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A Test Methodology for Multiple Sensor – Multiple Criteria Alarms

Abstract

Multiple sensor-multiple criteria fire alarms hold promise for improving fire detection by both increasing sensitivity to fire while decreasing nuisance alarms. Eventually, to provide a fair assessment of performance, some type of uniform testing protocol needs to be advanced in order to demonstrate to stakeholders (standards organizations, testing laboratories, manufacturers, governmental organizations, fire departments and affiliated national organizations, and consumers) the value of various alarm designs. Standard fire sensitivity tests provide one way to assess fire detection performance, but there are no consensus standards related to nuisance sources. NIST is working on a test methodology based on reproducing fire and nuisance conditions in the fire emulator/detector evaluator (FE/DE). Full-scale fire and nuisance tests conducted as part of the Home Smoke Alarm Project supplied the data for comparisons to scenarios emulated in the FE/DE. Comparisons of two of these tests, a smoldering chair and cooking oil fire, to their emulated scenarios in the FE/DE are described and shortcomings identified. Based on these results and previously reported emulated fire and nuisance tests, the proposed methodology shows promise in relating full-scale smoke alarm tests to reproducible laboratory tests at a level sufficient to assess alarm performance where sensors respond to convected heat, smoke and combustion gases, or nuisance products. However, more test development is needed in order to more closely match real-scale test conditions to emulations and to demonstrate repeatability.

Introduction

Available test methods are sufficient to assess the performance of current smoke alarm designs. However, new fire alarm designs may not be sufficiently challenged by current test methods. One of the main driving forces for new fire alarm designs is the desire to reduce nuisance alarms. Several designs have been proposed using

combinations of particulate, gas sensing, thermal and other sensors, with alarm criteria requiring anything from simple to more complex sensor signal processing and computations. Room-scale fire sensitivity tests found in EN 54 [1] and UL 268 [2] standards produce common potential fire environments, and present to an alarm all the stimuli it would experience during fire including: smoke, gas and heat exposures, and flow velocities produced by the fire plumes. No such testing protocols exist for nuisance alarm sources. While room-scale protocols for nuisance sources could be developed as a compliment to the fire sensitivity tests, another alternative is to reproduce both fire and nuisance test results in a laboratory-scale instrument to improve repeatability and reproducibility with less effort than room-scale experiments. This idea is not new. Denny [3] describes a small-scale test tunnel used to transport fire and non-fire stimuli to sensors to provide realistic data used to train a discriminating fire detector. Grosshandler [4] introduced the concept of a universal fire emulator/detector evaluator, who's objective is to produce well-controlled environments and to eliminate run-to-run variations observed in full-scale tests. The embodiment of Grosshandler's concept is the fire emulator/detector evaluator (FE/DE) tunnel [5], and this device is the crux of the test methodology introduced here. Full-scale fire and nuisance tests conducted as part of the Home Smoke Alarm Project [NIST TN 1455; 6] supplied the data for comparisons to scenarios emulated in the FE/DE.

The Home Smoke Alarm Project was a multi-year effort designed primarily to evaluate the current state of residential smoke alarms by examining how different types of smoke alarm technologies respond, and how their number, and locations in residential applications impact on life safety. The project included several aspects in the design of experiments to produce data needed to assess new technologies, and to more fully characterize the experimental conditions in order to reproduce those test environments in the FE/DE. Special attention was paid to the selection of realistic fire scenarios that emphasized the main types of fires that cause injury and death as indicated by U.S. residential fire statistics. These include upholstered furniture fires, and cooking fires. Fire tests were performed in both a single-story, and a two-story home. Nuisance source tests were also conducted in the single-story home; selected results from those tests are detailed in another paper in this conference [7].

Full scale fire scenarios included: flaming and smoldering upholstered chairs, flaming and smoldering mattresses, and cooking oil fires. The bulk of the nuisance scenarios were related to cooking activities including: frying, deep-frying, baking, broiling, boiling, and toasting, in addition to cigarette smoke and burning candle exposures. Additionally, smoldering cotton and wood block sources similar to the EN-54 fire sensitivity test fires TF2 and TF3 [1], and smoldering polyurethane foam block tests were performed to provide comparative results to the nuisance test series. The product of the number of tests (~70), and smoke alarm locations (~ 4 to 8) yielded over 400 separate alarm environments.

