Effect of Detector Sensitivity Changes on the Provision of Adequate Warning to Building Occupants

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Introduction

Some smoke detectors have the capability via internal software to adjust the sensitivity and alarm threshold of the detector if exposed to low levels of smoke in the atmosphere for an extended period of time. Other detectors may not adjust sensitivity or alarm thresholds despite exposure to low levels of smoke for extended periods of time. A series of experiments were recently conducted by Dinaburg and Gottuk (2012) to document the sensitivity drift in air sampling detectors (ASDs) after being exposed to a modest smoke environment.

The experiments involved exposing ASDs to a constant ‘background’ smoke density for a period of 24 hours. The range of smoke densities included in the experimental program was 0.04 %/m (0.012 %/ft) to 0.16 %/m (0.049 %/ft). The optical density of the “smoke exposure was measured only by the detector under test (DUT), and was not controlled by any independent reference.” (Dinaburg and Gottuk, 2012).

The data reported from the experimental program included (Dinaburg and Gottuk, 2012):

1) “The measured and reported value of smoke concentration during constant smoke exposure (drift),
2) Any reported adjustments in the alarm threshold values or detector statuses (such as dirtiness or fault conditions), and
3) The change in sensitivity of each detector after the constant exposure as measured by a RTV test.”

Six different ASDs from six manufacturers were included in the experimental program. The ambient smoke tests were conducted by creating smoke from smoldering coal. This smoke was drawn into a mixing and sampling chamber where the individual ASD sampling ports were located. Changes in the response threshold measured in the ambient smoke experiments are presented in Tables 1-3.

Fire Simulation

A computational fluid dynamics software program, Fire Dynamics Simulator (FDS), was used to model two fire scenarios in this study. (McGrattan, et al., 2013).

Table 1. Sensitivity Test Results, 24 hour Exposure to 0.04%/m Ambient Smoke

	RTV0 (%/m)	RTVx (%/m)	Change[1] (%)
VLC	0.206	0.218	-5
FAAST	0.388	0.483	-20
Securiton	0.176	0.190	-7
Wagner	0.226	0.255	-11
IFD	0.297	0.559	-47
Senator	0.209	0.773	-73

[1] Change is relative to DUT's initial sensitivity

Table 2. Sensitivity Test Results, 24 hour Exposure to 0.08%/m Ambient Smoke

	RTV0 (%/m)	RTVx (%/m)	Change[1] (%)
VLC	0.206	0.221	-7
FAAST	0.388	0.480	-19
Securiton	0.176	0.218	-19
Wagner	0.226	0.294	-23
IFD	0.297	0.488	-39
Senator	0.209	0.665	-69

[1] Change is relative to DUT's initial sensitivity

Table 3. Sensitivity Test Results, 24 hour Exposure to 0.16%/m Ambient Smoke

	RTV0 (%/m)	RTVx (%/m)	Change[1] (%)
VLC	0.206	0.214	-4
FAAST	0.388	0.522	-26
Securiton	0.176	0.296	-41
Wagner	0.226	0.365	-38
IFD	0.297	0.458	-35
Senator	0.209	0.700	-71

[1] Change is relative to DUT's initial sensitivity

For both scenarios used in this study, a fire is located in a large open rectangular space representative of an airport terminal concourse or similar space. Dimensions are selected arbitrarily as 24 m x 76 m, with a ceiling height of 8.8 m. Natural ventilation in the space is provided via four 2 m x 2 m doorways, with one on each wall (some simulations include mechanical ventilation as outlined later). The fire is placed near the center of the room and is represented by a 0.4 m x 0.4 m gas burner.

With the compartment size for the simulation being very large, a multi-mesh setup is developed to manage the computation time needed to run a simulation. The surface area of the top of the burner is 0.4 m x 0.4 m (0.16 m^2); hence the length scale for each cell is based on the burner size (delta of 0.4 m). Fine mesh cells are half the size of the burner length and each grid cell is approximately 0.2 m x 0.2 m x 0.2 m.

