

NIST Technical Note TN 1684

**Discriminating Between
Smoldering and Flaming Fires
Using Alarm Signals**

William D. Davis

NIST Technical Note TN 1684

Discriminating Between Smoldering and Flaming Fires Using Alarm Signals

William D. Davis
*Engineering Laboratory
Fire Research Division
National Institute of Standards and Technology
Gaithersburg, Maryland 20899-8664
December, 2010*



U.S. Department of Commerce
Gary Locke, Secretary

National Institute of Standards and Technology
Patrick D. Gallagher, Director

Certain commercial entities, equipment, or materials may be identified in this document in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

**National Institute of Standards and Technology Technical Note 1684
Natl. Inst. Stand. Technol. Tech. Note 1684, 34 pages (December, 2010)**

Table of Contents

Introduction.....	1
Experiments	1
Flaming Fires.....	9
Smoldering Fires	15
Nuisance Source.....	20
Analysis.....	21
Issues.....	24
Conclusion	26
References.....	28

Discriminating Between Smoldering and Flaming Fires Using Alarm Signals

W. D. Davis

Abstract

Strategies are developed that make use of signals from smoke and heat alarms to deduce conditions in a room for both flaming and smoldering fires. The issue addressed is to determine how to provide useful information to incident command for smoldering fires using signals from smoke and heat alarms. Experiments were conducted to characterize the differences between small flaming and smoldering fires in a full-scale room. Based on these differences, a methodology was developed to interpret the alarm signals in a way to provide useful information for incident command.

Introduction

As technology continues to evolve in the fire service, the use of decision support systems for incident command will become commonplace. A decision support system for a building fire would collect electronic information from building systems, emergency responder sensing devices, weather stations, etc. and provide the incident commander with a simple display of the analyzed information. In this paper, a decision support system will be investigated that makes use of signals from smoke and heat alarms to deduce conditions in a room for both flaming and smoldering fires. Currently, a decision support system for flaming fires in buildings, the Sensor-Driven Fire Model (SDFM)¹, is capable of supplying information concerning fire and smoke spread and provides an analysis for visibility and thermal/toxic hazards throughout the building. This model is not designed to deal with smoldering fires. The issue addressed in this paper is to determine how to provide useful information to incident command for smoldering fires using signals from smoke and heat alarms. To this end, several experiments were conducted to characterize the differences between small flaming and smoldering fires in a full-scale room. Based on these differences, strategies were developed to provide useful information for smoldering fires to incident command.

Experiments

Experiments were conducted to investigate the use of signals from heat and smoke alarms to predict fire conditions in a room where the source was either smoldering or flaming. The experiments were conducted in a room with floor dimensions of 3.16 m by 3.05 m and a floor to ceiling height of 2.46 m. The fire sources studied included flaming fires of heptane, toluene, foam, and black polymethyl-methacrylate (PMMA); smoldering

sources with a cigarette used as an ignition source and placed on top of either 15 cm x 15 cm x 10 cm foam and cotton duct or shredded paper (Figure 1) and a nuisance source consisting of 30 mL of vegetable oil heated on top of a hot plate. The vegetable oil was placed in an iron skillet 14 cm in diameter and floated on top of 0.25 cm of water. The hot plate was set to low (Figure 2). The location of all the fuel sources was in the center of the room



Figure 1 Cigarette used as an ignition source for smoldering paper



Figure 2 Vegetable oil heated in a 14 cm diameter skillet on a hotplate

The flaming fires consisted of small dishes (89 mm diameter) of heptane (50 mL) and toluene (10 mL), a 15 cm x 15 cm x 10 cm piece of foam and a 7.6 cm x 7.6 cm x 1.27 cm block of black PMMA (Figure 3) that were placed on a load cell that was centered in the room. The distance from the floor to the top of the dish was 0.127 m. The Heat Release Rate (HRR) was obtained by measuring the mass loss rate and multiplying by the chemical heat of combustion of the fuel². For these small fires, the HRR was not oxygen limited. The HRR for the four flaming fires are shown in Figures 4, 5, 6 and 7 and the time duration shown excludes the burnout portion of each experiment.



Figure 3 Flaming PMMA on the load cell

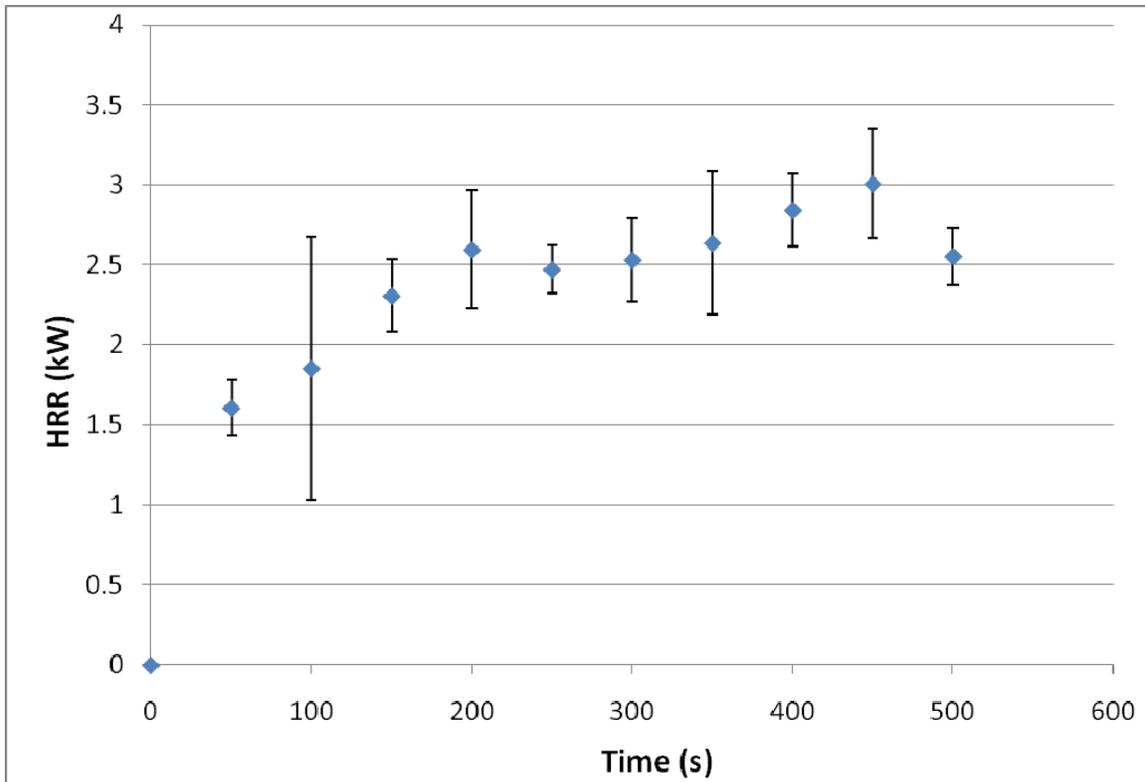


Figure 4 HRR for heptane. Uncertainty interval represents $\pm\sigma$.

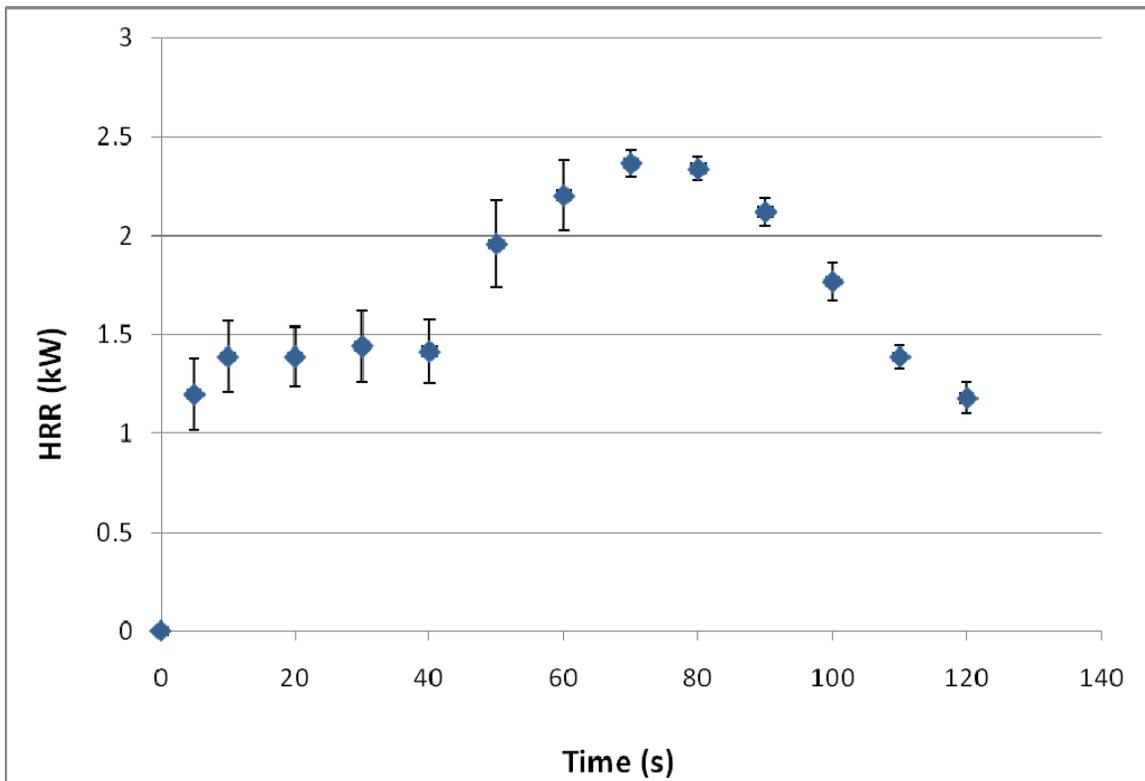


Figure 5 HRR for toluene. Uncertainty interval represents $\pm\sigma$.

