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CSC ON-SITE FIRE DETECTION TESTS

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1 Introduction

On-site detection tests were conducted to examine the detection performance of an Aspirating Smoke Detector (ASD) system using a hidden air sampling port (e.g. sampling points hidden in light fixtures). The performance of the ASD system with the hidden air sampling ports were compared to the existing sample point installed within the duct work.

The use of ASD devices is a high priority for Correctional Service Canada (CSC), as the successful implementation of such devices will allow CSC to meet the requirements of the National Building Code of Canada (NBCC) for smoke detection within cells while removing spot-type devices from cells. Spot-type devices (and protective cages over those devices) have historically been a source of nuisance alarms and tampering and have been used as suspension points for offenders who have attempted to self-harm by attaching a ligature to these devices or their protective coverings. For successful implementation of ASD systems, NRC and CSC have evaluated the performance of ASD systems against various fire sources that can be found in CSC inmate cells (Ko & Weinfurter, 2018).

Historically, when used within CSC facilities, the sampling points of ASD systems have been installed within return ventilation ducts. It came to CSC's attention that inmates can impede the ASD system through blocking the duct covers and thereby preventing the smoke from reaching the sampling point serving the cell in question.

Likewise, installing the sample points directly within the cell was subject to the same potential for tampering. The NRC study conducted in 2018 (Ko & Weinfurter, 2018) showed that blockages (e.g. wet toilet paper) over a sampling port would affect the measurements of smoke obstruction by the ASD systems.

Light-fixture enclosures, located within inmate cells, were considered as an alternative location for the installation of ASD sampling points. Compared to ventilation duct covers, light-fixture enclosures are designed to be tamper resistant and are therefore more difficult to obstruct than ventilation duct covers. This was inspired by a similar setup that is currently being implement in California, USA by the California Prison Board.

1.1 Objectives

The main objective of the on-site detection tests was to evaluate the response of ASD smoke systems using one or more hidden air sampling port(s) installed within a light fixture enclosures when exposed to smoke sources. This report describes the conducted on-site tests set-up and test results.

2 Test method

The tests were conducted in general conformance with CAN/ULC S529 "*Standard For Smoke Detectors For Fire Alarm Systems",* Section 41.2, "paper fire test" and Section 42, "smouldering smoke test" (CAN/ULC, 2015). The paper fire scenario was of particular interest to CSC since the scenario is presumed to be representative to potential fires in inmate cells.

CAN/ULC-S529 requires that the response time of a detector shall be not more than 240 seconds (4 minutes) for the paper fire scenario. Thus, the responses of the ASD systems were evaluated following that criterion and were used as the benchmark to represent the successful test criteria for detection.

The smouldering smoke test was conducted for the purpose of information gathering, but the performance criterion of CAN/ULC-S529 for smouldering fires was not used a benchmark for success as it was deemed by CSC that such fires did not reflect typical cell fires in that sustaining smouldering without leading to combustion would be difficult to achieve.

2.1 Test room set-up

The smoke detection tests were conducted at an inmate cell in Donnacona Institution in Donnacona QC. Figure 1 shows the test room set-up. The room has built-in furniture, a toilet and a sink, and the room had a door and a window. The ceiling was smooth, but a light fixture was installed on ceiling and wall corner.

A smoke source was placed at the center of the room on the floor as shown in Figure 1. The smoke obscuration level inside the test room was measured using an NRC smoke meter. Smoke particulates are sooty aerosols including light absorbing carbon (i.e. elemental carbon) and light scattering carbon (i.e., organic carbon). The smoke meter measures smoke obscuration/densities by correlating the opacity of light reduction to the densities of smoke. By passing a monochromatic light source through a test chamber, the device quantifies the extinction of the light based on the electrical signals received from a light transmitter and a receiver. The percent obscuration per foot, Od was calculated by Eq. (1), and the calculated values were compared with the smoke obscuration measured by the ASD systems. The path length of the light source used in the smoke meters was 0.5 m (1.64 ft). For the on-site tests, the smoke meter was calibrated for an OD range of approximately 2.7-13.2% obs/ft. The measurement accuracy of the smoke meter was within approx. 99%.

$$Od = [1 - (I/I_0)^{(1/L)}] \times 100 \qquad \text{Eq. (1)}$$

Where:

Od = The percent obscuration per meter or foot, [%obs/m or %obs/ft]
L = the path length of the light source through smoke [m or ft]
I = intensity of transmitted light
I_0 = Intensity of incident light

In most tests, the smoke meter was placed on the left side of the light fixture at a height of 2.5 m, at 10 cm away from the face of the light fixture and 1.23 m from the back wall. In some tests, the smoke meter was placed on the right side of the light fixture, at the same distance from the face of the light fixture and 2.1 m from the back wall.

Air movement in the test room was minimal yet the room ventilation system was operating at 50% of its capacity. The measured air velocity inside the duct was approximately 1 m/s. In the duct, there was a smoke sampling tube connected to the existing VLS system. Additional ASD smoke sampling tubes were installed in the light fixture unit located near the ceiling of the test cell.

Smouldering fire

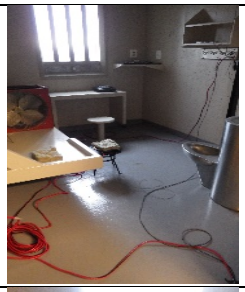
In smouldering combustion, fuels burn slowly with low temperatures and with no visible flames. It is known that smoke with large particle sizes is generated in smouldering combustion (Ohlemiller, 2002). Following CAN/ULC-S529, white pine strips (see Table 1 for details) were used for the smouldering fire test. To calibrate an amount of smoke generation and the number of white pine strips, the smouldering fires were pre-tested at the NRC fire lab. In the test cell, six white pine strips were placed on a hot plate with surface temperatures maintained between 300-500°C.

Paper fires

In flaming combustion, fuels generate relatively fine smoke particulates, yet the total amount of smoke released in general could be significant because of its fast combustion reaction with high mass burning rates due to high

flame temperatures (Ohlemiller, 2002). For a flaming combustion scenario, paper fires were prepared following CAN/ULC-S529 using shredded newsprint in strips. Shredded newsprint in strips (See Table 1 for details) were placed in a receptacle, and an igniter was placed at the bottom center of the receptacle.

Table 1. Smoke Sources

	Smoke Sources	Photo	Description	Note
1	White pine		6 White pine (19 mm by 38 mm by 90 mm long) as per CAN/ULC-S529 42.3 (b)	The 6 white pine strips placed on the hot plate. The top surface temperature was maintained between 300-500°C.
2	Shredded newsprint in strips		6-10 mm (W) and 25.4 - 102 mm (L), the total weight of 28.3 g	The paper placed into a receptacle (a diameter of 101 mm and 175 mm long) formed of metal.

2.2 ASD Detectors

The two ASD detection systems were tested; VLS and VEA systems. Both VLS and VEA have multi-channel microbore air-sampling systems equipped with powerful pumps, which draw air sample from the end of the sampling tube. VLS and VEA detectors allow to divide a protected space into multiple sampling sectors, which enables the systems to monitor smoke in each individual sector/cell and to pinpoint the location of an incident. Air samples drawn from each sampling line enter its laser detection chamber of VLS or VEA system.

VLS and VEA detector systems monitor a combined air sample from the multiple sample lines from all sectors/cells. The ASD detection system analyses smoke obscuration of air samples drawn to the laser detection chamber. In the laser detection chamber, smoke samples are exposed to a laser light source to measure smoke obscuration/densities. When smoke particles are detected in the combined air sample, and the smoke level reaches a scanning threshold, the system will sequentially scan each sector, one by one to identify the sector with the smoke condition. When the measured smoke level reaches an alarm threshold, the system will raise appropriate alarm conditions with an identification of the sector with smoke condition on its display and computing system.

