Fire research report

Smoke Alarms in Homes: Stage 2

This fire research report provides an analysis of smoke alarm performance with respect to type, position, location and toxic gas tenability limits in simulated residential fires

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Executive Summary

Modern day furnishings and building materials used in homes have dramatically changed the dynamics of residential fires. The combustion of widely used synthetic materials produces faster fires with higher levels of heat and toxic smoke than natural materials, leading to significantly decreased tenability windows for the safe egress of residents. Functional smoke alarms remain the primary means of alerting occupants to fires; however, questions arise as to their effectiveness in the modern home and whether the type and location of smoke alarms play a role.

In 2014, FRNSW commenced a research project to assess the effectiveness of residential smoke alarms. The project, conducted by the Fire Investigation & Research Unit (FIRU), sought to assess any differences in performance between photoelectric, ionisation and dual-sensor smoke alarms in their responses to smouldering and flaming fires. A key focus of the research was assessing whether smoke alarms provided adequate notification to allow occupants to exit a dwelling before tenability limits for temperature and toxic gases were reached. A comprehensive literature review and analysis of FRNSW incident data for the preceding 15 years was completed before an initial series of 10 research burns were conducted in a full scale replica residence built at the FIRU Fire Research Facility at Londonderry, NSW. The research identified that ionisation alarms were inferior to photoelectric and dual alarms in most fire scenarios, and that current smoke alarms failed to provide sufficient notification for safe egress when located only in the Hallway as required under current legislation.

In response to the report, the Australian Building Codes Board (ABCB) commissioned a critical review of the FRNSW research and other existing literature by the Centre for Environmental and Risk Engineering at Victoria University. The review identified that the FRNSW smoke alarm research was based on too few tests, did not consider an adequate range of fire scenarios, and that the ignition methods were not representative of real scenarios.

Based on feedback from the ABCB-commissioned review, FRNSW conducted a further series of tests, which included:

- Four smoke alarm types: photoelectric, ionisation, dual-sensor (photoelectric and ionisation) and multi-criteria (photoelectric and heat);

- A total of 48 smoke alarms, in clusters of four, in various locations within the residence. This included the ceiling, wall and dead space positions in each bedroom, hallway and living space.
- 27 test scenarios, including 10 smouldering fires, 13 flaming fires and four nuisance tests. Each scenario was repeated three times.

Testing found that of the four alarm types tested, dual-sensor alarms were overall the quickest to activate, while only ionisation alarms activated earlier than dual alarms in fast flaming fires.

The tests also revealed that non-activation rates were high for photoelectric and multi-criteria alarms, while ionisation and dual alarms were more likely to activate due to nuisance sources such as cooking fumes, cigarette smoke, and burning incense.

Analysis of the levels of toxic gases in the bedrooms and along the path of egress revealed that overall smoke alarm performance was poor in terms of the provision of adequate warning for the safe egress of occupants. It was found that often tenability limits were reached in the room of origin before hallway alarms were activated. Hallway alarms did not activate at all when the door to the room of origin was closed. This reinforces the recommendations by FRNSW in Stage 1, that smoke alarms be required in all hallways, bedrooms and living spaces, and should be interconnected (Engelsman, 2015).

Smoke alarms are an essential component in a suite of fire safety measures used to protect occupants from residential fires. The results indicate that current technologies are incapable of providing sufficient warning in flaming fires and that there is a need to improve tenability performance of smoke alarms in smouldering fires where smoke alarms have the potential to provide notification for the safe egress of occupants.

Considering the findings of the study, FRNSW notes a number of measures that can be implemented to improve fire safety in residential settings:

- Smoke alarms required in every living space, bedroom and hallway
- All smoke alarms within a residence to be interconnected
- Improvement of smoke alarm performance by including toxic tenability performance requirements in the standards, and
- The use of automated fire suppression systems (home sprinklers) to be used to mitigate fast flaming fires in residences.

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Nomenclature

ANOVA	Analysis of variance. Variance is a measure based on the squared deviations of individual scores/observations from the mean. ANOVA analyses the differences between independent group means.
F	F statistic, ratio of two mean square values
M	Mean value, the average value of a distribution
N	Sample size or population size
p	Statistical significance level $p = \alpha$
SD	Standard deviation, a measure of variability defined as the square root of the variance
χ^2	Chi-square statistic, a measurement of how results compare with expected values.

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1. Introduction

Modern day furnishings and building materials used in homes have dramatically changed the dynamics of residential fires. The combustion of widely used synthetic materials produces faster fires with higher levels of heat and toxic smoke than natural materials, leading to significantly decreased tenability windows for the safe egress of residents. Functional smoke alarms remain the primary means of alerting occupants to fires; however, questions arise as to their effectiveness in the modern home and whether the type and location of smoke alarms play a role.

In 2014, FRNSW commenced a research project to assess the effectiveness of photoelectric and ionisation alarms. The project, conducted by the Fire Investigation & Research Unit (FIRU), sought to assess any differences in performance between photoelectric and ionisation smoke alarms in their responses to smouldering and flaming fires. This research also examined the impact of smoke alarm location and the number of alarms in a dwelling on providing timely notification to occupants. A key focus of the research was assessing whether smoke alarms provided adequate notification to allow occupants to exit a dwelling before tenability limits for temperature and toxic gases were reached.

The research commenced with a comprehensive literature review and analysis of FRNSW incident data for the preceding 15 years. During 2015 an initial series of 10 research burns were conducted in a full scale replica residence built at the FIRU Fire Research Facility at Londonderry, NSW. Following analysis of the test data a draft report (Engelsman, 2015) was produced which identified that ionisation alarms were inferior to photoelectric and dual-type sensors in most fire scenarios, and that current smoke alarms failed to provide sufficient notification for safe egress when located only in the Hallway as required under current legislation.

In response to the report, the Australian Building Codes Board (ABCB) commissioned a critical review of the FRNSW research and other existing literature by the Centre for Environmental and Risk Engineering at Victoria University (Novozhilov et al., 2015). The review identified that the FRNSW smoke alarm research was based on too few tests, did not consider an adequate range of fire scenarios, and that the ignition methods were not representative of real scenarios. Based on the valuable feedback from the ABCB-commissioned review (Novozhilov et al., 2015), FRNSW organised a further series of research burns based on the scenarios suggested by (Novozhilov et al., 2015) (see Table 1).

This document details the methodology used in the testing, the results and provides and analysis of the findings.

2. Methodology

2.1 Burn unit and furnishings

A test burn cell was purpose-built at the FRNSW Research Facility at Londonderry, NSW for the Stage 1 testing in 2015 (Engelsman, 2015). The structure was set up as a two bedroom unit with a layout as illustrated in Figure 1 below for Stage 2 testing.

Figure 1 Layout of two-bedroom residence showing positions of smoke alarms, thermocouples and gas probes.

The frame of the residence was built from radiata pine with 16 mm fire resistant plasterboard panels lining the internal walls and ceiling. The outside of the building was lined with extra heavy duty premium wall wrap and clad with 7.5 mm plywood. The structure contains a solid timber front door and hollow core lightweight internal doors. Aluminium, glazed sliding windows were installed, ceiling heights were 2.4 m and bulkheads above doors were set at 2.1 m. The structure was roofed with a trim deck metal roof to prevent weathering.

Modern furniture and furnishings were purchased to furnish the rooms. The kitchen area was constructed from 4.5mm fibre reinforced cement sheeting for durability during testing. All rooms were carpeted with polypropylene carpet squares, except the kitchen and bathroom spaces, which were fitted with a vinyl floor covering.

Table 1 Test scenarios suggested by Novozhilov et al., (2015) [* denotes scenarios excluded in Stage 2]

Scenario	Location	Fire Type	Materials	Ignition Method	Conditions
1	Bedroom 1	Smouldering	Bedding	Cigarette/small electric heater	Bedroom 1 door closed; Bedroom 2 door open;
2	Bedroom 2	Smouldering	Bedding	Cigarette/small electric heater	Two bedroom doors open
3	Lounge	Smouldering	Upholstered couch	Cigarette/small electric heater	Bedroom 1 door open; Bedroom 2 door closed
4*	Bedroom 2	Smouldering	Bedding	Cigarette/small electric heater	Two bedroom doors open
5	Bedroom 2	Flaming	Bedding	LPG gas flame	Two bedroom doors open
6*	Bedroom 1	Smouldering	Bedding	Cigarette/small electric heater	Bedroom 1 door closed; Bedroom 2 door open
7	Bedroom 1	Smouldering	Bedding	Cigarette/small electric heater	Two bedroom doors open
8*	Lounge	Smouldering	Upholstered couch	Cigarette/small electric heater	Bedroom 1 door open; Bedroom 2 door closed
9*	Bedroom 2	Smouldering	Bedding	Cigarette/small electric heater	Two bedroom doors open
10	Bedroom 1	Flaming	Bedding	LPG gas flame	Two bedroom doors open
11	Kitchen	Smouldering	Electrical cable	LPG gas flame or alternative	All room doors open
12	Kitchen	Flaming	Electric equipment	Cartridge heater or alternative	All room doors open
13	Lounge	Flaming	Upholstered furniture	LPG gas flame or alternative	All room doors open
14	Lounge	Smouldering	Upholstered furniture	Cigarette/small electric heater	All room doors open
15	Lounge	Flaming	Papers	LPG gas flame or alternative	All room doors open
16	Lounge	Flaming	Wood chair	LPG gas flame or alternative	All room doors open
17	Kitchen	Flaming	Cooking pan	LPG gas flame or alternative	All room doors open
18	Kitchen	Flaming	Clothing	LPG gas flame or alternative	All room doors open
19	Laundry room	Smouldering	Electric equipment	Cartridge heater or alternative	All room doors open
20	Laundry room	Smouldering	Electric equipment	Cartridge heater or alternative	All room doors open except laundry room door
21*	Bedroom 1	Flaming	Pillow	LPG gas flame or alternative	All room doors open
22	Bedroom 1	Flaming	Pillow	LPG gas flame or alternative	All room doors open except Bedroom 1 door
23	Bedroom 2	Flaming	Paper	LPG gas flame or alternative	All room doors open
24	Bedroom 2	Flaming	Paper	LPG gas flame or alternative	All room doors open except Bedroom 1 door
25	Hall	Flaming	Wood chair	LPG gas flame or alternative	All room doors open
26	Hall	Smouldering	Upholstered furniture	Cigarette/small electric heater	All room doors open
27	Kitchen	Nuisance source	Cooking different foods	Cooking equipment	All room doors open
28	Bathroom	Nuisance source	Steam	Hot shower	All room doors open
29	Lounge	Nuisance source	Smoking cigarette(s)	Lighter	All room doors open
30	Lounge	Nuisance source	Candle(s)	Lighter	All room doors open

2.2 Test scenarios

In consultation with the ABCB, 25 test scenarios were selected from the 30 test scenarios suggested by Novozhilov et al. (2015) to be included in the Stage 2 test series. Scenarios 4, 6, 8, 9 and 21 were discarded to avoid repetition. A further two scenarios (7b and 14b) were included to investigate cigarettes as an ignition source in smouldering fires. The final test matrix, which includes a total of 27 scenarios, is presented in Table 2 below.

Table 2 Stage 2 Test scenarios and configurations

Scenario	Location	Fire Type	Materials	Ignition Method	Conditions
1	Bedroom 1	Smouldering	Bedding	Soldering iron	Bedroom 1 door closed; Bedroom 2 door open;
2	Bedroom 2	Smouldering	Bedding	Soldering iron	Two bedroom doors open
3	Lounge	Smouldering	Upholstered couch	Soldering iron	Bedroom 1 door open; Bedroom 2 door closed
5	Bedroom 2	Flaming	Bedding	Butane lighter	Two bedroom doors open
7a	Bedroom 1	Smouldering	Bedding	Soldering iron	Two bedroom doors open
7b	Bedroom 1	Smouldering	Bedding	Cigarette	Two bedroom doors open
10	Bedroom 1	Flaming	Bedding	Butane lighter	Two bedroom doors open
11	Kitchen	Smouldering	Electrical cable	Stove element	Two bedroom doors open
12	Kitchen	Flaming	Electric equipment	Toaster	Two bedroom doors open
13	Lounge	Flaming	Upholstered furniture	Butane lighter	Two bedroom doors open
14a	Lounge	Smouldering	Upholstered furniture	Soldering iron	Two bedroom doors open
14b	Lounge	Smouldering	Upholstered furniture	Cigarette	Two bedroom doors open
15	Lounge	Flaming	Papers	Butane lighter	Two bedroom doors open
16	Lounge	Flaming	Wood chair	Butane lighter	Two bedroom doors open
17	Kitchen	Flaming	Cooking pan	Butane lighter	Two bedroom doors open
18	Kitchen	Flaming	Tea towel	Butane lighter	Two bedroom doors open
19	Laundry room	Smouldering	Clothes iron	Clothes iron	Two bedroom doors open
20	Laundry room	Smouldering	Clothes iron	Clothes iron	Two bedroom doors open, laundry room door closed
22	Bedroom 1	Flaming	Pillow	Butane lighter	Bedroom 1 door closed; Bedroom 2 door open;
23	Bedroom 2	Flaming	Paper	Butane lighter	Two bedroom doors open
24	Bedroom 2	Flaming	Paper	Butane lighter	Bedroom 1 door closed; Bedroom 2 door open;
25	Hall	Flaming	Wood chair	Butane lighter	Two bedroom doors open
26	Hall	Smouldering	Upholstered chair	Soldering iron	Two bedroom doors open
27	Kitchen	Nuisance source	Toast	Oven/Grill	Two bedroom doors open
28	Bathroom	Nuisance source	Steam	Hot water urn	Two bedroom doors open
29	Lounge	Nuisance source	Smoking cigarettes	Butane lighter	Two bedroom doors open
30	Lounge	Nuisance source	Incense	Butane lighter	Two bedroom doors open

2.3 Fire ignition and extinguishment

Smouldering fires were initiated using a 60W, 240V soldering station (ESD Safe) with temperature control (160°C to 480°C). The soldering pencil was used with the conical tip removed exposing a 30 mm long, 8 mm diameter wide heated tube, pictured in Figure 2 below. Three 15 cm x 15 cm squares of 100% pure cotton batting (or wadding) were used to support sustained smouldering in all tests. Smouldering ignition was achieved with the soldering station set to 350°C and left in contact with the batting for six minutes. The test start time was recorded as the time at which the soldering iron is first in contact with the batting material.

Figure 2 Soldering iron and cotton batting sheets used to initiate smouldering fires

Two smouldering test scenarios (7 and 14) were repeated using cigarettes as the ignition source. A single cigarette was lit using a butane-lighter and placed into position on three squares of cotton batting as in the soldering iron tests. The cigarettes were not removed during these tests and were allowed to burn until they self-extinguished (typically around 10-12 minutes duration). A lit cigarette has a heat output typically in the range of 4 to 6W when it is not actively being puffed and a tip temperature of 630-690°C when placed horizontally on an insulating surface (Babrauskas, V., 2003). The thermal energy transferred from a lit cigarette smouldering for 12 minutes can be estimated by the power output multiplied by the contact time to be 2.9-4.3 kJ. In comparison, the soldering iron set at 350°C (~72% power) for six minutes, with ~20% of its surface area in contact with the batting material is transferring approximately 3.1 kJ. The results of the comparison tests were very similar in terms of resulting damage, which indicates that the ignition sources were similar in energy (see Sections 3.5, 3.6, 3.11, and 3.12).

Flaming fires were initiated using a butane barbecue lighter. The flame was held to the test material for approximately 15 seconds. The test start time was recorded at the start of ignition.

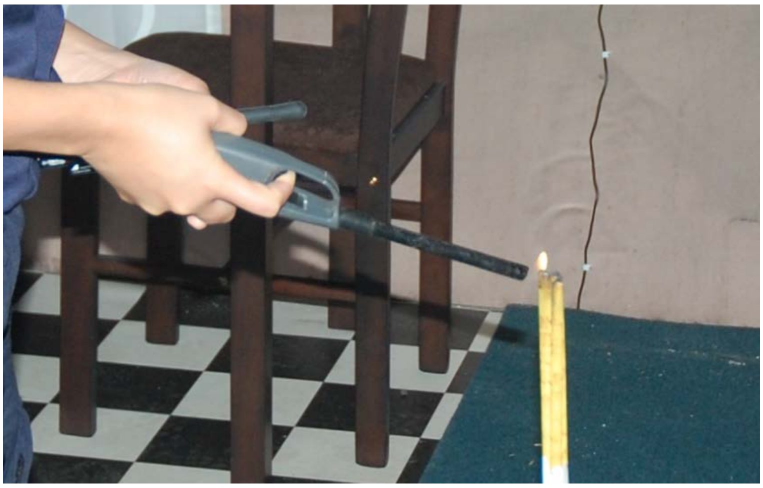

Figure 3 Butane BBQ lighter used in lighting flaming fires, pictured here used in lighting incense

2.4 Smoke alarms

Forty-eight battery-powered, AS 3786-1993-compliant, smoke alarms were installed in 12 locations throughout the unit. These included one photoelectric, one ionisation, one dual (photoelectric and ionisation) and one multi-criteria (photoelectric and heat sensing) alarm at every location. Alarms were installed in three positions: on the ceiling, wall and in dead space positions as defined in the Building Code of Australia Part 3.7.2.2 *Requirements for Smoke Alarms* (Australian Building Codes Board, 2016) (Figure 4).

A total of 476 smoke alarm samples were modified to supply a voltage output to a data logger on activation. This was achieved either by connecting to the LED indicator, the sounder, or the interconnect circuitry of the alarms (see Figure 5). All samples were verified for Directional Dependence and Initial Sensitivity in accordance with AS 3786 - 2014 (Standards Australia, 2014) at the CSIRO Fire Systems and Acoustics department in Clayton, Victoria prior to testing, with all except one alarm meeting the requirements (See

APPENDIX C CSIRO Smoke Alarm Verification Test Reports). One alarm (P111) was excluded from the sensitivity testing due to sounding errors and was subsequently excluded from the test series.

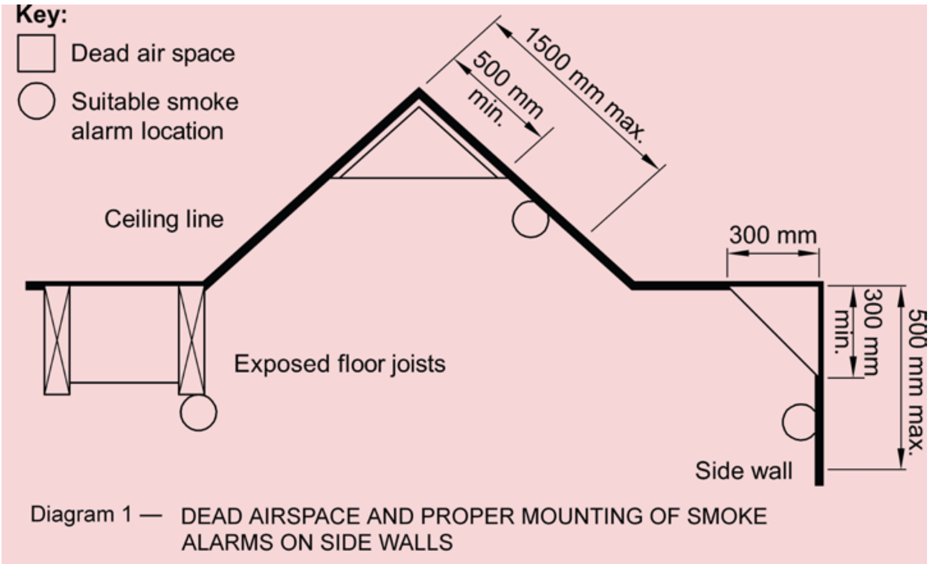

Figure 4 Diagram defining the dead air space and correct smoke alarm placement according to the Australian Building Codes Board (2016, p. 279)

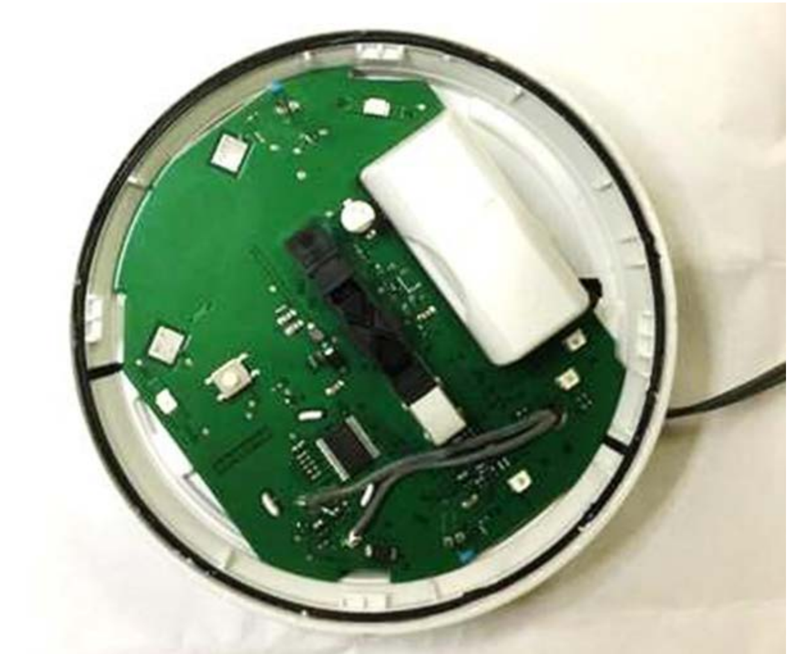

Figure 5 Wiring to the smoke alarm sounder

2.5 Instrumentation

Internal temperatures were measured via 24 *N* type thermocouples (measurement range -270°C to 1260°C), installed at six locations throughout the unit at heights of 0.5 m, 1 m, 1.5 m and 2.3 m from the floor. Ambient test conditions were monitored via a weather station (Vaisala Weather Transmitter WXT520) positioned outside the unit, measuring air temperature, air velocity, relative humidity and air pressure. Alarm activations and conditions were captured via a data acquisition system (DataTaker DT80) sampling at 12 channels per second.

Eight infrared digital video cameras were installed throughout the unit to provide video footage of the tests. In addition, a portable digital camera in a protective casing was used to provide close-up views of the fires.

Two Gasmet DX4000 units were used to monitor and analyse the gas levels within the fire compartments. A library of 41 gases, including CO, HCN, CO2, O2, HCl, HBr, HF, SO2, NO2, acrolein and formaldehyde, was included in the analyses which utilises Fourier Transform Infrared (FTIR) spectroscopy. The full list of gases and tenability limits used in the calculations is listed in APPENDIX B Tenability Criteria. Two high temperature sampling probes were placed at a height of 1.5 metres at two locations within the unit: one in the Hallway along the path of egress and the other in one of the two bedrooms (in Bedroom 2 when it was the room of origin and in Bedroom 1 otherwise). Gases were sampled every five seconds.

The residence was thoroughly ventilated and background tested between each test to enable a clean air environment as the baseline. Smoke alarms were checked following each test for evidence of damage or sounding, and replaced if it was deemed necessary due to low battery or any visual build-up of residue.

2.6 Data Analysis

The data acquired were processed using Microsoft Excel 2010. Tenability limits due to irritant and asphyxiant gases were calculated using the formulae presented by Engelsman (2015). The effective concentrations for the irritant gases used in the calculations are detailed in APPENDIX B Tenability Criteria.

All statistical analyses were conducted using IBM SPSS Statistics for Windows, Version 21.0 (Released 2012, IBM Corp., Armonk, NY). The statistical significance level alpha, α was set at 0.05.

2.7 Study Limitations

Although this study was limited due to time and cost considerations, care has been taken to design a robust program of tests which were repeatable and representative of typical fires occurring in residential units in NSW. The configurations of the scenarios were limited due to the construction of the residence, i.e. layout, room sizes, location of openings, ceiling heights and cornice design, surface finishes, furnishings, etc. The smoke alarm positions were limited to three locations per room, which included the ceiling, wall and dead space and were chosen for practicality. Furnishings were bought from bulk retailers for consistency, price and availability, and were the minimum required to realistically furnish each room for every test. The fires were contained at the conclusion each test to limit the damage to the structure and furnishings.

Weather and ambient conditions were a factor in the testing. The testing was undertaken in North-Western Sydney in late Autumn-early Winter, where temperatures varied throughout the day ranging from 5°C in the early morning to 20°C in the middle of the day.

Obscuration, radiant heat flux, mass loss, and audibility were not measured in this series.

3. Results

The 81 tests were completed over a six-week period between May and June 2016. These included three tests each of the 27 fire scenarios. The results of each test scenario are presented below.

3.1 SCENARIO 1: Smouldering bedding fire in Bedroom 1, door closed

In this scenario, a smouldering fire was initiated on the bed using the soldering iron heated to 350°C. The element was left in contact with three cotton batting sheets placed on the polyester quilt for six minutes and then removed. Firefighters then exited the room, closing the bedroom door behind them.

It was found that in all three tests, the bedding continued to smoulder for over 20 minutes but none of the smoke alarms in the Hallway outside of Bedroom 1 activated during this period. In Test 1, the smoulder continued for 30 minutes before transitioning to a flaming fire once the foam mattress had burnt through. The alarms positioned outside of Bedroom 1 all activated after the door was opened to extinguish the blaze.

Table 3 below summarises the smoke alarm activation times in the room of origin and hallway by alarm type and position for each test.

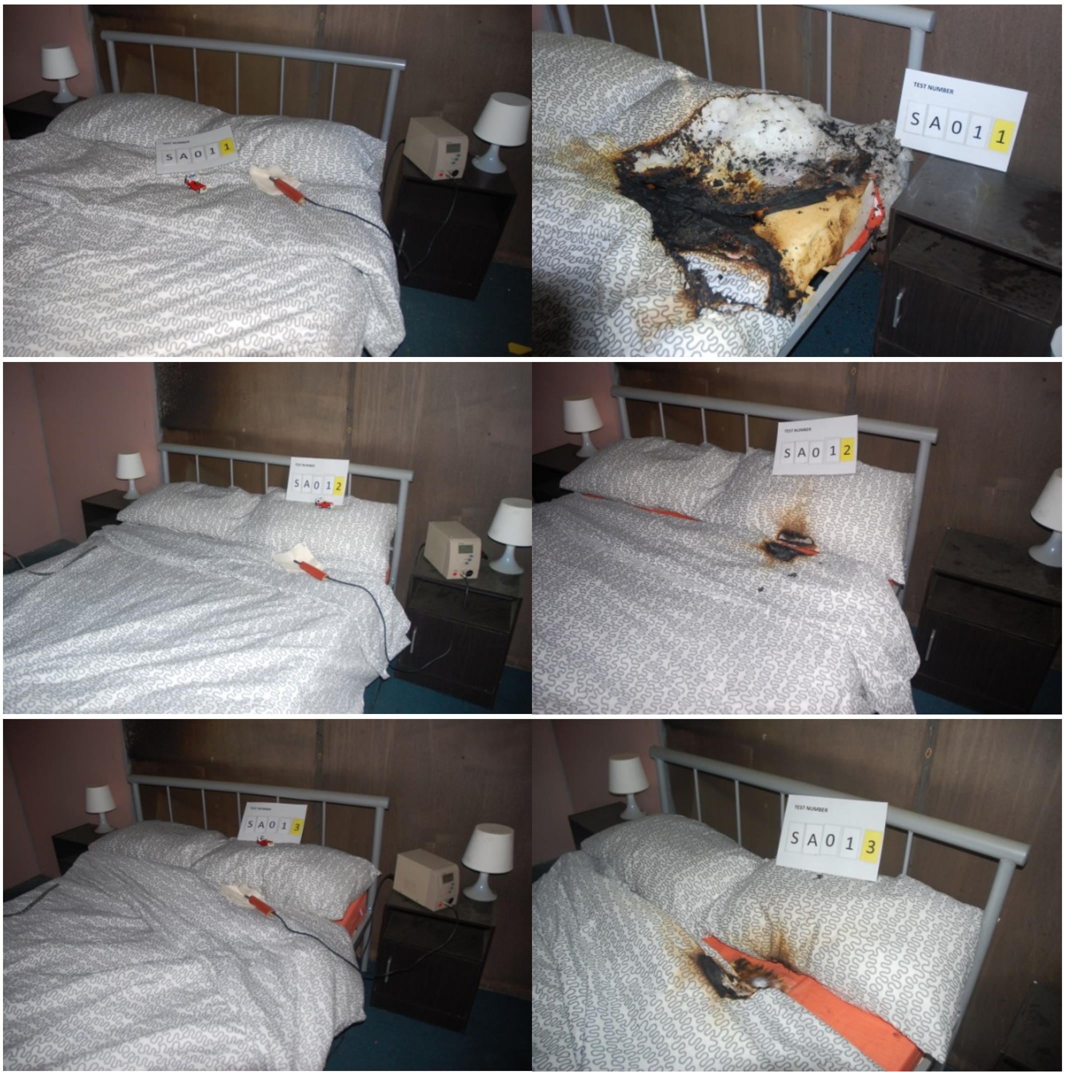

Figure 6 Before (left) and after (right) photographs of Scenario 1, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 3 Scenario 1 smoke alarm activation times (min:sec). Empty cells indicate non-activations.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	32:45	32:38	33:05	32:32								
Hall Wall	32:38	32:26	32:45	32:32								
Hall Dead-space	32:45	32:38	32:45	32:38								
ROO Ceiling	11:44	16:44	16:44	11:37	08:27	11:50	11:09	08:00	05:56	06:42	06:17	05:23

ROO Wall	12:23	12:49	12:03	12:17	09:05	09:58	08:39	08:59	05:56	06:09	05:37	06:09
ROO Dead-space	11:03	11:50	11:37	10:50	08:52	09:45	09:12	08:06	05:04	05:56	04:57	05:10

Figures 5 – 10 show a comparison of smoke alarm activations with the calculated fractional effective concentrations (FEC) for impaired escape and incapacitation, and fractional effective dose (FED) for asphyxiation (death).

The irritant gases contributing to escape impairment and incapacitation in Bedroom 1 included significant amounts of acrolein (up to 29 ppm), formaldehyde (up to 16 ppm), phenol (up to 17 pm), acetaldehyde (up to 66 ppm), and nitrogen dioxide (up to 17 ppm). Note the effective concentrations for escape impairment and incapacitation for these irritants are tabulated in

APPENDIX B Tenability Criteria.