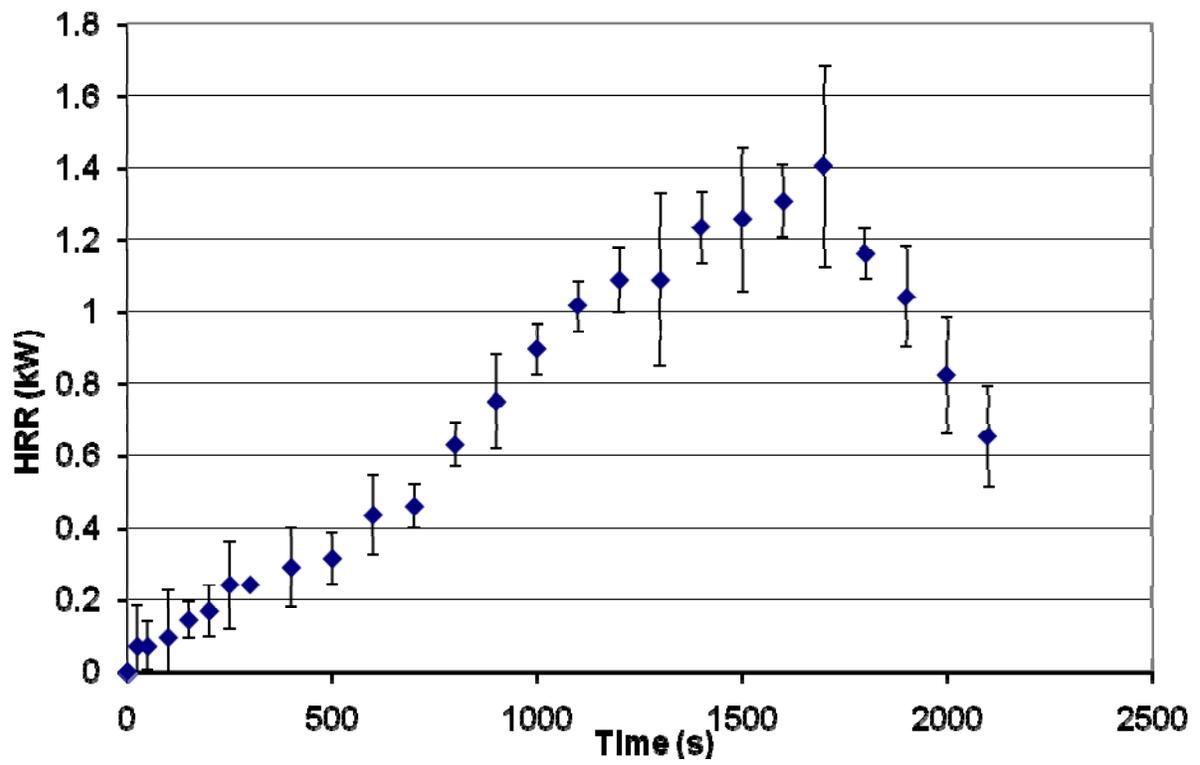


Figure 6 HRR for PMMA. Uncertainty interval represents $\pm\sigma$.

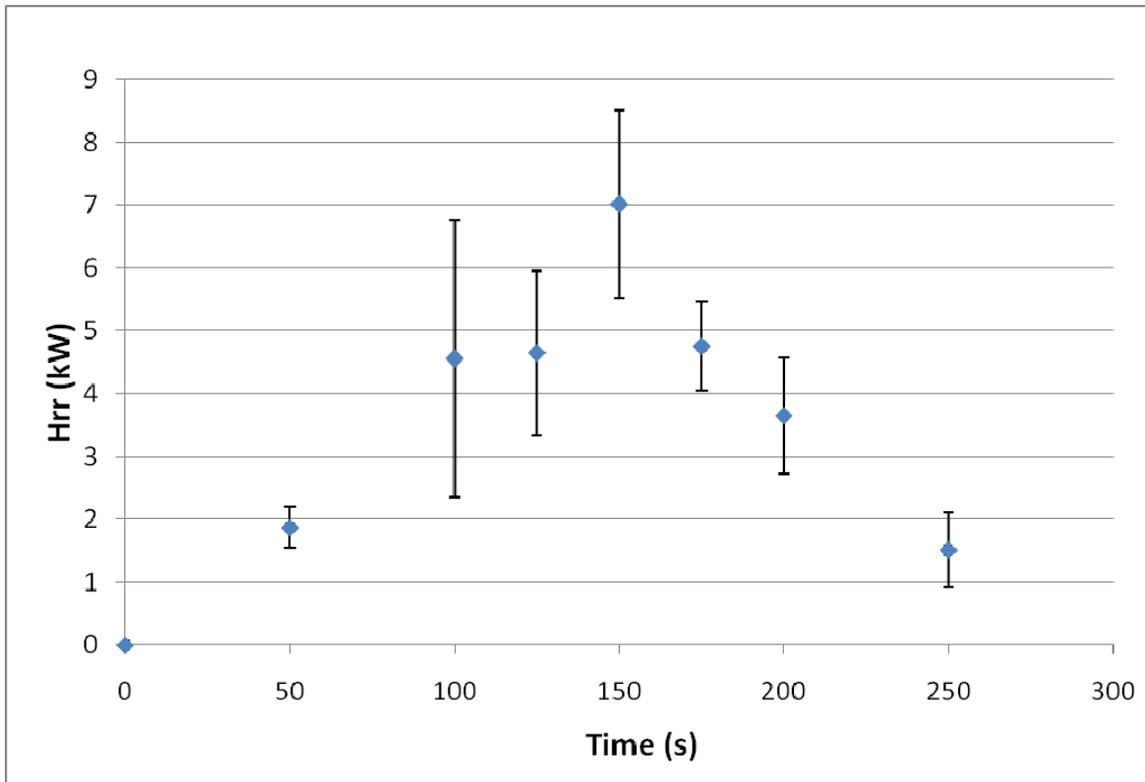


Figure 7 HRR for Foam. Uncertainty interval represents $\pm\sigma$.

The flat, smooth ceiling was made up of acoustic ceiling tile. The walls of the room were constructed of glazed cinderblocks except for one cinderblock that was constructed of ceiling tile. The door to the room was closed during the experiment.

Instrumentation included ceiling-mounted thermocouples, photoelectric and ionization smoke alarms, and a laser. Both a thermocouple tree and a photoelectric smoke alarm tree were used to determine the vertical distribution of temperature and smoke in the room. Smoke sensing was accomplished using photoelectric and ionization alarms that are sold for use in the home. These alarms were calibrated in the fire emulator/detector evaluator (FE/DE)³ using a burner supplied with propene gas. The alarms were placed in the FE/DE tunnel and the smoke density at the alarms was varied by controlling the gas flow of propene to the burner. The extinction in the FE/DE tunnel was measured using a diode laser operating at 630 nm. The voltage output of each smoke alarm was correlated with the extinction measurements using the diode laser. An air-cooled diode laser operating at 630 nm was used during the experiments for comparison with the commercial smoke alarms.

The placement of the instruments is shown in Figure 8. The radial positions are measured from the center of the fuel package. The thermocouples (TC) mounted 1.0 cm beneath the ceiling are shown as triangles with the thermocouple tree shown as a hexagon. Two types of smoke alarms were used in the experiments and are indicated by donut shapes and labeled with a “D” and a number with the photoelectric alarms having a

“P” designator and the ionization alarms having an “I” designator at the end. Both types of ceiling mounted smoke alarms sampled air flows 2.5 cm beneath the ceiling. The laser had a beam path of length 50 cm that was located 5 cm below the ceiling. The thermocouple tree had thermocouples located at 1 cm, 3 cm, 6 cm, 12 cm, 24 cm, 36 cm, and 50 cm below the ceiling (TC1 – TC7 respectively).

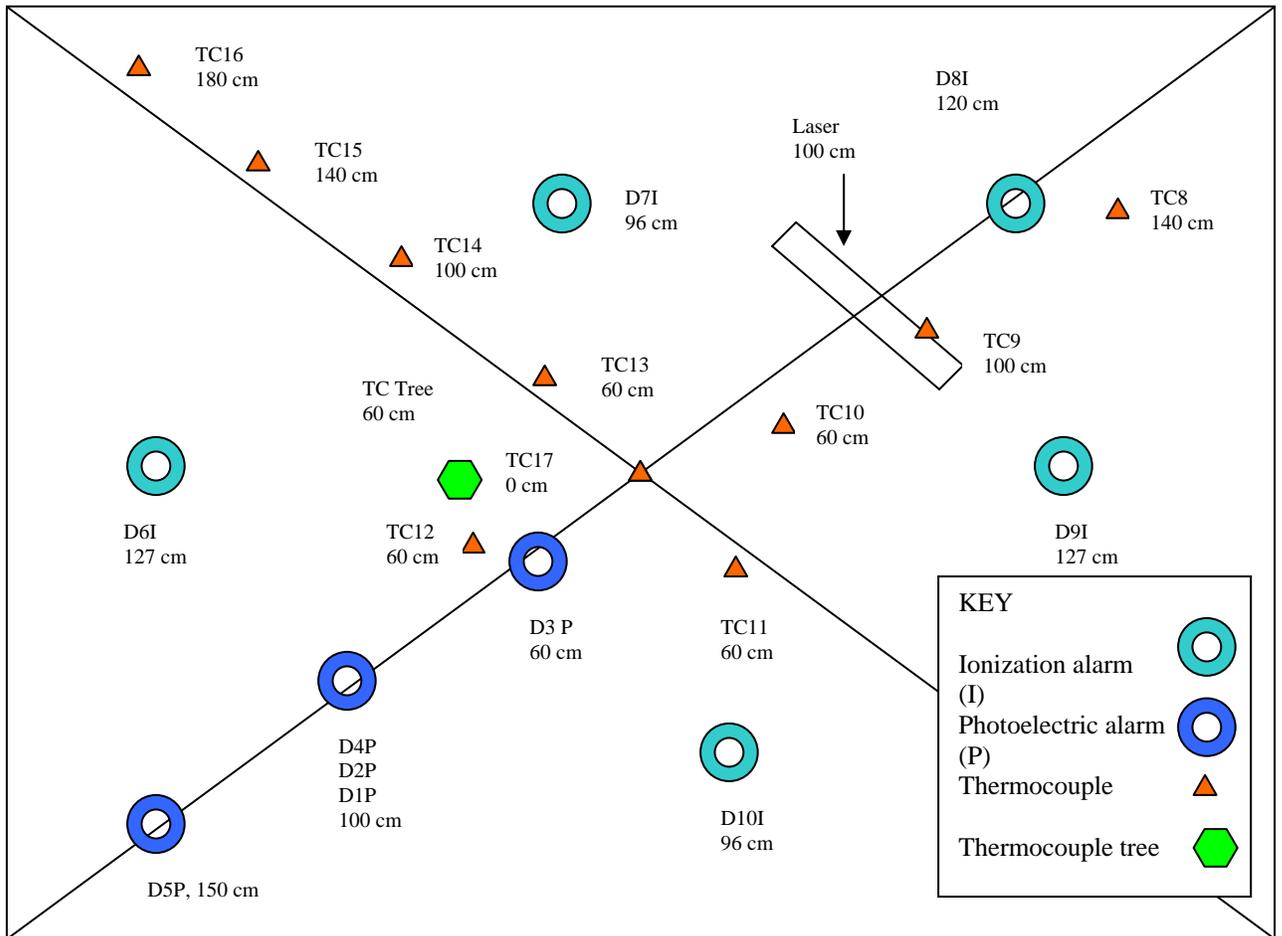


Figure 8 Layout of instruments – The photoelectric smoke alarm tree is designated as D4P, D2P and D1P located 2.5 cm, 62 cm, and 123 cm beneath the ceiling, respectively. The rectangle is a laser/diode detector. Distances are radial from the center of the fire source where TC17 is located.

