Performance of Smoke Detectors and Sprinklers in Residential and Health-Care Occupancies

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Executive Summary

This report provides an overview of a recent study intended to indicate the relative performance of smoke detectors and sprinklers in one- and two-family dwellings and apartments, commercial residential (i.e. hotels), and institutional occupancies. In so doing, the important roles of smoke detectors and sprinklers to mitigate fire events are illustrated. The studies included in this presentation include statistical analyses of smoke detector and sprinkler performance from fire incident data and data from experimental programs.

The trend in all of the numerous recent research investigations is that smoke alarms and smoke detectors respond prior to residential or ordinary sprinklers and thus have the capability of providing the earliest warning of a fire to building occupants. While responding later, sprinklers provide the complementary function of fire suppression to limit the development of hazardous conditions.

The comparison of performance will be based on several measures. In the review of data from the experimental programs, the relative performance of smoke detectors and sprinklers to fires will be assessed primarily in terms of response times or the period between activation and the available safe egress time. The performance measures applied for the comparison of smoke detectors and sprinklers based on fire incident data will be the proportion of fires judged to be too small for activation of the respective devices and casualty rates (fatal and non-fatal).

Ahrens' analysis of fire incident data includes a database of more than 378,000 fire incidents that occurred from 2003 to 2006 in U.S. homes. 96% of the homes were found to have at least one smoke alarm, but only 31% of households had smoke alarms in all bedrooms. Ahrens' analysis indicated that the fire death rate in homes without a working smoke alarm was approximately twice that in homes with working smoke alarms.

Hall's analysis of fire incident data in one- and two-family dwellings and apartments with sprinklers yielded the conclusion that the fire death rate was 80% lower in units with sprinklers than without. Ahrens noted a 23% decrease in fires in residences extending beyond room of origin with sprinklers.

Ahrens and Hall found that 5% of the fires in residences were judged to be too small for activation of smoke alarms, while 54% of the residential fires were too small to activate sprinklers. In Flynn's analysis of data from fire incidents in nursing homes, 72% of the fires were judged to be too small for sprinkler, while 78% of the fire incidents in hospitals and hospices were judged to be too small for sprinkler operation.

The analysis of NFIRS data conducted by the University of Maryland team considered the response of smoke detectors and sprinklers in fire incidents occurring from 2003-2007 in 1-, 2- and multi-family residential dwellings, commercial residential facilities and health-care facilities. Approximately 197,000 fire incidents were included in the analysis.

In all three of these occupancy groups, the proportion of fires judged to be too small for the operation of the smoke detectors was appreciably fewer than those for sprinklers. The following table summarizes the results:

Proportion of Fire Incidents Judged to be Too Small for Operation

	Smoke Detectors		Sprinklers
	Non-sprinklered property	Sprinklered Property	
1- and 2-family dwelling	13.1	12.8	38.9
Commercial residential	9.7	10.8	54.2
Health-care	11.4	17.8	65.4

The fact that fewer fires are judged to be too small for smoke detector operation than for sprinklers reflects the fact that smoke detectors are capable of responding to smaller fires than sprinklers. Those fires which are "too small" for smoke detector or sprinkler response still pose a significant hazard, as indicated in casualty rates (fatal and non-fatal) in such fires. The respective casualty rates per 100 fires are indicated in the following table:

Casualty Rates for Fires Judged Too Small for Operation

Occupancy	Too Small for Smoke Detector	Too Small for Sprinkler	Ratio: Sprinkler/ Smoke Detector
1- & 2-Family and, Multi-Family Residential	0.36	1.47	4.1
Commercial Residential	0.11	1.70	15.5
Health-care	1.06	3.08	2.9

The significant difference in casualty rates in the "too small" fires is an indication of the potential contribution of smoke detectors to fire safety in sprinklered buildings. In those fires in 1- & 2-family and, multi-family residential occupancies where sprinklers did not respond, smoke detectors alerted occupants in over 89% of the incidents. Similarly, in fire incidents in commercial residential occupancies, smoke detectors alerted occupants in approximately 94% of the cases where sprinklers did not operate. In health-care occupancies, smoke detectors alerted occupants in all of the cases where sprinklers did not operate.

The review of data obtained in several experimental programs unanimously indicates that smoke alarms respond prior to sprinklers. In addition, tenability analyses conducted using data from several of the experimental programs concluded that sufficient egress time is provided by smoke alarms, considering conditions existing at the time of their response. Often, sufficient warning and protection is also provided by sprinklers, with the principal exception being those fires where an obstruction is present preventing the sprinkler spray from reaching the burning fuel, referred to as a "shielded fire".

Casualty rates in fires that involve smoke detector and sprinkler operation are indicated in the following table. Here, the function of sprinklers to control the fire is demonstrated.

Casualty Rates in Fires with Smoke Detector and Sprinkler Operation

Occupancy	Operating Smoke Detector	Operating Sprinkler	Ratio: Sprinkler/ Smoke Detector
1- & 2-Family and Multi-Family Residential	3.17	2.06	0.65
Commercial Residential	2.38	0.91	0.38
Health-care	3.08	1.14	0.37

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1. Introduction

Fire detection and suppression systems are installed in buildings to mitigate the threat due to fires. The purpose of this report is to compile results from previous studies and indicate the relative performance of smoke detectors and sprinklers in one- and two-family dwellings and apartments, commercial residential (i.e. hotels), and institutional occupancies. In so doing, the important roles that each provide in reducing the threat due to fire will be illustrated.

The studies included in this report can be grouped into two categories based on the methodology followed. One category consists of statistical analyses of smoke detector and sprinkler performance from fire incident data. The other category consists of experimental programs conducted either with the explicit intent of assessing the performance of smoke detectors and/or sprinklers in laboratory settings or where such can be gleaned from a project that was conducted for another purpose.

The statistical analyses of fire incident data reported in the literature is supplemented by a new analysis of NFIRS fire incident data to be able to provide a more in-depth review of the performance of smoke detectors and sprinklers in the noted occupancies. In so doing, it is hoped that the respective benefits of smoke detectors and sprinklers in one- and two-family dwellings and apartments, commercial residential (i.e. hotels), and institutional occupancies can be better appreciated.

Smoke detectors and sprinklers perform different fire safety functions. As expressed by Budnick, *"Automatic sprinklers have been used to confine the fire to the room of origin; detectors are installed to provide adequate warning to persons outside the room to ensure escape or rescue."* [Budnick, 1984]. Budnick also indicates *"While the rate of temperature rise and smoke production are both functions of the rate of fire growth, quantities of smoke sufficient to activate a smoke detector generally precede a gas temperature sufficient to activate a sprinkler."* In 1984, Budnick projected that smoke detectors could reduce fatalities in residences by 50% and using both sprinklers and smoke detectors could reduce fatalities by 73% in residences.

Budnick's observations reflect the key distinctions between the basic intent of smoke detectors and sprinklers. Smoke detectors are intended to provide early warning of fires. Sprinklers are intended to provide warning and control the development of a fire. Smoke detectors do not have the capability to control the fire except by alerting occupants at an early enough stage when manual suppression still might be feasible.

Numerous studies have been conducted to assess the performance of various fire protection components in buildings, including smoke detectors and sprinklers. Some of these studies have included comparisons of the two fire protection approaches and some have included stand-alone analyses of their performance.

The comparison of performance of smoke detectors and sprinklers will be based on several measures. In the review of data from the experimental programs, the relative performance of smoke detectors and sprinklers to fires is assessed by primarily by considering either:

- response times of the respective component or
- the period between activation and the available safe egress time.

Using the fire incident data, the performance measures applied for the comparison of smoke detectors and sprinklers is primarily based on

- the proportion of fires judged to be too small for activation of the respective devices
- casualty rates (fatal and non-fatal)

2. Statistical Analyses of Fire Incident Statistics

2.1 Previous Statistical Analyses

Several statistical analyses of fire incidents in the U.S. have been conducted in recent years. Ahrens [2009], Hall [2009] and Flynn [2008, 2009] have provided the most comprehensive view of the performance of smoke detectors and sprinklers in fire incidents in the U.S. occurring in many occupancies.

2.1.1 Smoke Alarms in Residences

Ahrens' analysis includes more than 378,000 fire incidents that occurred from 2003 to 2006 in U.S. homes. 96% of the homes were found to have at least one smoke alarm, but only 31% of households had smoke alarms in all bedrooms. While the proportion of homes with at least one smoke alarm is commendable, the small proportion of homes with a smoke alarm in every bedroom indicates that the level of protection provided by smoke alarms in many homes is probably not in compliance with the current edition of NFPA 72 [2010].

Almost two-thirds (63%) of all home fire deaths in 2003-2006 occurred in homes which lacked working smoke alarms [Ahrens, 2009]. This means that the fire death rate in homes without a working smoke alarm is approximately twice that in homes with working smoke alarms. In contrast, the fire injury rate is approximately the same in homes with working smoke alarms and those homes without. A possible reason provided for this high injury rate is that occupants warned by smoke alarms may be attempting fire fighting actions and are getting injured in that attempt, though such a hypothesis is unproven.

Table 1 summarizes the performance of smoke alarms in all U.S. homes during the period. The fire was judged to be too small for a smoke alarm to activate in only 1% of the deaths, indicating that the fires posing a significant threat to human life were detected by a smoke alarm.[1] Ahrens and Hall [2009] note that the statistics probably provide a pessimistic view of smoke alarm performance relative to the proportion of fire incidents in which they respond. They propose that the underestimation of the role of smoke alarms in fire incident statistics is because of the unknown number of times that a smoke

[1] A fire which is deemed too small to cause a smoke alarm to activate would also likely produce too little heat to activate a sprinkler.

alarm alerts an occupant of a fire at an early enough stage that it can be controlled by the occupant and thus not be reported to the fire department (and thus not become an official fire incident). Given that their analysis involves only reported fire incidents and this scenario involves unreported fires, no statistics are available to indicate how frequently such a scenario occurs.

Table 1. Performance of Smoke Alarms in Fires in U.S. One- and Two-Family Dwellings and Apartments (2003-2006)

Performance	% Fires	% deaths
Operating smoke alarm	52	36
No operating smoke alarm	43	63
Fire too small	5	1

In a survey of fire incidents in residences by CPSC, the smoke alarm provided the first means of alerting in 10% of the fire incidents [Greene and Andres, 2008]. While occupants who are alert and present in the vicinity of a fire may notice a fire prior to activation of a smoke alarm, this statistic does indicate that there is an identifiable proportion of incidents where the response of the smoke alarm is key to alerting occupants of a fire in a timely manner.

The label “no working smoke alarm” in Table 1 includes cases where smoke alarms were not present or a smoke alarm was present but not in working condition. Hall [1987] indicated that as many as one-third of smoke alarms in U.S. homes may not be operational. In CPSC field investigations, 20% of homes were found to have had smoke alarms which were not working [Smith, 1993].

Table 2 provides a summary of the fire death rates in one- and two-family dwellings and apartments. As noted in the table, the presence of operating smoke alarms decreases the fire death rate in all home fires from 0.91 deaths per 100 reported fire incidents to 0.62 deaths per 100 reported fire incidents, representing a decrease of about 30%. The fire death rate in homes without an operating smoke alarm is more than twice that in homes with working smoke alarms.[2]

[2] The relative fire death rate in homes without an operating smoke alarm to that in homes with working smoke alarms is 2.11 (1.10/0.52).

Table 2. Death Rates per 100 Reported Fire Incidents U.S. One- and Two-Family Dwellings and Apartments (2003-2006)

	All Homes	1&2 family dwellings	Apartments
All fires	0.75	0.91	0.40
Operating smoke alarm	0.52	0.62	0.33
No operating smoke alarm	1.10	1.27	0.56
Fire too small	0.15	0.10	0.26

Ahrens identifies the following trends in the characteristics of victims suffering a fatal injury in fire incidents with a working smoke alarm [2009]:

- The victim is more likely to be in the room or area of origin and involved with the ignition process.
- The victim is more likely to either have been attempting extinguishment or unable to act (i.e. either extreme of the spectrum of possible behaviors).
- The victim is more likely to be at least 65 years old.

Marshall, et al. [1999] examined the impact of smoke alarms on preventing fire deaths in residences. They observed that smoke alarms reduced the risk of death in fire incidents by about 60% and contributed to a mounting body of scientific evidence for the effectiveness of these relatively inexpensive devices. As such, the benefit of smoke alarms has been relatively consistent from the 1990's and 2000's, as judged by Marshall's and Ahrens' analyses. In Marshall's analysis, he found that fires in buildings not provided with smoke alarms were more likely to have a greater fatality rate (52% vs. 43% in the fires with smoke alarms present) and cause a high level of destruction to the building.

2.1.2 Sprinklers in Residences

Hall's analysis of fire incident data in one- and two-family dwellings and apartments with sprinklers yielded the conclusion that the fire death rate was 80% lower in units with sprinklers than without [2009]. However, he does acknowledge that the number of fire incidents in sprinklered one- and two-family dwellings is relatively small, thus making it difficult to make a strong, definitive statement about the effectiveness of NFPA 13D systems. Table 3 summarizes the experience with sprinklers in one- and two-family dwellings and apartments.

Table 3. Performance of Sprinklers in U.S. One- and Two-Family Dwellings and Apartments (2003-2006) (Percent of fire incidents)[+]

	All Homes	1&2 family dwellings	Apartments
Operated and effective	45	40	46
Operated and ineffective	1	2	0
Fire too small	54	55	53
Failed to operate	1	3	0

[+] Numbers in columns may not add up to 100% due to round off.

One significant aspect of the data provided in Table 3 is the appreciable number of fires that are judged to be too small to activate the sprinklers. In both types of residences, the proportion of incidents where the fire is judged to be too small exceeds half of the total number of fire incidents. This is in contrast to the statistics indicated in Table 1, where the number of fires judged to be too small for smoke alarm activation is only 5% of the total. As such, the relative proportion of fires which are too small for sprinklers is about 10 times that for smoke alarms. This statistic from four years of fire incident data confirms Budnick's comment that smoke alarms respond to smaller fires.

Koffel [2005] reported that sprinklers were present in 16,900 fire incidents in one- and two-family dwellings over a ten-year period (1989-1998) and operated in 80% of those fires. He also noted that sprinklers operated in almost 88% of 50,000 fire incidents in apartments. Given that Koffel's review only includes fire incidents where sprinklers operated, his comment does not address the number of fires where the fire was deemed to be too small or where sprinklers were absent from the area of fire origin. In the residential fires where the sprinklers operated, they extinguished the fire in 19% of the incidents, providing support for Koffel's following statement:

> *"While property loss and life loss are greatly reduced in buildings protected with an automatic sprinkler system, the sprinkler system alone is not providing the entire increased protection."*

As such, sprinklers are effective in controlling the fire, though other unnamed systems are recognized as being important in the observed overall reduction. This could include smoke alarms and given that sprinklers extinguished the fire in only 19% of the incidents, some additional action is evidently needed by occupants or fire service personnel to achieve complete extinguishment.