The ASD detector technology can detect smoke with an obscuration range from 0.0003% to 6.10% obs/ft (0.001% to 20% obs/m). However, the smoke alarm threshold should be programmed individually. Table 2 shows sensitivity settings of the ASD systems used in the tests.

VEA-40

One unit of Xtralis VEA-40 was used in the tests. Smoke sampling tubes were installed through the back of the light fixture. The number of tubes and their installation locations are described in the test matrix (Table 3). During the tests, the fixture housing was kept closed. The two sensitivity settings (Standard and High) were configured for the VEA-40. The test matrix (Table 3) shows the smoke threshold used in each test.

VLS

The existing unit of VLS connected to the test room was also operated during the tests. Smoke samples were taken through the sampling point that was installed within the return ventilation duct of the test room. The smoke threshold configured in the existing VLS was 0.91%obs/ft.

Table 2. ASD sensitivity settings

ASD Detector		Smoke Thresholds
VEA	S (Standard)	2.5% obs/ ft
	H (High)	0.5% obs/ ft
VLS		0.91% obs/ ft

Figure 1. Test Room

3 Test results

The focus of the tests was evaluating the performance of VEA-40 to the paper fire scenario since the scenario is presumed to be representative to potential fires in inmate cells. The performance of the VLS using the sampling point installed within the return ventilation duct of the test room was also monitored only for comparisons with the VEA-40 using hidden air sampling ports. Thus, the response of the VEA-40 was evaluated using the performance criterion that a detector shall detect the paper fire scenario within 240 seconds (4 min) as required by CAN/ULC-S529. Output signals from the VEA and VLS units were retrieved and analysed. The output signals were also compared with the smoke obscuration measured by the NRC smoke meter.

3.1 Smoke profiles measured from the fire scenarios

The paper fire was prepared and tested following CAN/ULC-S529. CAN/ULC-S529 requires that the smoke obscuration resulted from the paper fire falls under the specified profile as shown in Figure 2. In an initial calibration test conducted in the test cell, the smoke obscuration measured from the paper fire fell under the required profile for the first about 100 seconds. After 120 seconds, the measured smoke obscuration went beyond the requirement, which can be attributed to the dimensions of the test cell (i.e. approximately 2.5 m wide by 3 m long) being significantly smaller than the test room required by CAN/ULC-S529 (i.e. 6-7 m wide by 6-7 m long).

The smouldering fire was also prepared and tested following CAN/ULC-S529. CAN/ULC-S529 requires that the smoke obscuration resulted from the smouldering fire falls within the maximum and minimum profiles specified as shown in Figure 3. Tested to the required smoke profile, detectors should respond before the obscuration levels exceed 6.0%/ft. As shown in Figure 3, the smouldering fire tested in the inmate cell produced smoke with profiles meeting the CAN/ULC-S529 requirements.

It should be note that the paper fire and the smouldering white pine produced very different profiles of smoke production over time. The smoke production from the smouldering pine was relatively low and at a slow rate. The smoke level measured in the room slowly increased, taking 9-10 minutes to reach an obscuration of 6%obs/ft in the room. On the other hand, the paper fire produced a large amount of smoke at a fast rate. In most tests, the smoke obscuration reached approximately 40-70%obs/ft in 30-60 seconds, after the paper sources were fully-ignited.

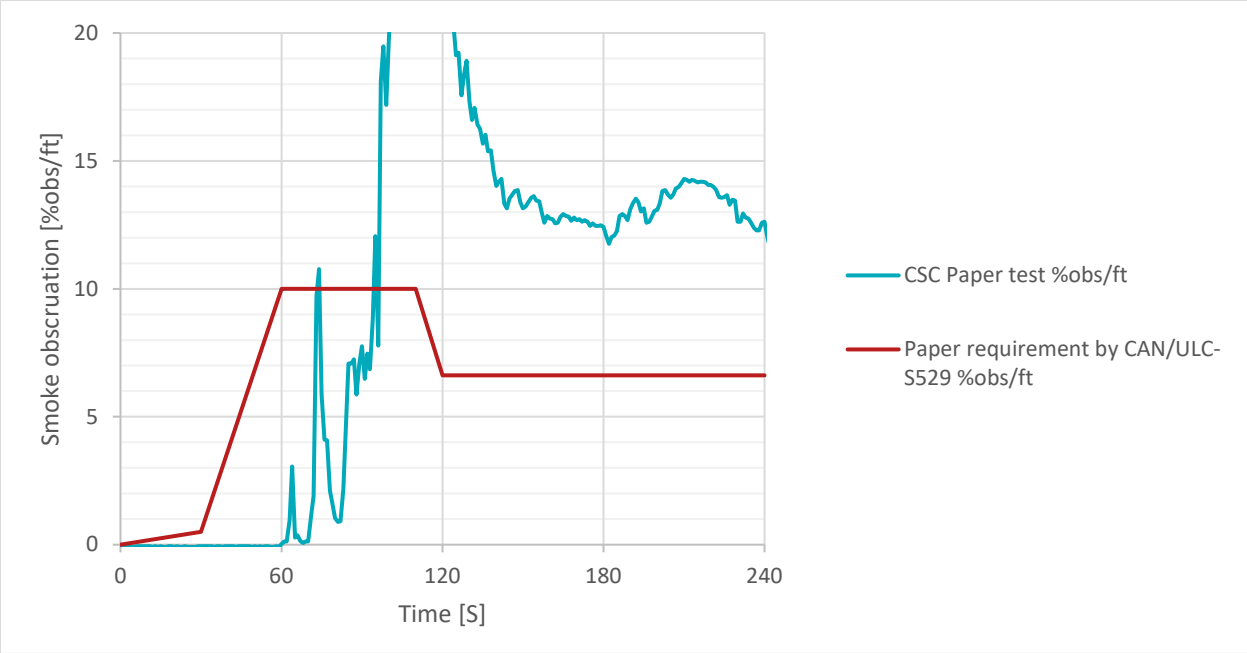


Figure 2 Comparisons of test data with CAN/ULC-S529 requirements for the paper fire