Flaming Fires

A flaming fire produces a buoyant plume, ceiling jet, and smoke layer which will maintain its stratification in the absence of strong ventilation flows as long as it remains significantly hotter than the ambient temperature. Examples of this behavior are shown in Figures 9 thru 14 for flaming heptanes, toluene and foam fires. The excess temperature plots of Figures 9, 11 and 13 clearly show the ceiling jet (TC1, TC2, TC3) just below the ceiling, the transition region to the smoke layer (TC4), and the smoke layer (TC5, TC6, TC7). The excess temperature is the temperature difference between the measured temperature and the ambient room temperature measured prior to the start of the experiment. The photoelectric alarms plotted in Figures 10, 12 and 14 show the ceiling jet (D4P) and the forming smoke layer (D1P, D2P). The ceiling jet is the flow of hot gas from the plume along the ceiling. The smoke layer is formed by the ceiling jet being reflected by the room walls and flowing back toward the fire plume. The smoke layer is characterized by a low velocity, fairly uniform temperature region that expands in time as the fire develops. The transition region separates the ceiling jet and smoke layer and supports a temperature gradient from the high temperature ceiling jet to the lower temperature smoke layer.

The thermocouples respond quickly to the changing temperature but the photoelectric alarms have entry characteristics that delay their response,^{4,5} particularly when flow velocities are low, which accounts for much of the timing differences of the signals. The positions of the two smoke detectors also contributed to the timing issue as they were located 62 cm and 123 cm beneath the ceiling; while the bottom thermocouple was located 50 cm beneath the ceiling.

Since the ceiling jet was just an extension of the buoyant plume, sampling the temperature, smoke, or gas concentrations provides the necessary information to deduce the strength of the fire source provided that the entrainment of gas from the smoke layer to the plume is included. Algorithms to do this calculation have been developed and are available in the Sensor-Driven Fire Model¹ (SDFM). Reference 1 provides a comparison between the HRR from a small heptanes fire and the HRR derived using SDFM and signals from either a thermocouple or a photoelectric smoke alarm.

As the HRR of the fires diminishes, the ceiling jet temperature approaches the layer temperature as shown for flaming foam, Figures 7 and 13. The toluene fire begins to show the same tendency, Figures 5 and 11. This effect demonstrates the close coupling between the fire plume and ceiling jet.

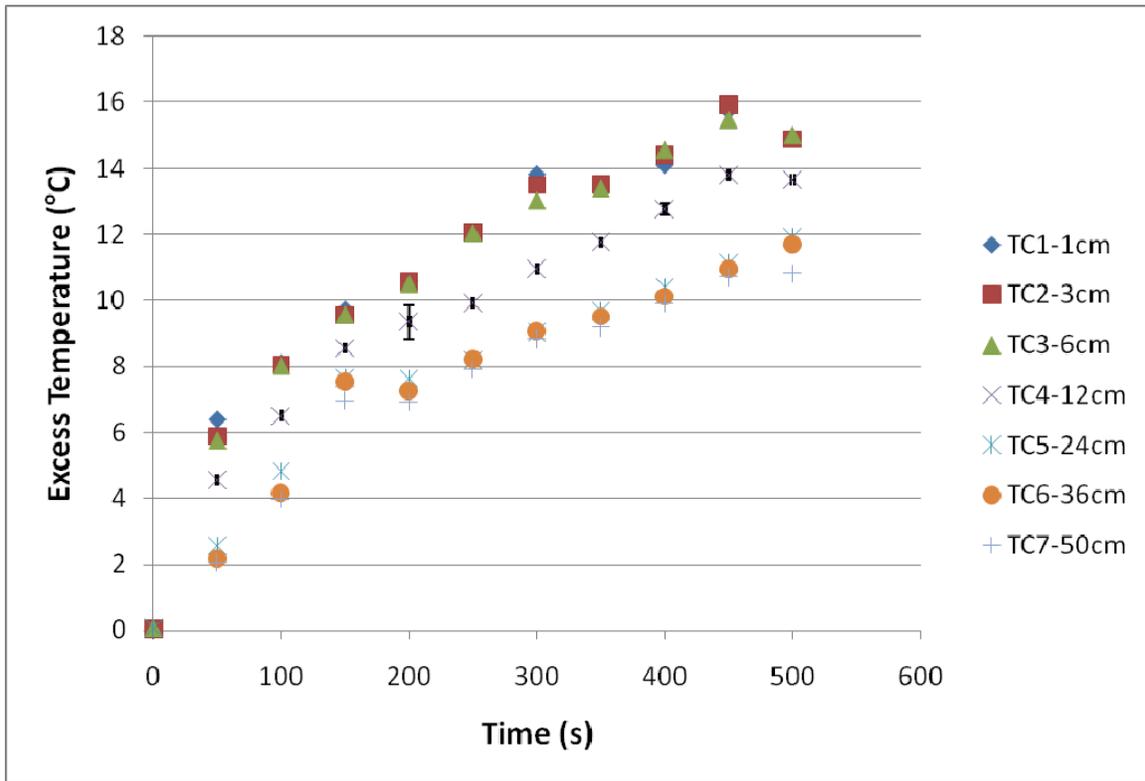


Figure 9 Flaming heptane excess temperature at the thermocouple tree location. Error bars are shown representing one standard deviation from five measurements centered at the data points 200 s and 400 s for TC3. These error bars are representative of the error bars for all data points. The location listed with each thermocouple is its distance beneath the ceiling.

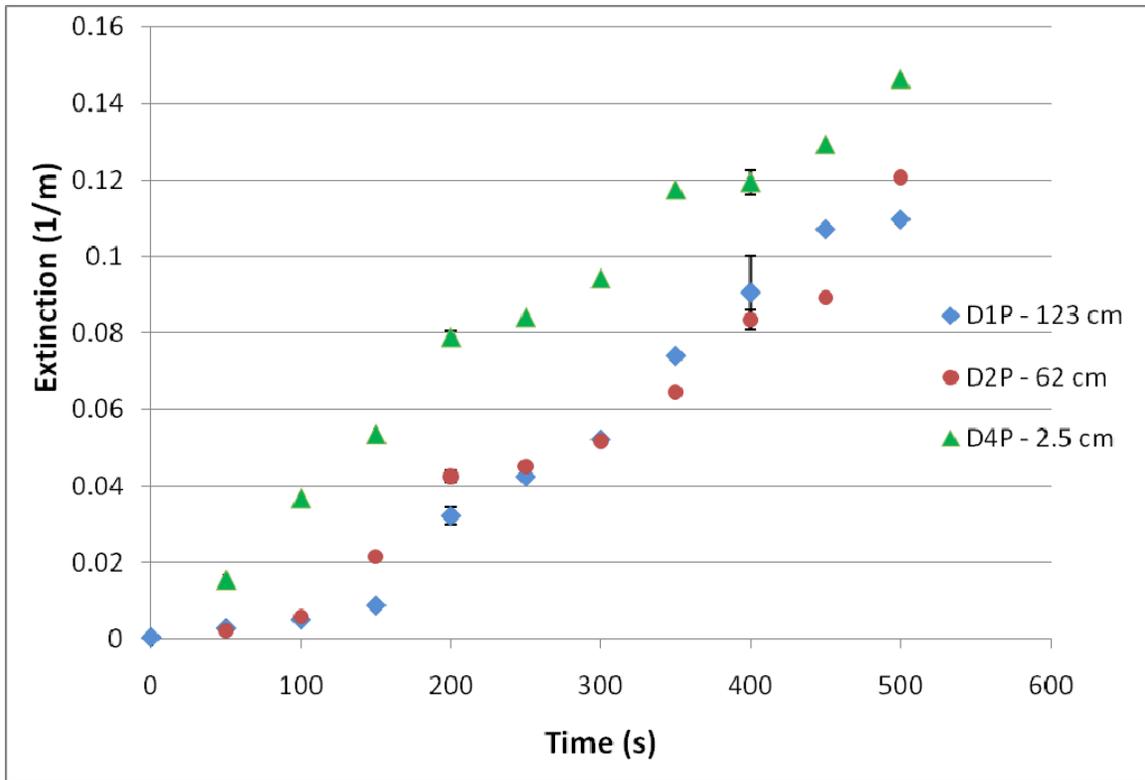


Figure 10 Flaming heptane extinction measured by the photoelectric alarm tree near the ceiling (D4P), and in the smoke layer (D1P and D2P). Error bars are shown representing one standard deviation from five measurements centered on data points for 200 s and 400 s. These error bars are representative of the error bars for all data points. Some error bars are about the size of their data point. The location listed with each alarm is its distance beneath the ceiling.