The first scenario conducted in this study is a slow, t-squared fire in the space, i.e. potentially reaching 1 MW in 600 seconds. The slow t-squared fire simulation is prescribed to have a 300 second run time, as presented in Figure 1. The duration is selected to allow for a sufficient duration to permit development of smoke with at least the minimum optical density to provide detection by an ASD detector, including the magnitude of sensitivity drift observed in the experiments by Dinaburg and Gottuk. The soot yield for the slow t-squared fire is 0.01 kg soot/kg fuel consumed. For the incipient fire, the assumed soot yield is 0.095 kg soot/kg fuel consumed (Milke, Mowrer and Gandhi, 2008).

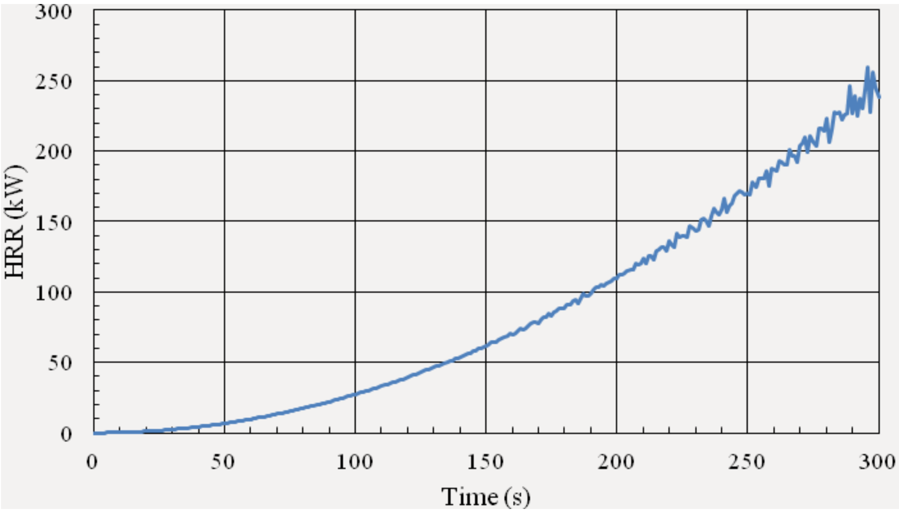


Figure 1. Heat Release Rate Profile for Slow t^2-Fire (Simulation #1)

The second scenario is an incipient, smoldering fire. The fire behavior input provided to FDS is based on experimental data on the heat release rate for burning polyurethane foam and fabric materials (see Figure 2). This simulation is prescribed to have a 360 second run time. The incipient fire was modeled based on a heat release rate curve of the burning of polyurethane foam and fabrics (Milke, Mowrer and Gandhi, 2008). For the incipient fire scenario, three ventilation conditions were simulated, including 0, 5 and 10 air changes per hour (ACH).

27 smoke detectors are placed on the ceiling following traditional smoke detector spacing rules, with detectors placed 8 m apart. FDS provides output of smoke obscuration measured at the detector locations on a percent per meter basis.

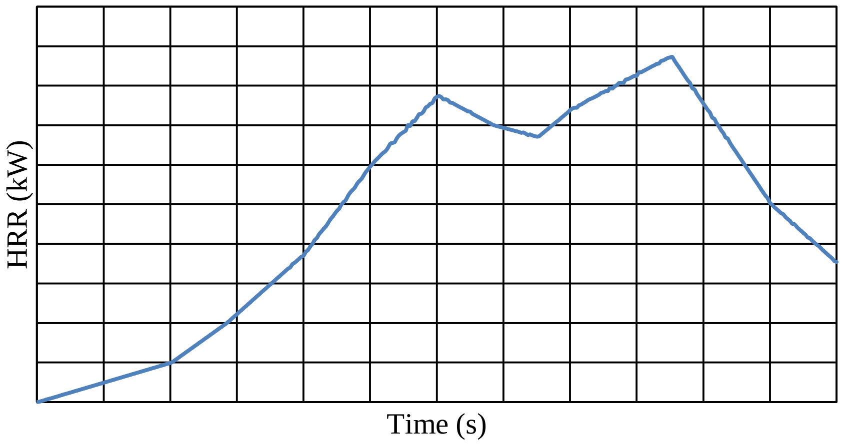


Figure 2. Heat Release Rate Profile for Incipient Fire (Simulation #2)

Analysis of Response Times from FDS Simulations

The FDS results of interest include smoke obscuration (to estimate ASD response) and temperature (to assess smoke layer characteristics). The impact of changes in detector sensitivity can be assessed by reviewing the time at which smoke obscuration conditions are observed in the simulations. The response times for the two scenarios are estimated based on the smoke conditions produced outside of the sampling units.