The desire is to identify a small subset of these (fire and nuisance) environments that captured characteristic alarm producing conditions for residential applications, and that can be successfully reproduced in the FE/DE. A suitable subset of emulated tests forms the basis of a test methodology for residential alarms where performance assessments are made based on realistic fire and nuisance scenarios. NIST TN 1455 has complete descriptions of nuisance tests and several emulated nuisance scenario tests performed in the FE/DE that demonstrated similar environments and would lead to nuisance alarms [6]. A previously emulated flaming fire scenario based on an EN54 TF4 polyurethane foam mat fire in a multi-room configuration demonstrated similar characteristics to the flaming chair and mattress tests [8]. Specifically, the FE/DE was programmed to reproduce rapid increases in flow velocity, smoke and CO concentration, and air temperature observed in the model calculations for two discrete detector locations. The rate of rise in smoke and CO concentration, air temperature, and flow speed were similar to the flaming chair and mattress tests, and within the range of the FE/DE. The exact details of a flaming chair or mattress fire scenario are yet to be programmed into the FE/DE.

The focus here is on the single-story home results of a smoldering chair test, and a cooking oil fire test. These two tests produced characteristically different environments in their pre-flaming stages compared to flaming fire tests, and they presented a challenge to emulate in the FE/DE.

Home Smoke Alarm Project Tests

The test structure was a complete manufactured home, constructed off-site and transported to NIST. Its nominal dimensions were 20.1 m long and 4.2 m wide, with an interior ceiling that was pitched from the centerline at a height of 2.4 m to a height of 2.1 m at the exterior walls. The home was placed inside the Large Fire Test Facility building for all tests conducted. A schematic of the single-story home is shown in figure 1. The approximate locations of selected smoke meters, thermocouples, detectors, gas sampling, and velocity probes are shown. The notation for these
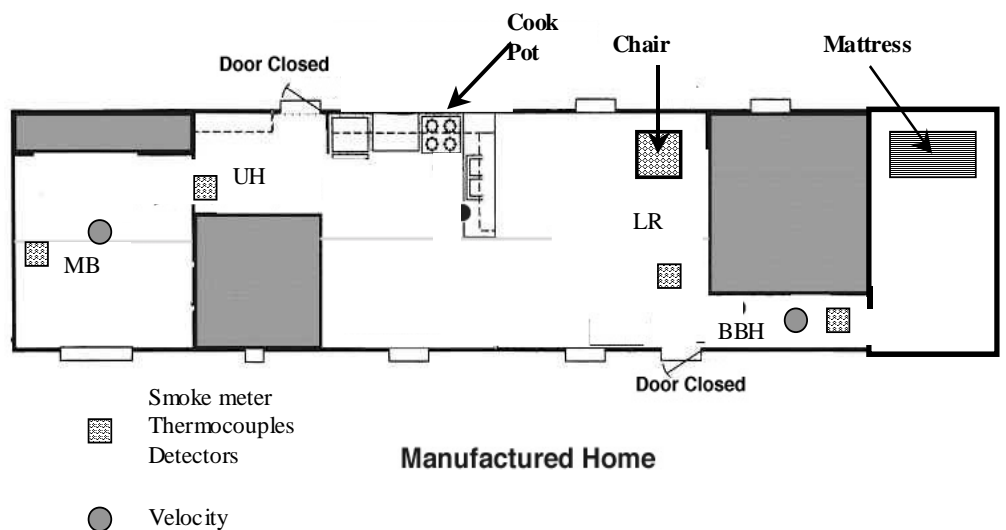

Figure 1. Schematic of Manufactured Home.

locations are: MB – master bedroom, UH – utility hallway, LR – living room, and BBH – back bedroom hallway. Dark shaded areas are closed off. Full details on the configuration, exact location of measurements points, and alarms, materials burned, and the scenarios are given in the final report (NIST TN 1455 [6].) Only a brief description of the two selected fire tests is presented here, along with selected data.

A smoldering chair test was examined (SDC 34 in [6]). The chair was remotely ignited by an electrically heated nichrome wire inserted into a slit made in the fabric and foam on the front face of the seat cushion. The heated wire initiated a smoldering process

that progressed until substantial portions of the chair foam were smoldering. The chair transitioned from smoldering to flaming after over an hour. At time = 0 s, the ignition sequence started.