Table 4 Scenario 1 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	ROO	Hall	ROO	Hall	ROO	Hall
FEC IMPAIRED ESCAPE 0.3	01:58	22:28	06:07	00:35	07:04	01:44
FEC IMPAIRED ESCAPE 1.0	06:42	33:14	11:33		08:44	01:44
FEC INCAPACITATION 0.3	11:09		12:57		10:49	
FEC INCAPACITATION 1.0	15:52					
FED ASPHYXIATION 0.3	30:53					
FED ASPHYXIATION 1.0						

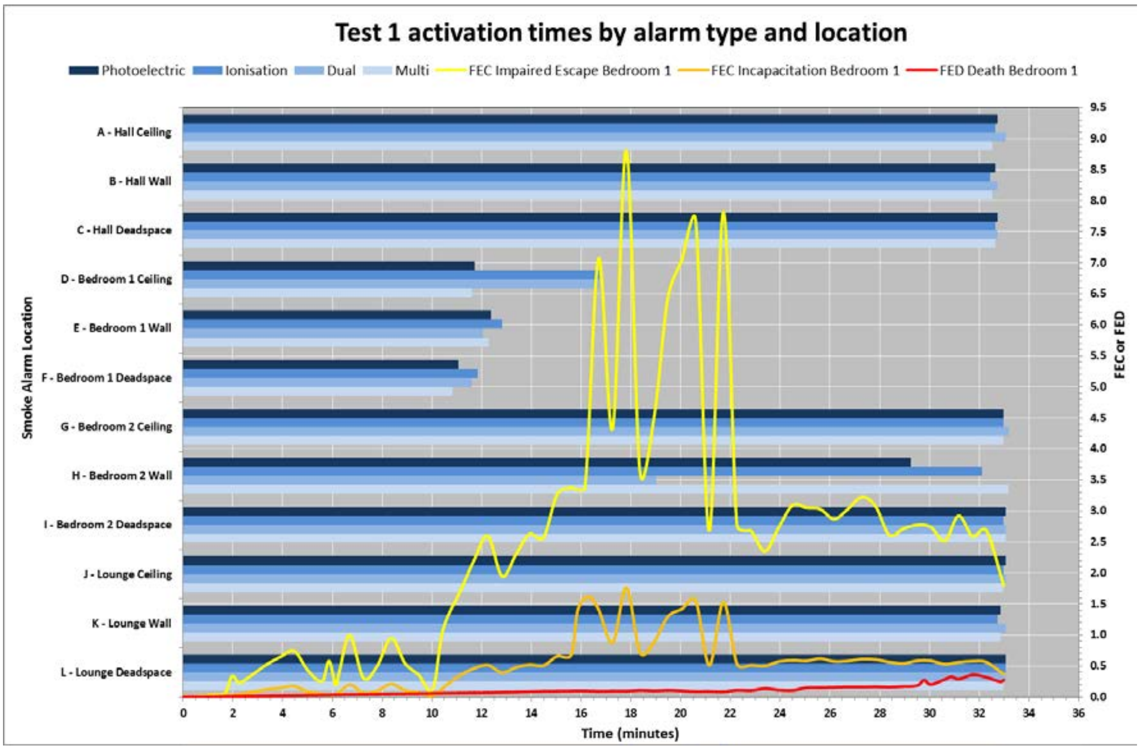

Figure 7 Scenario 1, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

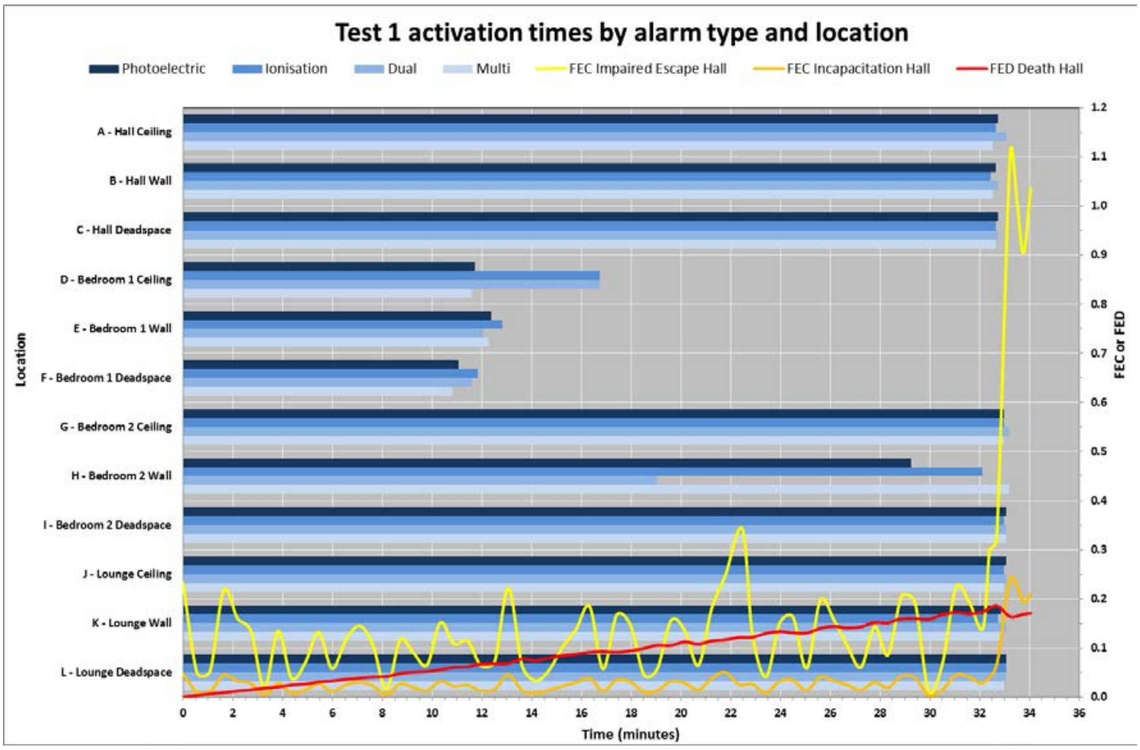

Figure 8 Scenario 1, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

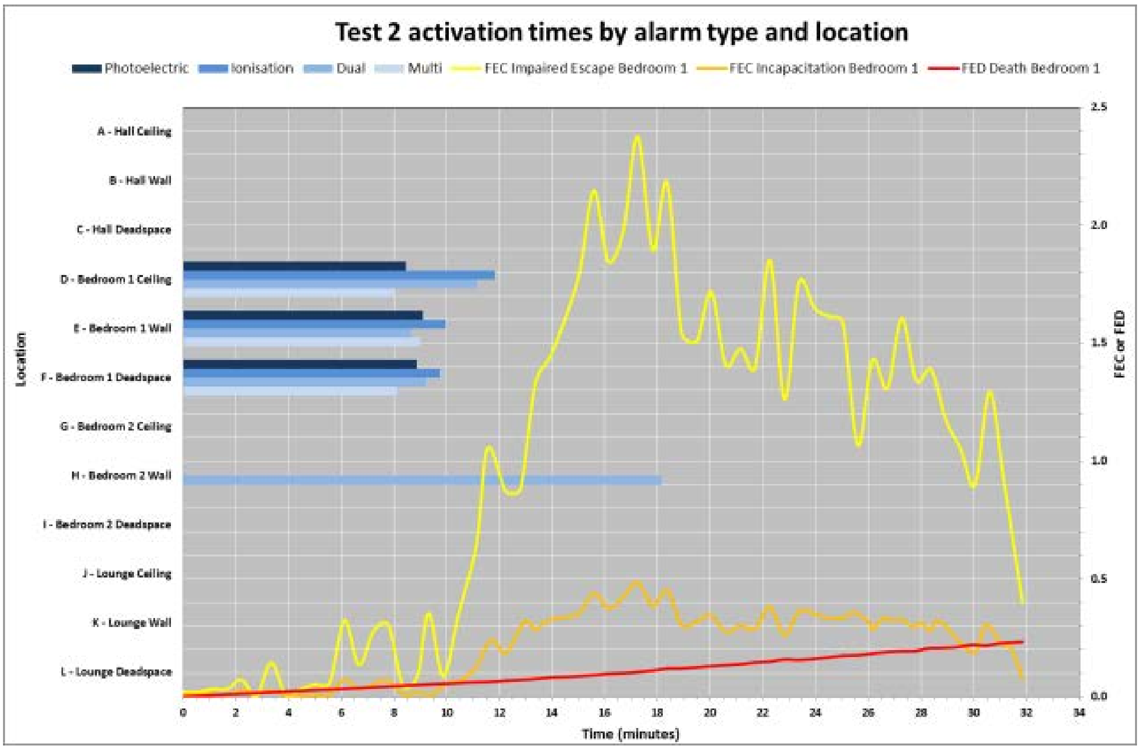

Figure 9 Scenario 1, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

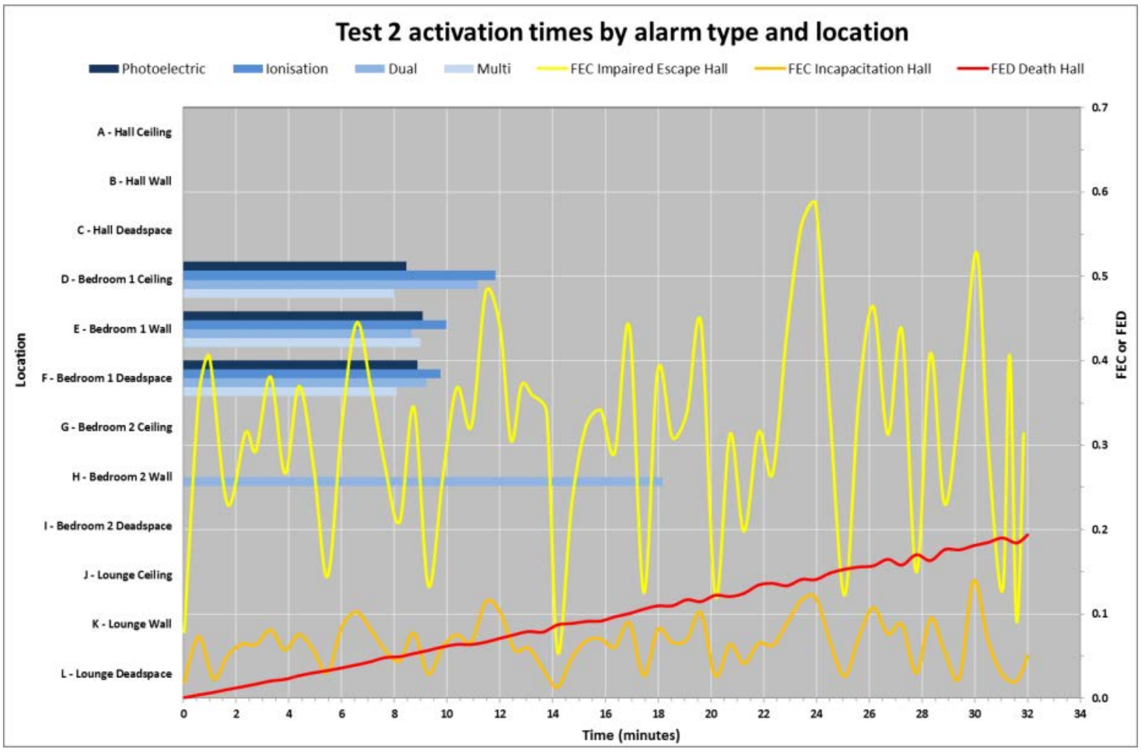

Figure 10 Scenario 1, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and FED.

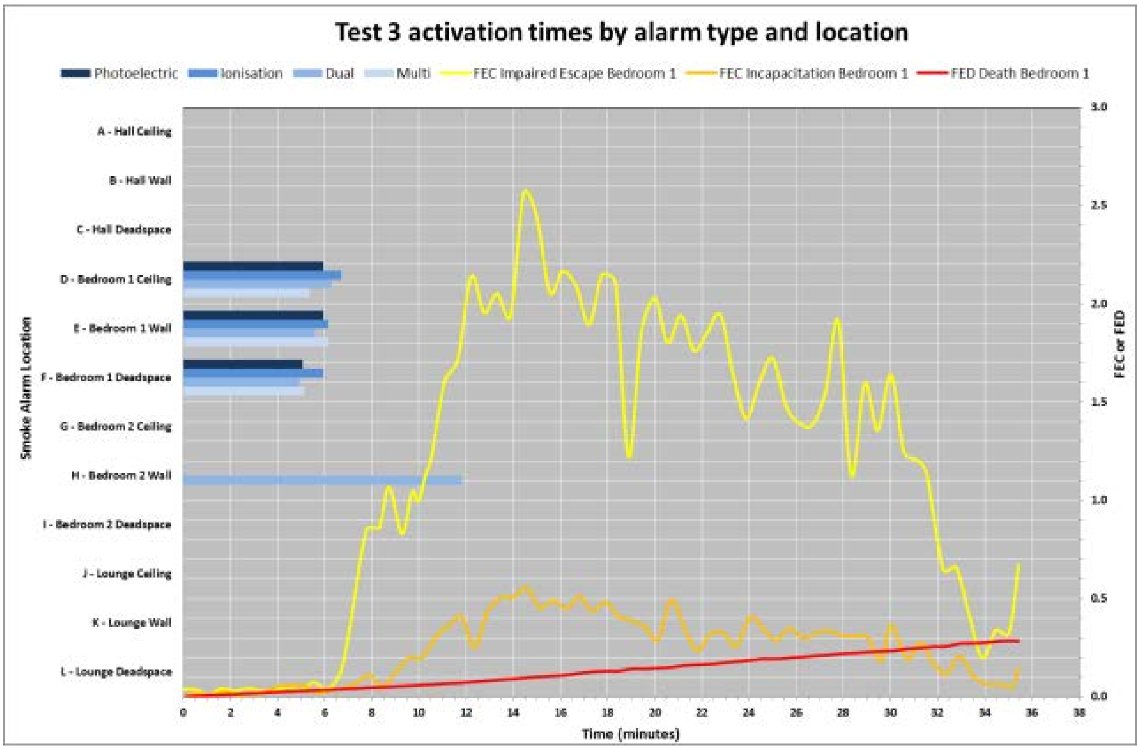

Figure 11 Scenario 1, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

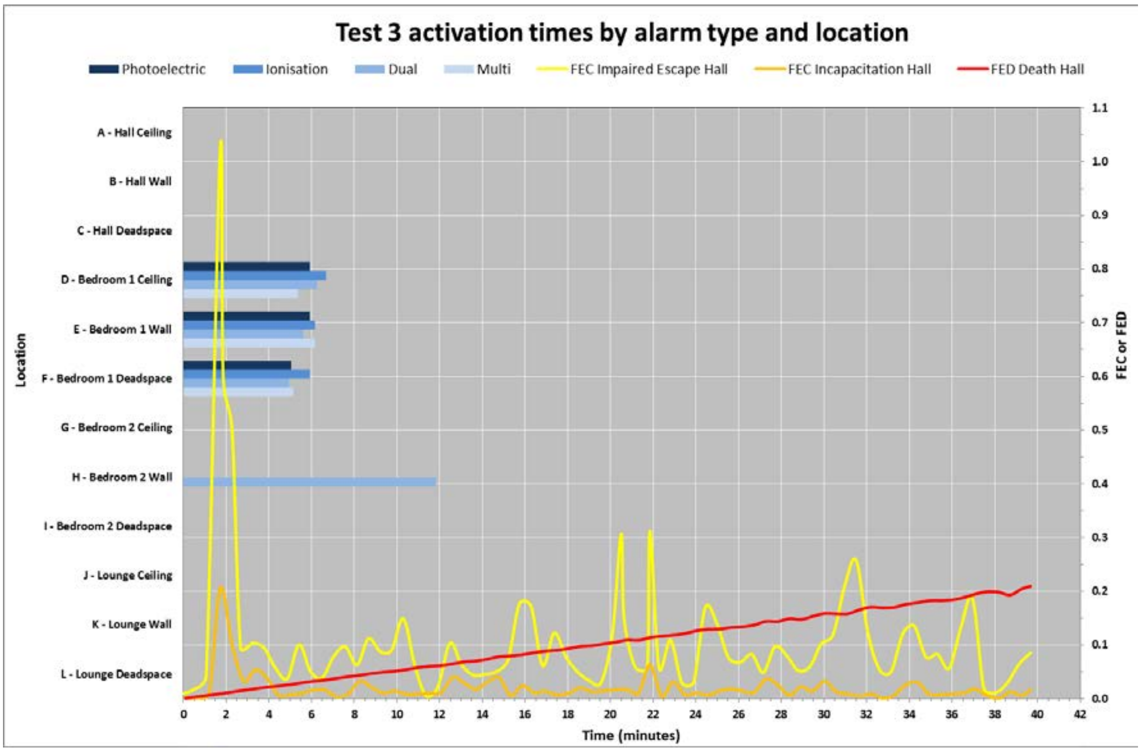

Figure 12 Scenario 1, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

The tenability limit for irritant induced incapacitation (FEC $_{INCAPACITATION}$ 0.3) is reached in Bedroom 1 in all three tests. The data shows that none of the Hallway-mounted smoke alarms gave adequate, if any, notification. In Test 1, the first Bedroom 1 alarm to activate did so at 10 min 50 sec into the test, which provides an available safe egress time (ASET) of only 19 seconds. All room alarms activated within the next six minutes. The gas analysis revealed that in this time, a room occupant would likely have an impaired ability to escape and possibly would have been incapacitated had they inhaled the gases sampled at 1.5 metres. In Test 2, most ROO alarms provided sufficient ASETs (above 135 seconds or 2.25 minutes). In Test 3, the ROO alarms gave ASETs of at least 4 minutes and 7 seconds.

Table 5 Scenario 1 Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Bedroom 1 tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	-21.60	-21.49	-21.93	-21.38	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Hall Wall	-21.49	-21.28	-21.60	-21.38	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Hall Dead-space	-21.60	-21.49	-21.60	-21.49	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Ceiling	-0.58	-5.59	-5.59	-0.47	4.51	1.12	1.79	4.95	4.88	4.12	4.54	5.44
ROO Wall	-1.24	-1.67	-0.91	-1.13	3.86	2.99	4.29	3.97	4.88	4.66	5.21	4.66
ROO Dead-space	0.09	-0.69	-0.47	0.31	4.08	3.20	3.74	4.85	5.76	4.88	5.87	5.65

While care is taken to repeat each scenario using the same materials and ignition source, the atmospheric conditions may affect the results. In this scenario, the drier atmospheric conditions in Test 1 may have attributed to the extended duration of the smoulder and consequently the transition to flame.

Table 6 Scenario 1 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.63	0.53	0.51
Air Temp (°C)	16.96	16.88	17.52
Rel. Humidity (%)	36.02	64.80	59.99
Air Pressure (mbar)	1019.81	1021.42	1018.51

3.2 SCENARIO 2: Smouldering bedding fire in Bedroom 2, doors open

In this scenario, a smouldering fire was initiated on the bed using the soldering iron heated to 350°C. The element was left in contact with three cotton batting sheets placed on the mattress between the pillow and quilt for six minutes and then removed. Firefighters then exited the room leaving the bedroom door open. The test was ended after 45 minutes at which time the smoulder had self-extinguished.

Figure 13 Before (left) and after (right) photographs of Scenario 2, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 7 Scenario 2 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	43:35		28:16		29:01		25:40	37:54	28:02		27:03	28:35
Hall Wall			26:15		29:08		26:22		27:55		24:52	30:08
Hall Dead-space			30:15		35:27		26:09		29:29		26:24	31:40
ROO Ceiling	13:20	14:37	07:17	07:10	10:34	09:55	08:56	09:48	22:41	12:13	11:33	12:00
ROO Wall	08:40	12:23	08:34	09:05	09:41	10:34	09:48	10:15	12:32	12:32	12:39	12:32
ROO Dead-space	06:51	08:21	06:37	06:25	09:09	08:50	06:11	08:50	11:07	11:07	10:54	10:40

The irritant gases contributing to escape impairment and incapacitation in Bedroom 2 included acrolein (up to 13.8 ppm), formaldehyde (up to 6.8 ppm), and phenol (up to 4.2 ppm).

Table 8 Scenario 2 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	ROO	Hall	ROO	Hall	ROO	Hall
FEC IMPAIRED ESCAPE 0.3	01:30	00:05	07:23	01:56	09:53	06:46
FEC IMPAIRED ESCAPE 1.0	10:57	11:56	10:02		11:00	
FEC INCAPACITATION 0.3	12:29	29:13	11:00		11:50	
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3	44:20		42:43		40:04	
FED ASPHYXIATION 1.0						

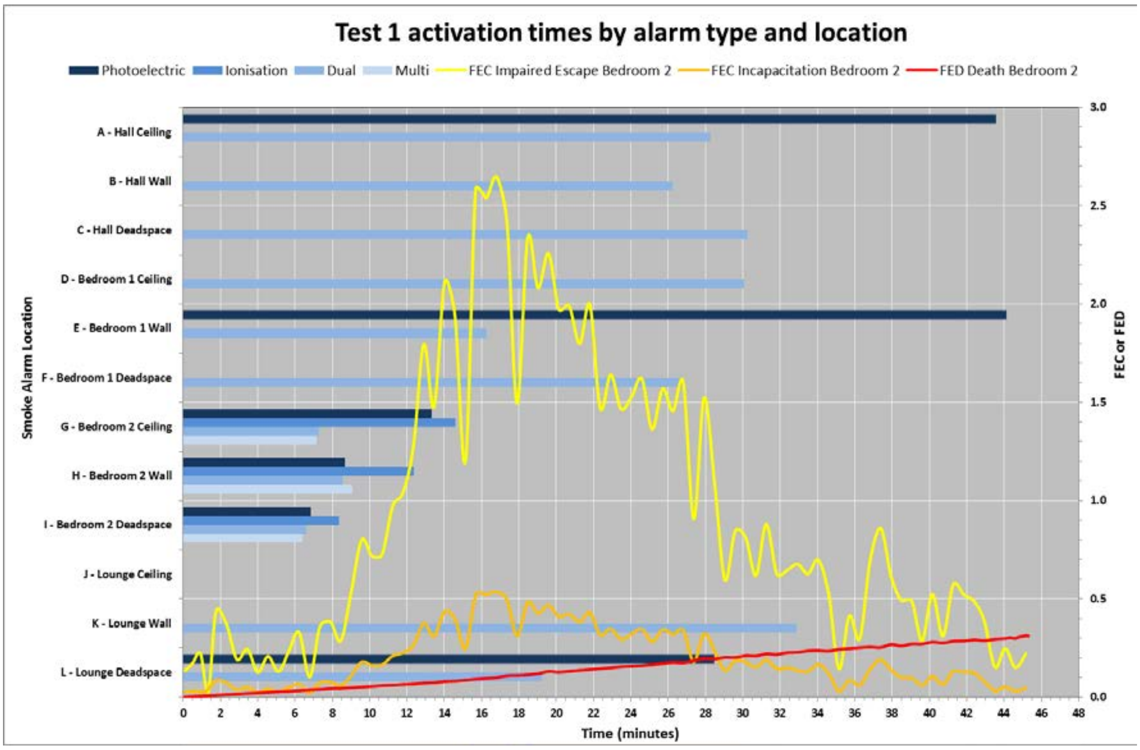

Figure 14 Scenario 2, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 2 FECs for impaired escape and incapacitation, and asphyxiation FED.

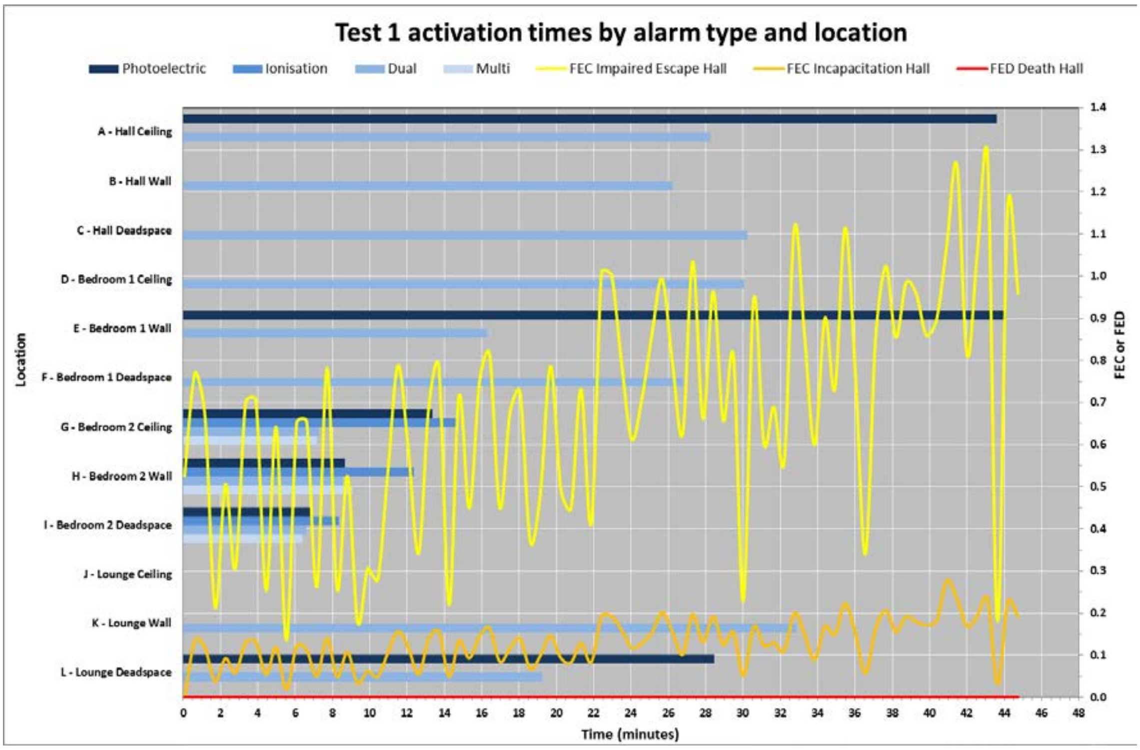

Figure 15 Scenario 2, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

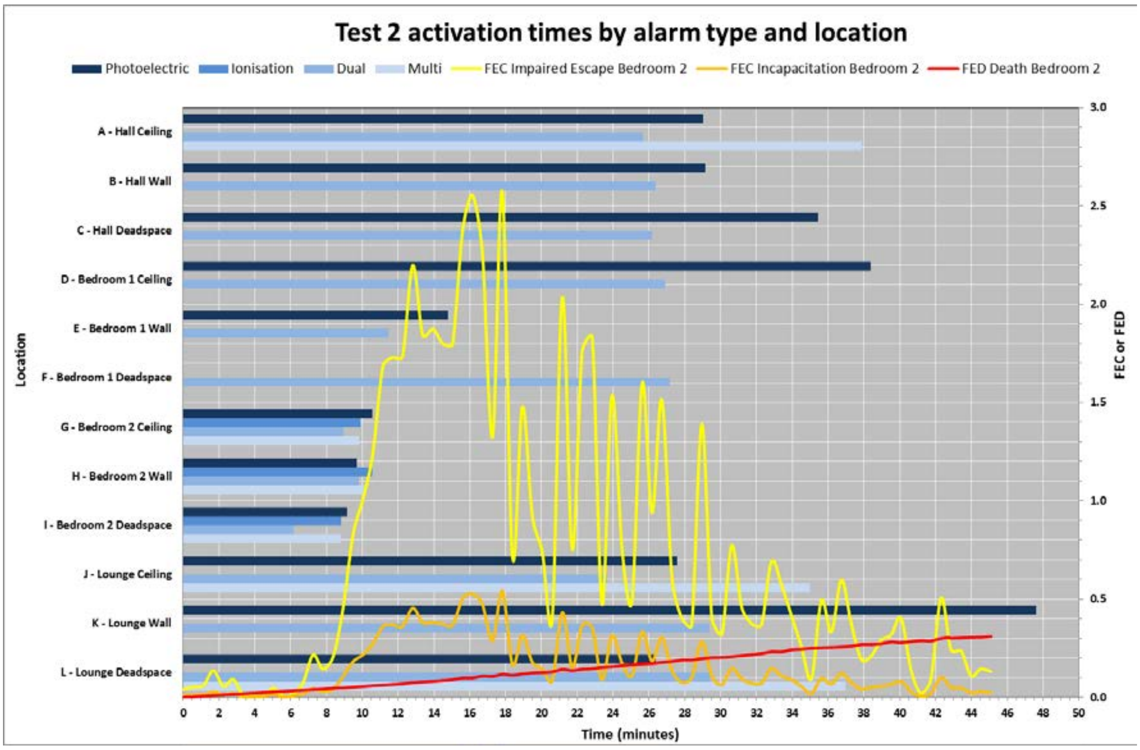

Figure 16 Scenario 2, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 2 FECs for impaired escape and incapacitation, and asphyxiation FED.

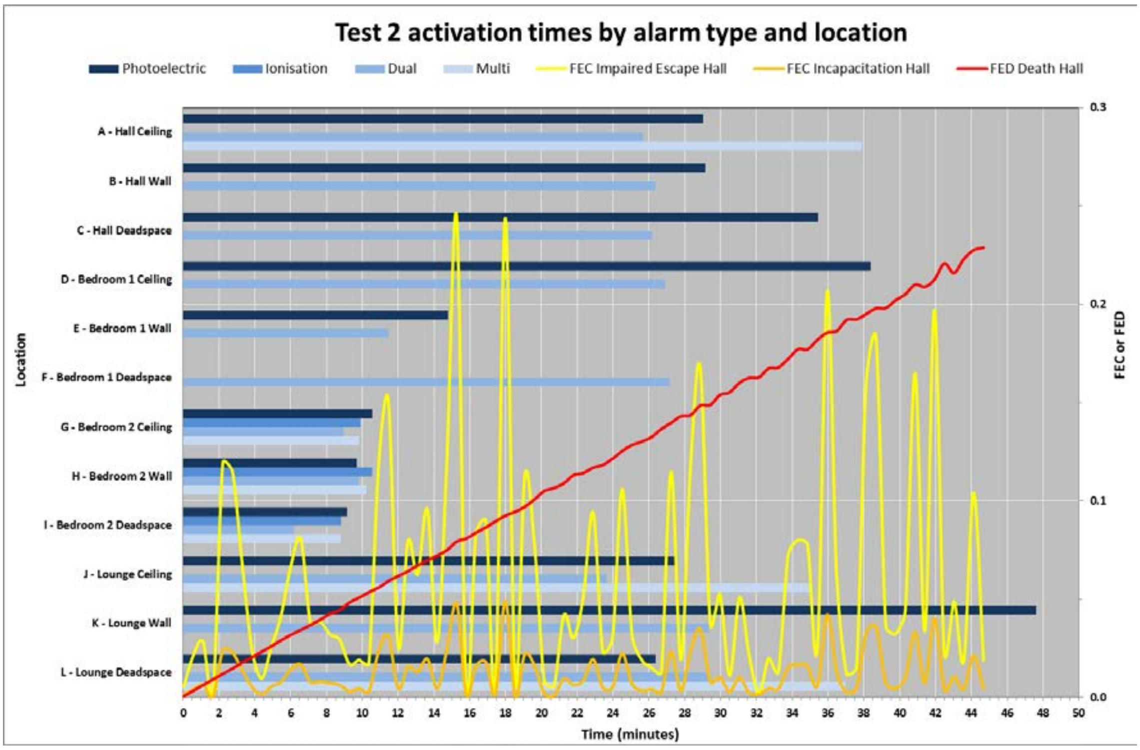

Figure 17 Scenario 2, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

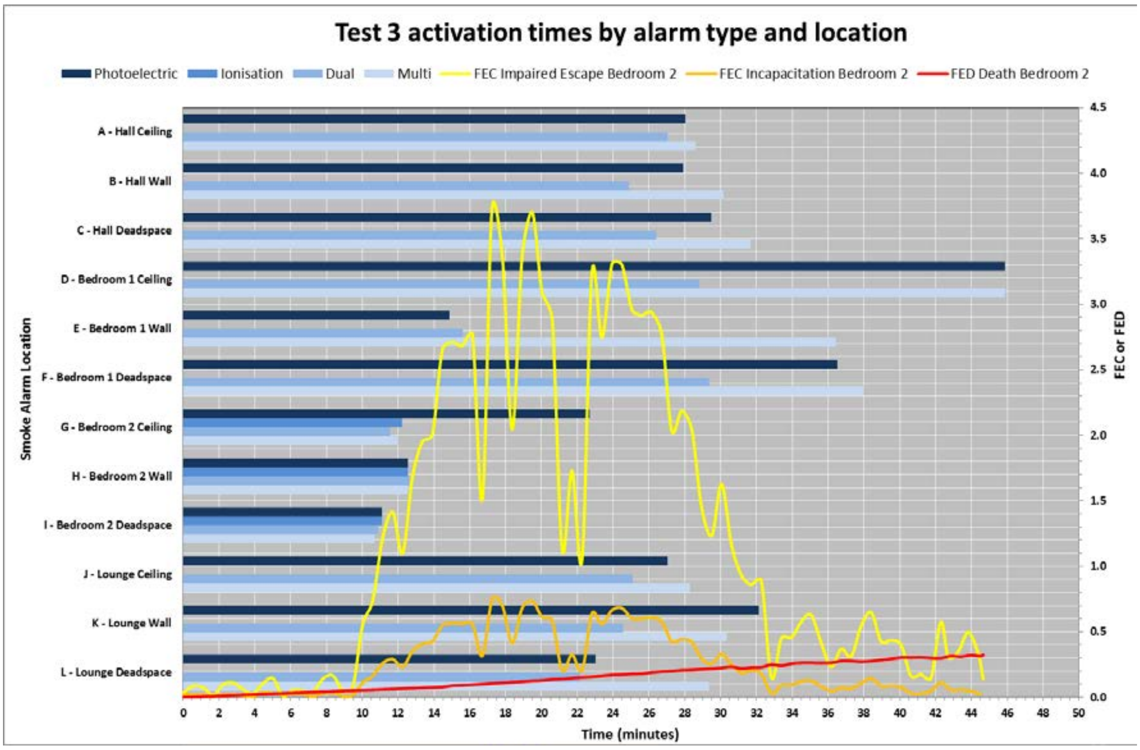

Figure 18 Scenario 2, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 2 FECs for impaired escape and incapacitation, and asphyxiation FED.

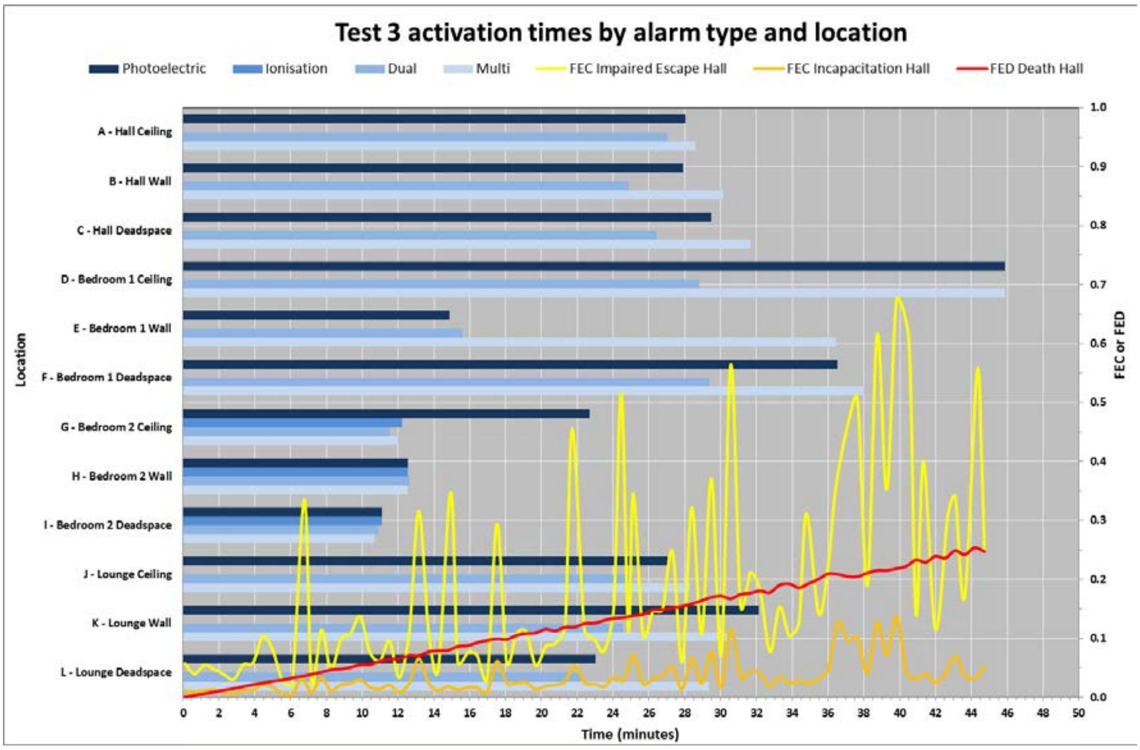

Figure 19 Scenario 2, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 9 Scenario 2 Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Bedroom 2 tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	*-31.10*	*#N/A*	*-15.78*	*#N/A*	*-18.02*	*#N/A*	*-14.67*	*-26.90*	*-16.19*	*#N/A*	*-15.21*	*-16.76*
Hall Wall	*#N/A*	*#N/A*	*-13.77*	*#N/A*	*-18.13*	*#N/A*	*-15.37*	*#N/A*	*-16.08*	*#N/A*	*-13.04*	*-18.30*
Hall Dead-space	*#N/A*	*#N/A*	*-17.77*	*#N/A*	*-24.45*	*#N/A*	*-15.15*	*#N/A*	*-17.65*	*#N/A*	*-14.56*	*-19.84*
ROO Ceiling	*-0.86*	*-2.13*	5.20	5.32	0.43	1.08	2.06	1.20	*-10.85*	*-0.38*	0.28	*-0.16*
ROO Wall	3.82	0.10	3.92	3.40	1.31	0.43	1.20	0.76	*-0.70*	*-0.70*	*-0.82*	*-0.70*
ROO Dead-space	5.64	4.13	5.86	6.07	1.85	2.17	4.82	2.17	0.72	0.72	0.94	1.16

Table 10 Scenario 2 Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Hallway tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	*-14.37*	*#N/A*	0.95	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*
Hall Wall	*#N/A*	*#N/A*	2.96	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*
Hall Dead-space	*#N/A*	*#N/A*	*-1.04*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*
ROO Ceiling	15.88	14.60	21.93	22.05	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*
ROO Wall	20.55	16.83	20.65	20.13	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*
ROO Dead-space	22.37	20.86	22.59	22.80	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*	*#N/A*

Table 11 Scenario 2 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.00	0.90	0.61
Air Temp (°C)	20.04	22.95	24.61
Rel. Humidity (%)	36.78	27.50	30.62
Air Pressure (mbar)	1012.32	1009.18	1013.80

3.3 SCENARIO 3: Smouldering lounge fire in lounge room, Bedroom 2 door closed

In this scenario, a smouldering fire was initiated on the lounge in the crevice between the armrest and the seat cushion using the soldering iron heated to 350°C. The element was left in contact with three cotton batting sheets for six minutes and then removed. Firefighters then exited the building. The door to Bedroom 2 is closed during the test. The test was ended after 30 minutes at which time the smoulder had self-extinguished.

Figure 20 Before (left) and after (right) photographs of Scenario 3, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 12 Scenario 3 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	6.98	#N/A	7.20	7.53	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Hall Wall	8.40	-2.15	7.75	8.07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Hall Dead-space	6.98	-2.36	7.86	6.65	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Ceiling	-3.36	#N/A	-12.61	7.75	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Wall	6.19	-1.91	6.86	8.28	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Dead-space	-6.78	#N/A	-2.15	-6.24	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

The irritant gases contributing to escape impairment and incapacitation in the Hallway included acrolein (up to 7.2 ppm), formaldehyde (up to 3 ppm), phenol (up to 4.7 ppm) and nitrogen dioxide (up to 8.5 ppm).

Note that none of the alarms in Bedroom 2 were activated during the three tests.

