Smoke Alarm Response: Estimation Guidelines and Tenability Issues – Part 1

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INTRODUCTION

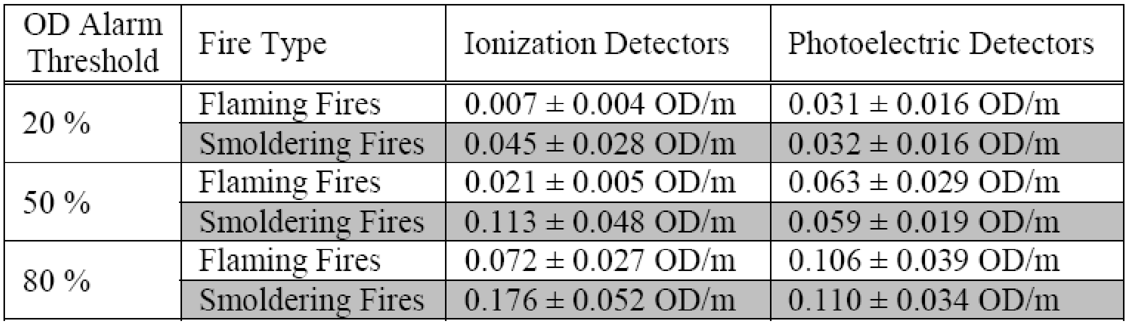
Performance-based design of fire alarm systems as well as the forensic recreation of fire events requires the prediction of the response of smoke detection equipment under a wide range of applications. Accordingly, multiple smoke detection response methodologies have been developed [1]. These methodologies include empirically based correlations, different alarm thresholds and the use of various fire models, such as computational fluid dynamics codes (e.g. Fire Dynamics Simulator). Given the array of methods, the need to validate these methodologies using experimental data sets is critical. Recent experimental test series have provided databases of detector responses and fire conditions for various installation configurations which can be used for this purpose. The primary objective of this paper is to evaluate the performance of the currently available smoke detection response methodologies using these experimental databases.

SMOKE DETECTION RESPONSE METHODOLOGIES

Early smoke detection response prediction methods were based solely upon discrete measurements that could be collected during fire testing (i.e., temperature, optical density of smoke, and velocity). However, over time the reliability and validity of detector response methods based solely on velocity or temperature has been appropriately challenged [1]. Emerging from this ongoing quest for a well established and accurate alarm response methodology, there are currently two primary methodologies that have been developed and focused on in the fire protection community.

The first method, developed by Geiman et al. [2], is based upon experimental data sets collected from a variety of tests in which smoke detector response and local smoke density measurements were collected. The authors analyzed the data available and developed alarm response thresholds that provide a statistical likelihood that a detector activates based upon a known smoke density around the detector. The average alarm thresholds developed by Geiman et al. are provided in Table 1 and represent the mean value of multiple data sets that incorporate different variables and research programs. It is important to note that this method does not suggest that an alarm is certain once a given smoke optical density per meter (OD/m) criteria is reached but instead applies a statistical likelihood that an alarm will have activated if smoke conditions have exceeded a given threshold.

Table 1. Smoke Alarm Activation Thresholds Determined by Geiman et al [2].



OD Alarm Threshold	Fire Type	Ionization Detectors	Photoelectric Detectors
20 %	Flaming Fires	0.007 ± 0.004 OD/m	0.031 ± 0.016 OD/m
	Smoldering Fires	0.045 ± 0.028 OD/m	0.032 ± 0.016 OD/m
50 %	Flaming Fires	0.021 ± 0.005 OD/m	0.063 ± 0.029 OD/m
	Smoldering Fires	0.113 ± 0.048 OD/m	0.059 ± 0.019 OD/m
80 %	Flaming Fires	0.072 ± 0.027 OD/m	0.106 ± 0.039 OD/m
	Smoldering Fires	0.176 ± 0.052 OD/m	0.110 ± 0.034 OD/m

As shown in Table 1, the authors provided three levels of probability with respect to detector alarm response. Variables considered in the study included detection technology, fire scenario, and nominal detector sensitivity; and in doing so the authors concluded that the appropriate thresholds are dependent upon the fire type and detector technology. For example, the mean smoke optical density was 0.059 m^{-1} when 50 percent of the photoelectric detectors alarmed to smoldering fires. This predictive method provides a quantitative basis to assess the level of accuracy of defining an activation threshold at which a smoke detector is expected to alarm. The method relies on other fire dynamics tools, such as models or experimental correlations, to determine the development and transport of smoke to the detector and the resulting smoke concentration at the detector location. As can be seen by the standard deviation

The second detector response method utilizes a smoke detector algorithm [3] that has been integrated into the computational fluid dynamics (CFD) model, Fire Dynamics Simulator (FDSv5). [4,5] The algorithm is based upon characteristic lag times associated with the migration of smoke into a smoke detector with respect to the development of smoke conditions outside the device. [6,7] The user must provide input parameters (or use default values) for device specific parameters used to calculate a characteristic lag time and activation thresholds. Based on other fire dynamics inputs (e.g., fire heat release curve and soot yield), FDS calculates velocity flow fields and smoke concentrations outside the detector as a function of time. Using this velocity and smoke data, the smoke detector algorithm calculates the transient smoke concentrations within the device. Finally, based upon the user defined activation threshold, the model calculates an activation time when the smoke concentration within the smoke detector reaches the assigned activation threshold.