A cooking oil fire was examined (SDC41 in [6]). 500 ml of cooking oil was placed in a 0.3 m diameter sauté pan, which was put on a propane gas range burner. The heat output from the burner was nominally 1.5 kW. At time t = 0 s, the propane burner was ignited. The oil continued to heat until it ignited about 1200 s later. Suppression followed soon after ignition.

Test series data from selected smoke meters, thermocouples, CO and CO_2 gas analyzers, and monitored smoke alarms are presented below. These graphs were constructed from the test data files [9]. Velocity measurements were made with 2-D sonic anemometers located 2 cm from the ceiling. According to the manufacturer, uncertainty in the velocity measurements is stated as 1 cm/s. The two velocity components were combined to give a scalar speed of the ceiling jet at the measurement location. The interconnect signal of residential smoke alarms were monitored and the transition from low to high voltage was used as the indication of alarm. Because of the built in delay between a local alarm and the interconnect signal, the uncertainty in the alarm time was estimated as 5 s. All data presented here was from devices and sampling locations nearest to one another, but in neither case were all measurements taken from the same location. This introduces uncertainty in the comparisons to the FE/DE tests where all measurements are taken at the same location.

FEDE Tests

The FE/DE was used to emulate a smoldering upholstered furniture fire, and a cooking oil fire. The objective here was to demonstrate that important features of the selected scenarios could be reproduced in the FE/DE. The FE/DE has been described elsewhere [5,6]. It is a single-pass "wind tunnel" that allows for the control of flow velocity, air temperature, gas species, and aerosol concentrations at a test section where sensors and alarms are exposed to these environmental conditions.

A foam block sample 10 cm x 10 cm x 8 cm in size, taken from an un-burned chair seat cushion of the same type smoldered in the fire test series, was used to produce the smolder smoke in the FE/DE emulation of the smoldering scenario. A nichrome wire loop, similar to the igniting wire in the full-scale tests, was inserted into a 3 cm long, 2 cm deep slit made in the foam block. The foam block was placed at the bottom of the vertical riser in the FE/DE, approximately 4 m from the test section. The wire was energized with an alternating current set at a level to initiate sustained smoldering in the block. The fan speed was set to provide mean flow velocity of 0.15 m/s in the duct.

Approximately 5.0 ml of corn oil placed in a 10 cm diameter glass dish which was put on a 750 Watt electric hot plate produced the smoke for the overheated cooking oil scenario. The hot plate was located at the bottom of the vertical riser in the FE/DE. The fan speed was set to provide a mean flow velocity of 0.1 m/s in the duct. Measurement uncertainty in smoke optical density, CO and CO_2 concentration, flow velocities and air temperatures recorded in the FE/DE have been previously estimated as $3x10^{-4}$ m^{-1}, $2.5x10^{-4}$ % volume fraction, $2x10^{-3}$ % volume fraction, 1 cm/s, and 1 ^{o}C respectively [5].

Results and Analysis

Results from the smoldering chair test are shown in figure 2. Figure 2A shows the optical density and air temperature 2 cm below the ceiling in the living room, and the time to reach alarm for the photoelectric and ionization alarms. Figure 2B shows the gas concentration results for CO and CO_2 at a sampling location 90 cm below the ceiling in the living room. The mean ceiling jet flow speed in back bedroom hallway, the closest measurement location to the living room area, was about 0.12 m/s for the time period prior to flaming.