0.04%/m Ambient Smoke Condition

The estimated response times from the simulations for the two fire scenarios with the original sensitivity and changed sensitivity are presented in Table 6. The proportional changes in the response times are also presented in Table 4.

Table 4. Estimated Response Times (sec)

	Slow t2-Fire			**Incipient Fire**		
DUT	RTV0	RTV_x	Change (%)	RTV0	RTV_x	Change (%)
VLC-505	110	112	**1.8**	101	102	**1.0**
FAAST 8100	137	151	**10**	131	140	**6.9**
Securiton 535-4	101	109	**7.9**	95	98	**3.2**
Wagner PRO-SENS	112	117	**4.5**	103	109	**5.8**
IFD Cirrus	123	164	**33**	119	143	**20**
Senator 200	110	188	**71**	101	162	**60**

The change in the response time for three of the detectors in the two scenarios was relatively modest, being less than 5% different than that for the initial sensitivity of the detector. However, the response time for the other three detectors was appreciable, being as great as 71%.

0.08%/m Ambient Smoke Condition

A similar estimate of response times from the simulations for the two fire scenarios with the original sensitivity and changed sensitivity of 0.08%/m are presented in Table 5. The proportional changes in the response times are also presented in Table 5.

Table 5. Estimated Response Times (sec)

	Slow t^2-Fire			**Incipient Fire**		
DUT	RTV0	RTV_x	Change (%)	RTV0	RTV_x	Change (%)
VLC-505	110	112	**1.8**	101	102	**1.0**
FAAST 8100	137	151	**10**	131	140	**6.9**
Securiton 535-4	101	112	**11**	95	102	**7.4**
Wagner PRO-SENS	112	123	**9.8**	103	119	**16**
IFD Cirrus	123	152	**24**	119	140	**18**
Senator 200	110	174	**58**	101	153	**51**

For these detectors subjected to the greater ambient smoke exposure, the changes in the response time was generally more significant than for the 0.04%/m set of tests. Only one of the detectors in the two scenarios experienced a relatively modest change, being less than 5% different. In one case the change in response time was substantial, being in excess of 50%.

0.16%/m Ambient Smoke Condition

A similar estimate of response times from the simulations for the two fire scenarios with the original sensitivity and changed sensitivity of 0.16%/m are presented in Table 6. The proportional changes in the response times are also presented in Table 6.

Table 8. Estimated Response Times (sec)

	Slow t^2-Fire			**Incipient Fire**		
DUT	RTV0	RTV_x	Change (%)	RTV0	RTV_x	Change (%)
VLC-505	110	111	**0.9**	101	102	**1.0**
FAAST 8100	137	154	**12**	131	141	**7.6**
Securiton 535-4	101	123	**22**	95	119	**25**
Wagner PRO-SENS	112	136	**21**	103	130	**26**
IFD Cirrus	123	149	**21**	119	139	**17**
Senator 200	110	180	**64**	101	158	**56**

For these detectors subjected to the greatest ambient smoke exposure, the greatest changes in response time were generally observed. Only one of the detectors in the two scenarios experienced a relatively modest change, being less than 5% different. Virtually all other detectors experienced a change of at least 10% in one case the change in response time was in excess of 60%. A compilation of the changes for the slow t^2–fires are presented in Figure 3. Similarly, the changes for the incipient fires are presented in Figure 4.