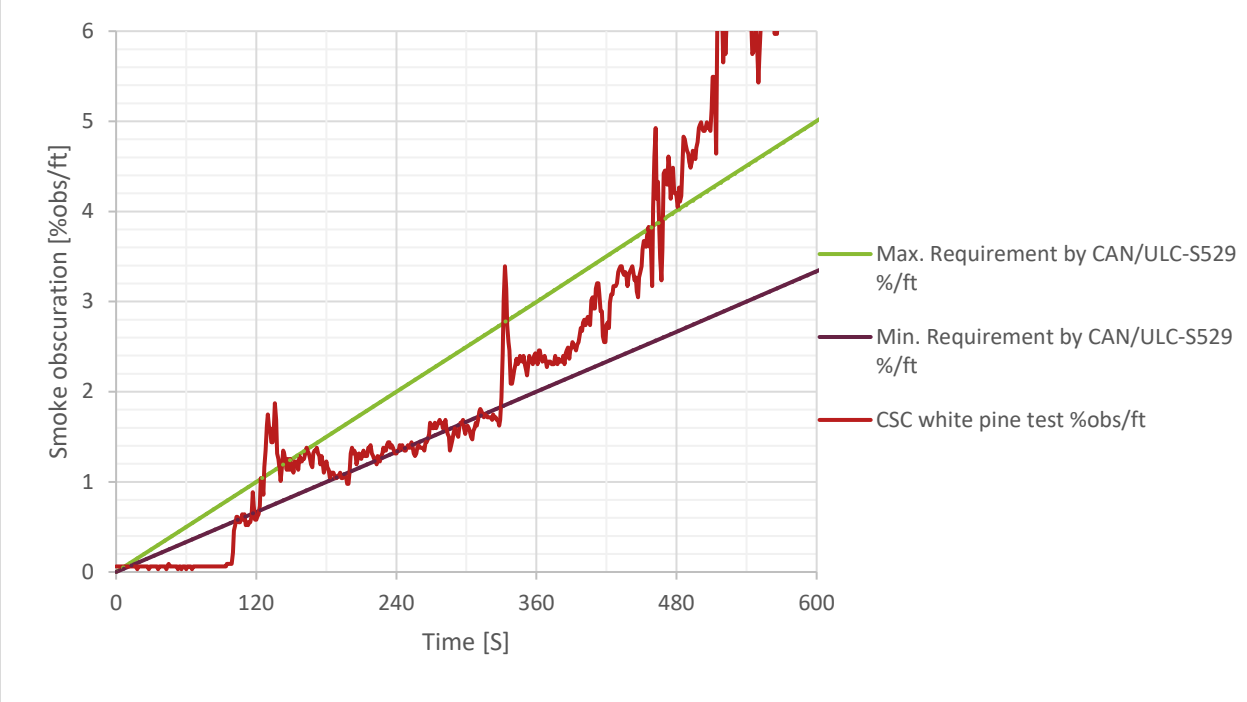


Figure 3 Comparisons of test data with CAN/ULC-S529 requirements for the smouldering fire

3.2 Performance of hidden air sampling ports

For the VEA-40, various hidden air sampling ports were tested. The ASD tubes were inserted into the light fixture through the electrical conduit behind the light fixture. Several installation locations for the ASD tubes inside the electrical conduit were explored in the tests to evaluate the sampling performance of the VEA system. These included:

- Location (1) inside the light fixture (left side and right side of the fixture)
- Location (2) inside the light fixture but behind a hole of a removed screw on the frame of the light fixture, and
- Location (3) inside the light fixture but with the tube attached to a mock rivet which penetrated the side of the light casing such that the sample hole was directly within the cell (yet disguised as a rivet).

Notably, the first few initial tests (Test SPP, S11 and S21) showed that the ASD tubes at these locations would draw very little smoke from the test room. This was later found to be due to the fact that an inadvertent positive pressure was created within the light fixture (when compared with the cell pressure) by air entering through the conduit from the shaft which was located behind the cell. With the electrical conduit sealed using duct tape, the light fixture returned to the same pressure as the cell which allowed for smoke samples to be drawn into the VEA system.

Location (1) ASD tubes inside the light fixture

One or two ASD tube(s) was freely placed inside the light fixture enclosure. The ASD tube(s) inside the light fixture enclosure drew air samples only through the gap around the light fixture cover. As a result, the VEA measured very low obscuration, which was 60%-90% lower than the actual obscuration measured in the test room.

Figure 4 shows detection times measured in the paper fire tests with various tube locations and sensitivity settings. With ASD tubes inside the light fixture at location (1), no alarm was reported by the VEA system within 240 seconds when the Standard (2.5%obs/ft) sensitivity setting was used for the paper fire. When the High (0.5%obs/ft) sensitivity setting was used; however, the VEA system detected the paper fire within 240 seconds (see Test P24 and P23) with two sampling tubes placed in the light fixture enclosure on left and right side of it. In Test P22, the VEA system detected smoke with an obscuration level higher than 0.5%obs/ft at 186 seconds, yet the system sent a delayed alarm at 411 seconds owing to the threshold obscuration (standard sensitivity of 2.5%obs/ft) used in the test.

It was also observed that the tube installed in the right hand side of the light fixture detected relatively faster than the tube installed in the other side. This is because the exhaust duct was located on the right hand side of the light fixture so that smoke moved mainly toward the exhaust duct.

In these tests, the existing VLS using the sampling tube installed within return ventilation duct sent alarms within 100 seconds with a sensitivity setting of 0.9%obs/ft.

Location (2) ASD tubes behind a removed screw hole

The results from the tests with an ASD tube installed behind a removed screw hole demonstrated that the VEA system with the Standard sensitivity setting is capable of detecting the paper fire within 240 seconds if there is no positive pressure inside the light fixture interrupting the smoke sampling through the screw hole. For the paper fire (Test P21), the VEA system with the Standard sensitivity setting detected the paper fire at 174 seconds through the ASD tube installed behind a removed screw hole. Similarly, the system detected the paper fire at 118 seconds in Test P41 in which some adjustments were made using putty to help the air sampling for the ASD tube installed behind a screw hole.

Location (3) ASD tubes on the sides of the light fixture

With two ASD tubes installed on the left and right side of the light fixture, the VEA system showed the sampling performance similar to the existing VLS using the sampling point in the ventilation duct. On each side of the light fixture, an ASD tube was installed through a mock rivet such that the tube can draw smoke from the test room. The VEA system read the obscuration comparable to the actual obscuration in the room. The VEA system detected the paper fire at 118 seconds through the drilled hole on the right hand side in Test P41 while the VLS detected at 71 seconds.

The results from a smouldering fire test also showed that the ASD system using the hidden sampling tubes at Location (3) detect smoke similarly to the existing VLS using the sampling point in the ventilation duct. Figure 5 compares the actual obscuration measured in the room at the detection time of the VEA and VLS for the smouldering fire tests. In Test S41, the VEA system successfully sent an alarm before the actual smoke level in the room reached the obscuration criterion of 6%obs/ft for the two sampling tubes hidden at Location (3). However, the ASD tube installed on the right hand side of the light fixture sent an alarm 300 seconds faster than the other side because the right side was close to the ventilation duct. In general, the smouldering fire was challenging for the ASD system when the sampling tubes were hidden at Lcation (1) or Location (2).

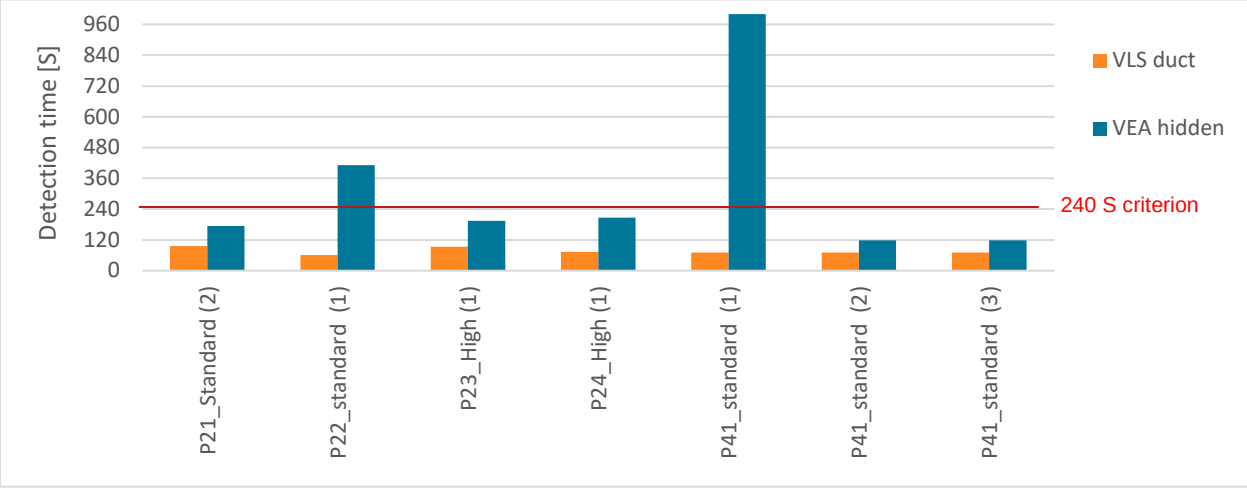


Figure 4 Detection times for paper fire tests with ASD tube locations of (1), (2) and (3)