The effectiveness of sprinklers to limit fire development in homes is illustrated in Table 4 [Hall, 2009]. Significant improvements are realized in terms of the proportion of fires which extend beyond the room of origin, though the significance of the improvement is tempered by the small proportion (1%) of fire incidents that occur in one- and two-family dwellings with sprinkler protection. This observation is also confirmed in a previous study by Thomas [2002].

Table 4. Percentage of Fires Limited to Room of Origin, U.S. One- and Two-Family Dwellings and Apartments (2003-2006)

Occupancy	Without Sprinkler	With Sprinkler	% Improvement with Sprinklers
All	77	95	23
1- & 2-family dwellings	71	83	17
Apartments	89	97	9.0

Butry, et al., [2007] conducted a benefit-cost analysis of sprinkler systems in new one- and two-family dwellings. Costs were assessed through six candidate designs in three home designs (colonial, townhouse, and ranch). Benefits were extracted from fire incident data from 2002-2005. The net conclusion of this analysis was that one- and two-family dwellings with a wet-pipe sprinkler system and smoke alarms were found, on average, to have 100% fewer civilian fatalities (from 0.82 deaths per 100 fires in homes with smoke alarms only to no deaths in homes with smoke alarms and sprinklers). Butry, et al., note that injury rates decrease from 4.03 injuries per 100 fires in homes with smoke alarms only to 1.74 injuries per 100 fires in homes with smoke alarms and sprinklers, a decrease of 57%. Property damage per fire decreased from $21,990 in homes with smoke alarms only to $15,028 in homes with smoke alarms and sprinklers, a decrease of 32%.

2.1.3 Smoke Detector and Sprinkler Performance in Other Occupancies

Budnick and Bukowski [1997] assessed the potential impact of smoke detection, sprinklers and construction in residential, commercial and institutional occupancies. The impact of each system was evaluated primarily based on NFIRS fire incident data and supplemented by specific analyses using predictive methods to estimate the role of these systems under common fire scenarios. Based on an analysis of fire incident data, they note that the general trend is for smoke detection to improve life safety while suppression and fire resistant construction decrease property loss. Thomas' study [2002] for all occupancies makes the same observation concerning the relative benefits of sprinklers, smoke detectors, and construction.

Concerning the performance of protection systems in institutional occupancies, Flynn provided data from fire incidents on the performance of sprinklers. In 2,810 fire incidents in U.S. nursing homes, the fire death rate was 0.26 deaths per 100 fire incidents in nursing homes with sprinklers, compared to 4.06 deaths per 100 fire incidents in nursing homes without sprinklers. The performance of sprinklers in these fire incidents is indicated in Table 5. The reasons for non-operation were not identified, though at least some of these are probably attributed to the fire being too small (as observed in residential fires).

Table 5. Sprinkler Performance in U.S. Nursing Home Fires, 2002-2005

Performance	% of Fire Incidents
Fires too small to operate	72%
Operated and effective	22%
Failed to operate	5%
Operated and not effective	1%
Unknown	1%

Similarly, the performance of sprinklers in fire incidents from 2003-2006 in hospitals and hospice facilities is presented in Table 6. Where sprinklers operated, they were effective in all cases.

Table 6. Sprinkler Performance in U.S. Hospital and Hospice Fires, 2003-2006

Performance	% of Fire Incidents
Operated	22%
No operation-fire too small	78%

2.2 Statistical Analysis Conducted in this Study

An analysis of NFIRS fire incident data for the five year period from 2003-2007 was conducted. A total of approximately 259,500 fire incidents were included in the analysis of fire incidents occurring in one- and two family dwellings, commercial residential (i.e. hotels) and health-care facilities. There were 33,892 fire incidents that included at least one death or injury.

The types dwellings included in this analysis were [NFIRS, 2008]:

419 1- or 2-family dwelling, detached, manufactured home, mobile home not in transit, duplex.
429 Multifamily dwelling. Includes apartments, condos, town houses, row houses, tenements.

The commercial residential occupancy included in this analysis was [NFIRS, 2008]:
449 Hotel/motel, commercial

The types of health-care facilities included in this analysis were [NFIRS, 2008]:
311 Nursing Home
321 Mental retardation/development disability facility that houses, on a 24-hour basis, four or more persons
323 Asylum, mental institution. Includes facilities for the criminally insane. Must include sleeping facilities
331 Hospital
332 Hospice: includes facilities where the care and treatment of the terminally ill is provided on a 24-hour basis.

Occupant characteristics included in the analysis were those people who were either

1. Intimate with the fire, in the room of origin, and died or were injured from:
    a. burns
    b. smoke inhalation
    c. combination of burns and smoke inhalation
2. Not intimate with the fire (i.e. not in the room of origin) and died or were injured from:
    a. burns
    b. smoke inhalation
    c. combination of burns and smoke inhalation
2. No casualty resulted from the fire.

The principal purpose of the analysis conducted in this study was to provide a more detailed analysis of the role of smoke alarms and sprinklers in the occupancies noted above, with special emphasis on exploring the role of these components on deaths and injuries.

The analysis divided the fire incidents in the above occupancies for the following conditions:

1. Non-sprinklered buildings with operational smoke detection
2. Fully-sprinklered buildings without smoke detection
3. Fully-sprinklered buildings with operational smoke detection

The complete results of from the analyses conducted are presented in the Appendix. The principal observations resulting from the analysis address the response of smoke detectors and sprinklers and the relationship between casualty rates and the performance of smoke alarms and sprinklers.

2.2.1 1- and 2-Family and Multiple Family Dwellings

A total of 192,559 fire incidents occurred from 2003 to 2007 in 1- and 2-family and multiple family dwellings. Of these cases, 188,143 cases occurred in non-sprinklered residential buildings and 4,416 occurred in sprinklered residential buildings.

The response of the smoke alarms in all of the residential fires included in the database is summarized in Table 7. The proportion of incidents where the fires were judged to be too small for operation of a smoke alarm is larger than that reported by Ahrens for the period from 2003-2006. Especially surprising is the significant difference in the number of smoke detectors which did not operate in non-sprinklered residences as compared to sprinklered residences. No reasons for smoke alarms that "failed to operate" are given in NFIRS. Some of these cases may be attributable to fire size (the assessment of the adequacy of fire size necessary is done subjectively by the individual completing the form for a particular incident) or other factors identified in the previous CPSC study [Smith, 1993].

Table 7. Smoke Detector Response in 1- and 2-Family and Multi-Family Residences

	Non-sprinklered 1- and 2-Family and Multi-Family Residences		Sprinklered 1- and 2-Family and Multi-Family Residences	
Response	Number of incidents	% of total in non-spr. residences	Number of incidents	% of total in spr. residences
Fire too small to operate	24646	13.1	564	12.8
Operated	105215	55.9	3097	70.1
Failed to operate	28703	15.3	283	6.4
Undetermined or no answer	29579	15.7	472	10.7
Total	188143		4416	

The performance of smoke detectors and sprinklers in sprinklered 1- and 2-family and multiple family dwellings is summarized in Table 8. The proportion of fires which were judged to be too small for sprinklers to operate was more than three times the proportion for smoke detectors (45.1% to 12.8%).

Table 8. Smoke Detector and Sprinkler Response in Sprinklered 1- and 2-Family and Multi-Family Residences

	Smoke Detectors		Sprinklers	
Response	Number of incidents	% of total of detectors	Number of incidents	% of total of sprinklers
Fire too small to operate	564	12.8	1990	45.1
Operated	3097	70.1	1738	38.9
Failed to operate	277	6.4	263	6.0
Undetermined or no answer	459	10.7	445	10.1
Total	4416		4416	

The casualty rates in fire incidents in residences in which smoke detectors or sprinklers were present are presented in Figures 1-3. In Figure 1, the casualty rate for fire incidents where a smoke detector failed to operate is indicated as being appreciably greater than that for fire incidents where smoke detectors operated. It's unclear why the casualty rate is greatest for the incidents where the fire was too small for a smoke detector to be expected to operate, especially relative to those casualties attributed to smoke inhalation.

For all types of casualties, the casualty rate per 100 fire incidents where a smoke detector failed to operate was 0.33 as compared to a value of 0.027 for fire incidents where a smoke detector operated, the difference being a factor of 12. Both of these cases were considered by the fire service individual providing the data input to NFIRS as being large enough for a detector to operate. As such, this difference is a key indication of the benefit provided by a functioning smoke detector.

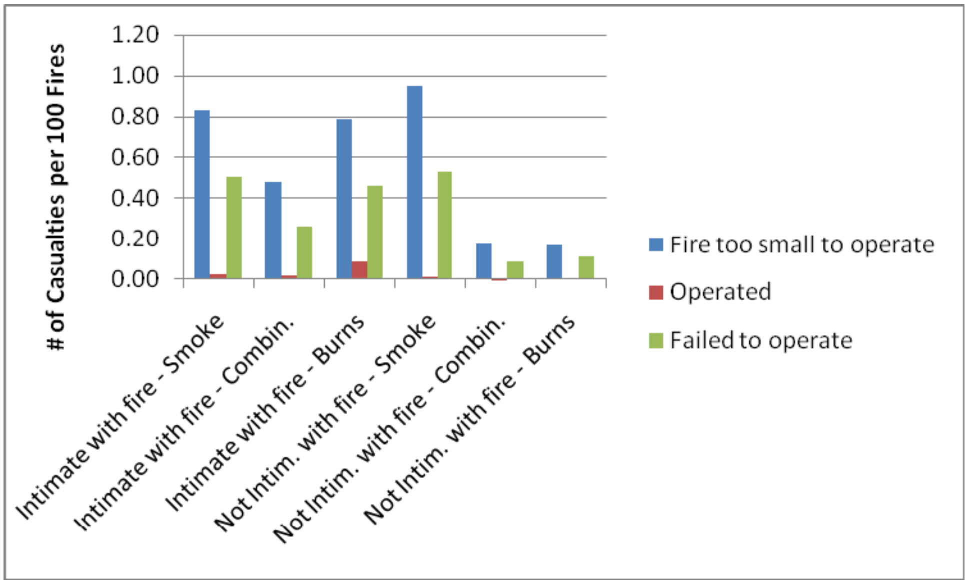


Figure 1. Casualty Rates in Non-Sprinklered 1- and 2-Family and Multi-Family Residences vs. Smoke Detector Operation

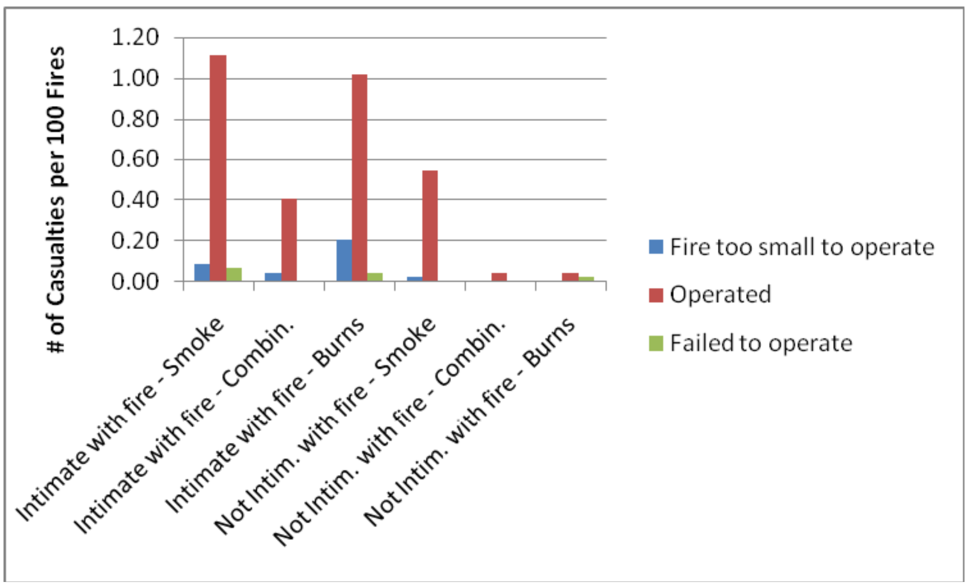


Figure 2. Casualty Rates in Sprinklered 1- and 2-Family and Multi-Family Residences vs. Smoke Detector Operation

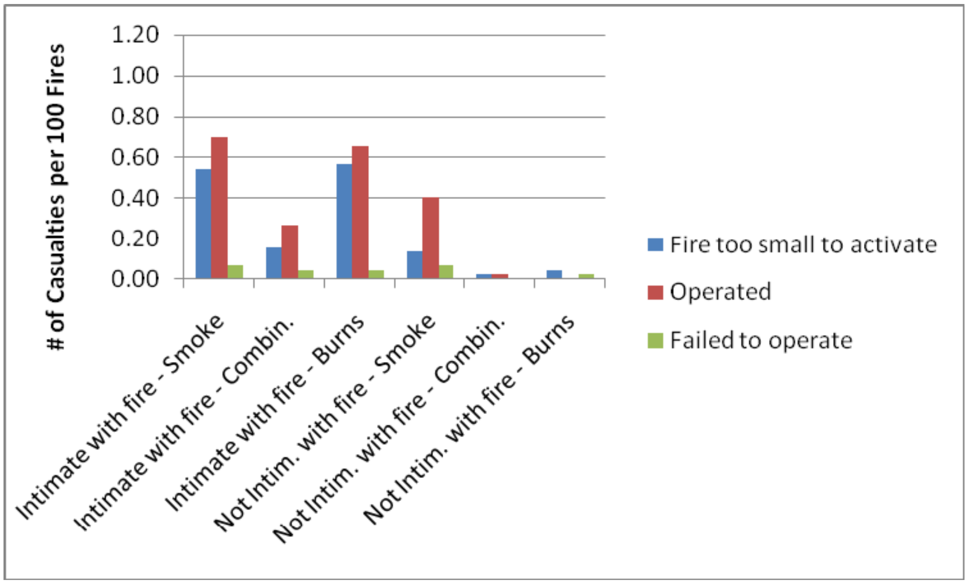


Figure 3. Casualty Rates in Sprinklered 1- and 2-Family and Multi-Family Residences vs. Sprinkler Operation

For all types of casualties, the casualty rate per 100 fire incidents where a smoke detector failed to operate was 0.33 as compared to a value of 0.027 for fire incidents where a smoke detector operated, the difference being a factor of 12. Both of these cases were considered by the fire service individual providing the data input to NFIRS as being large enough for a smoke detector to operate. As such, this difference is a key indication of the benefit provided to mitigate the threat from serious fires by a functioning smoke detector.

The trends indicated in the casualty rates depicted in Figures 2 and 3 are somewhat puzzling. The casualty rates are greater for those cases where smoke detectors and sprinklers operated than for those where they failed to operate. In some cases, this may be due to the smoke detectors or sprinklers being remote from the area of origin.

The performance of smoke detectors that operated in residences without sprinklers or where sprinklers did not operate is summarized in Table 9. As indicated in the table, occupants were alerted by smoke detectors in 96.6% of the fire incidents. No reasons are provided in NFIRS to explain why the failures in alerting occurred or why occupants did not respond appropriately.