Table 13 Scenario 3 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3	9:07	0:18	5:52	7:31	9:40	3:37
FEC IMPAIRED ESCAPE 1.0	18:34	5:18	13:39	31:01	17:52	11:13
FEC INCAPACITATION 0.3		14:24				
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

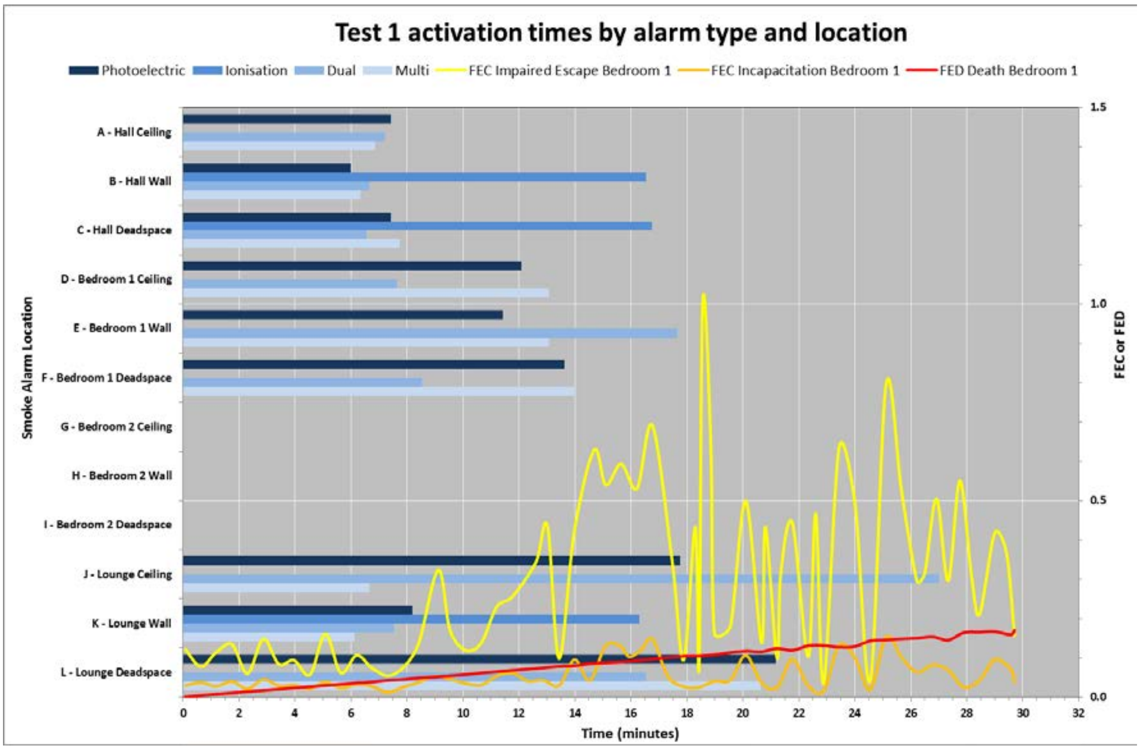

Figure 21 Scenario 3, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

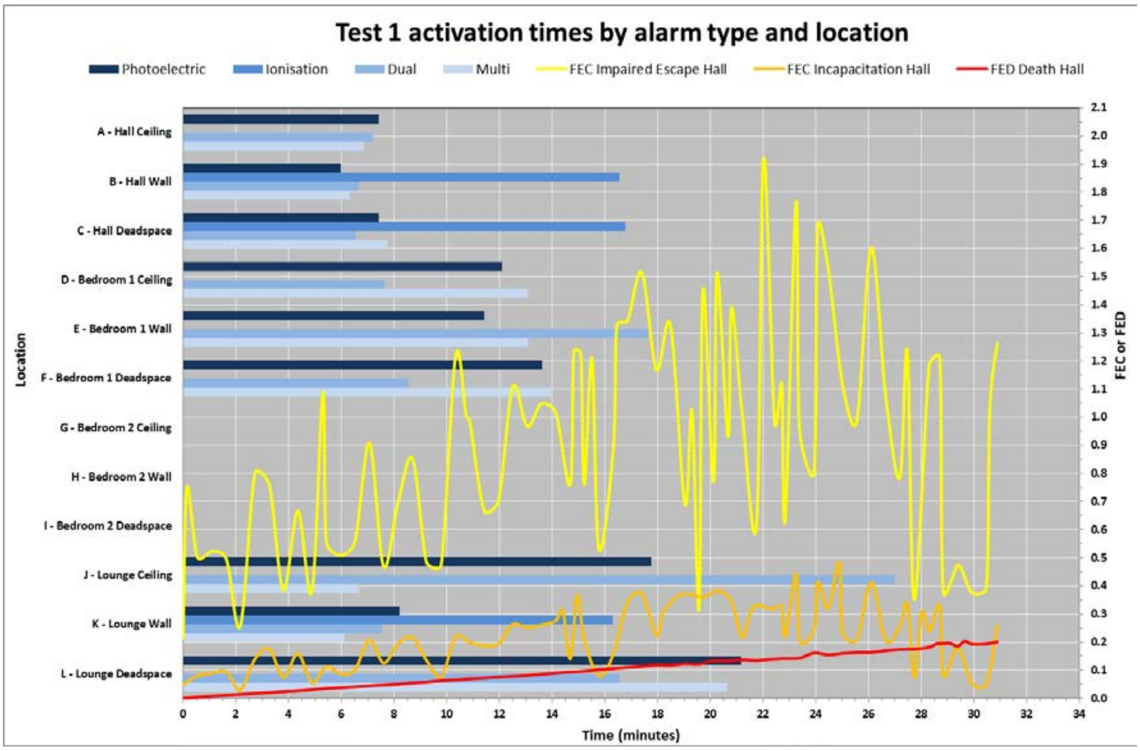

Figure 22 Scenario 3, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

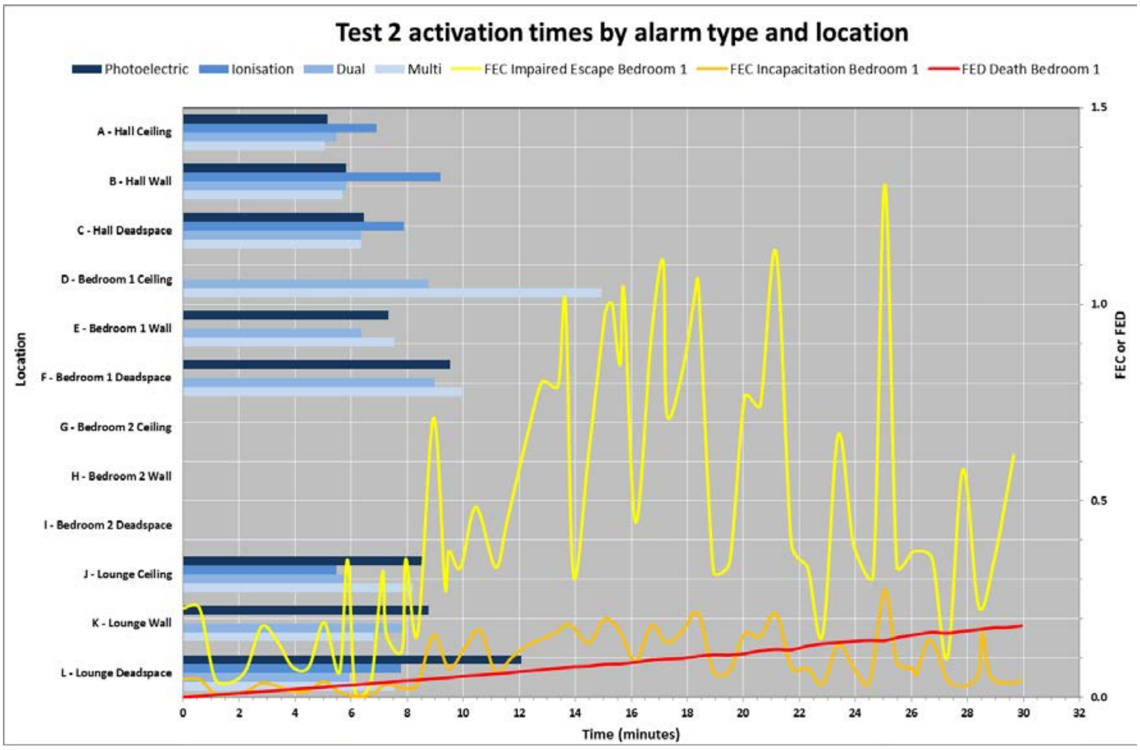

Figure 23 Scenario 3, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

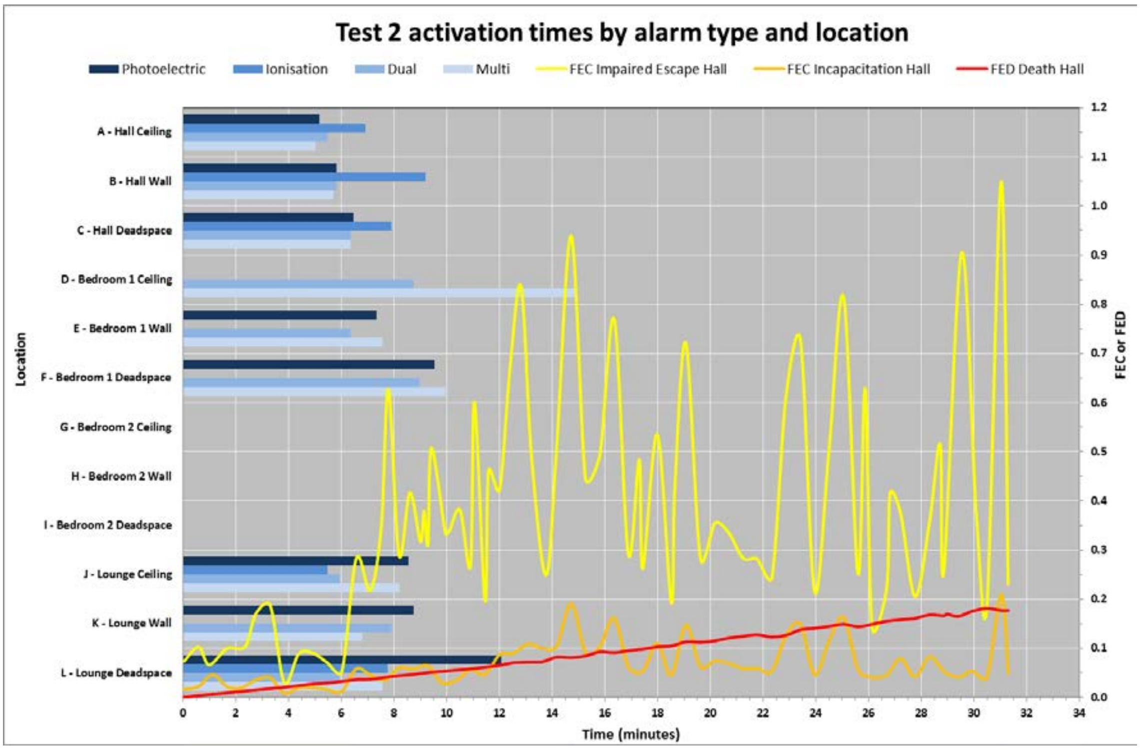

Figure 24 Scenario 3, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

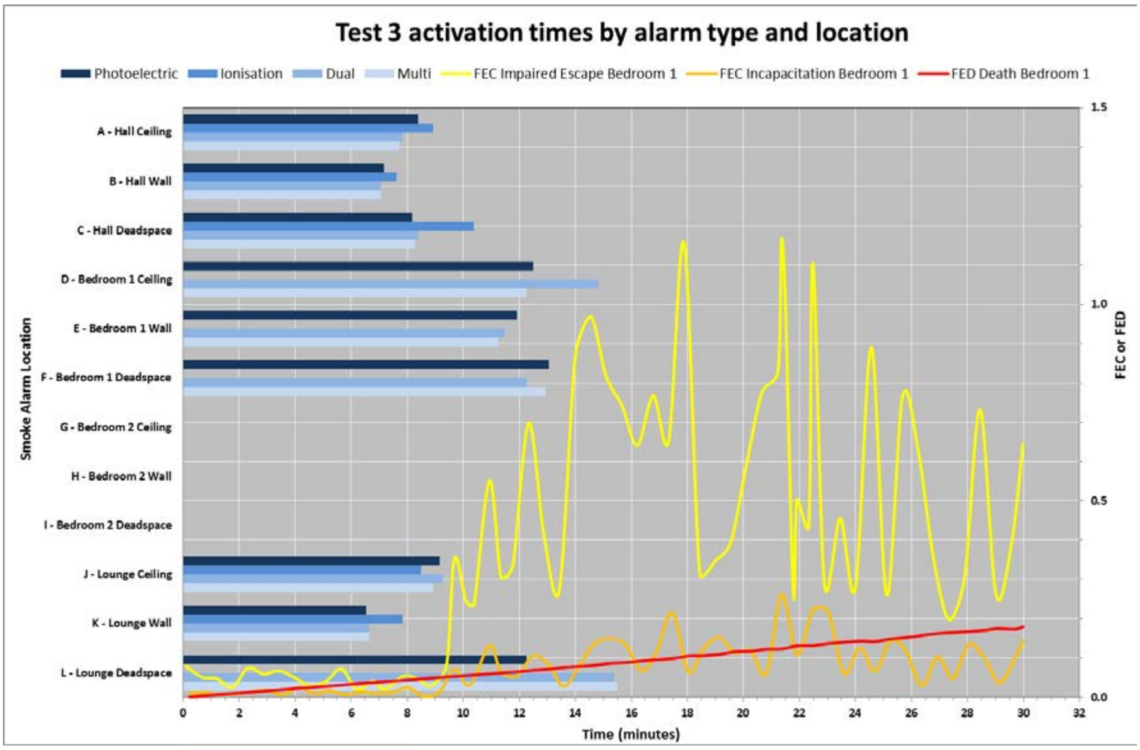

Figure 25 Scenario 3, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

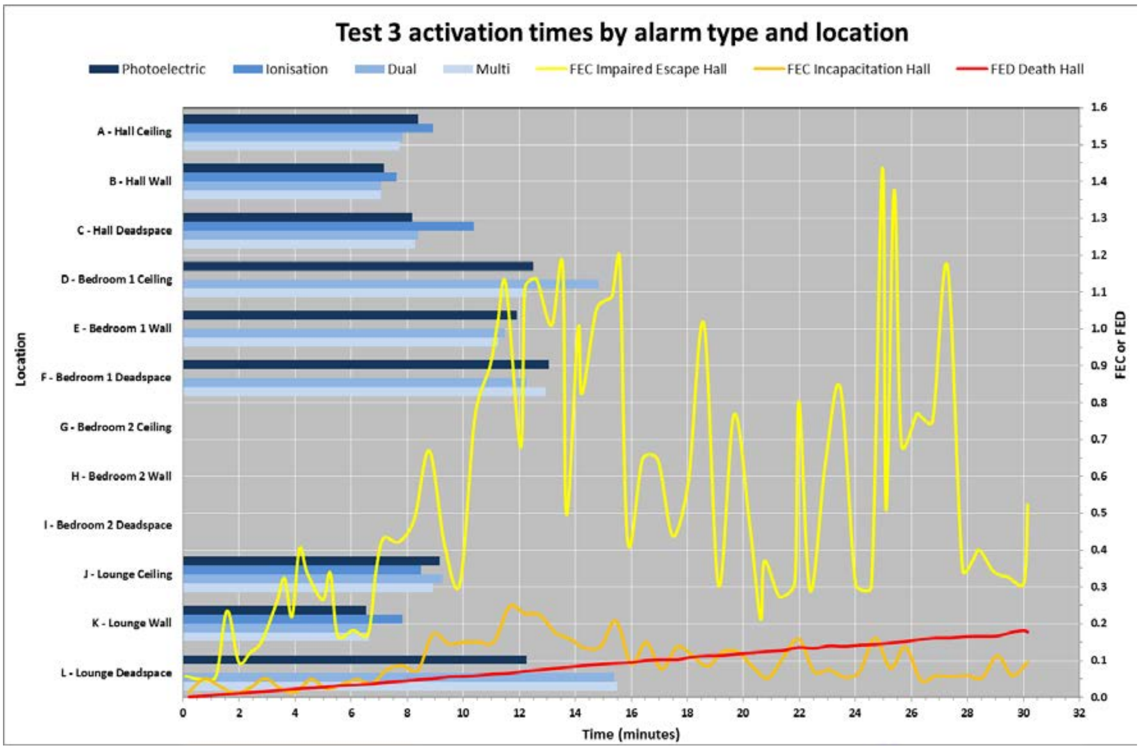

Figure 26 Scenario 3, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 14 Scenario 3 Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Hallway tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	6.98	14.40	7.20	7.53	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Hall Wall	8.40	-2.15	7.75	8.07	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Hall Dead-space	6.98	-2.36	7.86	6.65	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Ceiling	-3.36	14.40	-12.61	7.75	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Wall	6.19	-1.91	6.86	8.28	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Dead-space	-6.78	14.40	-2.15	-6.24	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Table 15 Scenario 3 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.60	0.59	0.78
Air Temp (°C)	15.21	19.88	22.48
Rel. Humidity (%)	48.80	32.07	20.33
Air Pressure (mbar)	1013.23	1011.11	1009.46

3.4 SCENARIO 5: Flaming bedding fire in Bedroom 2, bedroom doors open

In this scenario, a flaming fire was initiated on the polyester bed quilt using a butane barbeque lighter. The flame is left in contact with the quilt edge for 15 seconds and then removed. The fire was extinguished after 2-3 minutes.

The irritant gases contributing to escape impairment and incapacitation in Bedroom 2 included acrolein (up to 10.5 ppm), formaldehyde (up to 3.5 ppm), nitrogen dioxide (up to 28.5 ppm), phenol (up to 5 ppm) and sulfur dioxide (up to 3.5 ppm). The peak temperature measured in Bedroom 2 was 93.7°C at ceiling height, and 78.4°C at bed height. In this test, a dry sprinkler head was included in Bedroom 2. Video analysis showed that the sprinkler head cover released at a ceiling temperature between 52.2 and 63.4°C.

Figure 27 Before (left) and after (right) photographs of Scenario 5, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 16 Scenario 5 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	01:59	01:46	01:39	01:52	01:57	01:37	01:57	01:57	01:31	01:18	01:45	01:37
Hall Wall	01:59	01:33	01:46	01:52	01:51	01:37	01:57	01:57	01:45	01:31	01:45	01:37
Hall Dead-space	01:52	01:46	01:39	01:46	01:57	02:05	01:44	01:51	01:31	01:58	01:31	01:31
ROO Ceiling	01:06	00:46	00:46	01:00	01:17	00:50	01:24	01:10	01:11	00:44	00:44	00:51
ROO Wall	01:12	01:06	01:39	01:19	01:24	01:17	01:17	01:31	01:11	00:58	01:45	01:11
ROO Dead-space	01:19	01:00	01:33	01:06	01:37	01:04	01:10	01:24	01:04	00:58	01:04	01:04

Table 17 Scenario 5 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	ROO	Hall	ROO	Hall	ROO	Hall
FEC IMPAIRED ESCAPE 0.3	01:43	00:25	01:55	03:55	01:31	
FEC IMPAIRED ESCAPE 1.0	02:09	02:52	02:37		02:39	
FEC INCAPACITATION 0.3	02:09	04:04			02:46	
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

The tenability limit for irritant induced incapacitation is reached in Bedroom 2 in Tests 1 and 3 and in the Hallway in Test 1 only. The data shows that the presence of any ROO alarm would alert occupants before the tenability threshold is reached in the Hallway in Test 1, and provide a minimum of 2m25s for safe egress (up to 3m18s). For Hallway alarms, the ASET ranges between 2m5s and 2m31s.

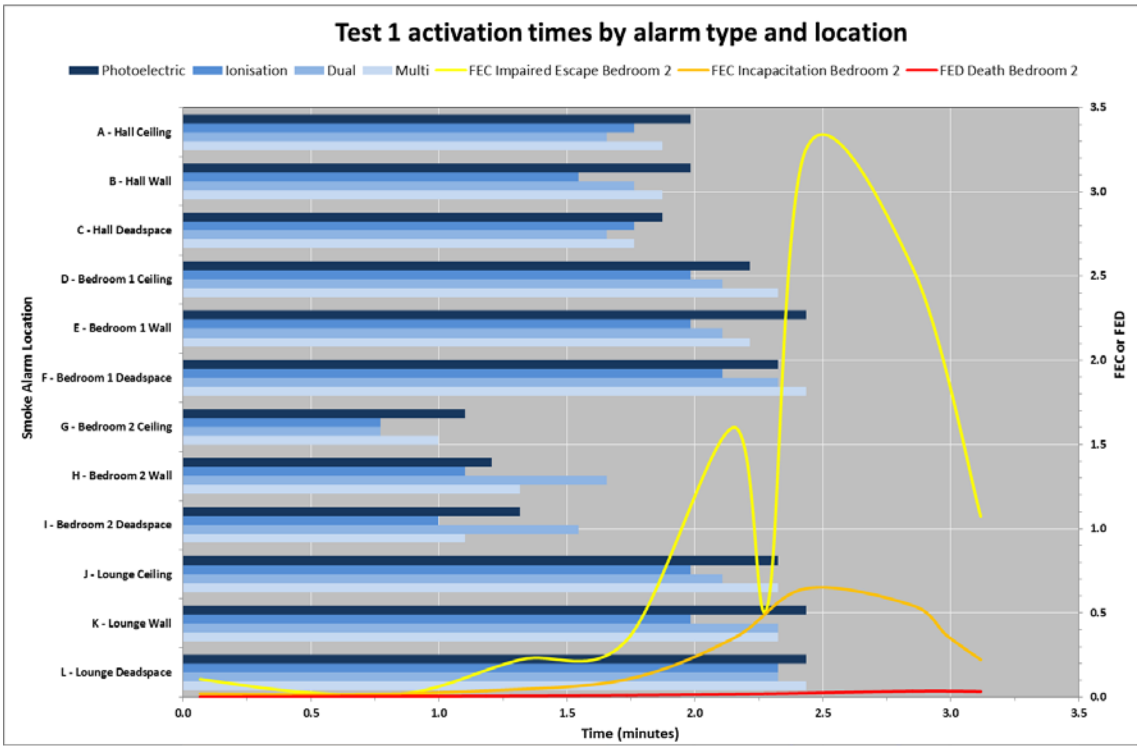

Figure 28 Scenario 5, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 2 FECs for impaired escape and incapacitation, and asphyxiation FED.

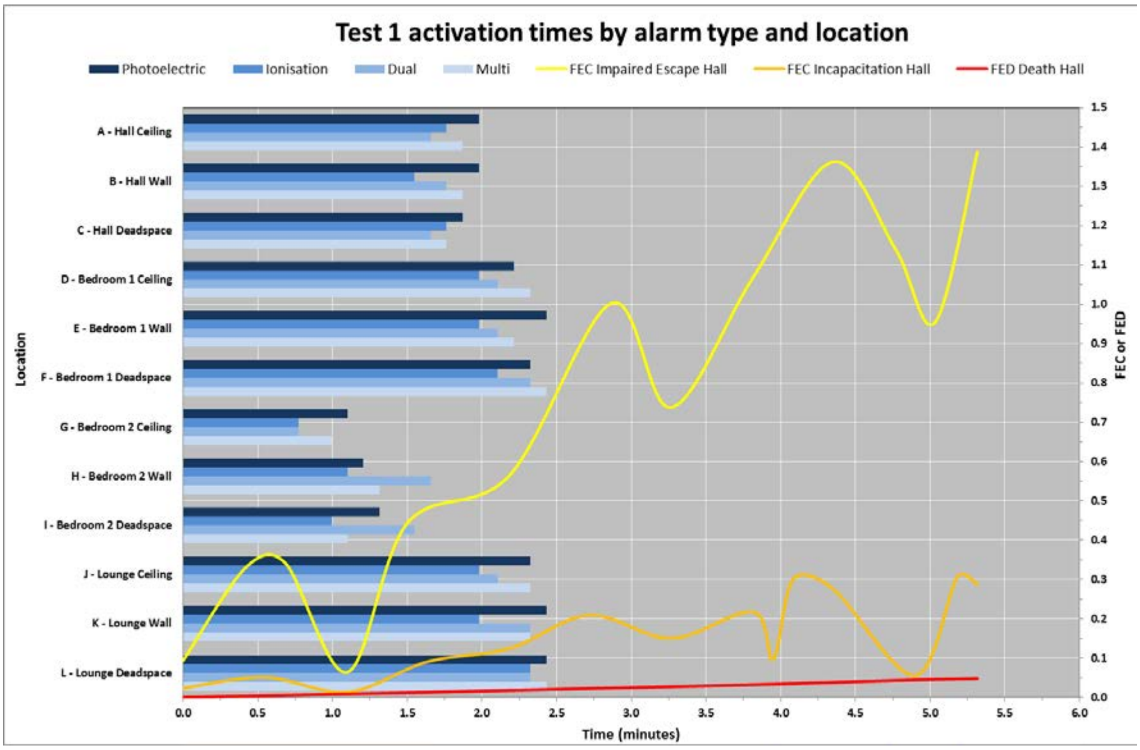

Figure 29 Scenario 5, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

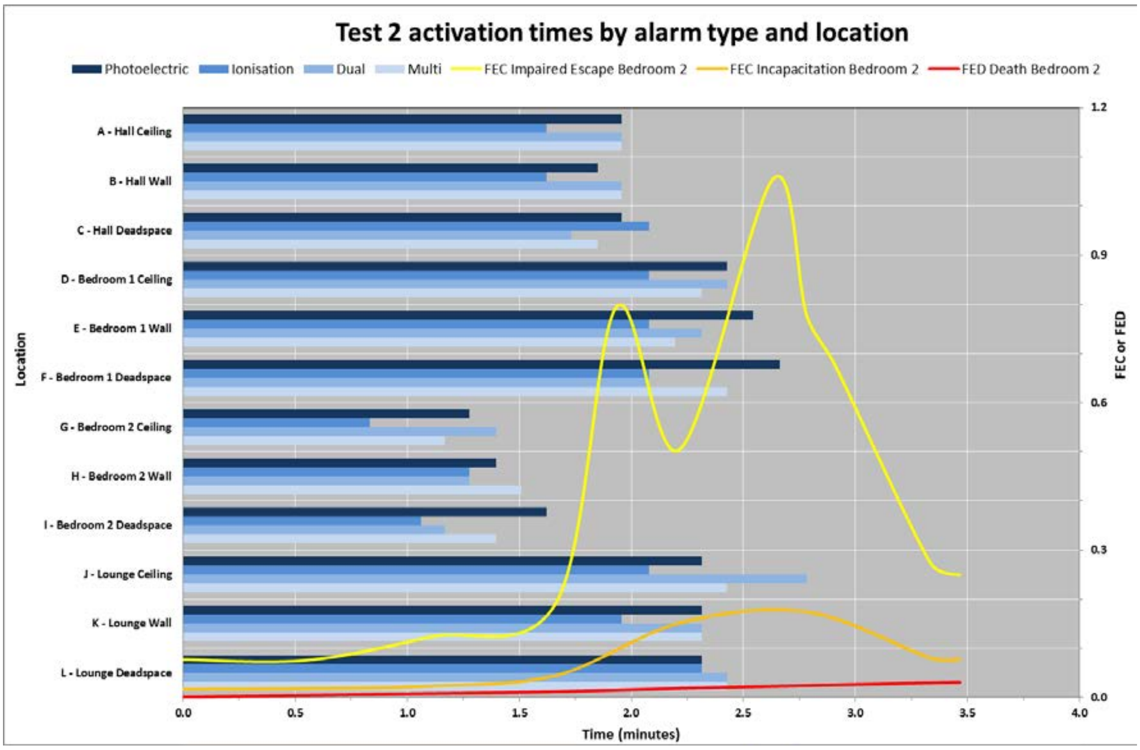

Figure 30 Scenario 5, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 2 FECs for impaired escape and incapacitation, and asphyxiation FED.

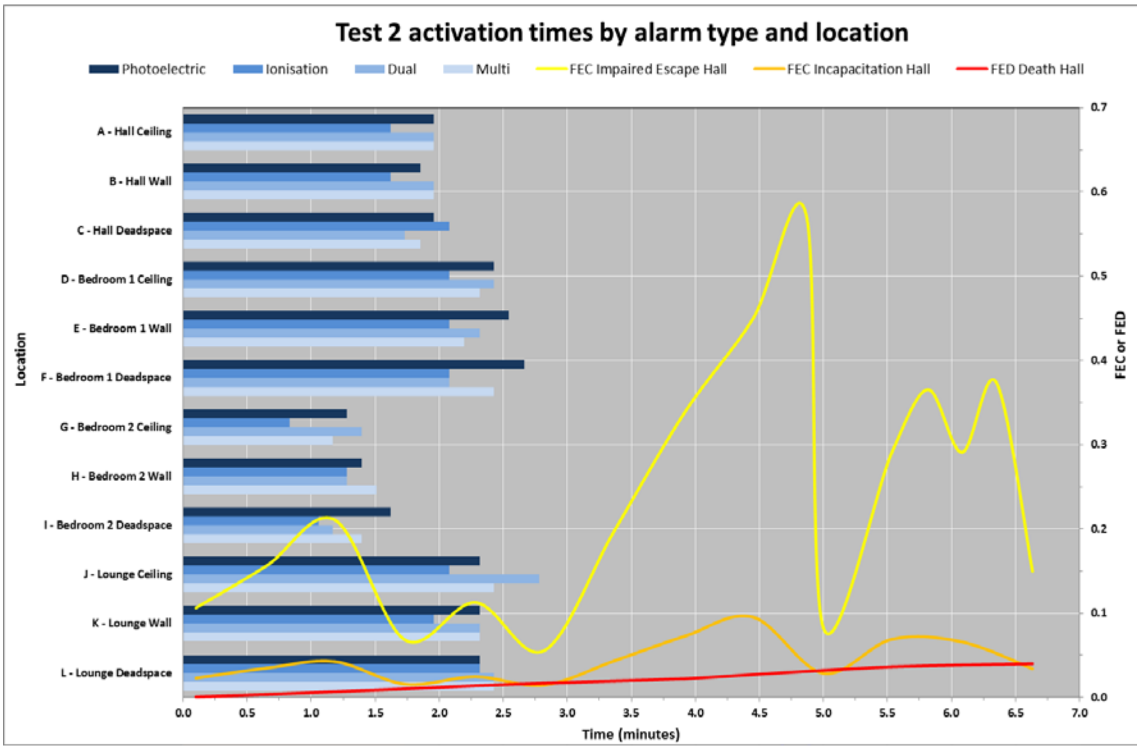

Figure 31 Scenario 5, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

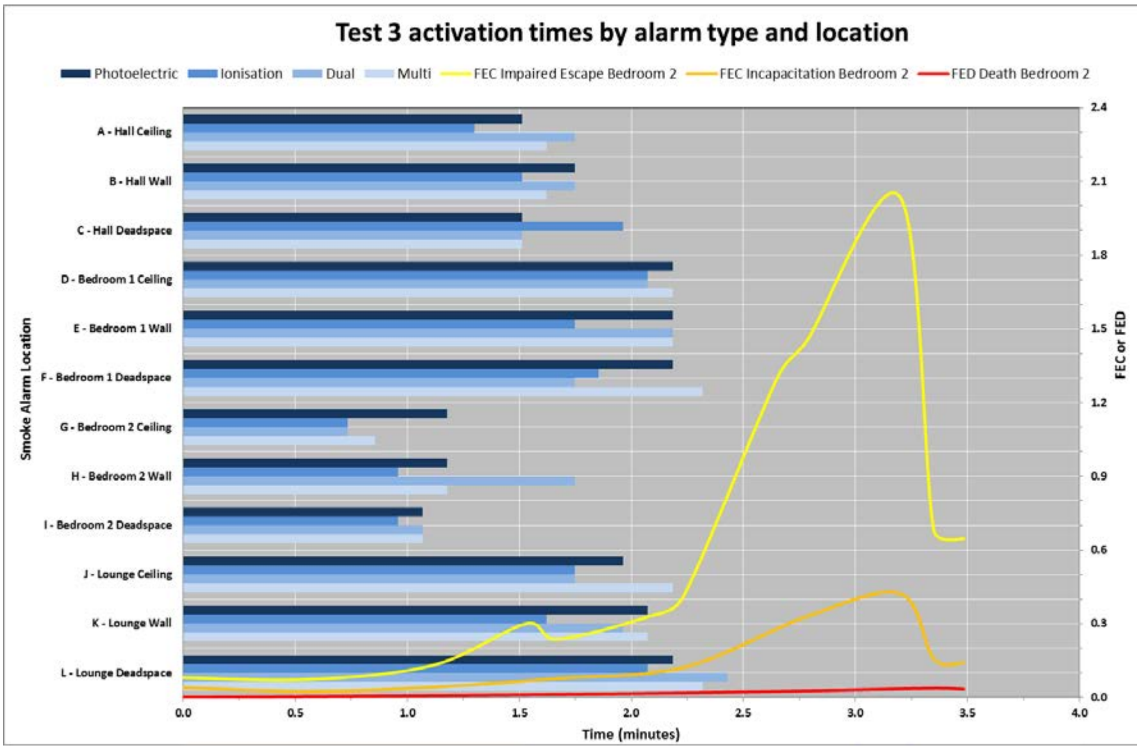

Figure 32 Scenario 5, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

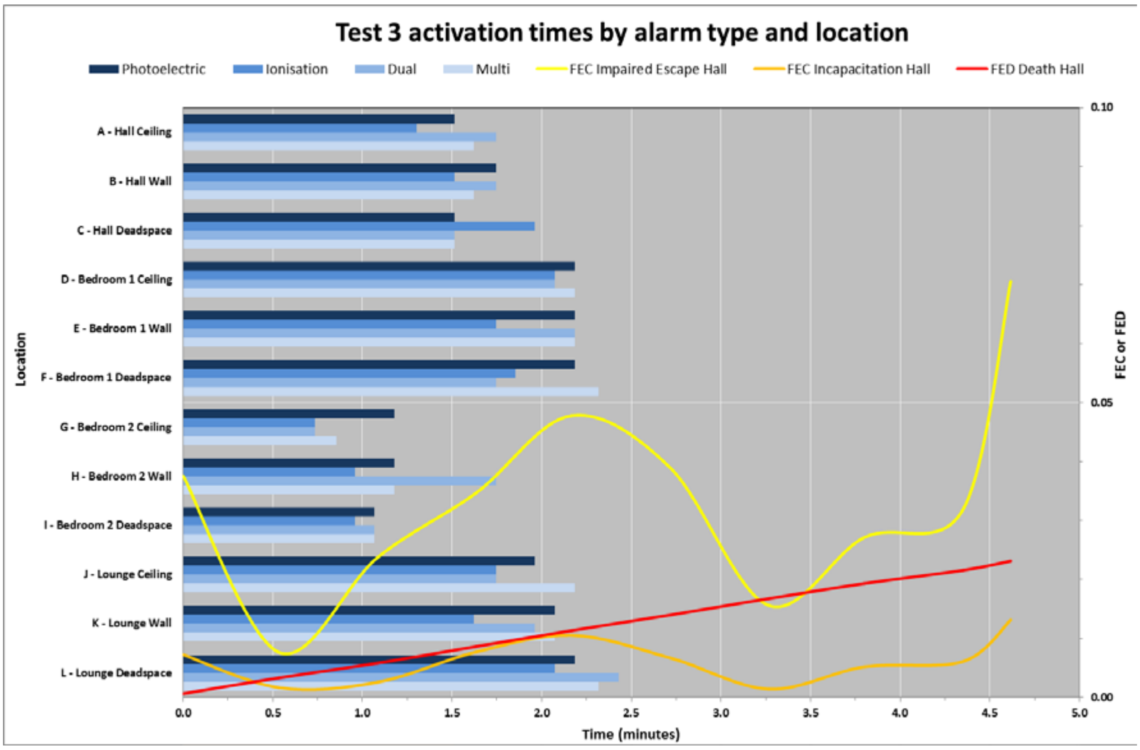

Figure 33 Scenario 5, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 18 Scenario 5 Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Bedroom 2 tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	0.17	0.39	0.49	0.28	#N/A	#N/A	#N/A	#N/A	1.27	1.48	1.04	1.16
Hall Wall	0.17	0.60	0.39	0.28	#N/A	#N/A	#N/A	#N/A	1.04	1.27	1.04	1.16
Hall Dead-space	0.28	0.39	0.49	0.39	#N/A	#N/A	#N/A	#N/A	1.27	0.82	1.27	1.27
ROO Ceiling	1.05	1.38	1.38	1.15	#N/A	#N/A	#N/A	#N/A	1.60	2.05	2.05	1.93
ROO Wall	0.94	1.05	0.49	0.83	#N/A	#N/A	#N/A	#N/A	1.60	1.82	1.04	1.60
ROO Dead-space	0.83	1.15	0.60	1.05	#N/A	#N/A	#N/A	#N/A	1.72	1.82	1.72	1.72

Table 19 Scenario 5 Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Hallway tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	2.10	2.32	2.43	2.21	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Hall Wall	2.10	2.54	2.32	2.21	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Hall Dead-space	2.21	2.32	2.43	2.32	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Ceiling	2.98	3.31	3.31	3.09	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Wall	2.88	2.98	2.43	2.77	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Dead-space	2.77	3.09	2.54	2.98	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Table 20 Scenario 5 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.47	0.88	1.21
Air Temp (°C)	26.24	27.30	27.13
Rel. Humidity (%)	40.68	33.96	34.54
Air Pressure (mbar)	1008.24	1007.51	1007.76

3.5 SCENARIO 7a: Smouldering bedding fire in Bedroom 1, doors open

In this scenario, a smouldering fire was initiated on the bed using the soldering iron heated to 350°C. The element was left in contact with three cotton batting sheets for six minutes and then removed. Firefighters then exited the room leaving the bedroom door open. The test ended after 30 minutes at which time the smoulder had self-extinguished.

