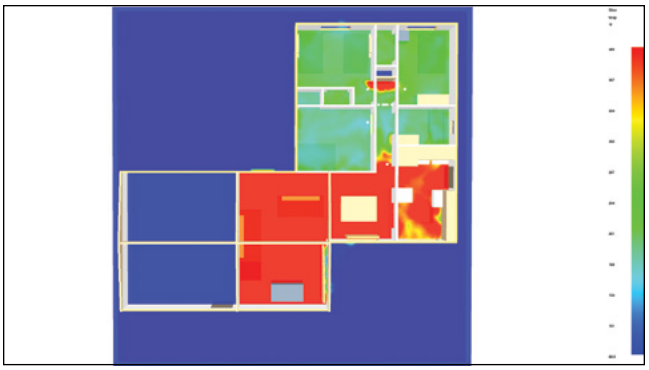

Figure 32
Temp @ 182 sec.

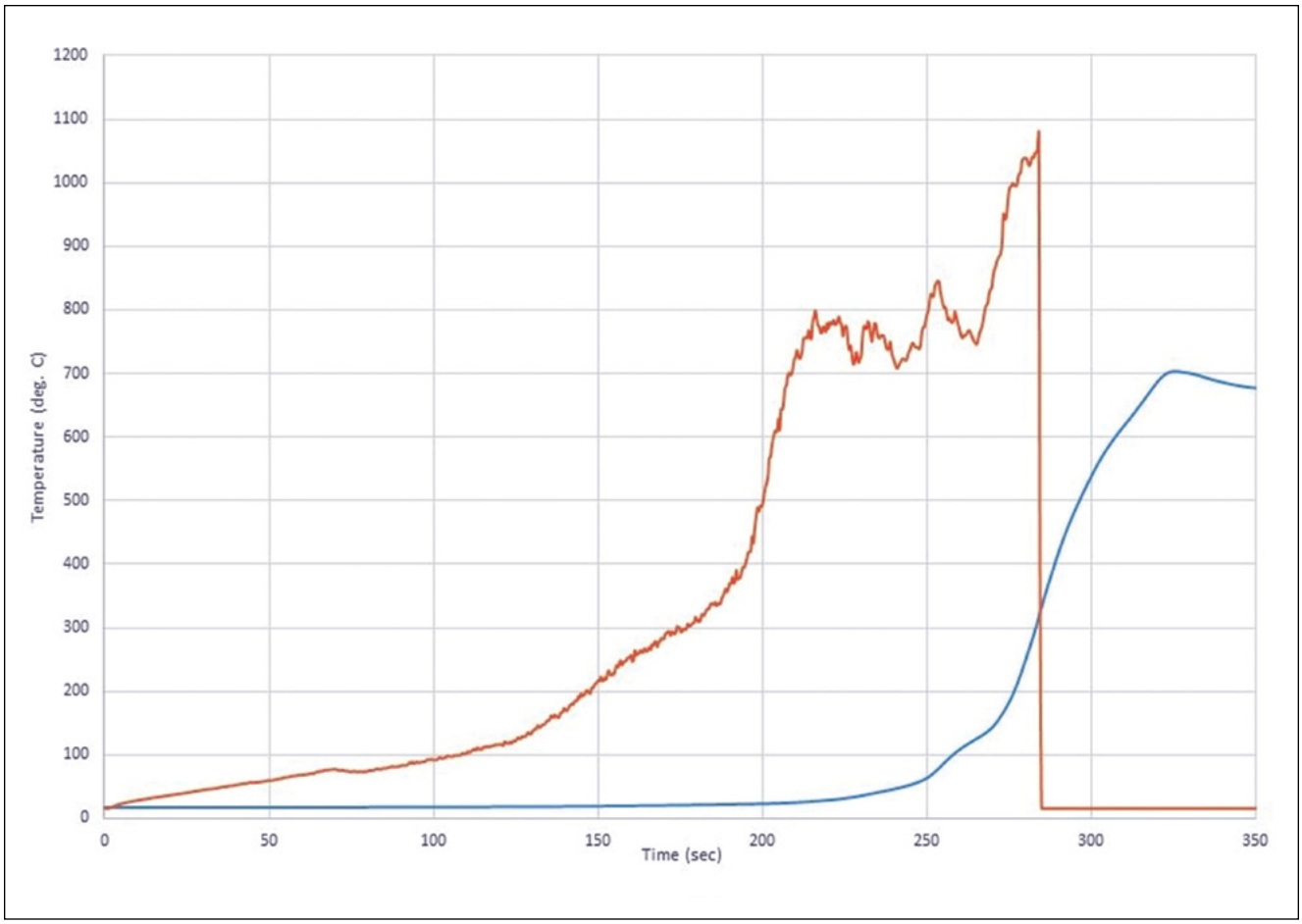

Figure 33
Q5 modified simulation temperatures @ 1-foot and 8-foot (red) elevations south wall.

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