Table 9. Detector Performance in 1- and 2-Family and Multi-Family Residences

Performance	Number of incidents, Un-sprinklered Resid.	Number of incidents, Sprinklered Resid.*	Combined Number of Incidents	% of total
Alerted occupants, occupants responded	75849	122	75971	93.0
Alerted occupants, occupants did not respond	2917	4	2921	3.6
Failed to alert occupants	2819	5	2824	3.5
Total	81585	131	81716	

* Sprinkler did not operate in these incidents.

2.2.2 Commercial Residential Facilities

A total of 2,356 fire incidents occurred from 2003 to 2007 in the commercial residential facilities. The response of the smoke detectors and sprinklers in these fire incidents is summarized in Tables 10 and 11. Only about 10% of the fires are judged to be too small for smoke detectors to operate in all commercial residential facilities.

Table 10. Detector Response in Commercial Residential Facilities

	Non-sprinklered hotels		Sprinklered Hotels	
Response	Number of incidents	% of total in non-spr. hotels	Number of incidents	% of total in spr. hotels
Fire too small to operate	143	9.7	95	10.8
Operated	789	53.6	646	73.2
Failed to operate	224	15.2	58	6.6
Undetermined or no answer	317	21.5	84	9.5
Total	1473		883	

Table 11. Detector and Sprinkler Response in Sprinklered Commercial Residential Facilities

	Detectors		Sprinklers	
Response	Number of incidents	% of total of detectors	Number of incidents	% of total of sprinklers
Fire too small to operate	95	10.8	545	54.2
Operated	646	73.2	199	19.8
Failed to operate	58	6.6	53	5.3
Undetermined or no answer	84	9.5	209	20.8
Total	883		1006	

The results in Table 11 indicate that there is a significantly greater portion of fires judged to be "too small to operate" for sprinklers than smoke detectors, i.e. 54.2% vs. 10.8%. Alternatively, smoke detectors responded in almost 75% of the fire incidents where both smoke detectors and sprinklers were present, while sprinklers operated in only about 20% of all incidents. The reason for this significant difference cannot be explained through the NFIRS data and thus is a matter of conjecture. One possible explanation follows Hall's suggestion that the early warning provided by smoke detectors may be providing occupants an opportunity to control the fire prior to operation of the sprinklers.

The casualty rates for the fire incidents in commercial residential facilities are presented in Figures 4-6. This data is based on a relatively limited number of fire incidents with few casualties.

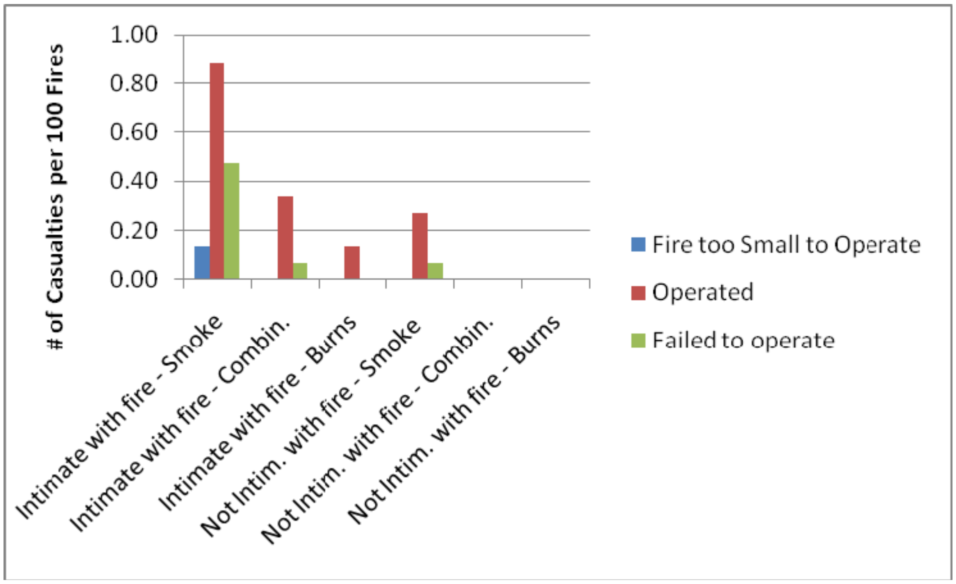


Figure 4. Casualty Rates in Non-Sprinklered Commercial Residential Facilities vs. Smoke Detector Operation

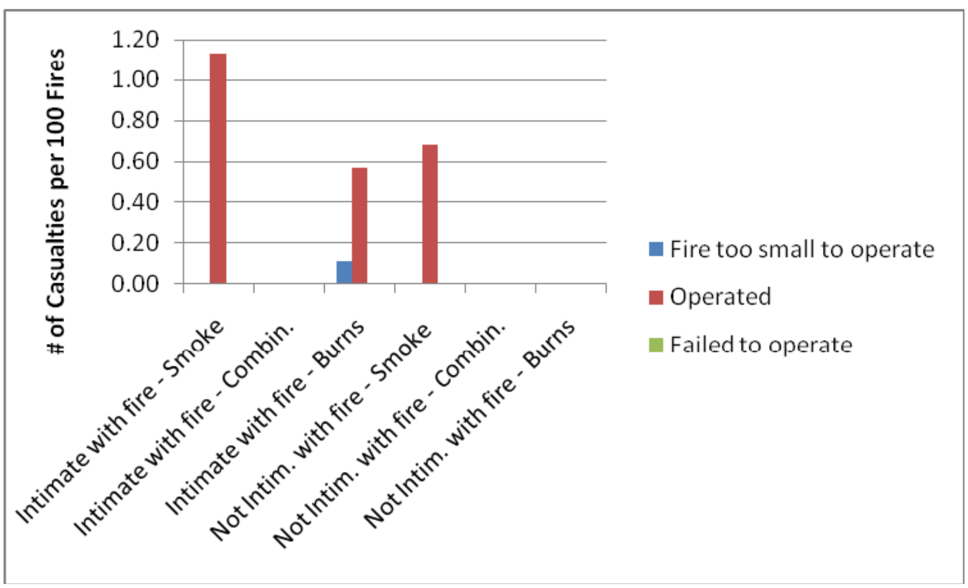


Figure 5. Casualty Rates in Sprinklered Commercial Residential Facilities vs. Smoke Detector Operation

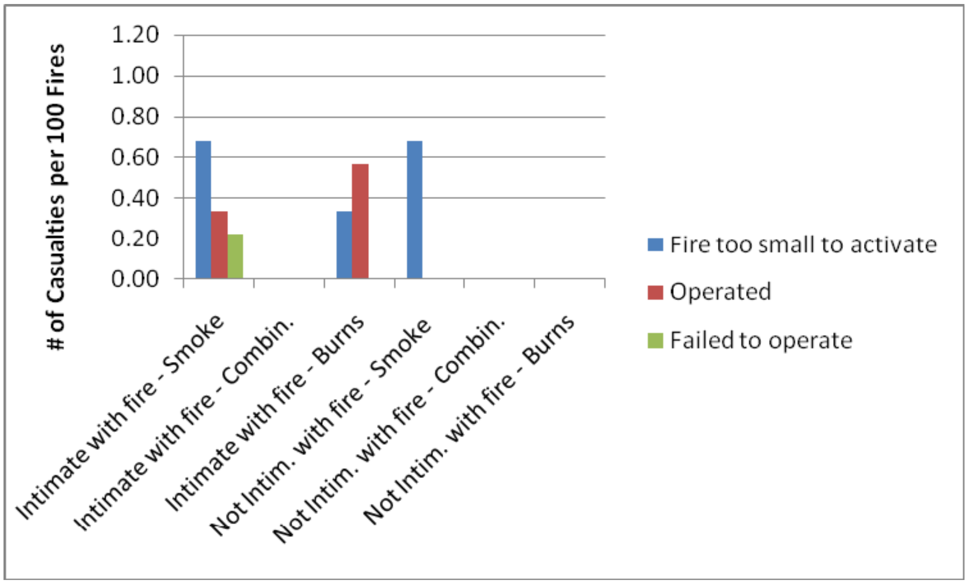


Figure 6. Casualty Rates in Non-Sprinklered Commercial Residential Facilities vs. Sprinkler Operation

The performance resulting from the activation of smoke detectors is summarized in Table 12. Smoke detectors alerted occupants in 98% of the fire incidents. The reasons for the failures to alert are not included in the NFIRS data.

Table 12. Detector Performance in Commercial Residential Facilities

Performance	Number of incidents, Un-sprinklered Comm. Resid.	Number of incidents, Sprinklered Comm. Resid.*	Combined Number of Incidents	% of total
Alerted occupants, occupants responded	532	91.1	562	91.3
Alerted occupants, occupants did not respond	43	7.4	43	7.0
Failed to alert occupants	9	1.5	10	1.6
Total	584		615	

*Sprinklers did not operate in these incidents.

2.2.3 Health-care Facilities

A total of 1,865 fire incidents occurred from 2003 to 2007 in the types of health-care facilities noted previously. The response of the smoke detectors in these fires is summarized in Tables 13 and 14. Fires were too small for a smoke detector to operate in 11.4% of all fires in non-sprinklered facilities and 17.8% in sprinklered health-care facilities. Combined, there were 285 fire incidents in health-care facilities, or 15.3% of the total, where fires were judged to be too small for smoke detectors to operate. This compares to 65.4% of the fire incidents which were judged to be too small for sprinklers to operate.

Table 13. Detector Response in Health-Care Facilities

	Non-sprinklered health-care facilities		Sprinklered health-care facilities	
Response	Number of incidents	% of total in non-spr. h-c facilities	Number of incidents	% of total in spr. h-c facilities
Fire too small to operate	84	11.4	201	17.8
Operated	574	78.1	823	72.7
Failed to operate	30	4.1	48	4.2
Undetermined or no answer	47	6.4	60	5.3
Total	735		1132	

Table 14. Detector and Sprinkler Response in Sprinklered Health-Care Facilities

	Detectors		Sprinklers	
Response	Number of incidents	% of total of detectors	Number of incidents	% of total of sprinklers
Fire too small to operate	201	17.8	743	65.4
Operated	823	72.7	155	13.6
Failed to operate	48	4.2	62	5.5
Undetermined or no answer	60	5.3	175	15.5
Total	1132		1132	

The casualty rates for smoke detector and sprinkler performance in health-care facilities are presented in Figures 7-8. The data depicted in the figures needs to be considered carefully. As an example, the casualty rate for fire incidents where smoke detectors operate are greater than those where the fire is deemed too small for them to operate. This is due to the fire risk being much smaller in fires that are too small, and should not be interpreted to indicate that the operation of the smoke detector increased the fire risk.

The smoke inhalation casualty rates are particularly noteworthy. The greatest casualty rate from the smoke detector perspective is observed for incidents where smoke detectors operated. From the sprinkler perspective, the greatest casualty rate is associated with the fires judged to be too small to operate sprinklers. The casualty rate for burn injuries sustained by those intimate with the fire, but the fire was too small for sprinkler operation, is about twice that for those fires that were too small for smoke detector operation.

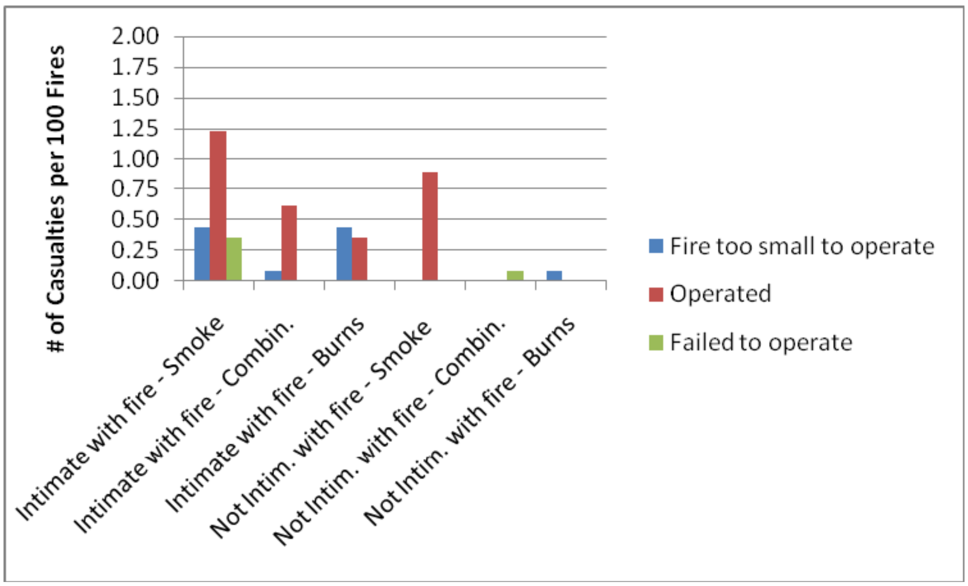


Figure 7. Casualty Rate for Fire Incidents in Sprinklered Health Care Facilities with Smoke Detectors.

The results of smoke detector operation are presented in Table 15. As noted in Table 15, when smoke detectors did operate, occupants responded in 98% of the cases. In only 2% of the cases, did the smoke detector fail to alert the occupants.

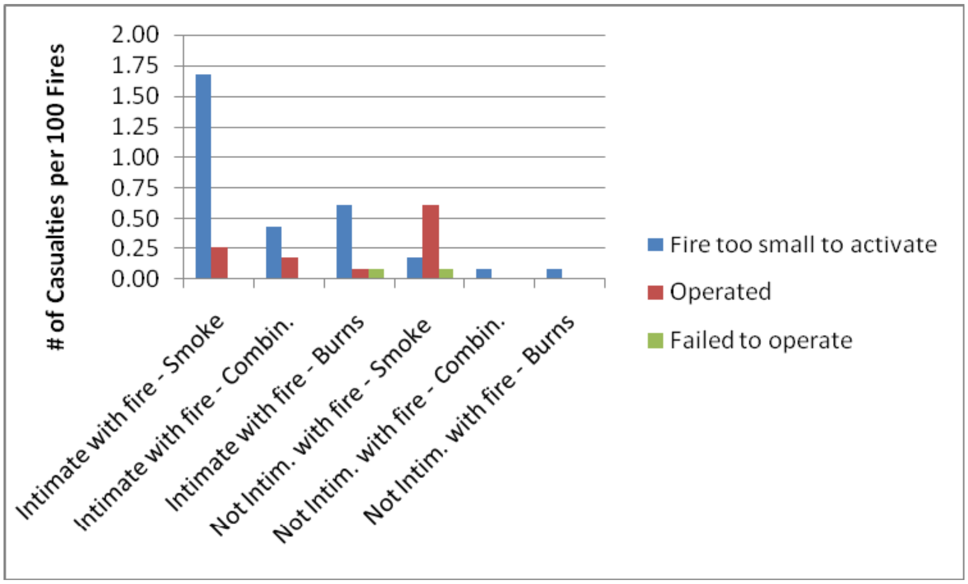


Figure 8. Casualty Rate for Fire Incidents in Health Care Facilities with Sprinklers

Table 15. Detector Performance in Health-Care Facilities

Performance	Number of incidents, Un-sprinklered Health-care	Number of incidents, Sprinklered Health-care*	Combined Number of Incidents	% of total
Alerted occupants, occupants responded	532	40	572	95.8
Alerted occupants, occupants did not respond	10	3	13	2.2
Failed to alert occupants	12	0	12	2.0
Total	554	43	597	

*Sprinklers did not operate in these incidents.