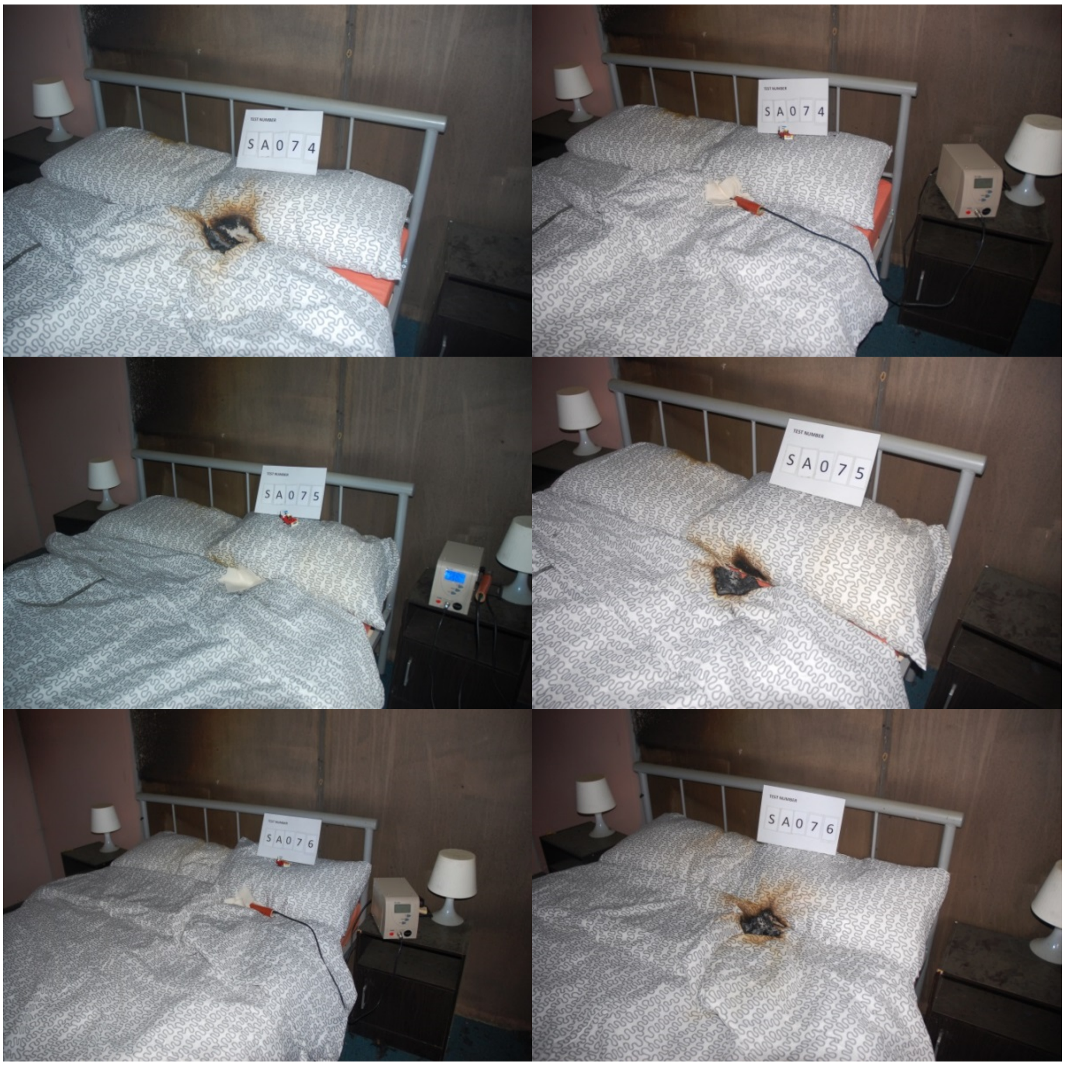

Figure 34 Before (left) and after (right) photographs of Scenario 7a, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 21 Scenario 7a smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	29:59	10:44	10:37	15:12			19:46				29:25	
Hall Wall	10:03	09:44	10:03	10:03							21:54	
Hall Dead-space	08:58		23:47	08:51	08:53	11:19	09:52	08:25	13:59		13:46	13:40
ROO Ceiling	05:49	06:15	05:55	05:37	04:33	05:41	05:28	04:20	07:14	07:39	07:33	07:00
ROO Wall	06:53	07:39	07:01	07:01	05:54	05:35	05:48	05:41	07:58	08:30	07:33	08:30
ROO Dead-space	05:23	05:16	05:23	05:10	05:07	04:46	05:07	04:20	07:58	07:39	07:39	08:05

The main constituents of the irritant gases detected in Bedroom 1 included acrolein (up to 9.1 ppm), and formaldehyde (up to 3.8 ppm).

Table 22 Scenario 7a Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	ROO	Hall	ROO	Hall	ROO	Hall
FEC IMPAIRED ESCAPE 0.3	03:25		05:54	14:10	00:54	
FEC IMPAIRED ESCAPE 1.0	04:49		08:24		09:23	
FEC INCAPACITATION 0.3	05:39		09:55		09:55	
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3		31:10	28:34	29:39	26:29	28:00
FED ASPHYXIATION 1.0						

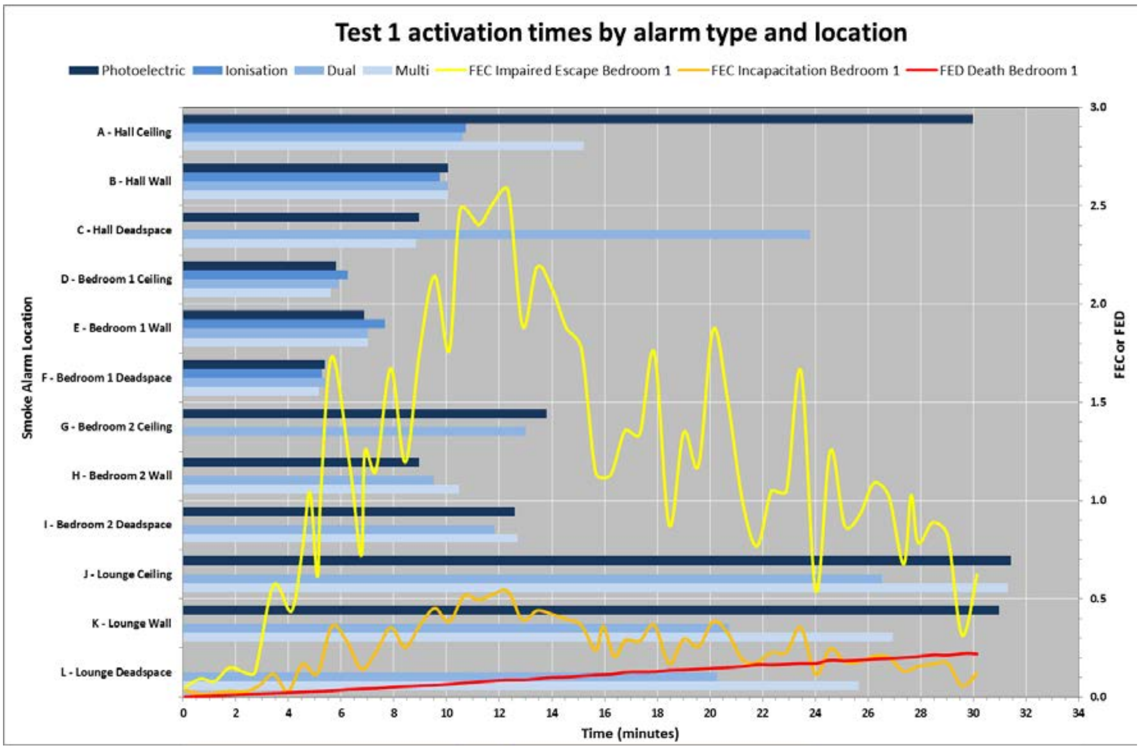

Figure 35 Scenario 7a, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

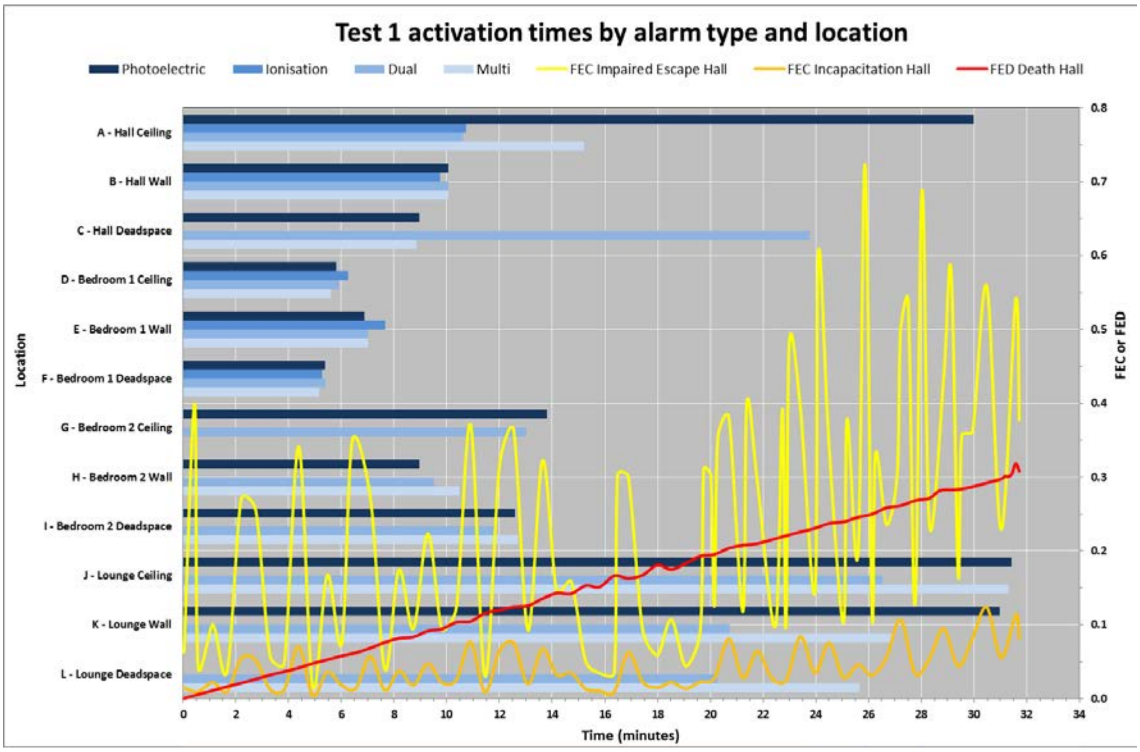

Figure 36 Scenario 7a, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

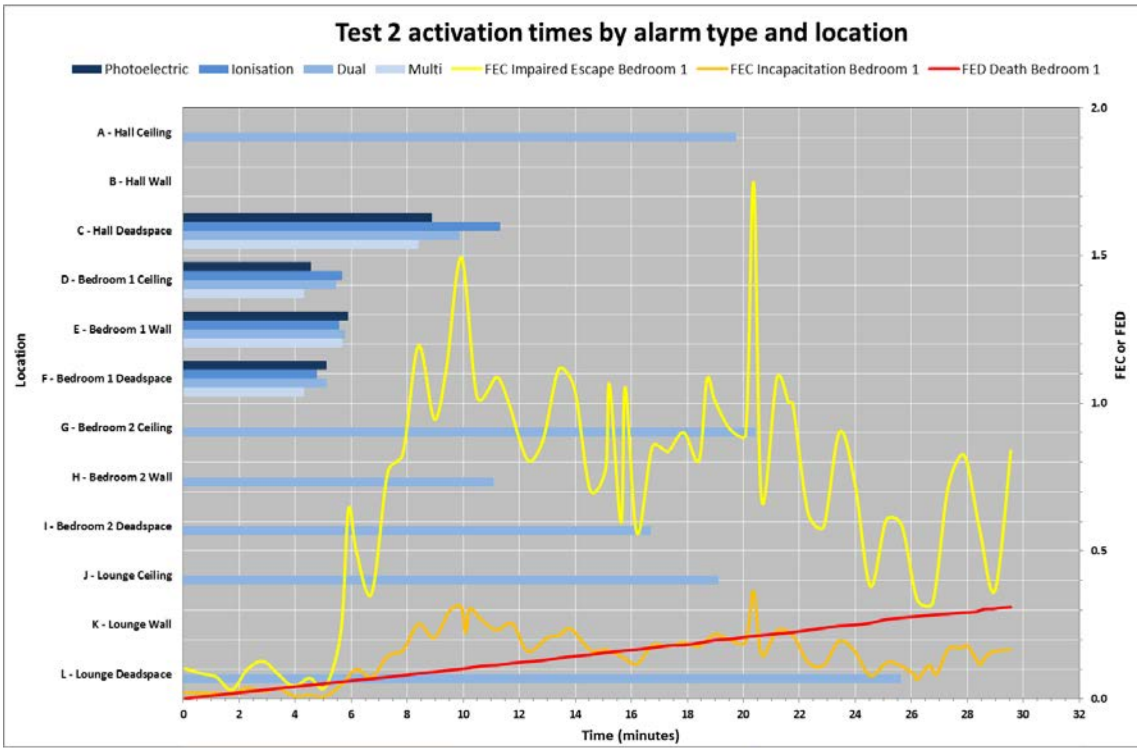

Figure 37 Scenario 7a, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

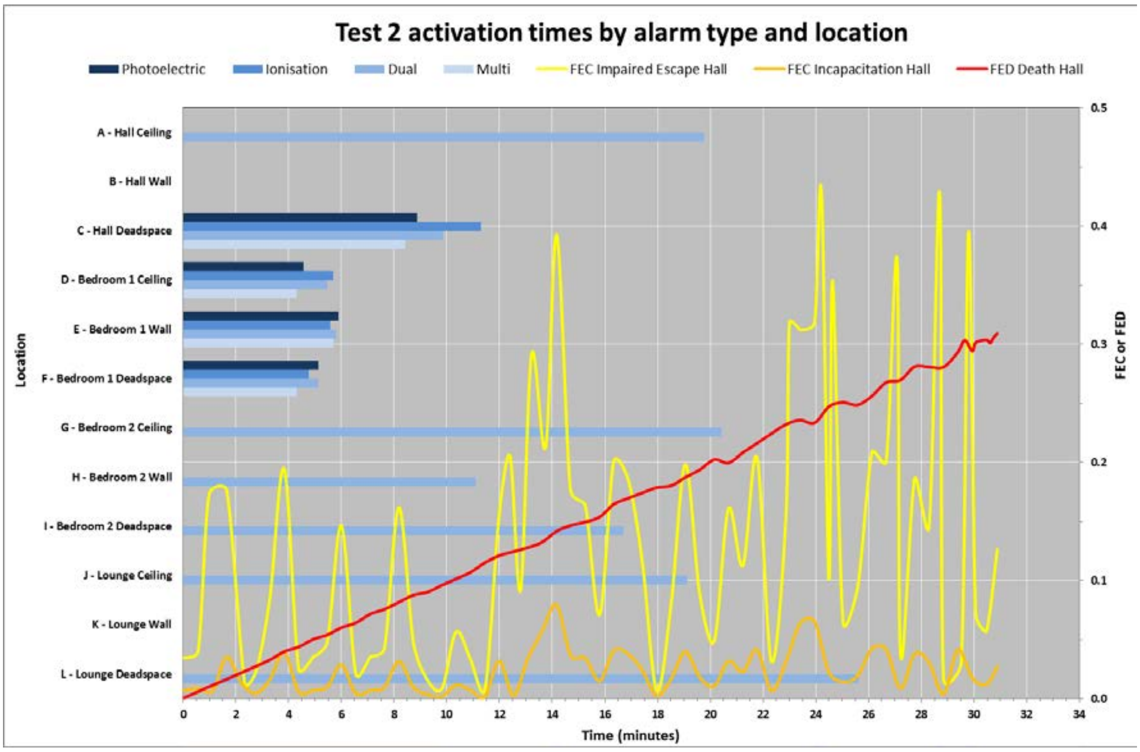

Figure 38 Scenario 7a, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

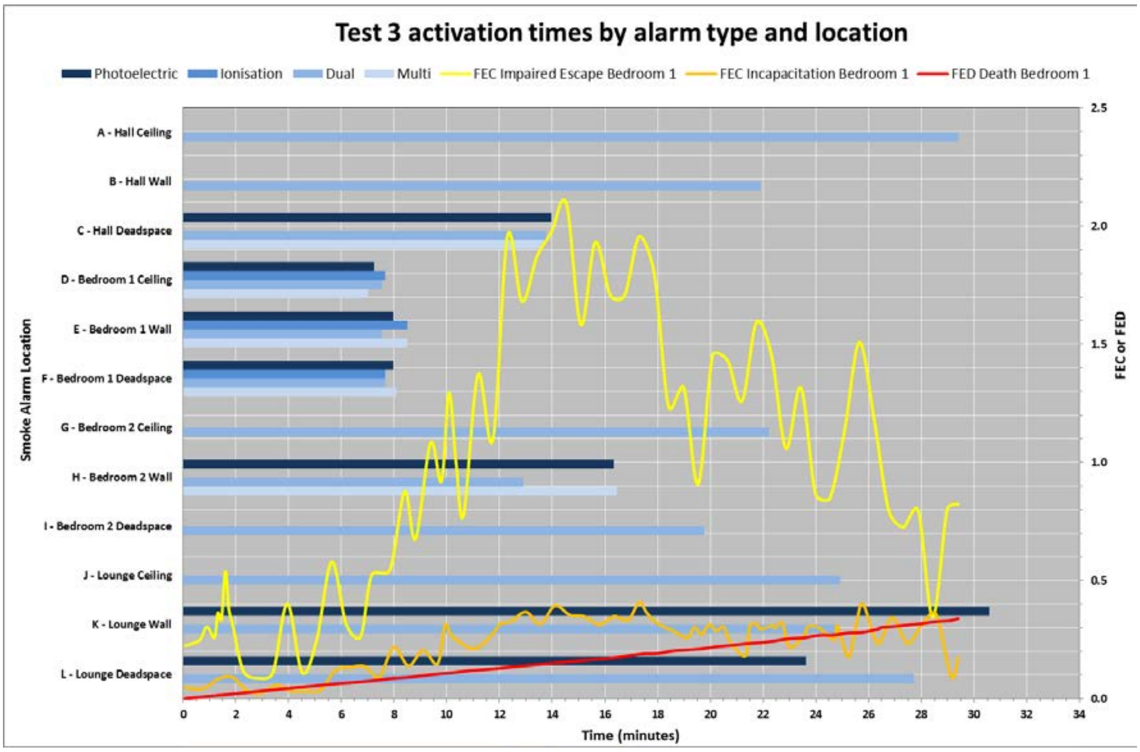

Figure 39 Scenario 7a, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

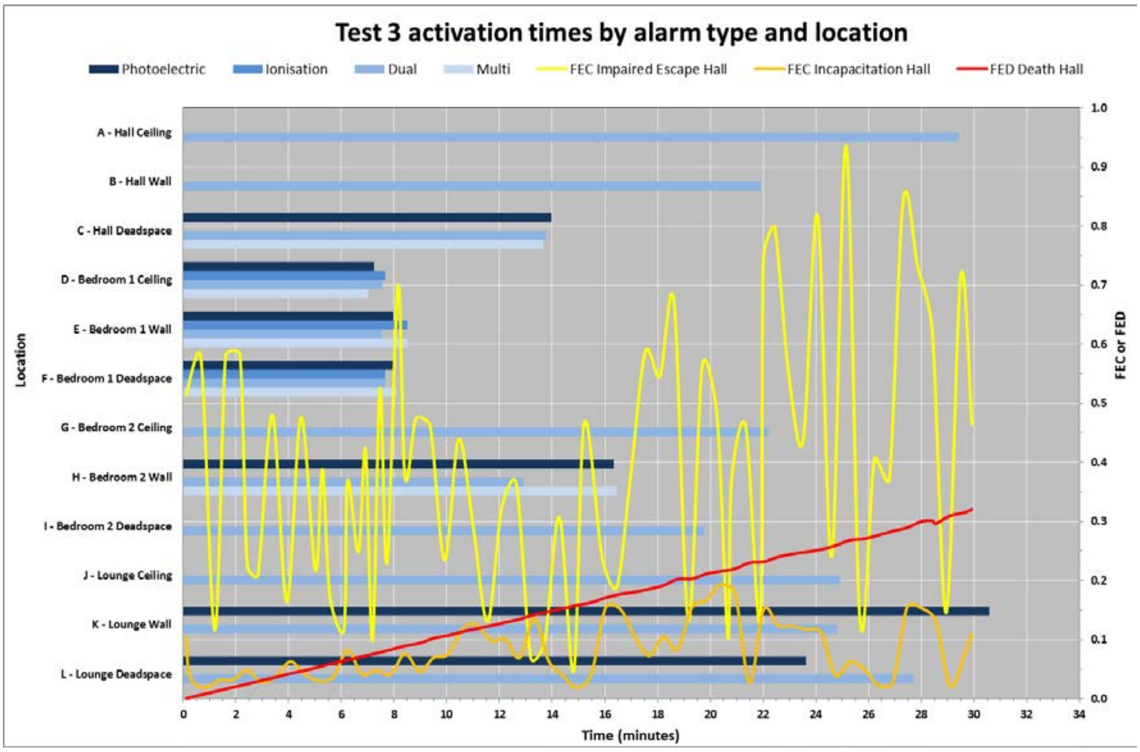

Figure 40 Scenario 7a, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 23 Scenario 7a Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Bedroom 1 tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	-24.34	-5.08	-4.96	-9.55	#N/A	#N/A	-9.83	#N/A	#N/A	#N/A	-19.48	#N/A
Hall Wall	-4.41	-4.09	-4.41	-4.41	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	-11.97	#N/A
Hall Dead-space	-3.32	#N/A	-18.13	-3.21	1.05	-1.38	0.07	1.52	-4.05	#N/A	-3.84	-3.73
ROO Ceiling	-0.17	-0.61	-0.27	0.04	5.38	4.24	4.46	5.61	2.70	2.28	2.38	2.93
ROO Wall	-1.24	-2.01	-1.36	-1.36	4.03	4.35	4.14	4.24	1.96	1.43	2.38	1.43
ROO Dead-space	0.27	0.38	0.27	0.48	4.81	5.16	4.81	5.61	1.96	2.28	2.28	1.86

Table 24 Scenario 7a atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.41	0.74	1.14
Air Temp (°C)	17.86	19.18	17.23
Rel. Humidity (%)	48.07	40.89	42.51
Air Pressure (mbar)	999.06	998.73	1000.71

3.6 SCENARIO 7b: Smouldering bedding fire in Bedroom 1, doors open, cigarette ignition

In this scenario, a smouldering fire was initiated on the bed using a lit cigarette. The cigarette was left in contact with three cotton batting sheets for the duration of the test. The test ended after 30 minutes at which time the smoulder had self- extinguished.

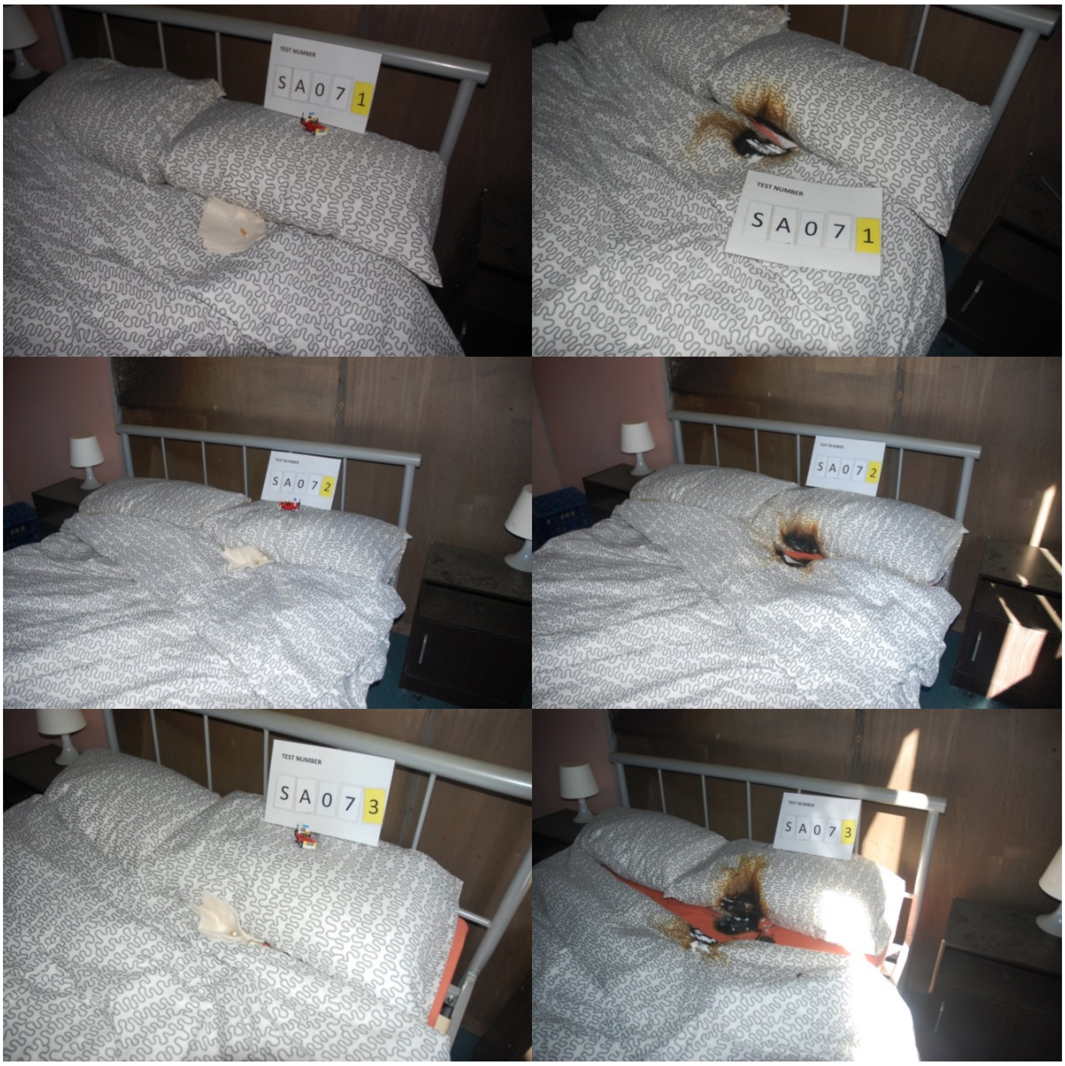

Figure 41 Before (left) and after (right) photographs of Scenario 7b, Tests 1 (top), 2 (middle) and 3 (bottom).

The main irritant gases detected in Bedroom 1 included acrolein (up to 13.4 ppm), formaldehyde (up to 5.6 ppm) and sulfur dioxide (up to 2.3 ppm).

Table 25 Scenario 7b smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling			24:50				26:34				26:21	
Hall Wall												
Hall Dead-space	15:00		14:27	14:53	11:27	15:22	12:32	11:21	13:17	14:30	13:51	13:17
ROO Ceiling	10:22	10:22	10:29	11:03	09:16	11:21	10:41	09:03	11:44	12:05	10:50	12:11
ROO Wall	11:03	14:01	10:10	10:55	09:56	09:50	10:03	10:03	13:04	14:23	11:52	12:56
ROO Dead-space	10:42	10:22	07:31	08:18	09:29	09:23	09:50	08:29	12:05	11:52	13:04	11:17

Table 26 Scenario 7b Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	ROO	Hall	ROO	Hall	ROO	Hall
FEC IMPAIRED ESCAPE 0.3	04:30		03:25		00:54	
FEC IMPAIRED ESCAPE 1.0	17:18		07:52		11:20	
FEC INCAPACITATION 0.3	17:26		12:52		11:45	
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3			27:05		28:18	
FED ASPHYXIATION 1.0						

