ABSTRACT

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Annual direct property damage for one- and two- family residential fires is estimated as $5.9 billion in the United States. Recent research has suggested that the level of fire hazard in contemporary homes is greater than legacy homes. This study utilizes national fire incident data from 2003 to 2010 to examine trends and characteristics of residential fires. The Item First Ignited and Heat Source for fires are analyzed in a risk model. Structural Member is the Item First Ignited that contributes the greatest amount of risk in one- and two- family houses. The Heat Source for Structural Member is concentrated among three main categories: Operating Equipment, Electrical Arcing, and Hot or Smoldering Objects. Grouping together the items Upholstered Sofas, Mattresses, and Bedding as representing soft furnishings in the house, contribute the second greatest amount of risk. The main Heat Source for these items is Other Open Flame or Smoking Materials.

FIRE HAZARD OF THE CONTEMPORARY AMERICAN HOME

By

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University of Maryland, College Park, in partial fulfillment
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Professor Andre Marshall
Professor Michael Gollner

Dedication

I dedicate this report to my parents, Sandra and Richard Hanson, for it is their love and support throughout my entire education that made this report possible.

Acknowledgements

This research was supported by State Farm. I would like to thank Pat Boyer and John Donovan for their guidance throughout the project.

I would also like to thank Seth Davis for his thorough work on the literature review of this broad topic.

Finally, I want to thank my committee members, Dr. Milke, Dr. Marshall, and Dr. Gollner. It was only with their insight and assistance that this thesis was achievable. I want to especially thank my advisor, Dr. Milke, for his dedication to the project from beginning to end.

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Chapter 1: Introduction

Fires are a major source of losses in the United States. The National Fire Protection Association estimates there were 1,240,000 fires reported in the United States in 2013. These fires caused 3,240 civilian deaths, 15,925 civilian injuries, and $11.5 billion in property damage [1]. Residential fires represent a large proportion of these losses. Home fires account for 74% of reported structure fires, 92% of civilian structure fire deaths, 87% of the civilian structure fire injuries, and 68% of direct structure property losses [2].

Recent research from UL and NIST has suggested that the level of fire hazard in the contemporary home is greater than in older homes. The major factors thought to contribute to the increase in the fire hazard are light frame floor construction, open plan construction, and contemporary furnishings, which reach higher peak heat release rates in shorter times once ignited than older furnishings.

This study looks to utilize national fire incident data to examine any trends and characteristics of residential fires for evidence of an increased risk in contemporary homes, homes constructed in the last few decades. The National Fire Incident Reporting System (NFIRS) is the database used to examine fire incident data. NFIRS is a database containing a large fraction of reported fires but does not include every fire reported to a fire department nor is it a random sample of fire incidents. Although it is not a random sample or contains the entire population of reported fires, it is the best available database and still contains some of the characteristics of a random sample [3].

NFIRS is a voluntary system for fire departments to report incidents they respond to in their area. Fire departments from all 50 states and the District of Columbia report data to NFIRS. The NFIRS database contains about 75% of all reported fires that occur annually [4]. This study concentrates on the fuel and heat source of the fires due to the well-defined fields of NFIRS in these areas.

Chapter 2: Literature Review

The traditional residential home in the United States has undergone many changes over the past few decades including changes in its size, geometry, contents, and construction materials. These changes have had a significant effect on increasing the fire load and hazard within the home.

2.1 Changes in Residential Building Design

Changing building materials for residences is affecting the fire hazard in residences. Structural components used to be made from solid old and new growth lumber. More recently, I-joists, trusses and other components are made from engineered lumber. As of 2005, 46% of residential houses are being constructed with engineered I-joists, 15% with wood trusses, and 39% with lumber joists [5]. In 2008, UL completed a study about the difference of load bearing capacity during fire conditions of engineered lumber versus solid old growth lumber. The engineered I-joist floor collapsed in 6 minutes, while traditional lumber collapsed in 18 minutes and 30 seconds [6]. In the same study, truss floors were tested with a gypsum wallboard protective layer, and they failed in less than 30 minutes, compared to the lumber which failed in about 45 minutes. The average response time for fire departments is about 6 minutes, which does not include the time for detection of the fire, relay of the information from the 911 operator to the fire department, or time of the firefighters setting up their operation [5]. Any decrease in time to collapse greatly increases the chances for collapse before firefighters can control the fire.

Another building material change consists of the wall linings. Plaster and lath linings have been replaced by unrated gypsum wallboard [5]. UL has conducted several experiments of the different wall linings and found that gypsum wallboard exceeded the deflection criteria of L/240 at 35 minutes, while the plaster and lath exceeded the criteria at 75 minutes. Excessive deflection leads to structural failure. The gypsum wallboard membrane was breached at 23 minutes during the test while the plaster and lath was breached around 74 minutes [6]. It was observed that the gypsum wallboard failed at the seams as it shrank, exposing a gap, while the plaster and lath did not have seams. When the gypsum fails, it allows heat to enter the wall space, which in turn ignites the structural components of the building more readily.

The size of homes has also increased appreciably. In 1973, the average area of a house was 1,600 ft^2. In 2008, the average size of a house was estimated to be 2,500 ft^2 [5]. In addition, 26% of all houses built in 2008 were greater than 3000 ft^2. The increasing size of the average U.S. homes taken over the past few decades is shown in Figure 2.1. With the increased area there is a greater potential for a larger fire.

Along with larger houses, housing lot sizes have decreased. In 1976, the average lot size was 10,100 square feet but in 2008 the average was down to 8,800 square feet [7]. Smaller lots and larger houses increase the likelihood of a fire spreading from one house to another because homes are closer together.

In addition, the increased area leads to a commensurate increase in volume, providing more air for the fire. This is significant as Kerber noted that with the fuel load present in residences, fires can quickly become ventilation limited [5]. Having additional air permits the fire to burn with a greater heat release rate for a longer period of time before becoming ventilation limited.

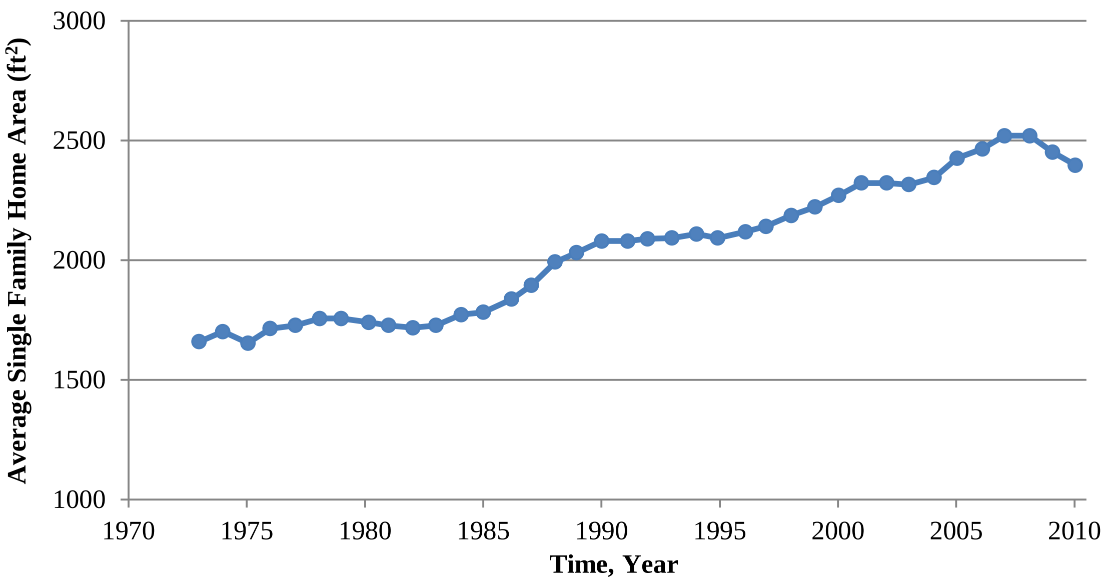


Figure 2.1: Increase in Average Size of Single Family House (1973-2010) [5]

The architectural layout of contemporary homes has also changed. New features include more open spaces such as great rooms, foyers, tall ceilings; overall floor plans are more open [5]. These features remove compartmentation which could otherwise provide a modest ability to reduce fire spread, even if the compartmentation is not fire resistance rated.

2.2 Residential Furnishings

There is a significant interest in the flammability of soft furnishings in residences due to their large contributions to the number of fire deaths in residences. Four percent of home fires occur in living rooms but account for 24% of home fire deaths. Eight percent of home fires occur in the bedroom but account for 25% of home fire deaths [8]. Soft furnishings, such as upholstered furniture and beds, ignite easily and have enough combustible mass to sustain a large fire.

Homes are dominated by the use of synthetic materials in upholstered furniture, mattresses, and other furnishings. The synthetic materials produce much faster growing fires than traditional (natural) materials. Considering the common fuels found in residential fires, it is observed that there are cooking materials, clothing, cased goods, flooring, textile products, and soft furnishings. The principal fuel load item in the residence includes soft furnishings. These can be ignited relatively easily, are fast burning, and have a high combustible mass [2]. According to Gann, soft furnishings are the major amplifiers of ignition sources in residences and improved flammability standards for upholstered furniture have the potential to greatly reduce fire loss [2]. He maintains that the contribution of upholstered furniture to fire losses is underestimated and it can be regulated successfully, such as in California [2]. Research from Gann and Ohlemiller has estimated the reduced fire risk from an improved mattress flammability standard, and suggest that a very significant reduction in fire risk could be achieved with stricter designs [9].

In 2008, NIST conducted a study to review the performance of smoke detectors which included temperature measurements at various heights in the room of fire origin. The room of origin was a bedroom, and the fire was started on the mattress. A similar study had been conducted in 1975, where similar measurements and test conditions were followed. In the 1975 study it took 970 ± 530 sec for the temperature to reach 65 °C at the burn room ceiling [10]. This is the temperature around which damage will begin to occur due to heat. In the recent study it only took 131 ± 40 sec to reach the same value of 65 °C at the burn room ceiling. This is a significant difference in fire growth times, and the soft furnishings being ignited had a dramatic effect on the fire growth. The study determined smoke detectors still provided enough warning for occupants but the amount of time is considerably less in the new study. The average time to untenable conditions for flaming tests was 3 minutes for the 2008 study compared to 17 minutes for the 1975 study [10]. These studies attempted to use a representative sample of important furnishings available on the market, but clearly did not cover the entire market. This study points to an increased fire risk from modern furnishings.

In 2009, Underwriter's Laboratory conducted a series of tests to examine the time to flashover in a room using modern furnishings compared to those used decades ago in a "mid twentieth century" house. It was a side-by-side comparison, and both rooms had nearly identical types, amounts, and placement of furnishings. Materials for furnishings in the modern room were predominantly synthetic contents readily found at various retail outlets. For example, a few of the items in the modern room were a polyester microfiber covered polyurethane foam filled sectional sofa (the location of fire ignition), a polyester throw, and a lamp with a polyester shade on top of it. The room also had polyester curtains hanging from the wall which was comprised of gypsum wallboard. The "legacy" room used contents that were found from various second hand outlets. Instead of a synthetic couch, a cotton-covered, cotton batting filled sectional sofa was used with a cotton throw placed on it. Cotton curtains were hung from the wall comprised of painted cement board [5].

The differences in the results from the tests were significant. It was found that the modern room transitioned to flashover in 3 minutes and 30 seconds; however, the legacy room took 29 minutes and 30 seconds to transition to flashover [5].

From a more objective and quantifiable point of view, the heat release rates of the two rooms were measured during the test and are presented in Figure 2.2. The peak heat release rate of the modern room (experiment 3) of 7,000 kW occurs at about 500 sec from ignition, nominally coincident with the transition to flashover. In contrast, in the legacy room (experiment 4), the heat release rate remains at a modest heat release rate for about 2,000 sec, subsequently reaching a peak heat release rate of 6,000 kW and then transitioning to flashover.

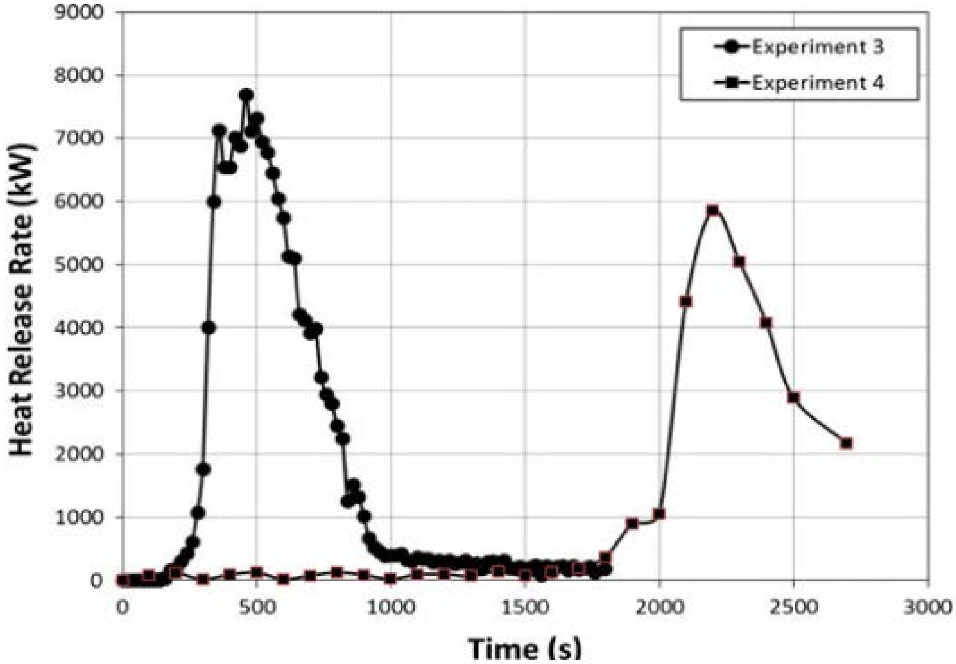


Figure 2.2: Heat Release Rate Curves from UL Furnishings Test [5]

Considering these tests results to be representative, fires in residential houses are growing faster and are transitioning to flashover much more quickly than before. This has many implications for combatting the fire problem. With the increased speed of growth, a room is likely to already be flashed over when the fire department arrives. As such, this problem can be mitigated only via a reduction in the combustibility of furnishings or a quicker attempt at suppression such as from automatic sprinklers installed in the residence.

UL also conducted research to determine possible ways to reduce the fire risk from upholstered furniture exposed to small open flames. Flame retardant foam used to meet the requirements of California TB 117 was examined along with commercially available high-loft barriers and flat fire barriers. The fire growth behavior of the TB 117 flame retardant treated foam was similar to that of the untreated polyurethane foam. Both foams had a rapidly growing fire with high peak heat release rates. The TB 117 foam only had a 15% reduction in average peak heat release rate for when ignited on the corner of the upholstered furniture. However, when the untreated polyurethane foam included a high loft fire barrier the fire growth was delayed and the average peak heat release rate was reduced by 70%. When a flat fire barrier was added along with a high loft barrier the fire growth was further delayed or there was only limited burning depending on the location of ignition. The average peak heat release rate when the cushion was ignited was reduced by 85%. UL's research shows there are plausible options to reduce the fire risk of upholstered furniture exposed to small open flames [11].

Many of the furnishings focused on in other experiments are under the jurisdiction of the Consumer Product Safety Commission (CPSC). There are many regulations that focus on these furnishings and more that are being considered. In 1972, regulation 16 CFR 1632 required mattresses to pass smoldering ignition tests. The mattress must not allow char to extend more than two inches from a lit cigarette [12]. This is designed to decrease the risk from a cigarette starting a fire on a mattress, which is one of the leading scenarios associated with fire deaths. In 2005, regulation 16 CFR 1633 required all new mattresses to have a maximum heat release rate of 200 kW during a 30 minute test and cannot exceed a total heat release rate of 15 MJ during the first 10 minutes of the test [13]. This regulation is designed to allow the occupants more time to escape a fire and decrease the available fuel load of a possible fire. In 2005, the CPSC issued an Advanced Notice of Proposed Rulemaking for a standard to address the open flame ignition of bedclothes.

Bedclothes are often involved with mattress fires as either an ignition source for the mattress or adding to the fire load of a mattress fire [14]. There has been no further development of this regulation as of 2012 due to resource constraints [15].

In 2008, the CPSC published a Notice of Proposed Rulemaking for 16 CFR part 1634, Standard for the Flammability of Residential Upholstered Furniture [16]. This regulation looks to reduce the risk of smoldering fires in upholstered furniture due to the high number of fire deaths from these fires. There are two possible ways to meet the standard. Type I furniture uses upholstery cover material that meets smoldering ignition resistance criteria. Type II furniture uses an interior fire barrier that complies with smoldering and small open flame ignition criteria. This allows manufacturers to use what would be considered unacceptable cover fabrics for Type I furniture but still decrease the risk from fires. This proposed regulation also tries to reduce the need for flame retardant chemicals due to their possible health hazards. Many comments from fire safety organizations pushed for both smoldering and open flame regulations. The CPSC stated that only about 10% of addressable fire deaths from upholstered furniture are attributable to open flame ignited fires [16]. There is evidence that the damage from upholstered furniture in fires is underestimated as the contribution of upholstered furniture as the primary fuel but not the first item ignited is difficult to capture [3]. As a primary fuel, but not the first item ignited, the mode of ignition will be open flame.

2.3 Fire Protection Systems

Smoke detectors have been credited with decreasing the number of fire deaths by about half since 1975. Three out of five home fire deaths resulted from fires in which no smoke alarms were present, or in which smoke alarms were present but did not operate [17]. Without smoke alarms, fire department notification is dependent upon occupant awareness of the fire. Smoke alarms were not present in 23 percent of the larger, non-confined fires in occupied residential houses [17]. If a fire death occurs in a home, it is likely that the occupants were either not aware or were notified too late in the fire's growth for escape.

Smoke alarm data for non-confined fires is shown in Table 2.1. It can be seen that smoke alarms are alerting occupants, if they operate. It is reported that in only 6% of cases did the smoke alarm fail to operate. In roughly 25% of non-confined fires the smoke alarms operated, and in only 0.7% of the incidents did the smoke alarms fail to alert occupants. The average alarm times for current smoke detectors, if properly placed, was measured and tested by NIST to be 47 ± 35 seconds for flaming fires [10].

Table 2.1 Smoke Alarm Data for Non-confined Fires in Residential Houses [17]

Presence of Smoke Alarms	Smoke Alarm Operational Status	Smoke Alarm Effectiveness	Count	Percent
Present	Fire too small to activate smoke alarm		13,891	5.4
	Smoke alarm operated	Smoke alarm alerted occupants, occupants responded	45,627	17.8
		Smoke alarm alerted occupants, occupants failed to respond	1,635	0.6
		No occupants	8,694	3.4
		Smoke alarm failed to alert occupants	1,916	0.7
		Undetermined	6,736	2.6
	Smoke alarm failed to operate		15,125	5.9
	Undetermined		19,046	7.4
None Present			59,540	23.3
Undetermined			83,473	32.6
Total Incidents			255,683	100.0

Automatic sprinklers are installed in a small proportion of residences, but are becoming a more popular means to decrease the risk from fire. Hall has conducted an extensive analysis of the performance and reliability of sprinklers based on NFIRS date and surveys by NFPA. Fire sprinklers reduce the cost of loss. In 2007-2011, 6% of reported home structure fires indicated there was a type of sprinkler present. In this report “home” includes single family homes as well as multifamily residences, such as apartments. The deaths per thousand reported fires rate was 82% lower when wet pipe sprinklers were present in homes. It is estimated that sprinklers reduce property damage in homes per fire by 68%. The damage per fire to a home (including apartments) is $20,000 without wet pipe sprinklers installed, but is reduced to $7,000 per home fire with wet pipe sprinklers [18]. Sprinklers have been found to be reliable and effective. For all reported properties, not just residential houses, the following statements can be made:

- For fires large enough to activate them, sprinklers operated in 91% of fires in sprinklered properties.
- For fires large enough to activate them, sprinklers operated and were effective in 87% of fires in sprinklered properties.
- Wet-pipe sprinklers operated and were effective in 89% of fires vs. 76% for dry-pipe sprinklers [18].

When sprinklers failed to operate, the most common reason given is that the system was shut off before the fire. The other reasons are shown in Figure 2.3.

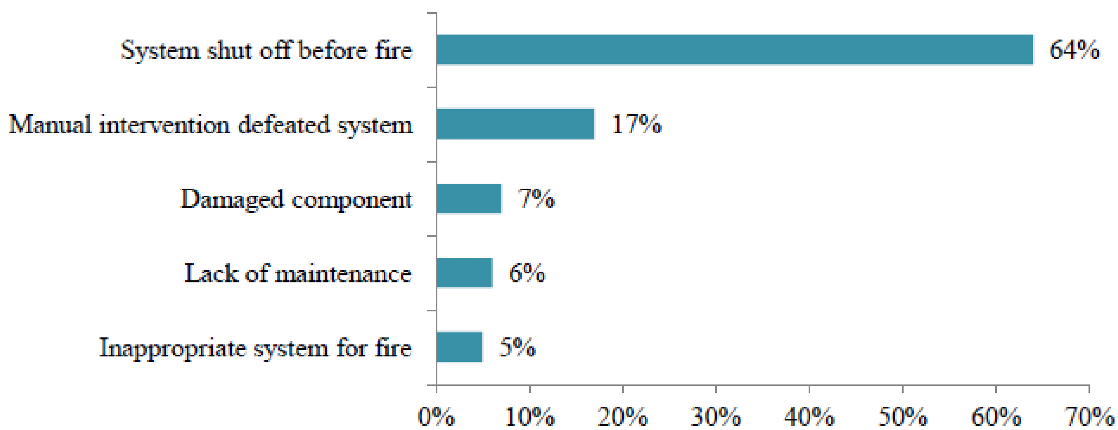


Figure 2.3: Reasons When Sprinklers Fail to Operate [18]

In 4% of fires, sprinklers operated but were ineffective. The most common reasons for this are that the water did not reach the fire, or not enough water was released to effectively suppress the fire. The remaining reasons are shown in Figure 2.4.

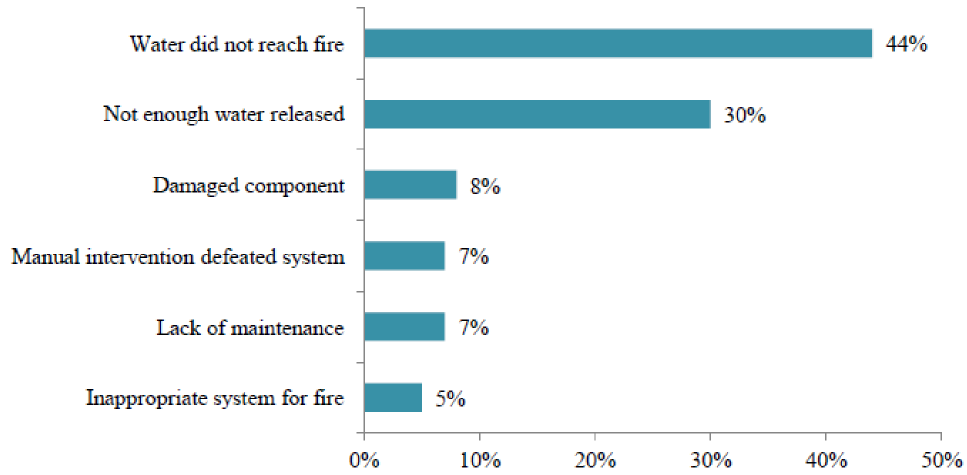


Figure 2.4: Reasons When Sprinklers are Ineffective [18]

The leading areas of origin in residential houses, when sprinklers failed or were ineffective due to not being the in fire area, are given in Table 2.2. This data excludes buildings under construction. The leading areas are attics, balconies and wall assemblies or concealed spaces.

Table 2.2. Leading Areas of Origin for Fires in Residential Houses in Which Sprinklers Failed or were Ineffective Because They Were Not in the Fire Area [18]

Area of Origin	Percent of Fires Where Wet-Pipe Sprinklers Were Present But not Present in Fire Area	Percent of All Fires
Attic or concealed space above top story	13%	4%
Exterior balcony or unenclosed porch	11%	2%
Wall assembly or concealed space	9%	5%
Garage	8%	0%
Exterior roof surface	7%	0%
Laundry room or area	4%	1%
Exterior wall surface	4%	18%
Kitchen	3%	3%
Unclassified structural area	3%	
Other area of origin	38%	62%
Total	100%	100%

2.4 Fire Incident Data

Fire losses for residential houses are significant. The National Fire Protection Association (NFPA) estimates that in recent years, fire departments in the U.S. respond to an average of 260,000 residential house fires per year. Annual direct property damage for these residential fires is estimated as $5.9 billion [19]. These estimates are based on data from the National Fire Incident Reporting System (NFIRS) and NFPA's annual fire department experience survey and include only those only those fires which are reported to U.S. fire departments.

The leading cause of fires in homes estimated by the United States Fire Administration is cooking, which comprises 33 percent of all fires. However, nearly all (91 percent) of the cooking fires were small, confined fires [17]. The remaining causes are summarized in Table 2.3.

Table 2.3. Leading Causes of Residential House Fires [17]

Cause	Percent (Unknowns Apportioned)
Cooking	32.9
Heating	17.0
Electrical malfunction	9.6
Other unintentional, careless	8.3
Open flame	5.7
Intentional	5.6

The extent of fire spread in residences from 2009-2011 is shown in Figure 2.5. Notable in this data is that the biggest category of fires (48%) is limited to the object of origin. A typical scenario for a confined fire would be a heated pan of oil that was left unattended on the stove and caught fire. The next largest category of fires is those which are limited to the room of origin (20%). As such, 68% of all fires are limited to the room of origin or less.

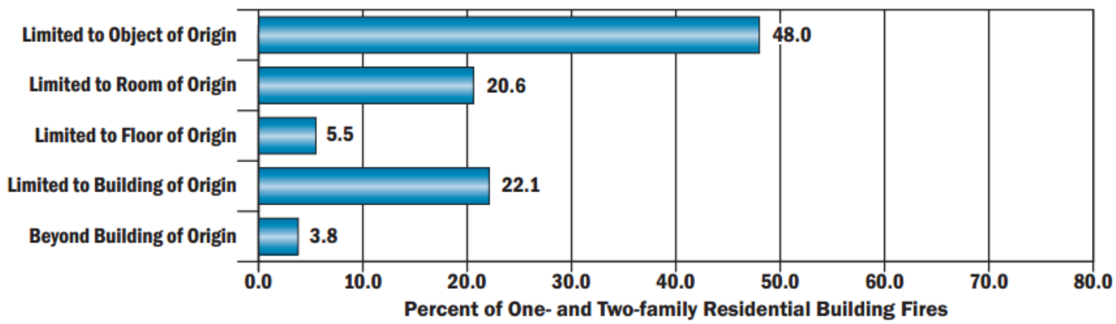


Figure 2.5: Extent of Fire Spread in Residential Houses [17]

Since many of these fires are small and confined, a better insight at what is causing large fire losses is to examine the non-confined fires, i.e. fires that are not contained by a pot, stove, or other container. The loss measures for confined and non-confined residential home fires are listed in Table 2.4. Average direct property loss per fire in non-confined fires is more than 100 times greater than for confined fires.

Table 2.4 Loss Measures for Residential House Fires [17]

	All Residential House Fires	Confined Residential House Fires	Non-Confined Residential House Fires
Average dollar loss/fire	$17,460	$220	$28,060

The leading causes of the non-confined fires are: unintentional (17%); electrical malfunctions (16%); intentional (12%); and open flame (11%). The leading areas of fire origin in non-confined residential house fires are shown in Table 2.4 [17]. By combining the leading causes and areas, the greatest losses in residential houses are unintentional and careless actions or electrical malfunctions in the kitchen or bedroom.

Table 2.5 Leading Areas of Fire Origin in Non-confined House Fires [17]

Areas of Fire Origin	Percent (Unknowns Apportioned)
Cooking area, kitchen	19.0
Bedrooms	13.2
Common room, den, family room, living room, lounge	6.6
Attic, vacant spaces	5.8
Exterior wall surface	5.2
Laundry Area	5.0
Vehicle storage area: garage carport	4.8

The extent of fire spread for only non-confined fires is presented in Figure 2.6. From the data, 48% of all fires are limited to the object or room of origin and though 36% extend to the entire building. As such, if a fire extends beyond the room of origin, involvement of most of the building is likely, which is a reflection of construction practices in one- and two-family homes where there are no fire barriers to separate spaces.

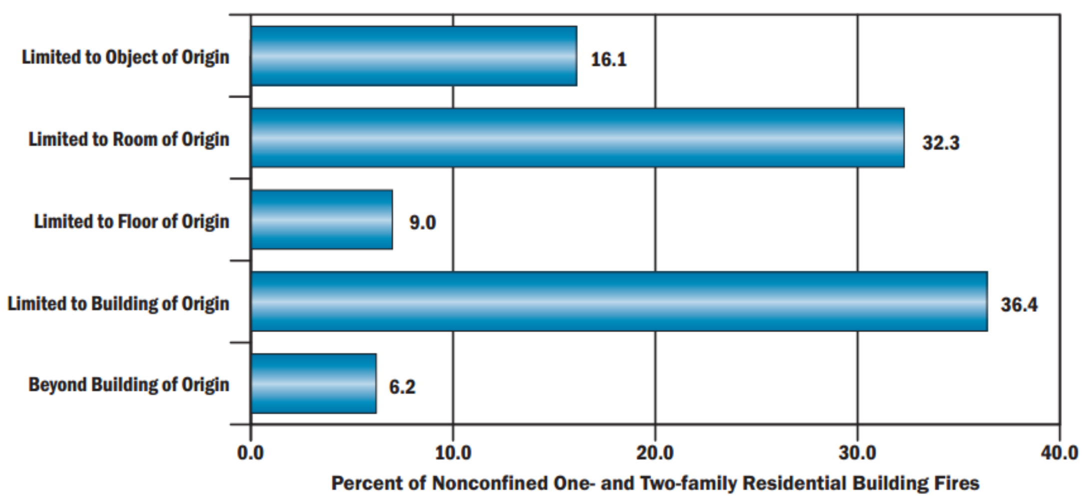


Figure 2.6: Extent of Fire Spread in Non-confined Residential House Fires [17]

Chapter 3: Risk Model Development

Risk is defined as "the potential for realization of unwanted, adverse consequences to human life, health, property, or the environment. Estimation of risk is usually based on the expected value of the conditional probability of the event occurring times the consequence of the event given that it has occurred" [20]. Typically, risk is calculated by equation 3.1.

$$\text{Risk} = \text{Probability} \times \text{Consequence} \tag{3.1}$$

A risk model attempts to define the probability and consequence of an event occurring. In this study, fire incident data is used to determine probability and consequence of selected parameters in residential fires in order to determine their relative contribution to the overall residential fire risk.

After responding to an incident, fire department personnel complete one or more of the NFIRS modules. The fire service uses their best judgment in completing the forms, answers are not necessarily based on a detailed analysis. There are eleven modules in the most recent version of NFIRS. The Basic Module is completed for every incident and includes general information on the incident. Only two other modules were utilized in this analysis, the Fire Module and the Structure Fire Module. The Fire Module describes each fire incident and the Structure Fire Module is used in conjunction with the Fire Module to describe each structural fire incident.

The scope of this project is to examine fire incidents in residential properties, specifically one- and two-family residential buildings. Microsoft Access is used to manipulate and organize the data. The Property Use and Incident Type fields in the Basic Module are set to only examine fire incidents in one- and two- family residential buildings. The Structure Type and Building Status fields in the Structure Module are also set to only show fires involving structures that are an “enclosed building” or a “portable/mobile structure” and either “occupied & operating” or “idle, not routinely used.” These requirements allow for only incidents that match the scope of the project to be analyzed.

For this analysis, data from 2003 to 2010 is used. Each fire incident is defined by five fields from NFIRS:

1. Area of Origin
2. Presence of Detectors
3. Fire Spread
4. Item First Ignited
5. Heat Source

The risk model used is illustrated in Figures 3.1 and 3.2.

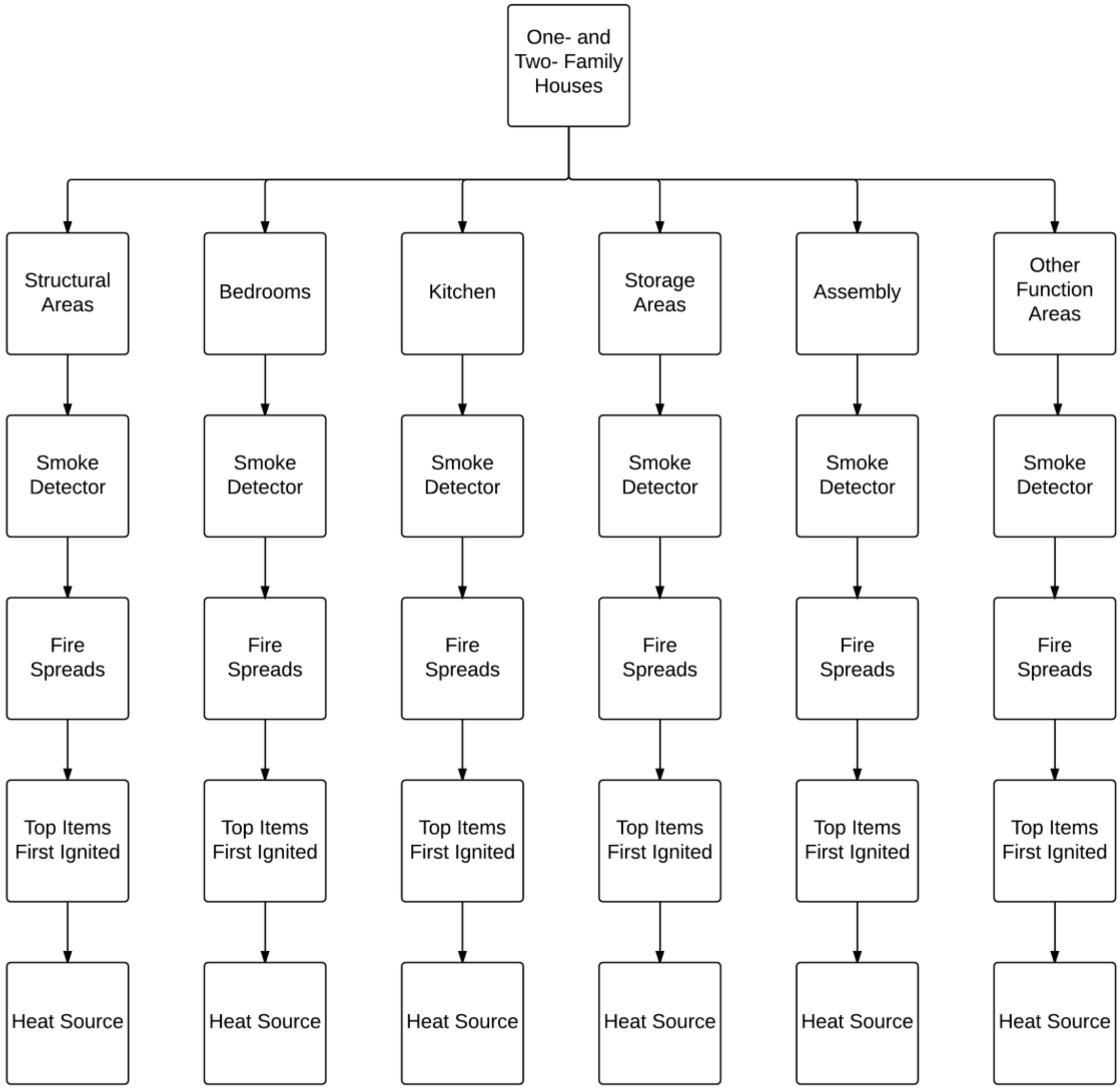


Figure 3.1: Overview of Risk Model

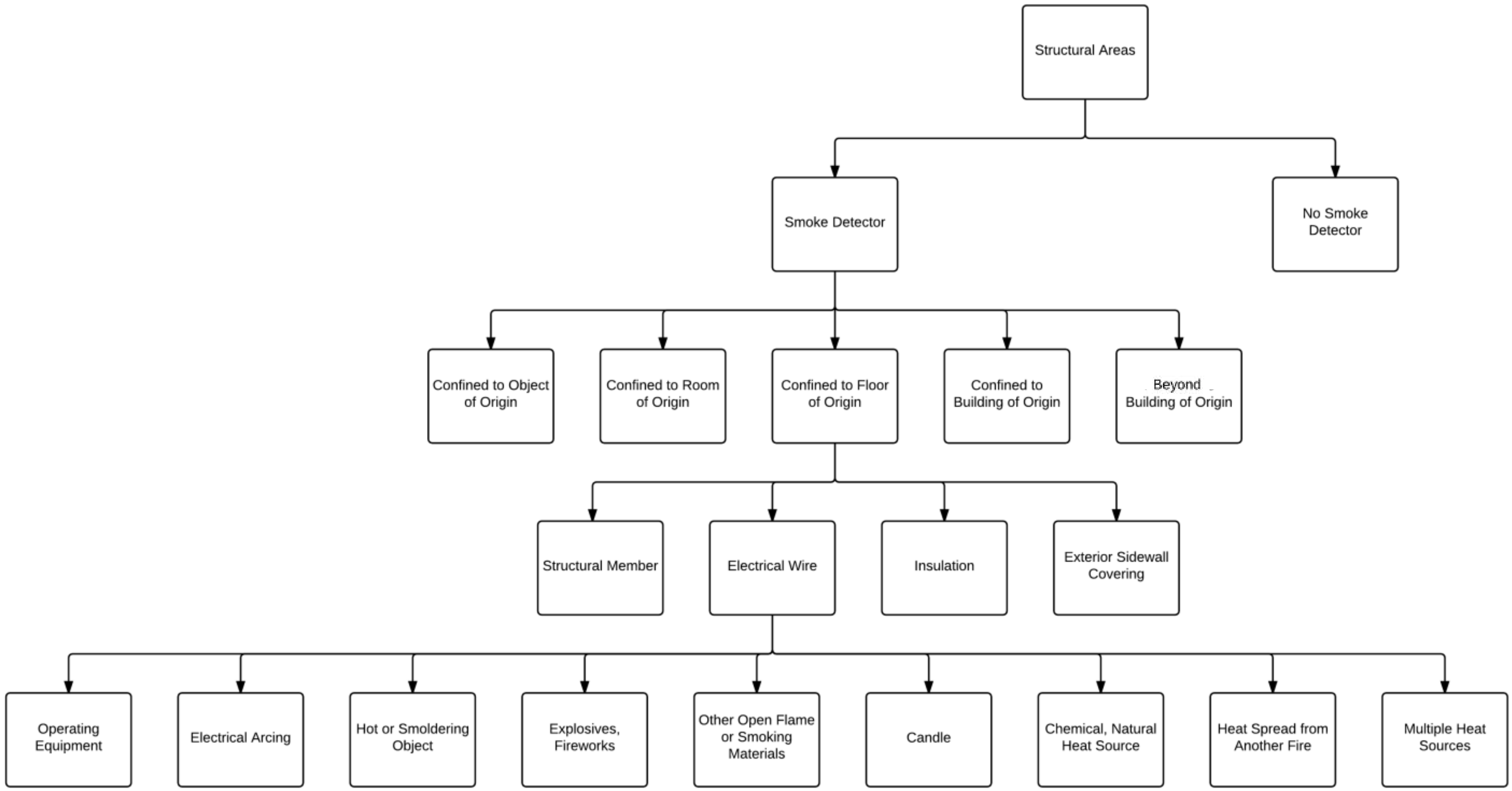


Figure 3.2: Structural Areas Portion of Risk Model

3.1 Area of Origin

The Area of Origin field from the Fire Module is defined as “the primary use of the area where the fire started within the property. The area of origin may be a room, portion of a room, a vehicle, a portion of a vehicle, or an open area devoted to a specific use. Every fire has an area of fire origin” [21]. There are 82 possible Area of Origin entries, separated into twelve categories. The full list of possible entries is tabulated in Appendix A. The distribution of the twelve categories of Area of Origin is shown in Figure 3.3. Six of these categories are not included in the analysis due to their low frequency of occurrence. The categories analyzed are Assembly, Bedrooms, Kitchen, Other Function Areas, Storage Areas, and Structural Areas, which collectively cover 88.9% of all fire incidents meeting the base requirements.