3. Experimental Programs

Several experimental programs have been conducted for the purpose of evaluating the response of smoke alarms or sprinklers. In some cases, both technologies were included in a particular experimental program. The principal performance parameters of interest involve the response time and conditions present at the time of response.

3.1 Smoke Alarm Performance in One- and Two-Family Dwellings

Two projects were conducted by the National Institute of Standards and Technology (NIST) and the National Research Council of Canada (NRCC) in the same time period with the primary purpose being to assess the response of smoke alarms in residences. The Home Smoke Alarm project, conducted by NIST, was intended "*to provide both insight into siting and response characteristics of residential smoke alarms and a set of reference data for future enhancements to alarm technology based on fires from current materials and constructions*" [Bukowski, et al., 2008]. The appropriateness of the existing siting requirements included in NFPA 72 was being investigated to see whether the requirements developed from the Indiana Dunes experiments conducted in the 1970's were still relevant. Revisiting the requirements was needed because of suspected changes in the fire characteristics of residential furnishings and advances in smoke alarms since the 1970's.

The experimental program consisted of 36 fire tests, conducted in two single family home designs. One home was a manufactured home[3] and the other a two-story home. A diagram of the manufactured home is provided as Figure 4. Fuels consisted of ordinary combustibles which could be found in the home, such as upholstered furniture, mattresses, and cooking oil. Both flaming and smoldering fire scenarios were considered; based on leading residential fatal fire scenarios. Measurements of temperature, light obscuration and gas concentrations were collected for the purpose of assessing when tenability would possibly be lost during each experiment. The response time of smoke alarms, CO alarms, heat alarms, and sprinklers were also documented.

[3] The size of the manufactured home was similar to that of an apartment or condominium unit and as such the authors noted that the results obtained in the manufactured home were also applicable to apartment and condominium units.

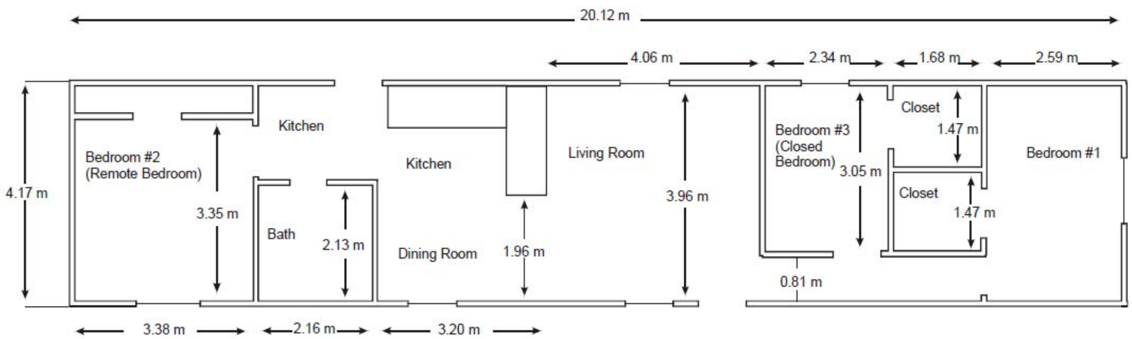


Figure 4. Floor Plan of Manufactured Home in Home Smoke Alarm Project [Bukowski, et al., 2008]

The results from a flaming mattress test initiated in Bedroom #1 are presented as an example of the relative performance of smoke alarms and sprinklers and the conditions present in the room of fire origin and adjacent hallway that were observed in the Home Smoke Alarm Project. The smoke alarms in the adjacent hallway and living room operated 32 and 42 sec after ignition. A telltale sprinkler (residential sprinkler with an operating temperature of 155 °F) in the room of origin operated 147 sec after ignition. The gas temperatures and optical density in the room of origin and adjacent hallway during this test are presented in Figures 5-8.

The notation of “initiation of suppression” in the figures relates to the manual operation of a water spray device, not the residential sprinkler (no water was supplied to the sprinkler to permit fire growth beyond the time of actuation of that sprinkler).

The temperature and optical density at the time of smoke alarm and telltale sprinkler operation in the two areas are presented in Table 11.

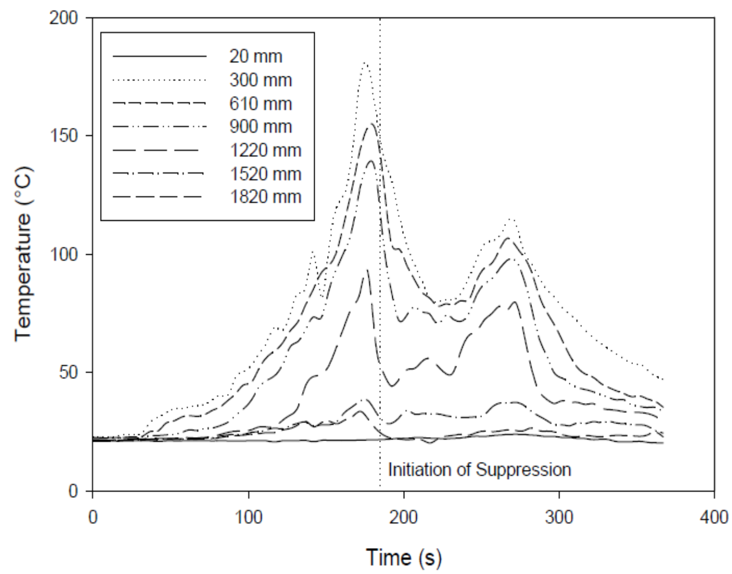


Figure 5. Gas Temperature in Room of Origin in Test SDC05, Home Smoke Alarm Project [Bukowski, et al., 2008] (Lengths refer to distance from ceiling).

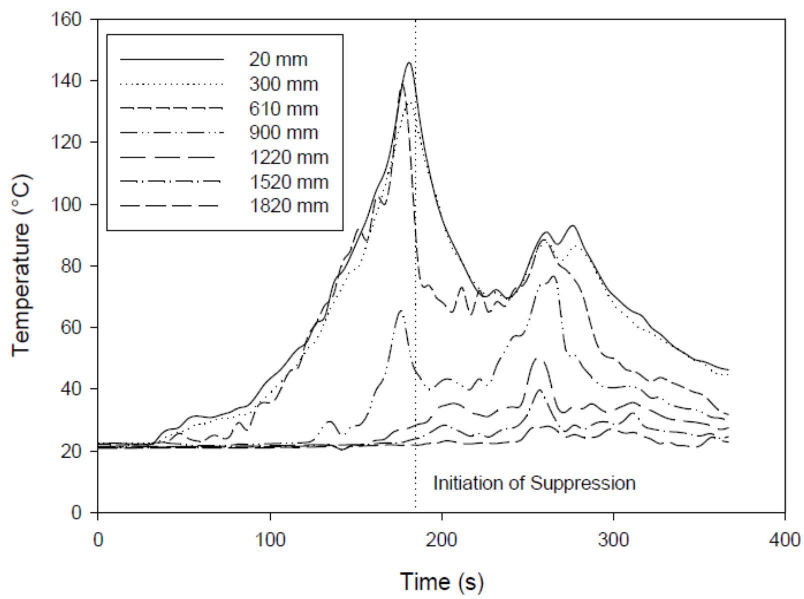


Figure 6. Gas Temperature in Hallway in Test SDC05, Home Smoke Alarm Project [Bukowski, et al., 2008] (Lengths refer to distance from ceiling).

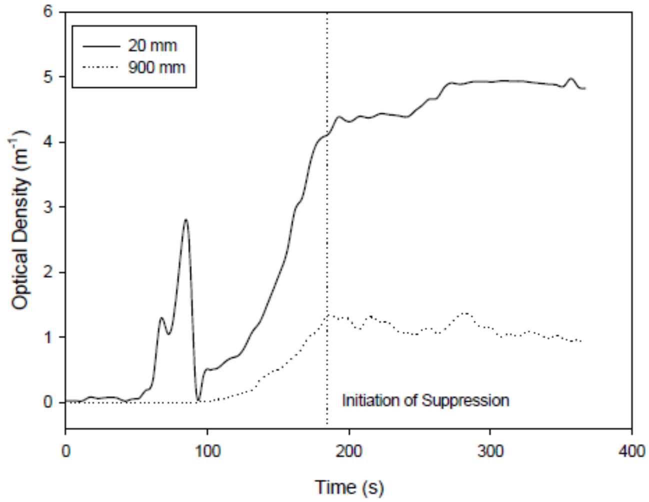


Figure 7. Optical Density in Room of Origin in Test SDC05, Home Smoke Alarm Project [Bukowski, et al., 2008] (Lengths refer to distance from ceiling).

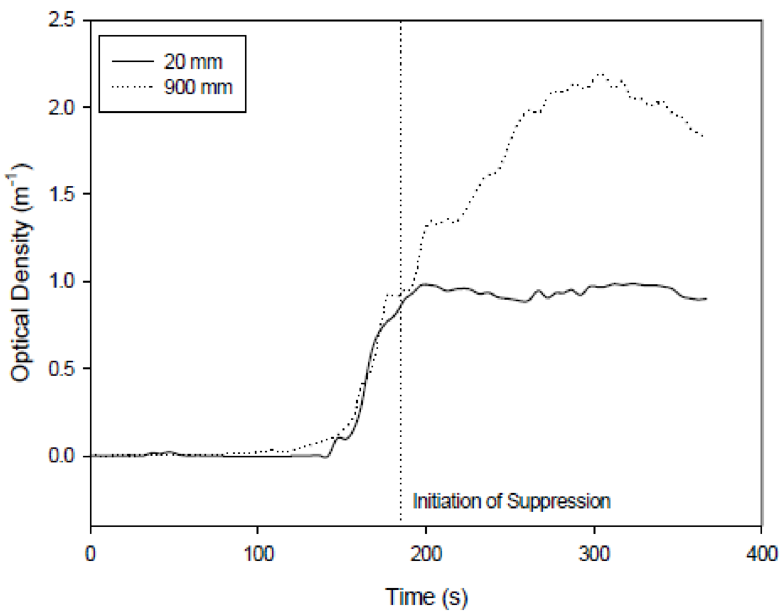


Figure 8. Optical Density in Hallway in Test SDC05, Home Smoke Alarm Project [Bukowski, et al., 2008] (Lengths refer to distance from ceiling).

Table 11. Conditions in Bedroom and Adjacent Hallway at Smoke Alarm and Sprinkler Activation Times, Test SDC 05, Home Smoke Alarm Project

	Bedroom		Hallway	
Component actuation	Near Ceiling Temperature °C (°F)	Visibility (ft)	Near Ceiling Temperature °C (°F)	Visibility (ft)
Smoke alarm in hallway (32 sec)	25 (77)	110	22 (72)	Infinite
Smoke alarm in living room (42 sec)	32 (90)	110	25 (77)	Infinite
Residential sprinkler (147 sec)	95 (203)	7	80 (176)	110

* Noted temperatures and visibilities are approximate. The visibility is estimated using the correlation: visibility in ft = 11.0/(optical density in m^{-1}) [Klote and Milke, 2002].

As indicated in Table 11, the conditions at the time of smoke alarm activation were relatively benign in this test. However, at the time of activation of the residential sprinkler, conditions are beginning to deteriorate in the room of origin and temperature rise in the hallway is noteworthy.

The principal conclusions of the effort were [Bukowski, et al., 2008]:

1. *"Smoke alarms of either the ionization type or the photoelectric type consistently provided time for occupants to escape from most residential fires."* This was concluded despite using a highly conservative parameter of light obscuration for tenability which would increase the margin of safety available for escape.

2. *"Smoke alarms may not provide protection for people directly exposed to the initial fire development."* This has also been observed in the fire incident statistics reviewed in the previous section.

3. *"Smoke alarms of either type installed on every level generally provided positive escape times for different fire types and locations. Adding smoke alarms in bedrooms increased the escape time provided, especially for smoldering fires."* This issue was raised by Ahrens, i.e. that the performance of smoke alarms could be improved with increased numbers of smoke alarms in residences to comply with the current requirements in NFPA 72.

4. *“Residential sprinklers activated well after the smoke alarms and after the heat alarms in all of the scenarios.”* This trend has also been observed in the fire incident statistics reviewed in the previous section.

The Kemano project conducted by the NRCC [Su, et al., 2003] consisted of 13 experiments in two single-family dwellings. One of the houses was one-story, while the other was two stories. In the NRCC experiments, fuels consisted of representative packages comprised of wood, polyurethane, cotton flannel, upholstered furniture and cooking oil. All of the fire scenarios used in the Kemano project started as smoldering fires, though they were permitted to transition to become flaming fires. The tests started with smoldering fires to involve longer response times for smoke alarms.

A floor plan for the single-story home is presented in Figure 9.

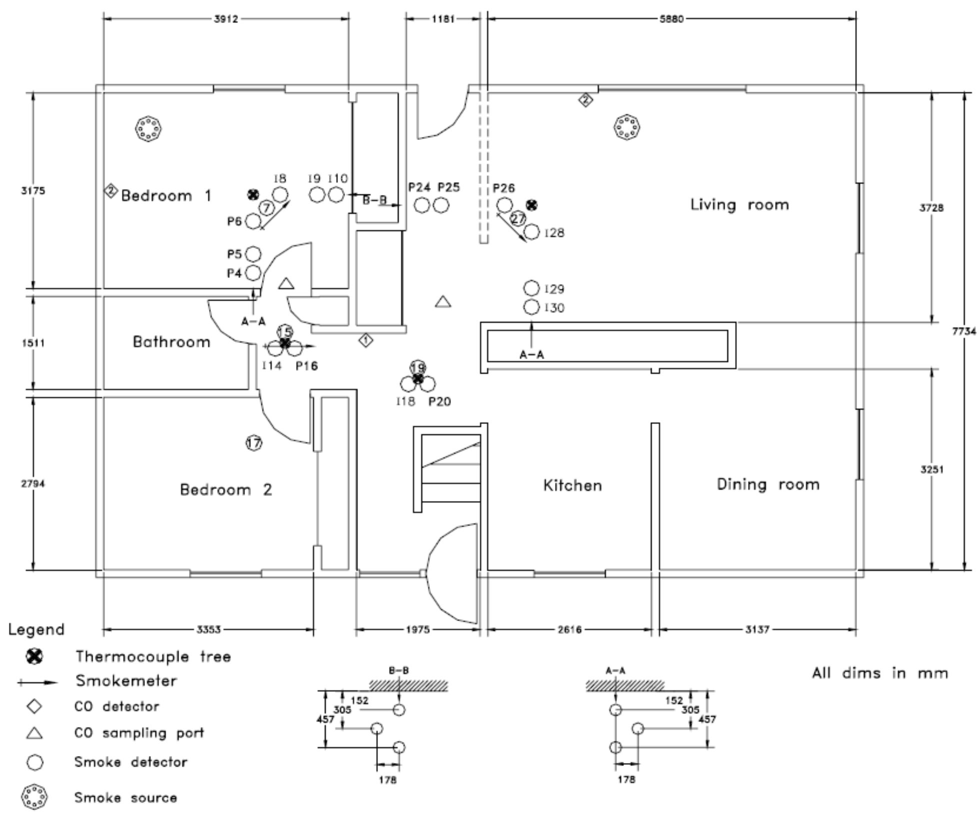


Figure 9. Floor Plan of Single-story Home in Kemano Project [Su, et al., 2003]

The results from one test in the bedroom of the single-story home conducted as part of the Kemano Project are described as an example of the performance of smoke alarms observed in this experimental program. The conditions present in the room of fire origin and adjacent hallway before, at, and following the time of smoke alarm activation are presented in Figures 10-13. In this test, all bedroom doors were left open. The fire source in Bedroom 1 consisted of 5 pine sticks. The fire began as a smoldering fire and transitioned to flaming after 388 sec.