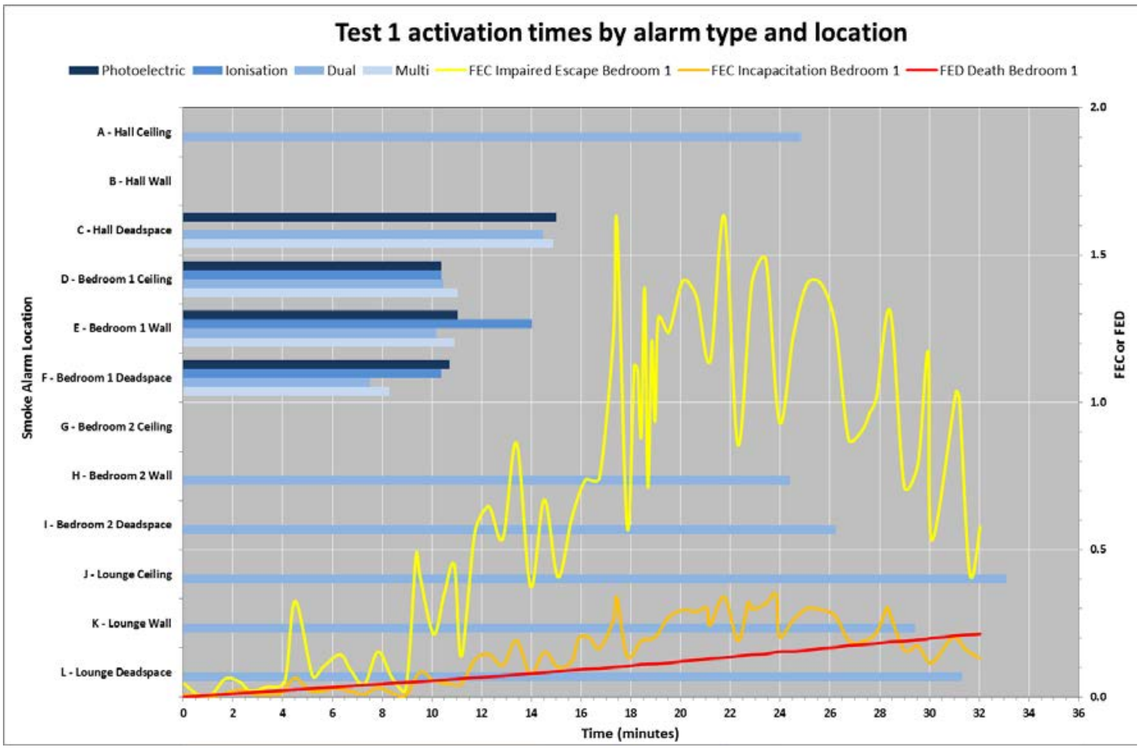

Figure 42 Scenario 7b, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

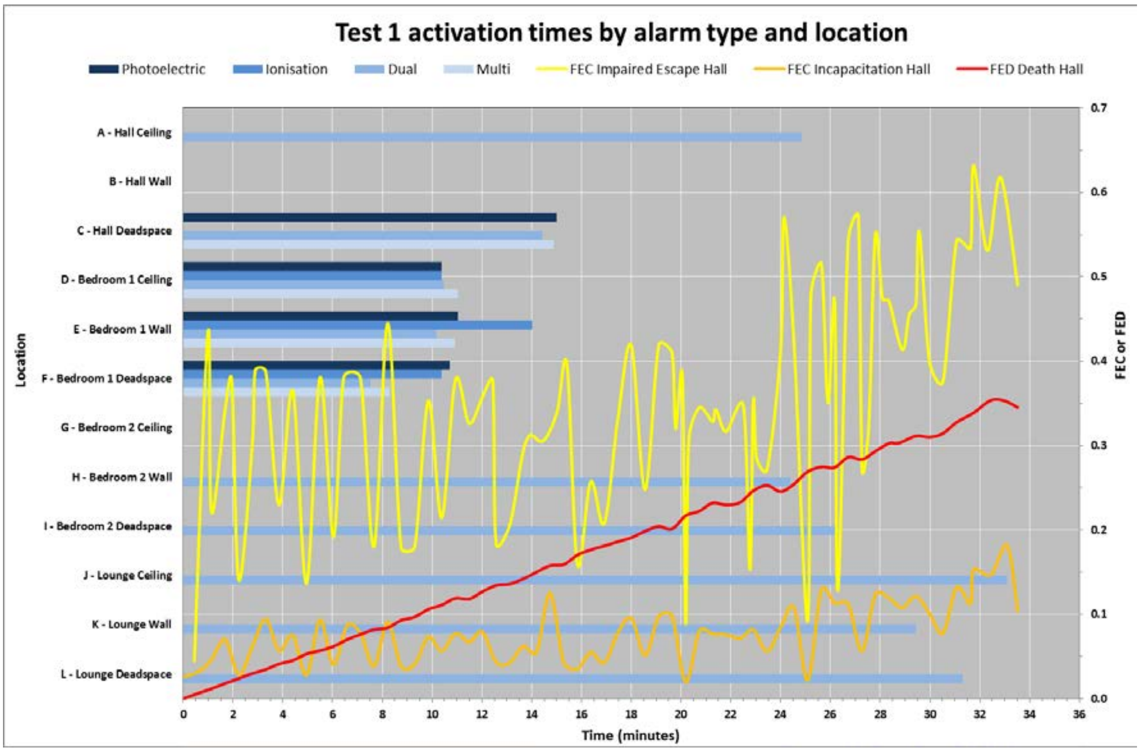

Figure 43 Scenario 7b, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

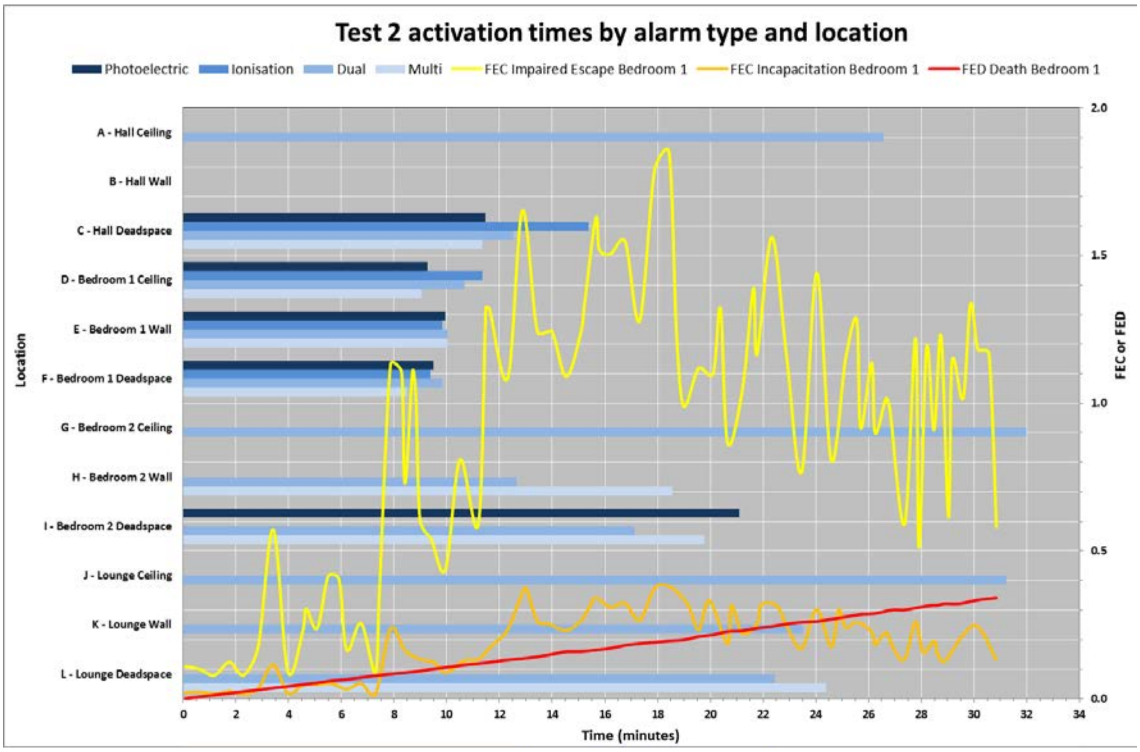

Figure 44 Scenario 7b, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

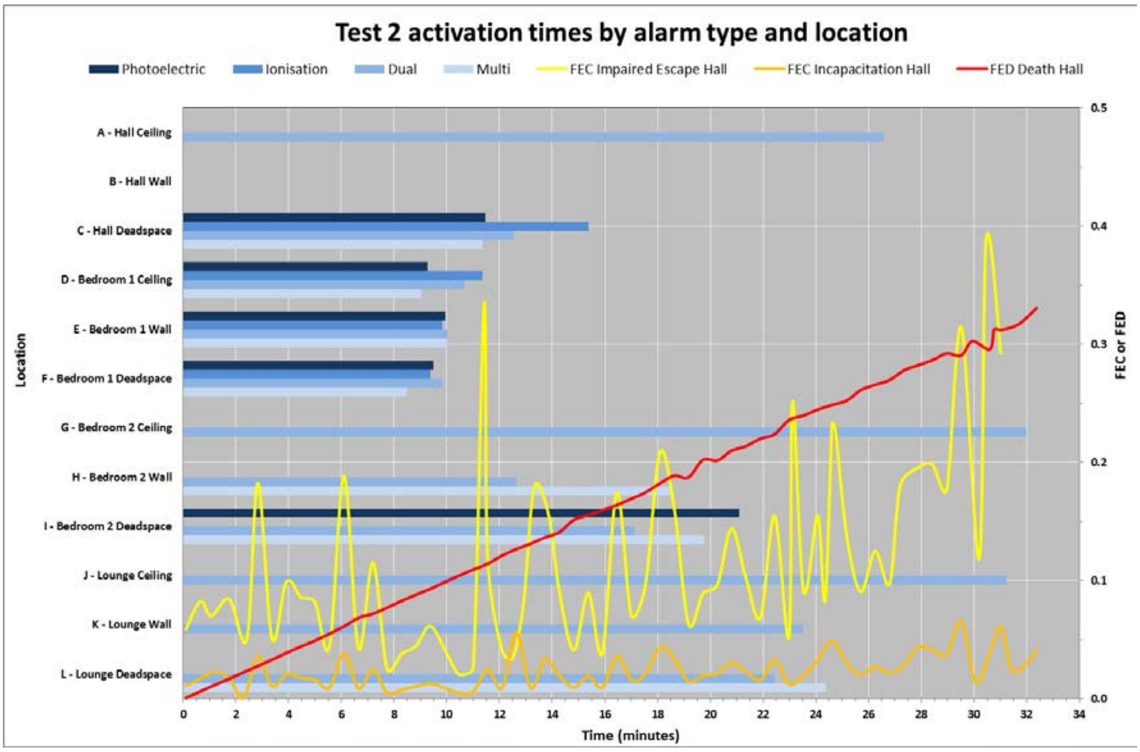

Figure 45 Scenario 7b, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

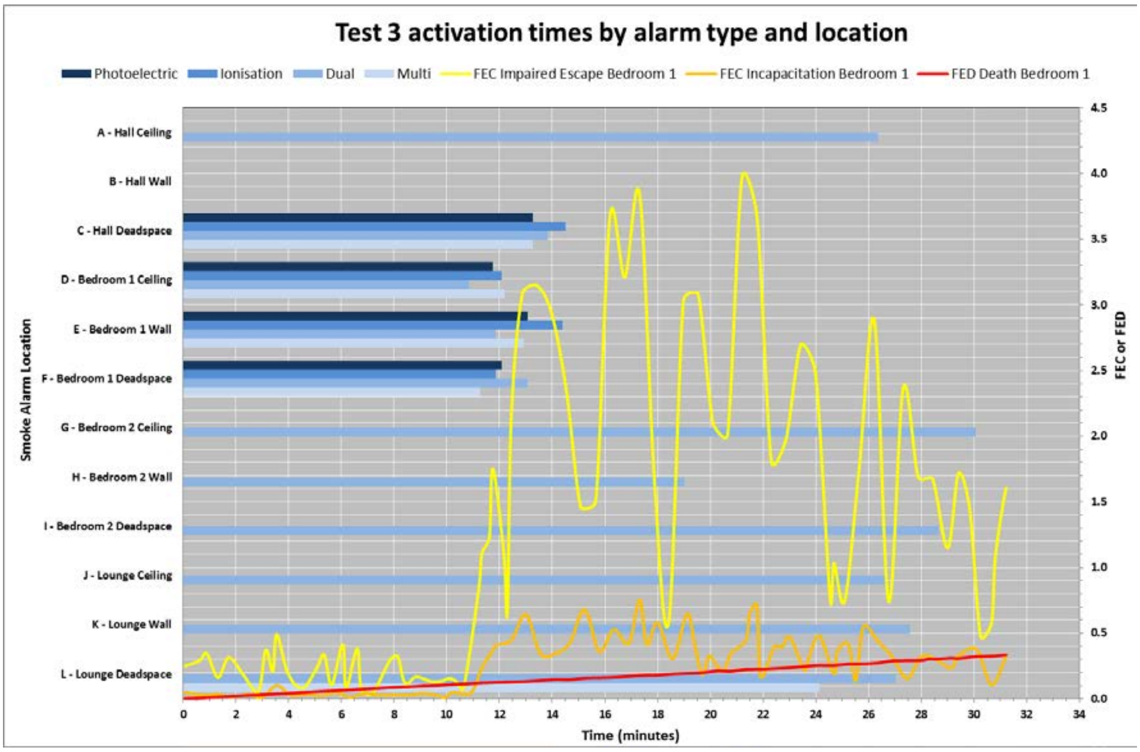

Figure 46 Scenario 7b, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

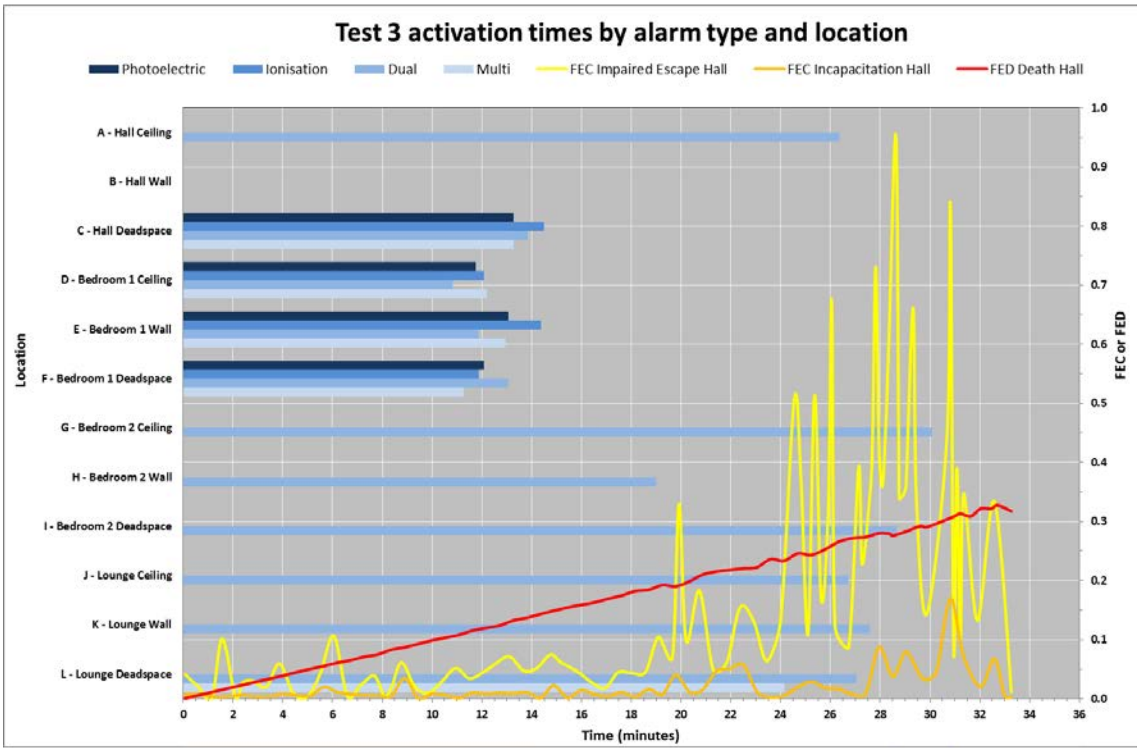

Figure 47 Scenario 7b, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 27 Scenario 7b Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Bedroom 1 tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	#N/A	#N/A	-7.39	#N/A	#N/A	#N/A	-13.70	#N/A	#N/A	#N/A	-14.60	#N/A
Hall Wall	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Hall Dead-space	2.43	#N/A	2.98	2.55	1.41	-2.50	0.33	1.52	-1.53	-2.75	-2.09	-1.53
ROO Ceiling	7.06	7.06	6.95	6.39	3.60	1.52	2.18	3.81	0.01	-0.33	0.91	-0.44
ROO Wall	6.39	3.42	7.27	6.51	2.93	3.04	2.82	2.82	-1.31	-2.64	-0.11	-1.19
ROO Dead-space	6.73	7.06	9.91	9.13	3.38	3.49	3.04	4.38	-0.33	-0.11	-1.31	0.47

Table 28 Scenario 7b atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.78	0.79	1.01
Air Temp (°C)	18.13	19.77	19.62
Rel. Humidity (%)	40.41	37.26	39.91
Air Pressure (mbar)	995.65	995.09	994.89

3.7 SCENARIO 10: Flaming fire in Bedroom 1, bedroom doors open

In this scenario, a flaming fire was initiated on the bed quilt using a butane barbeque lighter. The flame is left in contact with the quilt edge for 15 seconds and then removed. The fire was extinguished after two minutes.

Figure 48 Before (left) and after (right) photographs of Scenario 10, Tests 1 (top), 2 (middle) and 3 (bottom).

The main constituents of the irritant gases detected in Bedroom 1 included acrolein at 2.9 ppm, 4.7 ppm, and 2.9 ppm in Tests 1, 2 and 3 respectively, and formaldehyde at 2.9 ppm, 4.6 ppm and 1.8 ppm.

The peak temperature measured in Bedroom 1 was 100°C at ceiling height (Test 2), and 83.5°C at bed height (Test 3).

Table 29 Scenario 10 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	01:38	01:19	01:38	01:32	01:21	01:08	01:08	01:14	02:12	01:25	01:19	01:32
Hall Wall	01:38	01:19	01:26	01:32	01:14	01:08	01:21	01:14	01:39	01:19	01:32	01:39
Hall Dead-space	01:32	01:19	01:19	01:26	01:08	01:00	01:08	01:00	01:25	01:12	01:25	01:25
ROO Ceiling	01:06	00:39	00:47	00:59	00:54	00:41	00:47	00:47	#N/A	00:45	00:52	00:45
ROO Wall	01:12	00:53	01:52	01:06	00:54	00:47	00:54	00:54	00:52	00:58	00:58	01:12
ROO Dead-space	01:12	00:53	01:26	01:06	01:00	00:47	00:54	00:54	00:58	00:39	00:45	00:52

Table 30 Scenario 10 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	ROO	Hall	ROO	Hall	ROO	Hall
FEC IMPAIRED ESCAPE 0.3	00:54	02:35	00:01	02:40	01:17	
FEC IMPAIRED ESCAPE 1.0	01:03		00:18	03:30	01:58	
FEC INCAPACITATION 0.3			01:58			
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

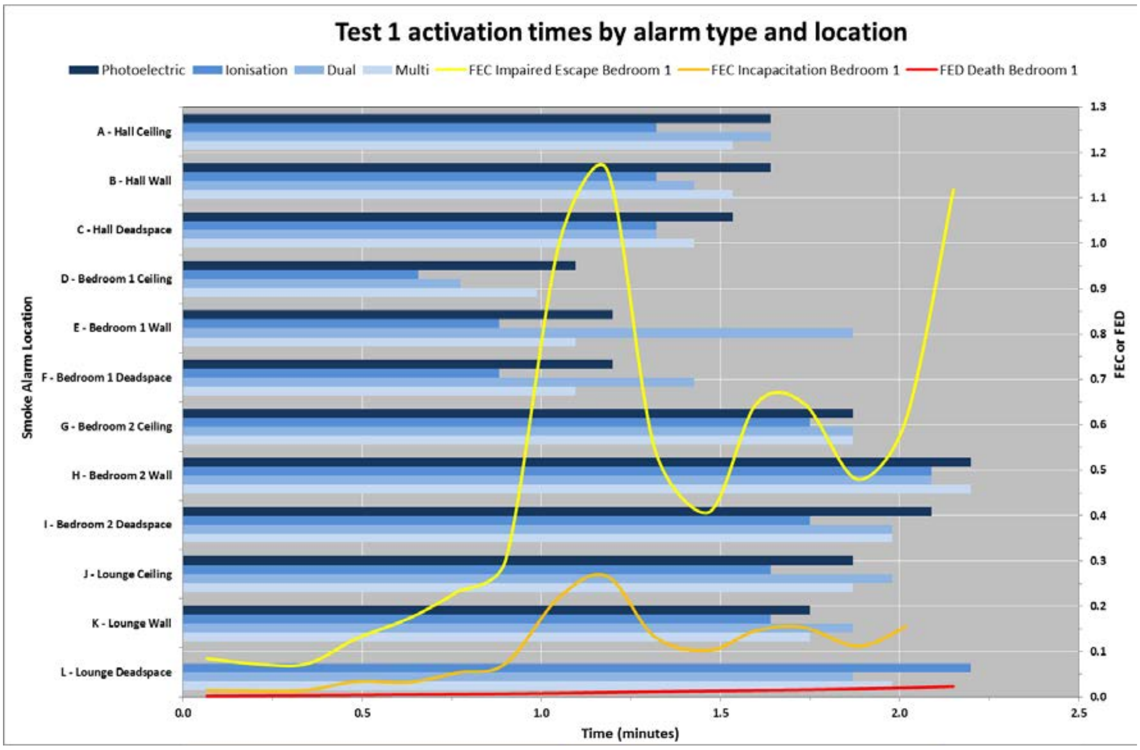

Figure 49 Scenario 10, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

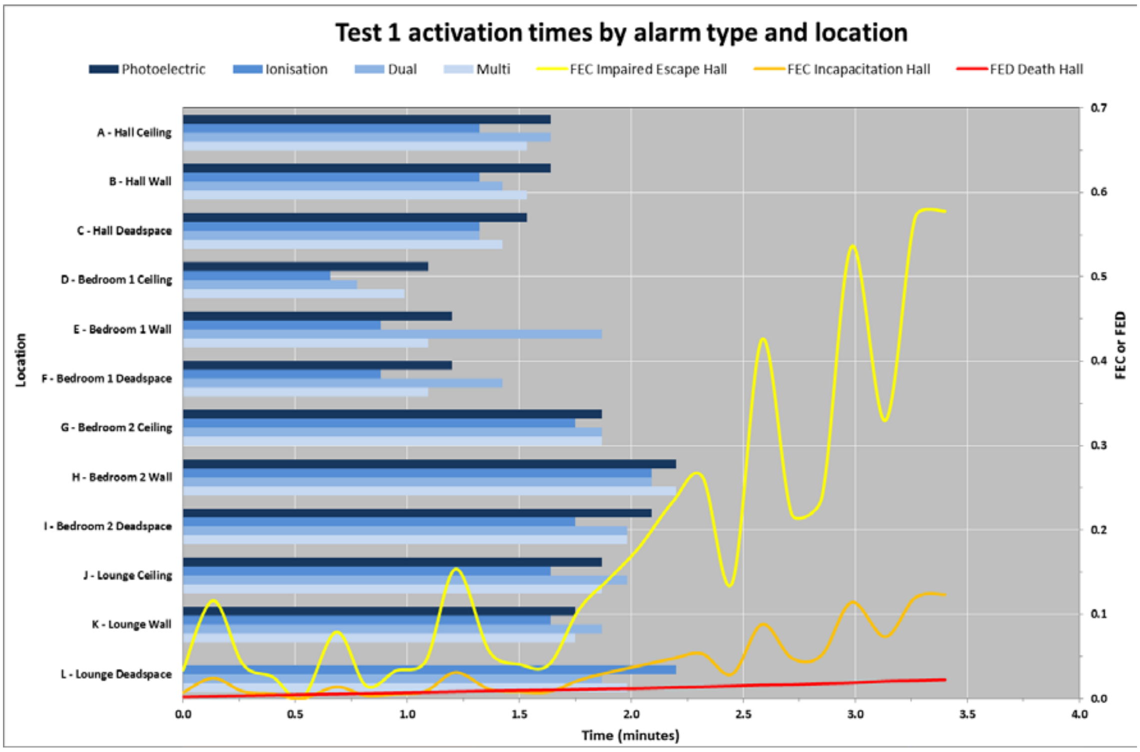

Figure 50 Scenario 10, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

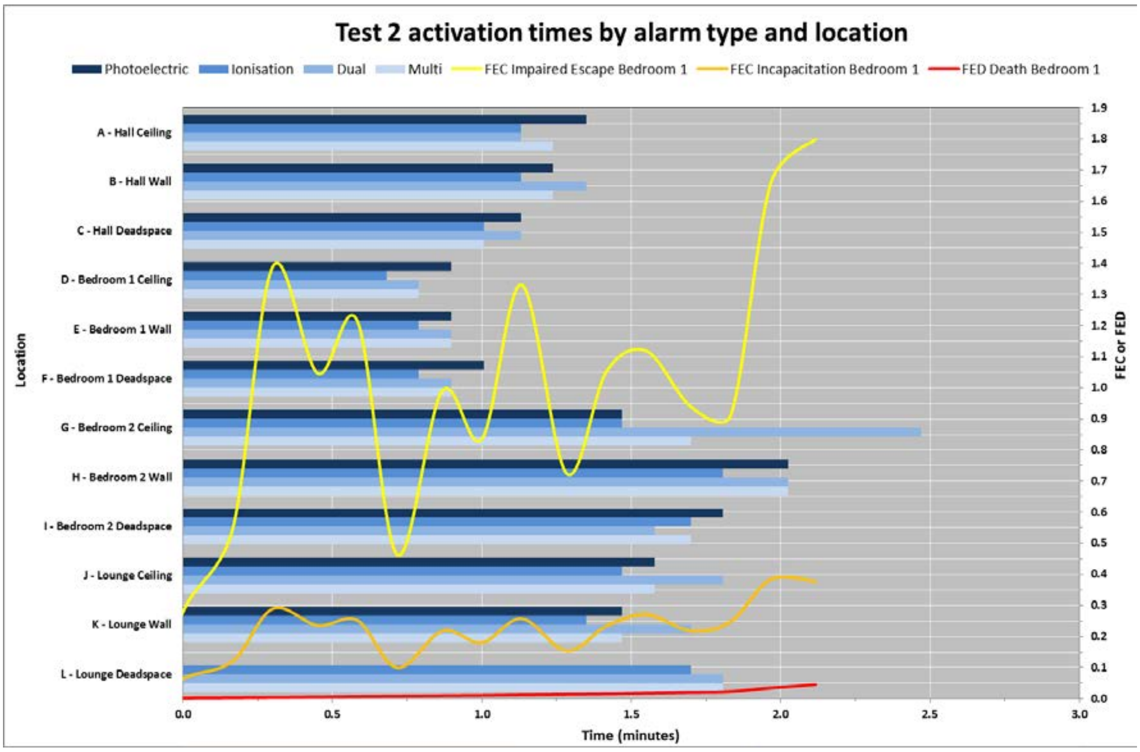

Figure 51 Scenario 10, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

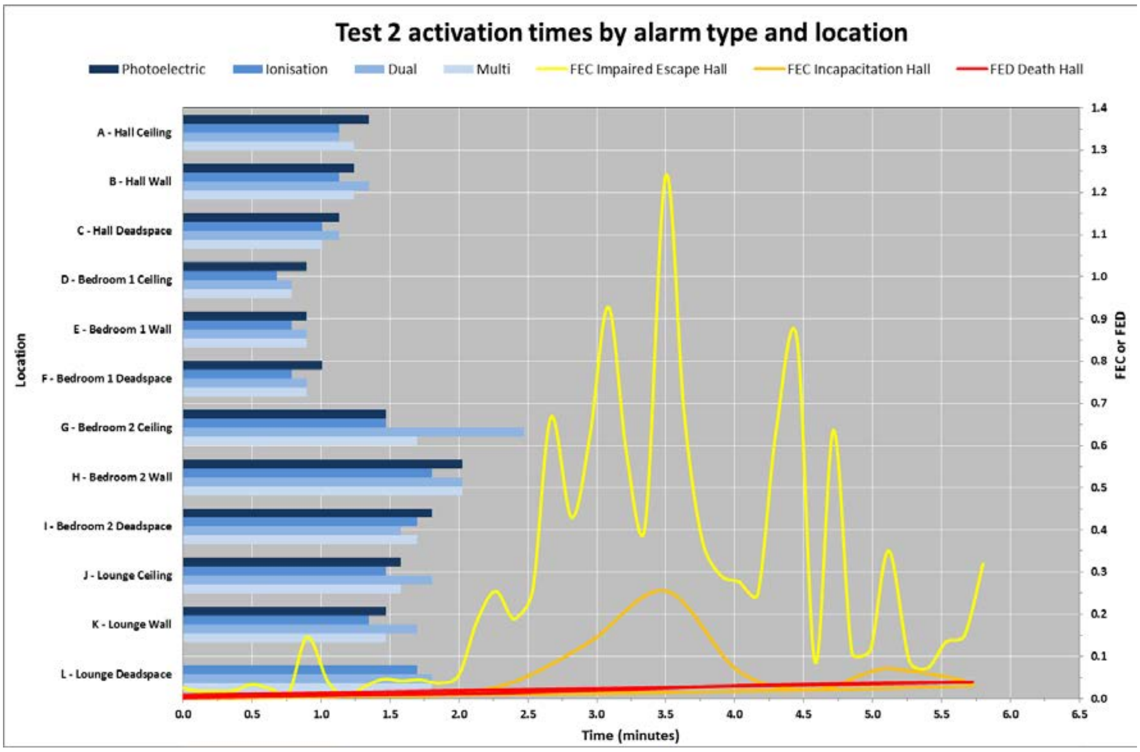

Figure 52 Scenario 10, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

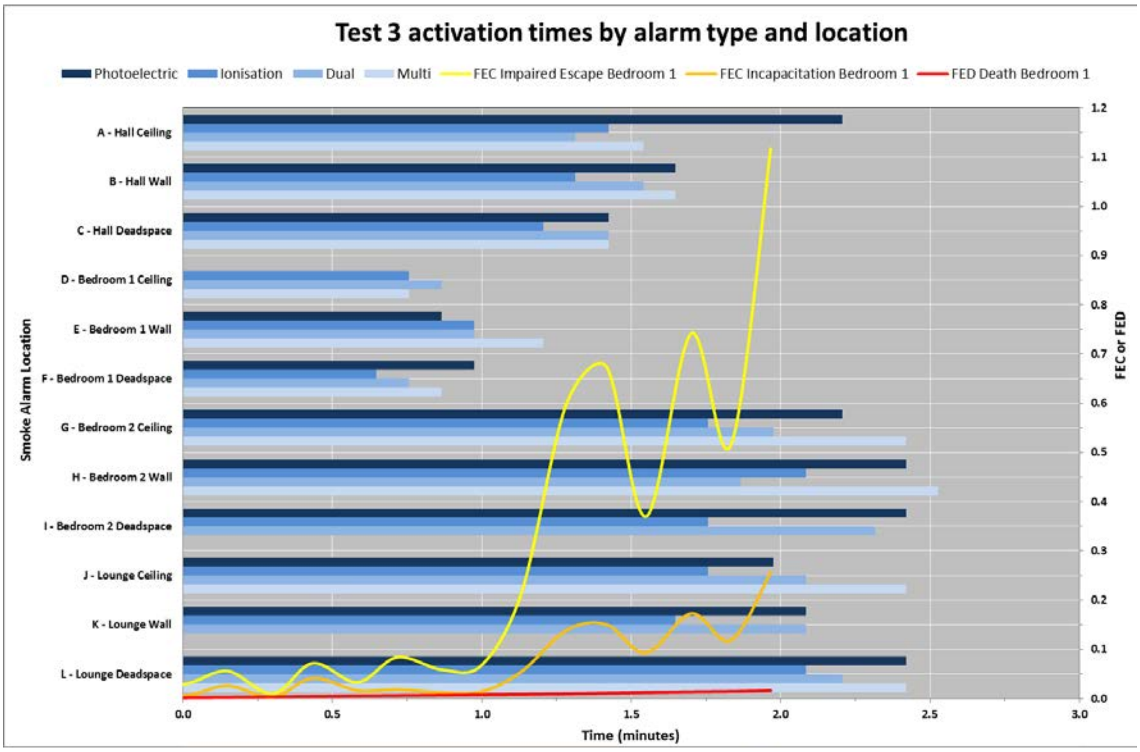

Figure 53 Scenario 10, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

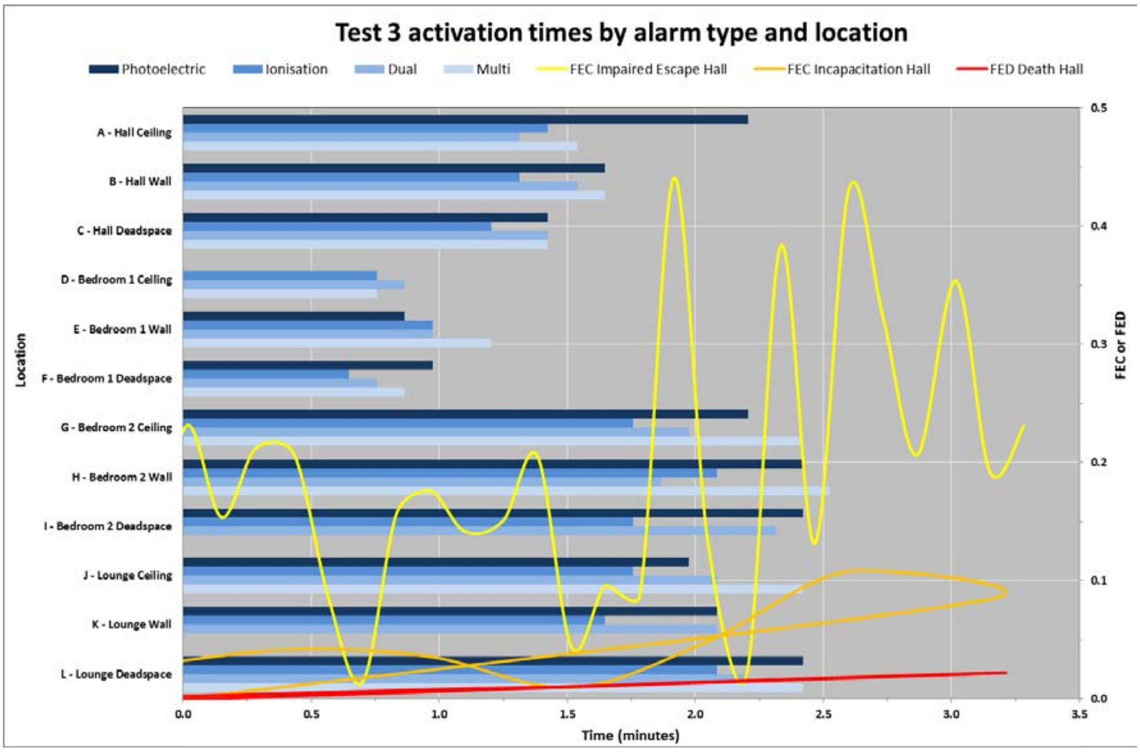

Figure 54 Scenario 10, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 31 Scenario 10 Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Bedroom 1 tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	#N/A	#N/A	#N/A	#N/A	0.62	0.84	0.84	0.73	#N/A	#N/A	#N/A	#N/A
Hall Wall	#N/A	#N/A	#N/A	#N/A	0.73	0.84	0.62	0.73	#N/A	#N/A	#N/A	#N/A
Hall Dead-space	#N/A	#N/A	#N/A	#N/A	0.84	0.96	0.84	0.96	#N/A	#N/A	#N/A	#N/A
ROO Ceiling	#N/A	#N/A	#N/A	#N/A	1.07	1.28	1.18	1.18	#N/A	#N/A	#N/A	#N/A
ROO Wall	#N/A	#N/A	#N/A	#N/A	1.07	1.18	1.07	1.07	#N/A	#N/A	#N/A	#N/A
ROO Dead-space	#N/A	#N/A	#N/A	#N/A	0.96	1.18	1.07	1.07	#N/A	#N/A	#N/A	#N/A

Table 32 Scenario 10 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.58	0.58	0.62
Air Temp (°C)	17.88	17.88	18.78
Rel. Humidity (%)	63.40	63.40	49.47
Air Pressure (mbar)	1016.83	1016.83	1013.19

3.8 SCENARIO 11: Smouldering electrical fire in kitchen, bedroom doors open

In this scenario, a smouldering fire involving an electrical cable was initiated on a stove element. The cable was placed over the element and the test started when the element was switched on to full heat. The test ended at 10-15 minutes.

Figure 55 Before (left) and after (right) photographs of Scenario 11, Tests 1 (top), 2 (middle) and 3 (bottom).

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 4.7 ppm), and sulfur dioxide (up to 2.6 ppm), however the tenability limits for occupant incapacitation were not reached during the three tests.