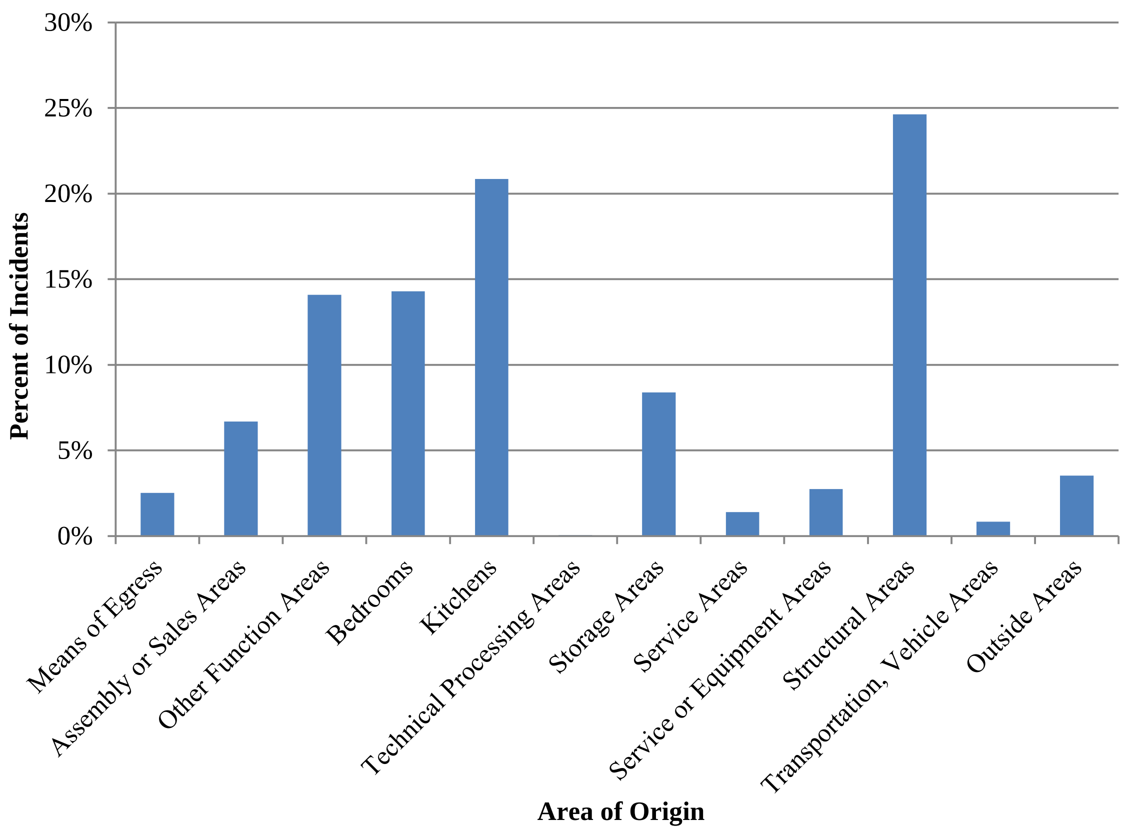


Figure 3.3: Distribution of Area of Origin

3.2 Presence of Detectors

The Presence of Detectors field is from the Structure Fire Module and is defined as "the existence of fire detection equipment within its designed range of the fire" [21]. Incidents with or without detectors are examined. Only smoke and combination smoke and heat detectors are examined. The probability of a smoke detector being present is dependent upon the Area of Origin. The differences in proportion of smoke detector presence among the six Area of Origins are shown in Figure 3.4.

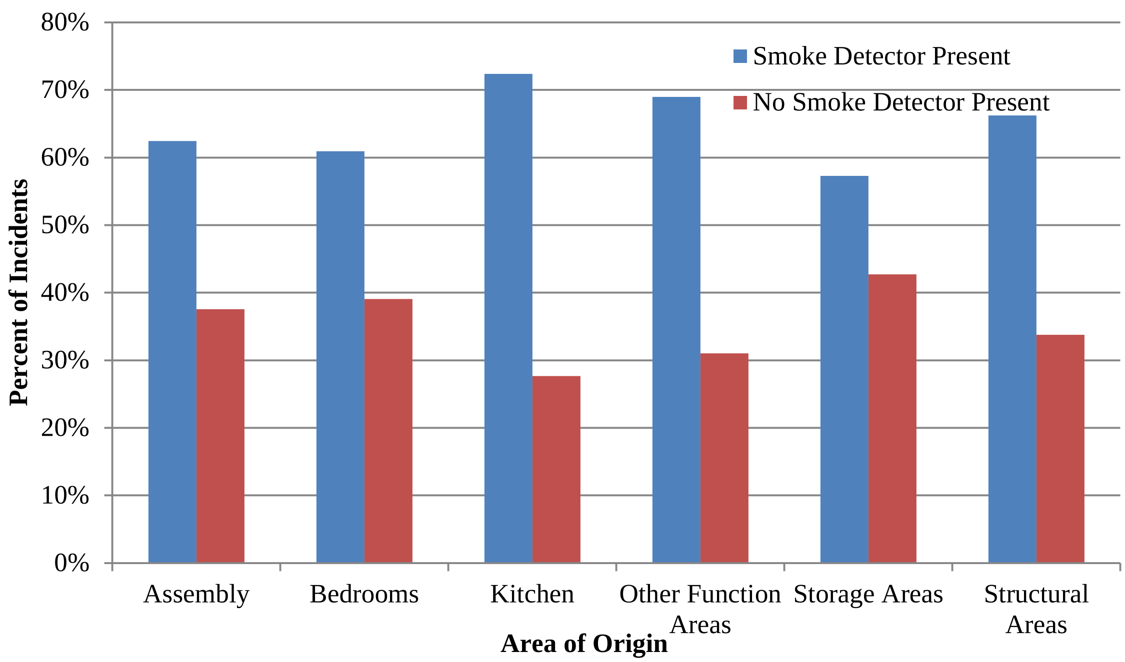


Figure 3.4: Probability of Smoke Detector Present by Area of Origin

3.3 Fire Spread

The Fire Spread field from the Basic Module is defined as "the extent of fire spread in terms of how far the flame damage extended. The extent of flame damage is the area actually burned or charred and does not include the area receiving only heat, smoke, or water damage" [21]. This field helps to define the size of the fire. There are five possible entries for Fire Spread:

1. Confined to object of origin (FS1)
2. Confined to room of origin (FS2)
3. Confined to floor of origin (FS3)
4. Confined to building of origin (FS4)
5. Beyond building of origin (FS5)

Differences in fire severity are a key parameter for determining trends. Larger fires cause more property damage than smaller fires. NFIRS distinguishes between incidents that are considered confined fires and incidents that are nonconfined fires. Confined fires are not required to complete the Fire Module portion of a report. This is important because the Fire Spread field, which is the field that is being used to measure the extent of property damage caused by fire, is found in the Fire Module portion. The Fire Spread field will often be not completed when the fire is considered confined. Confined fires are often underrepresented when the data is separated by the Fire Spread field.

For all Area of Origins, FS3 and FS5 make up a small portion of incidents. Kitchen has a much higher percent of FS2 and much lower percent of FS4 than the other Area of Origins.

All base incidents in each Area of Origin are separated by their Fire Spread, displayed in Figure 3.5. Each Area of Origin has two bars for each Fire Spread. There is one bar for smoke detector present and one bar for no smoke detector present. The impact of smoke detectors can be observed in the differences indicated in the figure for the frequency of Fire Spread for each Area of Origin.

All six Area of Origins have a higher proportion of FS2 and a lower proportion of FS4 when there is a detector present than when there is no detector. These differences are more significant for Assembly, Bedrooms, Kitchens, and Other Function Areas. Of specific interest is the observation that for the Kitchen Area of Origin, with smoke detectors present, the FS2 incidents comprise 56.9% and FS4 incidents are only 11.6% of incidents. Structural Areas has the smallest differences between the two smoke detector categories for the five Fire Spreads.

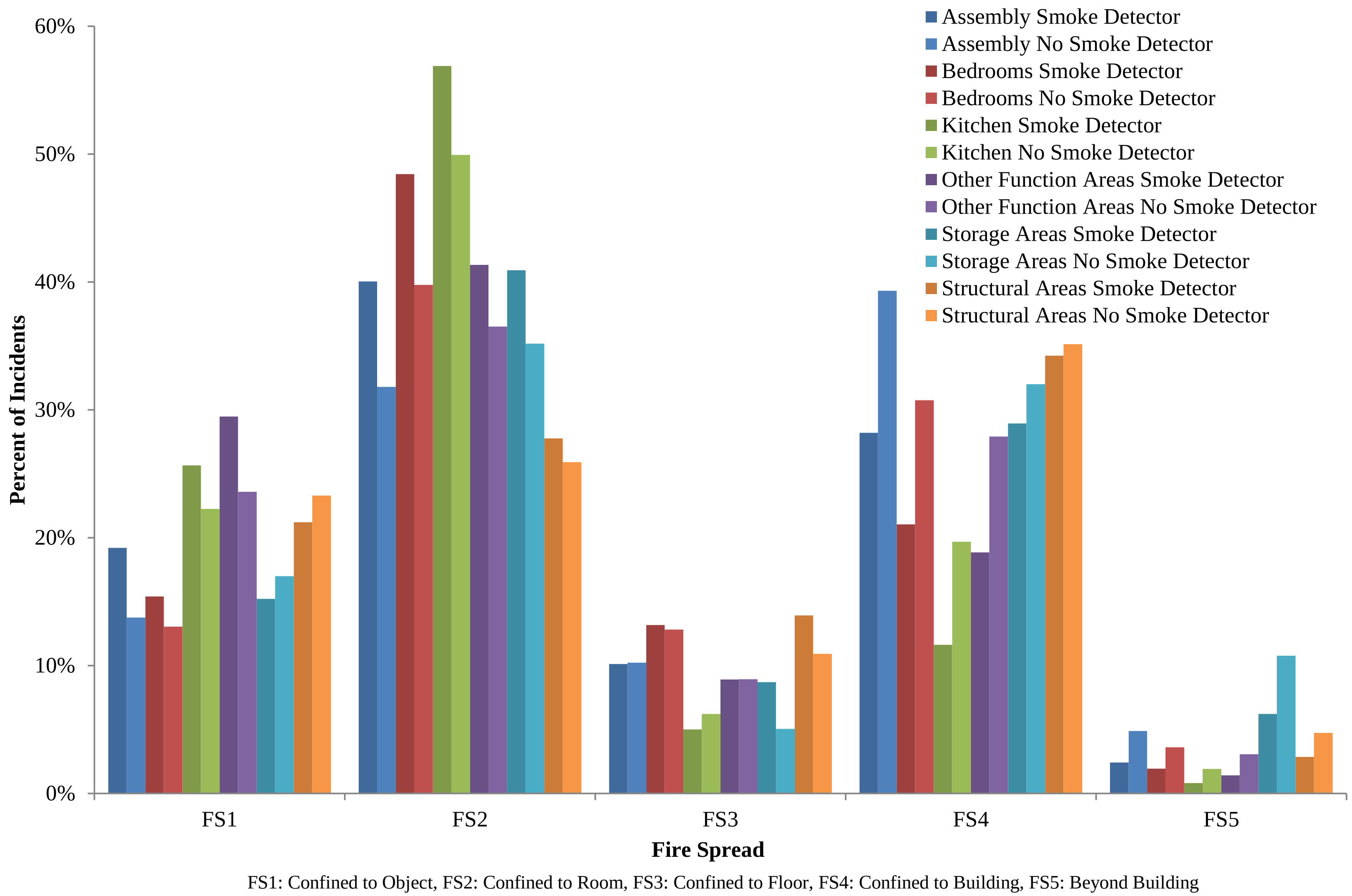


Figure 3.5: Distribution of Fire Spread by Area of Origin and Smoke Detector Presence

3.4 Item First Ignited

The Item First Ignited field from the Fire Module is defined as "the use or configuration of the item or material first ignited by the heat source. This block identifies the first item that had sufficient volume or heat intensity to extend to uncontrolled or self-perpetuating fire" [21]. There are 76 possible Item First Ignited entries, separated into eight categories. The full list of possible entries is tabulated in Appendix A.

Due to the large number of possible Items First Ignited only the most prevalent items in each Area of Origin and Fire Spread are examined. The top items are chosen by graphing the frequency of each possible Item First Ignited for each Area of Origin and Fire Spread then selecting the items that are more frequent. An abbreviated version of the Items First Ignited in the Structural Areas is graphed in Figure 3.6, with five different series for the five fire spreads. Structural Member, Exterior Sidewall Covering, Insulation, and Electrical Wire are the items that contain the largest portion of incidents. These four items contribute 62-65% of all incidents for each of the Fire Spread categories in Structural Areas. In all six Area of Origin categories the top Items First Ignited account for 43-80% of all incidents. Table 3.1 displays all of the top Items First Ignited for each of the six Areas of Origin and their corresponding prevalence.

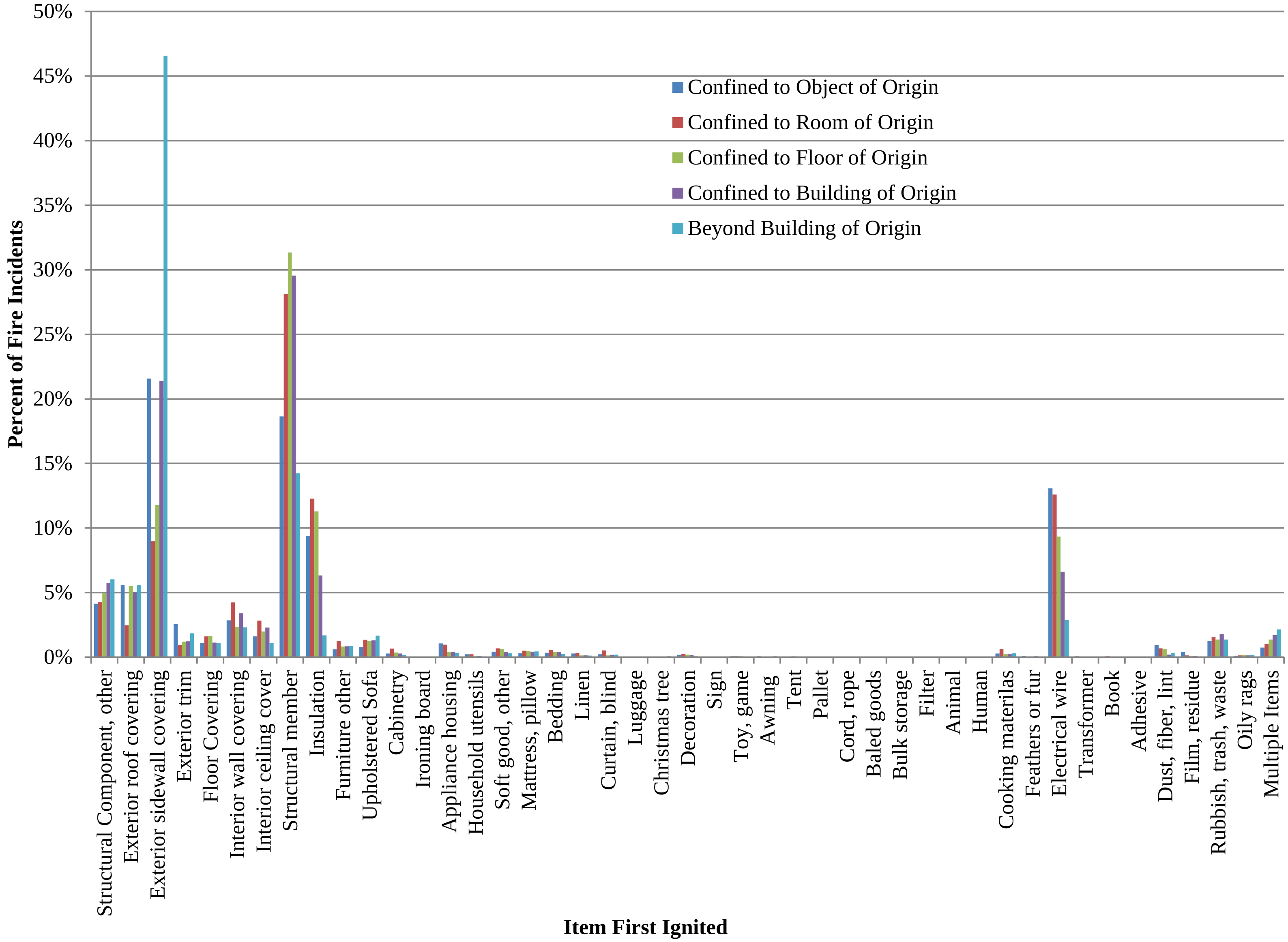


Figure 3.6: Items First Ignited Frequency in Structural Areas by Fire Spread

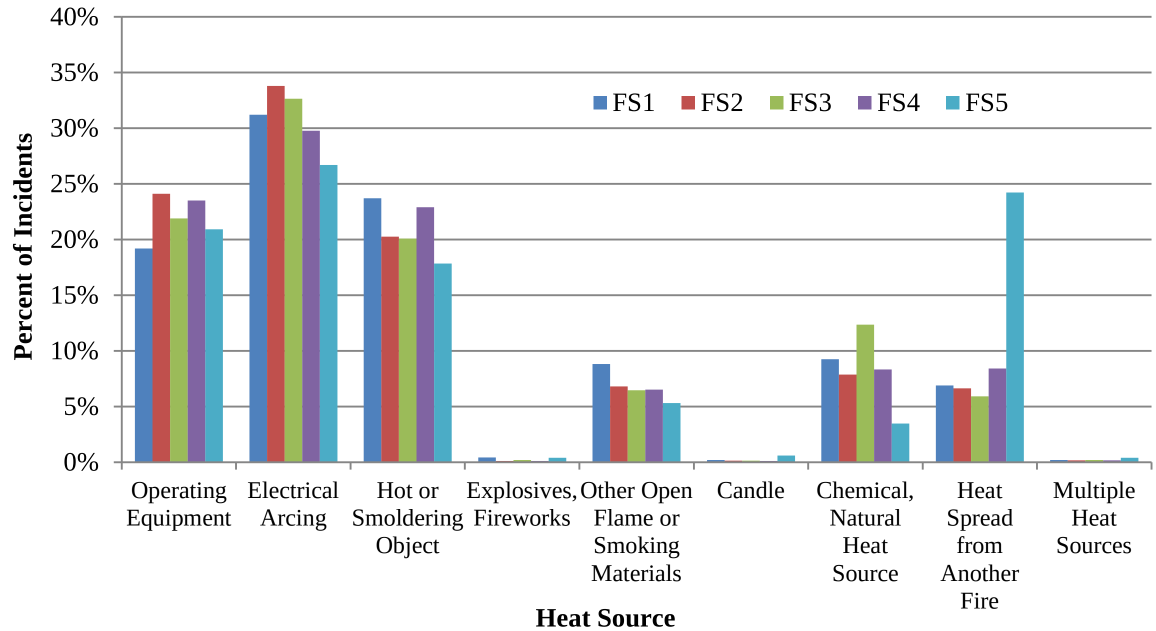
Table 3.1: Most Frequent Items First Ignited

Area of Origin	Item First Ignited	Percent of Incidents				
		FS1	FS2	FS3	FS4	FS5
Assembly	Upholstered Sofa	16.4	19.5	28.8	25.6	24.9
	Electrical Wire	14.8	8.7	7.7	6.6	6.8
	Structural Member	4.4	8.5	8.4	10.8	7.5
	Interior Wall Covering	4.7	5.9	4.7	8.2	5.6
	Floor Covering	6.0	7.6	7.4	7.7	8.8
Structural Areas	Exterior Sidewall Covering	21.6	9.0	11.8	21.4	46.6
	Structural Member	18.6	28.1	31.3	29.6	14.2
	Insulation	9.4	12.3	11.3	6.3	1.7
	Electrical Wire	13.1	12.6	9.3	6.6	2.9
Kitchen	Food	48.6	54.9	42.7	38.2	34.6
	Appliance Housing	10.0	5.9	5.3	5.3	5.3
	Electrical Wire	7.3	3.0	3.2	4.4	5.4
	Utensils	6.8	4.4	3.7	3.4	2.4
	Cabinetry	3.7	7.8	9.8	9.5	7.9
	Interior Wall Covering	2.1	4.0	6.8	9.3	9.1
Bedrooms	Mattress	20.1	13.1	12.2	10.0	10.4
	Bedding	14.3	17.5	21.3	21.5	21.2
	Other Furniture	8.6	9.0	10.3	9.1	8.6
	Electrical Wire	11.6	8.0	6.9	7.1	7.8
Storage Areas	Exterior Sidewall Covering	4.6	2.5	4.1	6.9	13.2
	Structural Member	5.9	6.5	11.6	13.2	11.7
	Clothes	7.9	9.8	9.3	4.7	1.6
	Box	4.4	7.1	4.8	4.5	3.7
	Electrical Wire	18.2	11.2	9.7	8.7	7.0
	Trash	6.1	7.3	4.0	6.1	5.9
Other Function Areas	Clothes	15.6	11.3	10.7	7.4	5.9
	Upholstered Sofa	3.1	4.8	8.5	9.7	12.5
	Structural Member	2.4	5.3	8.3	11.4	8.5
	Interior Wall Covering	2.9	6.4	6.9	10.1	9.4
	Electrical Wire	14.5	10.3	8.2	8.6	8.7
	Dust	13	6.4	5.0	3.3	2.3

3.5 Heat Source

The Heat Source field from the Fire Module is defined as "the heat source that ignited the Item First Ignited to cause the fire" [21]. There are 35 possible Heat Source entries, separated into nine categories. The NFIRS subgroupings are used except Electrical Arcing is separated from the Operating Equipment group and Candle is separated from the Other Open Flame or Smoking Materials group as these comprised an appreciable proportion of incidents in these two categories. The full list of possible entries is tabulated in Appendix A.

After the top Items First Ignited are determined for each Area of Origin, the Heat Source is determined for each of the top Items First Ignited specific to Fire Spread and Area of Origin. This analysis allows for the relationship between Heat Source and Item First Ignited to be examined, as well as Heat Source and Fire Spread, and Heat Source and Area of Origin. As an example, the distribution of Heat Source for Structural Member as the Item First Ignited in Structural Areas is shown in Figure 3.7. Every combination of Item First Ignited and Area of Origin has its version of Figure 3.7.



FS1: Confined to Object, FS2: Confined to Room, FS3: Confined to Floor, FS4: Confined to Building, FS5: Beyond Building

Figure 3.7: Distribution of Heat Source for Structural Member ignited in Structural Areas

The fields chosen are able to define where the fire started, how the fire started, what sustained the fire, how far the fire spread, and if smoke detectors were present. This sufficiently defines the each to determine any trends in residential fires.

3.6 Risk Model

These five NFIRS fields are used to define the probability portion of the risk equation. Equation 3.2 defines the probability.

$$\text{Probability} = \; P(A_i) \times P\left(D_j \middle| A_i\right) \times P\left(F_k \middle| D_j, A_i\right) \times P(I_m|F_k, A_i) \times P(H_n|I_m, F_k, A_i)$$

A_i = Area of Origin, where i = 1-6 (3.2)

D_j = Presence of Detectors, where j = 1-2

F_k = Fire Spread, where k = 1-5

I_m = Item First Ignited, where m = 1-18

$H_n =$ Heat Source, where n = 1-9

The Fire Spread field gives a qualitative assessment of the consequence. The Fire Spread field demonstrates that a fire “confined to building of origin” causes more damage than a fire that is “confined to object of origin,” but it does not answer the question of how much more damage does one fire spread cause compared to another. A quantitative assessment of the property damage is needed to conduct the calculation indicated in Equation 3.1. NFIRS has an Estimated Dollar Losses and Values field that allows for separate estimates of the property and contents dollar loss for each fire to be entered. These entries are rough approximations as it is firefighters who complete the form and not an appraiser. It is possible a better estimate of fire losses may be available after the report is completed, though reports are rarely updated. Consequently, these values are used as a comparative tool rather than absolute expected loss. The property value loss field is a better metric of fire spread than content value loss because the content value is dependent upon the configuration of the contents. A fire “confined to the room of origin” could have a similar content value loss than that of a fire “confined to the floor of origin” if the room of origin contains high value contents. The property value loss is expected to increase from the room of origin to the floor with no regard to the placement of high value contents.

The property loss values were recorded by Fire Spread category for the following Area of Origins: All, Assembly, Bedrooms, Kitchens, Other Function Areas, Storage Areas, and

Structural Areas. All values were converted to 2010 dollars based on the Consumer Price Index from the Bureau of Labor Statistics [22].

Upon examining the data there is a substantial portion of the data that seems unreasonable. For the “confined to building of origin” fire spread, about 15% of the property loss values are zero dollars. This is an extremely low amount for a fire that spread beyond the object, room, and floor of origin. For the “confined to object of origin” fire spread, over 5% of the property loss values are greater than $20,000 with the maximum property loss greater than $10,000,000. These are extremely high property value damages for fires that did not spread beyond the object of origin.

Each Fire Spread category needs to be represented by a number to quantify the damage. The mean is often a common value used to summarize a dataset. A problem with using the mean is that it is sensitive to large outliers. The median is also utilized to describe a dataset but it is completely not affected by outliers. To find a value that is affected by outliers but not skewed by them, a trimmed mean can be used. The trimmed mean is a compromise between the mean and median. A trimmed mean eliminates a certain percentage of the data from the minimum and maximum then takes the average of the remaining data. A 5% trimmed mean is the mean of the middle 90% of the data. Table 3.2 shows the calculated trimmed means for varying percentages. There is a large decrease in values from the mean to the 5% trimmed mean and then to the 10% trimmed mean, specifically for the “confined to object of origin” fire spread. The distribution of property loss values for all FS5 fires are displayed in Figure 3.8. This distribution shows a considerable increase for large outliers. The 10% trimmed mean was chosen to represent each Fire Spread category to eliminate the extreme outliers but still account for the large range of values.

Table 3.2: Trimmed Means of All Area of Origin Property Loss Values in 2010 Dollars

	FS1	FS2	FS3	FS4	FS5
Mean	4,673	10,154	30,845	53,500	75,182
5% Trimmed Mean	1,385	8,400	23,842	39,024	51,879
10% Trimmed Mean	792	4,920	20,996	33,881	43,676
15% Trimmed Mean	528	4,121	19,064	30,826	38,287
20% Trimmed Mean	371	3,598	17,741	28,576	34,702
25% Trimmed Mean	273	3,245	16,621	26,856	32,090
Median	51	2,309	15,192	23,702	27,040

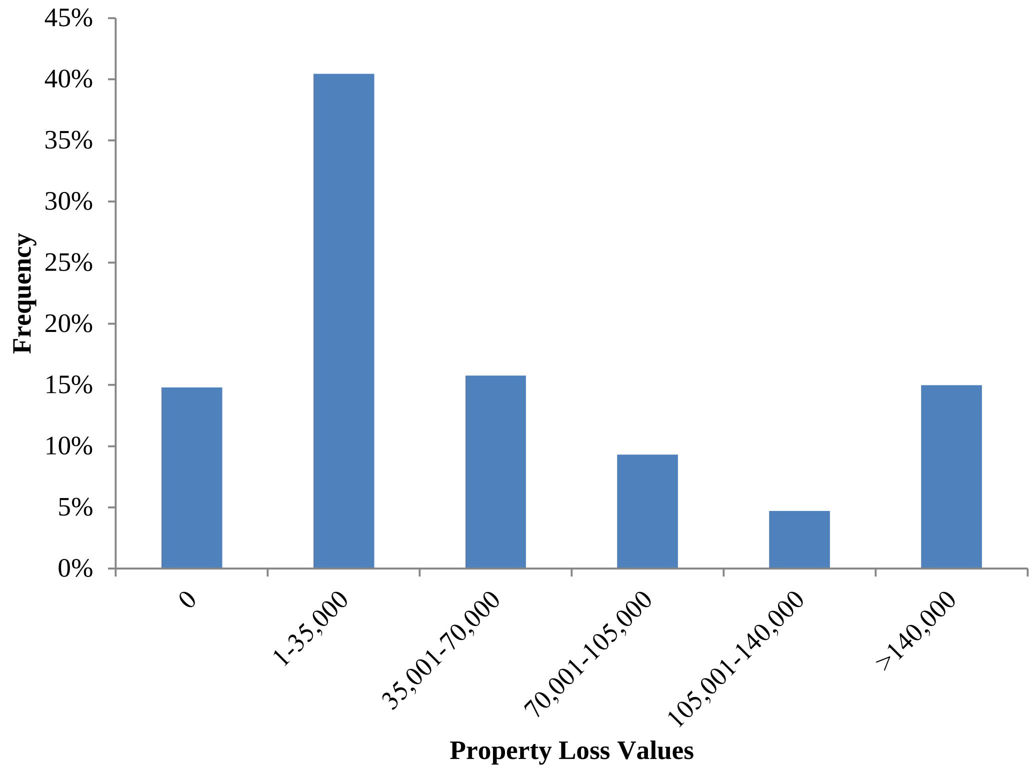


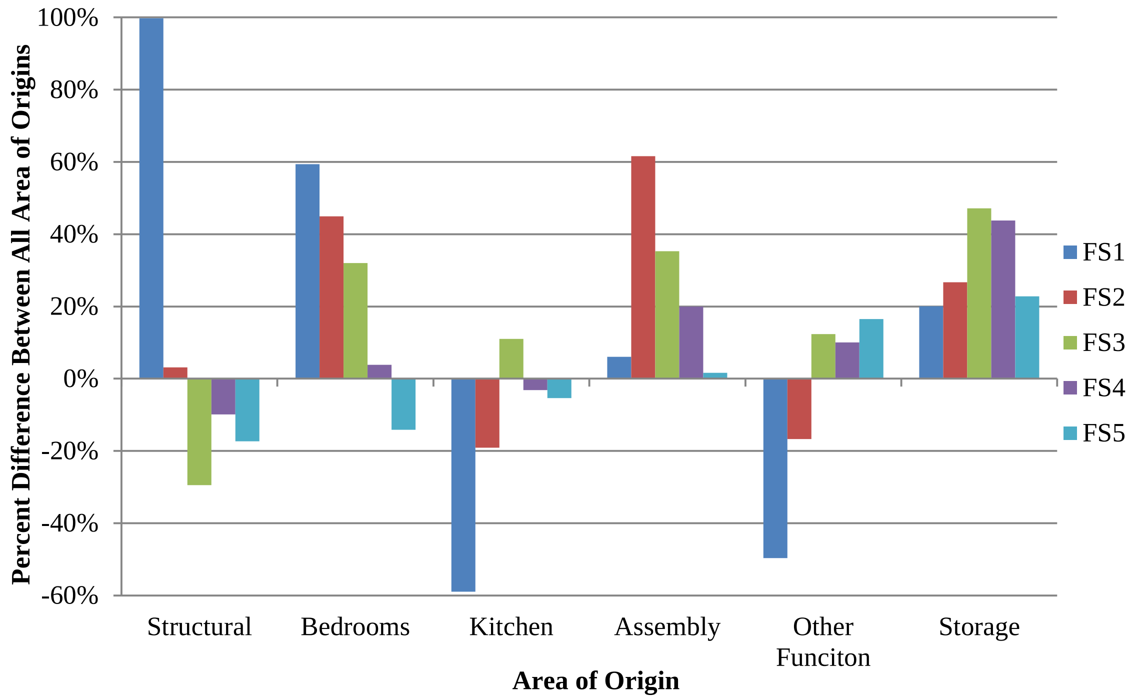
Figure 3.8: Property Loss Values for All Area of Origins with FS5

After determining the representative property loss value for the five different fire spreads, the property loss values are separated by the six Area of Origin groups. This process is repeated for each Area of Origin, to determine the representative property loss for each Fire Spread in each Are of Origin. Using the Area of Origin property loss values gives a more detailed picture of the fire problem in one- and two- family residences.

The 10% trimmed means for each fire spread of each Area of Origin are displayed in Table 3.3. The percent difference between each Area of Origin 10% trimmed mean and the 10% trimmed mean for all Area of Origins is graphed in Figure 3.9. From Table 3.3 and Figure 3.9 a few key observations can be made. Structural Areas have a 100% higher FS1 value but a 29% and 17% drop for FS3 and FS5. Bedrooms have considerable higher property loss values for the lower fire spreads with 59%, 45%, and 32% for FS1, FS2, and FS3, but a 14% decrease for FS5. The Kitchen property loss values for FS1 and FS2 are smaller by 59% and 19%. Assembly property loss values are all higher with the largest increases in FS2, FS3, and FS4 with 62%, 35%, and 20% increases. All five Storage values are moderately higher with 20%, 27%, 47%, 44%, and 23% increases. Other Function areas have a large drop of 50% for FS1. FS2 in Other Function Areas also decreases but only by 17%. FS3, FS4, and FS5 reverse the trend with moderate increases of 12%, 10%, and 16%.

Table 3.3: 10% Trimmed Means of Property Loss Values in 2010 Dollars

	FS1	FS2	FS3	FS4	FS5
All	792	4,920	20,996	33,881	43,676
Structural	1,582	5,074	14,815	30,516	36,124
Bedrooms	1,262	7,133	27,712	35,184	37,501
Kitchen	325	3,980	23,311	32,819	41,332
Assembly	840	7,952	28,410	40,659	44,381
Other Function	399	4,096	23,588	37,295	50,873
Storage	951	6,234	30,902	48,726	53,631



FS1: Confined to Object, FS2: Confined to Room, FS3: Confined to Floor, FS4: Confined to Building, FS5: Beyond Building

Figure 3.9: Percent Difference Between All Area of Origins and Each Area of Origin

The consequence part of Equation 3.1 is defined as the 10% Trimmed Mean for a given Area of Origin and Fire Spread. Using this definition for consequence and the definition for probability in Equations 3.2 gives a quantifiable equation for risk.

Once all of the probabilities and consequences are determined, a risk value can be calculated for every combination of Area of Origin, Presence of Detectors, Fire Spread, Item First Ignited, and Heat Source.