The first smoke alarm activated prior to any significant change in the temperature in the room of origin (see Figure 10), and over a minute before the transition to flaming combustion. Similarly, the optical density had just noticeably increased at the time of the activation of the first smoke alarm in the room of origin. Even so, at an optical density of 0.1 m^{-1}, the visibility would still be on the order of 100 ft, and hence would not hinder evacuation.

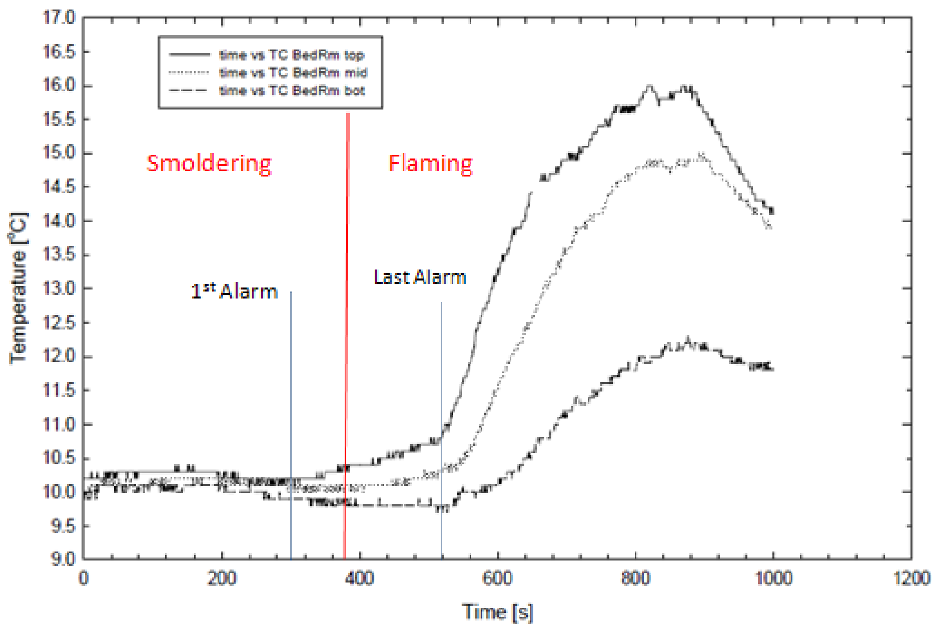


Figure 10. Gas Temperature in Room of Origin in Test 1, Kemano Project [Su, et al., 2003]

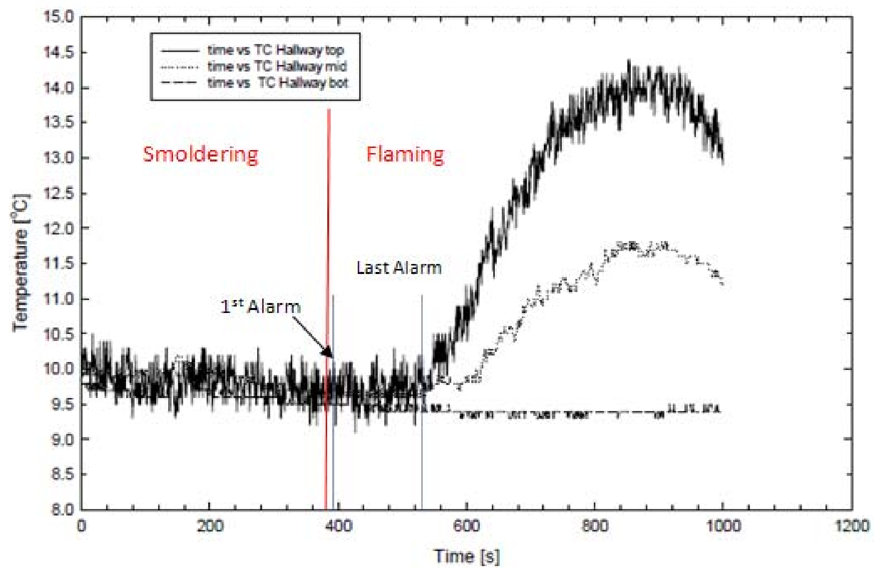


Figure 11. Gas Temperature in Hallway in Test 1, Kemano Project [Su, et al., 2003]

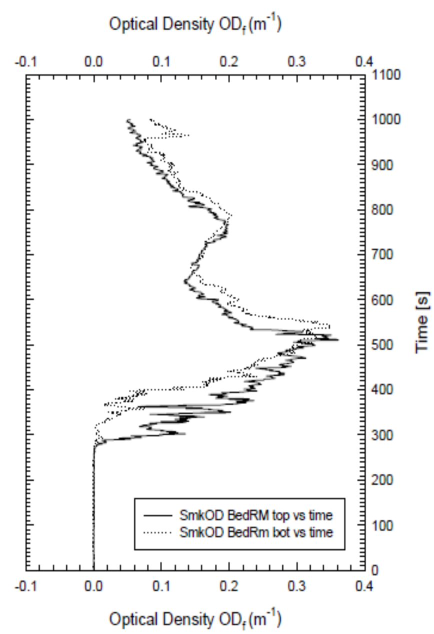


Figure 12. Optical Density in Room of Origin in Test 1, Kemano Project [Su, et al., 2003]

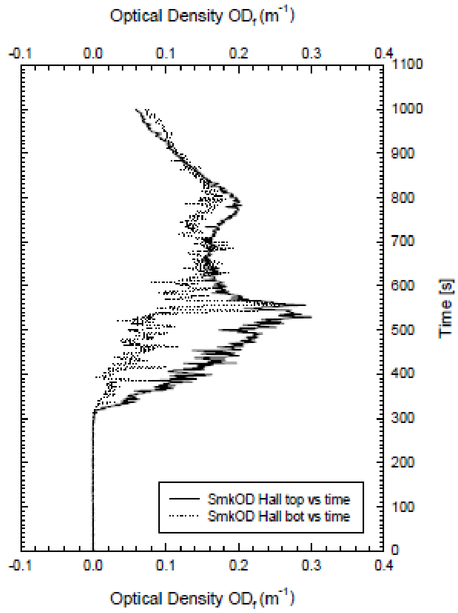


Figure 13. Optical Density in Hallway in Test 1, Kemano Project [Su, et al., 2003]

In the hallway, temperature conditions are unchanged from ambient at the time of activation of all smoke alarms. Similarly, the optical density is unchanged in the hallway when the first smoke alarm activates, though increases steadily thereafter.

In the Kemano Project, the smoke alarms within the room of origin responded within 10 minutes of ignition in every test. Smoke alarms outside of the room of origin responded at about the same time as those in the room of origin as long as all doors between the fire location and smoke alarm were open. Not surprisingly, closed doors between the fire location and smoke alarm caused an appreciable delay in the response of the smoke alarms. In some cases, smoke alarms responded only after a closed door between the fire and smoke alarm was opened. The range in optical densities measured at the time of response of the smoke alarms in the 13 tests was:

- 0.001-0.14 m^{-1} for ionization smoke alarms (visibility of at least 79 ft).
- 0.001-0.12 m^{-1} for photoelectric smoke alarms (visibility of at least 95 ft).
- 0.001-0.14 m^{-1} for multi-sensor (ionization-photoelectric) smoke alarms (visibility of at least 79 ft).

The modest optical densities noted at the time of smoke alarm response in the 13 tests further reinforces the notion that smoke alarms respond at early stages of fire development.

Two more recent experimental studies where the response of smoke alarms was evaluated in residential applications were those by Su, et al. [2008] and Mealy, et al. [2009]. The primary intent of the experimental program described by Su, et al., was to assess the response of several floor system designs for residences. The experimental program by Mealy was conducted primarily to improve fire investigation methods by observing conditions created by residential fires with limited ventilation. In both cases, smoke alarms were included in the experiments to collect data to provide additional insight on the response characteristics of smoke alarms.

Su, et al., conducted their experiments in a simulated two-story house with a basement. All fires were initiated in the basement with "reproducible" fuel packages, i.e. laboratory-assembled packages of similar composition to items commonly found in homes. The fuel packages consisted of a mock-up sofa constructed with 9 kg of exposed polyurethane foam and wood cribs placed beside and underneath the sofa. During the test, temperature, optical density, and gas concentration (CO, CO_2, and O_2) were measured to assess tenability. Both photoelectric and ionization smoke alarms were used in the experiments, with alarms placed in the basement.

The results of the experiments are presented in Table 12. In every scenario, smoke alarms responded within the first minute of ignition. The stipulated incapacitation limit for optical density of 2 m^{-1} relates to a visibility of 5.5 ft. The FED ("Fractional Effective Dose) refers to a tenability analysis based on gas concentrations. An FED of 0.3 is a conservative limit for incapacitation, involving a factor of safety of 3.3 for an average, healthy adult. As noted in the table, the incapacitation time determined from either visibility or gas concentrations ranges from 161 to 676 sec, depending on the conditions created in each test. The differences between smoke alarm response times and the earliest incapacitation time, i.e. Available Safe Egress Time (ASET), achieved in any test are summarized in Table 13. Considering the ASET's noted Table 13, the smoke alarms provided sufficient time to permit escape before loss of tenability in every test.

Table 12. Summary of Results [Su, et al., 2008]

Floor Assembly Type	Test	First Alarm	OD = 2 m^{-1}	FED=0.3-1 1st storey	FED=0.3-1 2nd storey	Structural Failure
Tests with open basement doorway						
Solid wood joist	UF-01	40	185	*205-235*	*225-255*	740
Wood I-joist A	UF-03	48	183	**205-213**	*225-247*	490
Steel C-joist	UF-04	30	195	**207-215**	*245-280*	462
Metal-plate wood truss	UF-05	40	190	*206-232*	*235-260*	469
Wood I-joist B	UF-06	45	170	*198*-**211**	*208-241*	382
	UF-06R	38	161	*198*-**199**	*207-241*	380
	UF-06RR	43	184	*203*-**216**	*218-248*	414
Metal web wood truss	UF-07	40	170	**192-207**	*230*-**255**	325
Tests with closed basement doorway						
Solid wood joist	UF-02	42	297	*466-676*	*362-501*	1200
Metal web wood truss	UF-08	50	360	*400*-**486**	*375-510*	474
Wood I-joist A	UF-09	44	319	*329-484*	*364-504*	778

Notes:

1. Values determined using the measurements at 1.5 m height (for gas concentrations and OD) or 1.4 m height (for temperatures);
2. The number with the *Italic* font represents the calculated time for reaching the CO incapacitation dose, while the number in **bold** represents the calculated time for reaching the heat incapacitation dose, whichever occurred first;
3. All values shown in the table are before fire suppression.

Table 13. Difference in Smoke Alarm Response Time and First Encountered Incapacitation Time in Tests by Su, et al. [2008]

Test	Smoke Alarm Response (sec)	First Incapacitation Limit (sec)	ASET (sec)
UF-01	40	185	145
UF-03	48	183	135
UF-04	30	195	165
UF-05	40	190	150
UF-06	45	170	125
UF-06R	38	161	123
UF-06RR	43	184	141
UF-07	40	170	130
UF-02	42	297	255
UF-08	50	360	310
UF-09	44	319	275

Seven experiments were conducted as part of the study by Mealy, et al. [2009]. These experiments were conducted in a mock-up of a one-bedroom apartment. The overall dimensions of the apartment were 30 ft by 15 ft. The fires included smoldering and flaming sources, including cotton batting, a sofa and a wooden kitchen cabinet. Photoelectric, ionization and multi-sensor smoke alarms were included in the tests. As with the NIST Home Smoke Alarm Project, tenability was determined through thermal, and carbon monoxide measurements and a visibility limit was identified from and light obscuration measurements.

Results of the tenability analysis conducted by Mealy, et al., are presented in Table 14. In the smoldering tests and flaming cabinet tests, the smoke obscuration limit was reached before either of the tenability limits (thermal or carbon monoxide). The first tenability limit reached was due to carbon monoxide levels except in the flaming sofa tests when the thermal tenability limit was reached first. With the exception of two of the smoldering tests, the response of all smoke alarms occurred prior to the onset of untenable conditions.

Milke, et al., [2001] examined the interaction of sprinklers and smoke in order to assess the level of hazard after residential sprinklers operate. The test facility represented a full-scale residential bedroom. The overall dimensions of the space were 16 ft by 18 ft, with a finished ceiling height of 7.67 ft. Several tests were conducted to explore temperature rise and CO, H_2S, and O_2 concentrations leading up to and following sprinkler operation. The operating temperature of the residential sprinklers used in the tests was 155 ^oF. Temperature measurements were taken at several elevations in the room of origin and CO, H_2S, and O_2 levels were recorded in the upper portion of the room of fire origin, as indicated in Figures 14 and 15.

The results from one test is presented in Figure 14. In this test, the temperatures quickly decreased in the space following sprinkler activation. A modest increase in temperature at the lower heights was observed following sprinkler operation, most likely due to mixing of the smoke throughout the space as a result of the thrust of the sprinkler spray and reduction in buoyancy of the smoke. This mixing behavior was also observed visually by noting that the entire room filled with smoke and visibility decreased appreciably at all elevations in the room following sprinkler activation.

CO and H_2S concentrations began to increase appreciably within the minute prior to sprinkler operation. Following sprinkler activation, the increasing CO and H_2S continued, even though the temperature measurements indicated that the fire was controlled by the sprinkler.