The emulated smolder test is shown in figure 3 along with the smoldering chair test graphs re-scaled for comparison in figure 4. During this test, the power was turned on at 60 s and the foam block transitioned to flaming at about 940 s. The fan speed setting that produced a mean flow speed of 0.15 m/s at the test section was consistent with the
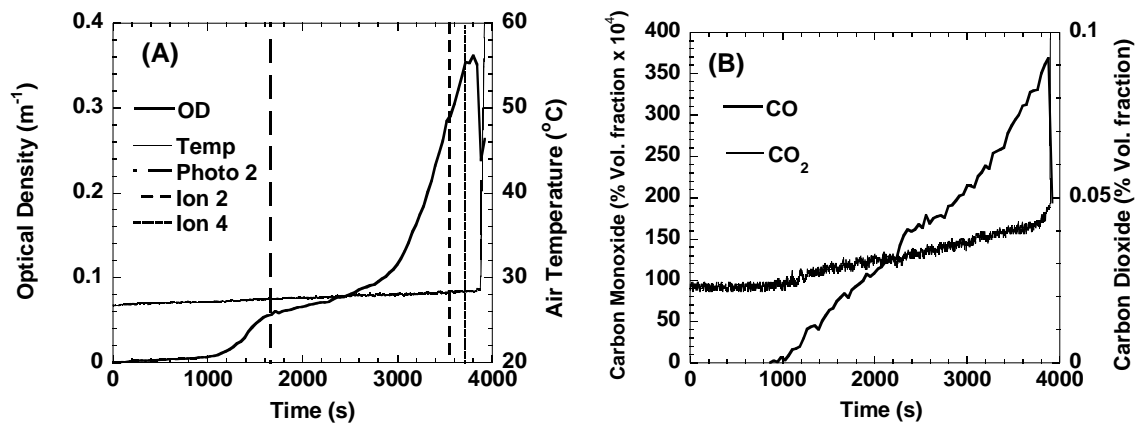
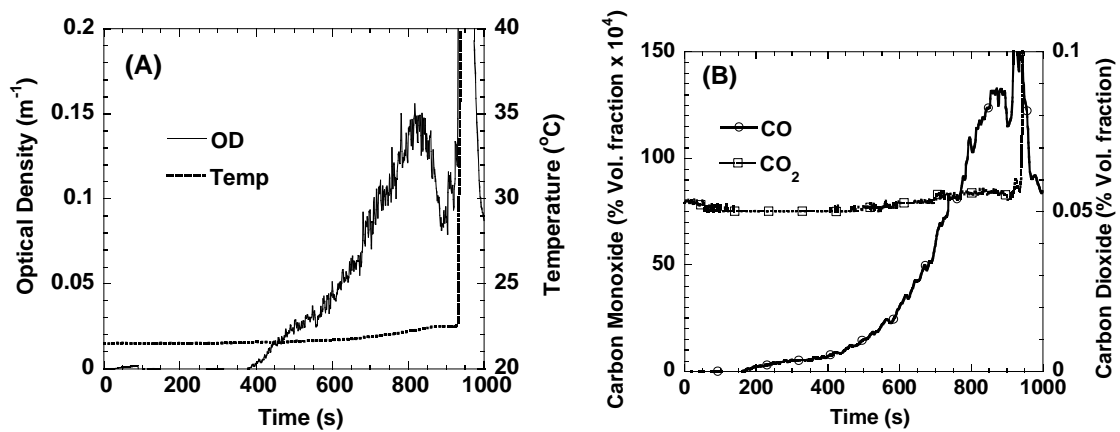**Figure 2. Results for the smoldering chair test.**

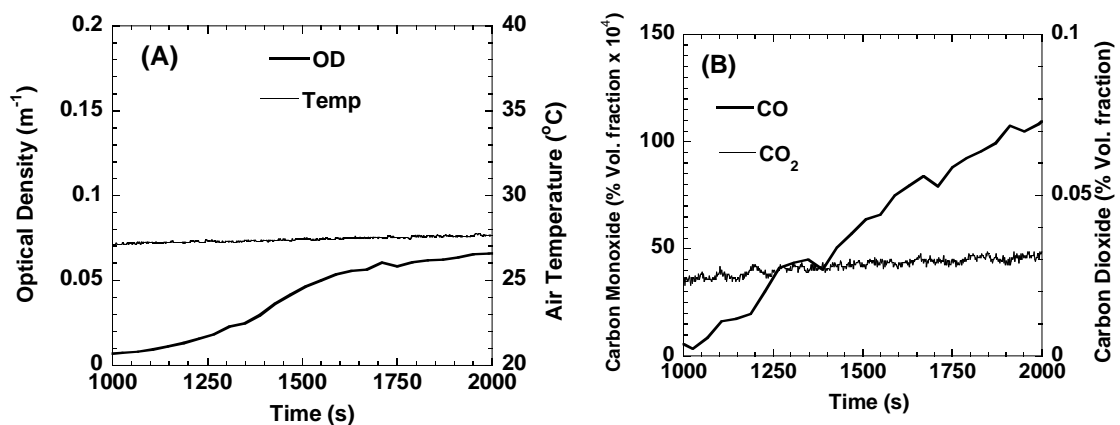**Figure 3. Results from the FE/DE smoldering foam block.**