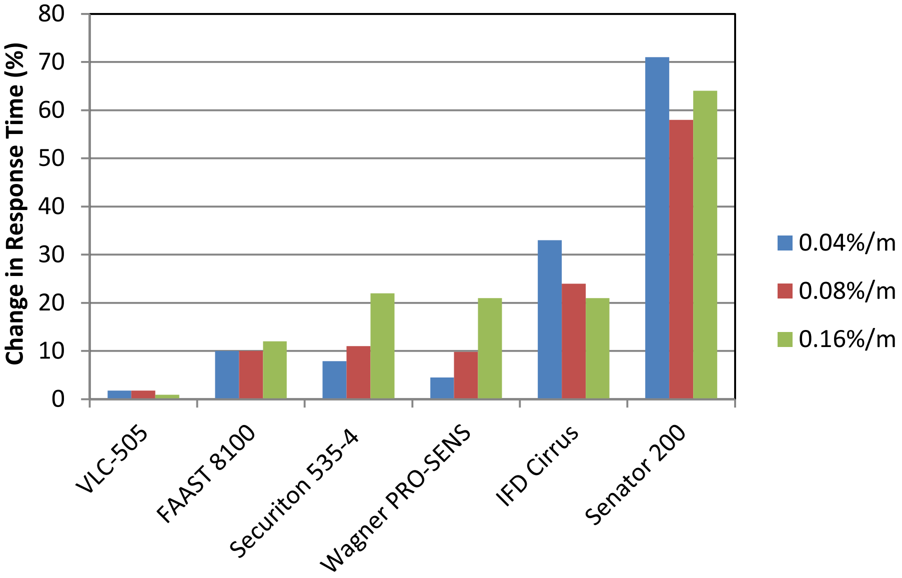


Figure 3. Response Time Changes for Slow t^2-Fires

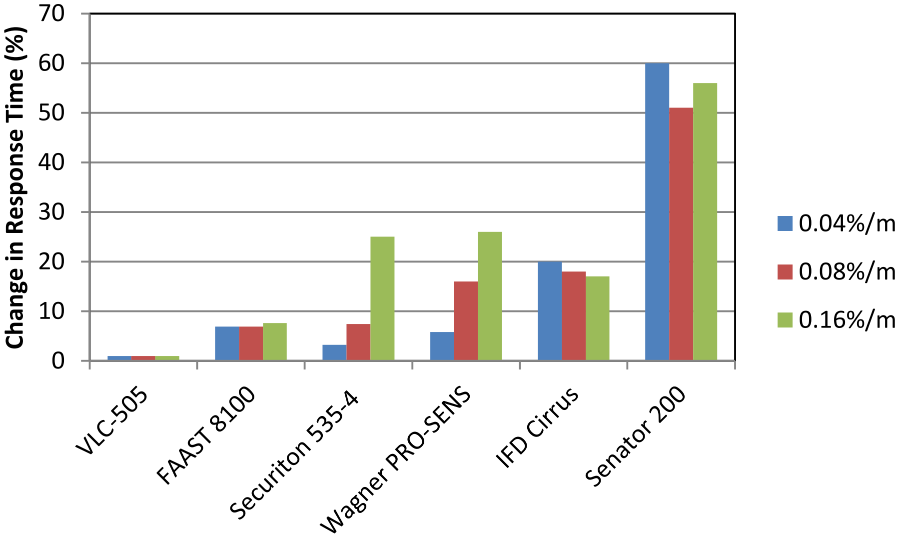


Figure 4. Response Time Changes for Incipient Fires

Ventilation Conditions

Smoke concentration under the simulated ventilation conditions are indicated in Figure 5. As expected, the obscuration level decreases with increasing ventilation. The difference in response times of the DUT's at their initial sensitivity setting and after exposure to 0.16%/m meter smoke for 5 and 10 ACH ventilation rates are presented in Figures 6 and

7. The differences are highlighted only for three selected DUTS for clarity in the figure, representing the ranges in differences noted.