Table 14. ASET Values for Thermal, Toxic Gas and Visibility Tenability Criteria [Mealy, et al., 2009]

Test ID	Alarm Scenario	1st Tenability Criterion (min.)	1st Visibility Criterion (min.)
SM1	1st Ion	52.9	43.8
	Last Ion	5.3	*-3.8*
	1st Photo	54.5	45.5
	Last Photo	11.5	2.5
	1st Combo	57.2	48.1
	Last Combo	36.3	27.3
SM2	All	N/R	-61
SM3	All	N/R	-5
SM4	1st Ion	89.5	73.4
	Last Ion	67.3	51.2
	1st Photo	91.4	75.3
	Last Photo	86.1	69.9
	1st Combo	92.7	76.5
	Last Combo	89.6	73.5
S1	1st Ion	5.7	4.0
	Last Ion	3.6	1.9
	1st Photo	2.2	0.5
	Last Photo	1.7	0.0
	1st Combo	5.2	3.5
	Last Combo	3.3	1.6
CH1	1st Ion	6.5	3.5
	Last Ion	4.2	1.2
	1st Photo	6.2	3.2
	Last Photo	4.4	1.4
	1st Combo	6.2	3.2
	Last Combo	4.8	1.8
CH2	1st Ion	4.8	2.4
	Last Ion	3.9	1.5
	1st Photo	5.0	2.6
	Last Photo	3.4	1.0
	1st Combo	4.9	2.5
	Last Combo	3.5	1.1

Key:
SM1: Smoldering cotton batting fire
SM2: Smoldering sofa fire
SM3: Smoldering sofa fire
SM4: Smoldering sofa fire
S1: Flaming sofa fire
CH1: Flaming wood cabinet fire
CH2: Flaming wood cabinet fire
N/R - Tenability criteria not reached.

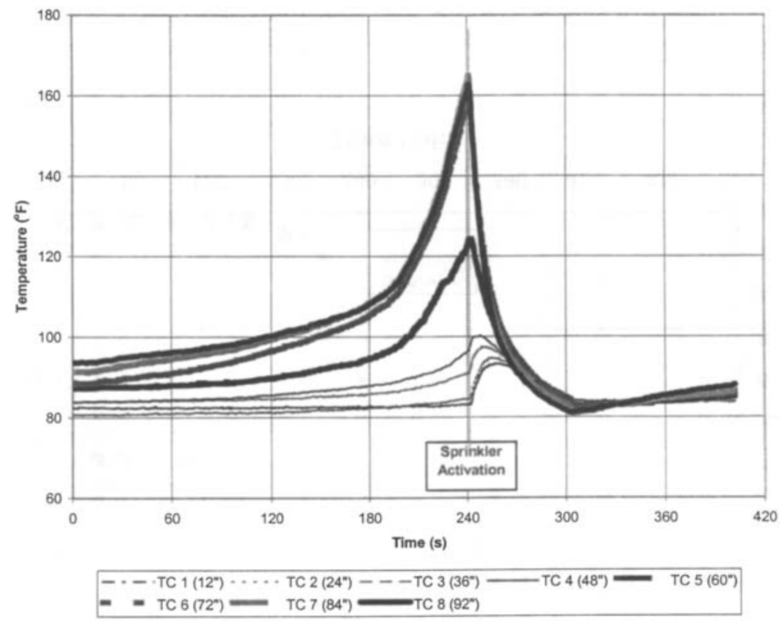


Figure 14: Temperatures for Test #4 [Milke, et al., 2001]

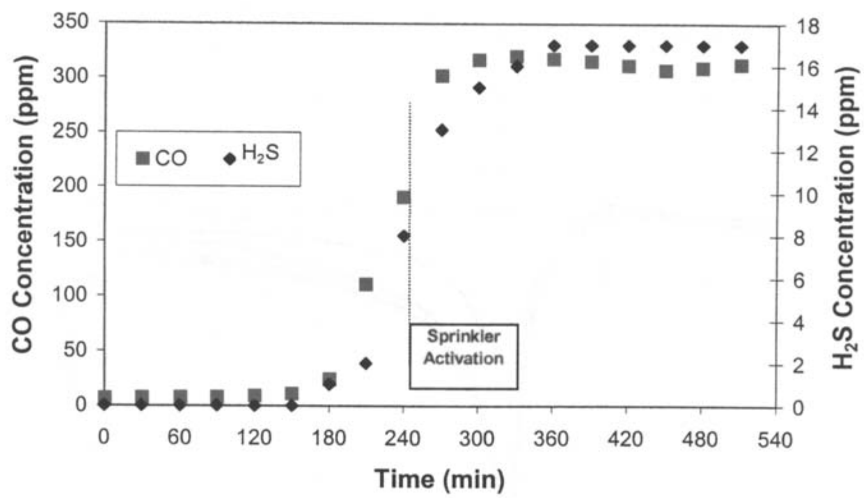


Figure 15: CO and H_2S Concentrations for Test #4 [Milke, et al., 2001]

Sekizawa, et al., [1997] conducted a series of experiments in a simulated living room in a residence. The room dimensions were 12.5 x 12 ft, with a ceiling height of 8 ft. Wood cribs were used as the fuel source. A standard spray sprinkler with an operating temperature of 160 °F was located in the room, as was a photoelectric smoke detector. In virtually all tests, the smoke detector activated at least a minute prior to the sprinkler.

Similar to Milke, et al., in some experiments the CO concentration and smoke density was observed to increase substantially following sprinkler operation. An example of that observation is depicted in Figure 16 for one of the experiments.

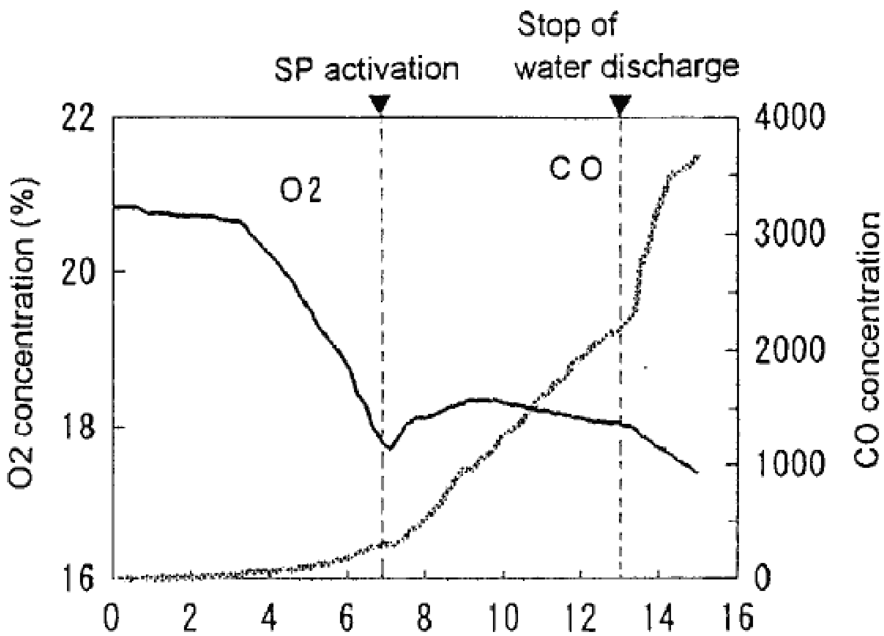


Figure 16. O_2 and CO Concentrations in Experiment by Sekizawa, et al. [1997]

3.2 Smoke Detectors and Sprinkler Performance in Hotels and Hospitals

Two sets of experiments were conducted in simulated commercial occupancies where observations of the response of sprinklers or smoke alarms were recorded. One of these was conducted in a simulated hotel room [Bill, 1990] [Bill and Kung, 1989] while the other was conducted in a simulated hospital room [Notarianni, 1993].

3.2.1 Hotels

Bill and Kung completed eight experiments of a simulated hotel room for the purpose of evaluating the performance of one model of an extended coverage horizontal sidewall sprinkler equipped with a fast-response link and the response of smoke detectors. Four of the experiments involved flaming chair and mattress fires, while four involved smoldering mattresses. For the flaming-chair tests, the room also contained draperies, a table, and a metal wastepaper basket with 10 sheets of newspaper. For flaming and smoldering mattress tests, the room contained the bed and a newspaper-filled basket. Ventilation conditions were altered between full mechanical ventilation (four air changes per hour), natural ventilation via an open room door, and no ventilation (closed room door). Tenability was evaluated as the time integrated concentration of carbon monoxide in the hotel room. Fifteen smoke detectors were installed at five stations in the room and hallway. Two pendant sprinklers were located in the bathroom and foyer and one sidewall QR-EC sprinkler was located in the living area.

For the flaming chair tests, the guest room smoke detectors activated at a gas temperature of 38 °C (100 °F) and an obscuration of 4.6 %/m (15 %/ft), which was approximately 3 minutes before sprinkler actuation. For all flaming tests with an open room door, obscuration approached 100 percent with a gas temperature of approximately 93 ° C (200 °F) when the sprinkler actuated. As an example, the temperature, carbon monoxide concentration and light obscuration are presented in Figures 17-19 for one test involving the flaming chair. In this test, sprinklers operated at 267 sec. Gas temperatures and carbon monoxide concentration in the room decreased appreciably shortly after sprinkler actuation. However, light obscuration in the room of origin and in the adjacent corridor increased substantially immediately following sprinkler actuation.

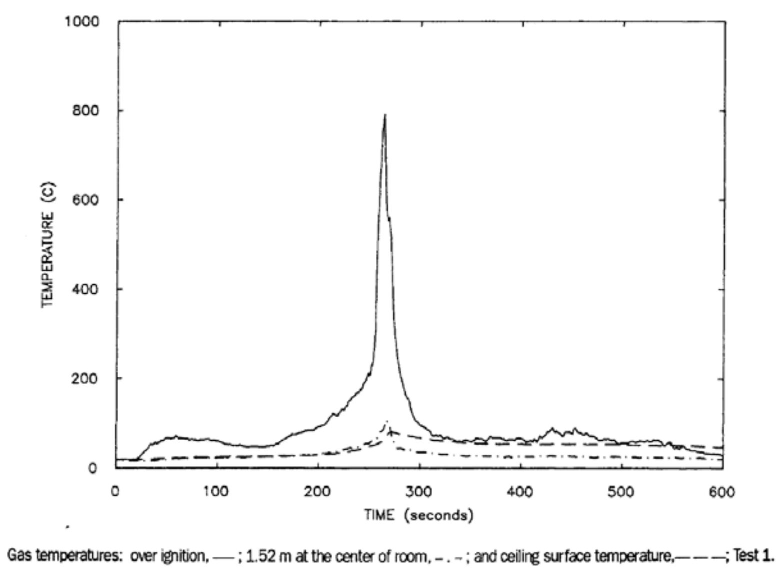
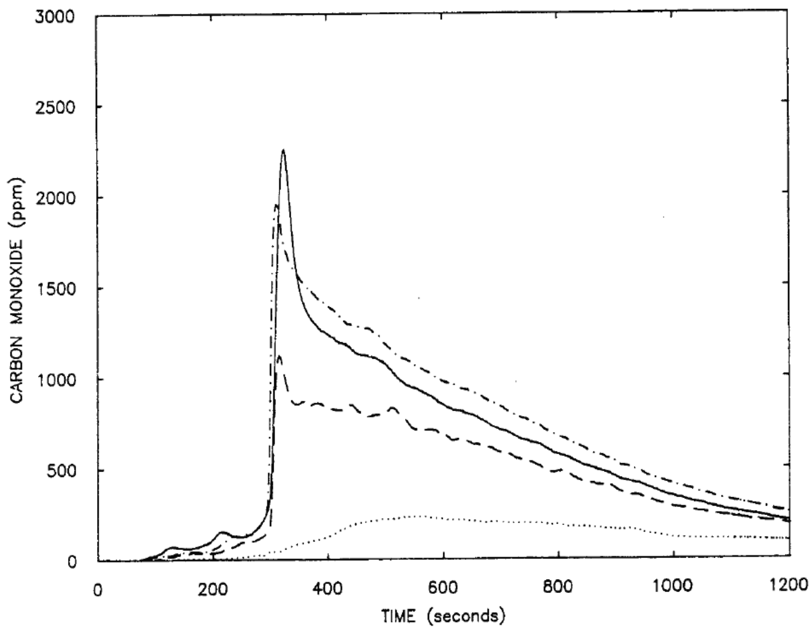
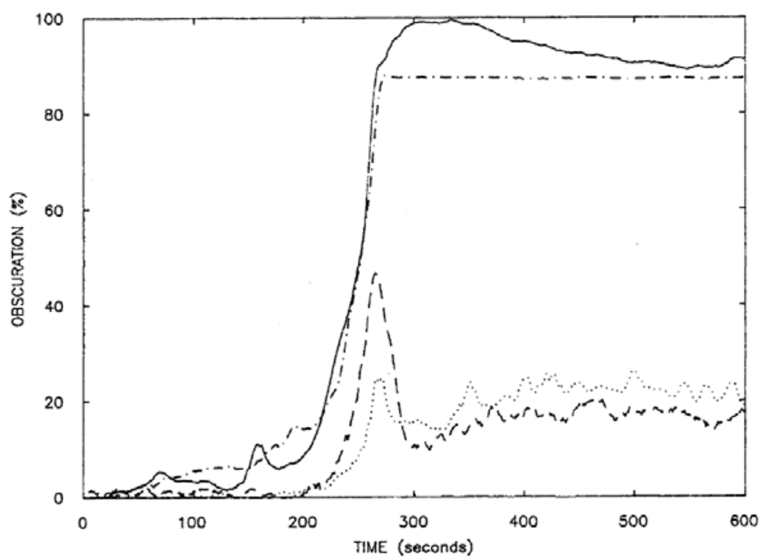


Figure 17. Temperature in Room, Flaming Chair Fire [Bill and Kung, 1989]



Carbon monoxide concentration: room center at ceiling, —— ; room center at 1.52 m, — . — ; foyer, — — — ; end of corridor, … ; Test 1.

Figure 18. Carbon Monoxide Concentration, Flaming Chair Fire [Bill and Kung, 1989]



Obscuration over a 0.30 m path length at 0.555 microns
Center room: 2.35 m, __ ; 1..52 m, _._ ; corridor: 2.35 m, _ _ ; 1.52 m, …

Figure 19. Light Obscuration, Flaming Chair Fire [Bill and Kung, 1989]

Bill concluded [1990]:

"The role of smoke detectors in life safety has also been clearly shown. Smoke detectors warn room occupants in either fast-growing or smoldering fires while the room environment is such that an occupant can easily escape. Moreover, the warning occurs when the fire is small. Thus, the fire may possibly be extinguished without intervention of sprinklers."

3.2.2 Hospitals

Notarianni's experiment consisted of a simulated two-bed hospital room with the original fire source being a wood crib [1993]. A diagram of the room is presented as Figure 20. She included temperature measurements for an assessment of tenability.