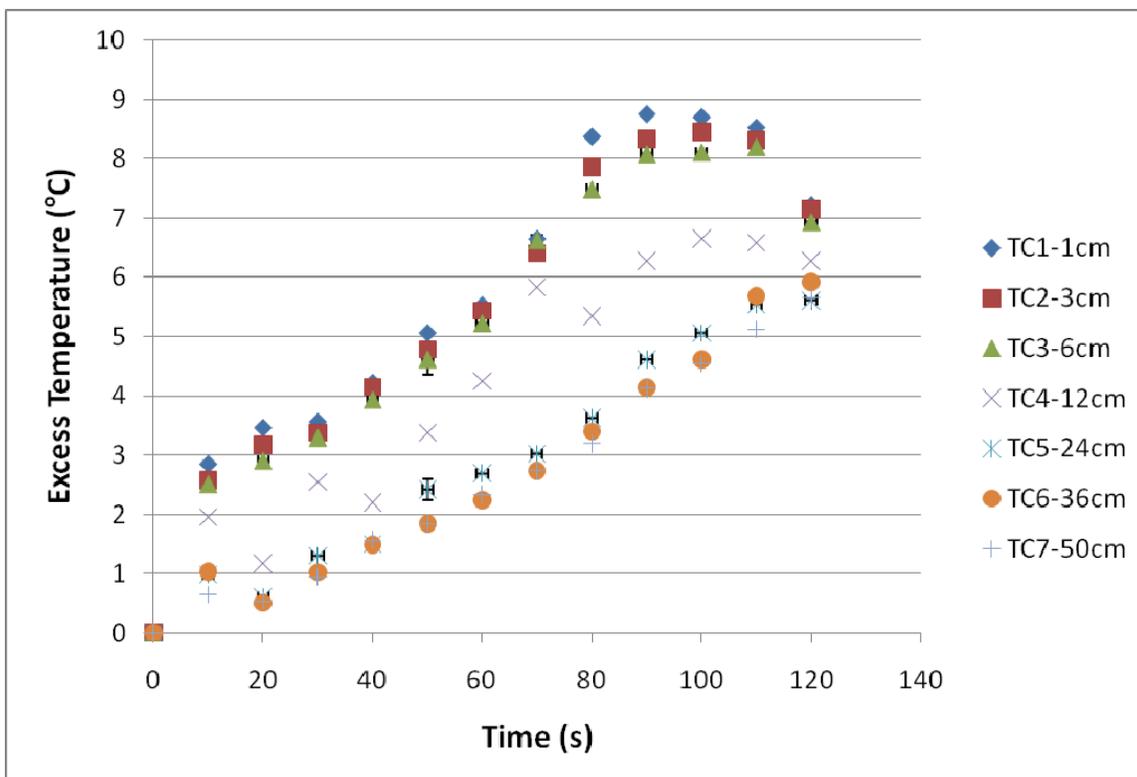


Figure 11 Flaming toluene excess temperature measured at the location of the thermocouple tree. Error bars are shown representing one standard deviation from five measurements centered on data points for 50 s. These error bars are representative of the error bars for all data points. The location listed with each thermocouple is its distance beneath the ceiling.

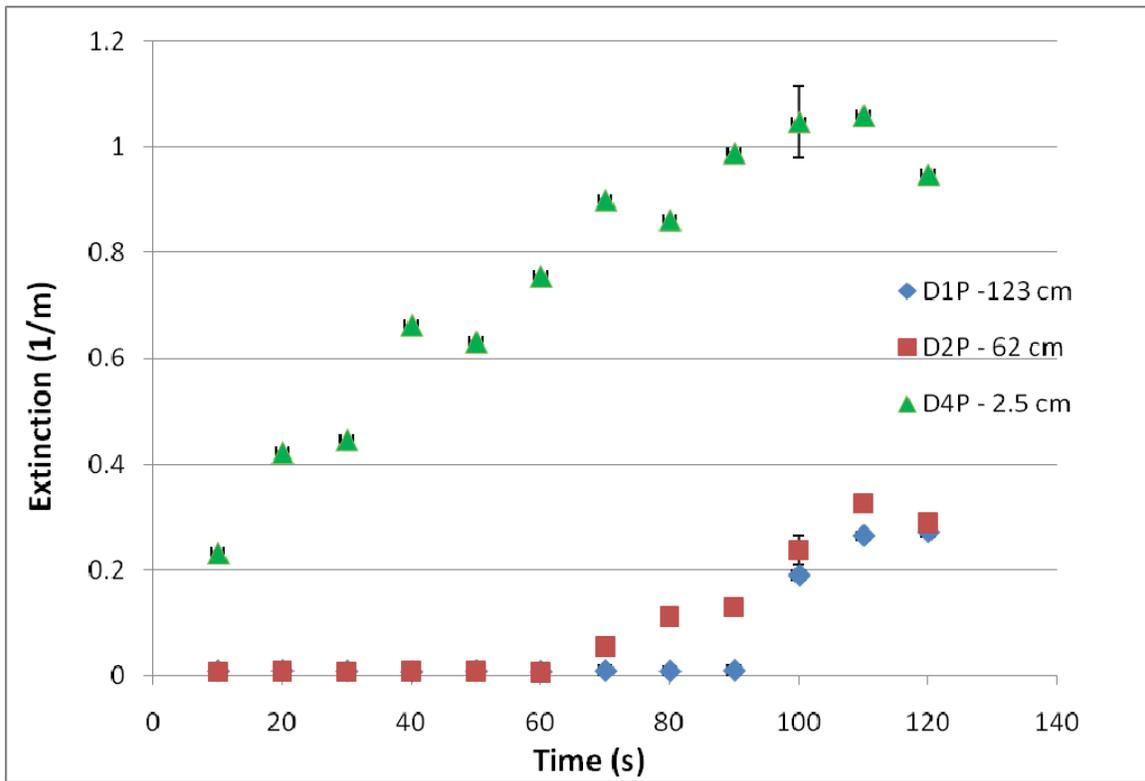


Figure 12 Extinction measured using the photoelectric alarm tree for flaming toluene. Error bars are shown representing one standard deviation from five measurements centered on data points at 100s. These error bars are representative of the error bars for all data points. The location listed with each alarm is its distance beneath the ceiling.

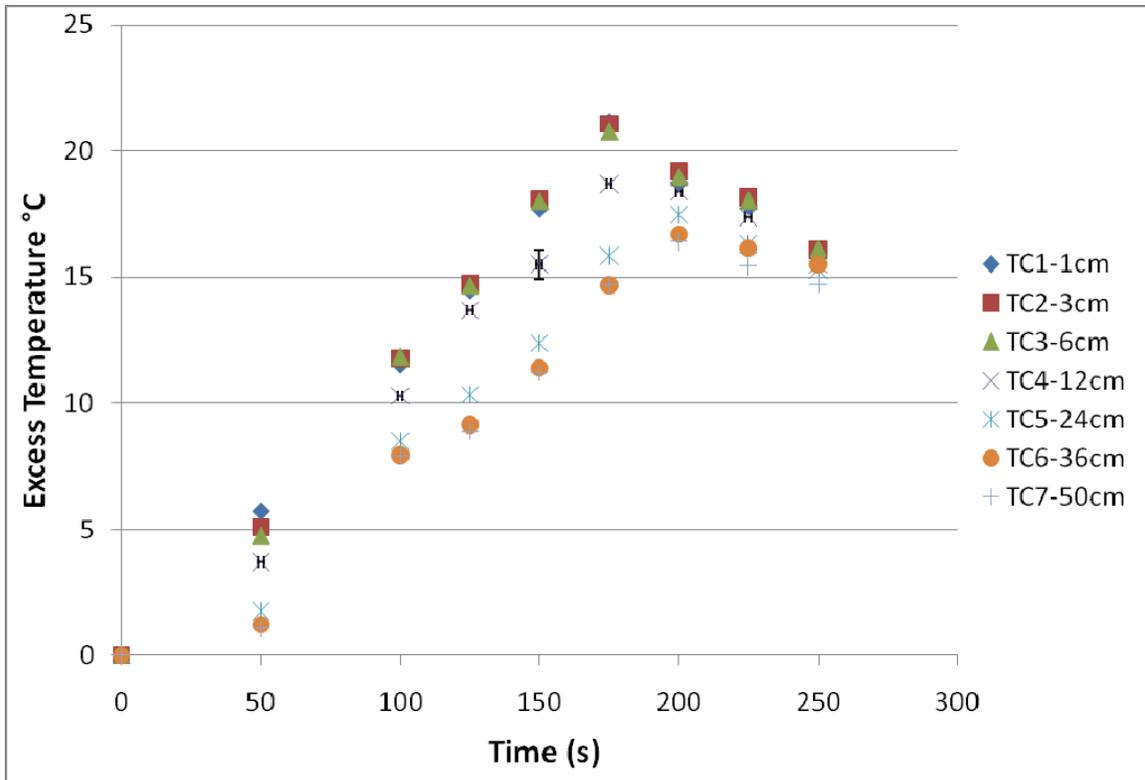


Figure 13 Flaming foam excess temperature measured at the location of the thermocouple tree. Error bars are shown representing one standard deviation from five measurements centered on data point TC4 at 150s. This error bar is representative of the error bars for all data points. The location listed with each thermocouple is its distance beneath the ceiling.