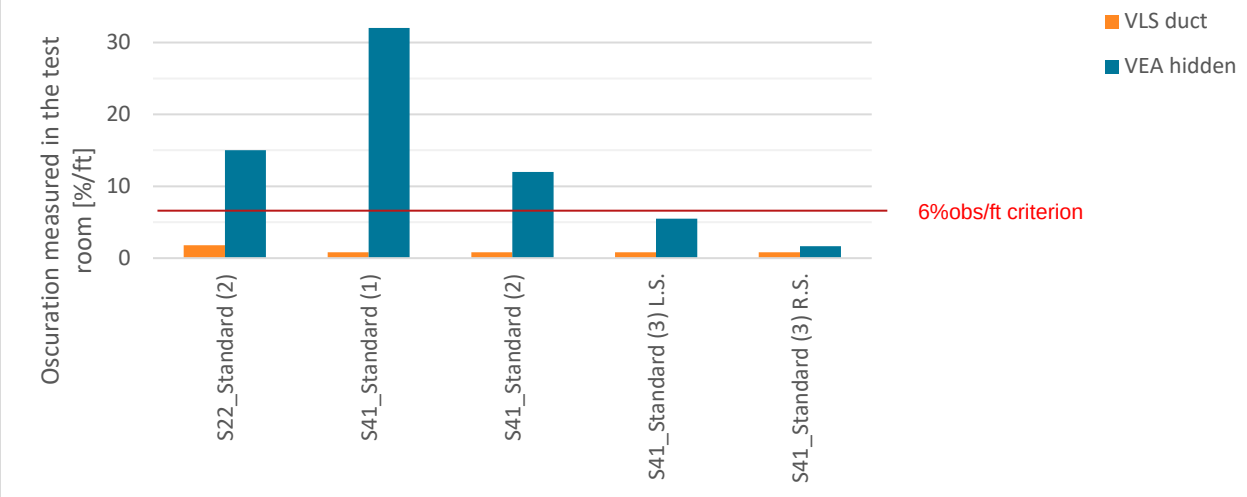


Figure 5 Detection obscuration for smouldering fire tests with ASD tube locations of (1), (2) and (3)

4 Conclusions

- The best installation point found from the on-site tests was on the side of the light fixture through a drilled hole (mock rivet). With these sampling points, the VEA system read the obscuration comparable to the actual obscuration in the room both for the paper and smouldering fire. The performance of the ASD tube hidden on the side of the light fixture close to the ventilation duct was similar to that of the sampling tube installed within return ventilation duct.
- Smoke detection was challenging with sample points hidden inside the light fixture enclosure; however, with High (0.5%obs/ft) sensitivity setting, the paper fire was detected within 240 seconds. Faster response times were generally observed for the sampling point located on the side of the light fixture that was closer to the ventilation duct opening (the right hand side in the tests) than for the sample point located on the far side. The far sample point could not be consistently observed to comply with the required benchmark.
- To ensure proper smoke sampling into the system, ASD tubes should be installed such that the tube can draw smoke from the test room while minimizing any differential pressure issues. The differential pressure issues created challenges particularly for the ASD tube installed in the light fixture enclosure (Location 1). In the on-site tests, to ease the pressure issues and to allow more smoke flow into the light fixture, the electrical conduit behind the light fixture was sealed, and gasket around the light fixture was removed.

Table 3 Test Matrix

Test ID	Placement of sampling tube(s)	Smoke source	Placement of smoke meter [1)]	VLS detection		VEA detection			Notes
				Detection threshold [%/ft]	Detection time [S]	Detection threshold [%/ft]	Tube	Detection time [S]	
SPP	Location (1) tube 01 –free inside light (R.S) [a)]	Pine 176.94 g	Location #a	0.9	98	2.5		No response for 20 min	
S11	Location (2) tube 01 –behind removed screw (R.S) [b)]	Pine 176.94 g	Location #b	0.9	86	2.5		No response for 20 min	
S21	Location (2) tube 01 - behind removed screw (R.S) [c)] tube 02 - behind removed screw (L.S.)	Pine 176.94 g	Location #a	0.9	83	2.5		No response for 20 min	At test end, it was noticed that as the cell door opened, VEA immediately saw FIRE 1. It was theorized that positive pressure from the corridor is forced into the cell and helps drive smoke into the tightly sealed light fixture.
S22	Location (2) tube 01 - behind removed screw (R.S) tube 02 - behind removed screw (L.S.) duct tape sealed	Pine 6 sticks 176.94 g	Location #b	0.9	74	2.5	Fire 1, Tube 2 Fire 1, Tube 1 Fire 1	1236 1236 1374	Electrical conduit behind light fixture was sealed using duct tape. This was to reduce any positive pressure air that might be entering the light fixture, stopping the tubes from being able to sample from the cell. The idea being that the light fixture and cell had different air pressures.
P21	Location (2) tube 01 - behind removed screw (R.S) tube 02 - behind removed screw (L.S.) duct tape sealed [d)] and gasket removed	Newsprint 28 g	Location #b	0.9	96	2.5	Fire 1, Tube 2 Fire 1, Tube 1	174 174	Light gasket removed. This was later considered unnecessary since the light fixture design is very tight, even with the gasket missing.
P22	Location (1) tube 01 - free inside light (R.S) tube 02 - free inside light (L.S.)	Newsprint 28 g	Location #b	0.9	61	2.5	Fire 1 Fire 1, Tube 1 Fire 2 Fire 1	411 476 412 498	This test was to determine if a simpler tube installation (loose) would also produce a FIRE 1 using Standard setting compare to the last paper test (behind screws hole).
P23	Location (1) tube 01 - free inside light (R.S) [e)] tube 02 - free inside light (L.S.)	Newsprint 28 g	Location #b	0.9	94	0.5	Fire 2 Fire 1 Fire 1, Tube 1 Fire 1, Tube 2	194 194 247 355	This test was to determine if a simpler tube installation (loose) would also produce a FIRE 1 using High setting compare to the 1st paper test (behind screws hole).
P24	Location (1) tube 01 - free inside light (R.S) tube 02 - free inside light (L.S.)	Newsprint 28 g	Location #b	0.9	74	0.5	Fire 1, Tube 2 Fire 1, Tube 1	207 207	The screws holding the light fixture shut were backed out by 4.10 mm, this created a slight air gap at the top edge of the fixture. The idea was to allow more smoke to enter the fixture.
S41	Location (1), (2) and(3) tube 01 - R.S. drilled hole, fitting #1, flush [f)] tube 02 - free inside light (L.S.) tube 03 - L.S. drilled hole, fitting #2, flush [g)] tube 04 - R.S. screw hole, putty sealed [h)]	Pine 6 sticks 176.94 g	Location #a	0.9	74	2.5	Fire 1 Tube 1 Fire 2 Fire 1, Tube 3 Fire 1, Tube 4 Fire 1, Tube 2	106 311 413 796 1588	This test was to done to implement the "best" ideas developed over the week for faster VEA detection. See images for more details
P41	Location (1), (2) and(3) tube 01 - R.S. drilled hole, fitting #1, flush [f)] tube 02 - free inside light (L.S.) tube 03 - L.S. drilled hole, fitting #2, flush [g)] tube 04 - R.S. screw hole, putty sealed [h)]	non-standard 28 g	Location #b	0.9	71	2.5	Fire 1, Tube 4 Fire 1, Tube 3 Fire 1, Tube 1	118 118 118	This test was to done to implement the "best" ideas developed over the week for faster VEA detection. See images for more details