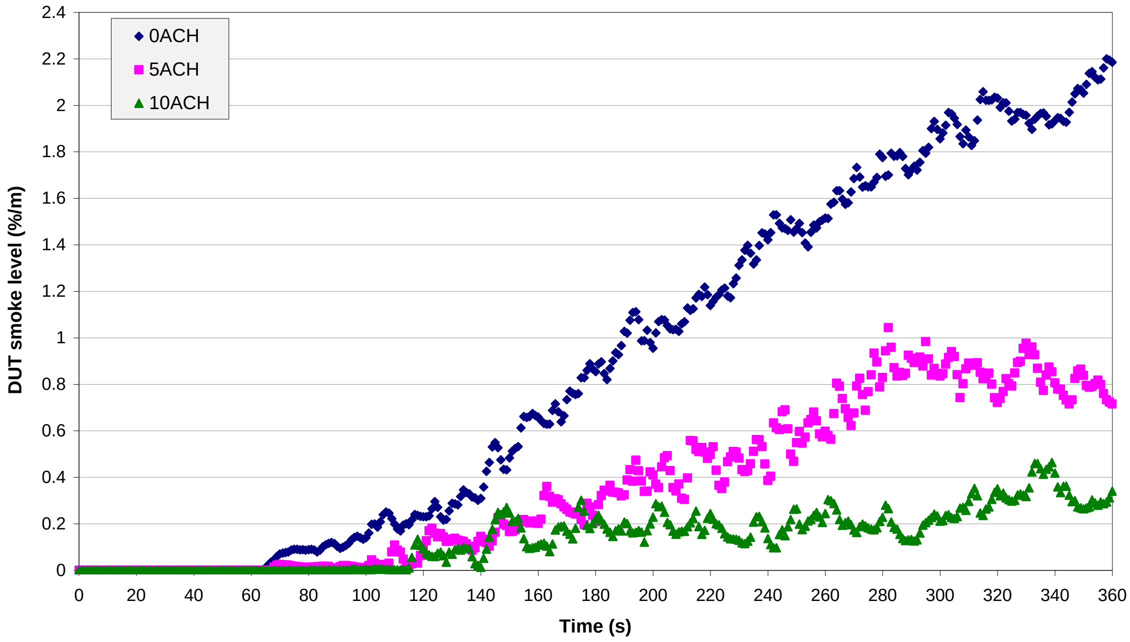
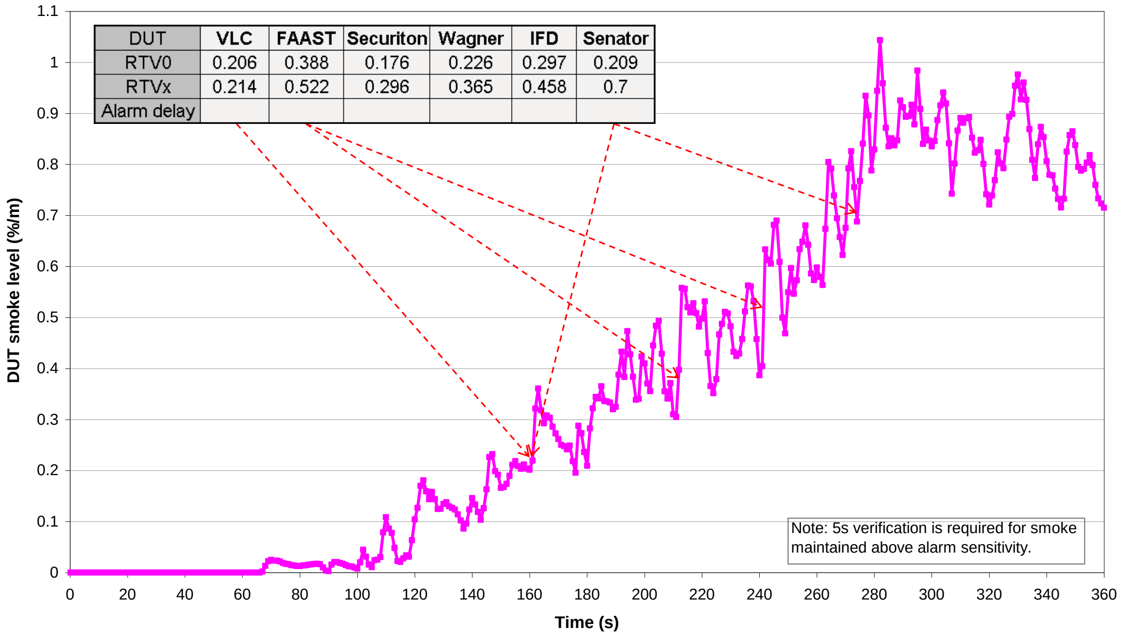