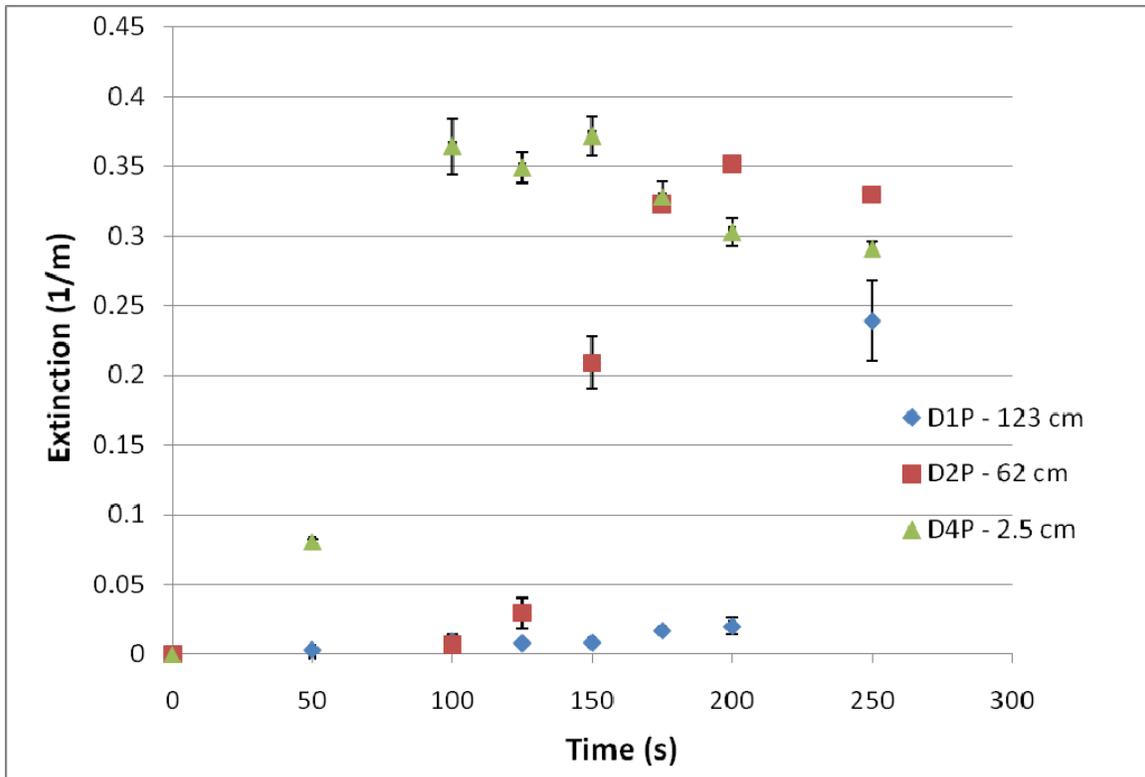


Figure 14 Extinction measured using the photoelectric alarm tree for flaming foam. Error bars are shown representing one standard deviation from five measurements centered on the data point. Some error bars may be smaller than the data point. The location listed with each alarm is its distance beneath the ceiling.

Smoldering Fires

Fires may begin by smoldering for an extended period of time before either extinguishing or transitioning to a flaming fire. Smoldering fires cannot be analyzed by a fire model that is based on a ceiling jet analysis as this feature will not generally form until the fire begins to flame. A newly smoldering fire is characterized by small HRR and tiny excess temperature measured at a distance from the smoldering source. The distribution of smoke and gases diffuse throughout the room rather than forming a layer.

Examples of this behavior are shown in Figures 15, 16, 17, and 18 for smoldering shredded paper that was ignited by a cigarette and smoldering foam with cotton duct also ignited by a cigarette. The excess temperature increases by less than 1 °C for the shredded paper and by about 1 °C for the smoldering foam. The smoke distribution for the shredded paper appears fairly uniform with the photoelectric alarms located at half and three-quarters of the ceiling height showing similar values to the ones at the ceiling. The photoelectric alarms for the smoldering foam with cotton duct suggest a small amount of stratification as the photoelectric alarms at half and three-quarters height

provide extinction measurements that are about three-quarters of the value that the ceiling mounted photoelectric-alarms yield. The thermocouple tree results do not support this stratification.

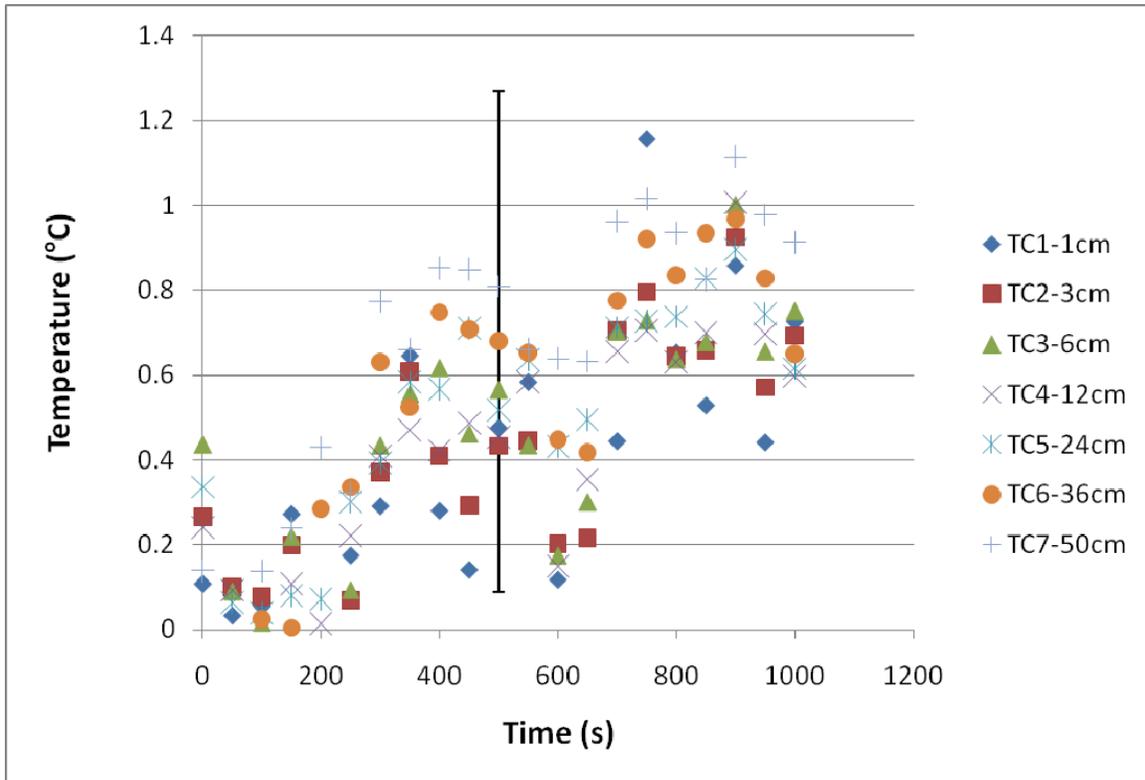


Figure 15 Smoldering shredded paper excess temperature at the thermocouple tree location. An error bar is shown representing one standard deviation from five measurements centered on the data point at 500 s. The location listed with each thermocouple is its distance beneath the ceiling.

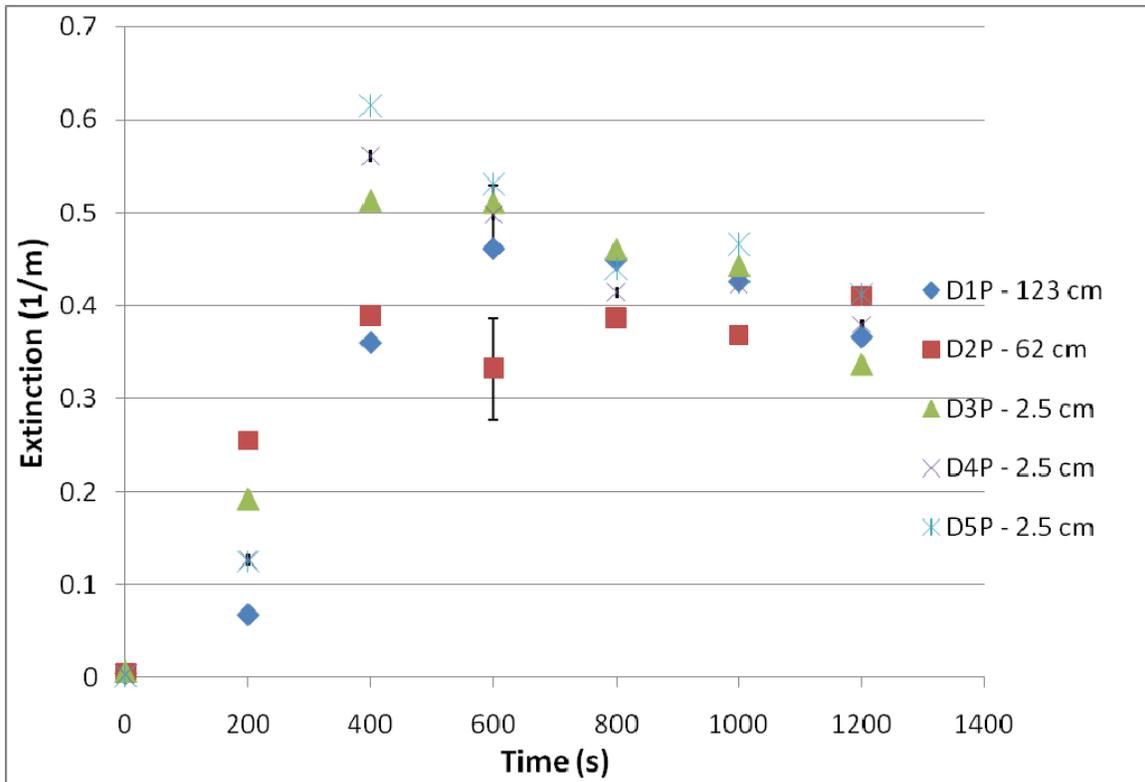


Figure 16 Smoldering shredded paper extinction measure by all the photoelectric alarms on the ceiling and in the photoelectric alarm tree. An error bar is shown representing one standard deviation from five measurements centered on the data point at 600 s. The location listed with each alarm is its distance beneath the ceiling.