An example is shown in equations 3.3 and 3.4 to determine the risk contribution for fires that start in Structural Areas, with a smoke detector present, are Confined to the Building of Origin (FS4), Item First Ignited as a Structural Member and Electrical Arcing as the Heat Source.

$$\begin{aligned}
\text{Risk} = {} & \text{P(Structural Area)} \times \\
& \text{P(Smoke Detector|Structural Areas)} \times \\
& \text{P(Confined to Building of Origin|Smoke Detector, Structural Areas)} \times \\
& \text{P(Structural Member|Confined to Building of Origin, Structural Areas)} \times \\
& \text{P(Electrical Arcing|Structural Member, FS4, Structural Areas)} \times \\
& \text{10\% Trimmed Mean for FS4 in Structural Areas}
\end{aligned} \tag{3.3}$$

$$\begin{aligned}
\text{Risk} = {} & 24.6\,\% \times \\
& 66.2\,\% \times \\
& 34.2\,\% \times \\
& 29.6\,\% \times \\
& 29.8\,\% \times \\
& 30{,}516 = 150
\end{aligned} \tag{3.4}$$

The summation of every risk value gives a total risk value for all of the variables examined. This total risk value is analyzed by the different variables to determine any trends in one- and two-family residential fires.

Chapter 4: Results and Analysis

4.1 All Area of Origins:

Starting from the beginning, the total risk value is separated by Area of Origin. The summation of all risk values in a particular Area of Origin gives a risk value for each Area of Origin grouping. The difference between the percent of incidents and the percent of risk value each Area of Origin contributes is displayed in Figure 4.1.

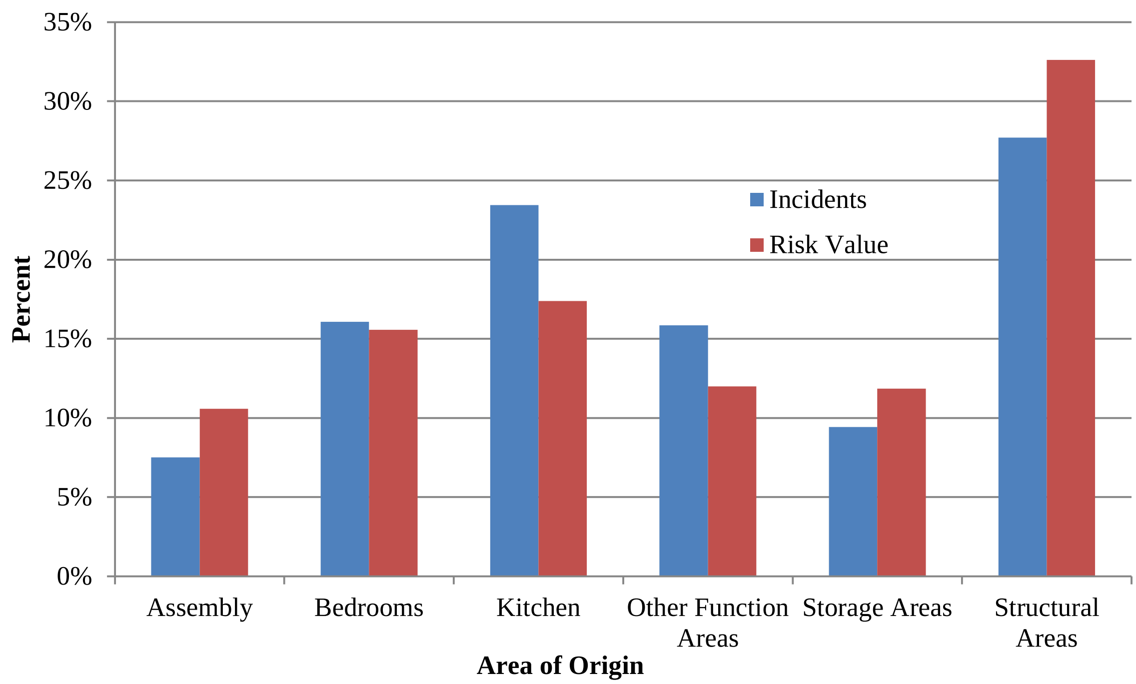


Figure 4.1: Distributions of Area of Origin Incidents and Risk

Structural Areas has the largest proportion of incidents with 27.7% of incidents, which increases to 32.6% of all risk. Kitchens contribute the second largest amount of incidents with 23.4% but this decreases to 17.4% for risk. Other Function Areas also has a significant decrease in proportion from incidents to risk. Assembly and Storage Areas have an increase from proportion of incidents to proportion of risk value. Bedrooms almost have the same proportion for incidents and risk value.

The next level of the risk model is smoke detectors. The distribution of risk among the two possible categories of smoke detector presence is displayed in Figure 4.2. The presence of smoke detector accounts for about 60% of the risk. This is misleading as there is a higher probability that a smoke detector will be present as seen in Figure 3.4. Similar to the Area of Origin analysis, the contribution of the risk has to be compared to the contribution of incidents. As seen in Figure 4.1 the Area of Origin also plays a role in comparing the contribution of risk to the contribution of incidents, so the Area of Origin needs to be controlled as well to determine any trends in the performance of smoke detectors.

The percent difference between the proportion of incidents and the proportion of risk for when there is and when there is not a smoke detector present for the different Area of Origins is displayed in Figure 4.3. All six Area of Origins have an increase in risk when there is no smoke detector present. The largest increases come from the Assembly, Kitchen, and Other Function Areas. The smallest increase comes from the Structural Areas.

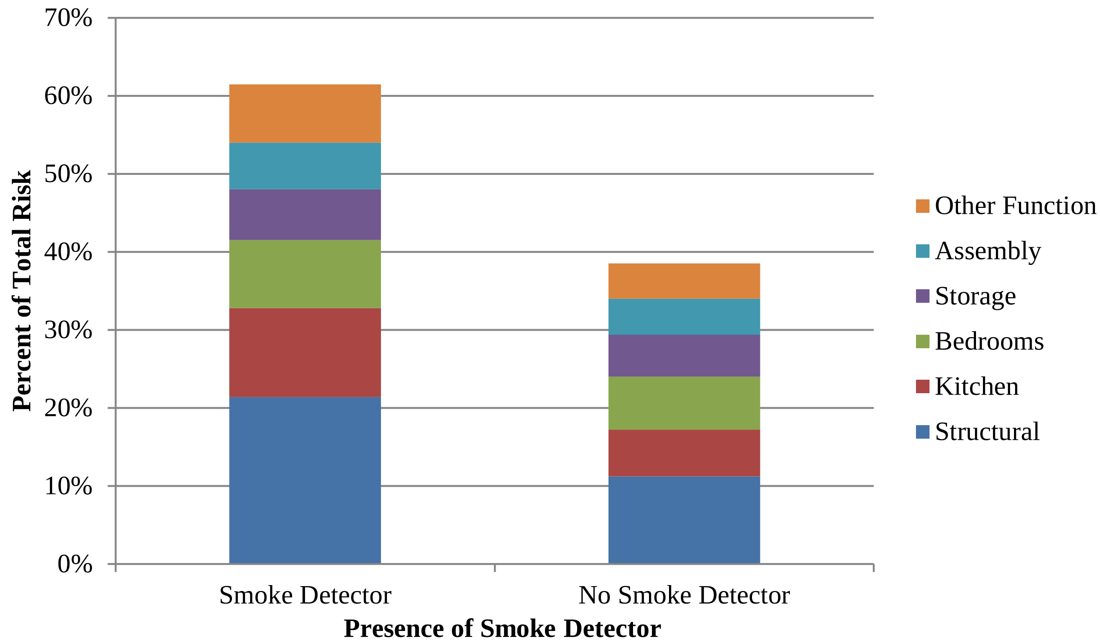


Figure 4.2: Distribution of Risk by Presence of Smoke Detector

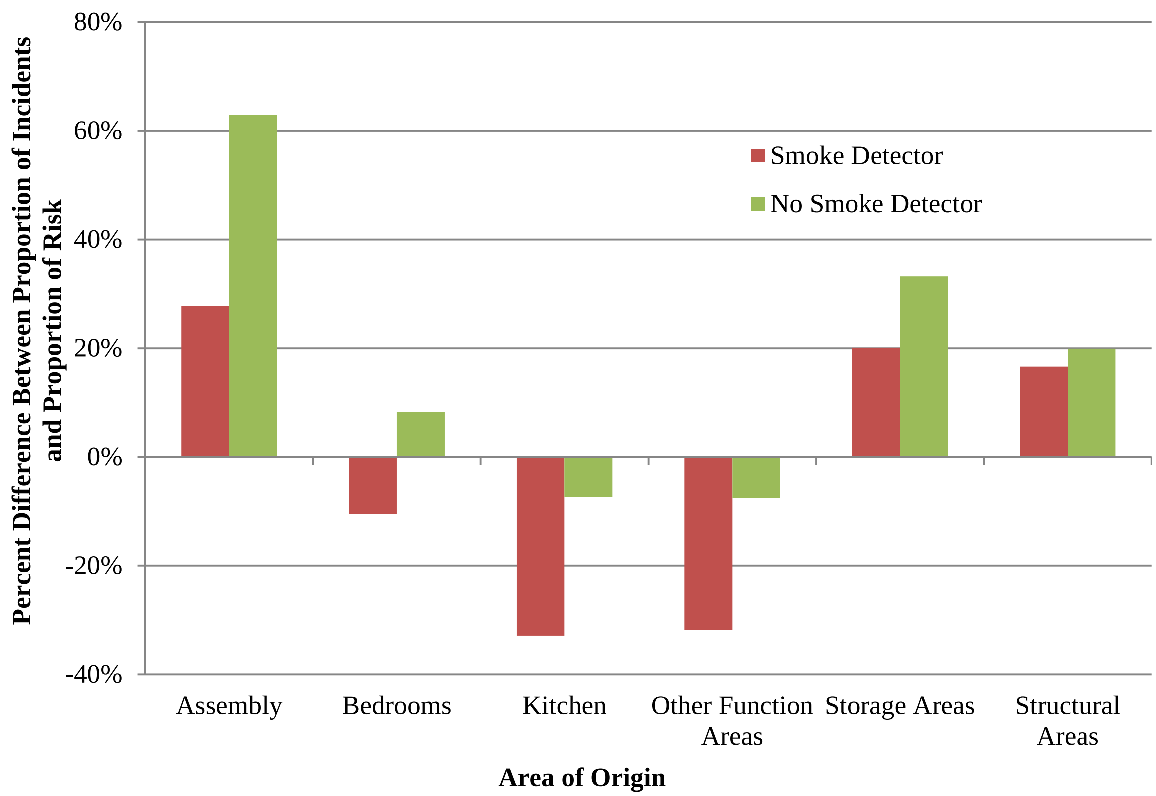
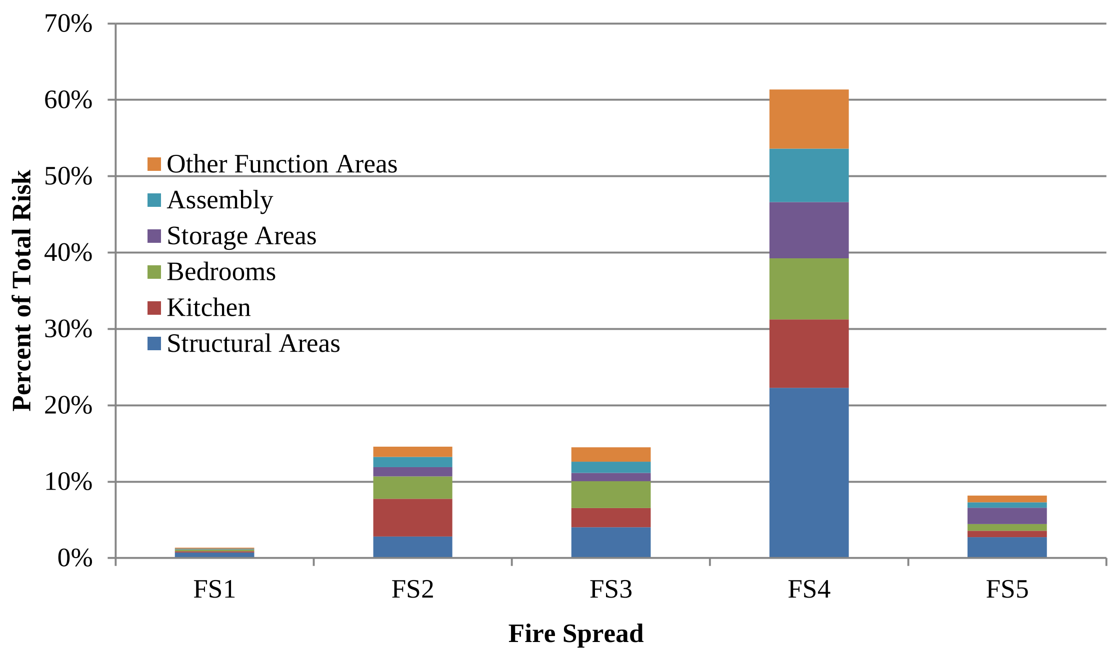


Figure 4.3: Percent Difference of Proportion of Incidents and Risk

The contribution of each Fire Spread category to the total risk value is displayed in Figure 4.4. Each fire spread category is also color coded by Area of Origin. Fire Spread category Confined to Building of Origin (FS4) accounts for the vast majority of risk with 61.3% of all risk value. Confined to Object of Origin accounts for only 1.3% of the risk value, this is expected as fires that do not spread beyond the first object should not have large property losses. Although the Beyond Building of Origin fire spread category has the highest consequence for all Area of Origins, it has a low probability of occurring as seen from Figure 3.5. This keeps its risk value low. Similarly, Confined to Floor of Origin accounts for about the same amount of the risk values as Confined to Room of Origin although FS3 has three to six times the risk weighting as FS2, depending on the Area of Origin. Confined to Building of Origin has such high risk values because it has high risk weightings and a high probability of occurring.



FS1: Confined to Object, FS2: Confined to Room, FS3: Confined to Floor, FS4: Confined to Building, FS5: Beyond Building

Figure 4.4: Total Risk Value by Fire Spread

The next factor the total risk value is separated by is Item First Ignited. The contribution of each individual Item First Ignited to the total risk value is illustrated in Figures 4.5 and 4.6. Figure 4.5 has each item's contribution color coded by Area of Origin and Figure 4.6 has each contribution color coded by Heat Source.

Overall Structural Member has the largest proportion of risk values. Although Structural Member contains risk values from Storage Areas, Assembly, Other Function Areas, and Structural Areas, the portion from Structural Areas alone is enough to make Structural Member the dominant Item First Ignited. Electrical Wire, Exterior Sidewall Covering and Food are the next three largest contributors. All of the risk from Food comes from the Kitchen Area of Origin. The vast majority of the risk from Exterior Sidewall Covering comes from Structural Areas. Electrical Wire is different in that its risk value is comprised of portions from all six Area of Origins. This exemplifies the prevalence of Electrical Wire as a possible Item First Ignited throughout the house. The next tier of largest Items First Ignited includes Upholstered Sofa, Interior Wall Covering, and Bedding. Upholstered Sofa has contributions from Assembly and Other Function Areas. Interior Wall Covering includes risk values from Kitchen, Assembly, and Other Function Areas. Bedding is completely from the Bedroom Area of Origin.

Using Figure 4.6 to examine the Items First Ignited by Heat Source reveals different trends. The total contribution for each item is not changed so Structural Member is still the leading Item First Ignited. Three Heat Sources make up the majority of its risk value, Operating Equipment, Electrical Arcing, and Hot or Smoldering Object. Electrical Arcing is the main player for Electrical Wire as the Item First Ignited. About half of the Exterior Sidewall Covering risk value comes from Heat Spread from Another Fire. The vast majority of the Heat Source for Food is Operating Equipment. The largest portion for both Upholstered Sofa and Bedding is Other Open Flame or Smoking Materials. Interior Wall Covering has large contributions from Operating Equipment and Electrical Arcing.

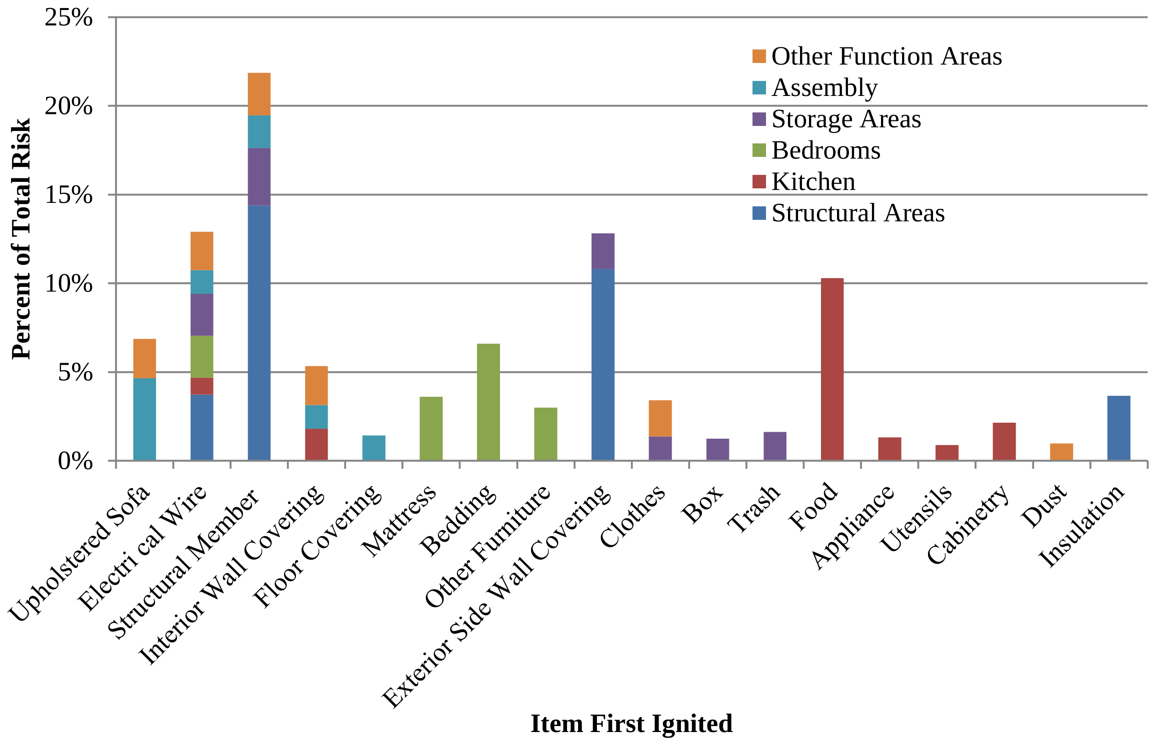


Figure 4.5: Total Risk Value by Item First Ignited and Area of Origin

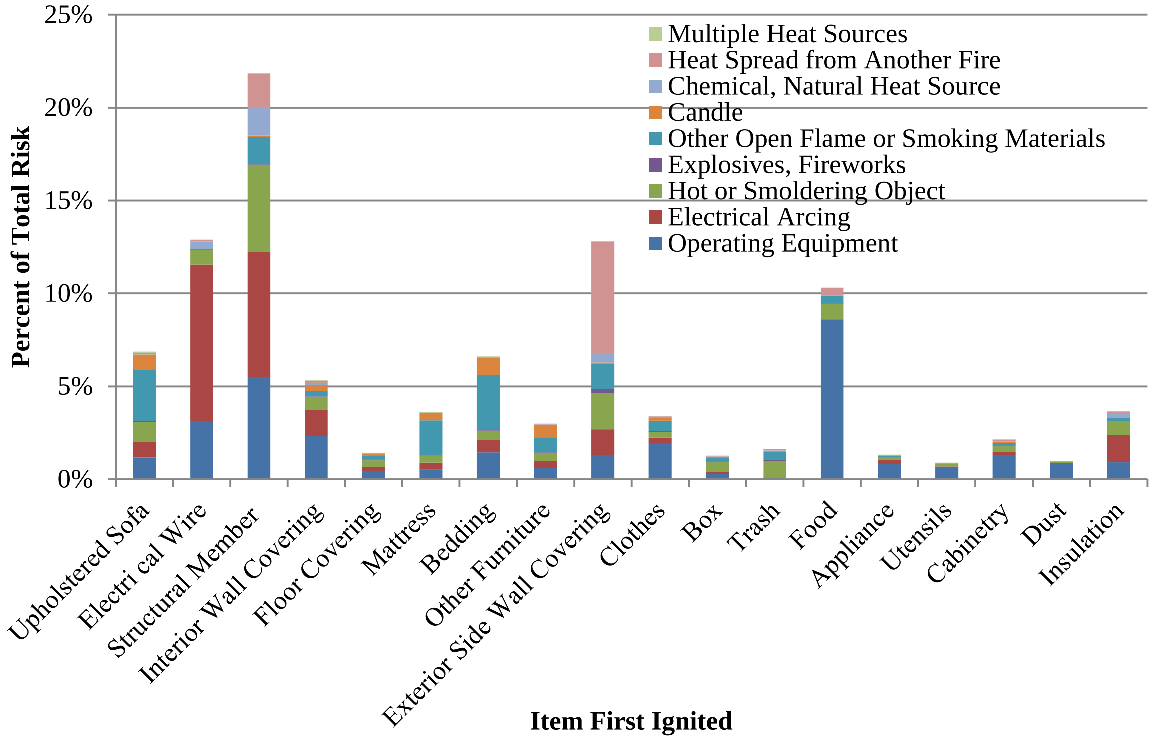


Figure 4.6: Total Risk Value by Item First Ignited and Heat Source

The contribution of each grouping of Heat Source to the total risk value is illustrated in Figures 4.7 and 4.8. Figure 4.7 is color coded by Area of Origin and Figure 4.8 is color coded by Item First Ignited. There is no difference in the Heat Source grouping totals between Figures 4.7 and 4.8.

Operating Equipment contributes the largest portion to the risk values of all of the Heat Source groupings. Of the Operating Equipment grouping, Food as the Item First Ignited contributes the largest amount of risk. Electrical Arcing has the second highest proportion of risk values. For Electrical Arcing the largest contributing Items First Ignited are Electrical Wire and Structural Member. Structural Member also contributes the biggest portion of the Hot or Smoldering Object Heat Source. Other Open Flame or Smoking

Materials is dominated by Bedding and Upholstered Sofa. Heat Spread from Another Fire is made up of mostly Exterior Sidewall Covering.

Operating Equipment’s largest portion comes from the Kitchen Area of Origin. Electrical Arcing and Hot or Smoldering Object both have considerable portions from all six Area of Origins but Structural Areas is the dominate one. The greatest portion of Other Open Flame and Smoking Materials and Candle comes from Bedrooms. The vast majority of the risk values of Chemical, Natural Heat Source and Heat Spread from Another Fire are attributed to Structural Areas.

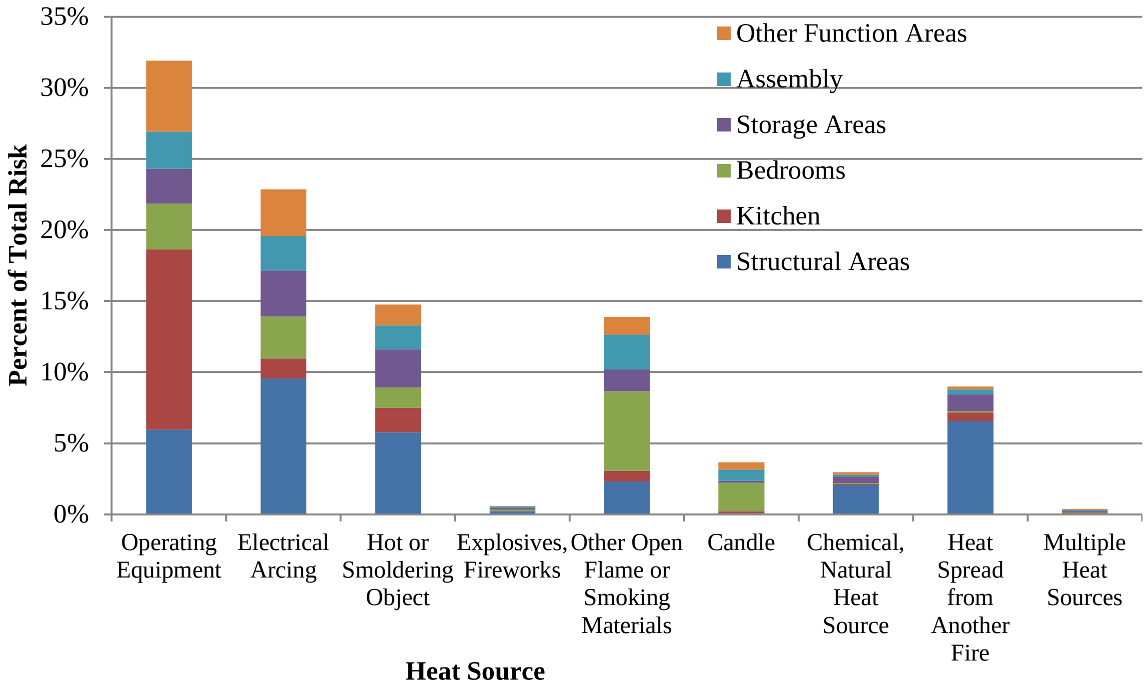


Figure 4.7: Total Risk Value by Heat Source and Area of Origin

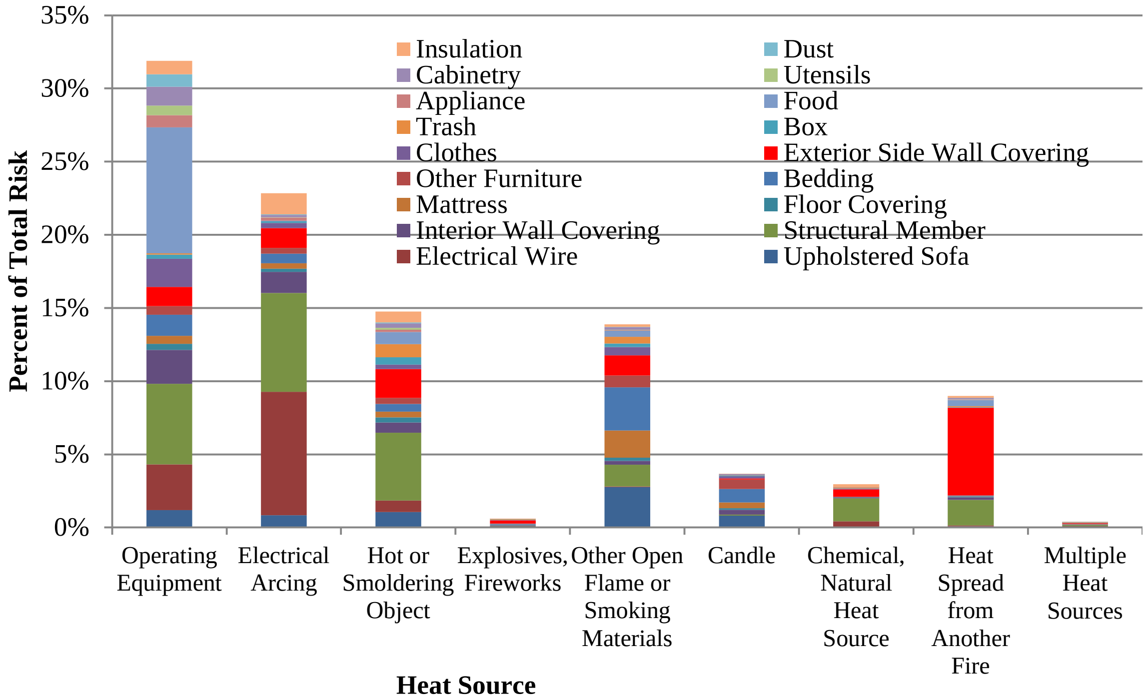


Figure 4.8: Total Risk Value by Heat Source and Item First Ignited

Separating the risk values in two groupings, Confined to Room of Origin and Beyond Room of Origin, illustrates any differences between small and large fires. The Confined to Room of Origin contains Fire Spread categories FS1 and FS2. Beyond Room of Origin contains FS3, FS4, and FS5. The contribution of each Item First Ignited to the risk values of these two groups is illustrated in Figure 4.9.

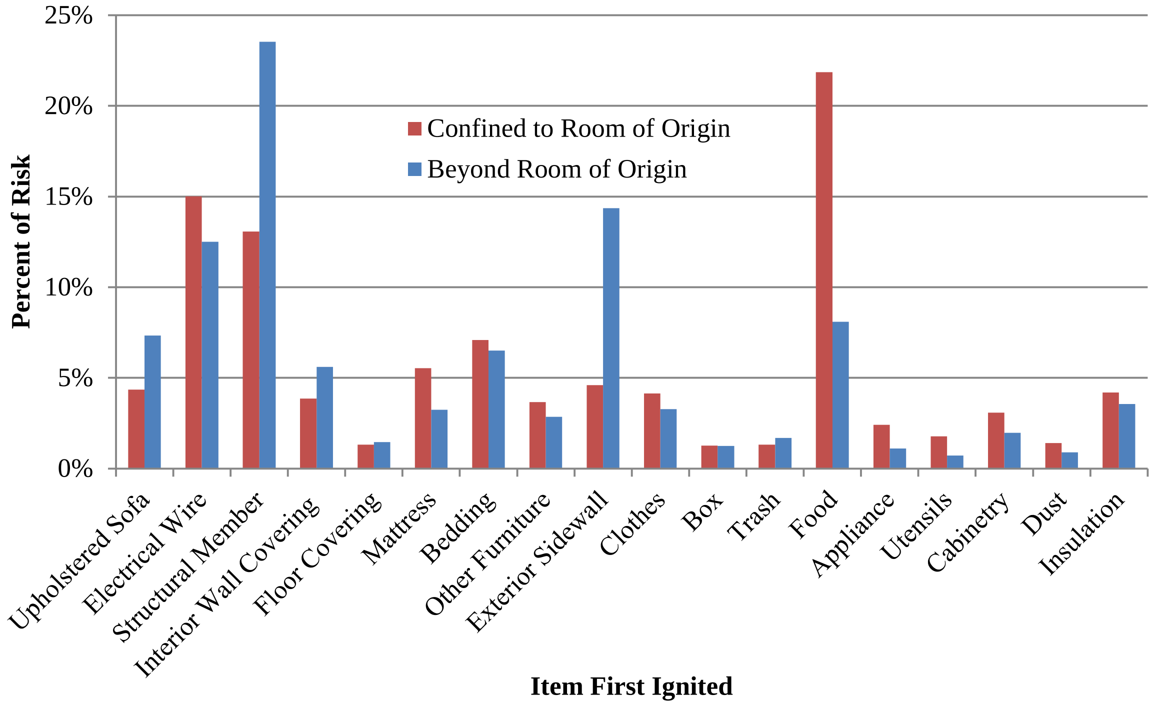


Figure 4.9: Risk by Item First Ignited

The largest difference is between the contributions of Food. Food is the dominant item for the smaller fires with 22.2% of risk values but only 8.7% of the risk values for the larger fires. There is also a large difference for the Structural Member contributions. Structural Member is the largest contributor for the larger fires but drops to the third largest contributor for smaller fires. Exterior Sidewall has a small impact on the smaller fires with only 4.7% but is the second largest contributor for the larger fires with 14.2%.

The differences in Heat Source for small and large fires are illustrated in Figure 4.10. The overall trend of the Heat Sources for small and large fires is very similar. Operating Equipment is the leading Heat Source for both categories with Electrical Arcing, Hot or Smoldering Object, and Other Open Flame or Smoking Materials contributing moderate portions to the overall risk value. One of the two major differences is an 11.4% drop in the proportion of Operating Equipment Heat Sources from fires Confined to the Room of Origin to fires Beyond the Room of Origin. The other difference is there is a 6.4% increase in the proportion of Heat Spread from Another Fire from the smaller fires to the larger fires.

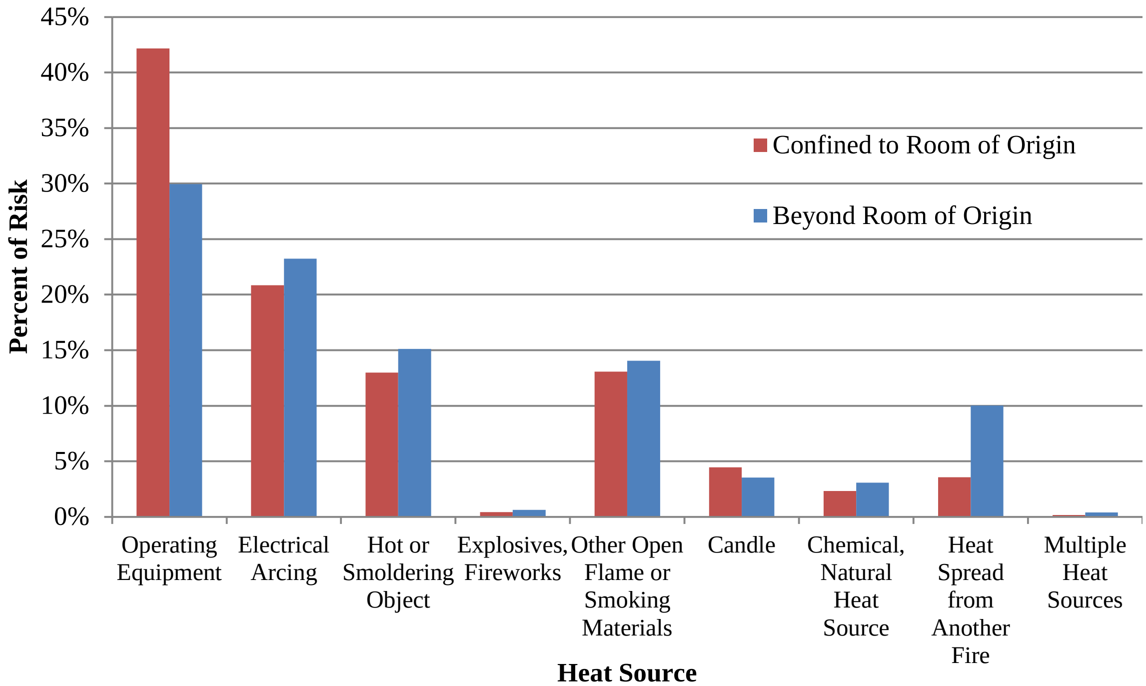


Figure 4.10: Risk by Heat Source

The top 25 scenarios by percent of total risk value are tabulated in Table 4.1. Each scenario is a particular combination of the five fields analyzed: Area of Origin, Presence of Smoke Detector, Fire Spread, Item First Ignited, and Heat Source. Trends similar to those seen in Figures 4.1- 4.8 are evident in Table 4.1. The vast majority of the top 25 scenarios are in Structural Areas, have a smoke detector present and are from Fire Spread 4. Eight of the top 25 scenarios include a Structural Member as the Item First Ignited. It is important to note that Food being ignited by Operating Equipment in the Kitchen makes the top 25 with three different Fire Spreads; 2, 3, and 4. This reiterates the large number of fire incidents in the Kitchen.

Table 4.1 Top 25 Scenarios

Area of Origin	Smoke Detector	Fire Spread	Item First Ignited	Heat Source	Percent of Total Risk
Kitchen	Yes	4	Food	Operating Equipment	2.4%
Structural	Yes	4	Exterior Sidewall Covering	Heat Spread From Another Fire	2.2%
Kitchen	Yes	2	Food	Operating Equipment	2.1%
Structural	Yes	4	Structural Member	Electrical Arcing	2.0%
Structural	Yes	4	Structural Member	Operating Equipment	1.6%
Kitchen	No	4	Food	Operating Equipment	1.6%
Structural	Yes	4	Structural Member	Hot or Smoldering Object	1.5%
Structural	No	4	Exterior Sidewall Covering	Heat Spread From Another Fire	1.1%
Structural	Yes	4	Electrical Wire	Electrical Arcing	1.1%
Structural	No	4	Structural Member	Electrical Arcing	1.1%
Kitchen	Yes	3	Food	Operating Equipment	0.9%
Structural	Yes	5	Exterior Sidewall Covering	Heat Spread From Another Fire	0.8%
Bedrooms	Yes	4	Bedding	Other Open Flame or Smoking Materials	0.8%
Structural	No	4	Structural Member	Operating Equipment	0.8%
Structural	No	4	Structural Member	Hot or Smoldering Object	0.8%
Bedrooms	No	4	Bedding	Other Open Flame or Smoking Materials	0.8%
Structural	Yes	4	Exterior Sidewall Covering	Hot or Smoldering Object	0.7%
Kitchen	No	2	Food	Operating Equipment	0.7%
Assembly	Yes	4	Upholstered Sofa	Other Open Flame or Smoking Material	0.7%
Structural	No	5	Exterior Sidewall Covering	Heat Spread From Another Fire	0.7%
Assembly	No	4	Upholstered Sofa	Other Open Flame or Smoking Material	0.6%
Structural	Yes	4	Exterior Sidewall Covering	Electrical Arcing	0.6%
Structural	Yes	4	Structural Member	Heat Spread From Another Fire	0.6%
Structural	Yes	4	Structural Member	Chemical, Natural Heat Source	0.6%
Structural	No	4	Electrical Wire	Electrical Arcing	0.6%

FS1: Confined to Object, FS2: Confined to Room, FS3: Confined to Floor, FS4: Confined to Building, FS5: Beyond Building

There are six Items First Ignited that appear as a top Item First Ignited in at least two Area of Origins. These give insight on how the location of the item affects the Heat Source. The percent of risk value for each item in a specific Area of Origin is graphed against Heat Source for all six repeated items in Figures 4.11-4.16.

Electrical Wire is a frequent Item First Ignited in all six Area of Origins and their corresponding Heat Source distributions are displayed in Figure 4.11. Electrical Wire is not heavily affected by the Area of Origin. The vast majority of risk values for all six Area of Origin are from the Electrical Arcing Heat Source and the remaining values from Operating Equipment.