The accuracy of both response methodologies depends on the ability of the person or model to properly calculate the smoke density outside of the detector. In addition, the FDS detector model also depends on its ability to resolve flow fields in the proximity of the smoke detector. The method developed by Geiman inherently accounts for the range of velocity conditions that occur for different fires since the OD alarm thresholds are based on multiple test series that include a wide range of building conditions and fire types. It is noteworthy that the detector specific parameters used to calculate the characteristic lag time are not readily available for most smoke detectors and smoke alarms. Also, the internal smoke alarm threshold used in the FDS detector model should be a device specific value; however, these values are not readily known. Therefore, the uncertainty of the FDS detector model must also be assessed relative to the uncertainties of selecting these model parameters.

EXPERIMENTAL TEST SERIES

Data from two recent experimental test series are used to validate the smoke detection response methodologies previously described. The first data set, identified as NIJ, was collected from a series of seven enclosure fires conducted using realistic fire scenarios. The second data set, identified as FPRF, was collected from a series of forty-three gas burner fires conducted beneath a highly variable corridor ceiling apparatus. The data sets from these test series provide a large population of detection alarm times and environmental fire measurements to be utilized and evaluated against the predictions of the smoke detection response methodologies.

The National Institute of Justice (NIJ) test series was conducted within a 41.8 m^2 (450 ft^2) apartment-style enclosure comprised of four, inter-connected rooms. An overview of the test enclosure is provided in Figure 1. A detailed description of the entire NIJ test series is provided in [8].

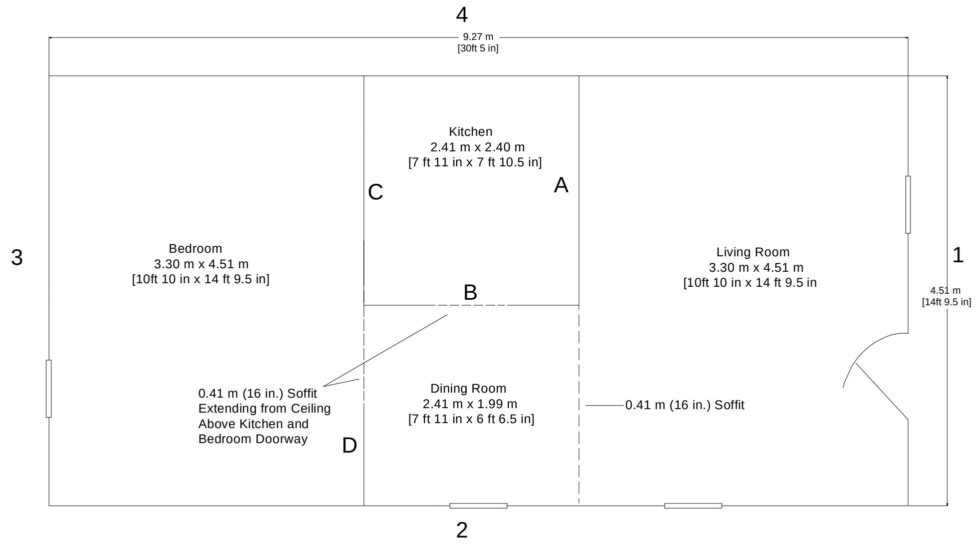


Figure 1. Overview of the NIJ test enclosure.

Conditions within the enclosure and in areas proximate to alarm clusters were characterized using thermocouples, gas sampling, and optical density meters, as well as other instrumentation for heat, flow and pressure measurements. Fire scenarios evaluated included both flaming and smoldering polyurethane sofa scenarios in the living room, flaming wooden cabinets in the kitchen, and smoldering cotton batting in the bedroom. For each fire scenario, two clusters of eight alarms each were installed along the path of egress within the enclosure. Each cluster was comprised of 3 ionization, 3 photoelectric, and 2 dual sensor alarms from three manufacturers. Alarm activation and fire conditions were measured via a data acquisition system sampling at 1Hz.

The FPRF test series was conducted using a highly variable corridor apparatus The apparatus was 14.6 m (48 ft) long, 3.7 m (12 ft) wide and was tested under varying widths, ceiling heights, and ceiling geometries (i.e., smooth or obstructed with beams). A complete description of the FPRF experimental test set-up is provided in reference [9]. Figure 2 shows a diagram of the corridor apparatus with beamed ceiling configuration. The figure presents the locations of spot smoke detectors, optical density meters and velocity probes. As shown in Figure 2, the corridor apparatus was fully-instrumented and incorporated pairs of ionization and photoelectric type detectors at various locations.