Table 33 Scenario 11 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	04:29	05:16	04:02	03:56	03:33	04:20	02:52	03:19	03:48	04:00	02:35	03:22
Hall Wall	04:09	04:36	04:15	03:56	03:05	03:45	03:12	03:05	03:35	04:48	04:27	03:48
Hall Dead-space	05:16	05:03	04:09	05:03	03:59	04:06	03:12	03:59	03:41	04:00	03:28	03:54
ROO Ceiling	02:10	02:30	02:17	02:10	02:33	02:20	02:59	02:20	05:47	06:34	05:34	06:08
ROO Wall	03:23	03:16	03:30	03:30	04:20	03:39	03:59	03:33	05:34	04:14	04:27	04:08
ROO Dead-space	02:50	02:57	02:43	02:50	#N/A	03:33	03:45	03:52	#N/A	09:13	07:34	05:01

Table 34 Scenario 11 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3				00:20		
FEC IMPAIRED ESCAPE 1.0				02:21		
FEC INCAPACITATION 0.3						
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

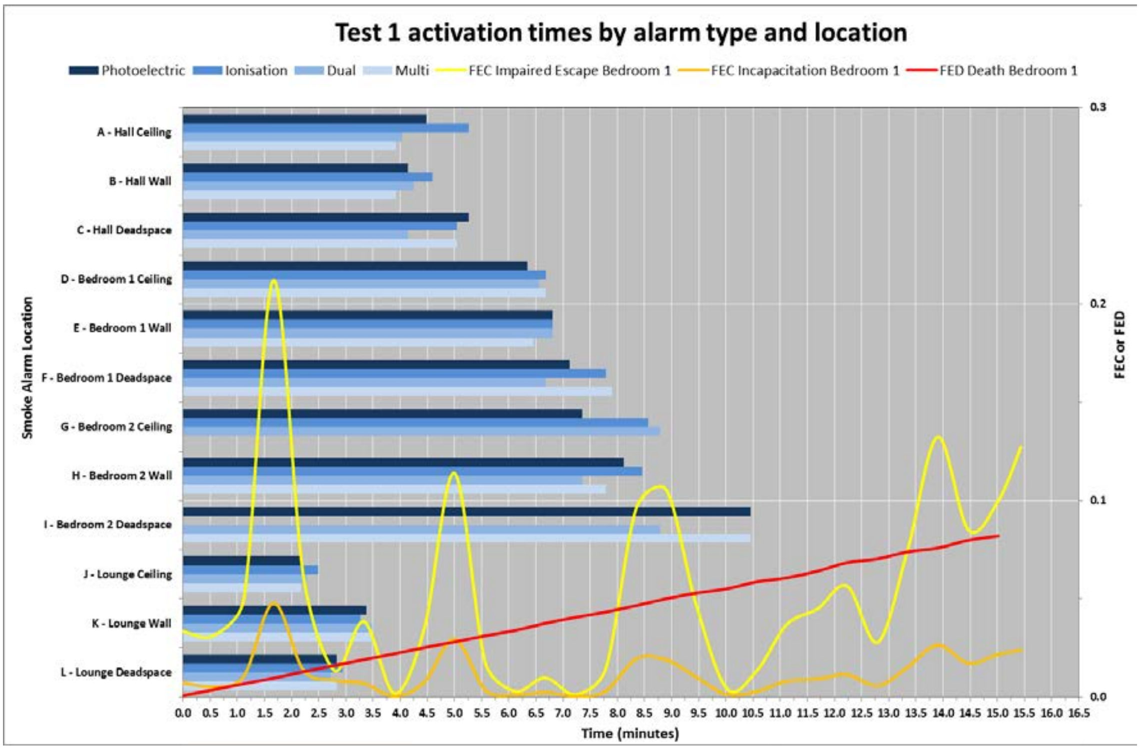

Figure 56 Scenario 11, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

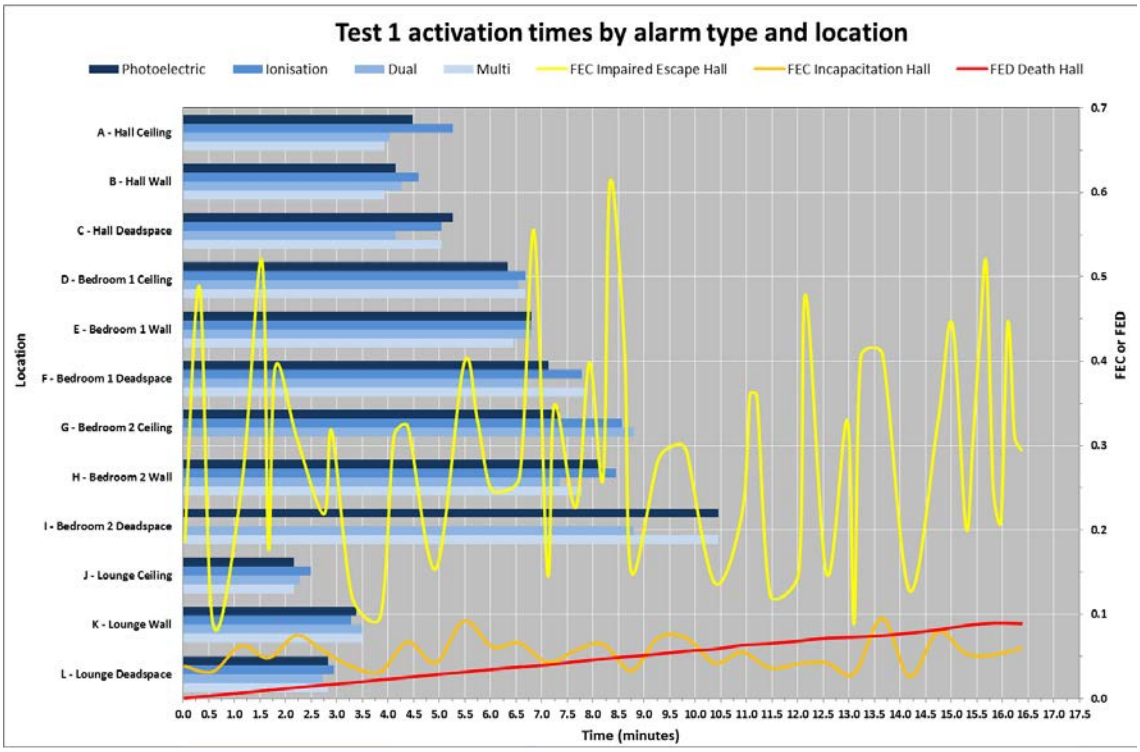

Figure 57 Scenario 11, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

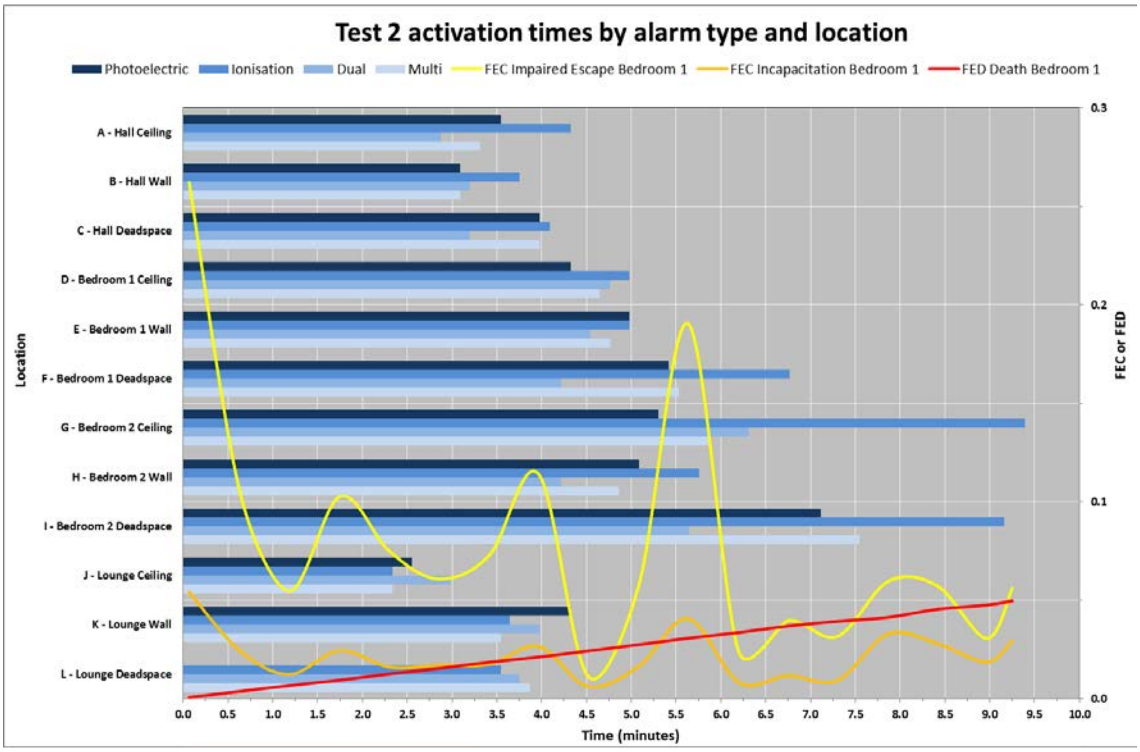

Figure 58 Scenario 11, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

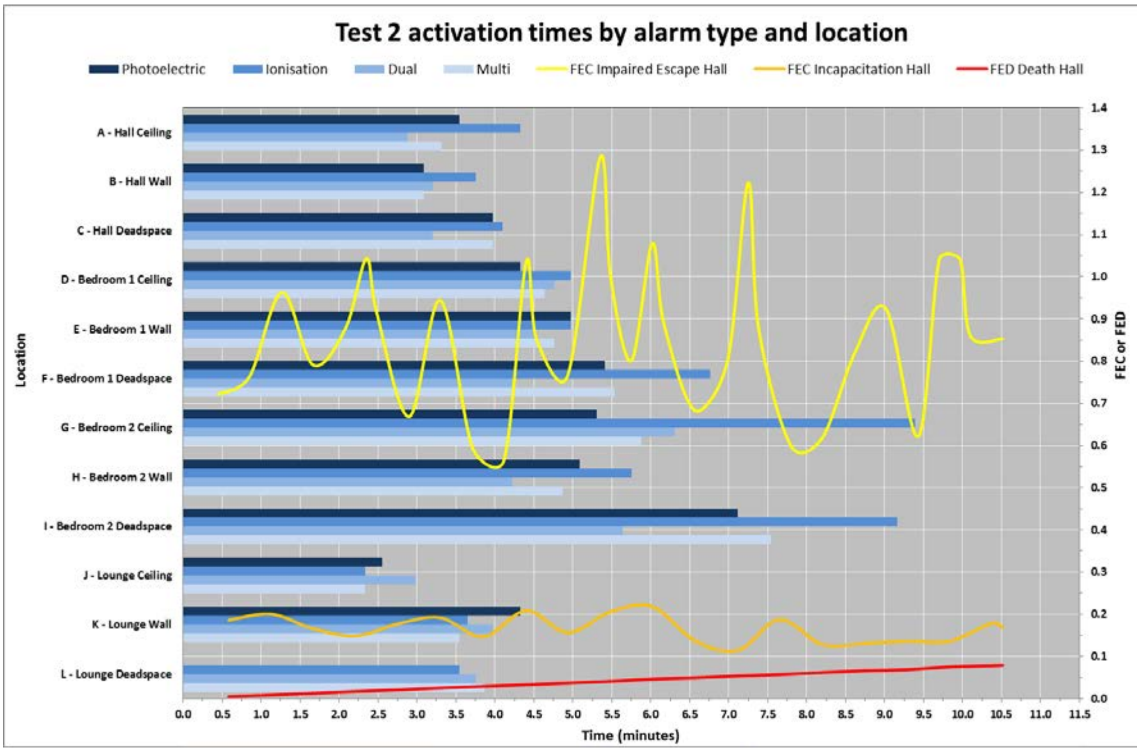

Figure 59 Scenario 11, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

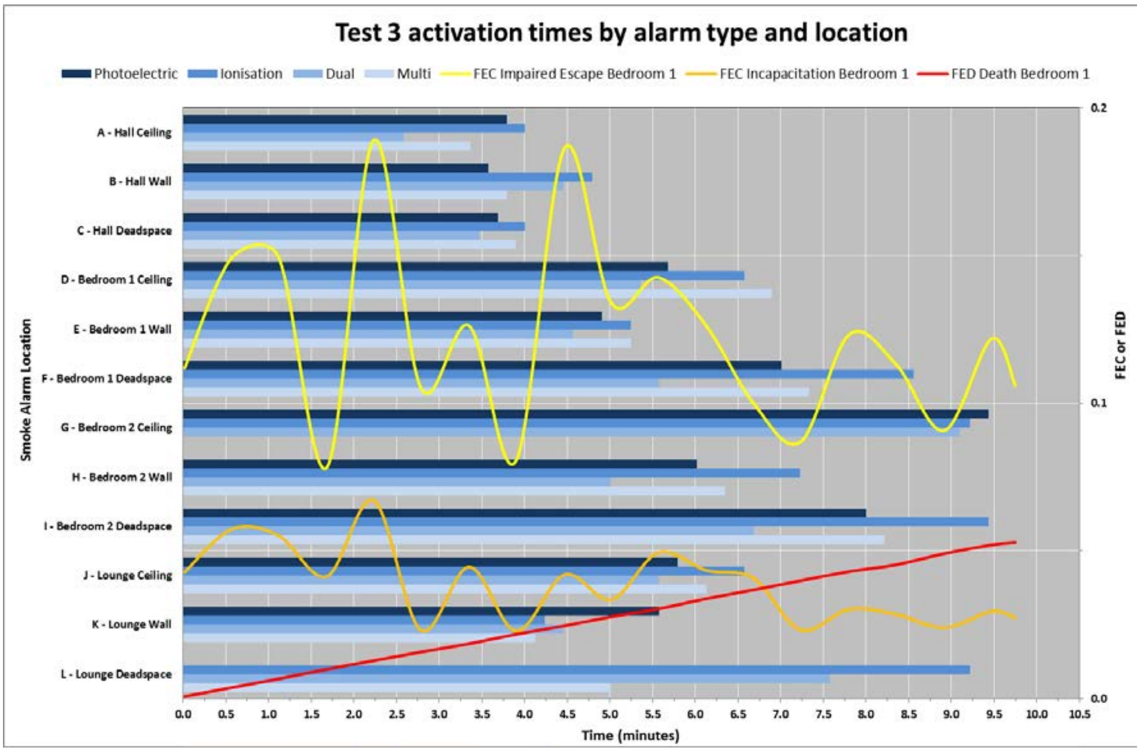

Figure 60 Scenario 11, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

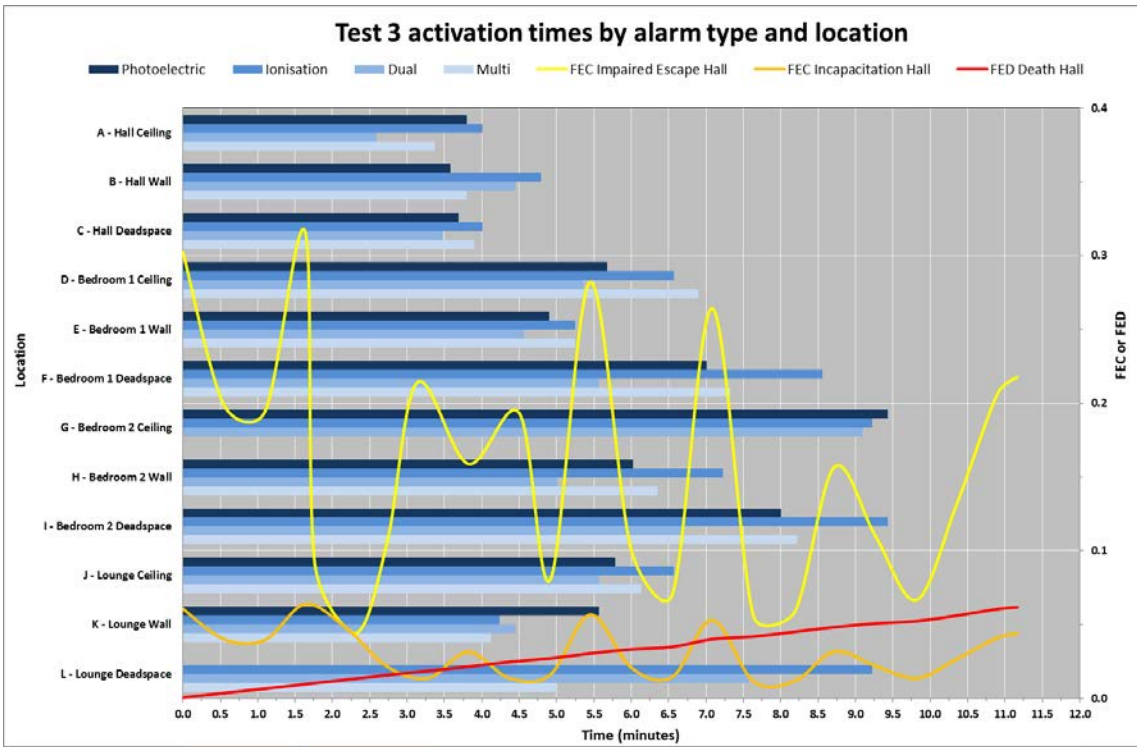

Figure 61 Scenario 11, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 35 Scenario 11 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.40	0.42	0.50
Air Temp (°C)	14.76	12.08	15.17
Rel. Humidity (%)	57.26	43.43	37.31
Air Pressure (mbar)	1000.47	1021.48	1020.90

3.9 SCENARIO 12: Flaming electrical fire in kitchen, bedroom doors open

In this scenario, a flaming fire was initiated in the kitchen involving an electric appliance (a pop-up toaster). The toaster was equipped with a timer cut-out, which prevented the appliance from overheating. In order to initiate a flaming fire, cardboard packing material soaked in 100ml of cooking oil was placed within the toaster as fuel. This caused the appliance to catch in 2m 45s, 2m30s, and 4m35s in Tests 1, 2 and 3, respectively.

Figure 62 Before (left) and after (right) photographs of Scenario 12, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 36 Scenario 12 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	03:49	03:42	03:49	03:35	02:13	02:47	01:40	01:53	04:42	04:16	04:49	04:09
Hall Wall	03:42	03:49	03:42	03:42	01:53	02:07	01:34	01:53	04:09	04:16	04:02	04:16
Hall Dead-space	03:55	04:21	04:02	03:55	02:34	03:33	02:47	02:40	05:29	06:37	05:09	06:30
ROO Ceiling	03:21	03:14	03:28	03:14	03:00	03:00	01:07	02:53	03:37	03:44	03:17	03:37
ROO Wall	03:28	03:21	03:42	03:21	03:26	03:13	03:26	03:07	06:03	05:48	04:42	05:48
ROO Dead-space	03:21	03:14	03:28	03:21	03:19	02:53	03:13	03:00	05:56	05:36	05:42	05:48

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 3 ppm) and formaldehyde (up to 0.8 ppm); however the tenability limits for occupant incapacitation were not reached during the three tests.

The peak temperature measured in the kitchen was 48.8°C at ceiling height (Test 2).

Table 37 Scenario 12 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3	05:18	02:59				00:51
FEC IMPAIRED ESCAPE 1.0						
FEC INCAPACITATION 0.3						
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

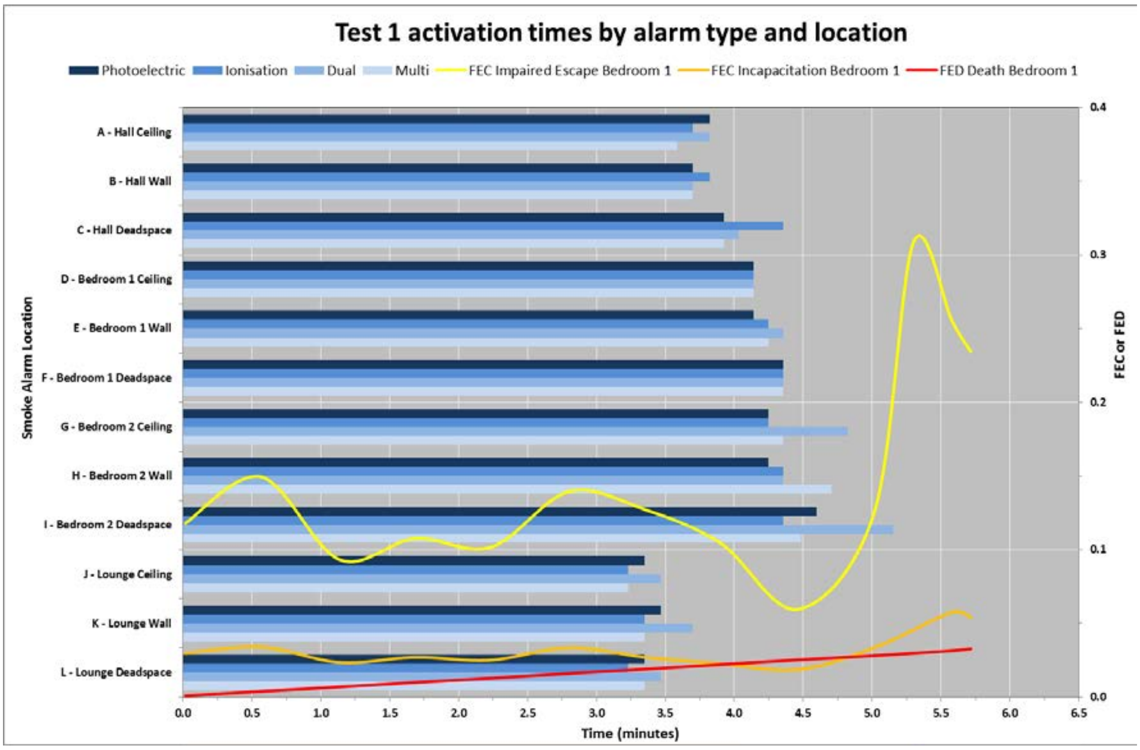

Figure 63 Scenario 12, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

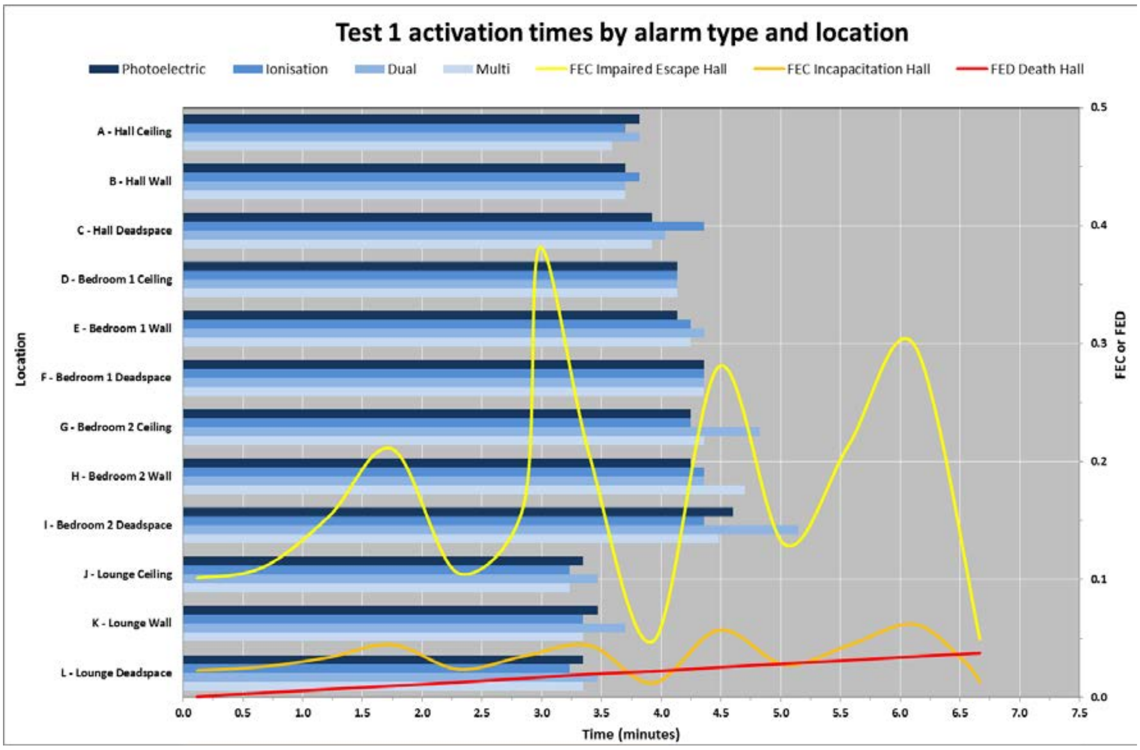

Figure 64 Scenario 12, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

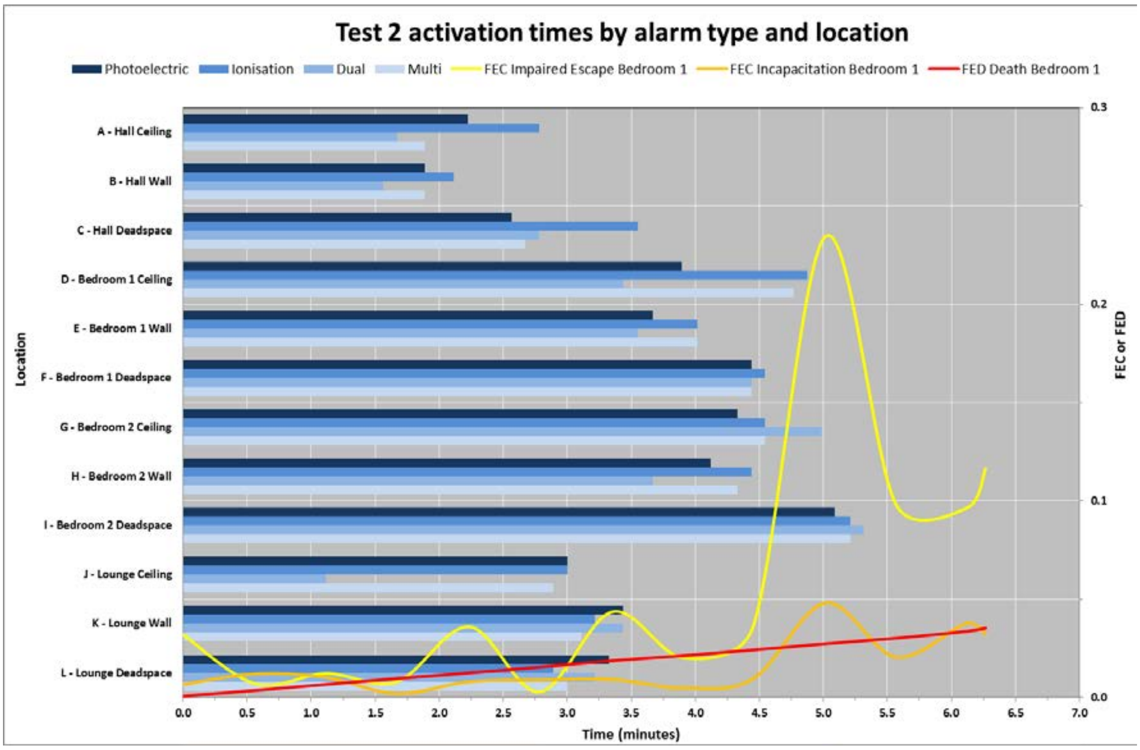

Figure 65 Scenario 12, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

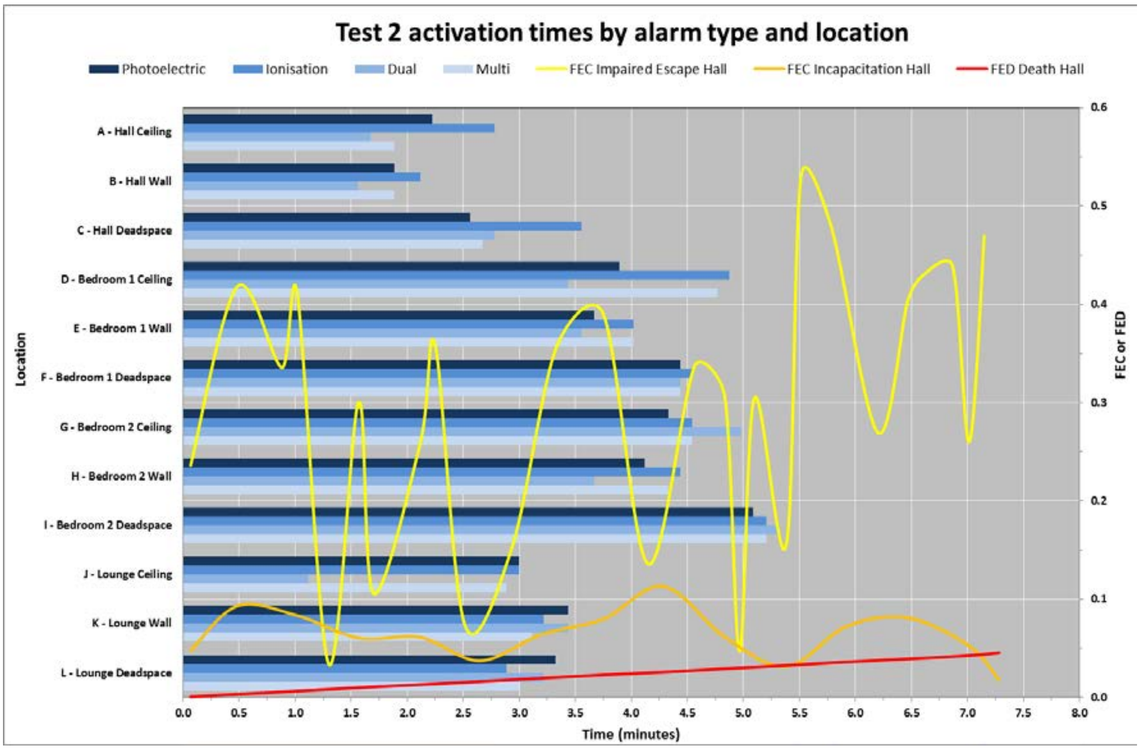

Figure 66 Scenario 12, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

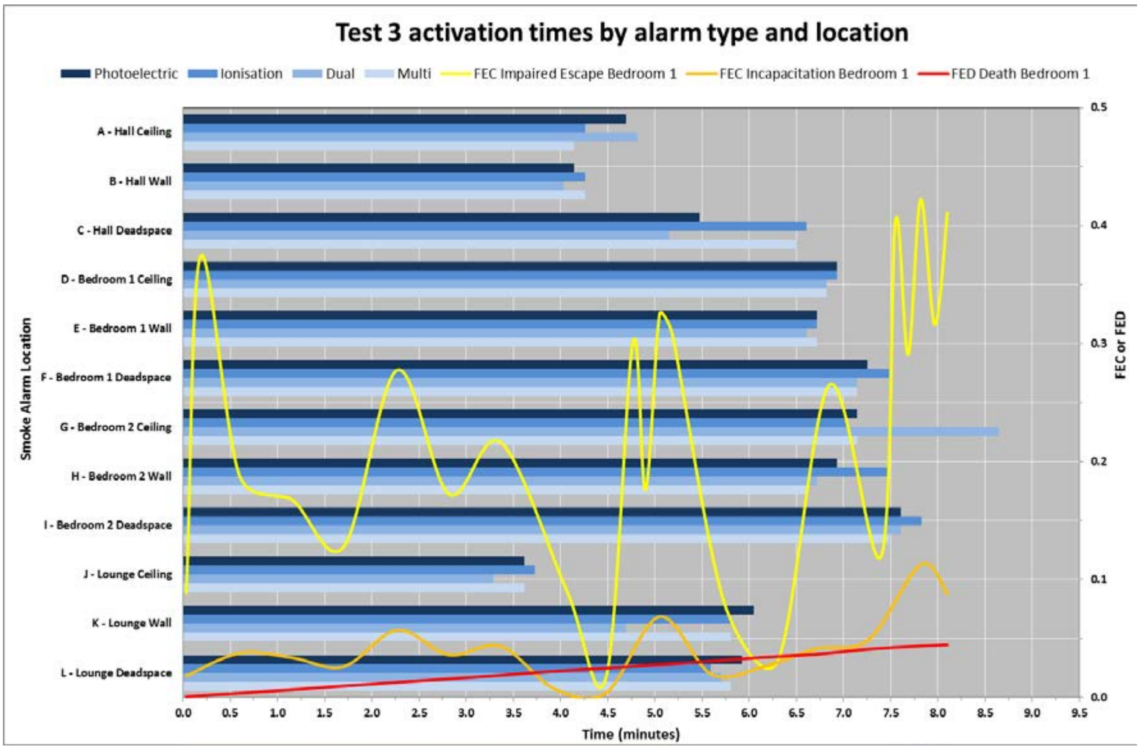

Figure 67 Scenario 12, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

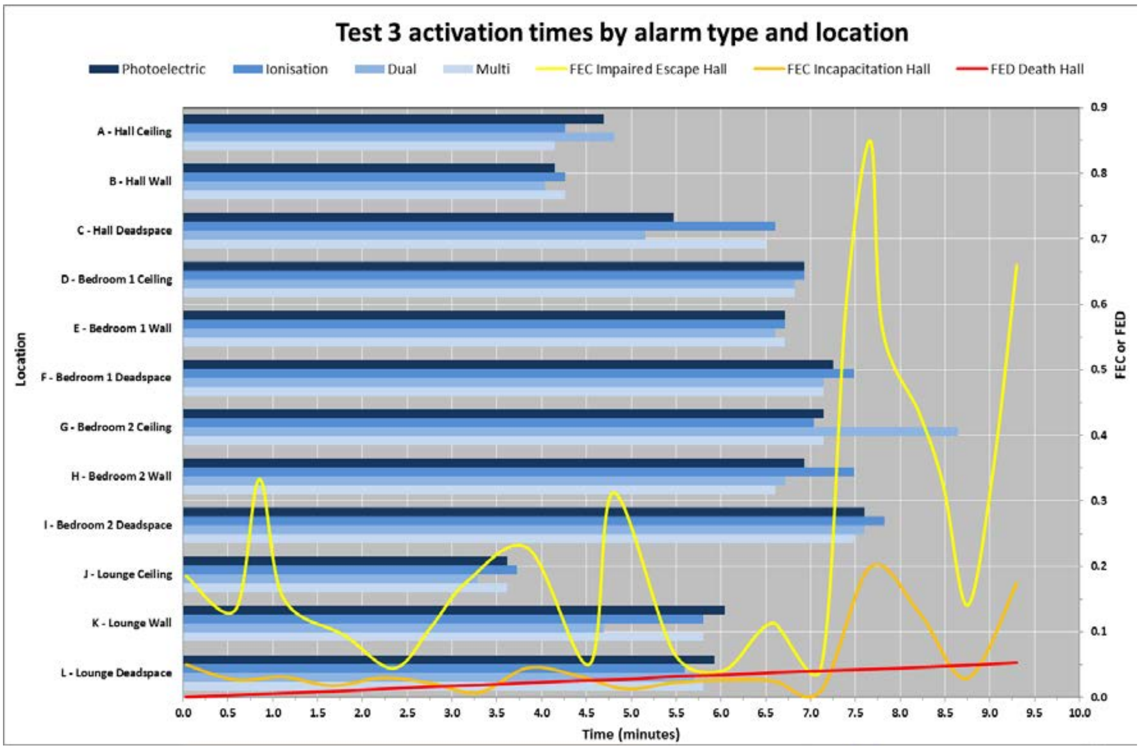

Figure 68 Scenario 12, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 38 Scenario 12 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.65	0.45	0.67
Air Temp (°C)	14.79	17.54	18.44
Rel. Humidity (%)	47.16	36.30	32.66
Air Pressure (mbar)	1013.20	1011.88	1010.88

3.10 SCENARIO 13: Flaming lounge fire in lounge room, bedroom doors open

In this scenario, a flaming fire was initiated on a two-seater lounge using a butane barbeque lighter. The flame was held in contact with the edge of the lounge cushion for 15 seconds before being removed. The fire is extinguished after three to four minutes.

Figure 69 Before (left) and after (right) photographs of Scenario 13, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 39 Scenario 13 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	02:29	01:35	01:48	02:22	02:26	02:00	02:00	02:26	02:32	01:52	01:38	02:25
Hall Wall	02:35	01:35	02:09	02:22	02:26	01:33	01:33	02:26	02:18	01:45	01:52	02:25
Hall Dead-space	02:41	02:02	02:29	02:35	02:40	01:53	02:13	02:34	02:39	01:52	01:59	02:39
ROO Ceiling	01:55	00:42	01:09	01:55	01:40	00:26	01:00	01:53	01:45	00:32	00:32	01:52
ROO Wall	02:15	01:09	01:42	02:15	01:53	01:12	01:20	02:07	02:12	01:18	01:18	02:12
ROO Dead-space	02:02	00:56	01:15	02:02	01:40	01:00	01:27	01:53	01:38	00:58	00:58	01:59

The irritant gases detected in the Hallway at 1.5 metres included significant amounts of acrolein (up to 3.6 ppm), formaldehyde (up to 1.8 ppm), nitrogen dioxide (up to 5.7 ppm), nitrogen monoxide (up to 89.4 ppm) and sulfur dioxide (up to 2.8 ppm).

The peak temperature measured in the Lounge room was 112°C at ceiling height (Test 3), and 57.8°C at seat height (Test 1).