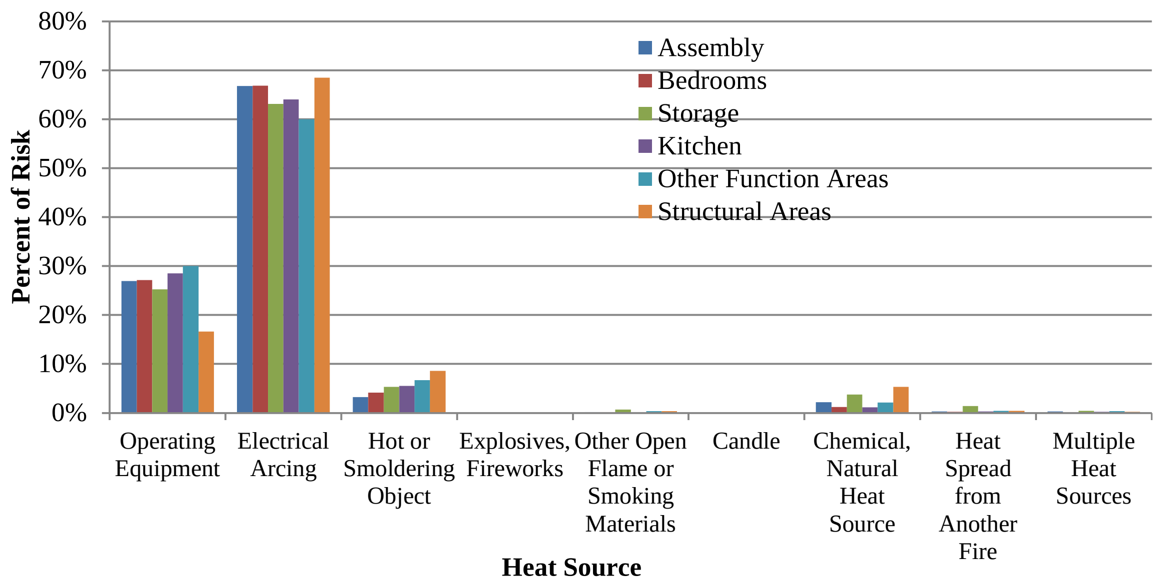


Figure 4.11: Electrical Wire Heat Source in Multiple Area of Origins

Interior Wall Covering is found in Assembly, Kitchen, and Other Function Areas. The corresponding Heat Source distributions are graphed in Figure 4.12. The Interior Wall Covering has extremely similar Heat Source breakdowns for Other Function Areas and

Assembly. Interior Wall Covering ignited in the Kitchen has a lower proportion of Electrical Arcing and much higher proportion of Operating Equipment than Other Function Areas and Assembly. This is most likely attributed to the high likelihood of a range being the equipment involved with ignition in the Kitchen.

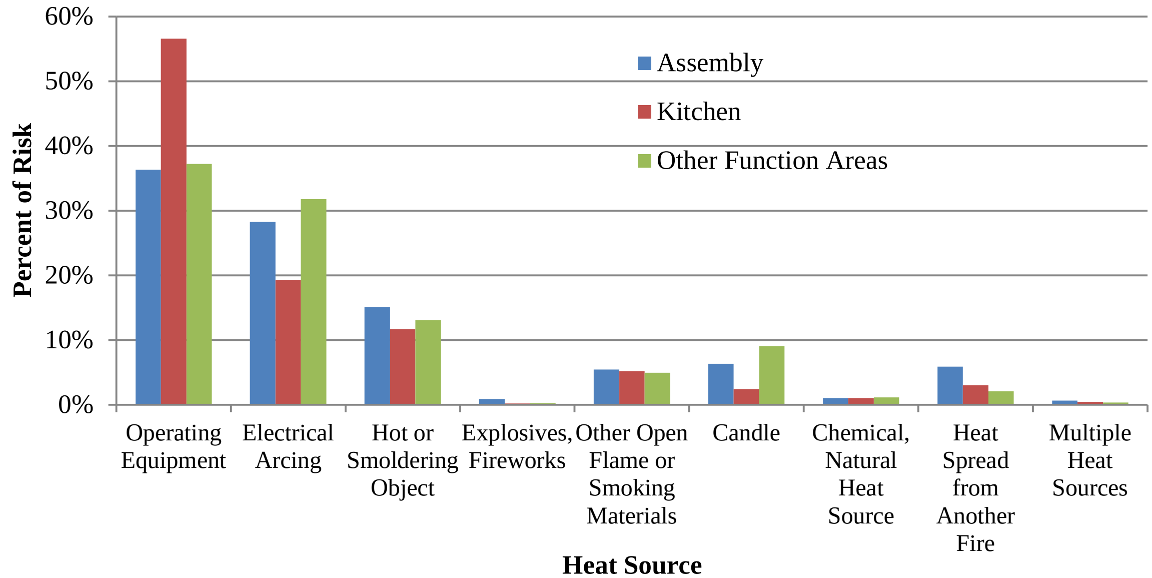


Figure 4.12: Interior Wall Covering Heat Source in Multiple Area of Origins

Upholstered Sofa is a top Item First Ignited in only two Area of Origins, Assembly and Other Function Areas. The two Heat Source distributions are graphed in Figure 4.13. Upholstered Sofa has similar breakdowns in Assembly and Other Function Areas except Assembly has a slightly higher proportion of Other Open Flame or Smoking Materials and Other Function Areas has a slightly higher proportion of Hot or Smoldering Object as the Heat Source.

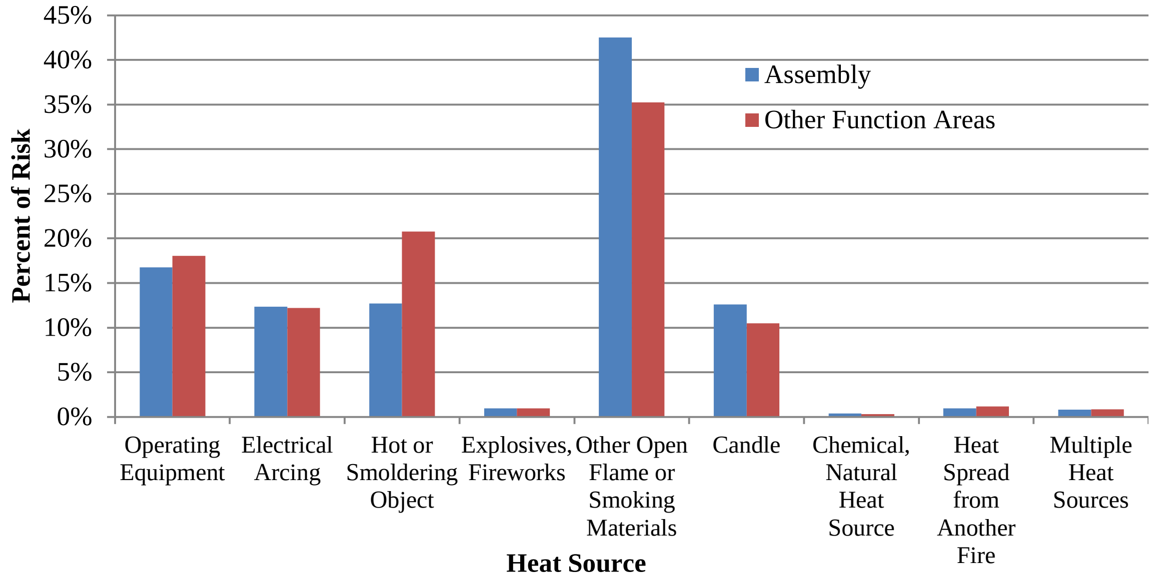


Figure 4.13: Upholstered Sofa Heat Source in Multiple Area of Origins

Structural Member is a top Item First Ignited in Assembly, Storage Areas, Other Function Areas, and Structural Areas. The Heat Source distributions are displayed in Figure 4.14. All four distributions are similar except Assembly has a higher proportion of Hot or Smoldering Object than Electrical Arcing where the other three have a higher proportion of Electrical Arcing. This may be due to the likely placement of fireplaces in Assembly areas.

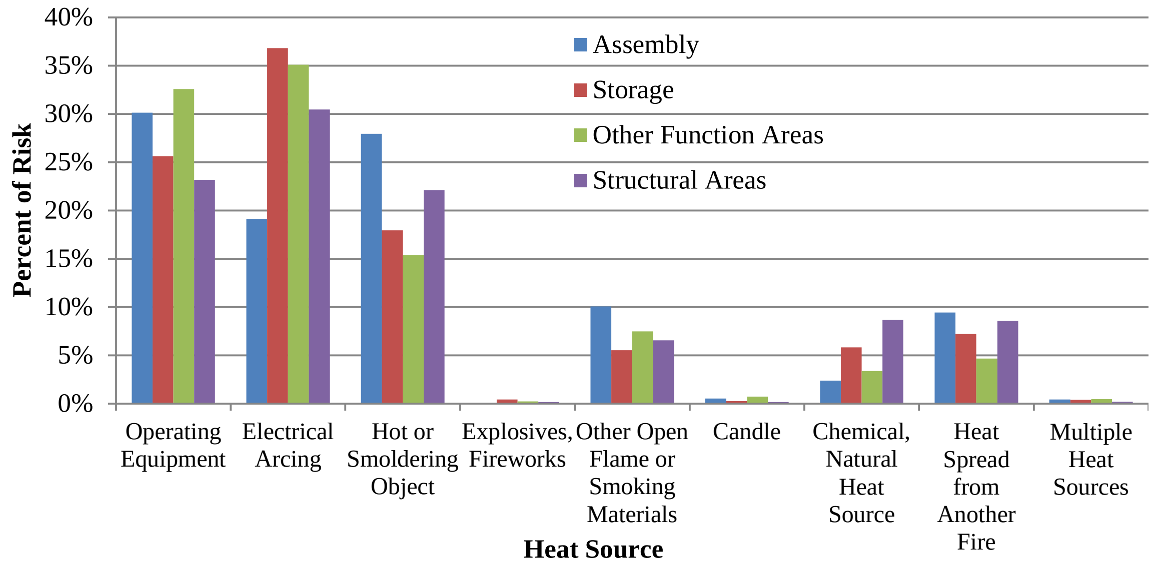


Figure 4.14: Structural Member Heat Source in Multiple Area of Origins

Clothes ignited in Storage and Other Function Areas have completely different Heat Source distributions, graphed in Figure 4.15. Other Function Areas is dominated by Operating Equipment, due to the large portion of Other Function Area fires being in the Laundry room and caused by dryers. Storage Areas has the majority of the risk distributed among Operating Equipment and Other Open Flame or Smoking Materials.

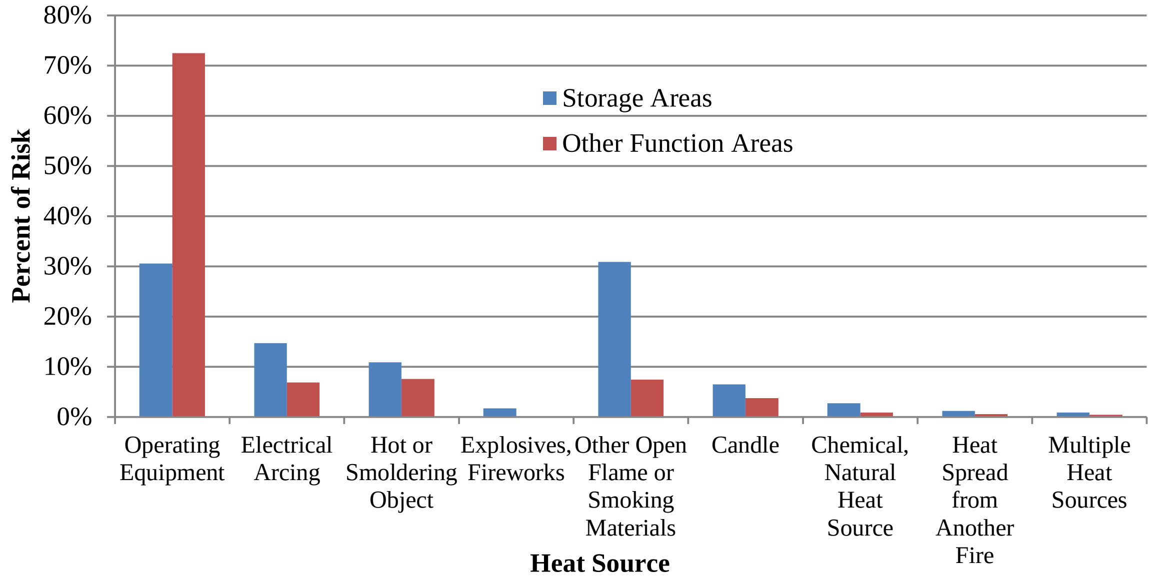


Figure 4.15: Clothes Heat Source in Multiple Area of Origins

Exterior Sidewall Covering is a top Item First Ignited in Storage and Structural Areas. The Heat Source distributions are graphed in Figure 4.16. The distributions are similar except Storage Areas has slightly higher Hot or Smoldering Object and lower Heat Spread from Another Fire than Structural Areas.

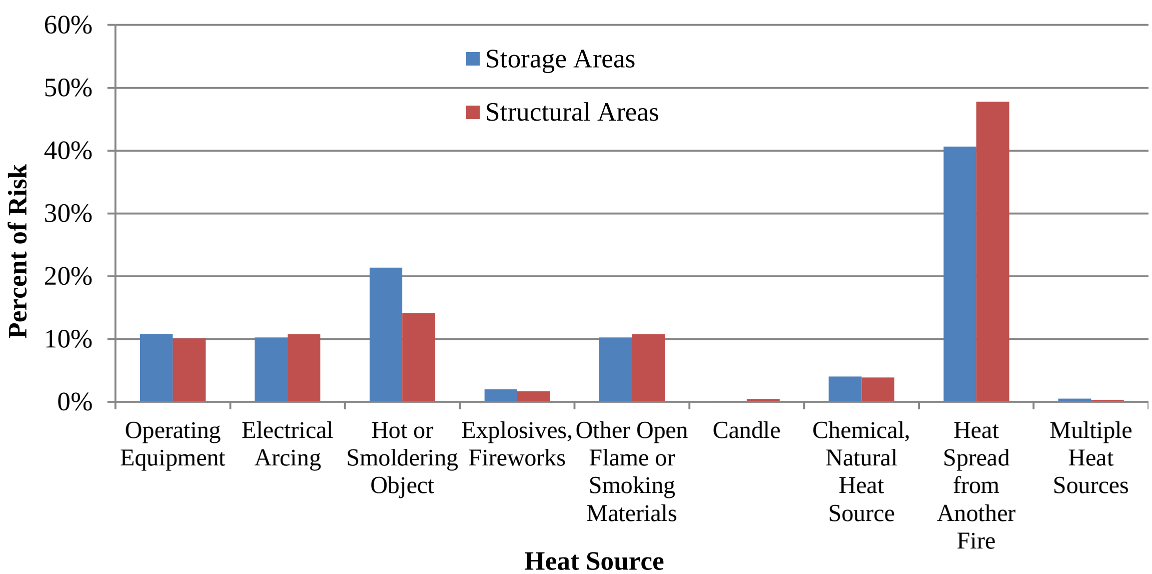


Figure 4.16: Exterior Sidewall Covering Heat Source in Multiple Area of Origins

4.2 Structural Areas

Each Area of Origin is examined separately to determine any trends specific to one area. Only the Structural Areas Area of Origin is discussed in this section. All Area of Origins are discussed in Appendix C. The percentage of incidents in Structural Areas for the top Items First Ignited is illustrated in Figure 4.17. Insulation and Electrical Wire have a decreasing trend of proportion with increasing Fire Spread. Exterior Sidewall Covering has an extremely high jump for Beyond Building of Origin. If the fire starts on the exterior of the building it increases the chance that the fire could spread beyond that building. The risk model here assumes a linear progression of the fire from confined to object, room, floor, building, beyond building. When the fire starts on the outside or outside of the building it does not follow this normal progression. Although the fire spreads beyond the building, it does not necessarily mean the fire is extremely large. This could lead to an inaccurate heavy weighting of these fires that spread beyond the building of origin.

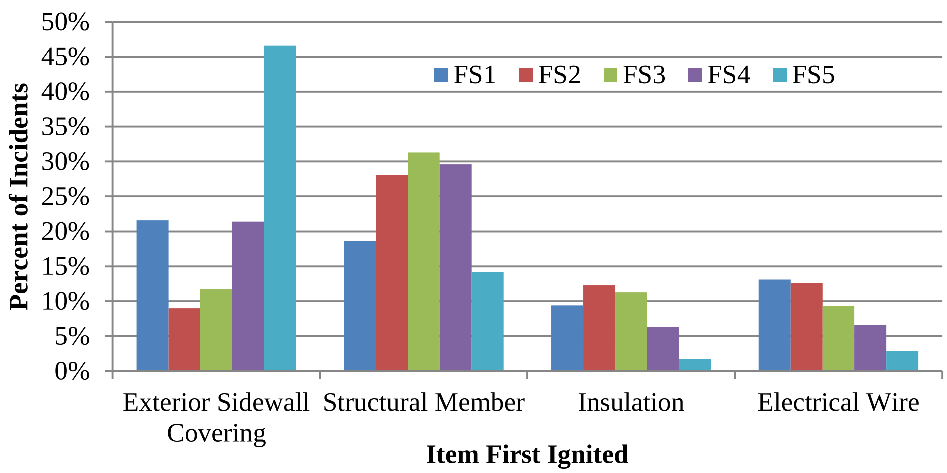


Figure 4.17: Top Items First Ignited Frequencies for Structural Areas

Figures 4.18 and 4.19 are the Structural Areas only version of Figures 4.6 and 4.8. Structural Member is the largest contributor to the risk value of Structural Areas. Structural Member is made up of many heat sources with three large portions from Operating Equipment, Electrical Arcing, and Hot or Smoldering Object. Exterior Sidewall Covering is the second largest contributor and half of its contribution is from the Heat Spread from Another Fire Heat Source. The Structural Area only Heat Source distribution has a different shape than the overall Heat Source distribution. Structural Area has only about half the contribution of Operating Equipment and Other Open Flame or Smoking Materials compared to the overall Heat Source distribution. Heat Spread from Another Fire more than doubles for Structural Areas.

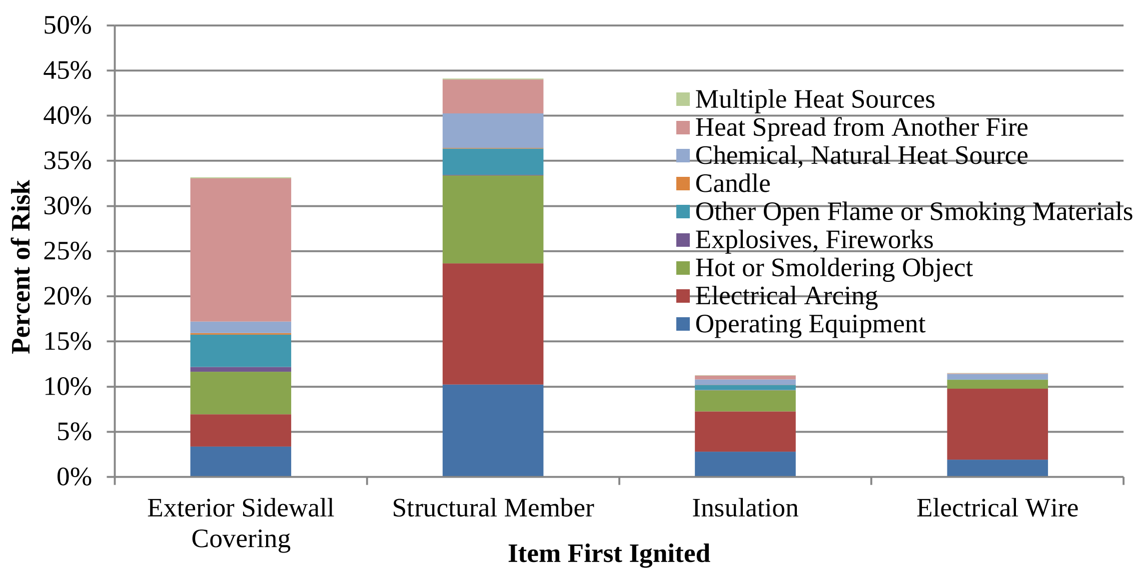


Figure 4.18: Structural Areas Risk by Item First Ignited and Heat Source

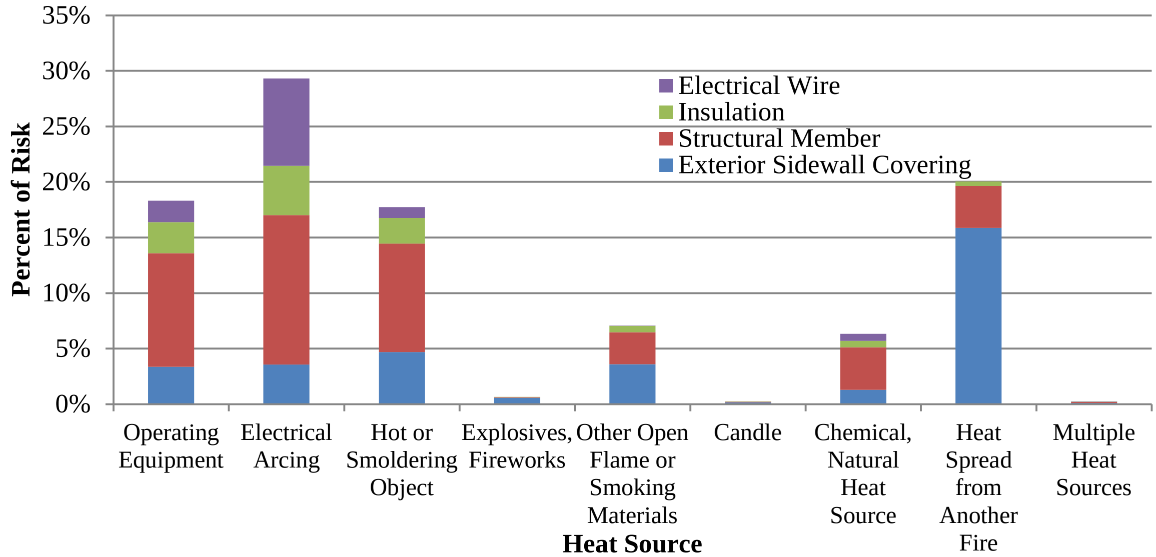


Figure 4.19: Structural Areas Risk by Heat Source and Item First Ignited

Figures 4.20 and 4.21 are the Structural Areas only version of 4.9 and 4.10. Insulation and Electrical Wire only account for half the proportion of large fires compared to their proportion of small fires. This decrease is made up almost entirely by Exterior Sidewall Covering, Structural Member shows no change. Figure 4.26 reflects these same changes. Electrical Arcing, the main Heat Source for both Insulation and Electrical Wire, decreases from those fires confined to the room to those beyond the room. Heat Spread from Another Fire is the dominant Heat Source for Exterior Sidewall Covering and has a large increase.

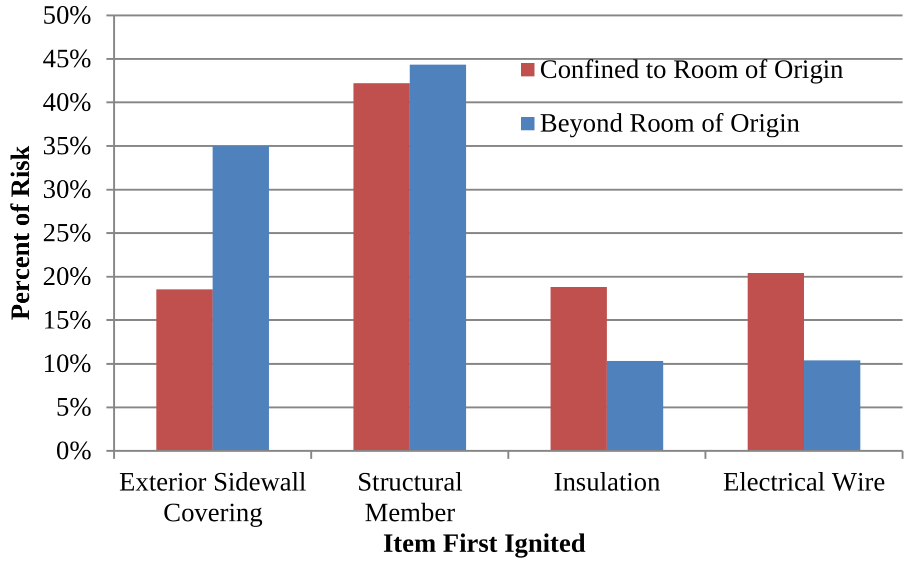


Figure 4.20: Structural Areas Risk by Item First Ignited

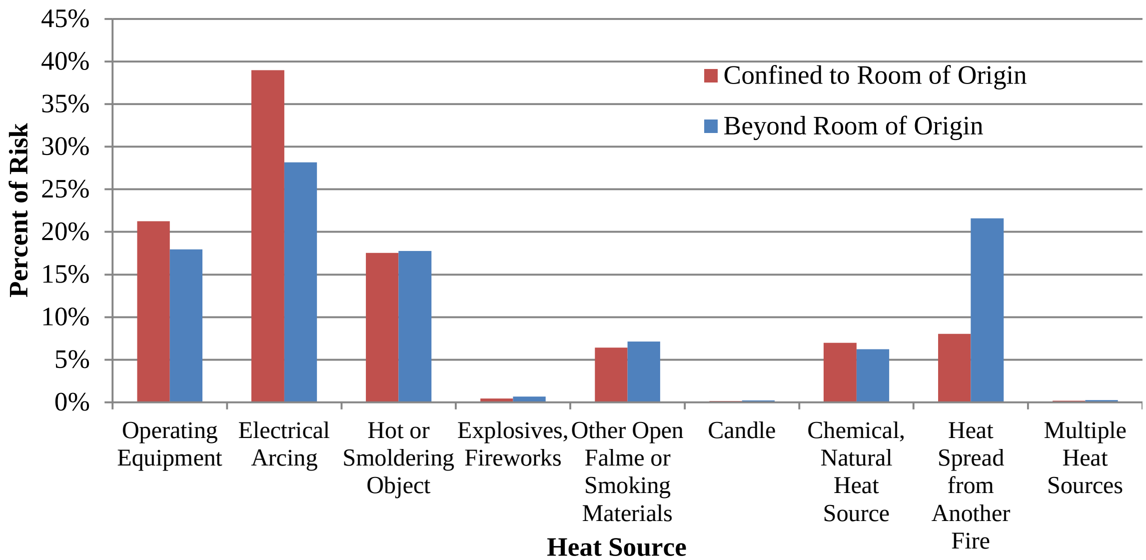
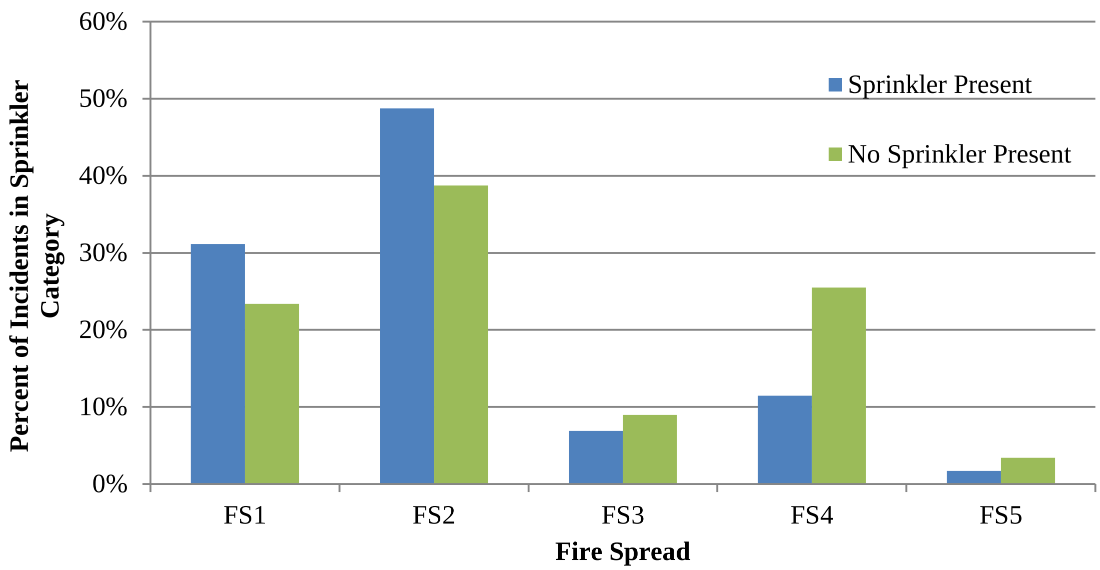


Figure 4.21: Structural Areas Risk by Heat Source

4.3 Presence of Sprinklers

The effect of the presence of automatic sprinkler systems is not included in the risk model due to the low number of incidents once separated by Area of Origin. Examining the effect of the presence of automatic sprinkler systems in all Area of Origins still gives insight on likely effects of sprinklers. Similar to the analysis for smoke detectors, the probability of each Fire Spread category is determined for different sprinkler categories. The performance of sprinklers is graphed in Figure 4.22 by examining Fire Spread distributions for when a sprinkler is present and when a sprinkler is not present. There are large increases in FS1 and FS2 frequencies and large decreases in FS4 and FS5 frequencies when a sprinkler is present. From Figure 4.4, the majority of the risk in one- and two- family houses comes from FS4. The large decrease in FS4 frequency with the presence of sprinklers suggests a large decrease in risk with the addition of sprinklers. Using the consequence values for All Area of Origins an estimate in risk can be made for the presence of sprinklers, graphed in Figure 4.23. There is a 38% reduction in the total risk value for when there are sprinklers present compared to when there are no sprinklers present.



FS1: Confined to Object, FS2: Confined to Room, FS3: Confined to Floor, FS4: Confined to Building, FS5: Beyond Building

Figure 4.22: Distribution of Fire Spread by Presence of Sprinklers

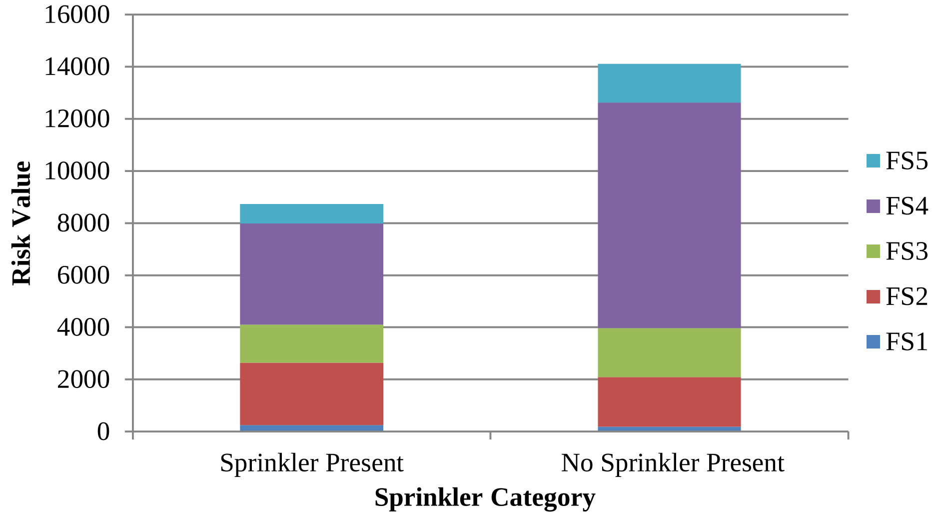


Figure 4.23: Risk by Presence of Sprinklers

4.4 Presence of Smoke Detectors

The effect of presence of smoke detectors can be examined in a similar fashion to the analysis for the presence of sprinklers. Since smoke detectors were included in the risk model, the risk from different Area of Origins is examined. The likelihood of a smoke detector being present is shown in Figure 3.4. The Fire Spread distribution for the different Area of Origins with and without smoke detectors is shown in Figure 3.5. The risk values for three different categories of smoke detector presence are shown in Figure 4.24. There is a 10.5% decrease in total risk from the current smoke detector coverage compared to if there were no smoke detectors. There is an additional 5.4% decrease in risk value if there is complete smoke detector coverage.

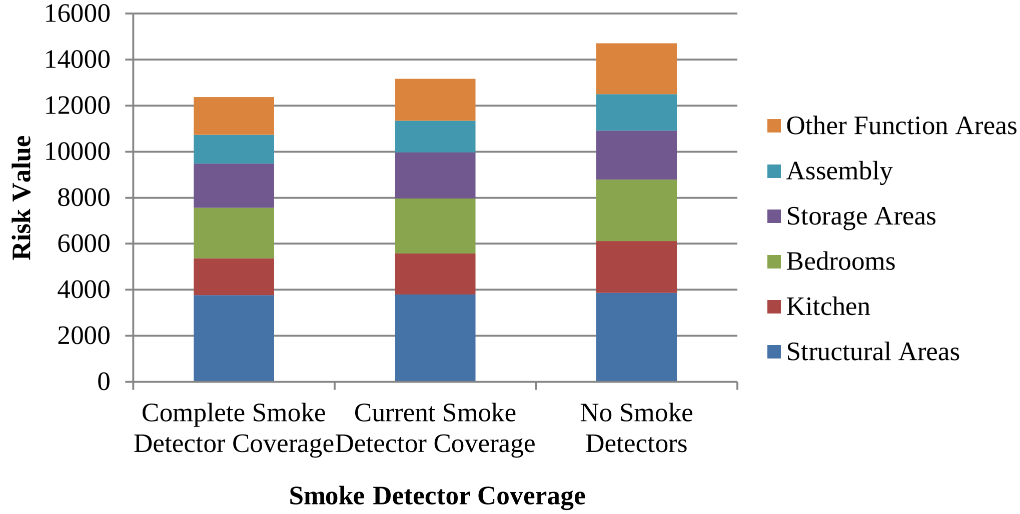


Figure 4.24: Risk by Presence of Smoke Detectors

Chapter 5: Discussion

The results of the risk model are used to determine areas to focus on to best reduce risk of fire in one and two residential houses. As seen in Figure 4.6, Structural Member contributes the greatest portion of risk as the Item First Ignited with 21.9% of the total risk examined. The greatest decrease in risk in one step would be achieved by preventing the ignition of Structural Members. Figures 4.6 and 4.14 give some insight on how Structural Members are ignited. Determining the process of how an item is ignited is the first step in decreasing the likelihood of the item igniting. Structural Members are ignited in Structural Areas, Storage Areas, Assembly, and Other Function Areas with the majority of the risk value coming from Structural Areas as seen in Figure 4.5. The Heat Source of Structural Members is made up of large portions by Operating Equipment, Electrical Arcing, and Hot or Smoldering Objects and smaller portions by Other Open Flame or Smoking Materials, Chemical, Natural Heat Source, and Heat Spread from Another Fire. As Structural Members are a top Item First Ignited in four Area of Origins, it is likely that the operating equipment involved with ignition vary for different Area of Origins. Since Structural Members have so many different modes of ignition it might be difficult to develop ignition prevention techniques for all types of ignition.

Rather than concentrating on prevention of fires, efforts can be concentrated on mitigating the impact of the fire. This study includes two mitigation options, smoke detectors and sprinklers. Remembering the majority of risk from Structural Members comes from the Structural Areas, any benefit from the effect of increasing the probability of smoke detectors will be shown in the distribution of fire spread of Structural Areas with a smoke detector. From Figure 3.5, a slight benefit with the presence of smoke detectors in Structural Areas can be observed. Structural Areas has the smallest benefit with smoke detectors of any of the Area of Origins. The implementation of sprinklers would be expected to substantially decrease the risk from Structural Members. Although the effect of the presence of sprinklers is not examined separately for different Items First Ignited or Area of Origins, Structural Areas has the greatest proportion of risk and sprinklers have such a large effect it is reasonable to assume the sprinklers will decrease the risk from Structural Members.

Electrical Wire is the next largest contributor of risk of the Items First Ignited. Electrical Wire is a top Item First Ignited in all six Area of Origins. The majority of the risk from Electrical Wire comes from Electrical Arcing. Electrical Arcing igniting Electrical Wire and Structural Members account for 15.2% of the total risk. Any advancement in preventing electrical arcing would have great effects on decreasing the risk from fire for one- and two- family residences.

Exterior Side Wall Covering is the third greatest contributor of the risk of the Items First Ignited. As discussed before the Exterior Side Wall Covering may be overrepresented due to the likelihood of the fire being on the outside of the building. About half of the Heat Source for Exterior Side Wall Covering is Heat Spread from Another Fire. If these other fires are from other residential structures then any benefit in preventing or mitigating those fires will stop them from spreading to other buildings. If the sizes of homes continue to increase as the sizes of the lots continue to decrease then these types of fires can be expected to grow. If the other fires are wildland fires then wildland fire prevention and mitigation strategies would be required to decrease the risk from Exterior Side Wall Coverings for one- and two- family residential buildings.

Food is the next greatest contributor of the risk of the Items First Ignited. The vast majority of the Heat Source for Food being ignited is Operating Equipment as seen in Figures 4.6 and 5.1. The percentage of incidents in Kitchens for the top Items First Ignited is found in Appendix C but illustrated in Figure 5.1for this discussion.