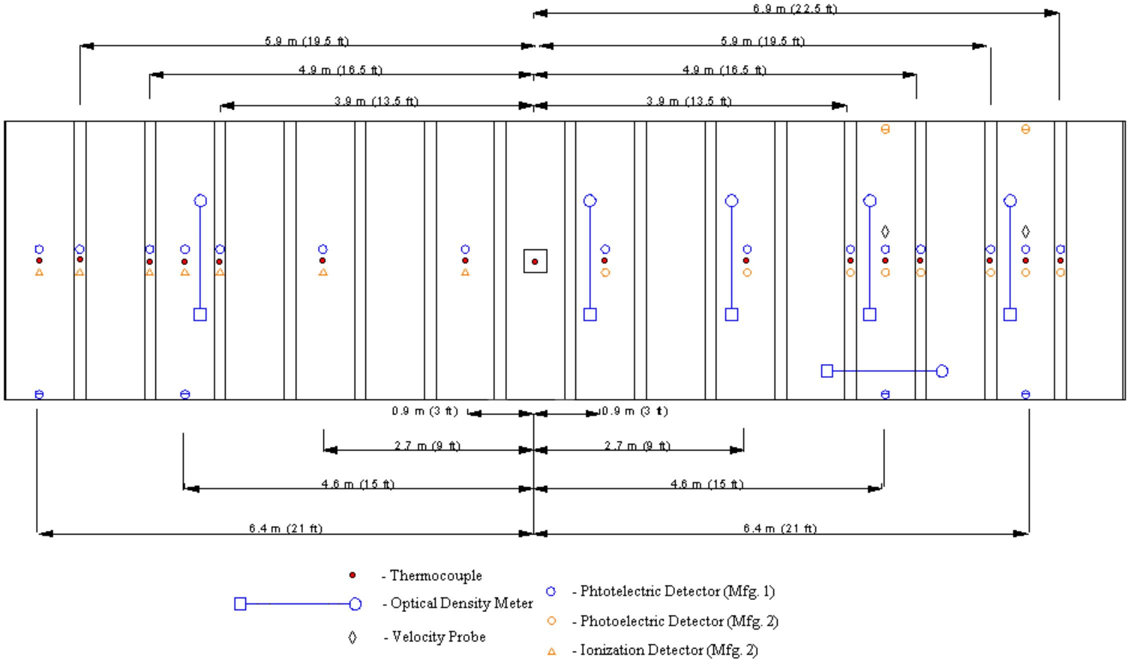


Figure 2. Diagram of instrumented FPRF corridor apparatus.

The fire exposures used in the FPRF test series consisted of strictly propylene gas burner fires located beneath the central-most beam pocket. The fire source used in this test series was a 0.31 m (1 ft) square sand burner constructed in general accordance with Annex A of ISO 9705 [10] producing a 100 kW fire exposure.

The times at which individual alarms activated were recorded for all devices in both test series. Furthermore, optical density meters, constructed in general accordance with the specifications of UL 268 [11], were used to measure smoke concentrations proximate to activating smoke alarms. This activation data and corresponding smoke concentration at time of alarm will be the primary data reported and compared in the following analysis. Complete data sets for both the NIJ and FPRF tests series are provided in the full reports for these test series. [8,9]

ANALYTICAL APPROACH

As is required by the FDS detector response methodology, model simulations were developed for the experimental test results being evaluated. Due to the large population of experimental data, only specific test runs conducted in the experimental test series were selected for modeling simulation comparisons. However, all experimental data was evaluated against the thresholds provided by Geiman.

The model simulations of the selected tests were performed using Fire Dynamics Simulator v5. Based upon the approach outlined in Ref [3], smoke sensitivity values, as reported on the back of each alarm by the manufacturers, were used as the alarm thresholds in the FDS detector model. The tests identified to evaluate the performance of the detection response methodologies were an unventilated flaming sofa fire test conducted in the NIJ test series as well as three smooth ceiling corridor tests with ceiling elevations of 2.7 m (9 ft), 3.7 m (12 ft), and 5.5 m (18 ft).

The time of activation for each detector and the corresponding smoke density in the vicinity of the alarm at time of activation is reported for the selected tests. This experimental data set is then tabulated and evaluated against the alarm threshold criteria provided by Geiman et al. to determine the applicability of the suggested threshold values. The smoke development and spread results of the model simulations are used as input for both the empirically-based predictive approach of Geiman and the FDS detector model.. The resulting alarm activation times obtained using both detector response methodologies are compared to the experimental alarm times. These comparisons provide insight into the accuracy and reliability of the detector response methods currently available to the fire protection community and provide an understanding of how these methods compare.

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