Notes [1)] Smoke meter Location #a (R.S. of light, close to grill) and Location #b (L.S. of light, 1.23 m from back wall, distance from light same)

a)

b)

c)

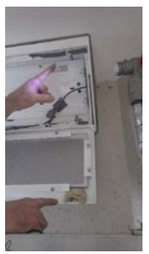
d)

e)

f)

g)

h)



5 Appendix: Data plots

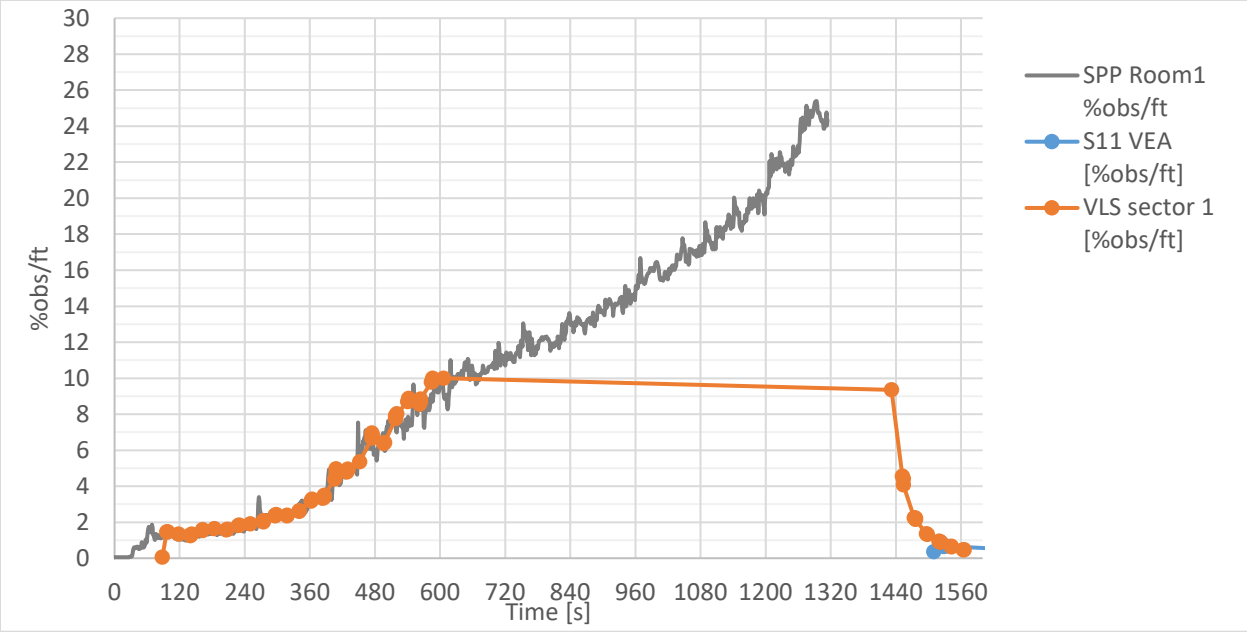


Figure 6. Test SPP: No VEA output within 20 minute.

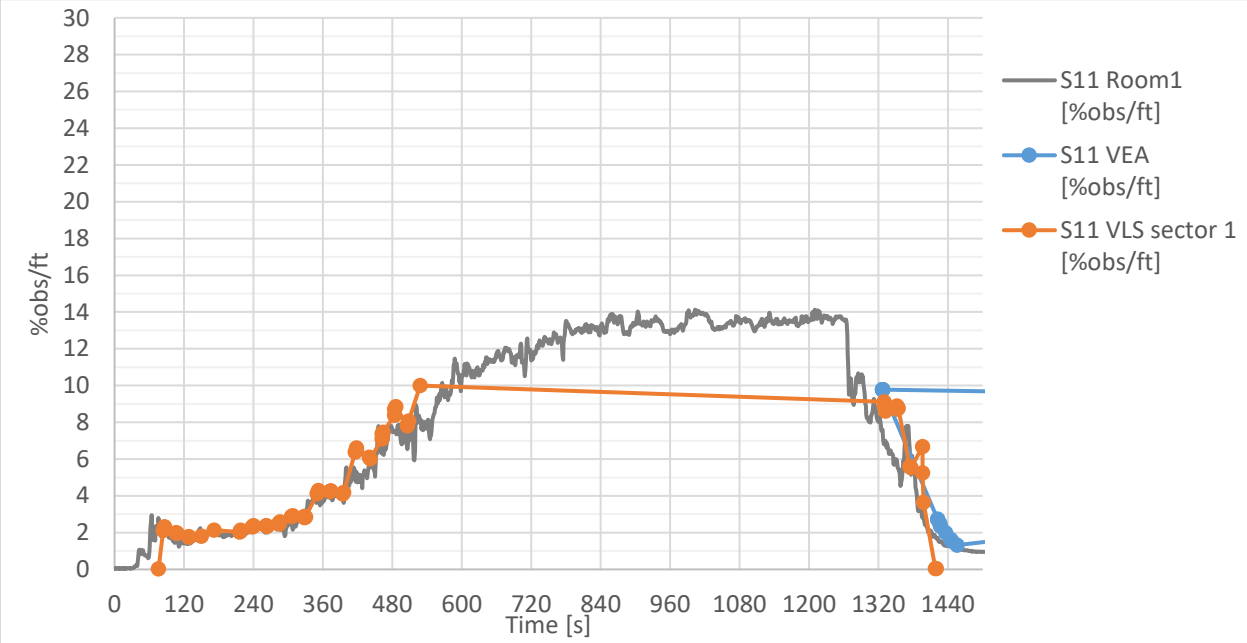


Figure 7. Test S11: No VEA output within 20 minute.

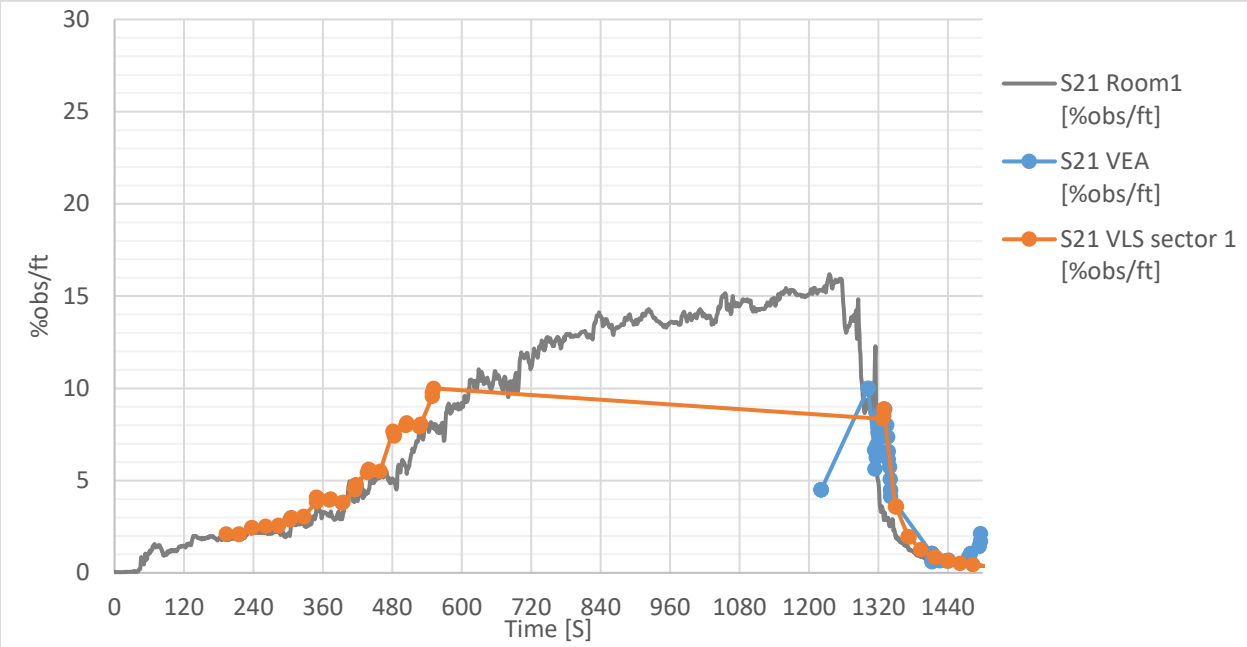


Figure 8. Test S21: No VEA output within 20 minute.