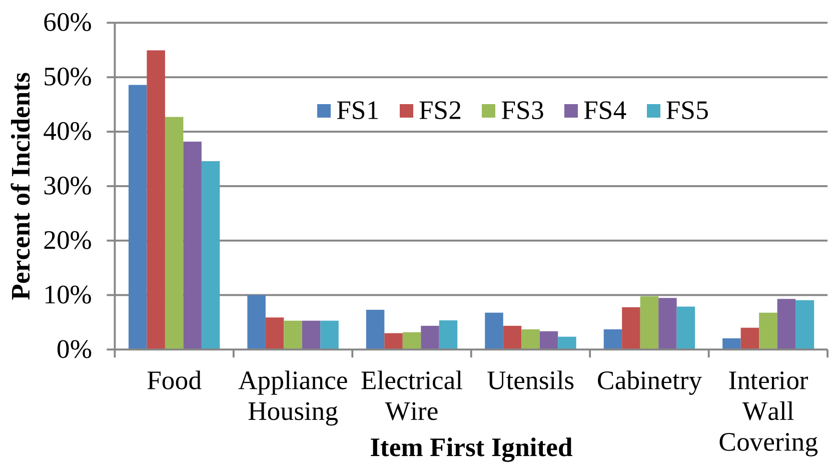


Figure 5.1: Top Items First Ignited Frequencies for Kitchen

The overwhelming Operating Equipment for Kitchens is a cooktop. Any increase in safety measures that prevent ignition of Food from a cooktop would have an impact on decreasing the fire risk of one- and two- family residential buildings. Smoke detectors decrease the expected risk from fires in the Kitchen Area of Origins as seen in Figure 3.5. Kitchens have one of the greatest effects from smoke detectors compared to other Area of Origins. Increasing the probability of having a smoke detector in the Kitchen would decrease the fire risk, but as seen in Figure 3.4 Kitchen already has the highest probability of having a smoke detector present. It may be more difficult to increase an already high probability. Research has been completed to pursuing advanced detection for cooking fires, which would decrease the risk further by increasing the effectiveness of the detectors [23].

As seen from the literature review there has been a lot of emphasis on fires involving Upholstered Sofas and Mattresses due to their high prevalence in fire deaths. Upholstered Sofas account for 6.9% of the risk from Item First Ignited. Although NFIRS does not record the year of manufacture, the majority of Upholstered Sofas ignited are assumed to be of the modern polyurethane foam type because of an estimated average useful life of 16 years [16]. By 1975 polyurethane foam accounted for greater than 90% of the cushioning material for upholstered furniture. Other Furniture accounts for an additional 3% of the total risk, all or a portion of this may include modern polyurethane foam furniture. NFIRS does not give any more details on the possible types of furniture that are included in the Other Furniture category. The percentage of incidents in Assembly for the top Items First Ignited is found in Appendix C but illustrated in Figure 5.2 for this discussion. The increasing proportion of incidents with increasing Fire Spread evident in Figure 5.2 suggests Upholstered Sofas are a hazardous item in the house.

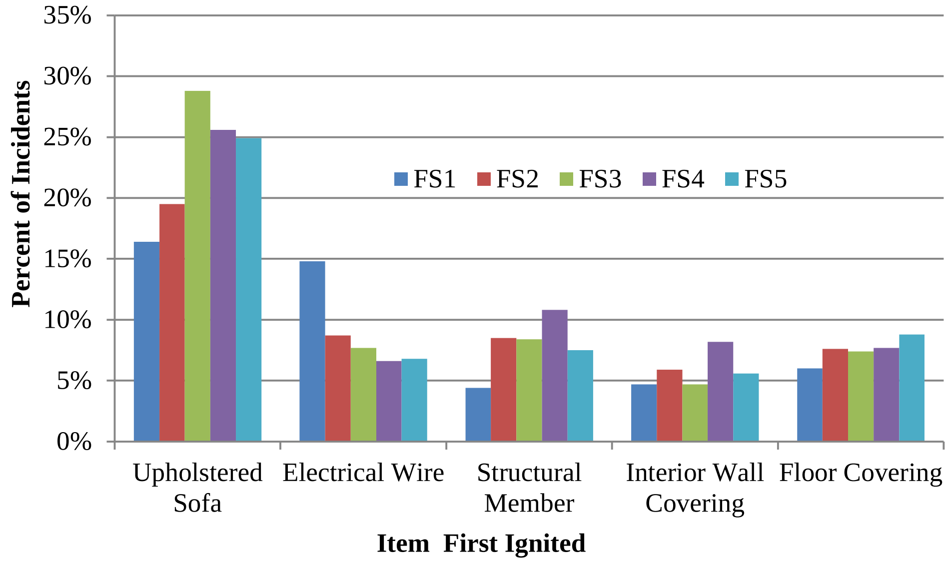


Figure 5.2: Top Items First Ignited Frequencies for Assembly

The greatest portion, about 40%, of the Heat Source for Upholstered Sofa is Other Open Flame or Smoking Materials. This Heat Source category is dominated by smoking materials that cause smoldering ignition. Proposed regulation 16 CFR Part 1643 concentrates on improving the smoldering ignition resistance of upholstered furniture, which includes smoking materials. Regulation 16 CFR Part 1643 does include open flame performance requirements for barriers to protect filling materials from smolder-prone materials that could cause a transition from smoldering to flaming burning [16]. The analysis conducted in this current study only accounts for risk when the item is only the item first ignited. Fires that start on carpeting but quickly spread due to subsequent ignition of upholstered furniture are only attributed to the floor covering.

Mattresses account for only 3.6% of the total risk value of the Items First Ignited. Mattresses are the subject of two CPSC regulations. Regulation 16 CFR Part 1632 concentrates on smoldering ignition and has been implemented since 1972. The CPSC states the mattress industry recommends replacement after 10 to 12 years but does not estimate an average life expectancy [13]. The earliest fire incident included in this analysis is over forty years after the regulation was implemented so it can be assumed the vast majority of mattresses meet 16 CFR Part 1632. Regulation 16 CFR Part 1633 concentrates on ignition of mattresses from open flames and was implemented in 2007. Since the data examined was from fire incidents that occurred from 2003 to 2010, it is assumed almost no mattresses meeting this requirement are included. The percentage of incidents in Bedrooms for the top Items First Ignited is found in Appendix C but illustrated in Figure 5.3 for this discussion. The distribution of Fire Spread for mattresses shown in Figure 5.3 demonstrates a large drop in proportion after FS1. This suggests 16 CFR Part 1632 is having a noticeable impact on the risk of fires from mattresses.

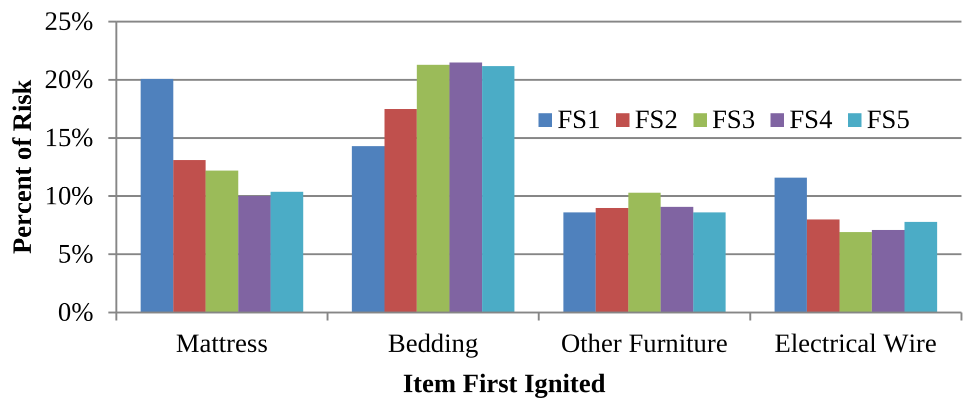


Figure 5.3: Top Items First Ignited Frequencies for Bedrooms

Bedding accounts for 6.6% of the total risk value of the Items First Ignited. Bedding is the subject of possible further regulation for flammability. Bedding and mattresses are often involved in a fire as a system because bedding is designed to be on mattresses. Regulation 16 CFR Part 1633 includes requirements for the heat release rate of mattresses to be limited. The burners for the test are designed to represent the local heat flux of burning bedclothes on a mattress. After mattresses meeting 16 CFR Part 1633 are widely in use the risk value from Bedding as Item First Ignited should be expected to decrease. With mattresses meeting 16 CFR Part 1633 these fires should not reach flashover and be contained to the room of origin. The Fire Spread distribution in Figure 5.3 for Bedding should show a large decrease in proportion after FS2 rather than an increasing proportion for FS3 and greater. This may make requiring a separate regulation for bedclothes unnecessary.

The presence of sprinklers is not directly included in the risk model, the benefits were estimated using the trimmed mean for All Area of Origins. The presence of sprinklers reduced the risk by 38%. Sprinklers work on multiple types of items in multiple Area of Origins, but only in areas where the system is present. As shown in Table 2.2 the presence of sprinkler systems is not uniform throughout a residence.

Although smoke detectors are normally considered a life safety system, the current coverage of smoke detectors reduces the total risk by 10.5% compared to having no smoke detectors. An additional 5.4% decrease in risk is possible if smoke detector coverage is expanded to 100%. As seen in Figure 4.3, not all Area of Origins have the same change in risk with the presence of smoke detectors. Assembly, Bedrooms, Kitchen, and Other Function Areas have the greatest decrease in risk with the presence of smoke detectors. These are the Area of Origins where occupants are more likely to be located in when a fire occurs. This allows for a quicker response for the occupants to appropriately respond to the fire.

Chapter 6: Summary and Suggestions for Future Research

6.1 Summary

Residential fires are a major source of loss in the United States. This study looks to examine national fire incident data to determine any useful trends and insights on the residential fire problem. The fire incident data is used to create a risk model. The location of the fire, whether or not smoke detectors are present, extent of fire spread, the item initially ignited, and the heat source causing ignition are all included in the risk model. Recent national fire incident data is used to give probabilities for each factor. Representative property loss values are calculated for each combination of Area of Origin and Fire spread category.

Structural Member is the Item First Ignited that contributes the greatest amount of risk in one- and two- family houses. The Heat Source for Structural Member is split among three main categories: Operating Equipment, Electrical Arcing, and Hot or Smoldering Objects.

Grouping together the Items First Ignited Upholstered Sofas, Mattresses, and Bedding as representing soft furnishings in the house, contribute the second greatest amount of risk. The main Heat Source for these items is Other Open Flame or Smoking Materials. There is some evidence that regulation 16 CFR Part 1632 has been successful. The analysis also shows the large risk from upholstered furniture and bed clothes that could be reduced from possible regulations currently under consideration.

Although smoke detectors are normally considered a life safety system, the current coverage of smoke detectors reduces the total risk by 10.5% compared to having no smoke detectors. An additional 5.4% decrease in risk is possible if smoke detector coverage is expanded to 100%.

The presence of sprinklers is not directly included in the risk model due to the low number of incidents in all possible Area of Origins. The benefits of the presence of a sprinkler system are still estimated at a 38% reduction in risk.

6.2 Future Research:

This study has given some insight into the residential fire problem but has also identified areas that need further research. This study uses a trimmed mean of property loss values as a representative consequence for each combination of Area of Origin and Fire Spread. The accuracy of these estimates would be improved if the NFIRS database could be combined with an insurance database with appraisals for damage from fires. The risk model could also be altered to include different consequence values for fires that involve injuries and deaths.

As more sprinkler systems are installed there will be more fires in residences with sprinkler systems present. Once there are sufficient incidents in all of the Area of Origins, the presence of sprinkler systems can be added to the risk model in a similar fashion to that of the presence of smoke detectors.

Adding the Item Contributing Most to Flame Spread field into the risk model may be able to give a deeper understanding of the residential fire problem. This field helps to identify the primary fuel of the fire even when the primary fuel is not the first item ignited. The analysis of this portion of the risk model would help with suggesting flammability regulations.

With the recent adoption of the new mattress and possible upholstered sofa flammability regulations, it is important to track the success or failure of these standards. Due to the extended lifetime of the furniture it would be decades before any assumptions about the furniture involved in the incident data meeting the standards could be made without any additional identification information. It may be too much of a data collection burden to add a field in NFIRS to identify if the furniture meets the new standards. Previously, special studies have been performed with NFIRS to collect more detailed information. This may be a viable option to evaluate the performance of these standards in a more timely fashion.

This study focuses on the items involved in one- and two- family houses because of the well-defined fields in NFIRS on this subject. Contemporary furnishings are only one aspect of the changes in residential buildings. The other changes in residential buildings need to be quantified and included the risk model.

The risk model does not directly include the involvement of the occupants. The behavior of the occupants could increase or decrease certain probabilities. These behaviors could be added to the probability portion of the risk model. Injuries and deaths are also not included as the consequence in this model is based solely on property damage estimates. Fire incidents with injuries and deaths could be weighed more heavily to be included in the risk model.

Appendix A: NFIRS Codes

Area of Fire Origin Codes

Means of Egress

01 Hallway corridor, mall.

02 Exterior stairway. Includes fire escapes, exterior ramps.

03 Interior stairway or ramp. Includes interior ramps.

04 Escalator: exterior, interior.

05 Entranceway, lobby.

09 Egress/exit, other.

Assembly or Sales Areas (Groups of People)

11 Arena, assembly area with fixed seats for 100 or more people. Includes auditoriums, chapels, places of worship, class rooms, lecture halls, arenas, theaters.

12 Assembly area without fixed seats for 100 or more people. Includes ballrooms, bowling alleys, gymnasiums, multiuse areas, roller or ice skating rinks.

13 Assembly area without fixed seats for less than 100 people. Includes meeting rooms, classrooms, multiuse areas.

14 Common room, den, family room, living room, lounge, music room, recreation room, sitting room.

15 Sales area, showroom. Excludes display windows (56).

16 Art gallery, exhibit hall, library.

17 Swimming pool.

10 Assembly or sales areas, other.

Bedrooms

21 Bedroom for less than five people. Includes jail or prison cells, lockups, patient rooms, sleeping areas.

22 Bedroom for more than five people. Includes barracks, dormitories, patient wards.

Kitchen

24 Cooking area, kitchen.

Other Function Areas

23 Dining room, cafeteria, bar area, beverage service area, canteen area, lunchroom

25 Bathroom, checkroom, lavatory, locker room, powder room, outhouse, portable toilet

26 Laundry area, wash house (laundry).

27 Office.

28 Personal service area. Includes barber/beauty salon area, exercise/health club,

20 Function areas, other.

Technical Processing Areas

31 Laboratory.

32 Dark room, photography area, printing area.

33 Treatment: first-aid area, surgery area (minor procedures).

34 Surgery area: major operations, operating room or theater, recovery room.

35 Computer room, control room or center, data processing center, electronic equipment area, telephone booth or area, radar room.

36 Stage area: performance, basketball court, boxing ring, dressing room , ice rink.

37 Projection room, spotlight area, stage light area.

38 Processing/manufacturing area, workroom, assembly area.

30 Technical processing areas, other.

Storage Areas

41 Storage room, area, tank, bin. Includes all areas where products are held awaiting process, shipment, use, sale.

42 Closet.

43 Storage: supplies or tools. Includes dead storage, maintenance supply room, tool room, basement (unfinished).

44 Records storage room, storage vault.

45 Shipping/receiving area: loading area, dock or bay, mail room, packing area.

46 Chute/container: trash, rubbish, waste. Includes compactor and garbage areas. Excludes incinerators (64).

47 Vehicle storage area: garage, carport.

40 Storage areas, other.

Service Areas

51 Dumbwaiter or elevator shaft.

52 Conduit, pipe, utility, or ventilation shaft.

53 Light shaft.

54 Chute. Includes laundry or mail chutes. Excludes trash chutes (46).

55 Duct. Includes HVAC, cable, exhaust.

56 Display window.

58 Conveyor.

50 Service areas, other.

Service or Equipment Areas

61 Machinery room or area. Includes elevator machinery room, engine room, head house, pump room, refrigeration room.

62 Heating room or area, water heater area.

63 Switchgear area, transformer vault.

64 Incinerator area.

65 Maintenance shop or area. Includes paint shop, repair shop, welding area, workshop.

66 Cell, test.

67 Enclosure, pressurized air.

68 Enclosure with enriched oxygen atmosphere.

60 Service or equipment areas, other.

Structural Areas

71 Substructure area or space, crawl space.

72 Exterior balcony, unenclosed porch. Excludes enclosed porches (93).

73 Ceiling and floor assembly, crawl space between stories.

74 Attic: vacant, crawl space above top story. Includes cupola, concealed roof/ceiling space, steeple.

75 Wall assembly, concealed wall space.

76 Wall surface, exterior.

77 Roof surface, exterior.

78 Awning.

70 Structural areas, other.

Transportation, Vehicle Areas

81 Operator/passenger area of transportation equipment.

82 Cargo/trunk area all vehicles.

83 Engine area, running gear, wheel area.

84 Fuel tank, fuel line.

85 Separate operator/control area of transportation equipment. Includes bridges of ships, cockpit of planes. Excludes automobiles, trucks, buses (81).

86 Exterior, exposed surface.

80 Vehicle areas, other.

Outside Areas

91 Railroad right-of-way: on or near.

92 Highway, parking lot, street: on or near.

93 Courtyard, patio, terrace. Includes screened-in porches. Excludes unenclosed porches

94 Open area, outside. Includes farmland, fields, lawns, parks, vacant lots.

95 Wildland, woods.

96 Construction/Renovation area.

97 Multiple areas.

98 Vacant structural area.

90 Outside areas, other

Item First Ignited Codes

Structural Component, Finish

11 Exterior roof covering, surface, finish.

12 Exterior sidewall covering, surface, finish. Includes eaves.

13 Exterior trim, appurtenances. Includes doors, porches, and platforms.

14 Floor covering or rug/carpet/mat, surface.

15 Interior wall covering. Includes cloth wall coverings, wood paneling, and items permanently affixed to a wall or door. Excludes curtains and draperies (36) and decorations (42).

16 Interior ceiling covering or finish. Includes cloth permanently affixed to ceiling and acoustical tile.

17 Structural member or framing.

18 Thermal, acoustical insulation within wall, partition or floor/ceiling space. Includes fibers, batts, boards, loose fills.

10 Structural component or finish, other.

Furniture, Utensils. Includes built-in furniture.

21 Upholstered sofa, chair, vehicle seats.

22 Non-upholstered chair, bench.

23 Cabinetry. Includes filing cabinets, pianos, dressers, chests of drawers, desks, tables, and bookcases. Excludes TV sets, bottle warmers, and appliance housings (25).

24 Ironing board.

25 Appliance housing or casing.

26 Household utensils. Includes kitchen and cleaning utensils.

20 Furniture, utensils, other.

Soft Goods, Wearing Apparel

31 Mattress, pillow.

32 Bedding: blanket, sheet, comforter. Includes heating pads.

33 Linen, other than bedding. Includes towels and tablecloths.

34 Wearing apparel not on a person.

35 Wearing apparel on a person.

36 Curtain, blind, drapery, tapestry.

37 Goods not made up. Includes fabrics and yard goods.

38 Luggage.

30 Soft goods, wearing apparel, other.

Adornment, Recreational Material, Signs

41 Christmas tree.

42 Decoration.

43 Sign. Includes outdoor signs such as billboards.

44 Chips. Includes wood chips.

45 Toy, game.

46 Awning, canopy.

47 Tarpaulin, tent.

40 Adornment, recreational material, signs, other.

Storage Supplies

51 Box, carton, bag, basket, barrel. Includes wastebaskets.

52 Material being used to make a product. Includes raw materials used as input to a manufacturing or construction process. Excludes finished products.

53 Pallet, skid (empty). Excludes palletized stock (58).

54 Cord, rope, twine, yarn.

55 Packing, wrapping material.

56 Baled goods or material. Includes bale storage.

57 Bulk storage.

58 Palletized material, material stored on pallets.

59 Rolled, wound material. Includes rolled paper and fabrics.

50 Storage supplies, other.

Liquids, Piping, Filters

61 Atomized, vaporized liquid. Included are aerosols.

62 Flammable liquid/gas (fuel) in or escaping from combustion engines.

63 Flammable liquid/gas in or escaping from final container or pipe before engine or burner. Includes piping between the engine and the burner.

64 Flammable liquid/gas in or escaping from container or pipe. Excludes engines, burners, and their fuel systems.

65 Flammable liquid/gas, uncontained. Includes accelerants.

66 Pipe, duct, conduit, hose.

67 Pipe, duct, conduit, or hose covering. Includes insulating materials whether for acoustical or thermal purposes, and whether inside or outside the pipe, duct, conduit, or hose.

68 Filter. Includes evaporative cooler pads.

60 Liquids, piping, filters, other.

Organic Materials

71 Agricultural crop. Includes fruits and vegetables.

72 Light vegetation (not crop). Includes grass, leaves, needles, chaff, mulch, and compost.

73 Heavy vegetation (not crop). Includes trees and brush.

74 Animal, living or dead.

75 Human, living or dead.

76 Cooking materials. Includes edible materials for man or animal. Excludes cooking utensils (26).

77 Feathers or fur not on a bird or animal, but not processed into a product.

70 Organic materials, other.

General Materials

81 Electrical wire, cable insulation. Do not classify the insulation on the wiring as the item first ignited unless there were no other materials in the immediate area, such as might be found in a cable tray or electrical vault.

82 Transformer. Includes transformer fluids.

83 Conveyor belt, drive belt, V-belt.

84 Tire.

85 Railroad ties.

86 Fence, pole.

87 Fertilizer.

88 Pyrotechnics, explosives.

91 Book.

92 Magazine, newspaper, writing paper. Includes files.

93 Adhesive.

94 Dust, fiber, lint. Includes sawdust and excelsior.

95 Film, residue. Includes paint, resin, and chimney film or residue and other films and residues produced as a byproduct of an operation.

96 Rubbish, trash, waste.

97 Oily rags.

99 Multiple items first ignited. Use only where there are multiple fires started at approximately the same time on the same property and more than one item was initially involved.

Heat Source Codes

Operating Equipment

11 Spark, ember, or flame from operating equipment.

12 Radiated or conducted heat from operating equipment.

10 Heat from operating equipment, other.

13 Electrical arcing.

Hot or Smoldering Object

41 Heat, spark from friction. Includes overheated tires.

42 Molten, hot material. Includes molten metal, hot forging, hot glass, hot metal fragment, brake shoe, hot box, and slag from arc welding operations.

43 Hot ember or ash. Includes hot coals, coke, and charcoal; and sparks or embers from a chimney that ignite the roof of the same structure. Excludes flying brand, embers, and sparks (83); and embers accidentally escaping from operating equipment (11).

40 Hot or smoldering object, other.

Explosives, Fireworks

51 Munitions. Includes bombs, ammunition, and military rockets.

53 Blasting agent, primer cord, black powder fuse. Includes fertilizing agents, ammonium nitrate, and sodium, potassium, or other chemical agents.

54 Fireworks. Includes sparklers, paper caps, party poppers, and firecrackers.

55 Model and amateur rockets.

56 Incendiary device. Includes Molotov cocktails and arson sets.

50 Explosive, fireworks, other.

Other Open Flame or Smoking Materials

61 Cigarette.

62 Pipe or cigar.

63 Heat from undetermined smoking material.

64 Match.

65 Lighter: cigarette lighter, cigar lighter.

67 Warning or road flare; fusee.

68 Backfire from internal combustion engine. Excludes flames and sparks from an exhaust system (11).

69 Flame/torch used for lighting. Includes gas light and gas-/liquid-fueled lantern.

60 Heat from open flame or smoking materials, other.

66 Candle.

Chemical, Natural Heat Sources

71 Sunlight. Usually magnified through glass, bottles, etc.

72 Spontaneous combustion, chemical reaction.

73 Lightning discharge.

74 Other static discharge. Excludes electrical arcs (13) or sparks (11).

70 Chemical, natural heat sources, other.

Heat Spread From Another Fire. Excludes operating equipment.

81 Heat from direct flame, convection currents spreading from another fire.

82 Radiated heat from another fire. Excludes heat from exhaust systems of fuel-fired, fuel-powered equipment (12).

83 Flying brand, ember, spark. Excludes embers, sparks from a chimney igniting the roof of the same structure (43).

84 Conducted heat from another fire.

80 Heat spread from another fire, other.

Other Heat Sources

97 Multiple heat sources, including multiple ignitions. If one type of heat source was primarily involved, use that classification.

Appendix B: Distribution of Heat Source for Each Combination of Area of Origin and Item First Ignited separated by Fire Spread

Assembly:

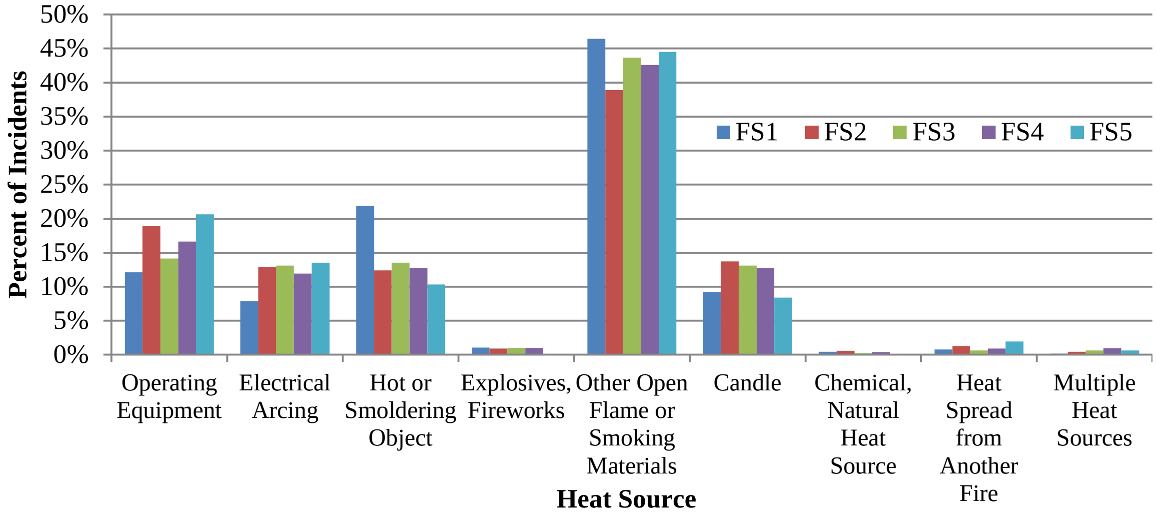


Figure B1: Distribution of Heat Source for Upholstered Sofa ignited in Assembly

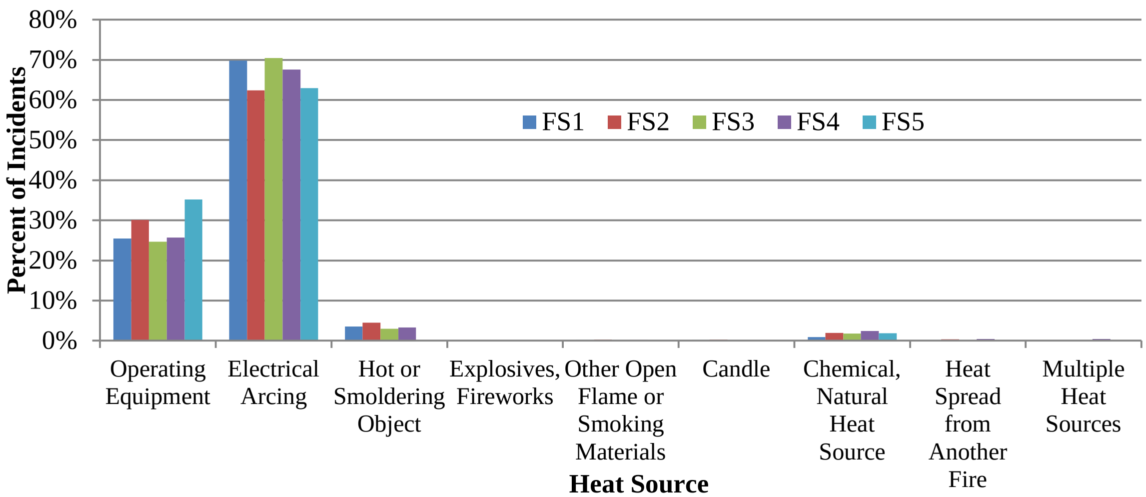


Figure B2: Distribution of Heat Source for Electrical Wire ignited in Assembly

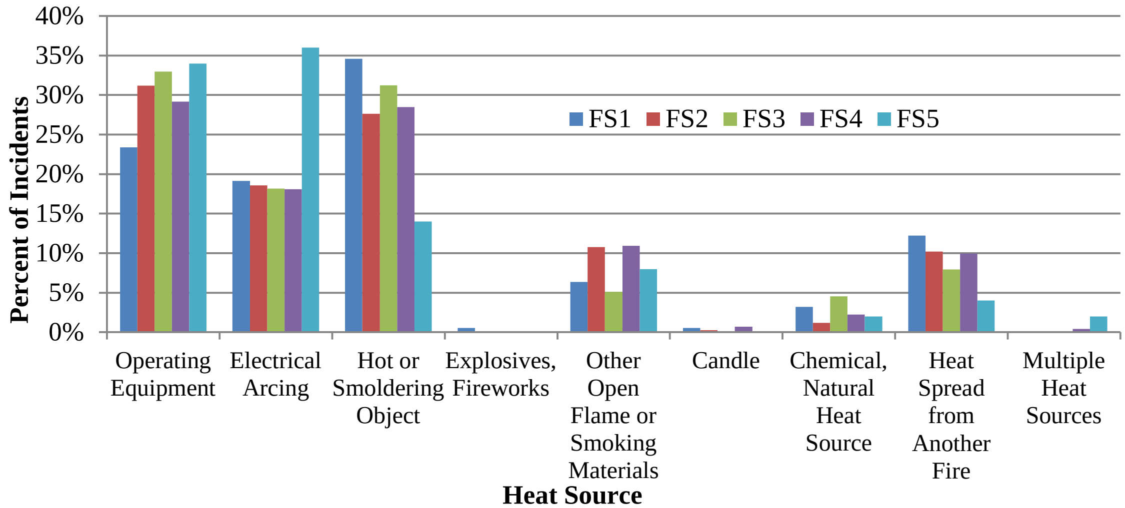


Figure B3: Distribution of Heat Source for Structural Member ignited in Assembly

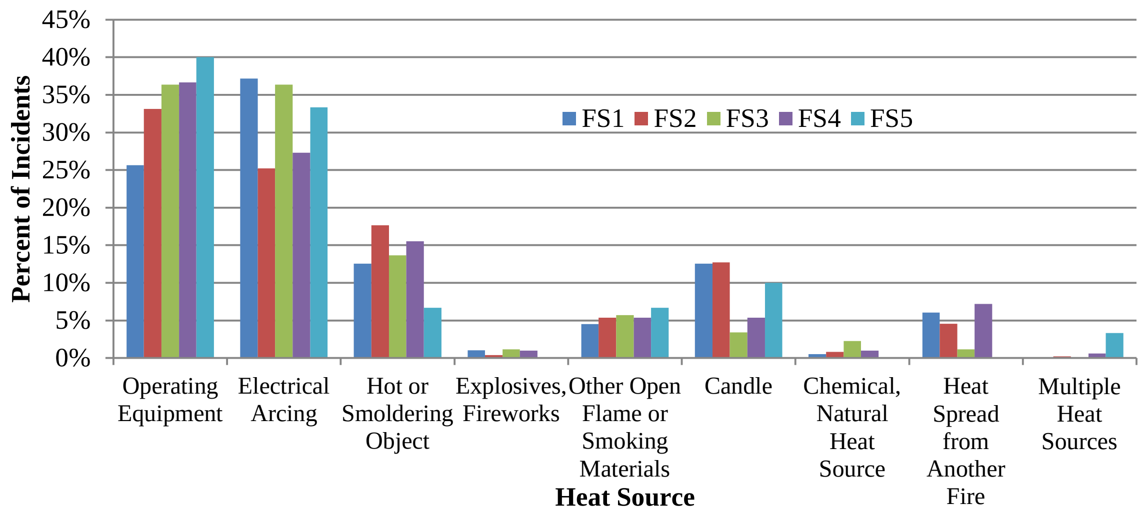


Figure B4: Distribution of Heat Source for Interior Wall Covering ignited in Assembly

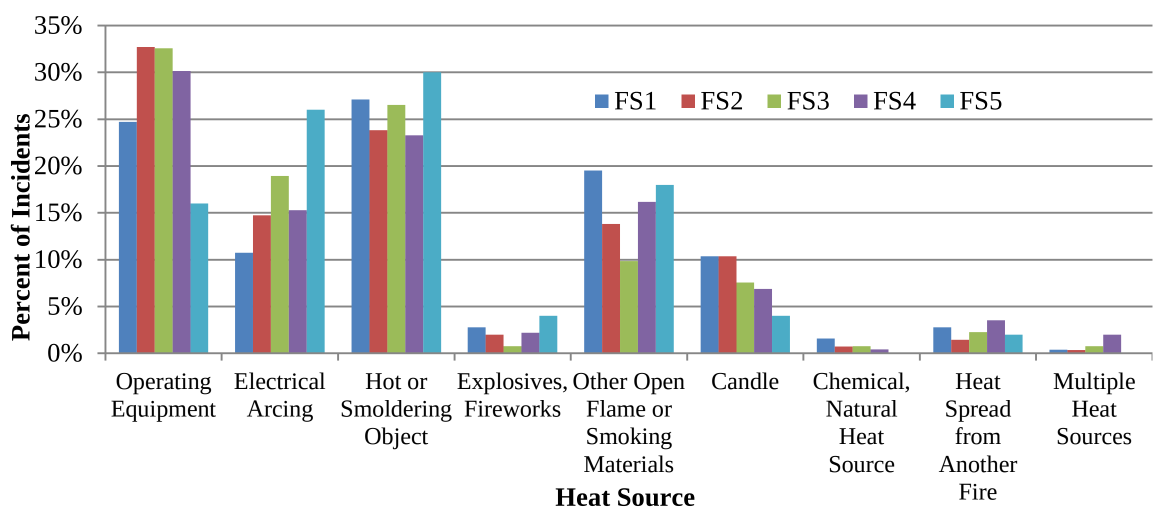


Figure B5: Distribution of Heat Source for Floor Covering ignited in Assembly

Bedrooms:

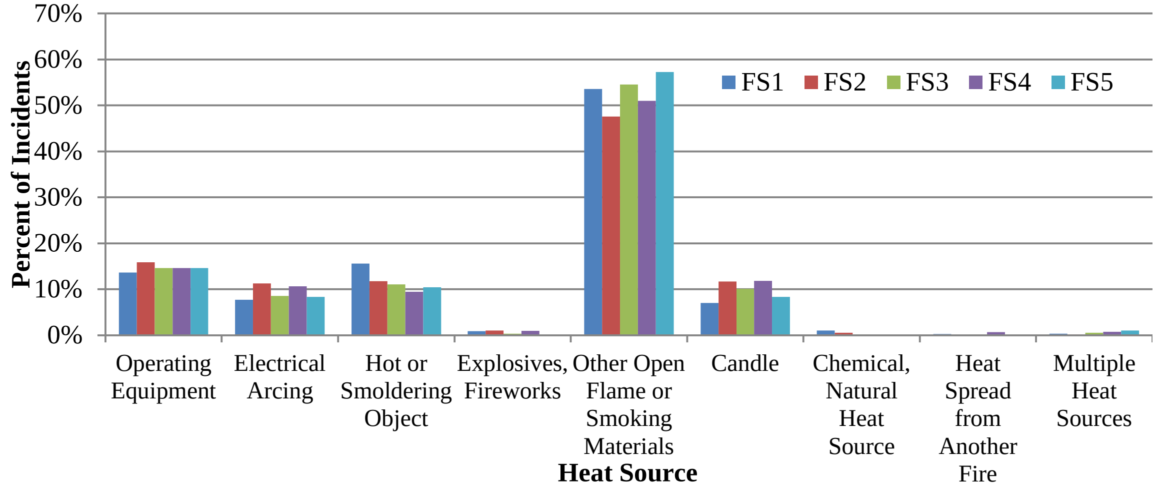


Figure B6: Distribution of Heat Source for Mattress ignited in Bedrooms

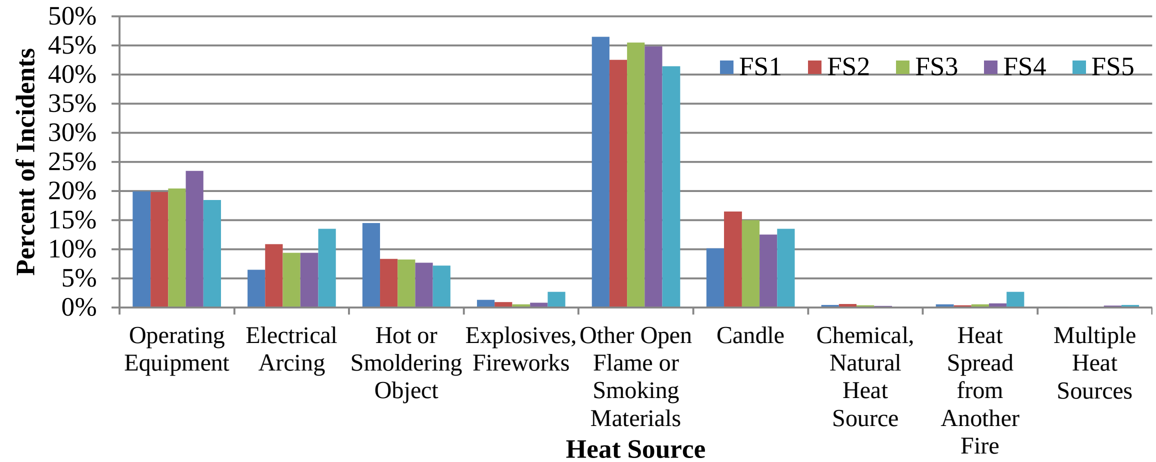


Figure B7: Distribution of Heat Source for Bedding ignited in Bedrooms

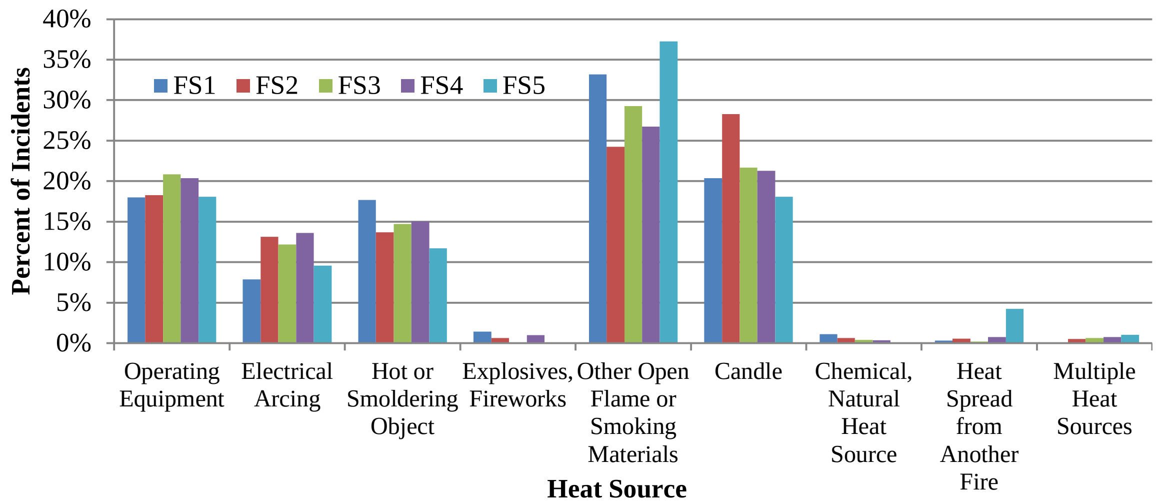


Figure B8: Distribution of Heat Source for Other Furniture ignited in Bedrooms

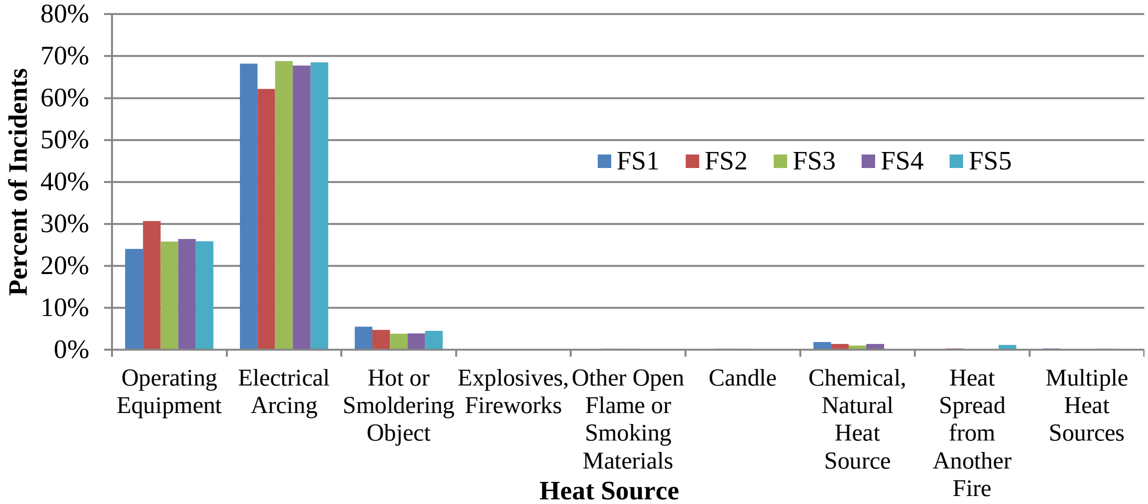


Figure B9: Distribution of Heat Source for Electrical Wire in Bedrooms

Kitchen:

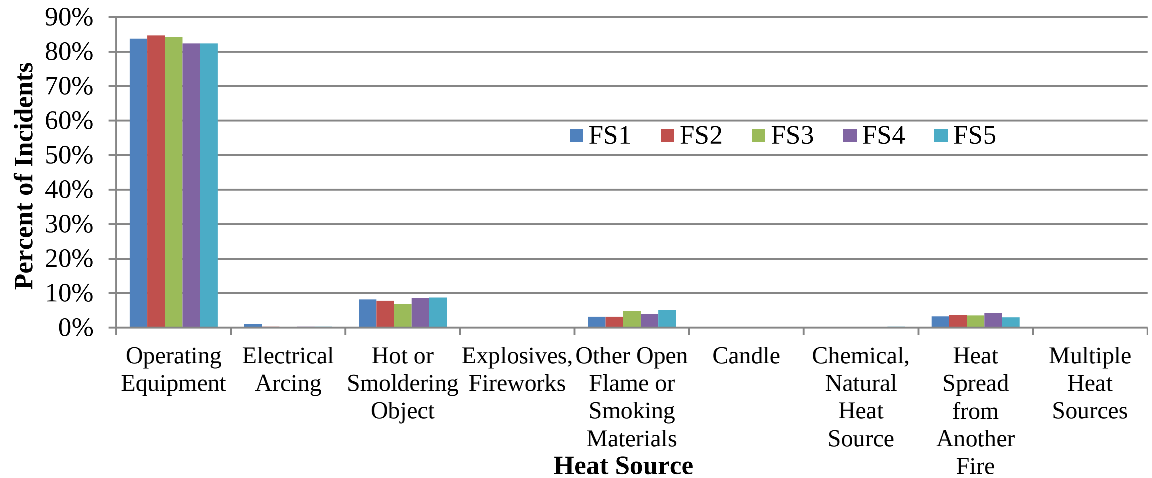


Figure B10: Distribution of Heat Source for Food ignited in Kitchens

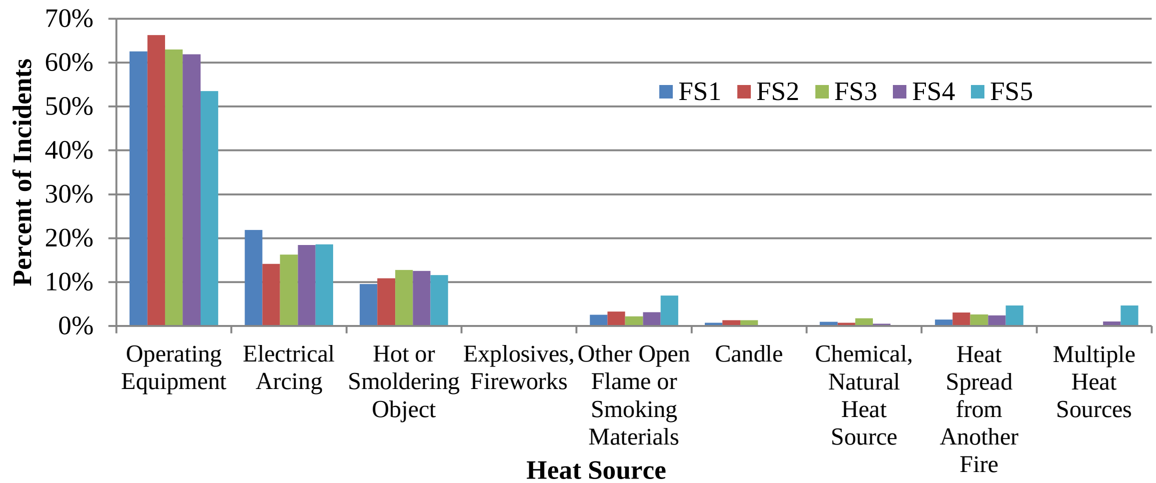


Figure B11: Distribution of Heat Source for Appliance Housing ignited in Kitchens

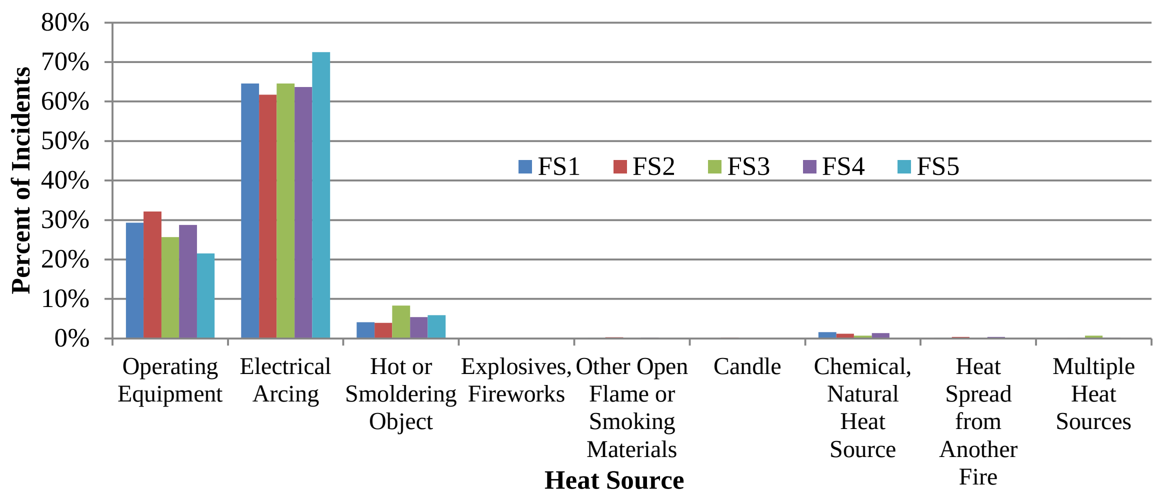


Figure B12: Distribution of Heat Source for Electrical Wire ignited in Kitchens

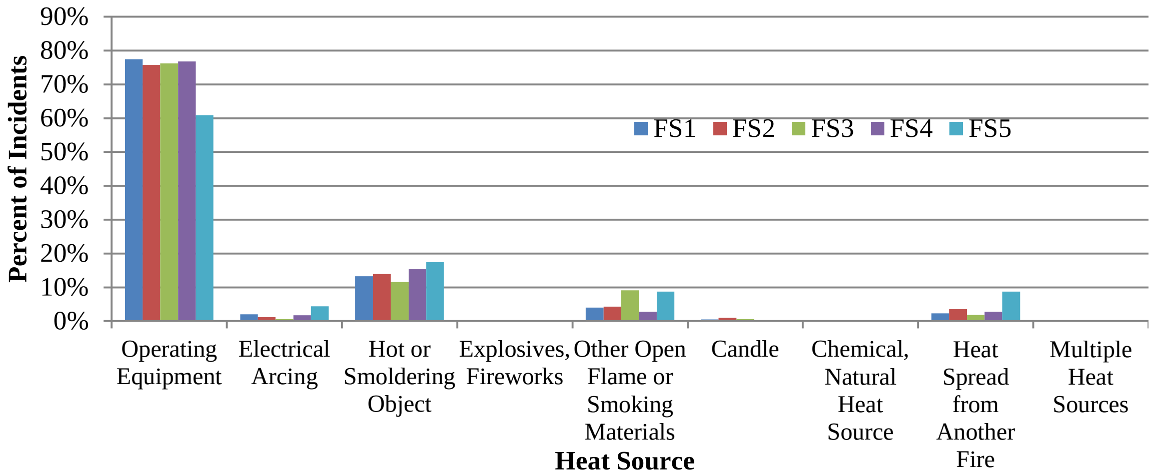


Figure B13: Distribution of Heat Source for Utensils ignited in Kitchens

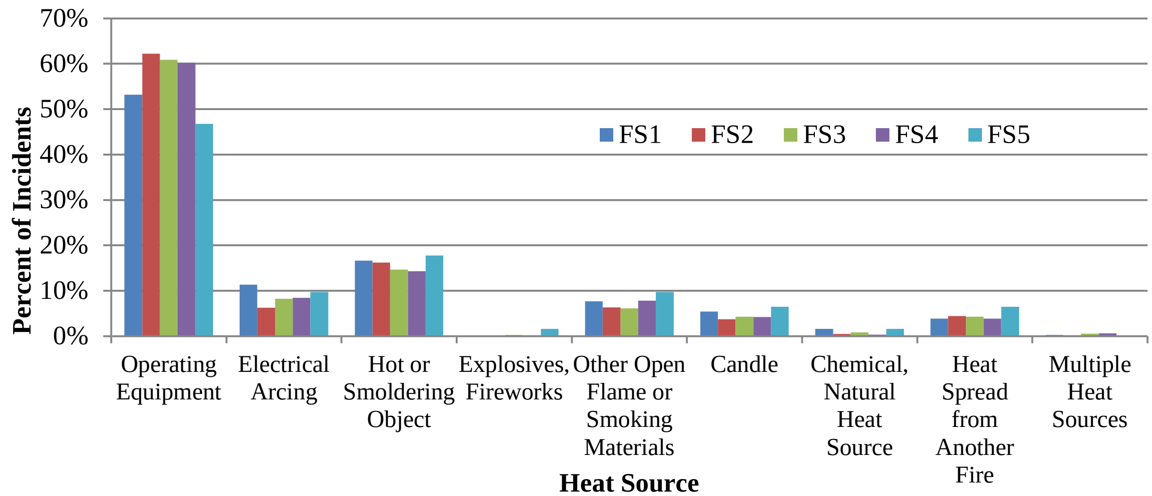


Figure B14: Distribution of Heat Source for Cabinetry ignited in Kitchens

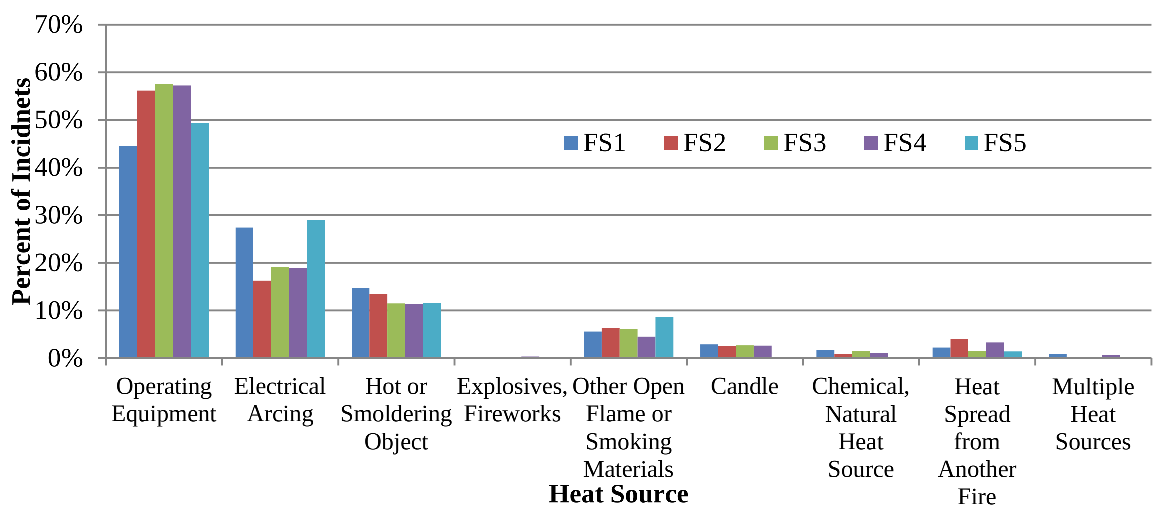


Figure B15: Distribution of Heat Source for Interior Wall Covering ignited in Kitchens

Other Function Areas:

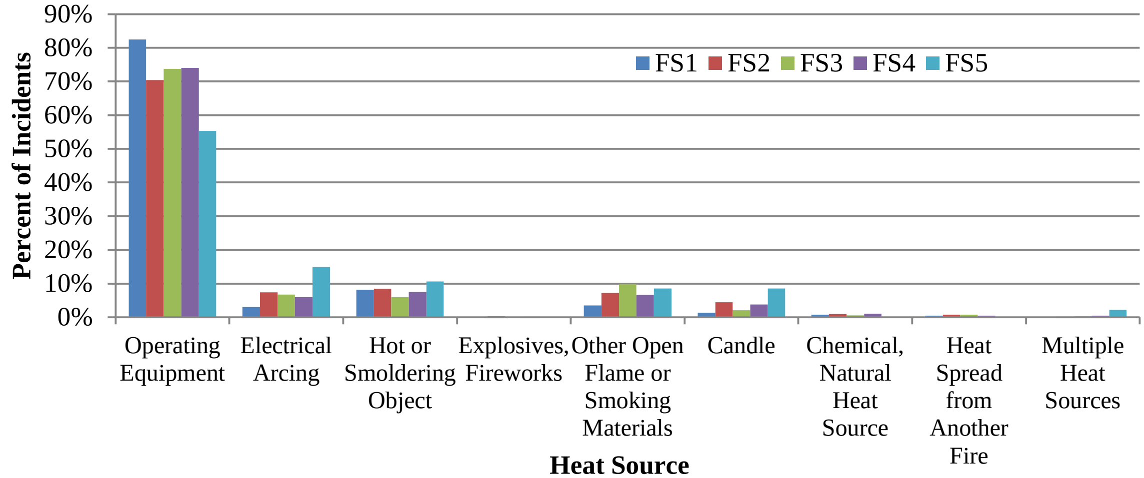


Figure B16: Distribution of Heat Source for Clothes ignited in Other Function Areas

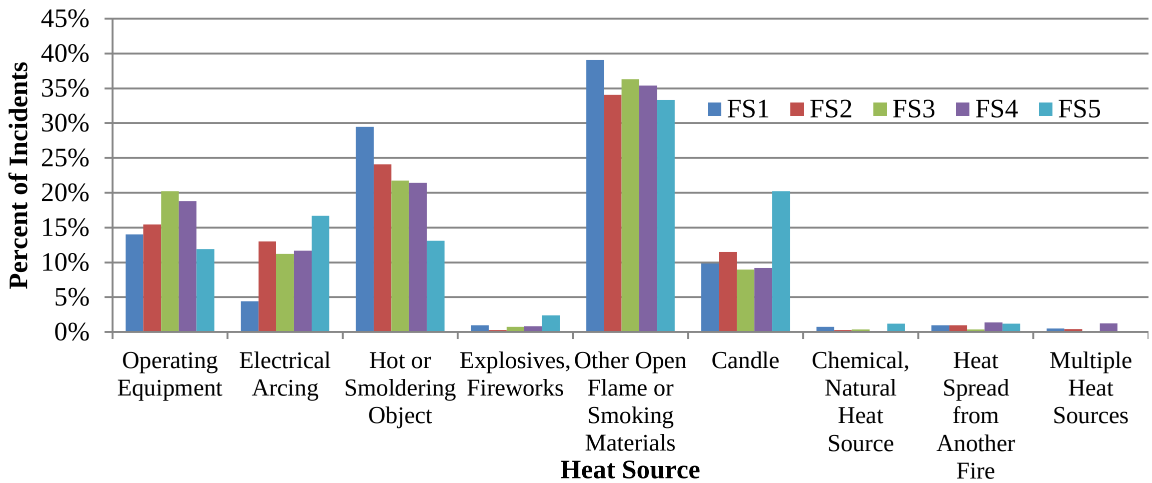


Figure B17: Distribution of Heat Source for Upholstered Sofa ignited in Other Function Areas

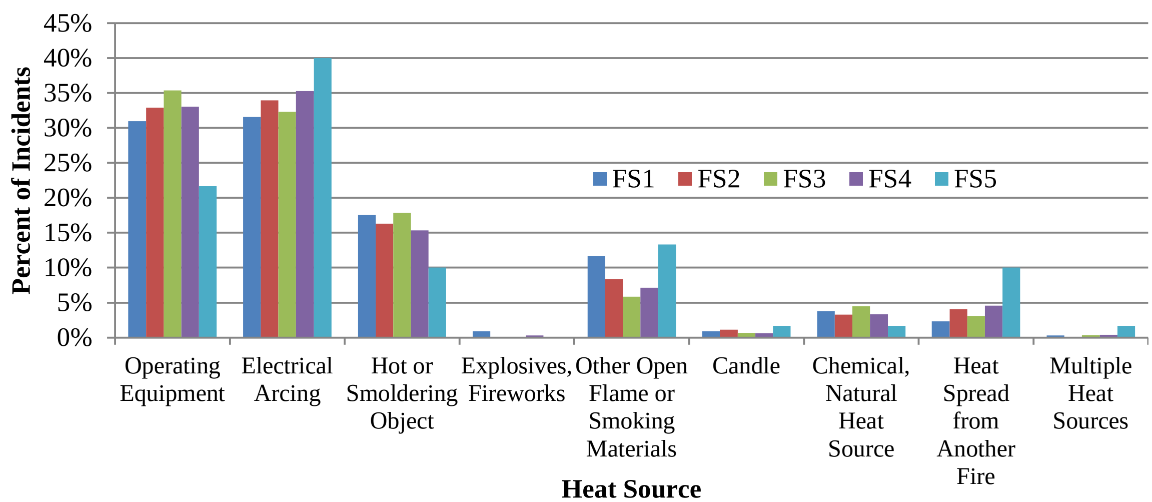


Figure B18: Distribution of Heat Source for Structural Member ignited in Other Function Areas

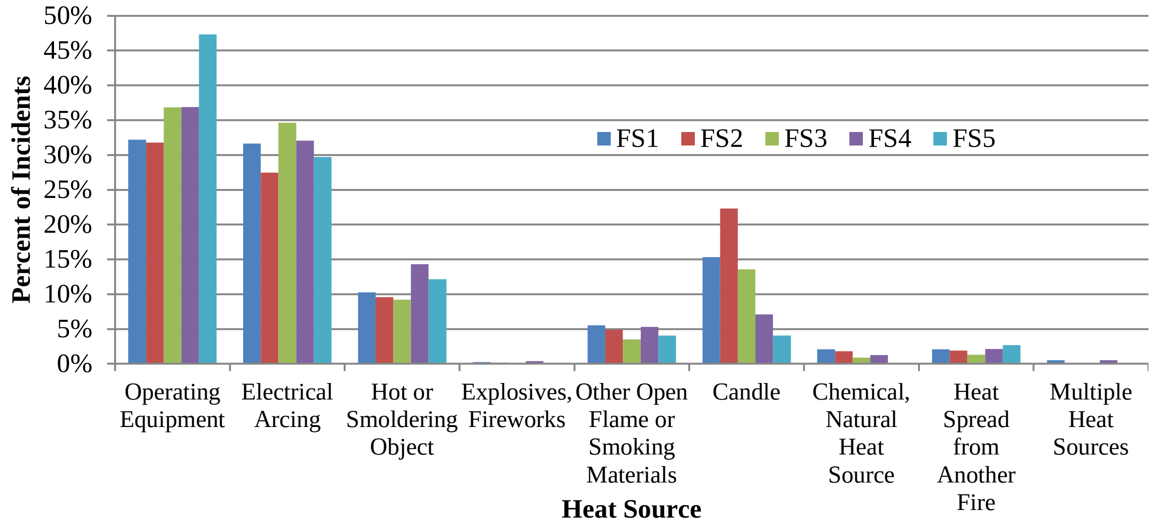


Figure B19: Distribution of Heat Source for Interior Wall Covering in Other Function Areas

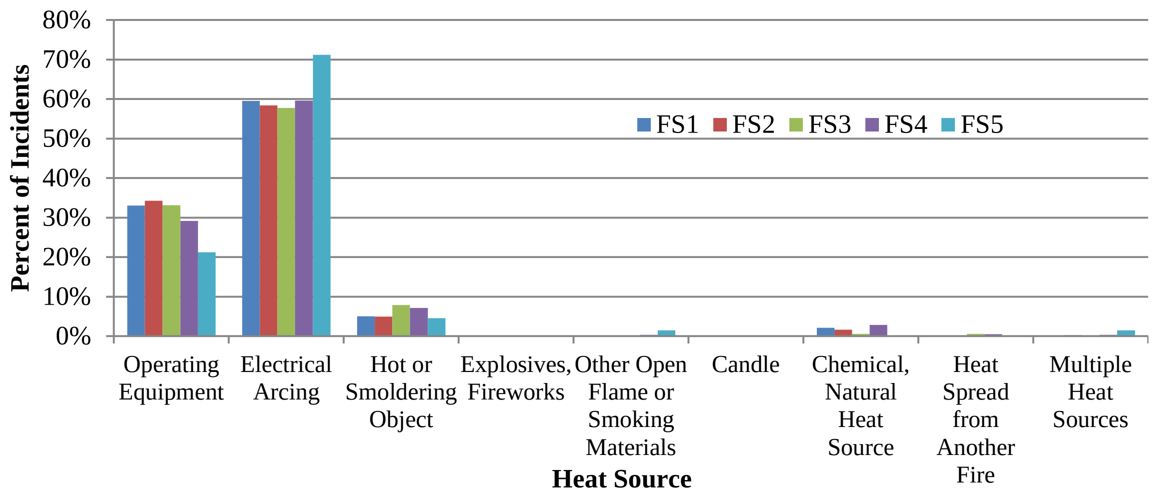


Figure B20: Distribution of Heat Source for Electrical Wire ignited in Other Function Areas

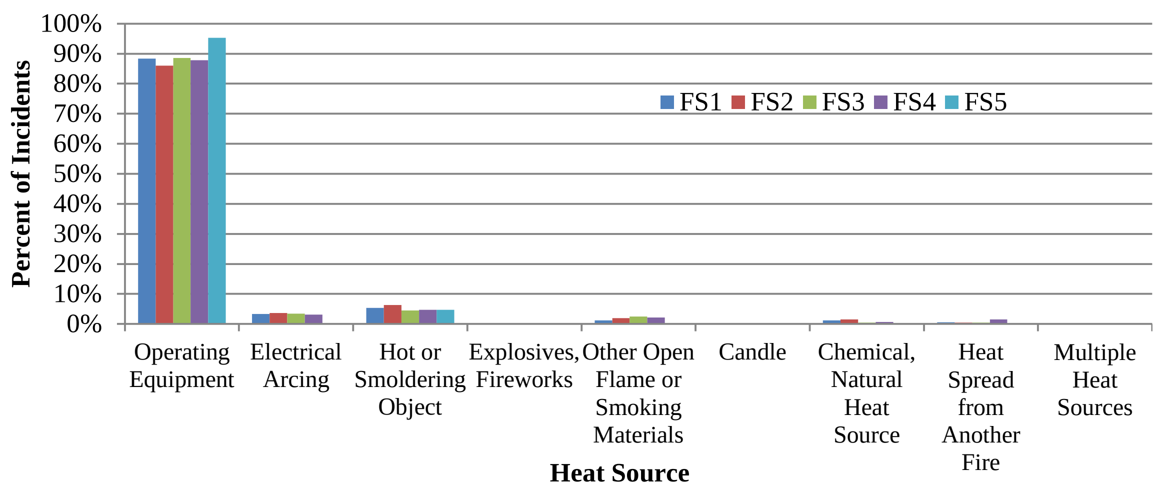


Figure B21: Distribution of Heat Source for Dust ignited in Other Function Areas

Storage Areas:

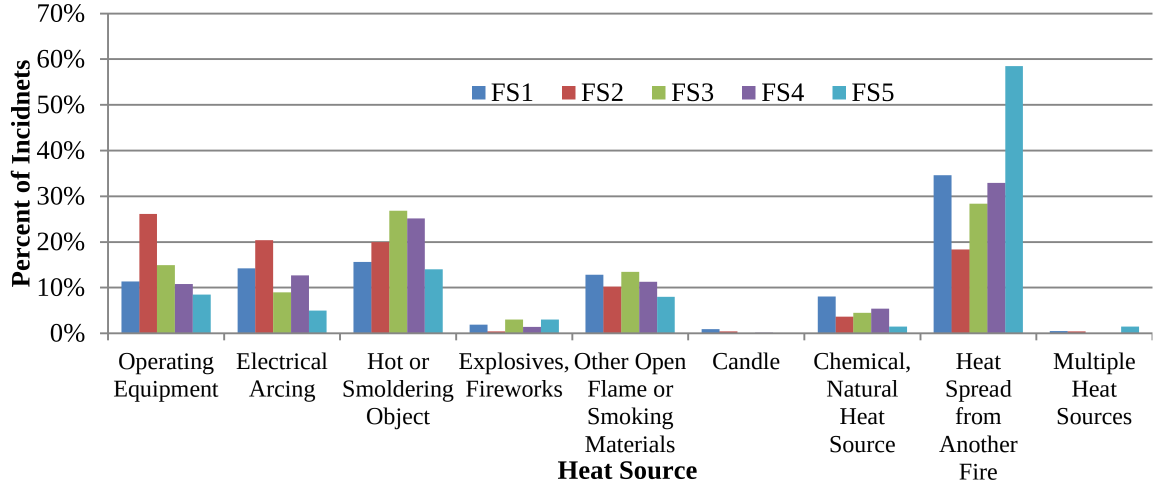


Figure B22: Distribution of Heat Source for Exterior Sidewall Covering ignited in Storage Areas

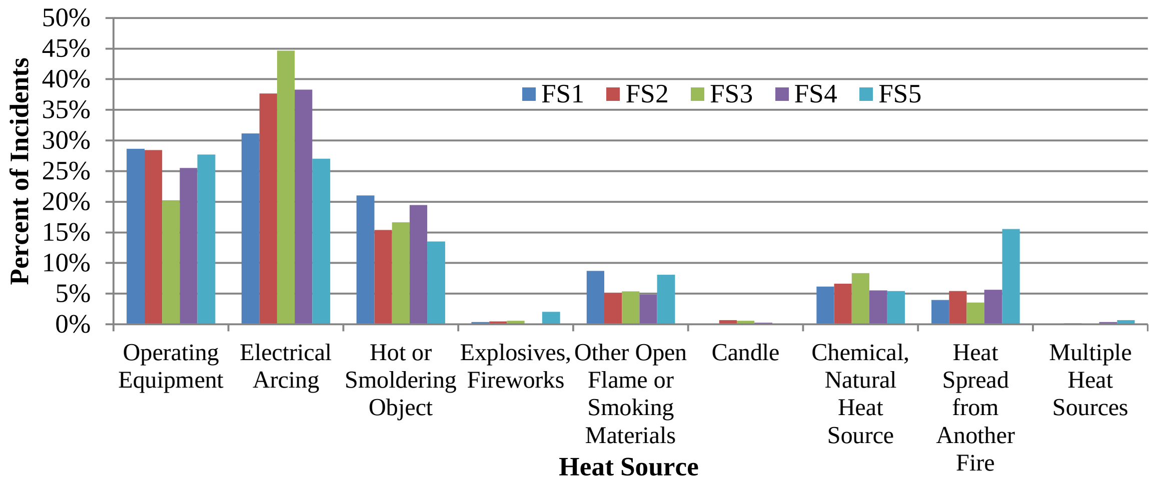


Figure B23: Distribution of Heat Source for Structural Member ignited in Storage Areas

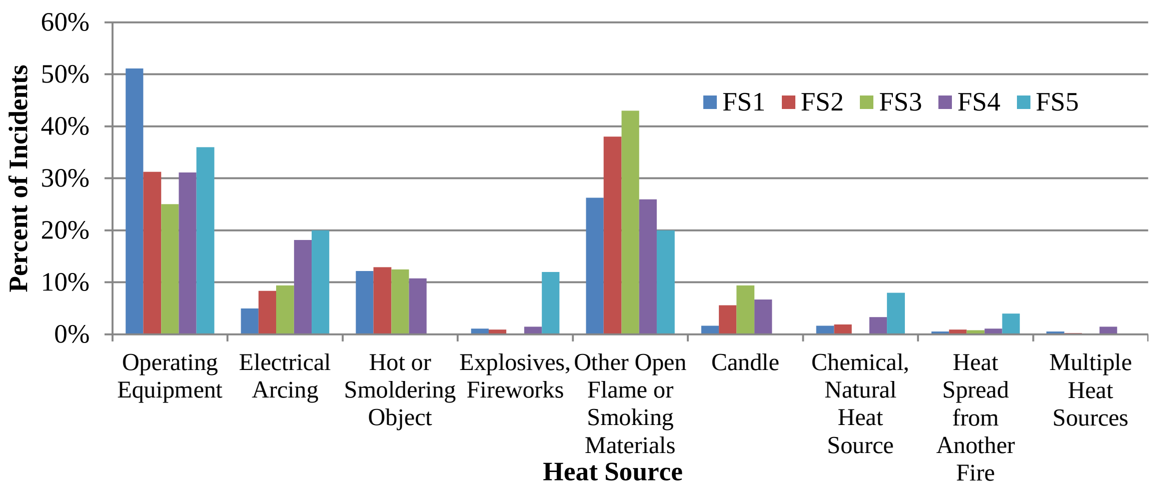


Figure B24: Distribution of Heat Source for Clothes ignited in Storage Areas

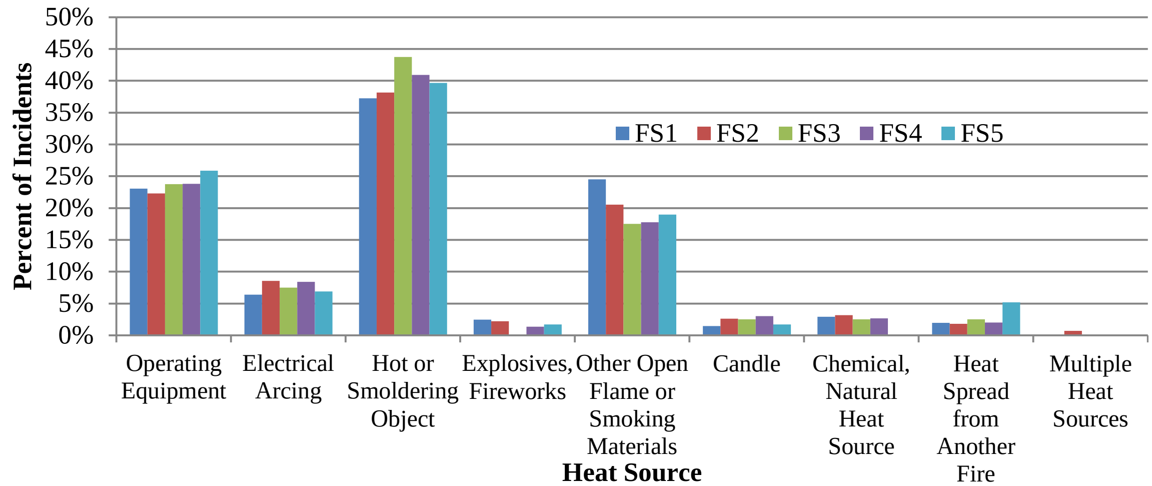


Figure B25: Distribution of Heat Source for Boxes ignited in Storage Areas

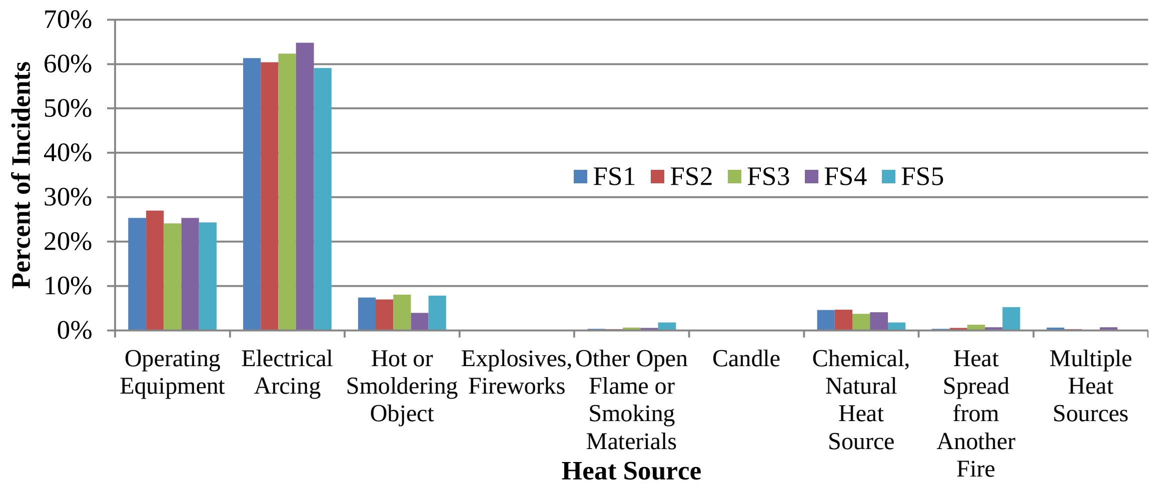


Figure B26: Distribution of Heat Source for Electrical Wire ignited in Storage Areas