Figure 4. Results from the smoldering chair test – re-scaled graphs.

chair test results. Prior to flaming ignition, air temperature and carbon dioxide concentration increased slightly, which was the same trend observed in the smoldering fire test. Carbon monoxide started to increase around 200 s, while the smoke optical density started to increase 200 s later. The initial rates of smoke and carbon monoxide increase were greater in the FE/DE test than the smoldering chair test. The FE/DE smoke optical density reached a value twice as high as the fire test, while the CO values were comparable at the end of the time comparison.

Results from the cooking oil fire test are shown in figure 5. Figure 5A shows the optical density and air temperature 2 cm below the ceiling in the living room, and alarm times for the living room location. Figure 5B shows the gas concentration results for CO and CO_2 at a sampling location 90 cm below the ceiling in the living room location. No velocity data was gathered during this test however, comparable velocity data from a nuisance cooking source test (hot oil deep frying with a LP gas cook top [6]) gathered from a living room location yielded a mean ceiling jet speed of 0.15 m/s. The initial carbon dioxide and temperature increase prior to oil ignition was attributed to the propane burner. Optical density started to increase around 100 s, gradually at first, then more rapidly after 400 s. Carbon monoxide concentration started to increase around 400 s.

The emulated cooking oil test is shown in figure 6 along with cooking oil fire graphs re-scaled for comparison in figure 7. Power to the electric hot plate was turned on at 60 s and turned off at 1980 s; the oil never ignited. The air temperature started to increase around 500 s, indicative of the time it took to heat up the hot plate. Optical density started to increase around 1000 s while CO concentration started to increase 500 s later. The CO_2 was essentially constant throughout the test. The FE/DE cooking oil test lacks the CO_2 from the propane combustion and early smoke (perhaps from the burner) that activated an ionization alarm. The rate of increase observed for smoke, CO and temperature were similar for the FE/DE emulation and the cooking oil test, however, the CO concentration lagged the smoke optical density during the FE/DE test.
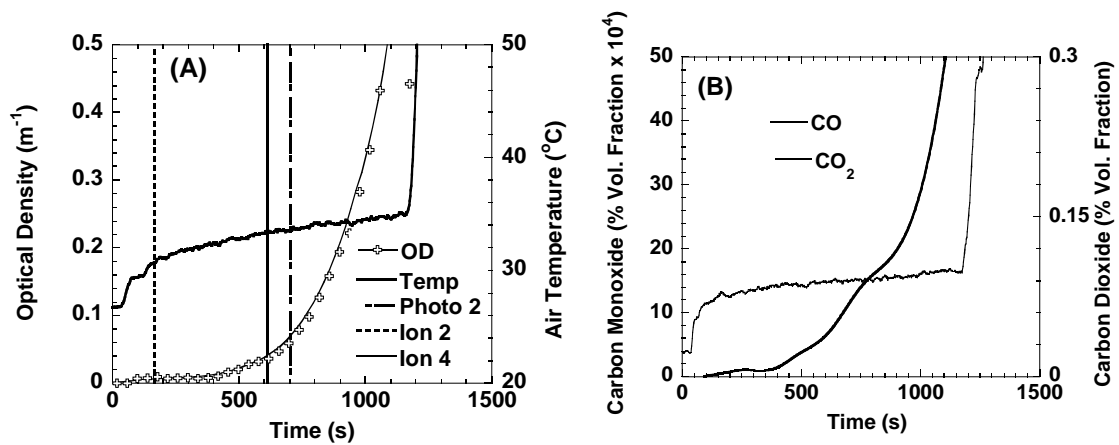
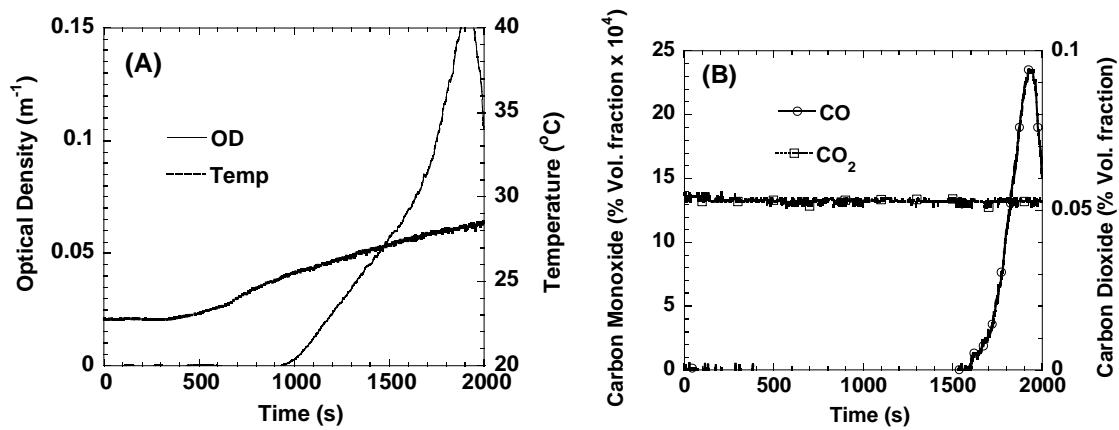**Figure 5. Results for the cooking oil test.**