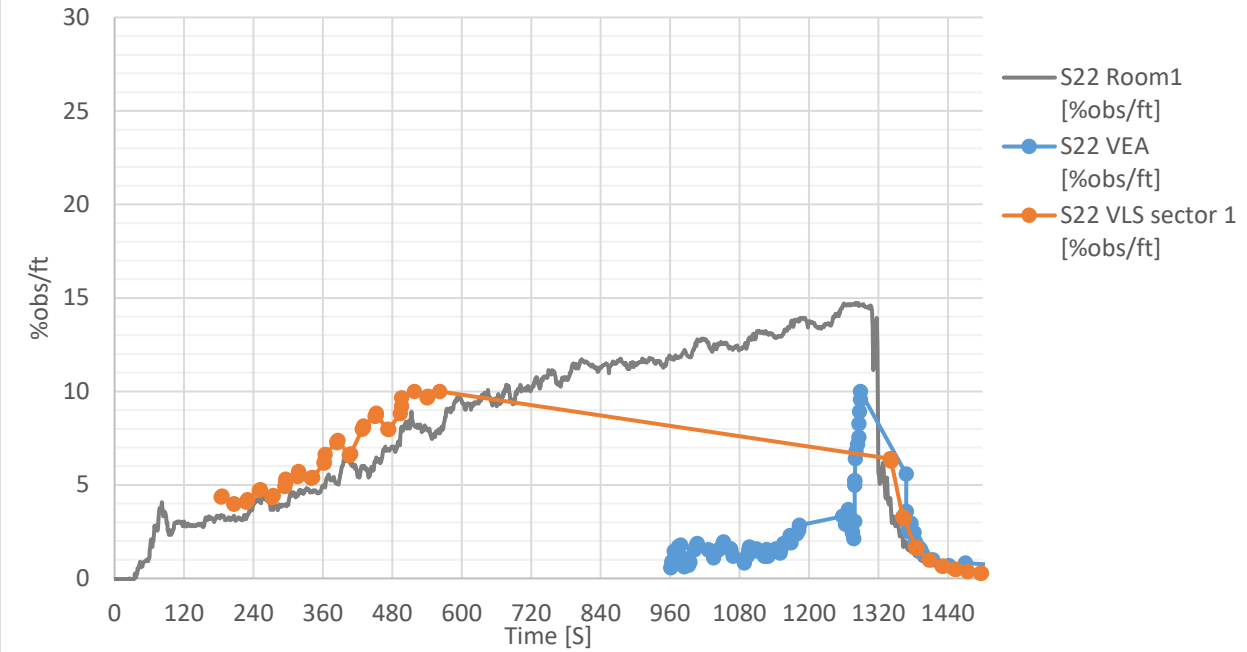


Figure 9. Test S22: VEA outputs 0.5%obs/ft at 961 S, 2.5%obs/ft at 1182 S. VEA system detection time is 1236 S for the Standard sensitivity setting.

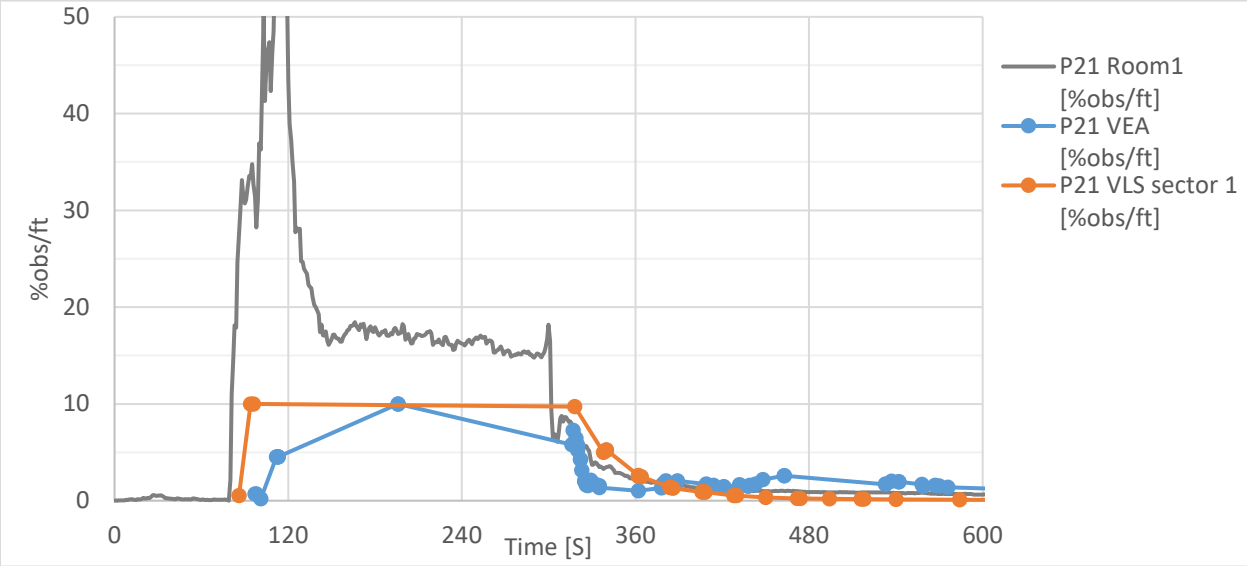


Figure 10. Test P21: VEA outputs 0.5%obs/ft at 98 S, 2.5%obs/ft at 110 S. VEA system detection time is 174 S for the Standard sensitivity setting.