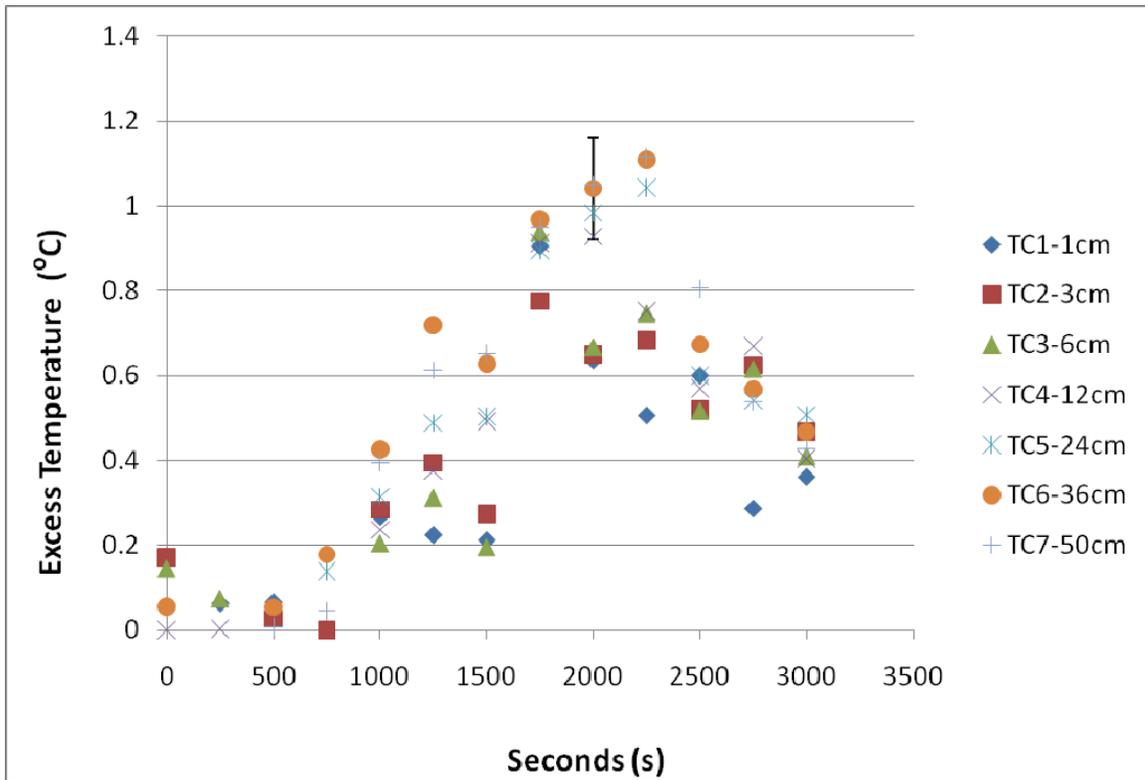


Figure 17 Smoldering foam with cotton duct excess temperature at the thermocouple tree location. An error bar is shown representing one standard deviation from five measurements centered on the data point at 2000 s. The location listed with each thermocouple is its distance beneath the ceiling.

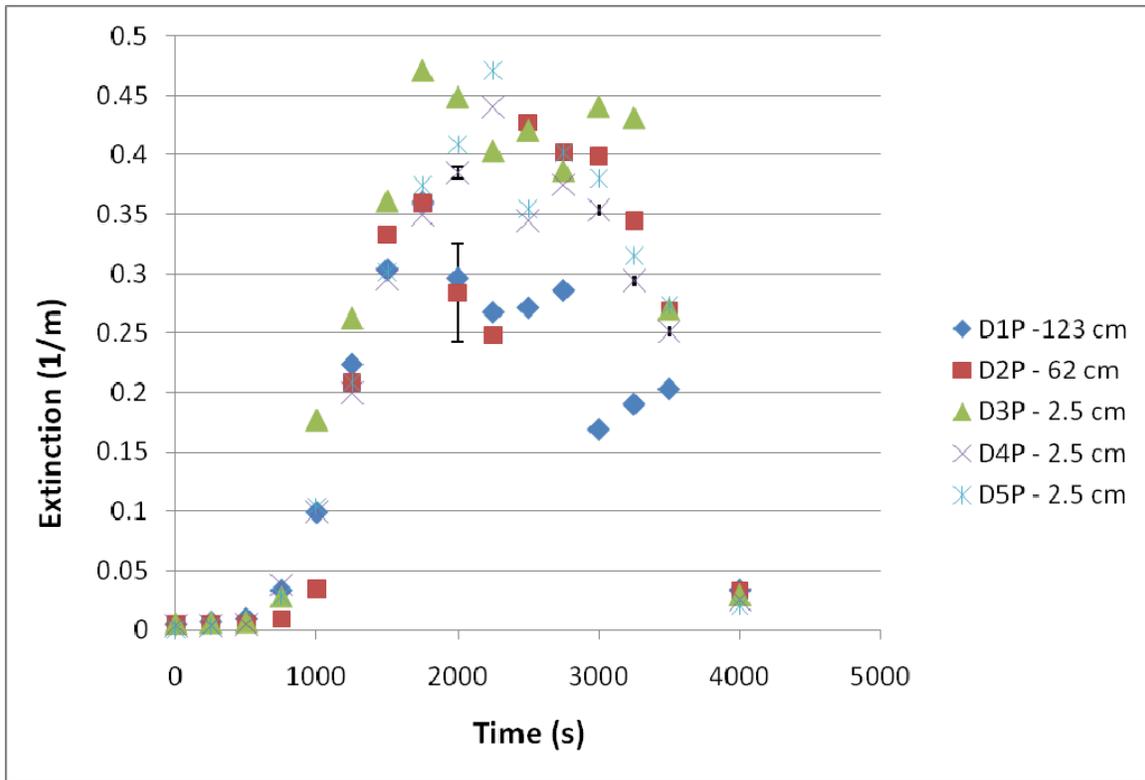


Figure 18 Smoldering foam with cotton duct extinction measure by all the photoelectric alarms on the ceiling and in the photoelectric alarm tree. D1-P and D2-P are located at half and three-quarters of the ceiling height. An error bar is shown representing one standard deviation from five measurements centered on the data point at 2000 s. The location listed with each alarm is its distance beneath the ceiling.

Nuisance Source

Nuisance sources produce smoke or heat in sufficient quantities to activate smoke or heat alarms but would not be regarded as a fire threat. Examples of nuisance sources would be smoking toast in a toaster or the opening of the door of a hot oven. Vegetable oil floating on a thin water layer and heated by a hot plate was used as a representative nuisance source. The hot plate is the primary source of heat with the vegetable oil being the source of the smoke. The vegetable oil did not flame during the measurements. Excess temperatures nearly reached 4.5 °C and the temperature plot began to show stratification (Figure 19) although not to the degree that the hotter flaming fires produced. Stratification was clearly evident in the smoke alarm plot (Figure 20) with the ceiling mounted smoke alarms showing almost twice the extinction as the alarms mounted below the ceiling.

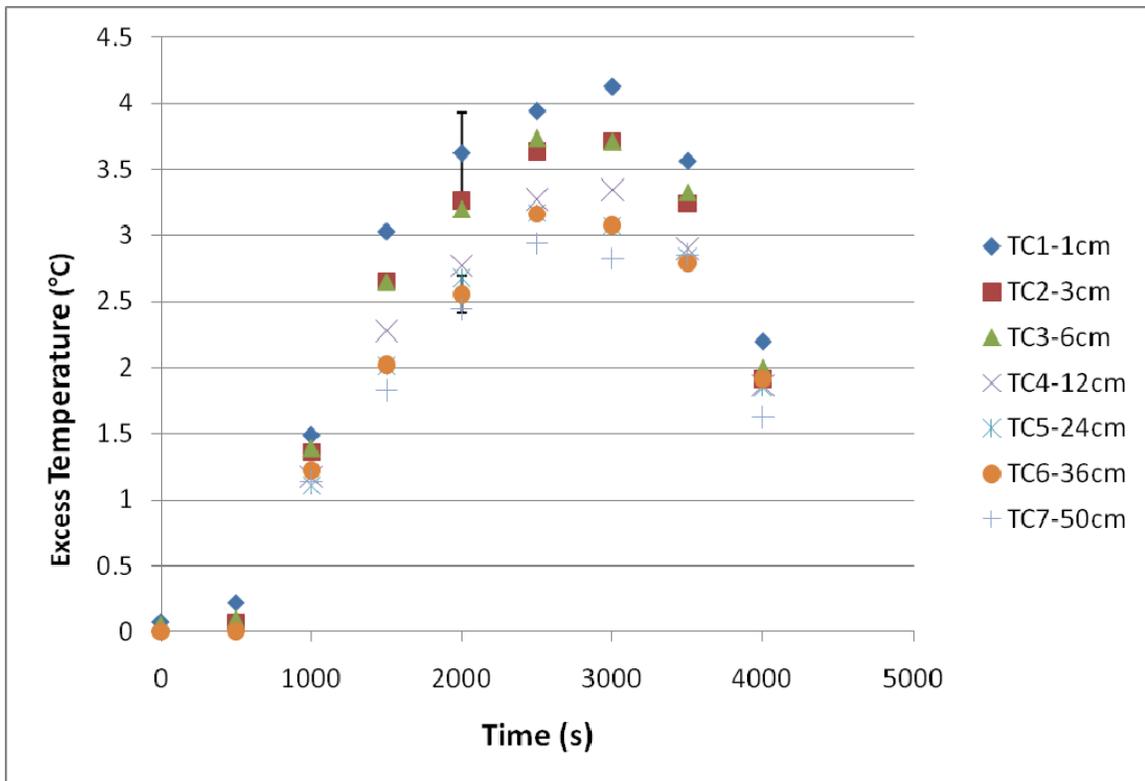


Figure 19 Vegetable oil excess temperatures at the thermocouple tree location. Error bars are shown representing one standard deviation from five measurements centered on the data points at 2000 s. The location listed with each thermocouple is its distance beneath the ceiling.