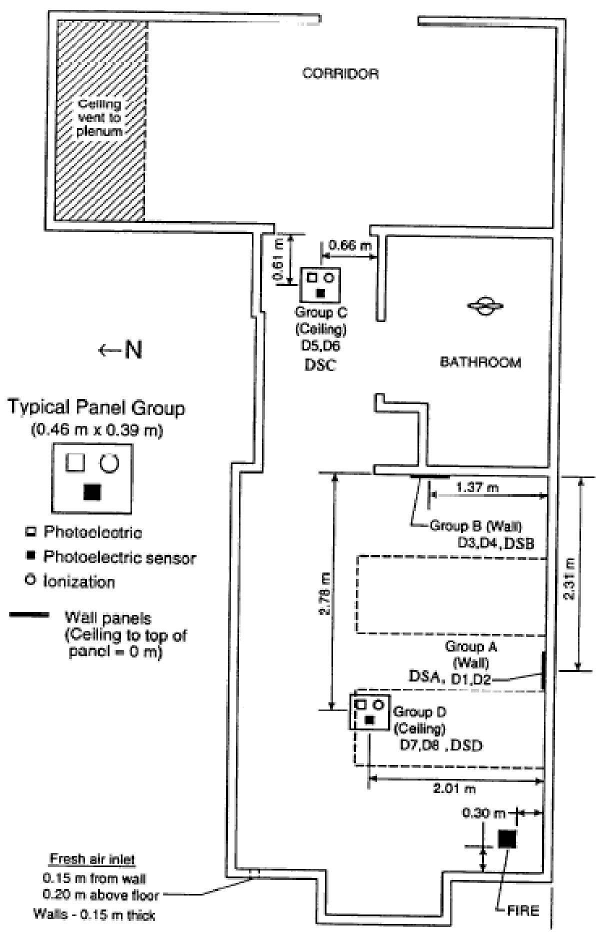


Figure 19. Diagram of Simulated Hospital Room [Notarianni, 1993]

In all tests, an ionization smoke detector responded before the sprinklers. In some tests, a photoelectric detector responded prior to a sprinkler. The reason for the slower response by photoelectric detectors than sprinklers in some tests was attributed to the use of heptane as the initial fuel source, which produces relatively small particles which the photoelectric detector is not as sensitive to.

The temperature at the time of activation of the quick response sprinklers was at or below 77 °C (171 °F) at the 5 ft level and at or below 48 °C (118 °F) at the 3 ft level between the patient beds, in all tests with the exception of the shielded fire scenario[4] where temperatures at the 5 and 3 ft levels reached 111 °C (232 °F), and 78 °C (172 °F) respectively. As an example, the temperature conditions in the room of origin at the time of sprinkler response are presented in Table 10. Consequently, detectors and sprinklers in all locations actuated before tenability was lost in all scenarios with unshielded fires.

Device Number	Description	Activation Time min: s	Activation Time s	1.5 m (5 ft) Elevation Between Beds Temp °C	0.91 m (3 ft) Elevation Between Beds Temp °C
D2	ion, south wall, between beds	0:27	27	22	22
D8	ion, ceiling, center of room	0:36	36	22	22
D4	ion, east wall, bathroom	2:13	133	24	22
D6	ion, ceiling, near room door	2:37	157	25	23
S12	QR sidewall, overhead bed #1	5:58	358	38	26
S4	QR pendent, above foot bed #1	7:02	422	49	29
S11	QR sidewall, overhead bed #2	7:11	431	50	29
D7	photo, ceiling, center of room	7:19	439	52	30
DSC	photo sensor, ceiling, near room door	7:20	440	52	30
S3	QR-EC pendent, center of room	7:20	440	52	30
D3	photo, east wall, bathroom	7:21	441	53	31
S2	QR pendent, above foot bed #2	7:29	449	53	31
DSD	photo sensor, ceiling, center of room	7:33	453	54	31
DSB	photo sensor, east wall, bathroom	7:37	457	55	31
D5	photo, ceiling, near room door	7:40	460	56	31
S5	QR sidewall, across foot bed #1	8:27	507	63	35
S10	QR concealed pendent, above foot bed #1	8:28	508	64	35
S7	QR sidewall, across foot bed #2	8:59	539	70	37
S8	standard pendent, above foot bed #1	9:09	549	70	39
S9	QR concealed pendent, above foot bed #2	9:22	562	75	40
S1	QR-EC sidewall, east wall, bathroom	9:39	579	76	40
S6	standard sidewall, across foot bed #2	–	–	–	–
D1 n/a	photo, south wall, between beds	–	–	–	–
DSA	photo sensor, south wall, between beds	–	–	–	–

Table 10. Gas Temperatures in Room of Origin at the Time of Sprinkler Response, Closed Door Tests [Notarianni, 1993]

4 "Shielded fire" refers to the case where an obstruction is present to prevent the sprinkler spray from reaching the burning fuel.

In the shielded fire test, some sprinklers activated after the thermal tenability criterion was exceeded. Smoke detector activations occurred between 232-377 seconds prior to activation of the first sprinkler, and 552-722 seconds prior to activation of the QR-EC sidewall sprinkler.

Notarianni noted:

> *"Sprinklers in all locations tested actuated before the patient's life would be threatened by this nominally 65 kW fire for the closed door, closed door privacy curtain, and open door privacy curtain tests. However, in the shielded fire test, the sprinklers at locations S6 and S1, the standard sidewall across from the foot of patient bed #2, and the EC sidewall, on the east wall near the bathroom, respectively, activated after the life safety criterion in HAZARD I with regard to temperature was exceeded. Ionization and photoelectric detectors in all locations alarmed before the patient's life would be threatened."*

4. Summary

The relative role of smoke alarms and sprinklers has been demonstrated in numerous recent research investigations. The trend in all of the studies is that smoke alarms respond prior to residential or ordinary sprinklers and thus have the capability of providing the earliest warning of a fire to building occupants. While responding later, sprinklers provide the additional function of fire suppression to limit the development of hazardous conditions.

From the analysis of NFIRS fire incident data in this study, the proportion of fires judged to be too small for operation of the smoke detectors was appreciably fewer those for sprinklers in all three occupancy groups analyzed. The following table summarizes the results.

Proportion of Fire Incidents Judged to be Too Small for Operation

	Smoke Detectors		Sprinklers
	Non-sprinklered property	Sprinklered Property	
1- and 2-family dwelling	13.1	12.8	38.9
Commercial residential	9.7	10.8	54.2
Health-care	11.4	17.8	65.4

The fact that fewer fires are judged to be too small for smoke detector operation than sprinklers, especially when both are present in sprinklered buildings, reflects the faster response capabilities of smoke detectors.

While Bill's following quote on the benefit of smoke detectors was relative to an experimental program for hotel rooms, the comment is applicable to a wide variety of occupancies, as reflected in the variety of experimental and statistical indications:

"The role of smoke detectors in life safety has also been clearly shown. Smoke detectors warn room occupants in either fast-growing or smoldering fires while the room environment is such that an occupant can easily escape. Moreover, the warning occurs when the fire is small. Thus, the fire may possibly be extinguished without intervention of sprinklers."

The need for warning while the fire is small is reflected in the casualty statistics for those fires which are judged too small for smoke detector and sprinkler activation. Even for these "small" fires, some casualties do occur.
Nonetheless, where fire control is provided by sprinklers, rather than extinguishment, the environment following sprinkler operation is not pristine. This is caused by a decrease in the efficiency of the combustion process caused by the water application from sprinklers on burning fuels. In such instances, the generation of carbon monoxide increases during fire control. In addition, light obscuration becomes very significant throughout the room of origin, especially in small rooms. Such small rooms are characteristic of residences and health care facilities.

As such, having both smoke alarms and sprinklers has significant advantages. With smoke alarms providing the early indication of fires, this permits people to evacuate (or be evacuated if assistance is needed) prior to the response of sprinklers. In this way, people can evacuate prior to the potential loss of visibility in the room of origin (and thus find their way most easily without encountering obstructions) and not be subjected to the increase in carbon monoxide (and other gases produced from incomplete combustion).

5. References

Ahrens, Marty, 2009, "Home Structure Fires," Quincy, MA: NFPA, January.

Bill, Robert, 1990, "A Life-Safety Team: Smoke Detectors and Sprinklers in Hotels," Fire Journal, Vol. 84, No. 3, May/June.

Bill, R.G., Jr and Kung, Hsiang-Cheng, 1989, "Evaluation of an Extended Coverage Sidewall Sprinkler and Smoke Detectors in a Hotel Occupancy," *Journal of Fire Protection Engineering*, vol. 1, no. 3, p. 77-98.

Budnick, Edward K., 1984, "Estimating Effectiveness of State-of-the-Art Detectors and Automatic Sprinklers on Life Safety in Residential Occupancies," Fire Technology, Vol. 20, No. 3, August.

Bukowski, R. W.and Budnick, E. K., 1997, Fire Research and Engineering, Second (2nd) International Conference. (ICFRE2). Proceedings, National Institute of Standards and Technology and Society of Fire Protection Engineers. August 10-15, 1997, Slaughter, K. C., Editor, p. 49.

Bukowski, R. W.; Peacock, R. D.; Averill, J. D.; Cleary, T. G.; Bryner, N. P.; Walton, W. D.; Reneke, P. A.; Kuligowski, E. D., 2008, "Performance of Home Smoke Alarms Analysis of the Response of Several Available Technologies in Residential Fire Settings," NIST TN 1455, Gaithersburg, MD: National Institute of Standards and Technology, February 2008 Revision.

Butry, David T., Brown, M. Hayden, Fuller, Sieglinde K., 2007, "Benefit-Cost Analysis of Residential Fire Sprinkler Systems," NISTIR 7451, Gaithersburg, MD: National Institute of Standards and Technology, September.

Flynn, J., 2009, "Structure Fires in Medical, Mental Health and Substance Abuse Facilities," Quincy, MA: NFPA, February.

Flynn, J., 2008, "US Structure Fires in Nursing Homes," Quincy, MA: NFPA, September.

Greene, Michael A. and Andres, Craig D., 2008, *"2004-2005 Residential Fire Survey,"* Presentation to the Public-Private Fire Safety Council, May 15.

Hall, John R., Jr., 2009, "US Experience with Sprinklers and Other Automatic Fire Extinguishing Equipment, Quincy, MA: NFPA, January.

Hall, JR. 1987, "When Detectors Don't Operate—A Growing Problem." *Fire Safety Journal*, Vol. 14, No. 1-2, 1987, p. 25-32.

Klote, J.H., and Milke, J.A., 2002, "Principles of Smoke Management," Atlanta: ASHRAE.

Koffel, William E., 2005, “Reliability of Automatic Sprinkler Systems,” SUPDET Conference, Quincy, MA: Fire Protection Research Foundation.

Marshall, Stephen.W., Runyan, Carol W., Bangdiwala, Shrikant I., Linzer, Mary A., Sacks, Jeffrey J. and Butts, John D., “Fatal Residential Fires: Who Dies and Who Survives?” Journal of the American Medical Association, Vol. 279, no. 20, 1998, p. 1633-1637.

Mealy, Chris, Wolfe, Andrew and Gottuk, Daniel, 2009, “Smoke Alarm Response and Tenability,” AUBE09: 14th International Conference on Automatic Fire Detection, Duisberg, Germany, September.

Milke, James A., Hang, T. David and Meadows, David J. 2001. “The Effect of Sprinkler Activation on Smoke Characteristics.” Journal of Applied Fire Science, Vol. 10 (1) 67-86.

NFIRS, 2008, National Fire Incident Reporting System 5.0: Complete Reference Guide, Washington, DC: National Fire Data Center, US Fire Administration, Federal Emergency Management Agency, January.

Notarianni, Kathy A., 1993, “Measurement of Room Conditions and Response of Sprinklers and Smoke Detectors During a Simulated Two-Bed Hospital Patient Room Fire,” NISTIR 5240, Gaithersburg, MD: National Institute of Standards and Technology, July.

A. Sekizawa, A. Takemoto, K. Kozeki, E. Yanai, and K. Suzuki, 1997, Experimental Study on Fire Hazard of Residential Fires Before and After Sprinkler Activation, Fire Research Institute, Fire Defense Agency, presented at the 13th Meeting of the UJNR Panel on Fire Research and Safety, March 13-20, 1996, Gaithersburg, MD, Vol 2.

Smith, Charles L., 1993, “Smoke Detector Operability Survey – Report on Findings, Bethesda, MD: Consumer Product Safety Commission.

Su, Joseph Z., Crampton, George P., Carpenter, Don W., McCartney, Cameron, and Leroux, Patrice, 2003, Kemano Fire Studies – Part 1: Response of Residential Smoke Alarms,” Research Report 108, Ottawa, Canada: National Research Council of Canada, April.

Su, Joseph.Z.; Bénichou, N., Bwalya, A.C.; Lougheed, Gary D.; Taber, B.C.; Leroux, Peter, Proulx, Guylene, Kashef, A.; McCartney, Cameron, and Thomas, J.R., 2008, “Fire Performance of Houses. Phase I. Study of Unprotected Floor Assemblies in Basement Fire Scenarios. Summary Report,” Research Report 252, Ottawa, Canada: National Research Council of Canada.

Thomas, Ian R., 2002, “Effectiveness of Fire Safety Components and Systems,” *Journal of Fire Protection Engineering*, Vol. 12, No. 63, p. 63-78.