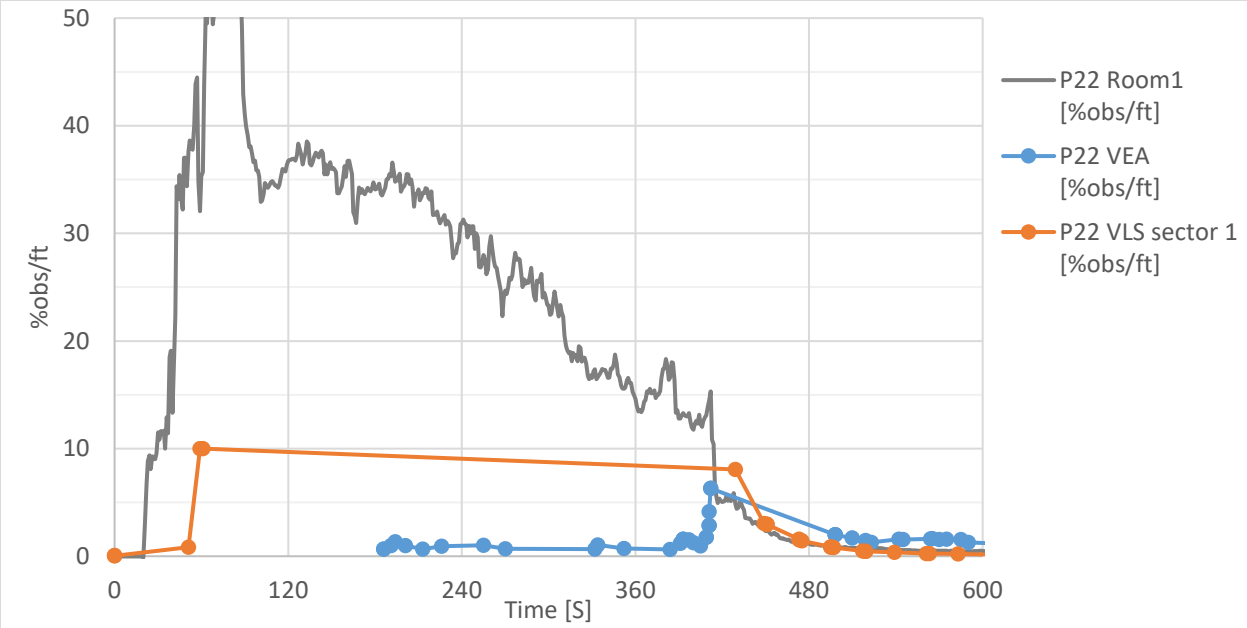


Figure 11. Test P22**:** VEA outputs 0.5%obs/ft at 186 S, 2.5%obs/ft at 411 S. VEA system detection time is 411 S for the Standard sensitivity setting.

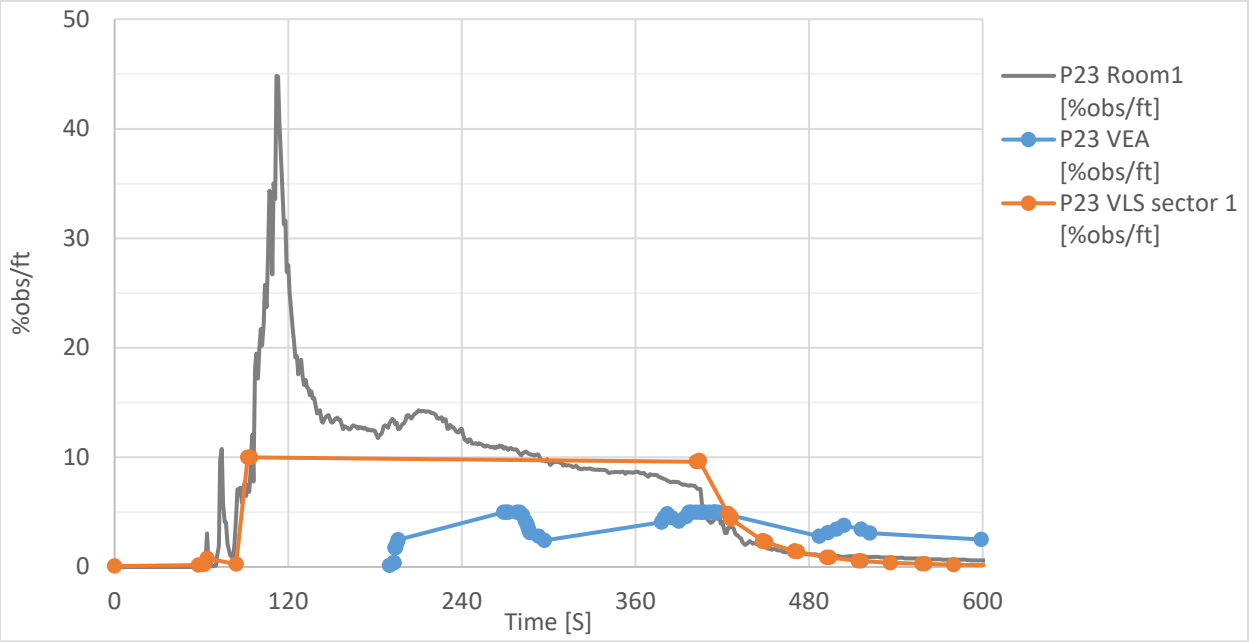


Figure 12. Test P23: VEA outputs 0.5%obs/ft at 194 S, 2.5%obs/ft at 200 S. VEA system detection time is 247 S for the High sensitivity setting.

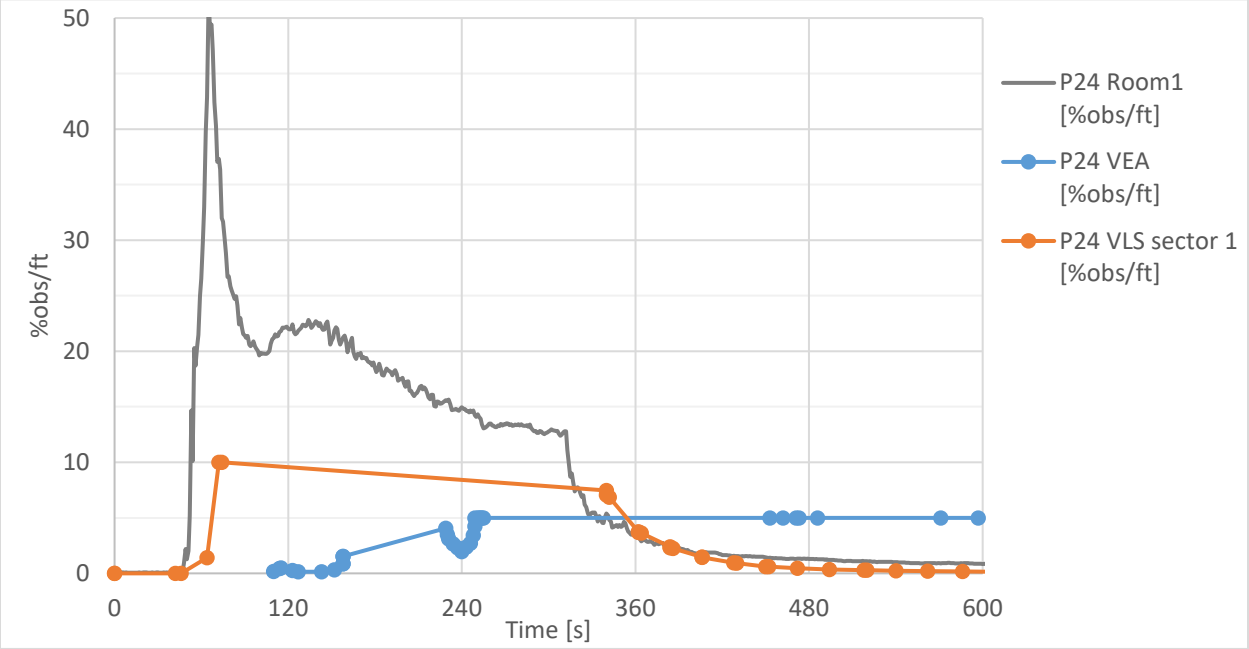


Figure 13 Test P24: VEA outputs 0.5%obs/ft at 158 S, 2.5%obs/ft at 200 S. VEA system detection time is 207 S for the High sensitivity setting.