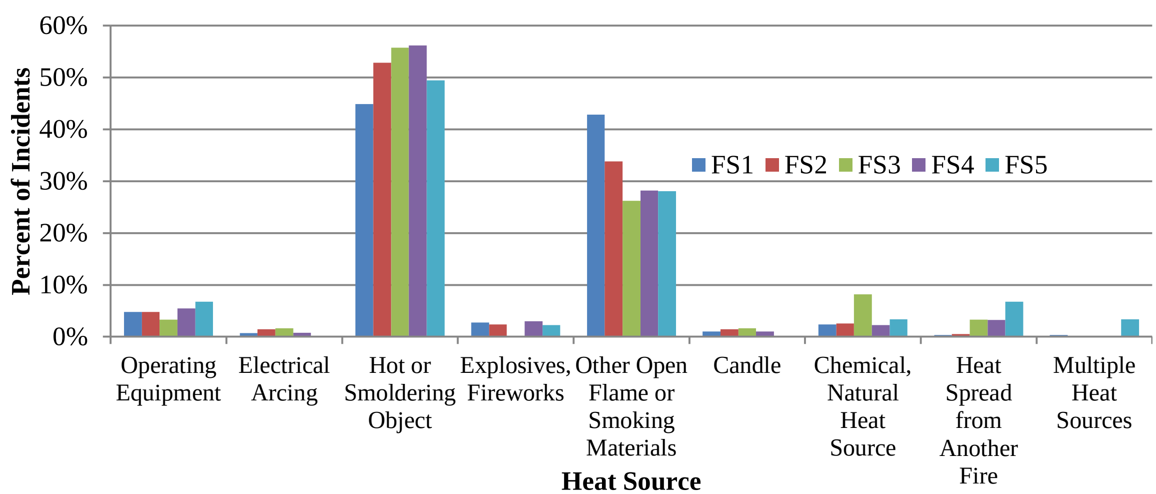


Figure B27: Distribution of Heat Source for Trash ignited in Storage Areas

Structural Areas:

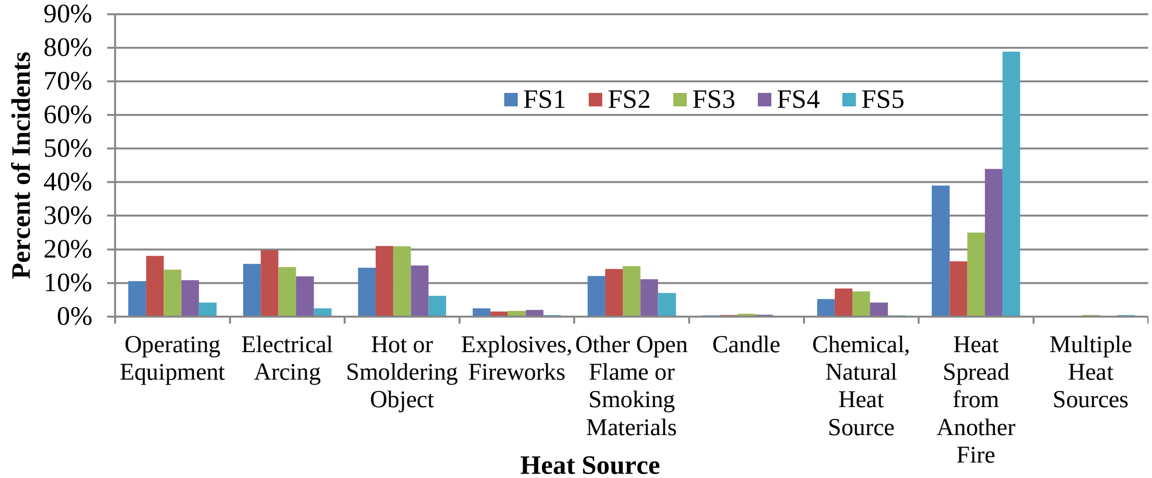


Figure B28: Distribution of Heat Source for Exterior Sidewall Covering in Structural Areas

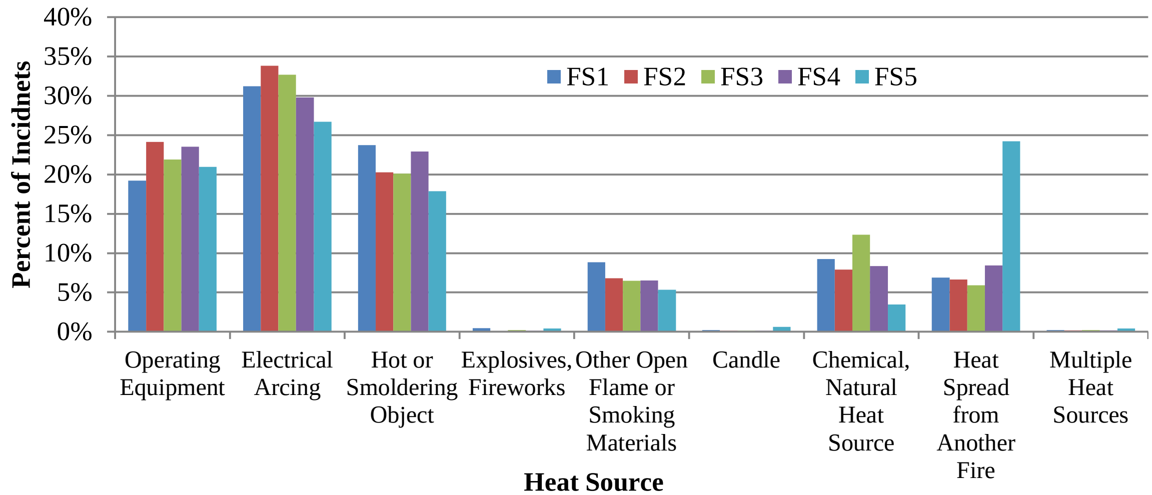


Figure B29: Distribution of Heat Source for Structural Member in Structural Areas

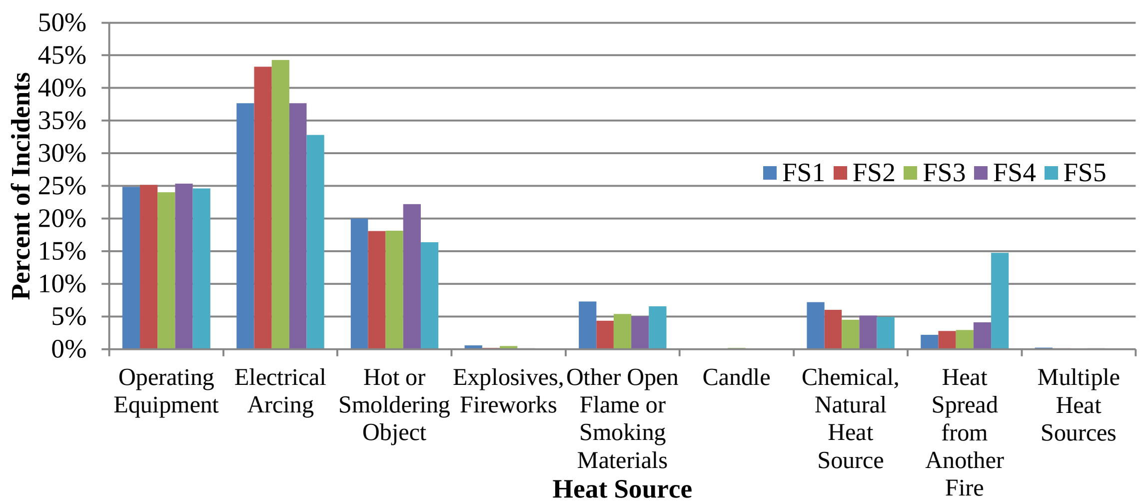


Figure B30: Distribution of Heat Source for Insulation in Structural Areas

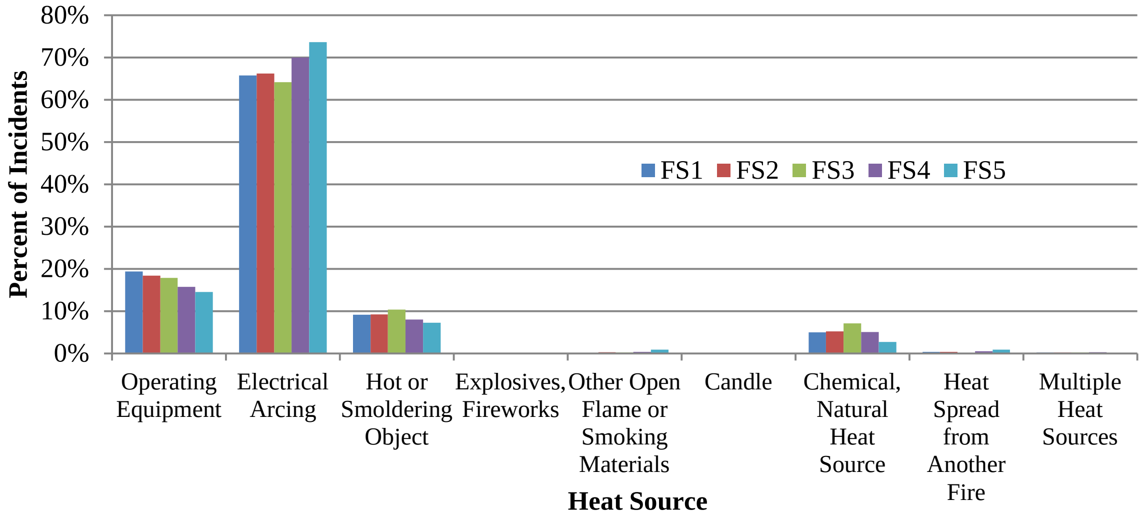


Figure B31: Distribution of Heat Source for Electrical Wire in Structural Areas

Appendix C: Individual Area of Origins Risk Summaries

Structural Areas

Each Area of Origin is examined separately to determine any trends specific to one area. The percentage of incidents in Structural Areas for the top Items First Ignited is illustrated in Figure C1. Insulation and Electrical Wire have a decreasing trend of proportion with increasing Fire Spread. Exterior Sidewall Covering has an extremely high jump for Beyond Building of Origin. If the fire starts on the exterior of the building it increases the chance that the fire could spread beyond that building. The risk model here assumes a linear progression of the fire from confined to object, room, floor, building, beyond building. When the fire starts on the outside or outside of the building it does not follow this normal progression. Although the fire spreads beyond the building, it does not necessarily mean the fire is extremely large. This could lead to an inaccurate heavy weighting of these fires that spread beyond the building of origin.

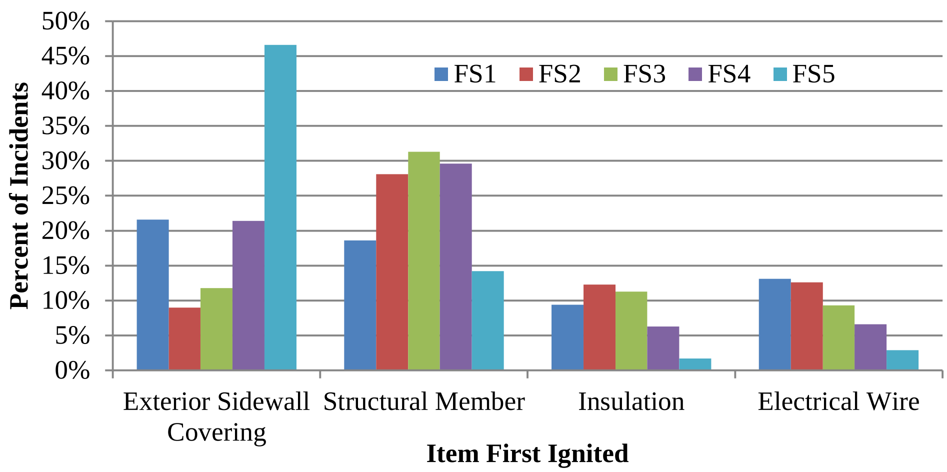


Figure C1: Top Items First Ignited Frequencies for Structural Areas

Figures C2 and C3 are the Structural Areas only version of Figures 4.6 and 4.8. Structural Member is the largest contributor to the risk value of Structural Areas. Structural Member is made up of many heat sources with three large portions from Operating Equipment, Electrical Arcing, and Hot or Smoldering Object. Exterior Sidewall Covering is the second largest contributor and half of its contribution is from the Heat Spread from Another Fire Heat Source. The Structural Area only Heat Source distribution has a different shape than the overall Heat Source distribution. Structural Area has only about half the contribution of Operating Equipment and Other Open Flame or Smoking Materials compared to the overall Heat Source distribution. Heat Spread from Another Fire more than doubles for Structural Areas.

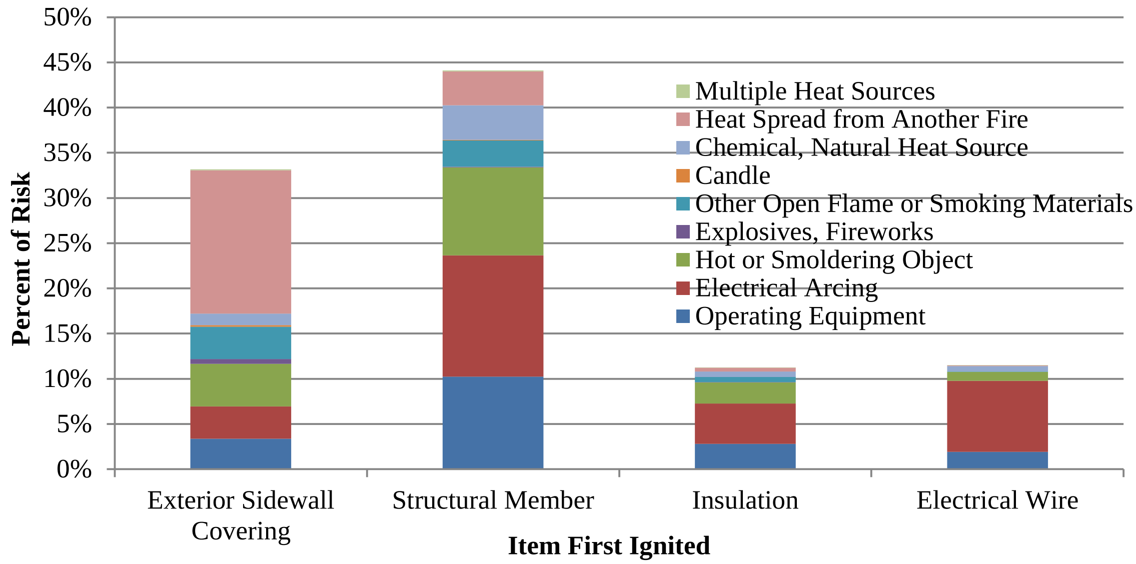


Figure C2: Structural Areas Risk by Item First Ignited and Heat Source

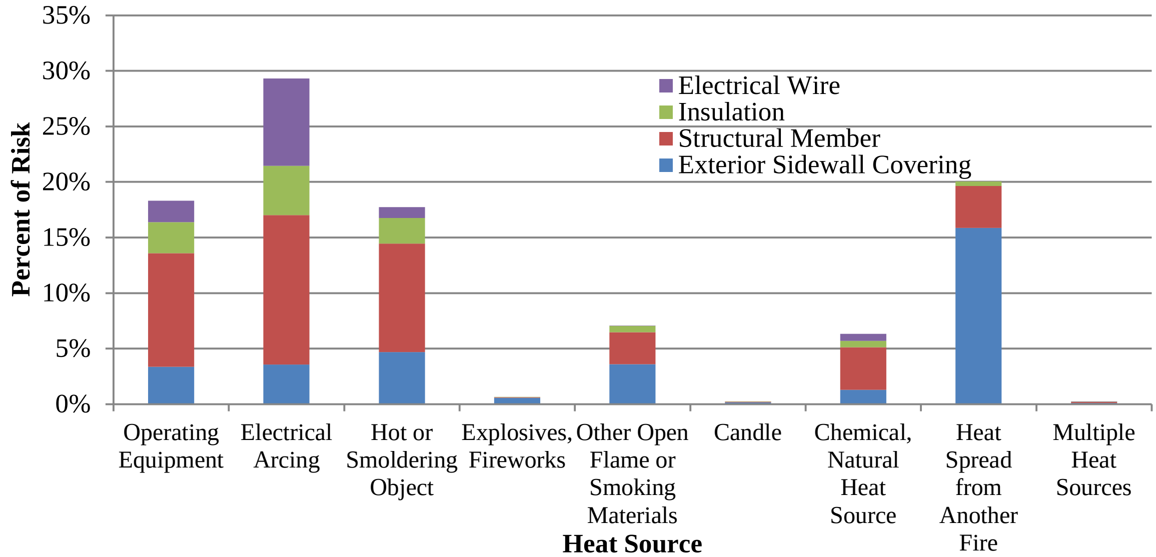


Figure C3: Structural Areas Risk by Heat Source and Item First Ignited

Figures C4 and C5 are the Structural Areas only version of 4.9 and 4.10. Insulation and Electrical Wire only account for half the proportion of large fires compared to their proportion of small fires. This decrease is made up almost entirely by Exterior Sidewall Covering, Structural Member shows no change. Figure C5 reflects these same changes. Electrical Arcing, the main Heat Source for both Insulation and Electrical Wire, decreases from those fires confined to the room to those beyond the room. Heat Spread from Another Fire is the dominant Heat Source for Exterior Sidewall Covering and has a large increase.

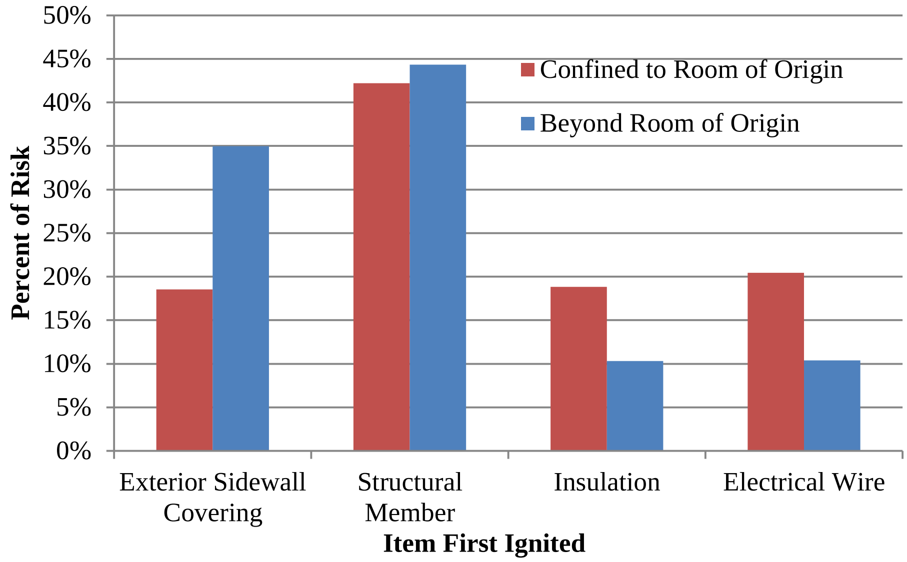


Figure C4: Structural Areas Risk by Item First Ignited

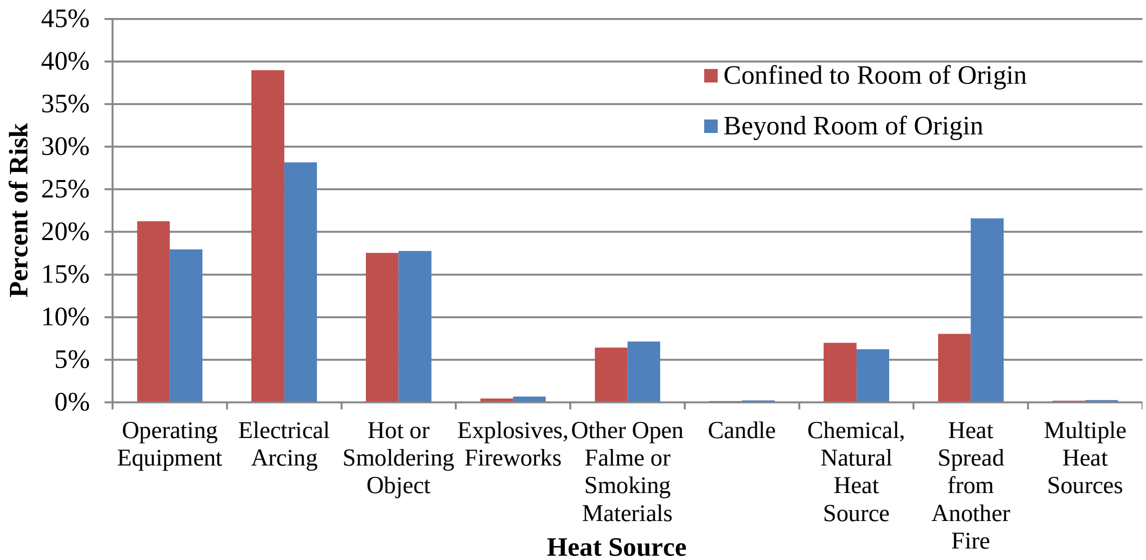


Figure C5: Structural Areas Risk by Heat Source

<u>Assembly</u>

Each Area of Origin is examined separately to determine any trends specific to one Area of Origin. The frequencies of the top Items First Ignited for Assembly are illustrated in Figure C6. The most important observations are the higher proportions for FS3, FS4, and

FS5 for Upholstered Sofa compared to FS1 or FS2. This suggests Upholstered Sofas are more likely to spread beyond the room of origin. The large drop in Electrical Wire after FS1 suggests Electrical Wire is more likely to be contained to itself.

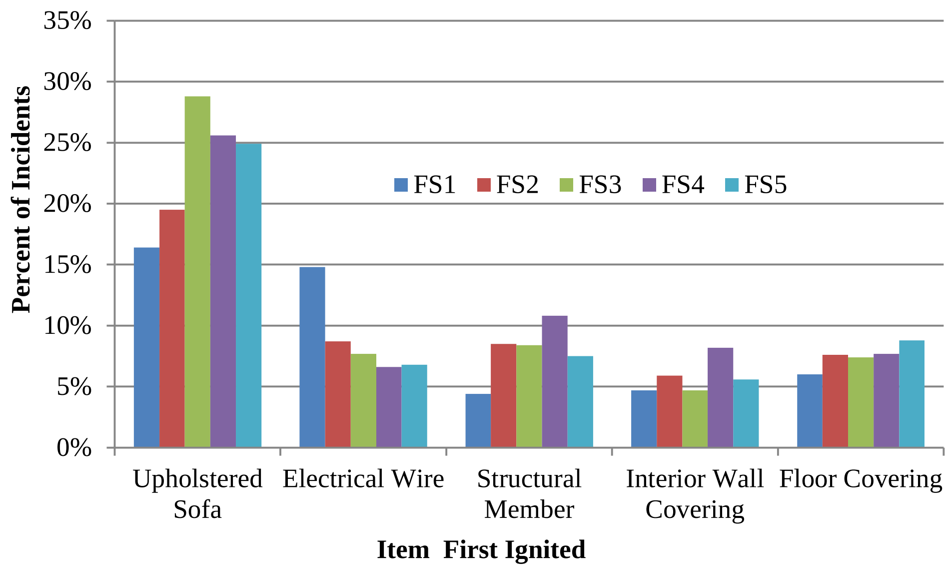


Figure C6: Top Items First Ignited Frequencies for Assembly

The total risk value for Assembly is examined by Item First Ignited and Heat Source in Figures C7 and C8 similar to Figures 4.6 and 4.8 for all Area of Origins.

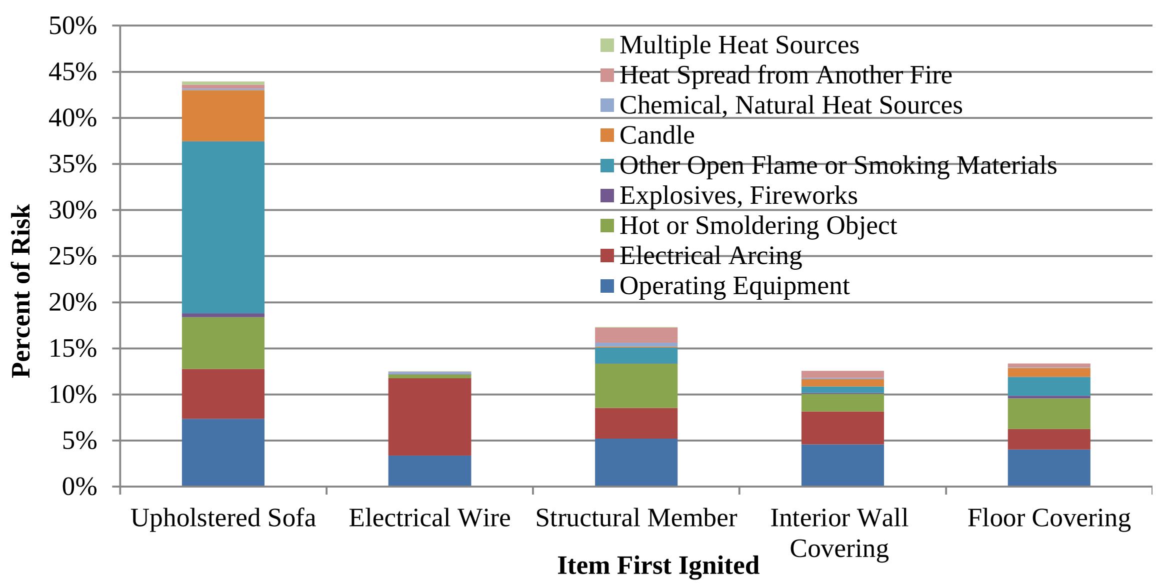


Figure C7: Assembly Risk Value by Item First Ignited and Heat Source

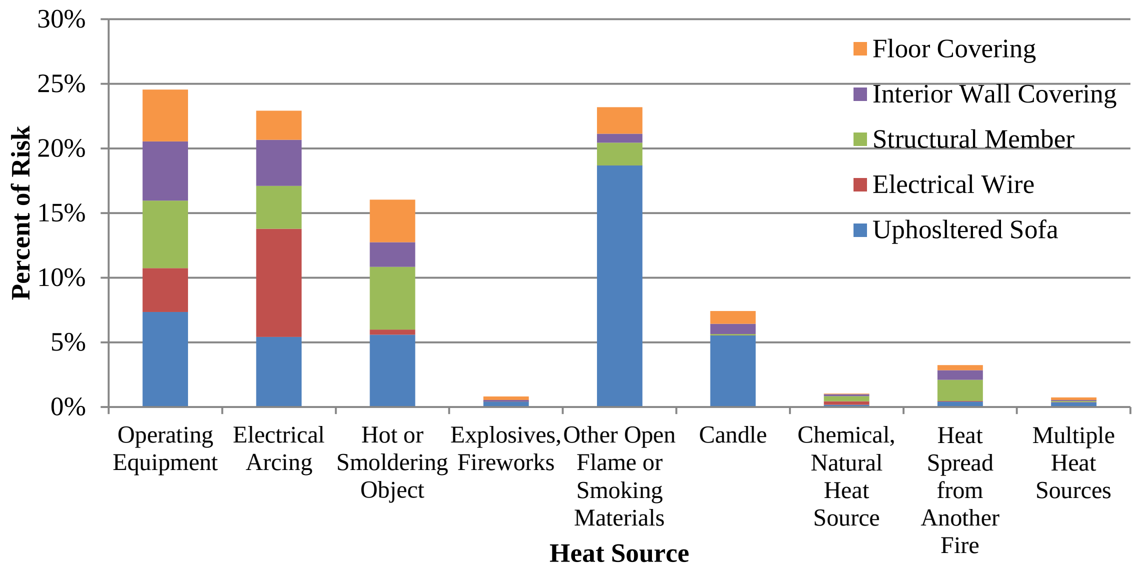


Figure C8: Assembly Risk Value by Heat Source and Item First Ignited

For Assembly, Upholstered Sofa is by far the largest Item First Ignited contributing to the risk value. Of the risk value of Upholstered Sofa, the major Heat Source is Other Open Flame and Smoking Materials, but this category is about even with Operating Equipment and Electrical Arcing for all of Assembly. Assembly has lower contributions from Operating Equipment and Electrical Arcing and higher Other Open Flame or Smoking Materials compared to all Area of Origins. Operating Equipment and Electrical Arcing is made up of contributions from all of the top Items First Ignited in Assembly, while Other Open Flame or Smoking Heat Source is almost completely created by Upholstered Sofa.

Figures C9 and C10 are the Assembly only versions of Figures 4.9 and 4.10. The Assembly Area of Origin has very similar distributions for fires that stay in the room of origin and fires that spread beyond the room of origin for both Item First Ignited and Heat Source. Upholstered Sofa has a minor increase for the larger fires compared to fires that stay in the room of origin. Other Open Flame or Smoking Materials also has this increase since it is the major Heat Source for Upholstered Sofa. Electrical Wire has a considerable decrease from confined to beyond room of origin. This closely mirrors Figure 4.17 which shows the raw proportion of Item First Ignited per fire incident in Assembly.

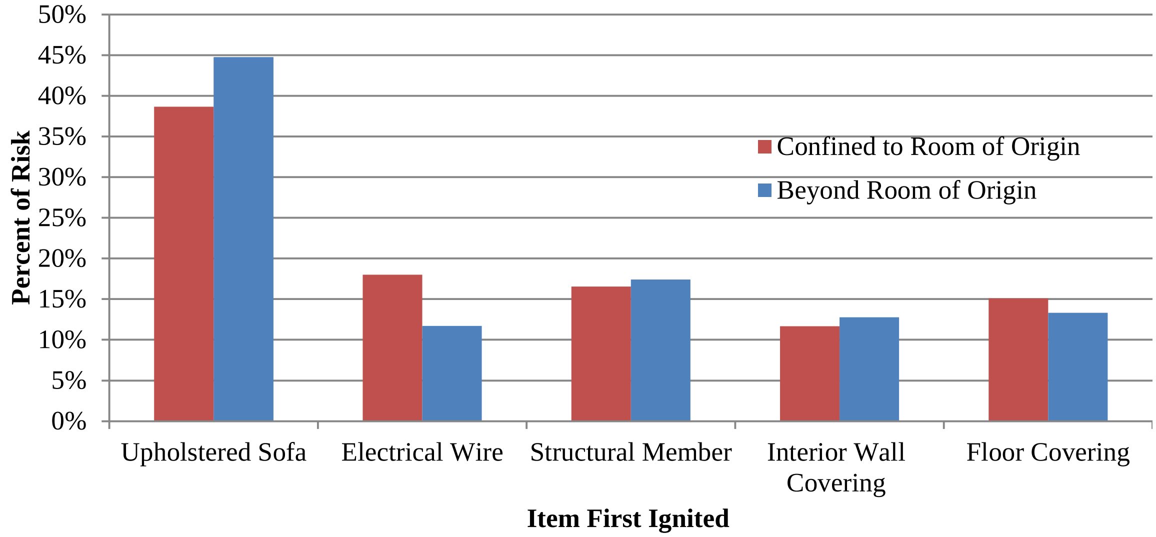


Figure C9: Assembly Risk by Item First Ignited

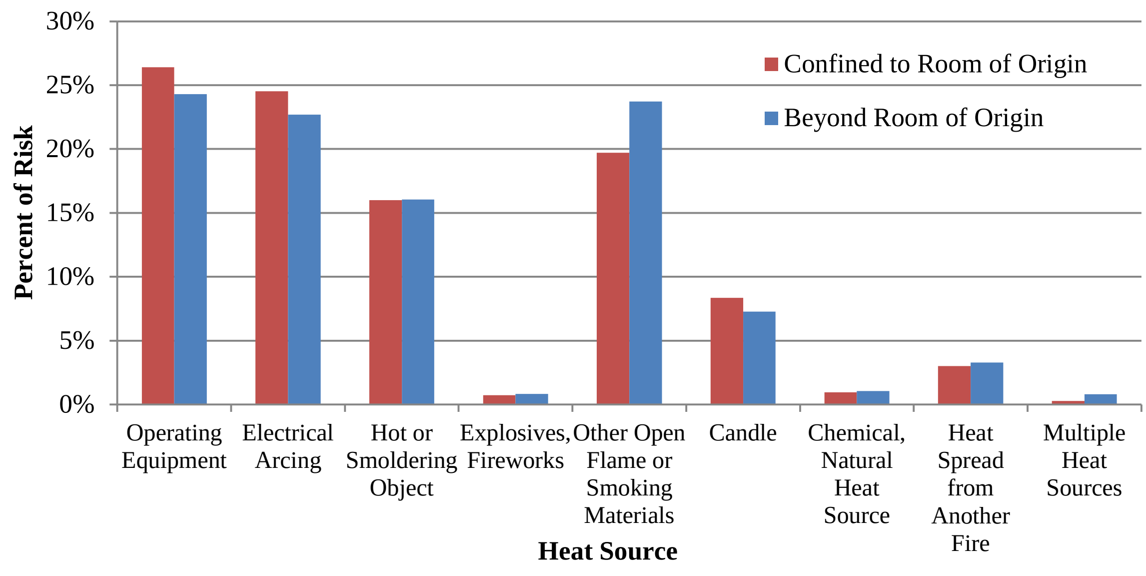


Figure C10: Assembly Risk by Heat Source

Kitchen

The percentage of incidents in Kitchens for the top Items First Ignited is illustrated in Figure C11. Although Food has a generally decreasing trend with increasing Fire Spread, Food is still the Item First Ignited for the majority of incidents, regardless of Fire Spread. No other item gets more than 10% for one Fire Spread category.

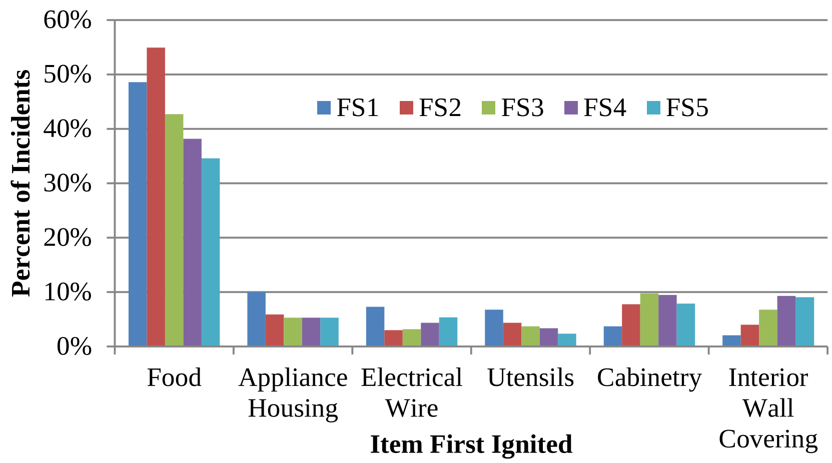


Figure C11: Top Items First Ignited Frequencies for Kitchen

Figures C12 and C13 are the Kitchen only version of Figures 4.6 and 4.8. The dominance of Food as the Item First Ignited and Operating Equipment as the Heat Source are illustrated in Figures C12 and C13.

Figures C14 and C15 are the Kitchen only version of Figures 4.9 and 4.10. There is a slight decrease for both Food and Operating Equipment from confined to the room to beyond the room, but both are still the main player for their respective categories. Interior Wall Covering more than doubles from 5% to 12.7% for Beyond Room of Origin.