Figure 6. Results from the FE/DE heated oil test.
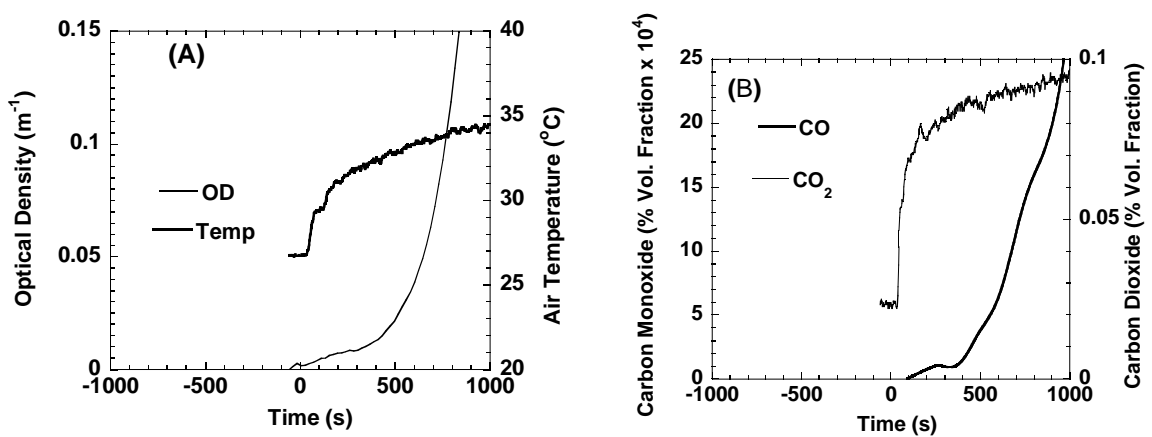

Figure 7. Results from the cooking oil fire test – re-scaled graphs.

Conclusions

The levels of smoke, combustion gases, and temperatures developed during the selected fire tests showed that they are within the operational range of the FE/DE. The FE/DE smoldering foam block test displayed early fire signatures of smoke CO and CO_2 production, temperature and flow velocities comparable to the smoldering chair test. The FE/DE heated cooking oil test lacked early smoke production observed in the cooking oil fire test. For the most part, temperature, CO, optical density observations were similar to the cooking oil fire test. More testing needs to be performed to demonstrate a level of repeatability for these emulated test conditions. Successful emulation of these and other fire conditions in the FE/DE will allow for continued smoke alarm evaluation against the fire environments produced in the comprehensive Home Smoke Alarm Project test series for years to come. Furthermore, in addition to these tests, emulation of residential nuisance sources and standard fire sensitivity test conditions in the FE/DE would provide a more complete assessment of the performance of advanced multi-sensor, multi-criteria alarms.

References

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