Table 40 Scenario 13 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3		02:59	05:01	01:22	04:07	03:11
FEC IMPAIRED ESCAPE 1.0		03:40		06:08		
FEC INCAPACITATION 0.3		03:48				
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

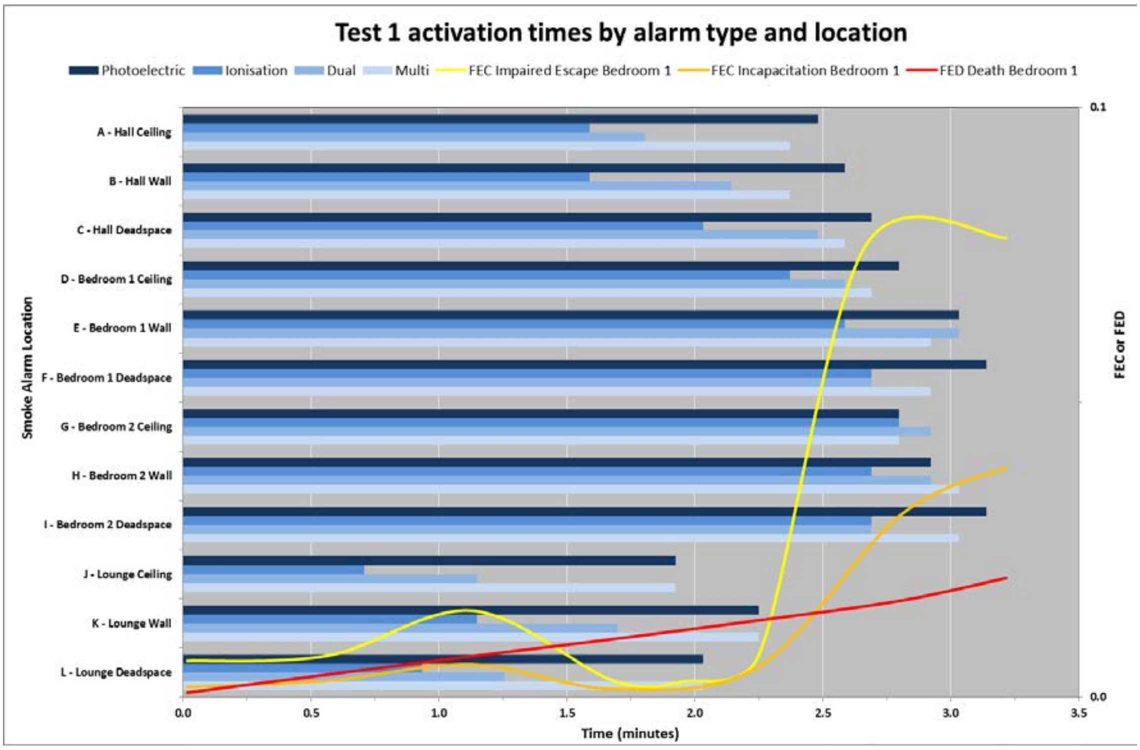

Figure 70 Scenario 13, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

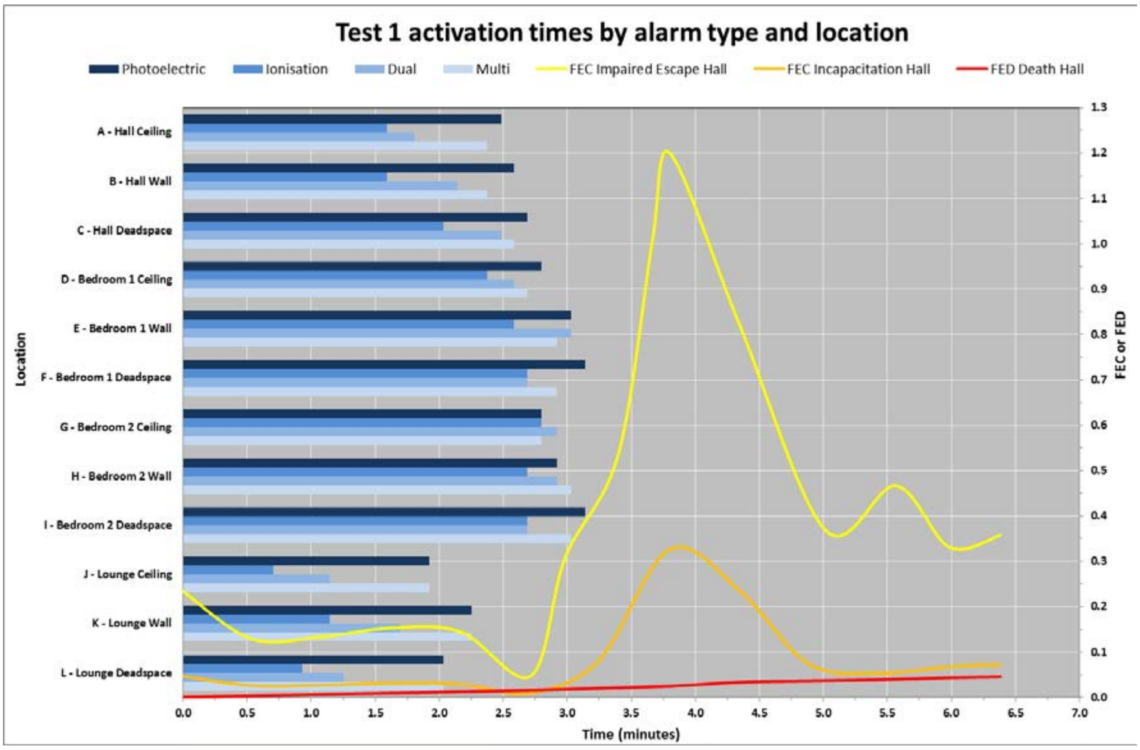

Figure 71 Scenario 13, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

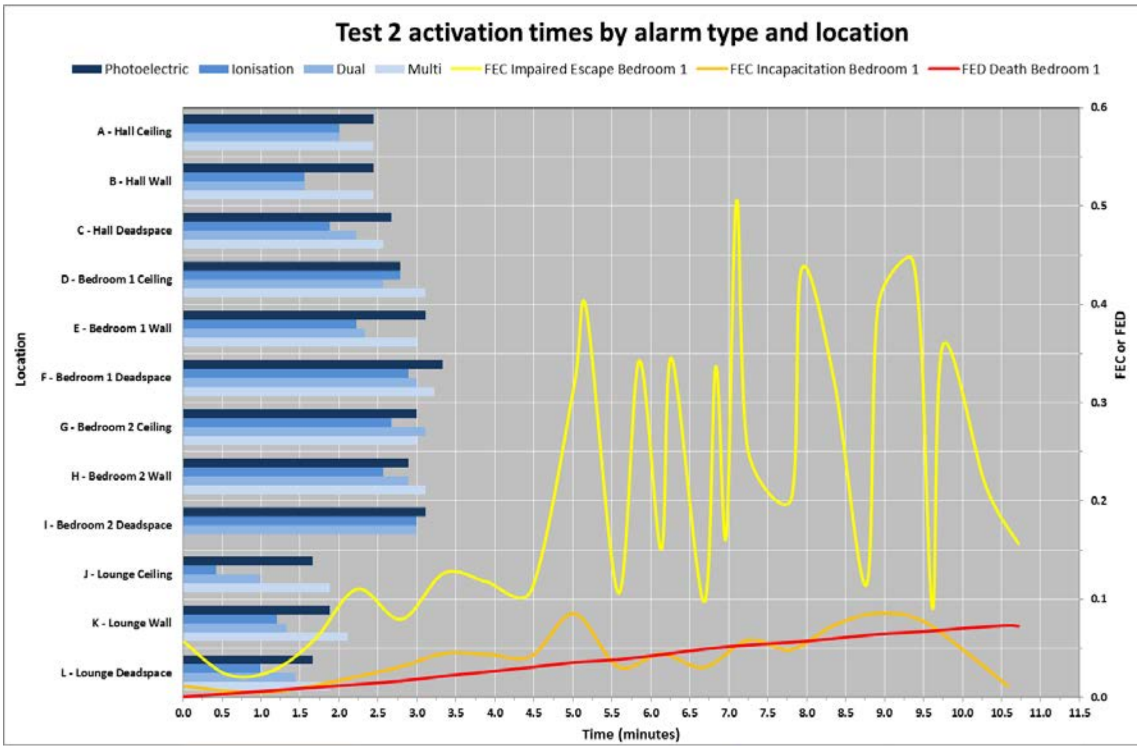

Figure 72 Scenario 13, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 2 FECs for impaired escape and incapacitation, and asphyxiation FED.

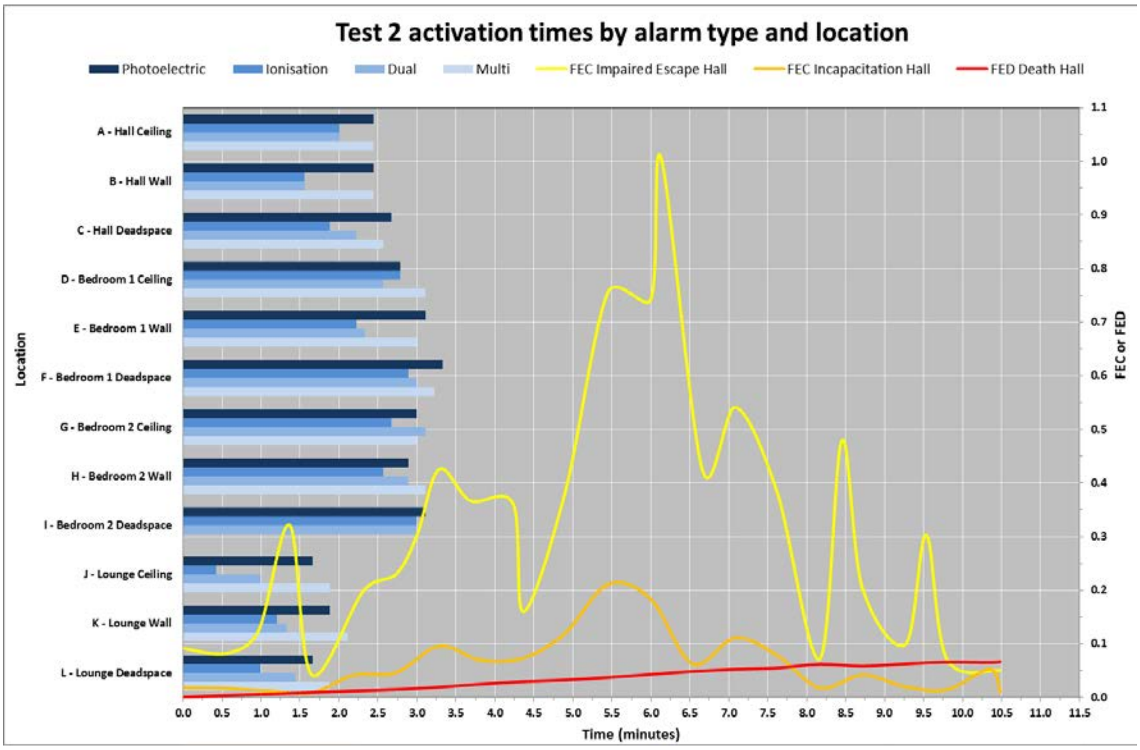

Figure 73 Scenario 13, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

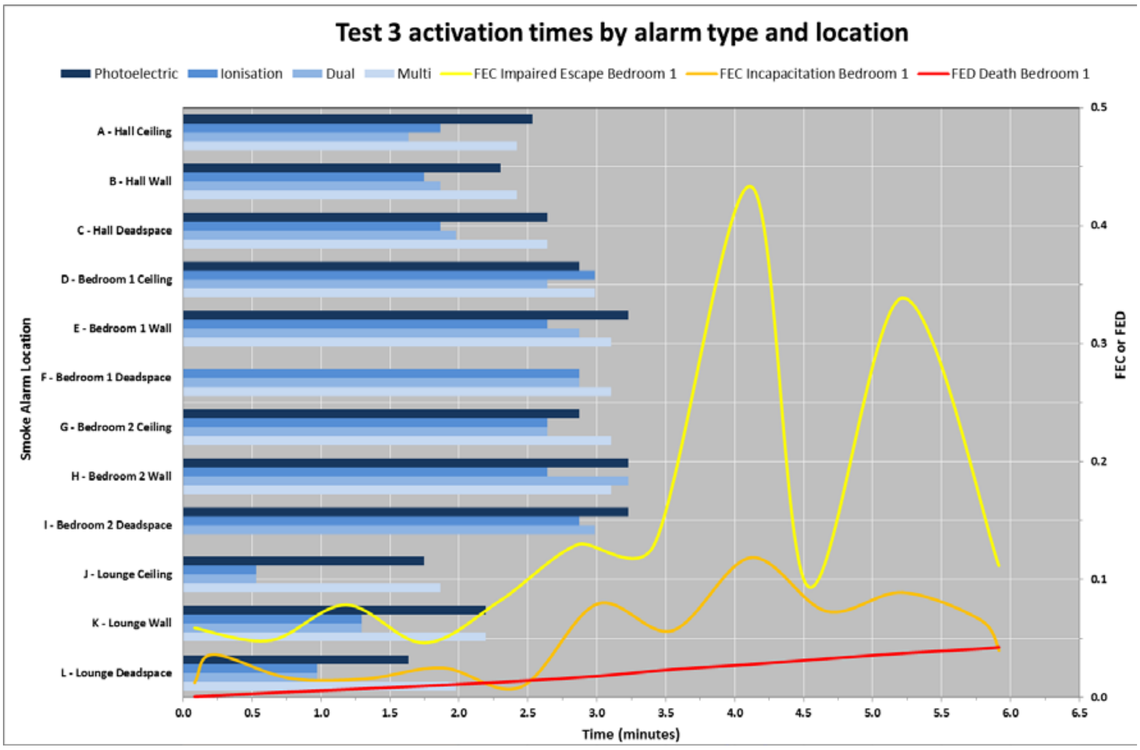

Figure 74 Scenario 13, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 2 FECs for impaired escape and incapacitation, and asphyxiation FED.

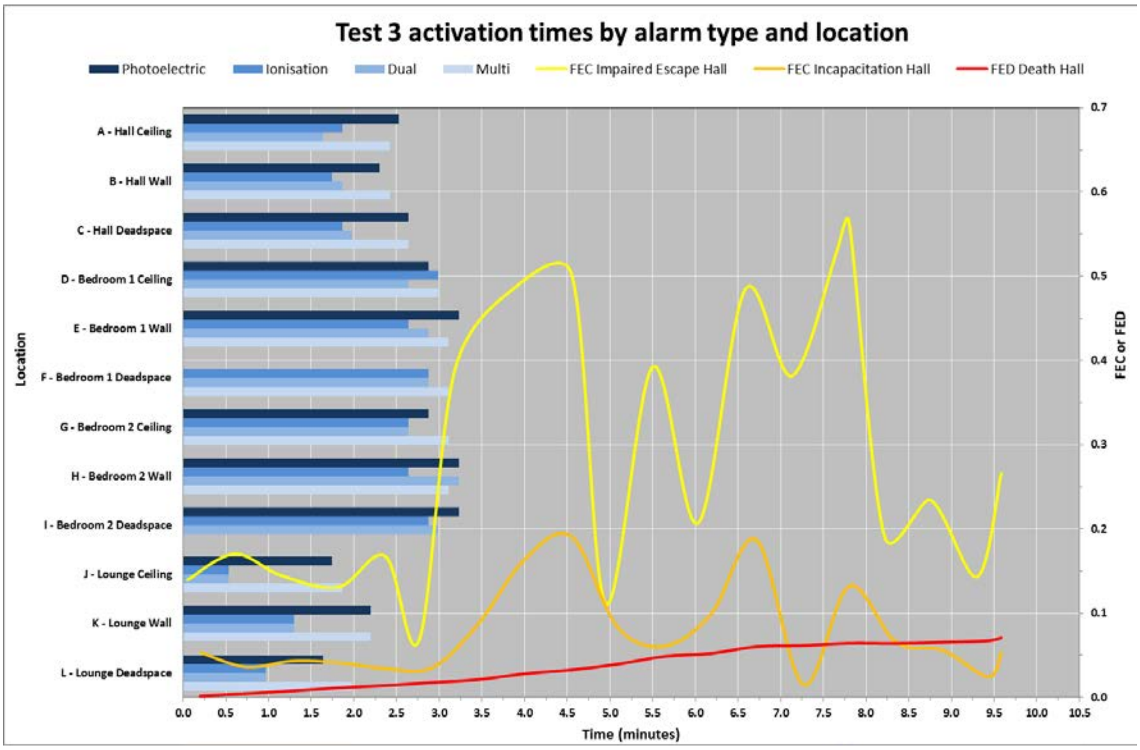

Figure 75 Scenario 13, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 41 Scenario 13 Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Hallway tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	1.32	2.21	2.00	1.43	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Hall Wall	1.21	2.21	1.66	1.43	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Hall Dead-space	1.11	1.77	1.32	1.21	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Ceiling	1.88	3.09	2.65	1.88	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Wall	1.55	2.65	2.10	1.55	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ROO Dead-space	1.77	2.87	2.54	1.77	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Table 42 Scenario 13 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.81	0.46	0.26
Air Temp (°C)	18.04	19.32	14.53
Rel. Humidity (%)	29.06	45.67	70.24
Air Pressure (mbar)	998.98	1026.23	1018.09

3.11 SCENARIO 14a: Smouldering lounge fire in lounge room, bedroom doors open

In this scenario, a smouldering fire was initiated on a two-seater sofa using the soldering iron heated to 350°C. The element was left in contact with three cotton batting sheets for six minutes and then removed. The test ended after 30 minutes at which time the smouldering fires had self-extinguished.

Figure 76 Before (left) and after (right) photographs of Scenario 14a, Tests 1 (top), 2 (middle) and 3 (bottom).

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 6.3 ppm) and formaldehyde (2.4 ppm).

Table 43 Scenario 14a smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	07:13	07:39	05:27	05:00	09:48	17:39	09:27	09:21	09:46	11:26	10:32	08:54
Hall Wall	05:27	05:59	05:47	05:40	09:34	15:54	08:55	09:01	09:01	10:13	09:27	08:41
Hall Dead-space	06:06	07:52	06:12	05:59	10:47	10:53	09:27	10:27	10:13	10:06	09:39	09:53
ROO Ceiling	07:26	05:27	05:33	05:27	12:04	14:54	15:14	09:08	08:22	07:49	08:09	07:36
ROO Wall	06:33	06:52	05:59	05:33	09:08	10:14	07:29	08:55	08:22	07:56	08:09	08:22
ROO Dead-space	07:32	07:32	08:06	14:39	#N/A	15:07	11:26	10:27	#N/A	07:49	06:51	06:57

Table 44 Scenario 14a Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3	09:24	03:44	12:28	04:13	13:50	10:14
FEC IMPAIRED ESCAPE 1.0			23:02	15:55		
FEC INCAPACITATION 0.3				25:51		
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3	27:54	29:43	30:07	28:58		
FED ASPHYXIATION 1.0						

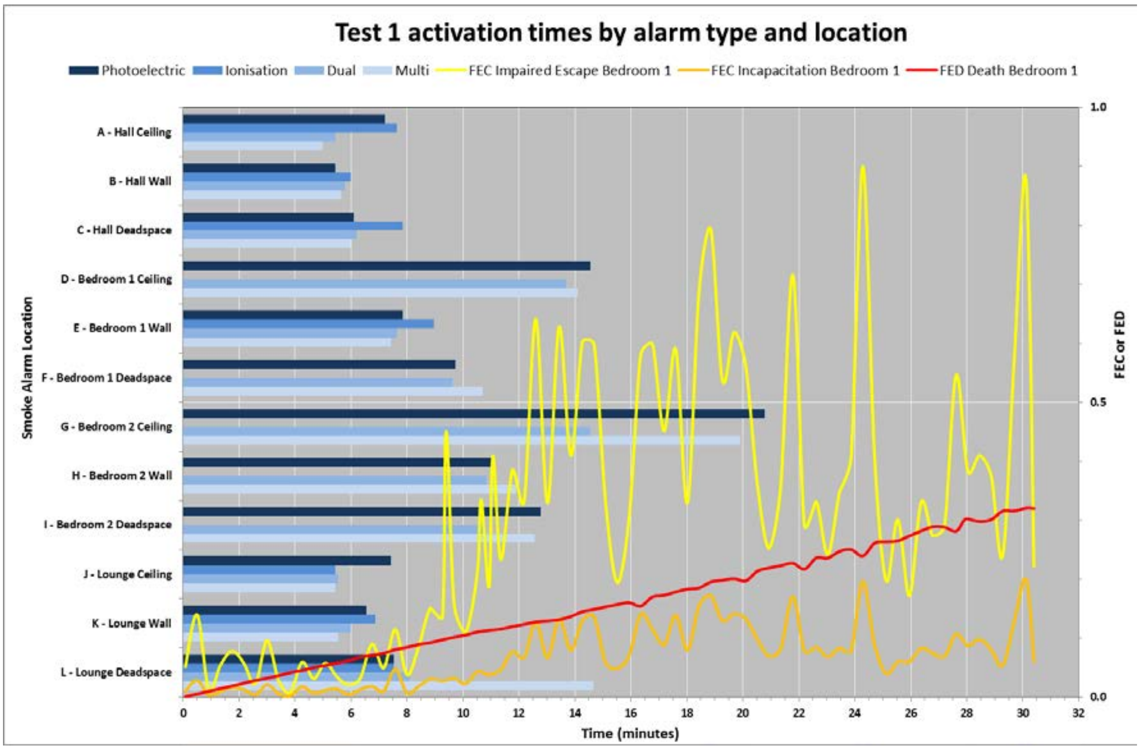

Figure 77 Scenario 14a, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

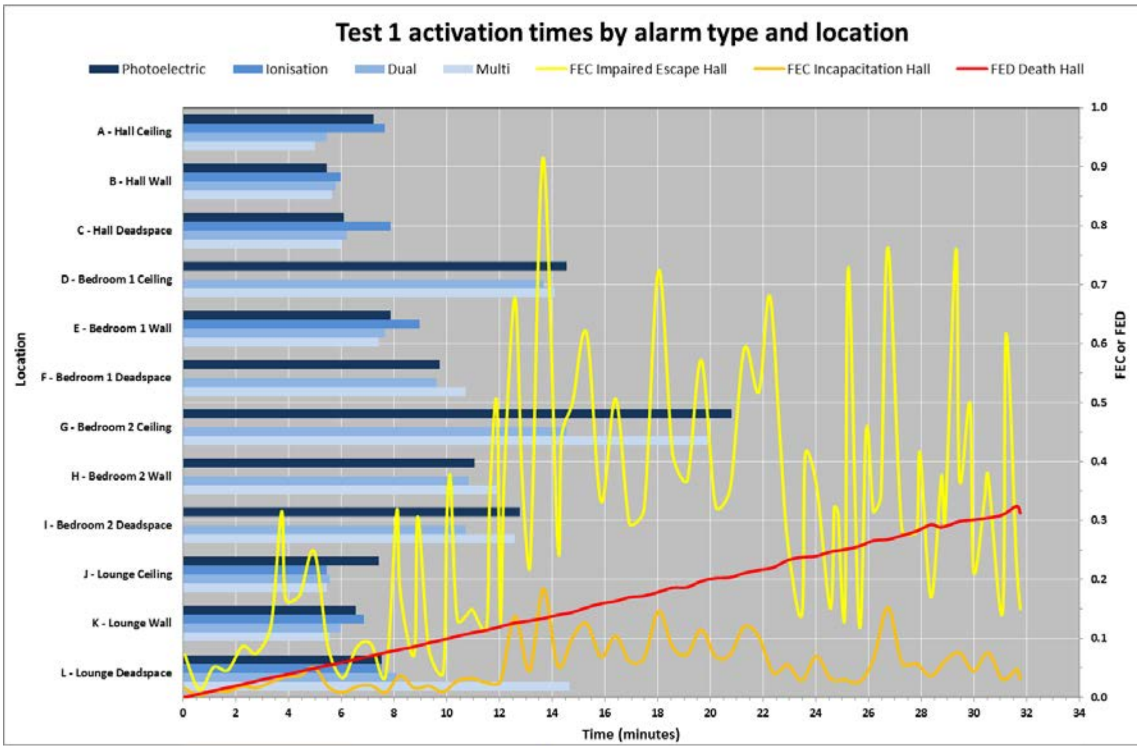

Figure 78 Scenario 14a, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

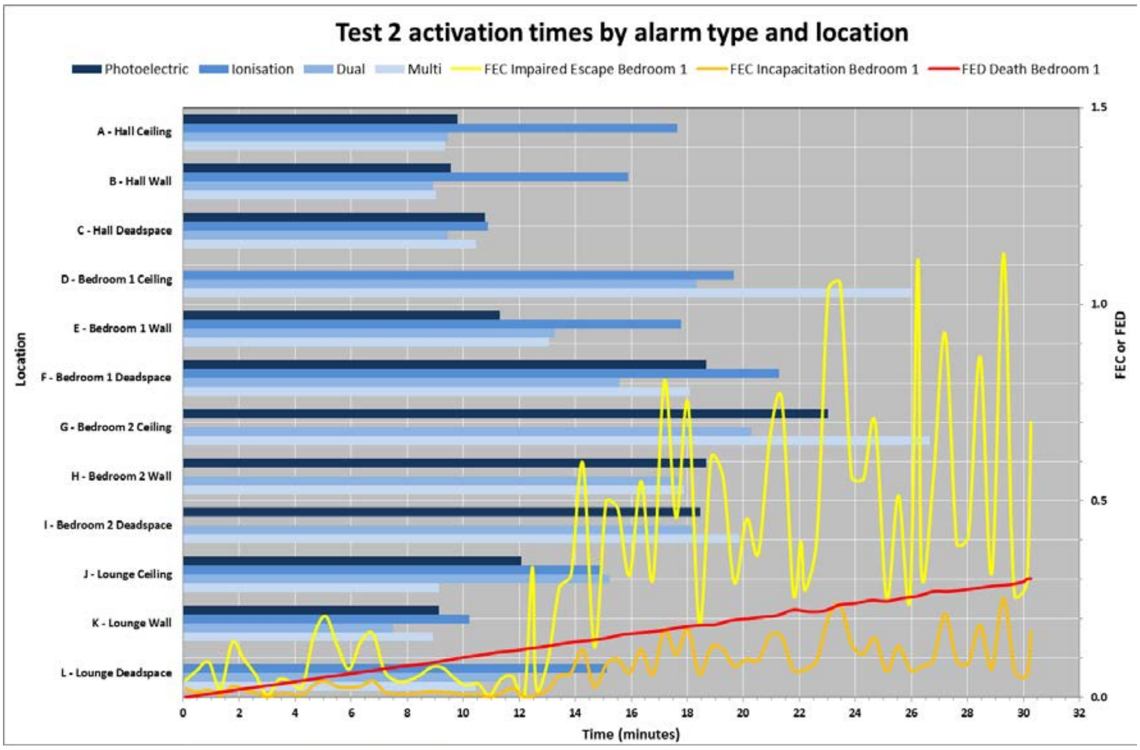

Figure 79 Scenario 14a, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

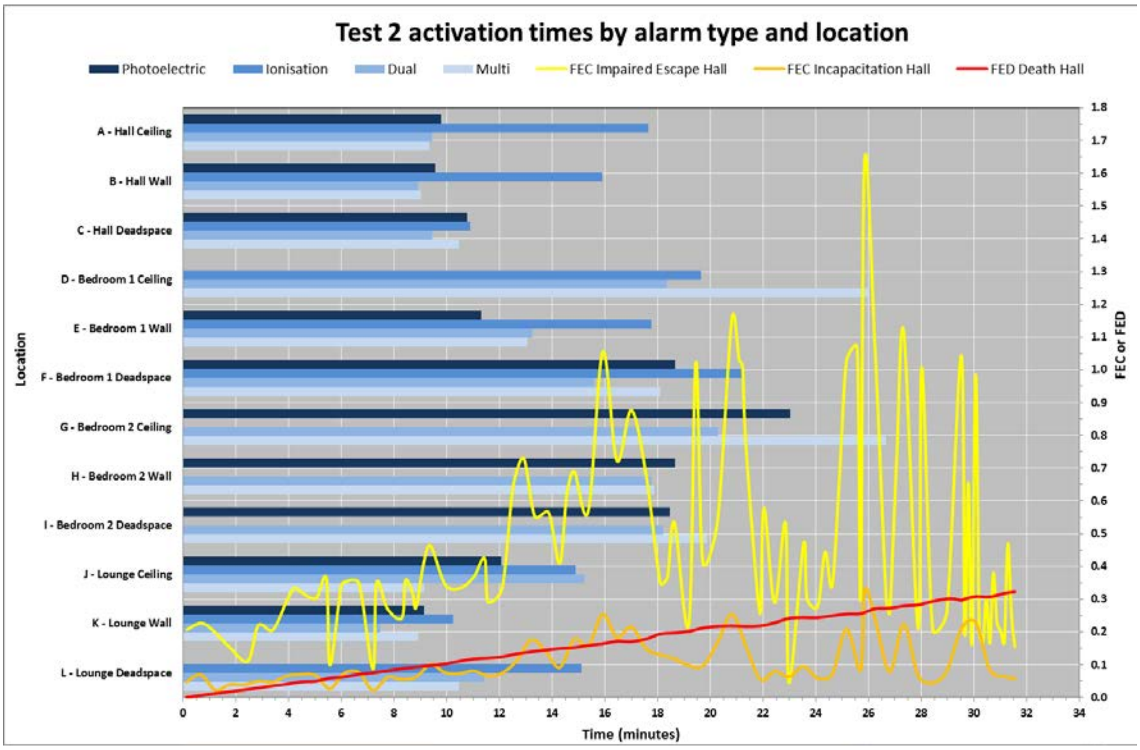

Figure 80 Scenario 14a, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

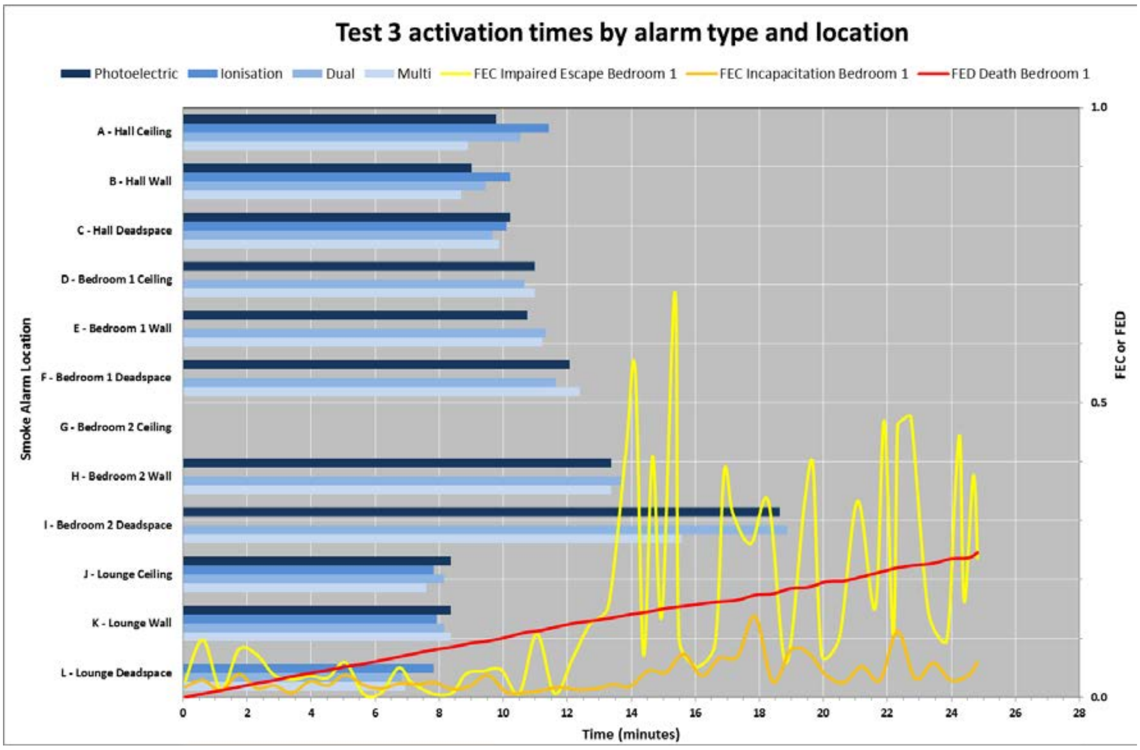

Figure 81 Scenario 14a, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

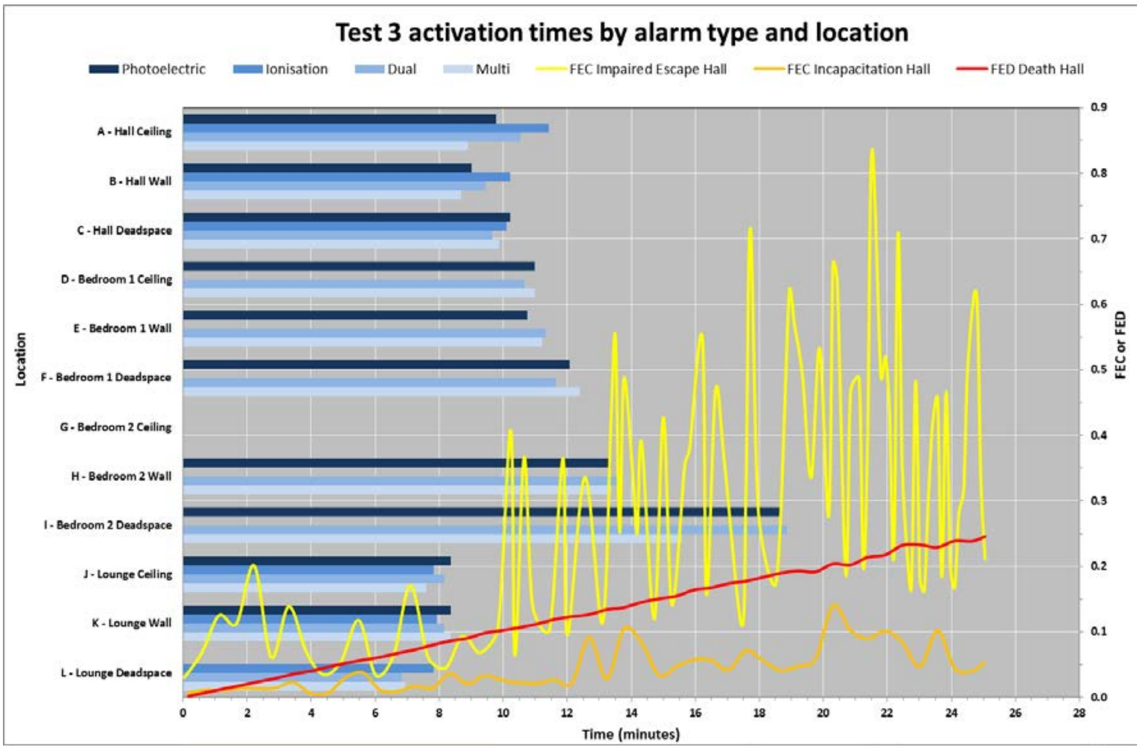

Figure 82 Scenario 14a, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 45 Scenario 14a Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Hallway tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	#N/A	#N/A	#N/A	#N/A	16.06	8.19	16.40	16.51	#N/A	#N/A	#N/A	#N/A
Hall Wall	#N/A	#N/A	#N/A	#N/A	16.29	9.94	16.94	16.83	#N/A	#N/A	#N/A	#N/A
Hall Dead-space	#N/A	#N/A	#N/A	#N/A	15.07	14.96	16.40	15.40	#N/A	#N/A	#N/A	#N/A
ROO Ceiling	#N/A	#N/A	#N/A	#N/A	13.78	10.95	10.62	16.72	#N/A	#N/A	#N/A	#N/A
ROO Wall	#N/A	#N/A	#N/A	#N/A	16.72	15.62	18.36	16.94	#N/A	#N/A	#N/A	#N/A
ROO Dead-space	#N/A	#N/A	#N/A	#N/A	#N/A	10.73	14.42	15.40	#N/A	#N/A	#N/A	#N/A

Table 46 Scenario 14a atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.63	0.68	0.27
Air Temp (°C)	17.84	15.91	14.86
Rel. Humidity (%)	56.53	72.40	73.21
Air Pressure (mbar)	1022.53	1022.35	1020.83

3.12 SCENARIO 14b: Smouldering lounge fire in lounge room, bedroom doors open

In this scenario, a smouldering fire was initiated on a two-seater sofa using a lit cigarette. The cigarette was left in contact with three cotton batting sheets for the duration of the test. The test ended after 30 minutes at which time the smouldering fires had self-extinguished.