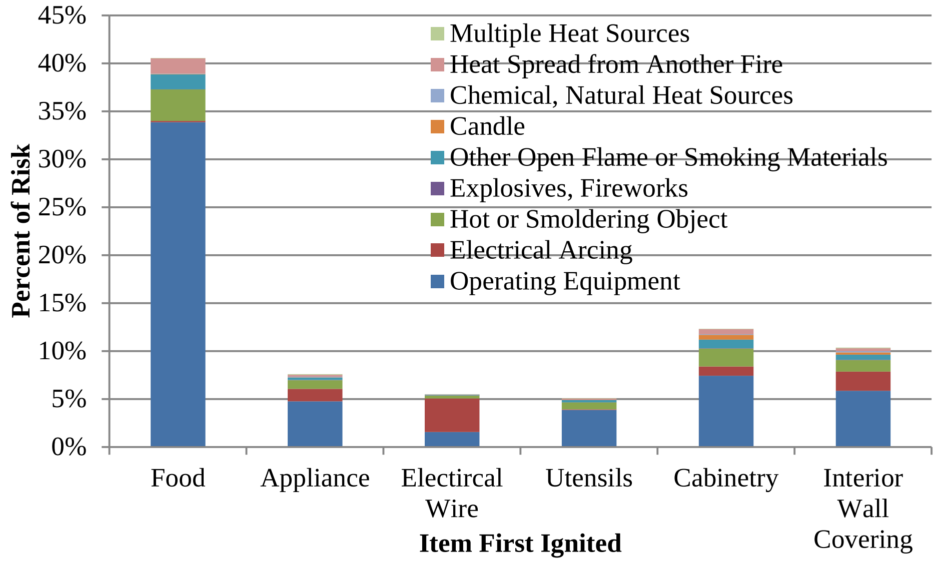


Figure C12: Kitchen Risk Value by Item First Ignited and Heat Source

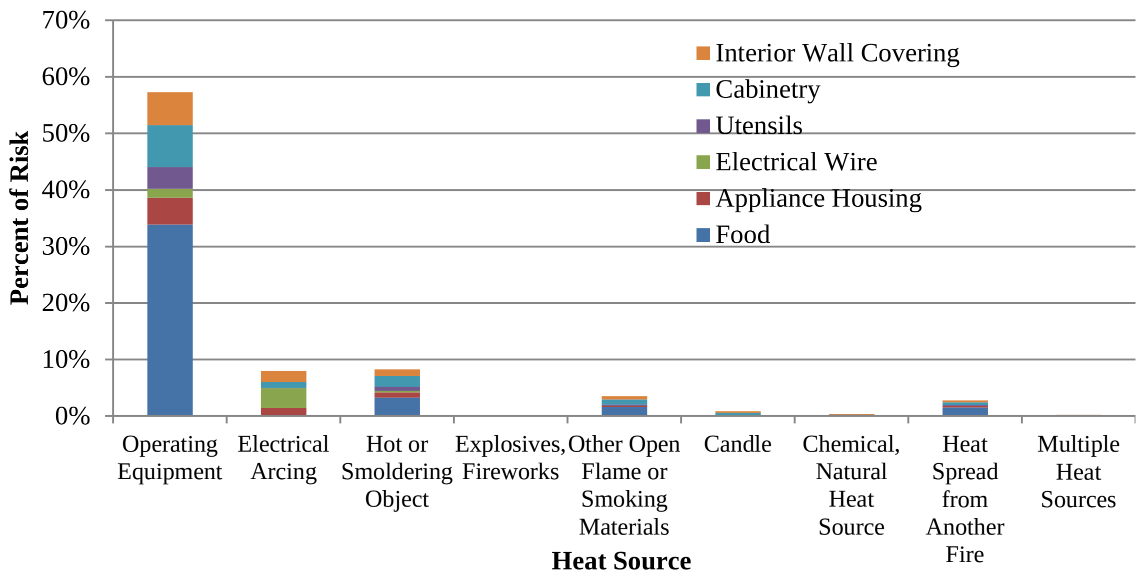


Figure C13: Kitchen Risk Value by Heat Source and Item First Ignited

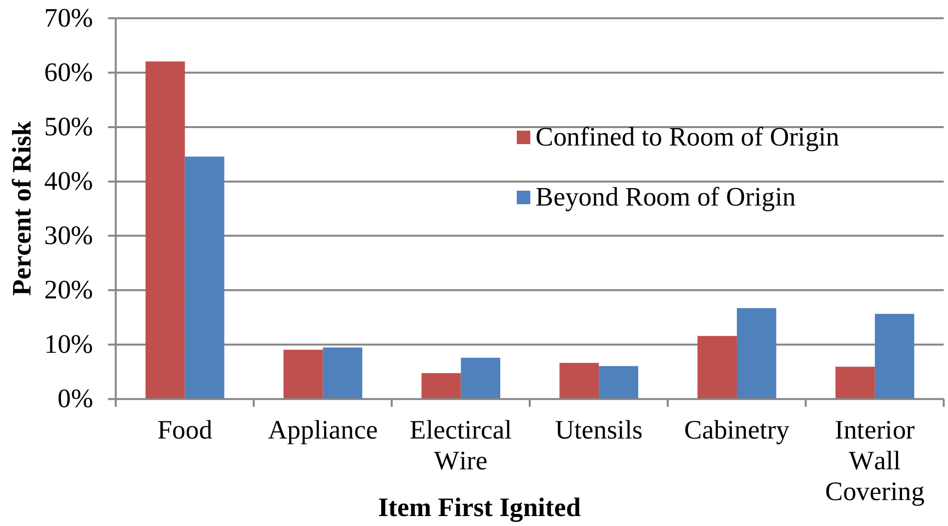


Figure C14: Kitchen Risk by Item First Ignited

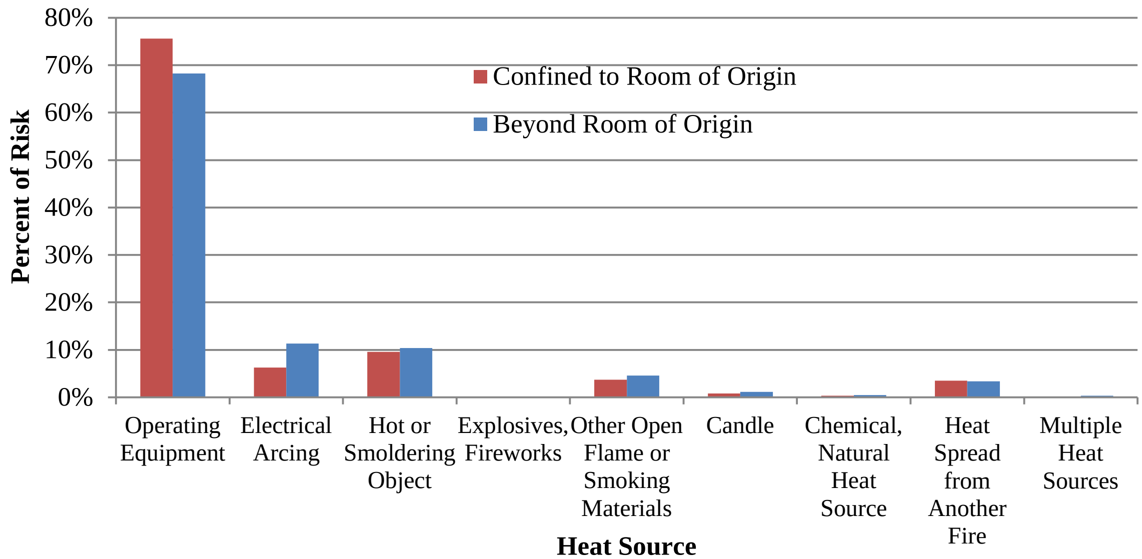


Figure C15: Kitchen Risk by Heat Source

<u>4.5 Storage Areas</u>

The percentage of incidents in Storage Areas for the top Items First Ignited is illustrated in Figure C16. Storage has multiple top items that are repeated from other Area of Origins. Electrical Wire has the same trend as seen in Assembly and Structural Areas, a decreasing proportion with increasing fire spread. The large decrease after FS1 also occurs in the Assembly Area of Origin. Exterior Sidewall Covering has the same pattern in Storage Areas as it did in Structural Areas, a large increase for the beyond building of origin Fire Spread. Structural Member has a slightly different pattern in Storage Areas than in Structural Areas and Assembly. In Storage Areas, Structural Member has a clear increase in percentage for fires that are beyond the room of origin. Clothes has a clear decrease in percentage for fires that are beyond the floor of origin.

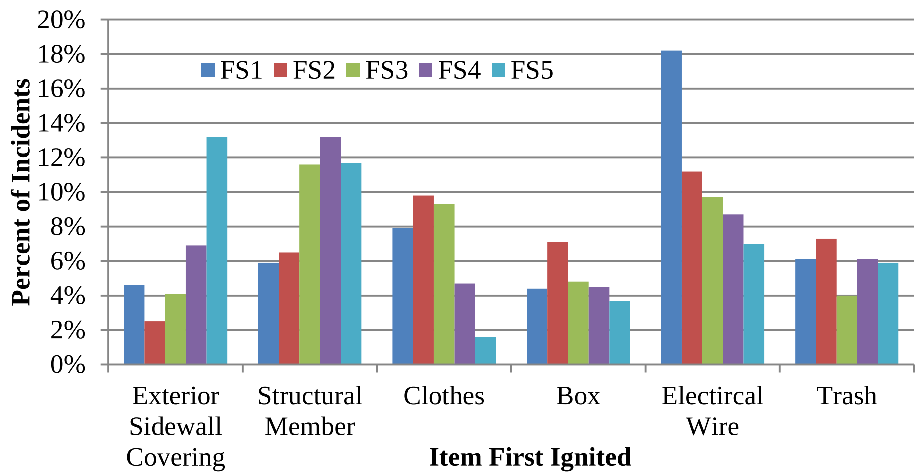


Figure C16: Top Items First Ignited Frequencies for Storage Areas

Figures C17 and C18 are the Storage Areas only version of 4.6 and 4.8. Structural Member and Electrical Wire are the top two Items First Ignited. Electrical Arcing is a large Heat Source for both of these items, making it the most prevalent Heat Source in Storage Areas. Hot or Smoldering Object has the second largest proportion of risk values in Storage Areas. Trash as the Item First Ignited contributes to a large portion of this Heat Source.

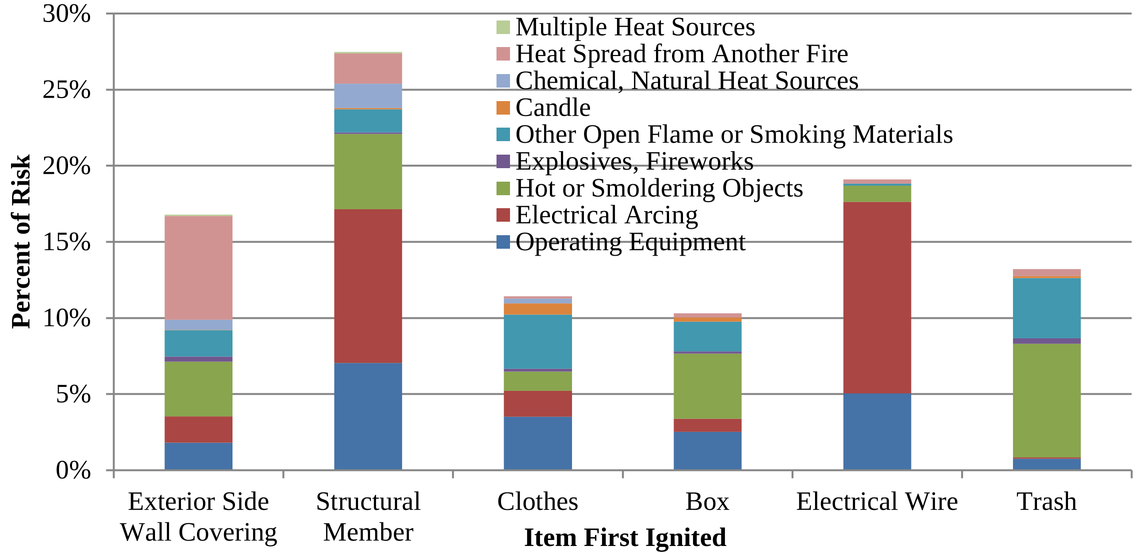


Figure C17: Storage Areas Risk by Item First Ignited and Heat Source

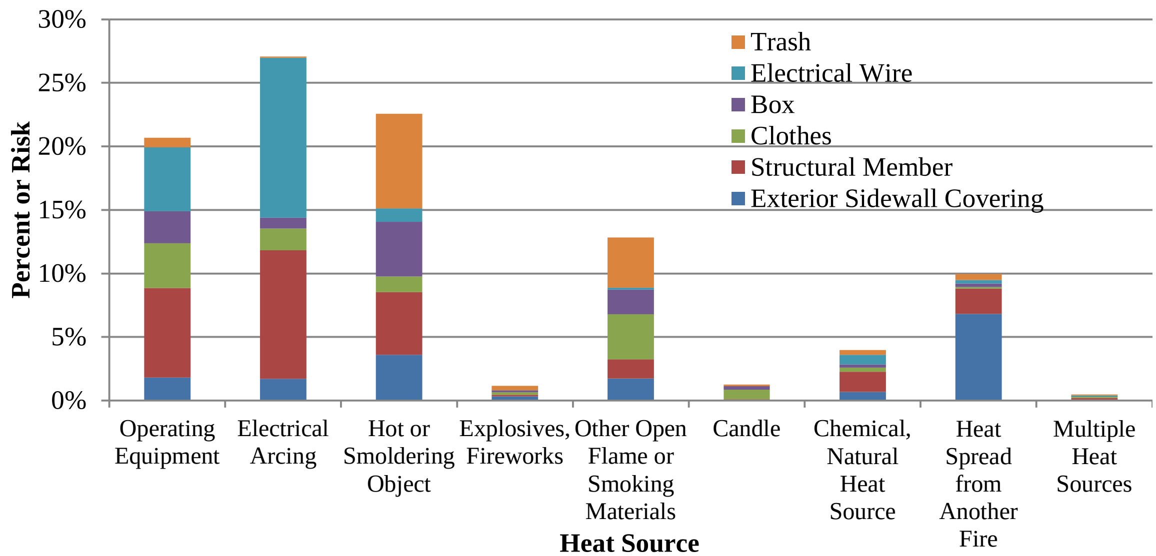


Figure C18: Storage Area Risk by Heat Source and Item First Ignited

Figures C19 and C20 are the Storage Areas only version of 4.9 and 4.10. Storage Areas has a completely different pattern of the top Items First Ignited for Beyond the Room of Origin compared to Confined to the Room of Origin. Exterior Sidewall Covering and Structural Member have much larger proportions of the risk value of Beyond Room than Confined to Room. Clothes, Box, and Electrical Wire have much smaller proportions of the risk value for Beyond Room. The Heat Source distributions are remarkably similar considering how different the Items First Ignited distributions are. Other Open Flame or Smoking Materials has a considerable decrease and Heat Spread from Another Fire has a large increase in proportions from Confined to Beyond Room of Origin.

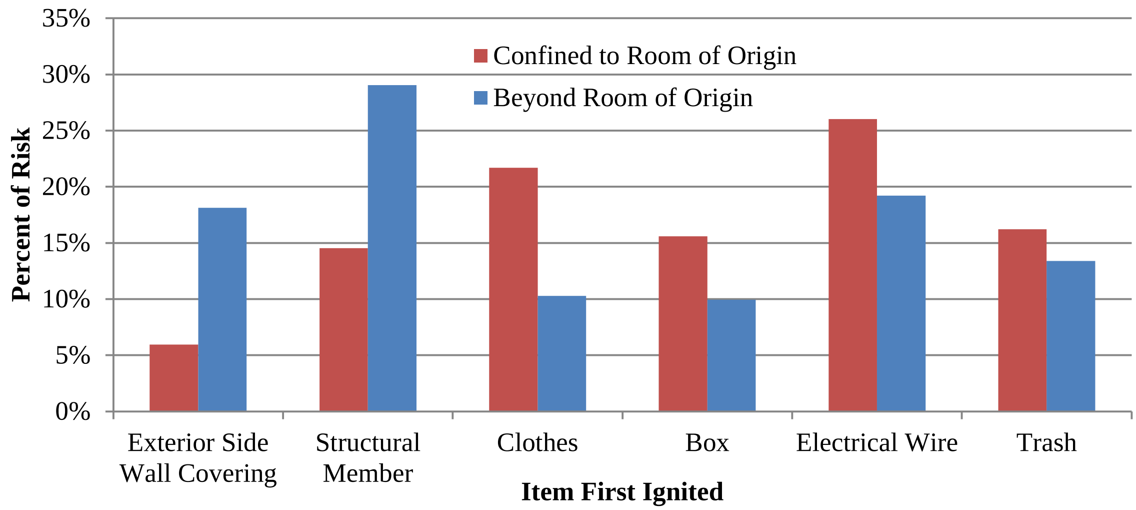


Figure C19: Storage Areas Risk by Item First Ignited

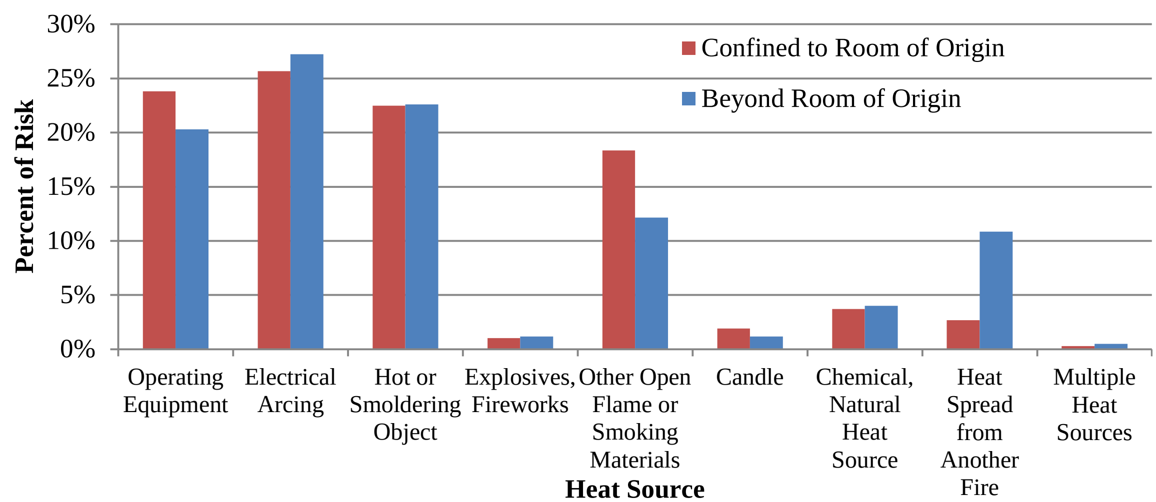


Figure C20: Storage Areas Risk by Heat Source

Bedrooms

The percentage of incidents in Bedrooms for the top Items First Ignited is illustrated in Figure C21. Electrical Wire has a decrease in percentage after FS1 similar to Storage

Areas and Assembly. Mattress has a similar trend with a large decrease after FS1 and an overall decreasing trend. Other Furniture has an almost constant 9% contribution. Bedding has an increase after FS1 and FS2 then a steady proportion.

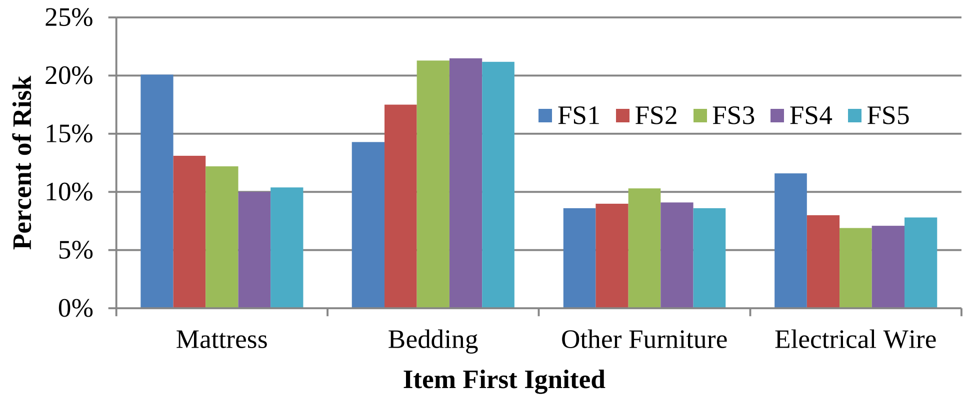


Figure C21: Top Items First Ignited Frequencies for Bedrooms

Figures C22 and C23 are the Bedrooms only version of Figures 4.6 and 4.8. Bedding dominates the risk value for the Items First Ignited in Bedrooms. The main Heat Source for Bedding is Other Open Flame or Smoking Materials, which is the main Heat Source for all of Bedrooms. It makes up the majority of the Heat Source for Mattresses and a large portion of Other Furniture.

Figures C24 and C25 are the Bedrooms only version of Figures 4.9 and 4.10. The only significant difference between the two series is that Bedding is higher and Mattress is lower for fires that spread beyond the room of origin. The two series are almost the same for Heat Source in Bedrooms. Other Open Flame or Smoking Materials has a slightly higher proportion of the risk values for those fires Beyond the Room of Origin and Candle has a slightly lower proportion.

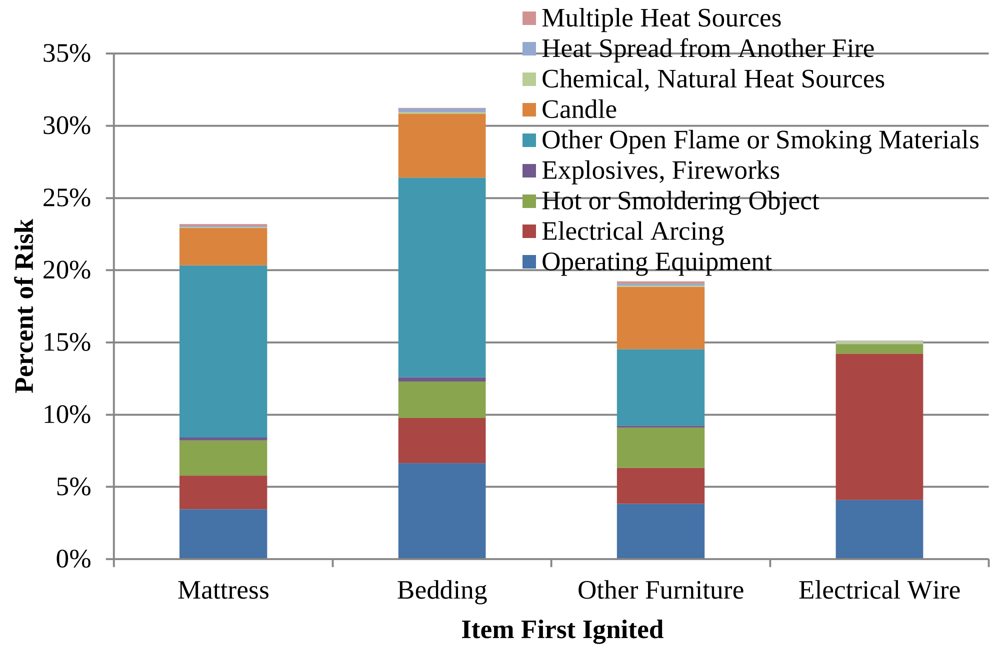


Figure C22: Bedroom Risk Value by Item First Ignited and Heat Source

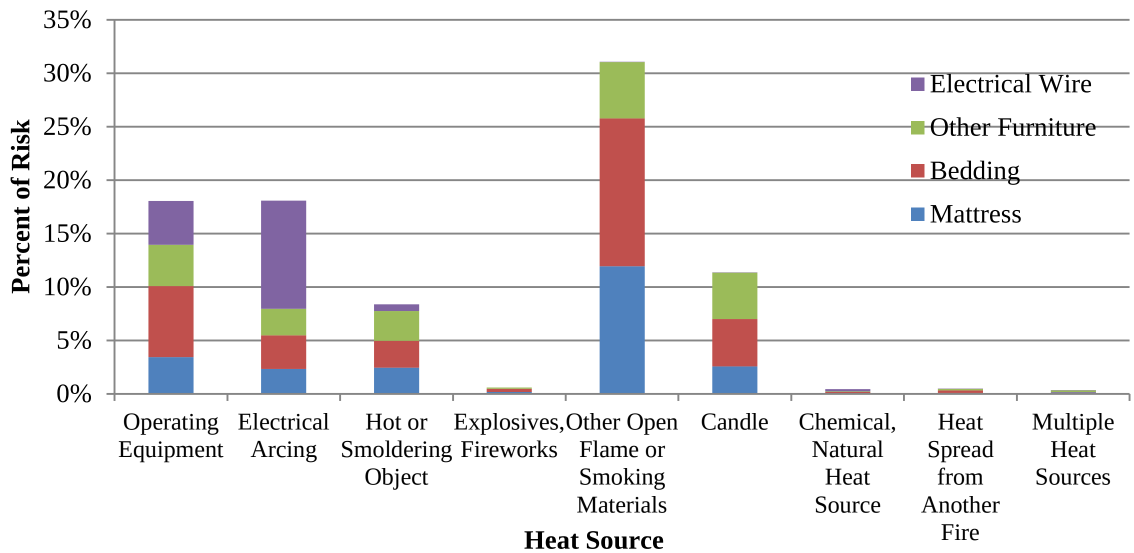


Figure C23: Bedroom Risk Value by Heat Source and Item First Ignited

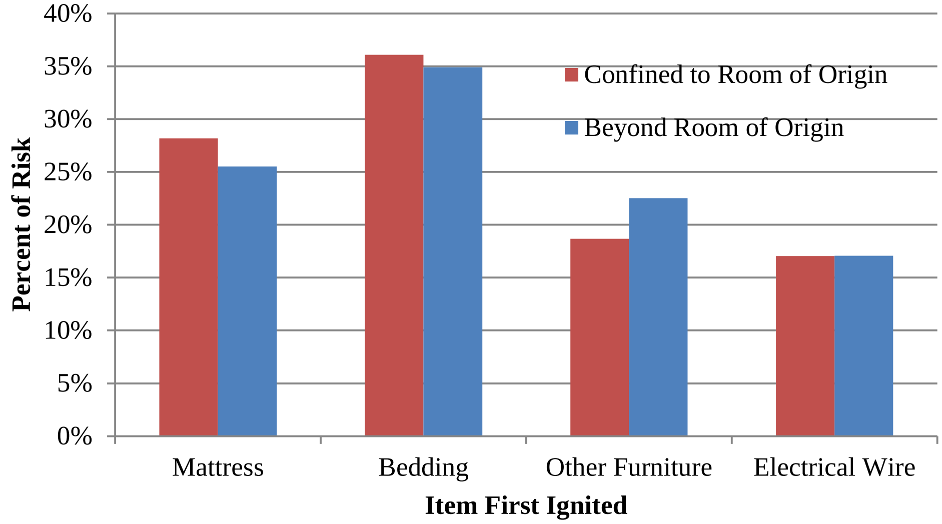


Figure C24: Bedroom Risk by Item First Ignited

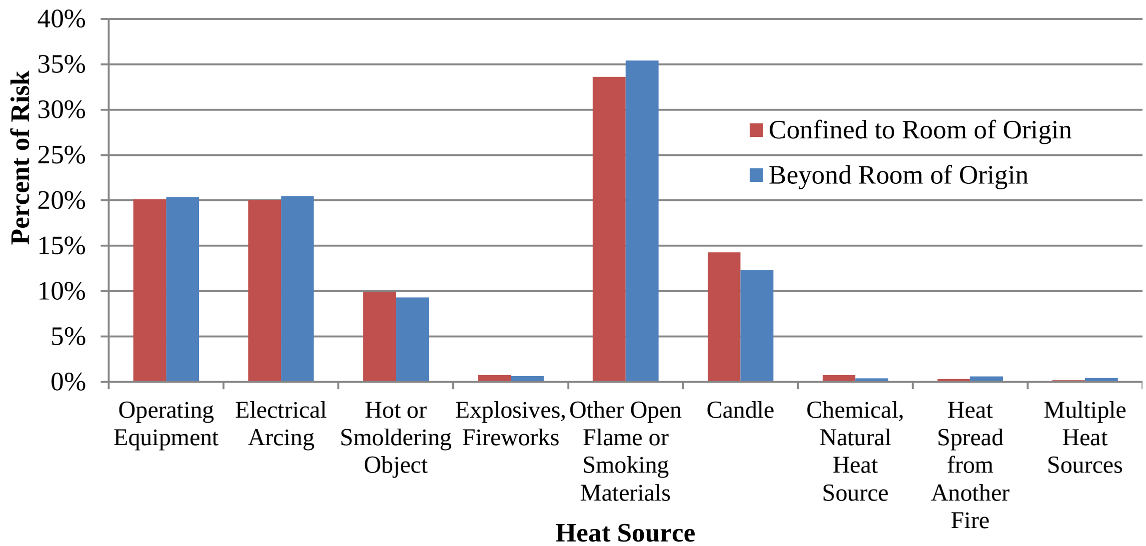


Figure C25: Bedroom Risk by Heat Source

Other Function Areas

The proportion of incidents in Other Function Areas for the top Items First Ignited is displayed in Figure C26. Electrical Wire has a drop in proportion after FS1 similar to the distributions in Assembly, Storage Areas, and Bedrooms. Dust and Clothes have a stark decreasing trend with increasing fire spread. Sofa, Structural Member, and Interior Wall Covering all have generally increasing proportions with increasing fire spread.

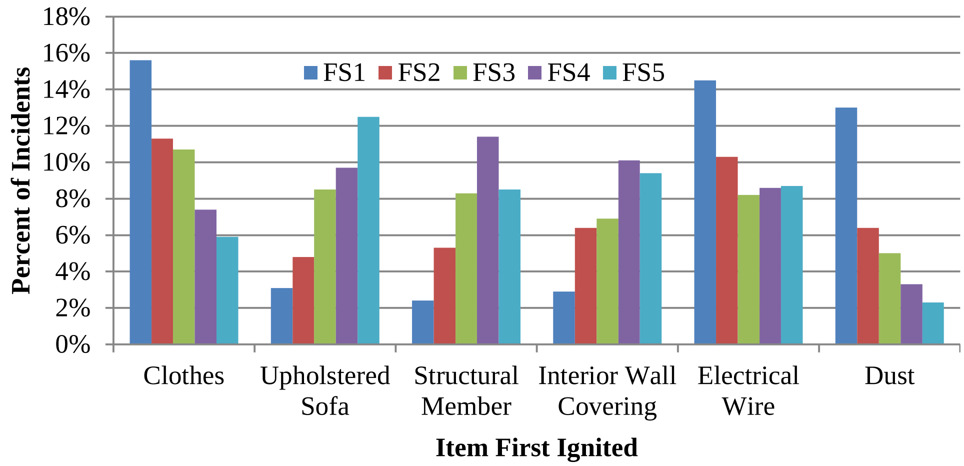


Figure C26: Top Items First Ignited Frequencies for Other Function Areas

Figures C27 and C28 are the Other Function Areas only version of 4.6 and 4.8. Other Function Areas has no one major player for the risk value by Item First Item Ignited. Clothes, Upholstered Sofa, Structural Member, Interior Wall Covering, and Electrical Wire are all about equal with 16.7-20.2 percent of the risk value of Other Function Areas. Dust only contributes 7.8% of the risk value.

Although there is no one leading Item First Ignited, Operating Equipment is the leading Heat Source, accounting for over 40 percent of the risk value in Other Function Areas. Electrical Arcing also contributes a large portion with over 25%.

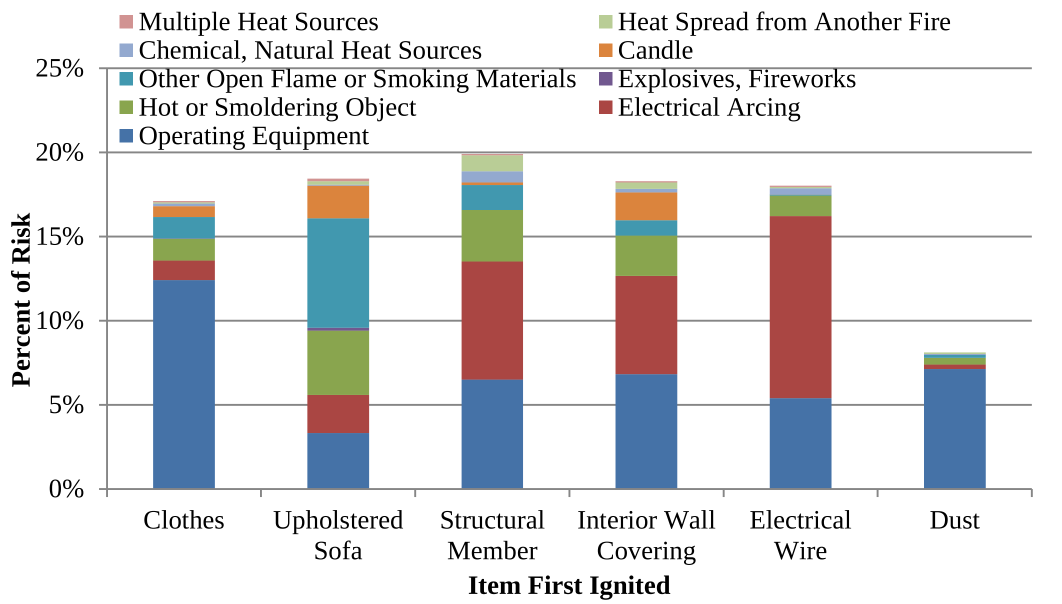


Figure C27: Other Function Areas Risk by Item First Ignited and Heat Source

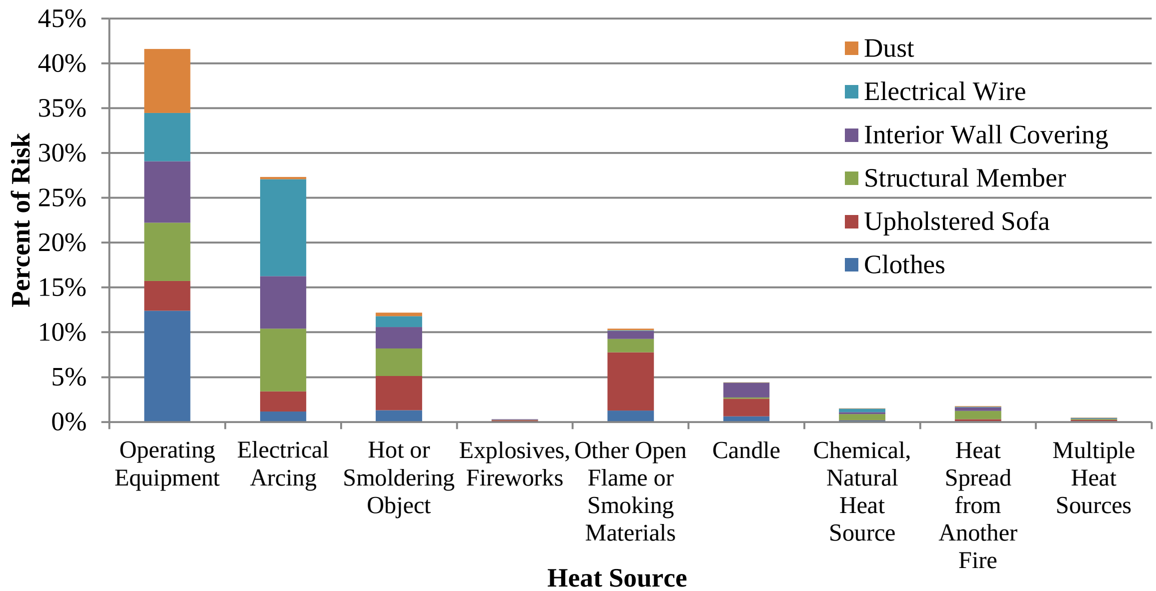


Figure C28: Other Function Areas Risk by Heat Source and Item First Ignited

Figures C29 and C30 are the Other Function Areas only version of Figures 4.9 and 4.10. Clothes, Electrical Wire, and Dust have smaller contributions to the confined to room of origin category than the beyond room of origin. Upholstered Sofa, Structural Member, and Interior Wall Covering have greater proportions of the beyond room of origin category.

The Heat Source distributions are similar with the biggest difference being a drop from 49.3% for the Confined to Room of Origin category to 40.2% for the Beyond Room of Origin category for Operating Equipment.

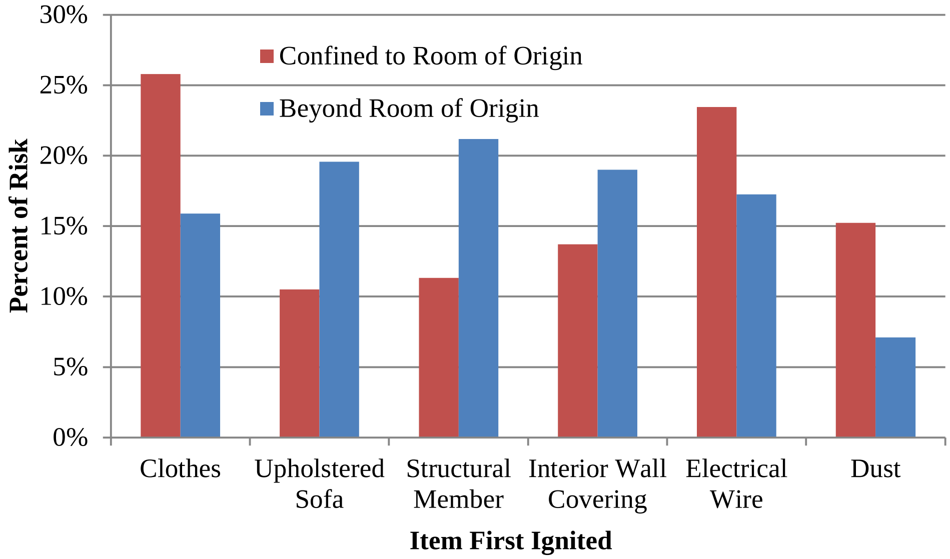


Figure C29: Other Function Areas Risk by Item First Ignited

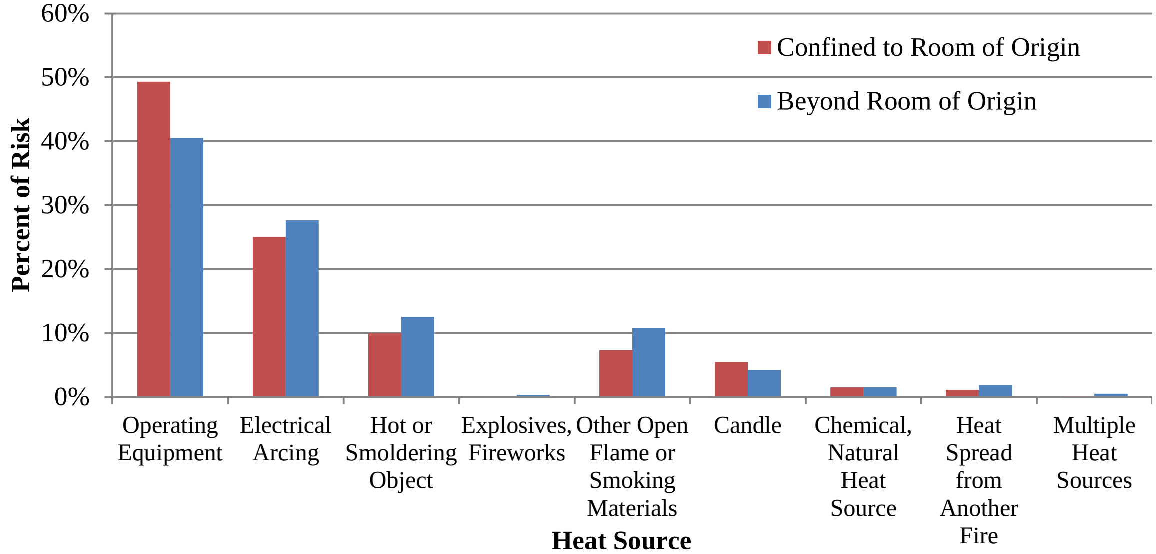


Figure C30: Other Function Areas Risk by Heat Source

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