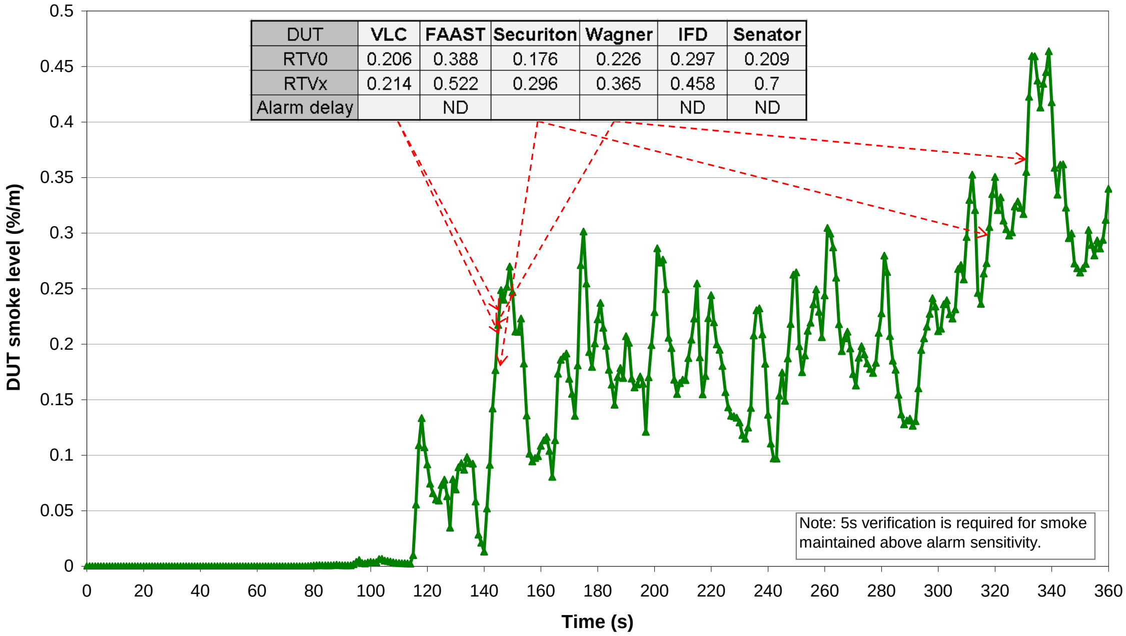
Figure 5. Smoke Conditions for Ventilation Rates



DUT	VLC	FAAST	Securiton	Wagner	IFD	Senator
RTV0	0.206	0.388	0.176	0.226	0.297	0.209
RTVx	0.214	0.522	0.296	0.365	0.458	0.7
Alarm delay						

Note: 5s verification is required for smoke maintained above alarm sensitivity.

Figure 6. Response Time Changes at 5 ACH



DUT	VLC	FAAST	Securiton	Wagner	IFD	Senator
RTV0	0.206	0.388	0.176	0.226	0.297	0.209
RTVx	0.214	0.522	0.296	0.365	0.458	0.7
Alarm delay		ND			ND	ND

Note: 5s verification is required for smoke maintained above alarm sensitivity.

Figure 7. Response Time Changes at 10 ACH

Summary

An analysis of the smoke conditions generated in two fire scenarios has been performed using computer simulations with FDS. The resulting light obscuration conditions produced in the smoke layer are applied as a metric to estimate the response time of ASD's. Two sensitivities of the ASD's are adopted as response thresholds based on an experimental program that assessed the sensitivity of the ASD's both before and after being subjected to low ambient smoke levels.

The differences in response times caused by the changes in sensitivity are noteworthy for some models. These differences are especially significant as the ASD units considered by this research are considered to be fast-response detectors. That advantage is compromised if the sensitivity decreases appreciably as a result of the exposure to low levels of ambient smoke for an extended period.

References

Dinaburg, Joshua and Gottuk, Daniel T., 2012, "Xtralis Aspirated Smoke Detector Exposure Testing: Full Report of Tests," Hughes Associates, Baltimore, MD.

McGrattan et al., 2013a, McGrattan, , Kevin, Hostikka, Simo, McDermott, Randall, Floyd, Jason, Weinschenk, Craig, and Overholt, Kristopher, Fire Dynamics Simulation Technical Reference Guide: Volume 1: Mathematical Model, NIST SP 1018, 6th Ed., National Institute of Standards and Technology, Gaithersburg, MD.

Milke, J.A., Mowrer, F.W., and Gandhi, P., Validation of a Smoke Detection Performance Prediction Methodology, Fire Protection Research Foundation, Quincy, MA, October 2008.