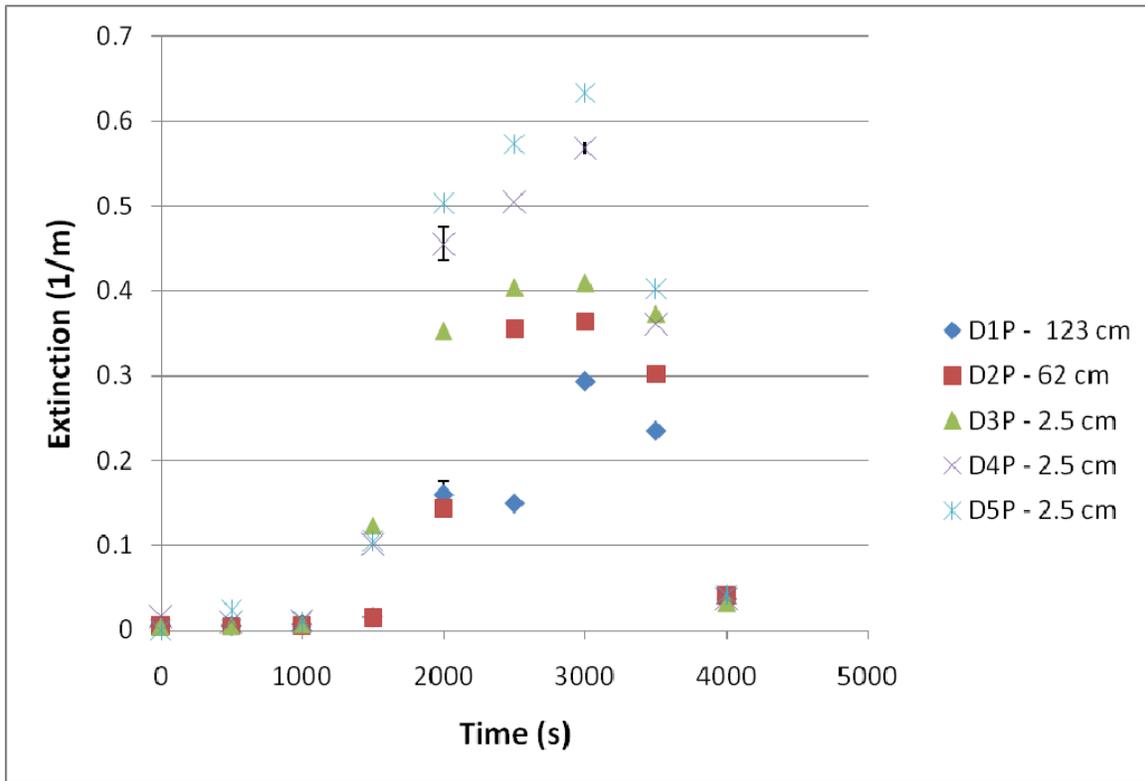


Figure 20 Vegetable oil extinction measured by all photoelectric alarms on the ceiling and in the photoelectric alarm tree. D1P and D2P are located at half and three-quarters of the ceiling height. Error bars are shown representing one standard deviation from five measurements centered on the data points at 2000 s. The location listed with each alarm is its distance beneath the ceiling.

Analysis

A decision support system that is capable of analyzing both flaming and smoldering fires must receive signals from different alarms such as the combination of heat and smoke alarms used in these experiments. A single alarm will not provide the necessary information to identify smoldering and to discriminate between flaming and smoldering. For a combination of heat and smoke alarms located in the room of fire origin, the first signal of interest will come from the smoke alarm and will indicate that a situation is starting to occur⁶. To sort out whether it is a flaming or smoldering source, the heat alarm would be checked to determine the excess temperature and rate of change of the excess temperature measured by the alarm. Early in the development of the fire, the excess temperature will be small for both types of fires. As the event progresses, the difference between flaming and smoldering becomes evident as shown for this set of experiments summarized in table 1.

Fire Type	Fuel	$>4\text{ }^{\circ}\text{C},$ $> 0.01\text{m}^{-1}$	TCJ – Tlyr ($^{\circ}\text{C}$)	$\Delta\text{T}/\Delta\text{t}$ ($^{\circ}\text{C}/\text{s}$)	D4P – D1P (m^{-1})
Flaming	Heptane	Yes/Yes	3.7 ± 0.7	0.02	0.03 ± 0.01
Flaming	Toluene	Yes/Yes	2.9 ± 0.9	0.08	0.68 ± 0.22
Flaming	Foam	Yes/Yes	3.9 ± 1.7	0.13	0.25 ± 0.13
Smoldering	Cotton duct	No/Yes	-0.2 ± 0.2	0.003	0.05 ± 0.07
Smoldering	Shredded paper	No/Yes	-0.17 ± 0.17	0.0005	0.04 ± 0.08
Nuisance	Vegetable oil	No/Yes	0.54 ± 0.29	0.002	0.16 ± 0.14

Table 1 The third column represents conditions measured at the ceiling in the fire room; the fourth column provides the average temperature difference between the three thermocouples sampling the ceiling jet (TCJ) and the three thermocouples sampling the smoke layer (Tlyr); the fifth column shows the temperature rate of change in the ceiling jet; the sixth column provides the difference in extinction measured by a photoelectric alarm near the ceiling and one located at half the ceiling height.

When the extinction level exceeded 0.01 m^{-1} , if the excess temperature exceeded $4\text{ }^{\circ}\text{C}$ and the rate of change of the excess temperature exceeded $0.01^{\circ}\text{C}/\text{s}$, the fire was a flaming fire and the algorithms in the SDFM¹ could be used to provide information about heat release rate, smoke spread, and temperature. If the extinction level exceeded 0.01 m^{-1} but the excess temperature remained below $4\text{ }^{\circ}\text{C}$ or the rate of change of the excess temperature was less than $0.01\text{ }^{\circ}\text{C}/\text{s}$, the fire was identified as a smoldering fire. To determine smoke spread for a smoldering fire, the smoke alarm signals can be used to determine the extinction in each room as the smoke should be fairly uniform in density between floor and ceiling (see Table 1 and Figures 16 and 18). The room temperature can also be provided using the ceiling mounted heat alarms because of the lack of stratification (Table 1 column 4 and Figures 15 and 17). The vegetable oil would be identified as a smoldering fire based on the rate of change of the excess temperature and underscores the difficulty of separating out nuisance sources from smoldering and flaming fires.

While the smoke alarms identify the smoldering events, the room temperature for smoldering events will be of use in monitoring the transition to flaming in the fire room and identifying additional ignition sources in other locations. If the excess temperature should exceed $4\text{ }^{\circ}\text{C}$ and the rate of change of the excess temperature exceeds $0.01\text{ }^{\circ}\text{C}/\text{s}$, the fire has probably transitioned or will transition from smoldering to flaming and the resulting fire plume and ceiling jet will permit SDFM¹ algorithms to follow the fire.

Examples of the temperature response for smoldering fires or when the fire transitions from smoldering to flaming are available in reference 6 for experiments conducted in a house. Table 2 provides a summary of the tests that transitioned from smoldering to flaming with the researchers providing a temperature/time curve for the fire room with a thermocouple positioned 7.6 cm below the ceiling in the fire room.

Test	ΔT_s (°C)	Δt_s (s)	$(\Delta T/\Delta t)_s$ (°C/s)	ΔT_f (°C)	Δt_f (s)	$(\Delta T/\Delta t)_f$ (°C/s)	Fuel	Location
JR 2	0	600 0	0	38	450	0.08	Chair (cotton)	Living Room
JR 3	0	245 0	0	144	360	0.4	Chair (polyurethane)	Living Room
JR 11	5.6	762 0	0.0007	72	60	1.2	Heavily padded box springs	Basement
JR 22	0	165 0	0	50	120	0.4	Chair (cotton/rayon/metallic /no seat cushion)	Basement
JR 24	0	646 0	0	92	120	0.8	Sectional sofa (cotton/nylon/metallic)	Basement
JR 26	3	510 0	0.009	56	300	0.2	Couch (rayon/cotton/nylon/metallic /no seat cushion)	Basement

Table 2 Summary of experiments that transitioned from smoldering to flaming from reference 6. ΔT_s is the maximum excess temperature change during smoldering, Δt_s is the time interval during smoldering, $(\Delta T/\Delta t)_s$ is the maximum rate of change of excess temperature during smoldering except for the value given for JR 26 which was due to a furnace air flow rather than the smoldering fire; ΔT_f is the maximum excess temperature change during flaming, Δt_f is the time interval over which the excess temperature reached maximum, $(\Delta T/\Delta t)_f$ is the maximum rate of change of excess temperature for the start of flaming, Fuel is the object that smoldered/burned and Location provides the location of the Fuel in the house.

The reader is referred to reference 6 for the details concerning room size, doors and windows open or closed and furnace operations. The basement ceiling was flat and had a height of 2.1 m while the living room had a curved ceiling with a maximum height of 4.0 m at the center and 3.4 m at the wall⁷. The thermocouple used for the living room data was positioned 7.6 cm below the 4.0 m high ceiling. The 3 °C temperature increase during smoldering and the 0.009 °C/s rate of excess temperature change for JR 26 was due to the furnace heating the air and was not large enough to change the fire classification to flaming. Only one of the six fires from reference 6, JR 11, became hot enough during smoldering to exceed the excess temperature requirement of 4°C but would fail the requirement that the rate of change of the excess temperature exceed 0.01 °C/s and remain classified as a smoldering fire until flaming actually occurred.

Table 3 provides a summary of the suggested criteria to distinguish between smoldering and flaming fires for compartments with ceiling mounted heat and smoke alarms, no ventilation and ceiling heights less than 4 m.

Fire Type	Excess Temperature (°C)	Obscuration (m ⁻¹)	Rate of Change Excess Temperature (°C/s)
Flaming	>4.	>0.01	>0.01
Smoldering	<4.	>0.01	<0.01
Transition from Smoldering to Flaming	>4.	>0.01	>0.01

Table 3 Criteria to Discriminate between Smoldering and Flaming Fires

The criteria for the transition from smoldering to flaming was based on the smoky environment rapidly heating up from the small excess temperatures at the ceiling experienced with smoldering fires to the large excess temperatures produced by the ceiling jet of flaming fires. These values were derived using experiments where the ceiling height was 2.46 m, and the smoke alarms and thermocouples were located as shown in Figure 8. A second set of experiments, table 2, was used to verify that these values were reasonable for larger spaces, different ceiling heights, and realistic size fuel sources. The rate of change of excess temperature was needed as a second criterion for the transition between smoldering and flaming based on experiment JR 11 in table 2 as this was the only smoldering fire of the eight analyzed that exceeded the 4 °C excess temperature. All the smoldering fires satisfied the <0.01 °C/s rate of temperature change requirement.

Issues

The methodology outlined in the analysis section appears to be straightforward but there are a number of factors that must be tested before this type of analysis becomes trustworthy. The fire to ceiling height of the experiments used to deduce target excess temperatures and extinction is 2.46 m. To extend these target values (excess temperature of 4 °C, extinction of 0.01 m⁻¹ above ambient, and the maximum rate of change of excess temperature greater than 0.01 °C/s) to higher ceiling spaces for the size of fire investigated in these experiments, it would be assumed based on plume theory that the target excess temperature should decrease as the height to the 5/3 power for flaming fires⁸. Higher ceilings will result in a higher threshold/uncertainty in order to discriminate between flaming and smoldering as the excess ceiling temperature is reduced for the flaming fires. For small flaming fires, stratification in high ceiling structures may prevent the fire plume from reaching the ceiling.