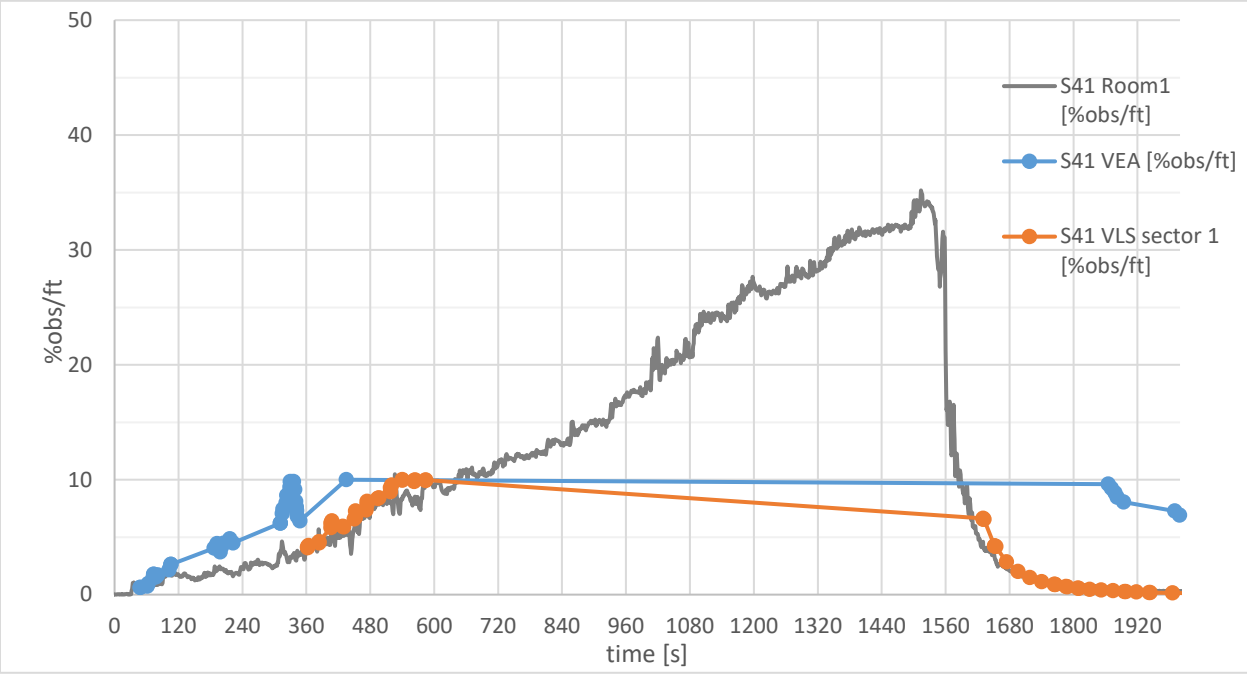


Figure 14 Test S41: VEA outputs (from the 4 tubes) 0.5%obs/ft at 48 S, 2.5%obs/ft at 106 S. VEA system detection time is 106 S for the Standard sensitivity setting.

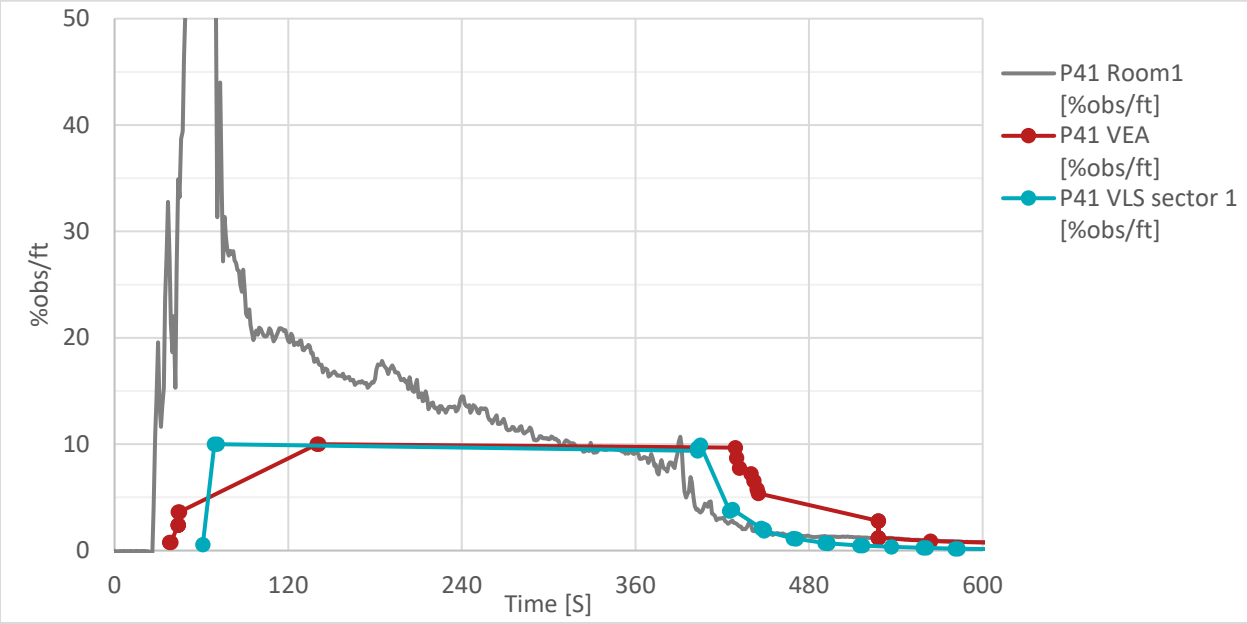


Figure 15 Test P41: VEA outputs (from the 4 tubes) 0.5%obs/ft at 39 S, 2.5%obs/ft at 44 S. VEA system detection time (from the tube through a drilled hole) is 118 S for the Standard sensitivity setting.

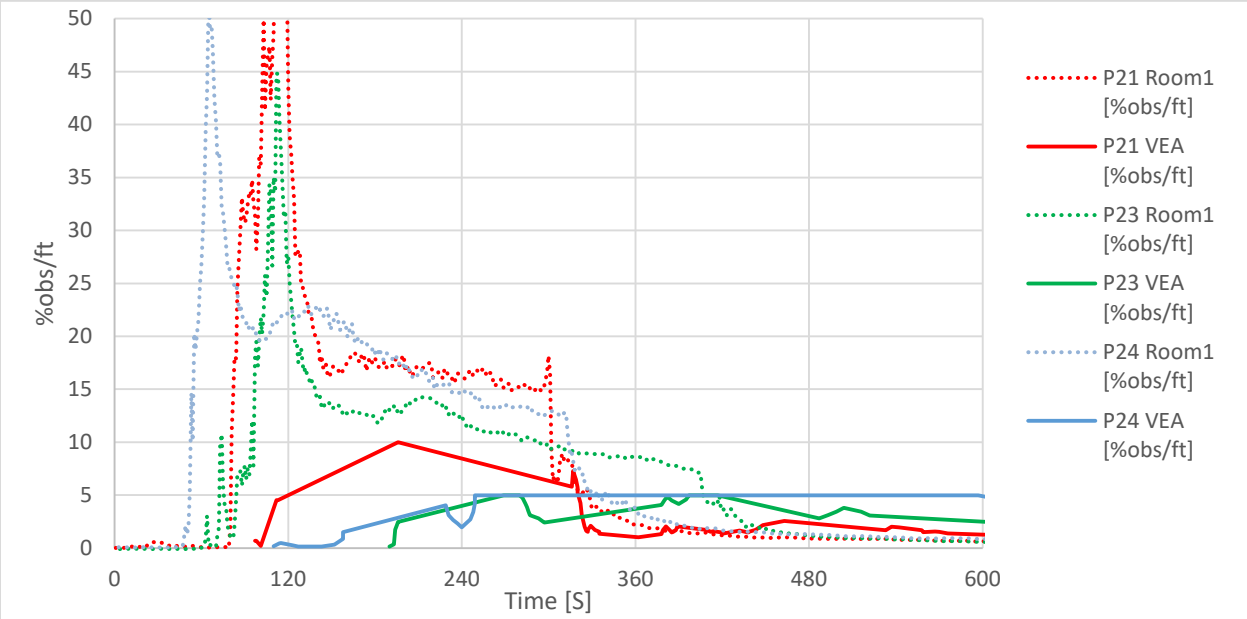


Figure 16 Comparisons of the results from the paper fire tests