Appendix: Results from Analysis of NFIRS Data

Legend

Letter	Scenario
A	Intimate with fire - Primary symptom = smoke inhalation
B	Intimate with fire - Primary symptom = Combination
C	Intimate with fire - Primary symptom = Burns
D	Not Intimate with fire - Primary symptom = smoke inhalation
E	Not Intimate with fire - Primary symptom = Combination
F	Not Intimate with fire - Primary symptom = Burns
G	No Casualty (Note: Cannot provide detailed information on

Smoke Detector Alerting Capabilities, Non-sprinklered Residential (DACNSR)

		Smoke Detector						**Age**		**Impaired?**	
	TOTAL	1 - Alerted occupants, occupants responded	2 - Alerted occupants, occupants failed	3 - There were no occupants	4 - failed to alert occupants	U - Undetermined	Null	Adult	Child	Ambulatory	Otherwise impaired
A	1566	753	59	17	43	78	616	1295	269	1070	216
B	911	337	44	6	26	84	414	829	81	563	190
C	1477	708	19	11	26	107	606	1265	210	1012	174
D	1786	740	68	38	56	103	781	1345	440	1324	145
E	330	118	8	3	8	23	170	280	50	233	42
F	317	182	5	3	8	13	106	291	25	236	19
G	181756	73011	2714	14764	2652	8380	80235	N/A	N/A	N/A	N/A
Total	188143	75849	2917	14842	2819	8788	82928	5305	1075	4438	786

Smoke Detector Alerting Capabilities, Non-sprinklered Commercial Residential (DACNSCR)

		Smoke Detector						Age		Impaired?	
	TOTAL	1 - Alerted occupants, occupants responded	2 - Alerted occupants, occupants failed	3 - There were no occupants	4 - failed to alert occupants	U - Undetermined	Null	Adult	Child	Ambulatory	Otherwise impaired
A	25	13	0	0	0	0	12	25	0	15	4
B	7	4	1	0	0	0	2	6	0	2	1
C	3	1	0	0	0	1	1	3	0	2	0
D	5	3	1	0	0	0	1	4	1	3	1
E	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0
G	1433	532	43	124	9	57	668	N/A	N/A	N/A	N/A
Total	1473	553	45	124	9	58	684	38	1	22	6

Smoke Detector Alerting Capabilities, Non-sprinklered Hospital (DACNSH)

		Smoke Detector						Age		Impaired?	
	TOTAL	1 - Alerted occupants, occupants responded	2 - Alerted occupants, occupants failed	3 - There were no occupants	4 - failed to alert occupants	U - Undetermined	Null	Adult	Child	Ambulatory	Otherwise impaired
A	12	10	0	0	0	1	1	12	0	7	3
B	2	2	0	0	0	0	0	2	0	1	1
C	3	0	0	0	0	0	3	1	2	0	1
D	26	26	0	0	0	0	0	26	0	10	3
E	6	6	0	0	0	0	0	6	0	6	0
F	1	1	0	0	0	0	0	1	0	0	1
G	685	487	10	12	5	14	157	N/A	N/A	N/A	N/A
Total	735	532	10	12	5	15	161	48	2	24	9

Non-sprinklered Residential (NSR)

		Smoke Detector					Age		Impaired?	
	TOTAL	1 - Fire too Small to Operate	2 - Operated	3 - Failed to operate	U - Undetermined	Null	Adult	Child	Ambulatory	Otherwise impaired
A	1566	49	950	397	170	0	1295	269	1070	216
B	911	34	497	200	180	0	829	81	563	190
C	1477	170	871	255	181	0	1265	210	1012	174
D	1786	30	1005	481	270	0	1345	440	1324	145
E	330	1	160	94	75	0	280	50	233	42
F	317	17	211	67	22	0	291	25	236	19
G	181756	24345	101521	27209	28681	0	N/A	N/A	N/A	N/A
Total	188143	24646	105215	28703	29579	0	5305	1075	4438	786

Non-sprinklered Commercial Residential (NSCR)

		Smoke Detector					Age		Impaired?	
	TOTAL	1 - Fire too Small to Operate	2 - Operated	3 - Failed to operate	U - Undetermined	Null	Adult	Child	Ambulatory	Otherwise impaired
A	25	2	13	7	3	0	25	0	15	4
B	7	0	5	1	1	0	6	0	2	1
C	3	0	2	0	1	0	3	0	2	0
D	5	0	4	1	0	0	4	1	3	1
E	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0
G	1433	141	765	215	311	1	N/A	N/A	N/A	N/A
Total	1473	143	789	224	316	1	38	1	22	6

Non-sprinklered Hospital (NSH)

		Smoke Detector					Age		Impaired?	
	TOTAL	1 - Fire too Small to Operate	2 - Operated	3 - Failed to operate	U - Undetermined	Null	Adult	Child	Ambulatory	Otherwise impaired
A	12	0	11	1	0	0	12	0	7	3
B	2	0	2	0	0	0	2	0	1	1
C	3	3	0	0	0	0	1	2	0	1
D	26	0	26	0	0	0	26	0	10	3
E	6	0	6	0	0	0	6	0	6	0
F	1	0	1	0	0	0	1	0	0	1
G	685	81	528	29	47	0	N/A	N/A	N/A	N/A
Total	735	84	574	30	47	0	48	2	24	9

Sprinklered Residential (SR)

		Smoke Detector					Age		Impaired?	
	TOTAL	1 - Fire too Small to Operate	2 - Operated	3 - Failed to operate	U - Undetermined	Null	Adult	Child	Ambulatory	Otherwise impaired
A	58	4	49	3	2	0	56	2	41	12
B	24	2	18	0	4	0	24	0	18	4
C	59	9	45	2	3	0	53	6	37	11
D	29	1	24	0	4	0	26	3	21	2
E	2	0	2	0	0	0	2	0	1	1
F	3	0	2	1	0	0	3	0	3	0
G	4241	548	2957	277	459	0	N/A	N/A	N/A	N/A
Total	4416	564	3097	283	472	0	164	11	121	30

Sprinklered Commercial Residential (SCR)

		Smoke Detector					Age		Impaired?	
	TOTAL	1 - Fire too Small to Operate	2 - Operated	3 - Failed to operate	U - Undetermined	Null	Adult	Child	Ambulatory	Otherwise impaired
A	11	0	10	0	1	0	11	0	6	3
B	0	0	0	0	0	0	0	0	0	0
C	9	1	5	0	3	0	8	1	5	3
D	6	0	6	0	0	0	4	2	6	0
E	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0
G	857	94	625	58	80	0	N/A	N/A	N/A	N/A
Total	883	95	646	58	84	0	23	3	17	6

Sprinklered Hospital (SH)

		Smoke Detector					Age		Impaired?	
	TOTAL	1 - Fire too Small to Operate	2 - Operated	3 - Failed to operate	U - Undetermined	Null	Adult	Child	Ambulatory	Otherwise impaired
A	21	6	11	4	0	0	21	0	12	4
B	5	0	5	0	0	0	5	0	1	2
C	11	5	6	0	0	0	9	2	5	6
D	9	0	9	0	0	0	9	0	8	0
E	1	0	0	1	0	0	1	0	0	1
F	1	1	0	0	0	0	1	0	1	0
G	1084	189	792	43	60	0	N/A	N/A	N/A	N/A
Total	1132	201	823	48	60		46	2	27	13

Sprinklered Residential Sprinkler Performance (SRSP)

		Smoke Detector					Sprinkler Operation					
	TOTAL	1 - Fire too Small to Operate	2 - Operated	3 - Failed to operate	U - Undetermined	Null	1 - Operated and effective	2 - Operated and not effective	3 - fire too small to activate	4 - failed to operate	U - Undetermined	Null
A	58	4	49	3	2	0	30	1	24	3	0	0
B	24	2	18	0	4	0	12	0	7	2	0	3
C	59	9	45	2	3	0	28	1	25	2	0	3
D	29	1	24	0	4	0	16	2	6	3	0	2
E	2	0	2	0	0	0	1	0	1	0	0	0
F	3	0	2	1	0	0	0	0	2	1	0	0
G	4241	548	2957	277	459	0	1564	63	1925	252	101	336
Total	4416	564	3097	283	472	0	1651	67	1990	263	101	344

	Sprinkler Failure										
	1 - System Shut off	2 - Not enough agent discharged	3 - Agent discharged but did not reach fire	4 - wrong type of system	5 - fire not in area protected	6 - system components damaged	7 - lack of maintenance	8 - manual intervention	0 - other	U - undetermined	Null
A	0	1	0	0	5	0	0	1	0	0	51
B	0	0	1	1	1	0	0	0	1	1	19
C	2	1	1	0	1	0	0	1	0	0	53
D	0	1	1	0	1	0	0	0	0	3	23
E	0	0	0	0	0	0	0	0	0	1	1
F	0	0	0	0	1	0	0	0	1	0	1
G	30	3	4	20	251	7	5	12	75	80	3754
Total	32	6	7	21	260	7	5	14	77	85	3902

Sprinklered Residential Sprinkler Performance (SRSP) (continued)

	Age		Impaired?	
	Adult	Child	Ambulatory	Otherwise impaired
A	56	2	41	12
B	24	0	18	4
C	53	6	37	11
D	26	3	21	2
E	2	0	1	1
F	3	0	3	0
G	N/A	N/A	N/A	N/A
Total	161	11	118	30

Sprinklered Commercial Residential Sprinkler Performance (SCRSP)

		Smoke Detector					Sprinkler					
	TOTAL	1 - Fire too Small to Operate	2 - Operated	3 - Failed to operate	U - Undetermined	Null	1 - Operated and effective	2 - Operated and not effective	3 - fire too small to activate	4 - failed to operate	U - Undetermined	Null
A	11	0	10	0	1	0	3	0	6	2	0	2
B	0	0	0	0	0	0	0	0	0	0	0	0
C	9	1	5	0	3	0	5	0	3	0	0	4
D	6	0	6	0	0	0	0	0	6	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0	0
G	857	94	625	58	80	0	185	6	530	51	5	198
Total	883	95	646	58	84	0	193	6	545	53	5	204

	Sprinkler Failure Reasons										
	1 - System Shut off	2 - Not enough agent discharged	3 - Agent discharged but did not reach fire	4 - wrong type of system	5 - fire not in area protected	6 - system components damaged	7 - lack of maintenance	8 - manual intervention	0 - other	U - undetermined	Null
A	0	0	0	0	2	0	1	0	0	0	8
B	0	0	0	0	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	9
D	0	0	0	0	0	0	0	0	0	0	6
E	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0
G	1	0	1	3	49	0	1	8	18	33	744
Total	1	0	1	3	51	0	2	8	18	33	767

Sprinklered Commercial Residential Sprinkler Performance (SCRSP) (continued)

	Age		**Impaired?**	
	Adult	Child	Ambulatory	Otherwise impaired
A	11	0	6	3
B	0	0	0	0
C	8	1	5	3
D	4	2	6	0
E	0	0	0	0
F	0	0	0	0
G	N/A	N/A	N/A	N/A
Total	23	3	17	6

Sprinklered Hospital Sprinkler Performance (SHSP)

		Smoke Detector					**Sprinkler**					
	TOTAL	1 - Fire too Small to Operate	2 - Operated	3 - Failed to operate	U - Undetermined	Null	1 - Operated and effective	2 - Operated and not effective	3 - fire too small to activate	4 - failed to operate	U - Undetermin ed	Null
A	23	5	14	4	0	0	3	0	19	0	0	1
B	8	1	7	0	0	0	2	0	5	0	0	1
C	9	5	4	0	0	0	1	0	7	1	0	0
D	10	0	10	0	0	0	7	0	2	1	0	0
E	1	0	0	1	0	0	0	0	1	0	0	0
F	1	1	0	0	0	0	0	0	1	0	0	0
G	1084	189	792	43	60	0	139	3	708	60	10	164
Total	1136	201	827	48	60	0	152	3	743	62	10	166

	Sprinkler Failure Reasons										
	1 - System Shut off	2 - Not enough agent discharged	3 - Agent discharged but did not reach fire	4 - wrong type of system	5 - fire not in area protected	6 - system components damaged	7 - lack of maintenance	8 - manual intervention	0 - other	U - undetermined	Null
A	0	0	0	0	4	0	0	1	2	0	16
B	0	0	0	0	1	0	0	0	0	0	7
C	0	0	0	0	0	0	0	0	0	0	9
D	0	0	0	0	1	0	0	0	0	0	9
F	0	0	0	0	0	0	0	0	0	0	1
G	0	0	0	0	0	0	0	0	0	0	1
Total	4	2	0	4	45	0	2	14	24	38	951

Sprinklered Hospital Sprinkler Performance (SHSP) (continued)

	Age		**Impaired?**	
	Adult	Child	Ambulatory	Other impairment
A	23	0	15	3
B	8	0	3	3
C	8	1	3	6
D	10	0	9	0
E	1	0	0	1
F	1	0	1	0
G	N/A	N/A	N/A	N/A
Total	51	1	31	13

Sprinkler Didn't Operate Residential (SDOR)

		Smoke Detector						Age		Impaired?	
	TOTAL	1 - Alerted occupants, occupants responded	2 - Alerted occupants, occupants failed	3 - There were no occupants	4 - failed to alert occupants	U - Undetermined	Null	Adult	Child	Ambulatory	Otherwise impaired
A	3	1	0	1	0	1	0	3	0	2	0
B	2	1	1	0	0	0	0	2	0	1	1
C	2	1	0	0	0	0	1	1	1	1	1
D	1	0	0	0	1	0	0	1	0	1	0
E	2	0	0	0	0	0	2	0	2	2	0
F	1	0	0	0	0	0	1	1	0	1	0
G	252	119	3	14	4	9	103	N/A	N/A	N/A	N/A
Total	263	122	4	15	5	10	107	8	3	8	2

Sprinkler Didn't Operate Commercial Residential (SDOCR)

		Smoke Detector						Age		Impaired?	
	TOTAL	1 - Alerted occupants, occupants responded	2 - Alerted occupants, occupants failed	3 - There were no occupants	4 - failed to alert occupants	U - Undetermined	Null	Adult	Child	Ambulatory	Otherwise impaired
A	2	1	0	0	0	0	1	2	0	1	0
B	0	0	0	0	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0
G	51	30	1	0	2	0	18	N/A	N/A	N/A	N/A
Total	53	31	1	0	2	0	19	2	0	1	0

Sprinkler Didn't Operate Hospital (SDOH)

		Smoke Detector						Age		Impaired?	
	TOTAL	1 - Alerted occupants, occupants responded	2 - Alerted occupants, occupants failed	3 - There were no occupants	4 - failed to alert occupants	U - Undetermined	Null	Adult	Child	Ambulatory	Otherwise impaired
A	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0
C	1	1	0	0	0	0	0	1	0	1	0
D	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0
G	55	39	3	0	0	0	13	N/A	N/A	N/A	N/A
Total	56	40	3	0	0	0	13	1	0	1	0

Sprinklered residential type of AES (SRTAES)

-		Sprinkler Type			Age		Impaired?	
	TOTAL	1 - Wet Pipe	2 - Dry-pipe	3 - Other Sprinkler system	Adult	Child	Ambulatory	Otherwise impaired
A	58	53	5	0	56	2	41	12
B	24	22	1	1	24	0	18	4
C	59	55	1	3	53	6	37	11
D	29	24	5	0	26	3	21	2
E	2	2	0	0	2	0	1	1
F	3	3	0	0	3	0	3	0
G	4241	3903	253	85	N/A	N/A	N/A	N/A
Total	4416	4062	265	89	164	11	121	30

Sprinklered commercial residential type of AES (SCRTAES)

		Sprinkler Type			Age		Impaired?	
	TOTAL	1 - Wet Pipe	2 - Dry-pipe	3 - Other Sprinkler system	Adult	Child	Ambulatory	Otherwise impaired
A	11	8	3	0	11	0	6	3
B	0	0	0	0	0	0	0	0
C	9	9	0	0	8	1	5	3
D	6	6	0	0	4	2	6	0
E	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0
G	857	790	57	10	N/A	N/A	N/A	N/A
Total	883	813	60	10	23	3	17	6

Sprinklered Hospital type of AES (SHTAES)

		Sprinkler Type			Age		Impaired?	
	TOTAL	1 – Wet Pipe	2 - Dry-pipe	3 - Other Sprinkler system	Adult	Child	Ambulatory	Otherwise impaired
A	23	19	0	4	23	0	15	3
B	8	8	0	0	8	0	3	3
C	9	9	0	0	8	1	3	6
D	10	9	1	0	10	0	9	0
E	1	1	0	0	1	0	0	1
F	1	1	0	0	1	0	1	0
G	1084	953	125	6	N/A	N/A	N/A	N/A
Total	1136	1000	126	10	51	1	31	13