The response of smoke alarms to fire is very fuel dependent with the ionization alarms responding best to fires that produce large numbers of small particles while the photoelectric alarms respond best to fires the produce particles with high reflectivity. An example that highlights the differences in behavior of these alarms comes from a black PMMA flaming fire. The ceiling mounted ionization smoke alarms responded quickly with all of the alarms giving at least an extinction of 0.02 m⁻¹ by 400 s (Figure 21). The photoelectric alarms exhibited a substantial time delay before responding with the earliest

responding photoelectric alarm reaching an extinction of 0.02 m^{-1} by 900 s (Figure 22) with the laser exhibiting the same behavior as the photoelectric alarms. This fuel produced the largest deviation of response between the two types of smoke alarms and underscores the need to understand how smoke alarms respond to different fuels in order to use their signals to predict threats and visibility during fire development.

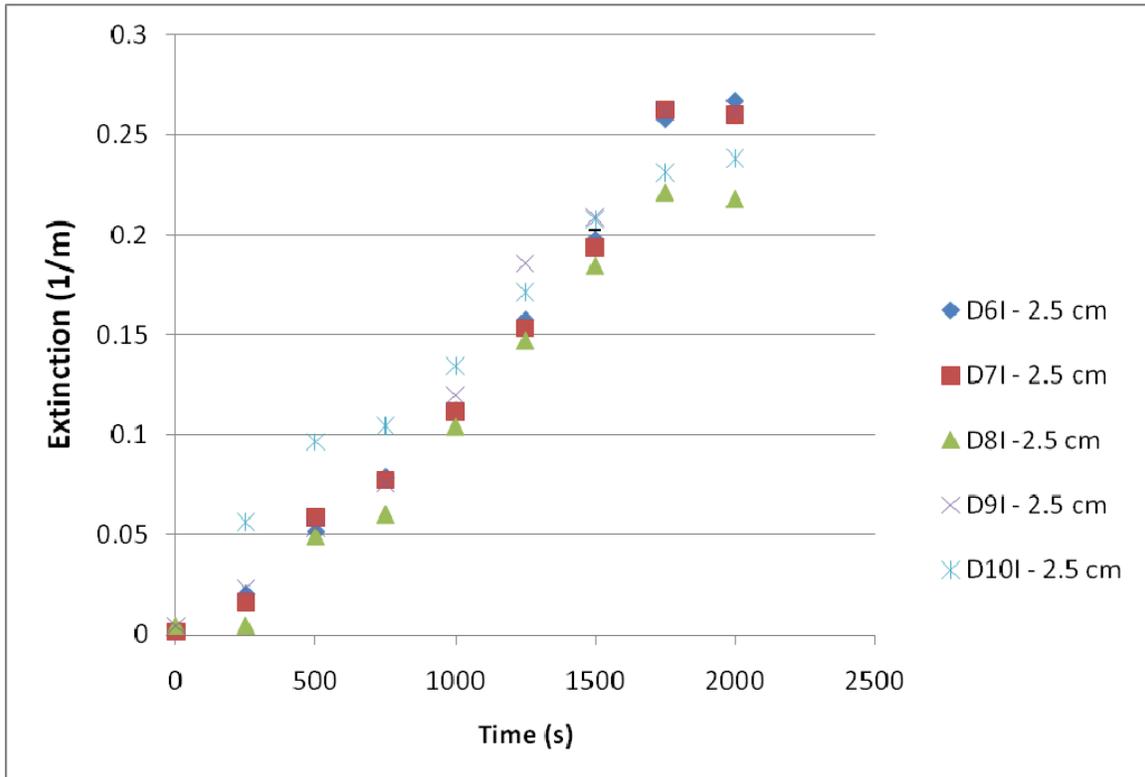


Figure 21 Ion smoke alarm response to a flaming PMMA fire. Error bars are shown representing one standard deviation from five measurements centered on the data point. The error bars are about the same size as a data point. The location listed with each alarm is its distance beneath the ceiling.

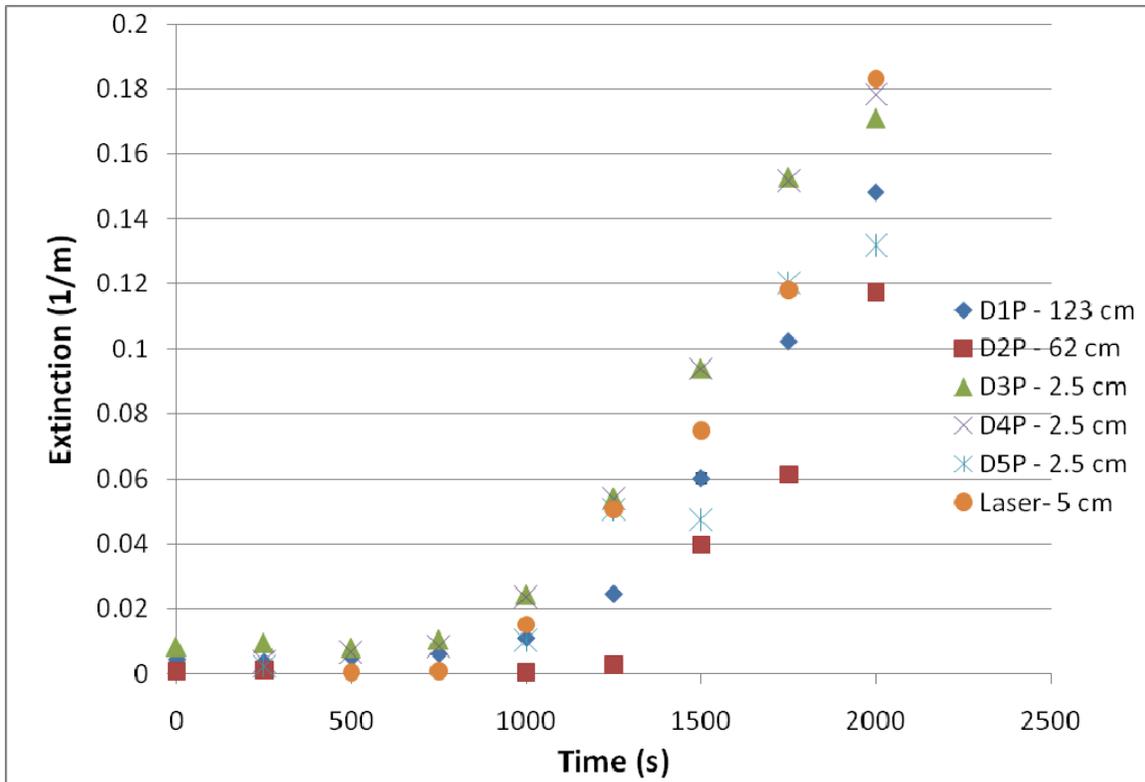


Figure 22 Photoelectric smoke alarm response to a flaming PMMA fire. Error bars are shown representing one standard deviation from five measurements centered on the data point. The error bars are about the same size as a data point. The location listed with each alarm and the laser is its distance beneath the ceiling.

The smoldering/flaming experiments described in reference 6 introduce additional issues associated with the season and air conditioning. Specifically, for experiments conducted with the house in a heating mode, smoke was uniformly distributed from floor to ceiling but with the air conditioning operating in the summer, the smoke stratified in a layer which did not reach the ceiling. This stratification was observed in the fire room as well as the other rooms of the home. With this type of stratification, signals from ceiling mounted alarms would not provide accurate information about smoke conditions.

Conclusion

Fire fighters entering a building need to know the location and severity of the fire and which areas smoke would be in concentrations that obscure vision, incapacitate residents, and require breathing apparatus⁹. It has been shown that a combination of temperature and smoke sensing are sufficient to discriminate between smoldering and flaming fires for a number of fuels in a real-scale and realistic room size geometry. For smoldering fires, the output of ceiling mounted heat and smoke alarms could be used to provide visibility and temperature estimates characterizing the entire room. Flaming fires require the use of algorithms such as the ones in the SDFM¹ to determine smoke and temperature

levels in a room. The current sets of experiments that provide the basis for these conclusions was conducted in a room with no ventilation and a flat ceiling and were augmented with experiments conducted in a home where summer air conditioning created an observed stratification of smoke. This observed stratification was not observed in the winter with the furnace operating. Additional testing is needed in circumstances where there is significant air flow caused by open windows and doors, or in large spaces with high or sloped ceilings or in air conditioned rooms to test these conclusions. In addition, a material database needs to be developed to provide a sound basis for understanding the response of photoelectric and ionization smoke alarms to smoldering and flaming fires for a wide range of fuels.

References

- 1 Davis, W. D., A Sensor-Driven Fire Model Version 1.2, To be published as a NISTTN (2010).
- 2 Tewarson, A., “Generation of Heat and Chemical Compounds in Fires,” *The SFPE Handbook of Fire Protection Engineering*, NFPA, 2002, pp. 3-38 – 3-161.
- 3 Grosshandler W (1997) “Toward the Development of a Universal Fire Emulator-Detector Evaluator,” *Fire Safety Journal*, 29: 113-128
- 4 Cleary, T. G.; Chernovsky, A.; Grosshandler, W. L.; Anderson, M. . “Particulate Entry Lag in Spot-Type Smoke Detectors.” *Fire Safety Science. Proceedings. Sixth (6th) International Symposium. International Association for Fire Safety Science (IAFSS)*. July 5-9, 1999, Poitiers, France, Curtat, M., Editor, 779-790 pp, 2000.
- 5 Davis, W. D., Cleary, T. G., Donnelly, M. K., and Hellerman, S. D., “Predicting Smoke and Carbon Monoxide Detector Response in the Ceiling Jet in the Presence of a Smoke Layer,” *National Institute of Standards and Technology*, NISTIR 6976, 2003, pp. 1-34.
- 6 Bukowski, R. W., Waterman, T. E., and Christian, W. J., “Detector Sensitivity and Siting Requirements for Dwellings,” *National Institute of Standards and Technology*, NBS GCR 75-51, 1975, pp. 1- 337.
- 7 Bukowski R. W., Private Communication (2010).
- 8 Heskestad, G., “Fire Plumes,” *The SFPE Handbook of Fire Protection Engineering*, 1992, p. 1-112.
- 9 Holmberg, D.G., Davis, W.D., Treado, S. J., Reed, K. A., “Building Tactical Information System for Public Safety Officials,” *National Institute of Standards and Technology*, NISTIR 7314, January, 2006, pp. 1-65.