Figure 83 Before (left) and after (right) photographs of Scenario 14b, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 47 Scenario 14b smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	09:44	11:04	10:30	09:30	20:46	22:11	19:09	20:01	10:02	10:22	10:35	09:49
Hall Wall	09:44	10:03	09:57	09:30	20:14	21:24	20:39	20:07	09:56	10:41	09:05	09:43
Hall Dead-space	10:17	11:04	10:50	10:17	20:39	22:11	17:01	20:39	10:35	10:54	11:33	10:28
ROO Ceiling	09:57	09:37	09:37	09:57	22:17	20:07	19:48	20:33	09:43		09:36	09:36
ROO Wall	09:44	09:57	09:37	09:37	21:58	21:31	21:31	21:24	09:24	09:36	10:08	09:43
ROO Dead-space	13:42	11:10	11:23	16:51	22:32	21:18	19:48	22:17	08:51	11:26	09:05	08:38

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 11.2 ppm) and formaldehyde (up to 2.2 ppm).

Table 48 Scenario 14b Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3	01:58	22:28	06:07	00:35	07:04	01:44
FEC IMPAIRED ESCAPE 1.0	06:40	33:14	11:33		08:44	01:44
FEC INCAPACITATION 0.3	11:09		12:57		10:49	
FEC INCAPACITATION 1.0	15:52					
FED ASPHYXIATION 0.3	30:53					
FED ASPHYXIATION 1.0						

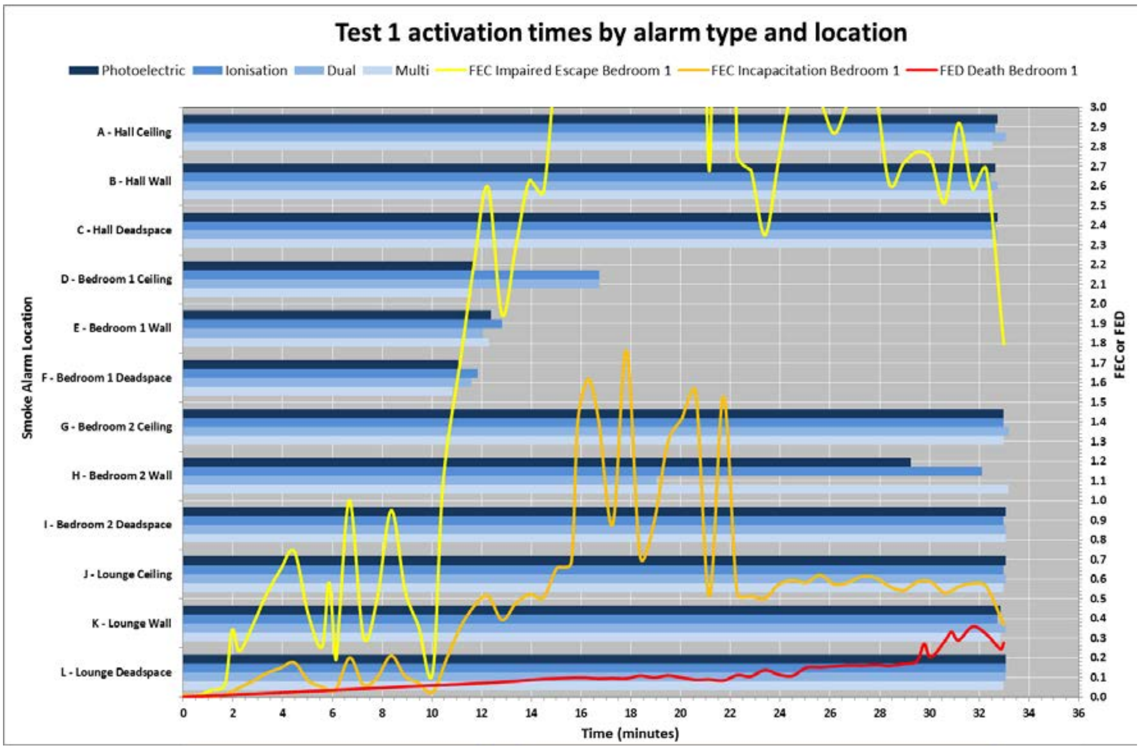

Figure 84 Scenario 14b, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

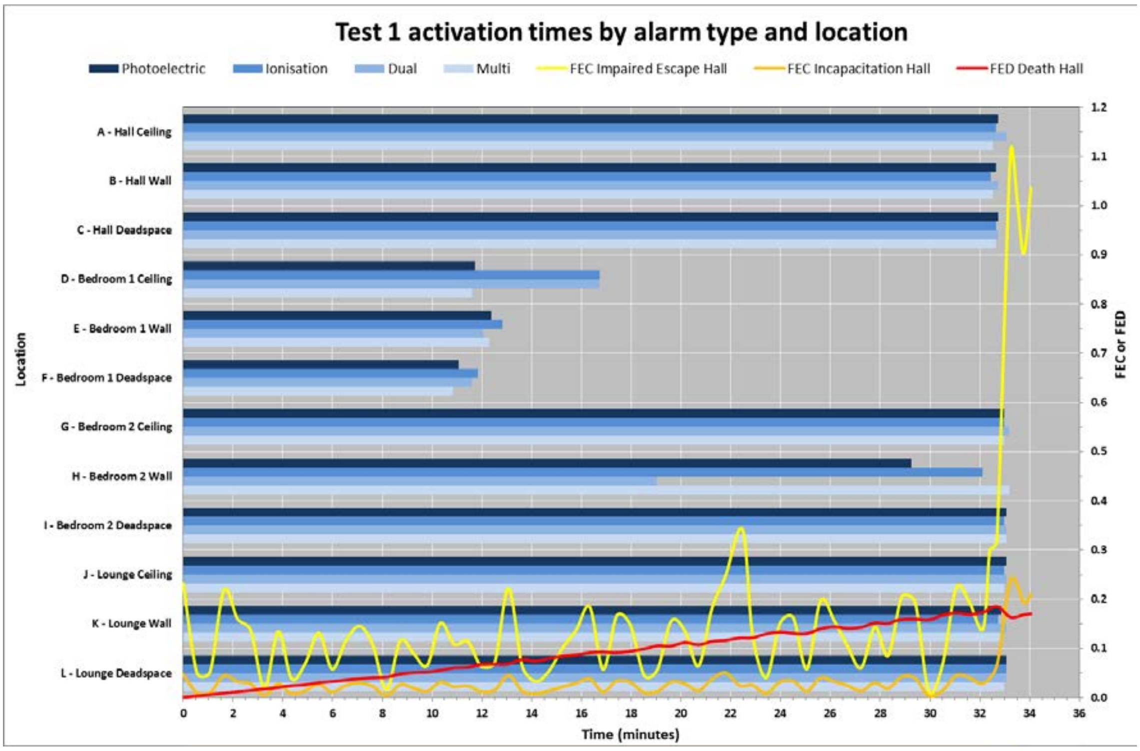

Figure 85 Scenario 14b, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

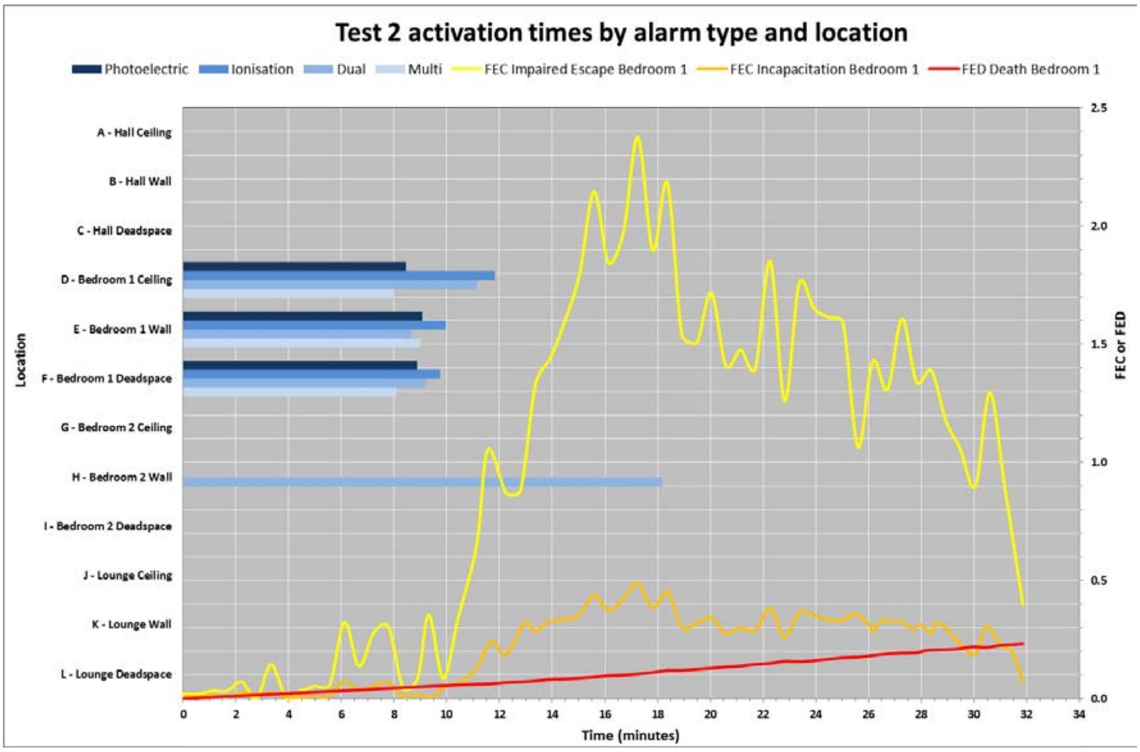

Figure 86 Scenario 14b, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

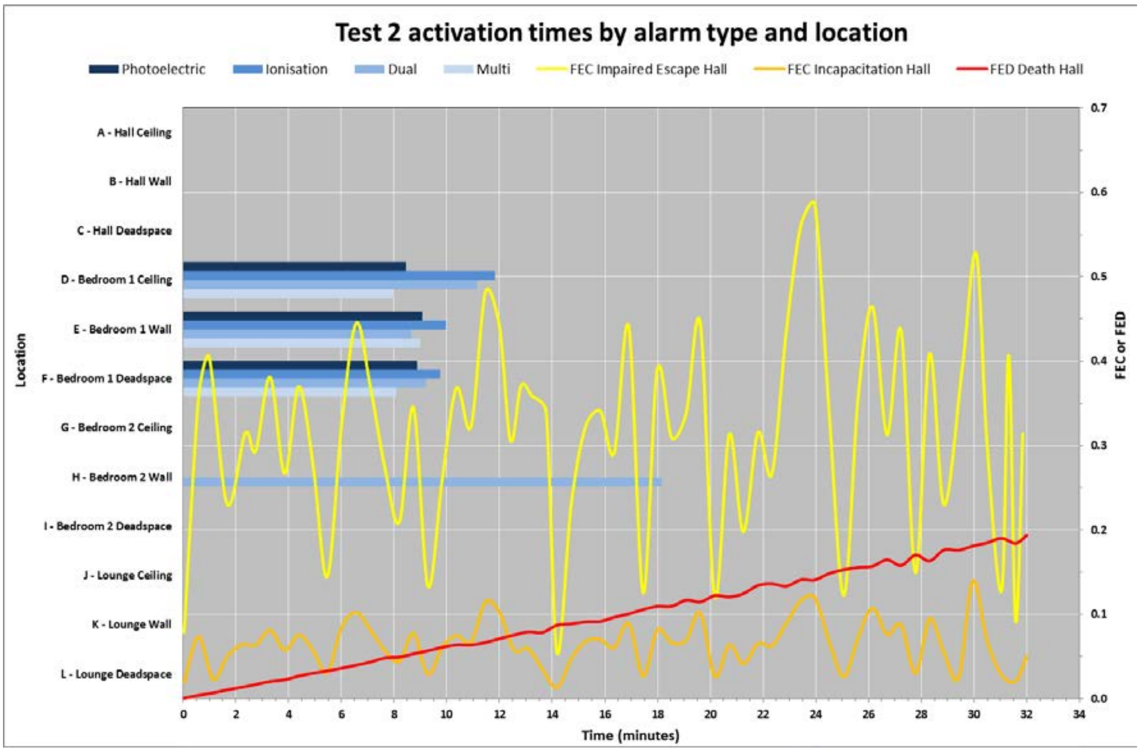

Figure 87 Scenario 14b, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

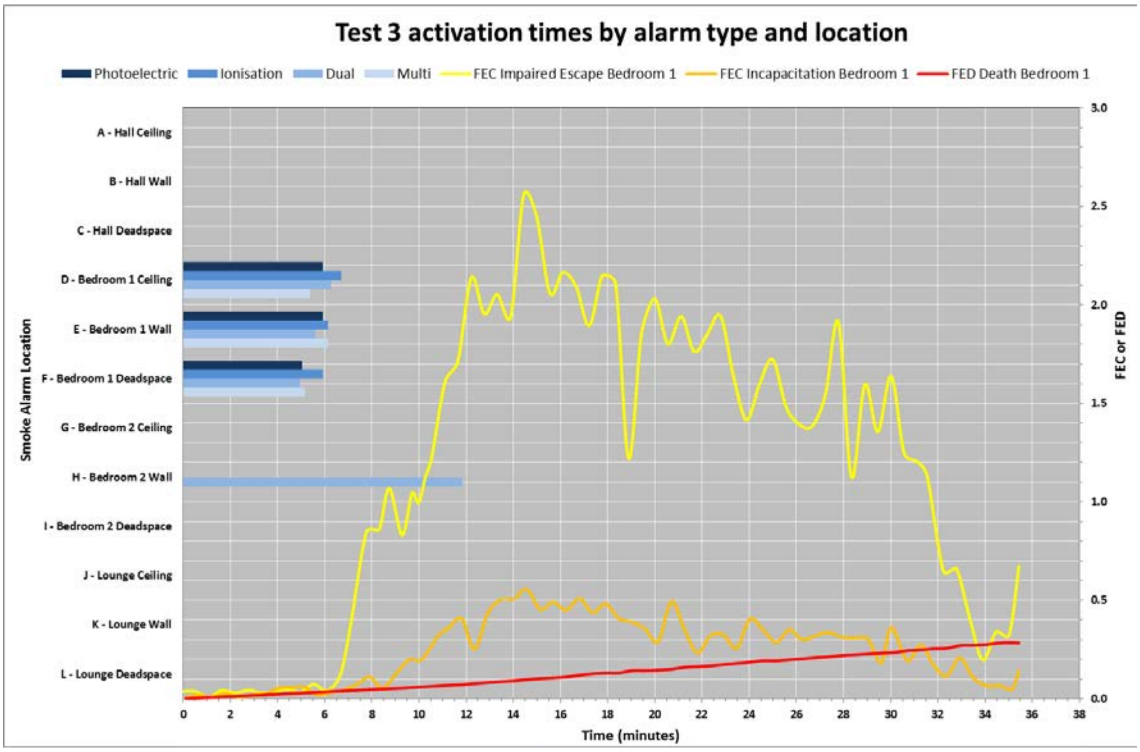

Figure 88 Scenario 14b, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

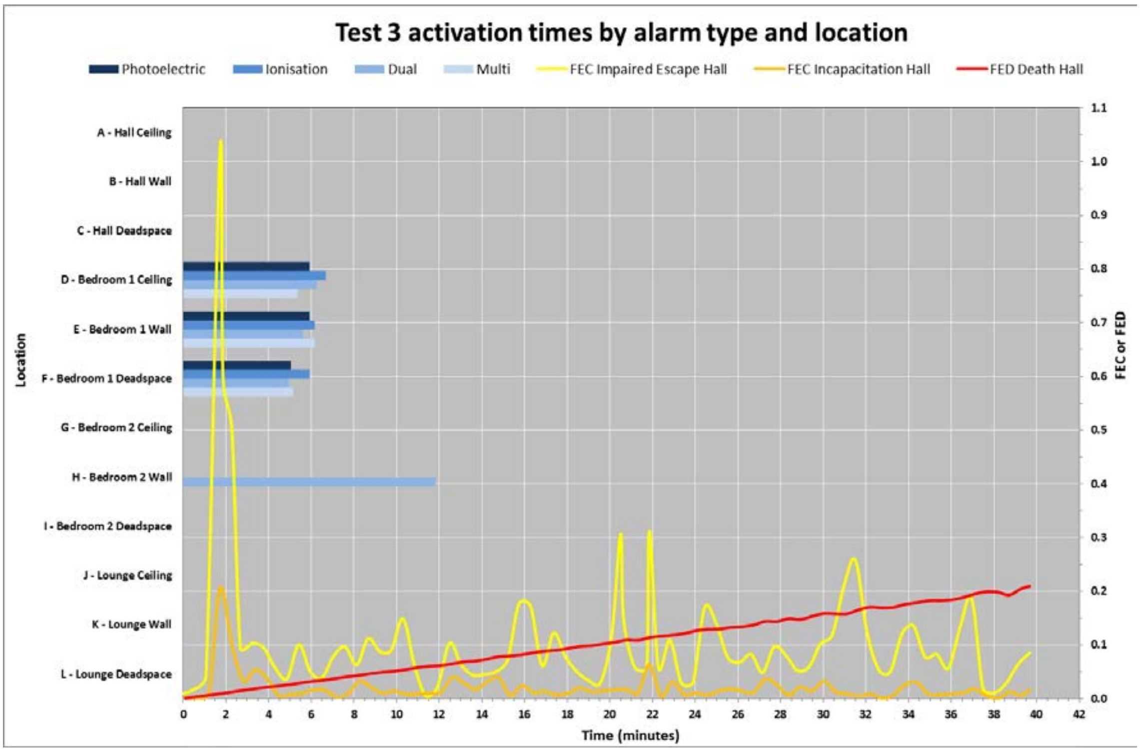

Figure 89 Scenario 14b, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 49 Scenario 14b Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Hallway tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	#N/A	#N/A	#N/A	#N/A	-14.63	-16.05	-13.02	-13.88	3.52	3.19	2.97	3.73
Hall Wall	#N/A	#N/A	#N/A	#N/A	-14.09	-15.27	-14.52	-13.98	3.62	2.87	4.47	3.84
Hall Dead-space	#N/A	#N/A	#N/A	#N/A	-14.52	-16.05	-10.88	-14.52	2.97	2.65	2.00	3.08
ROO Ceiling	#N/A	#N/A	#N/A	#N/A	-16.16	-13.98	-13.66	-14.41	3.84	#N/A	3.95	3.95
ROO Wall	#N/A	#N/A	#N/A	#N/A	-15.83	-15.39	-15.39	-15.27	4.16	3.95	3.41	3.84
ROO Dead-space	#N/A	#N/A	#N/A	#N/A	-16.39	-15.16	-13.66	-16.16	4.71	2.11	4.47	4.92

Table 50 Scenario 14b atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.63	0.53	0.51
Air Temp (°C)	16.96	16.88	17.52
Rel. Humidity (%)	36.02	64.80	59.99
Air Pressure (mbar)	1019.81	1021.42	1018.51

3.13 SCENARIO 15: Flaming paper fire in lounge room, bedroom doors open

In this scenario, a flaming fire was initiated in a waste bin containing 50 sheets of copy paper using the butane barbeque lighter. The flame was left in contact with the paper for 15 seconds and then removed.

Figure 90 Before (left) and after (right) photographs of Scenario 15, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 51 Scenario 15 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	06:16	03:26	03:07	06:03	05:46	04:34	04:13	05:46	03:20	00:56	01:23	03:12
Hall Wall	06:03	03:07	02:54	05:57	05:52	04:13	03:34	06:52	03:20	00:56	01:23	03:12
Hall Dead-space	06:23	03:07	02:54	06:29	06:46	04:27	03:34	06:33	03:39	01:03	01:09	03:33
ROO Ceiling	02:35	01:02	03:00	02:35	03:15	01:10	02:28	02:54	02:31	00:23	00:23	02:19
ROO Wall	05:24	02:01	03:00	05:31	05:52	02:40	03:21	06:13	02:44	00:36	00:56	02:44
ROO Dead-space		01:02	01:22	02:35		01:16	01:16	05:00		00:23	00:23	02:04

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 9.60 ppm), formaldehyde (up to 3.2 ppm) and sulfur dioxide (up to 5.1 ppm).

The peak temperature measured at the ceiling in the Lounge room was 26.8°C.

Table 52 Scenario 15 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3	04:03	01:29	00:47	00:00	04:31	00:27
FEC IMPAIRED ESCAPE 1.0		05:01	08:26	04:24		03:35
FEC INCAPACITATION 0.3		06:07		07:32		05:37
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

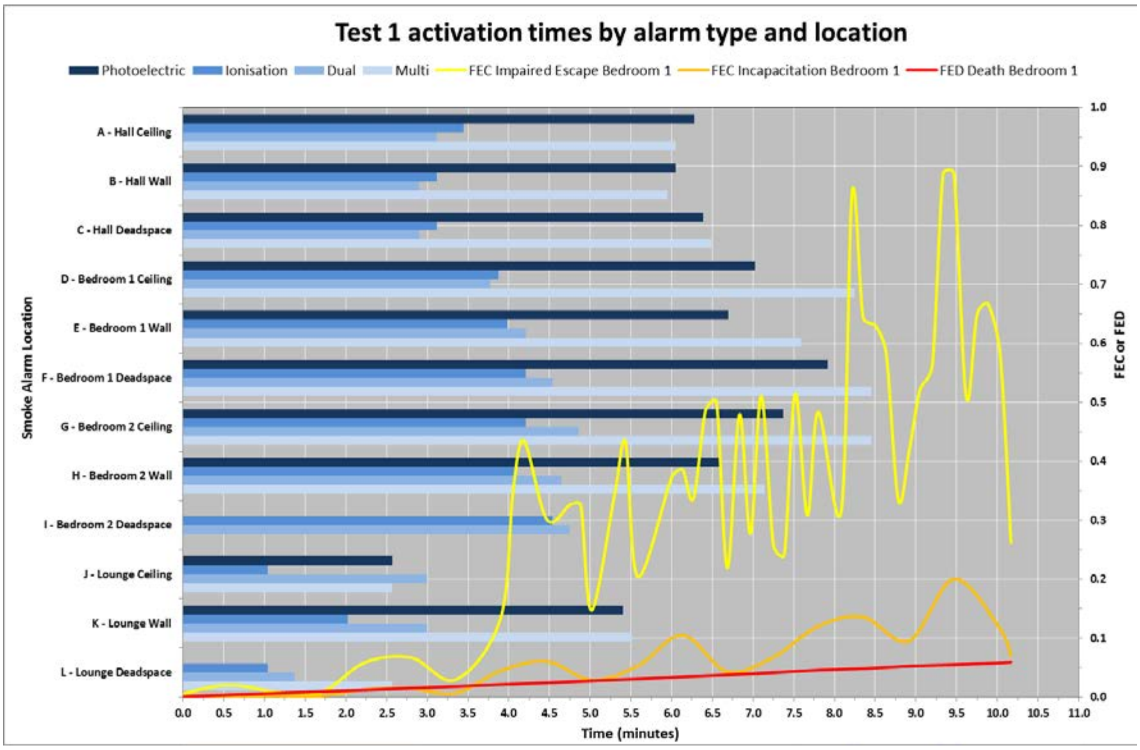

Figure 91 Scenario 15, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

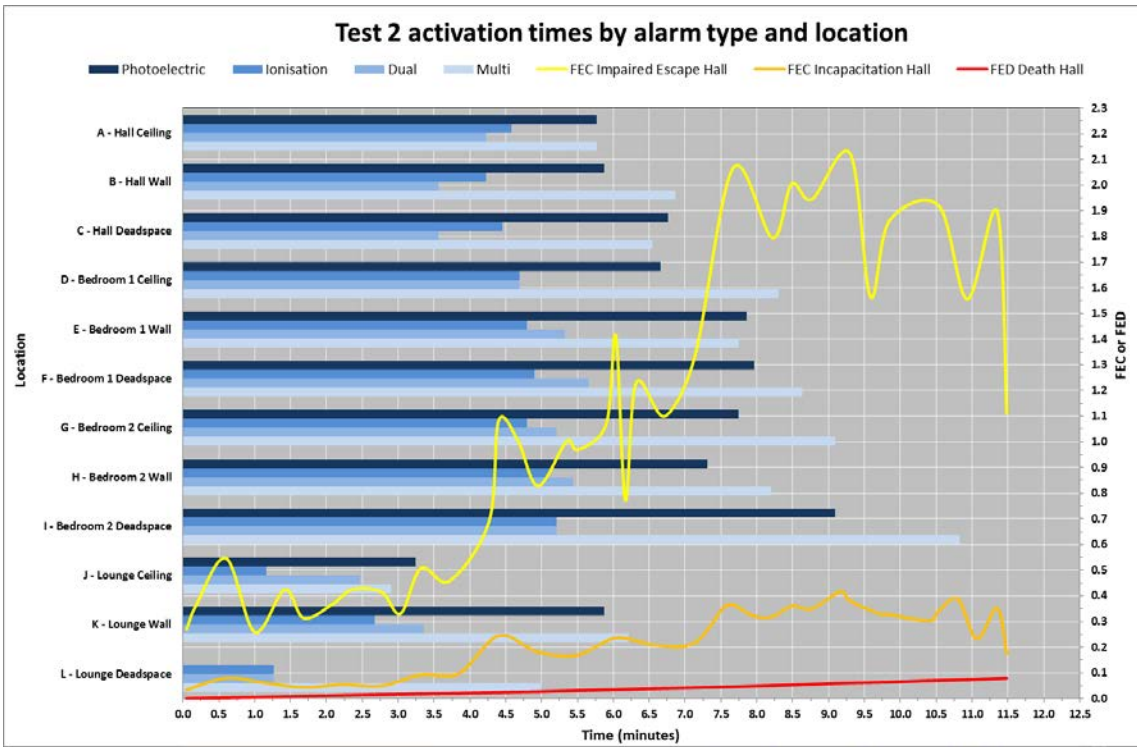

Figure 92 Scenario 15, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

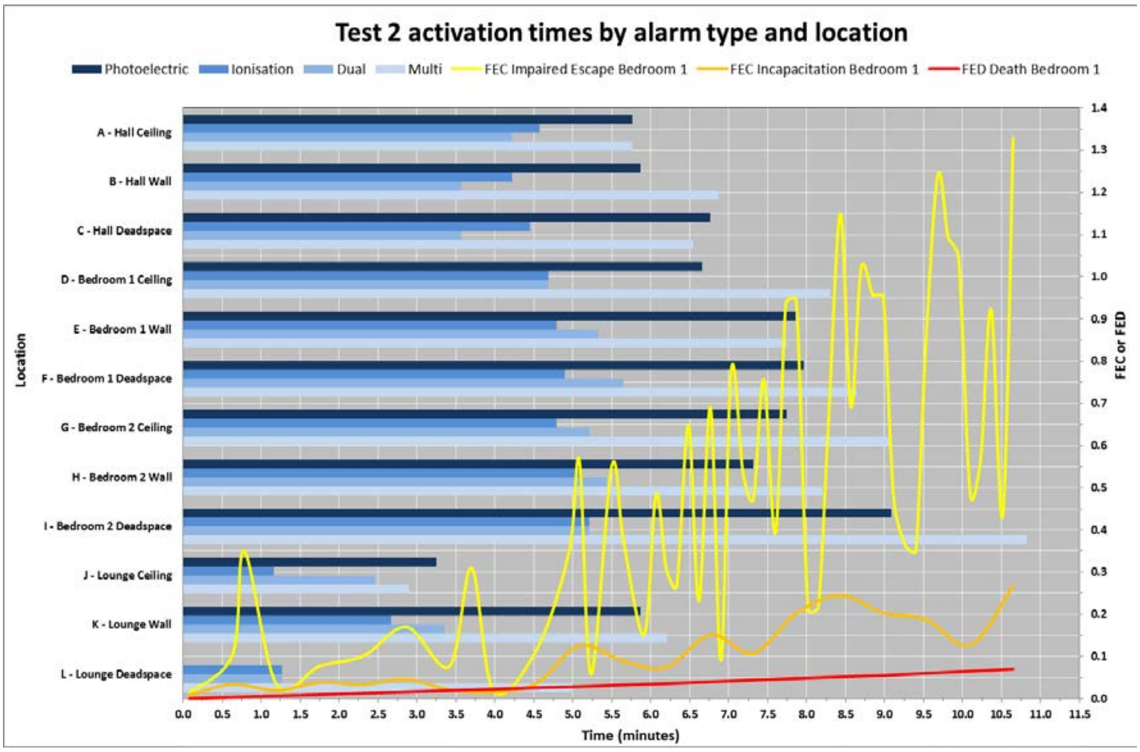

Figure 93 Scenario 15, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

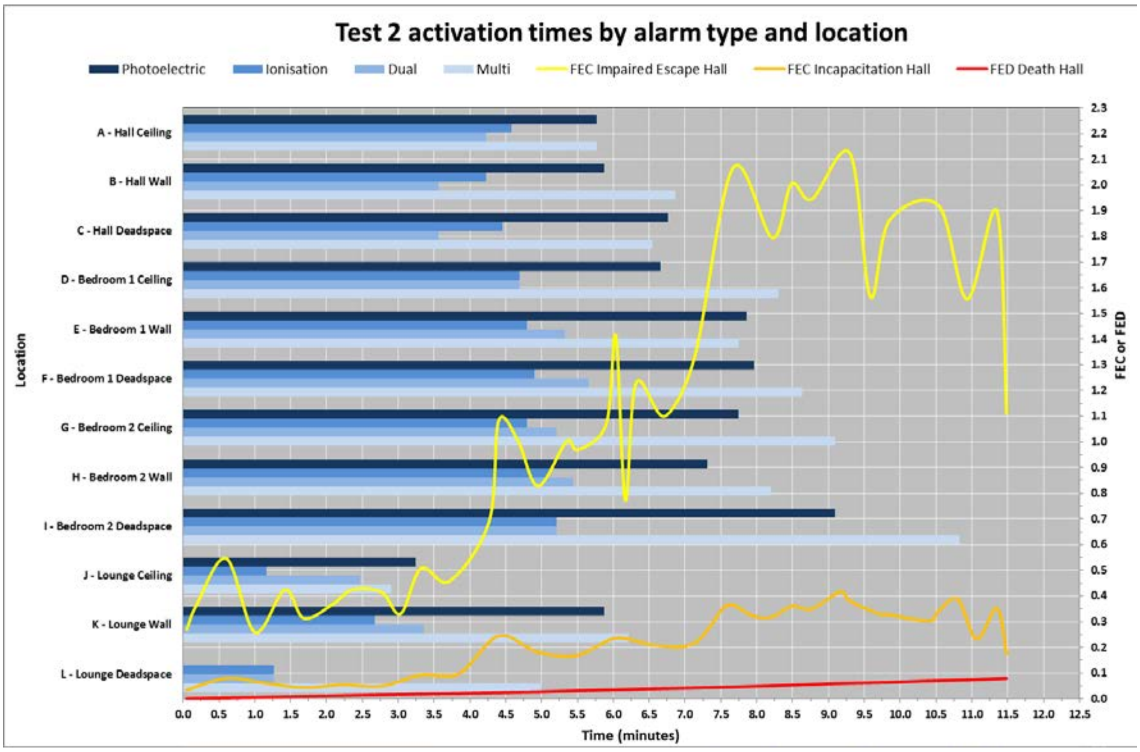

Figure 94 Scenario 15, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

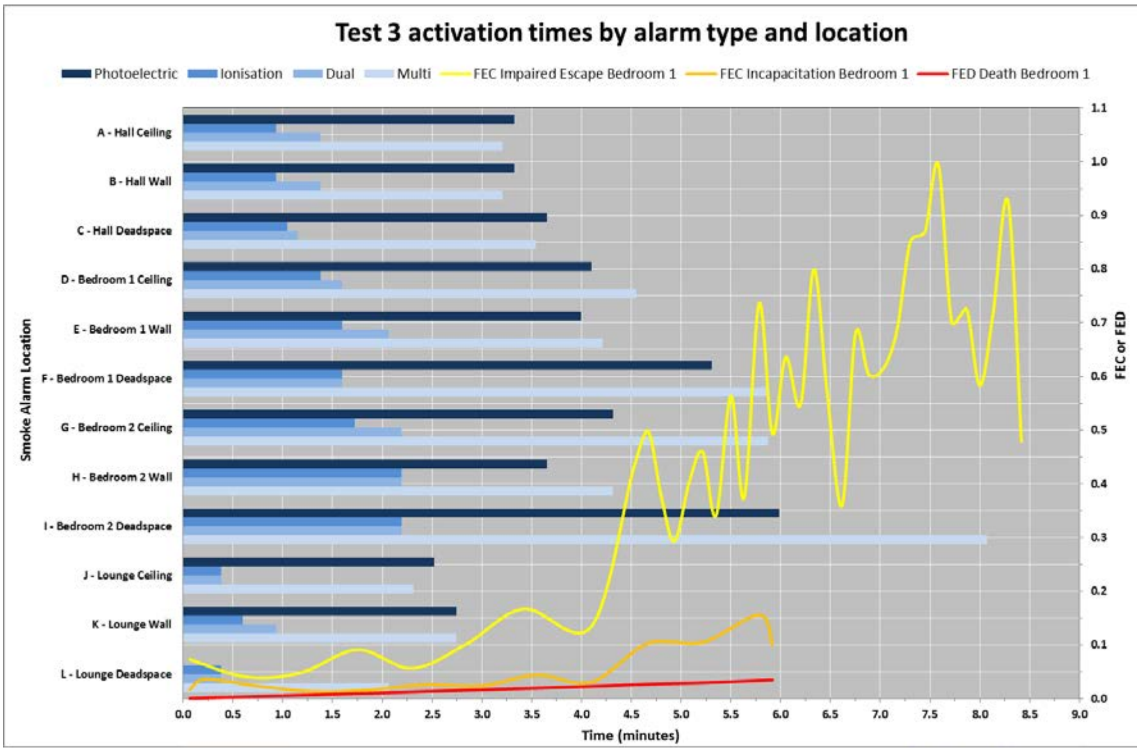

Figure 95 Scenario 15, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

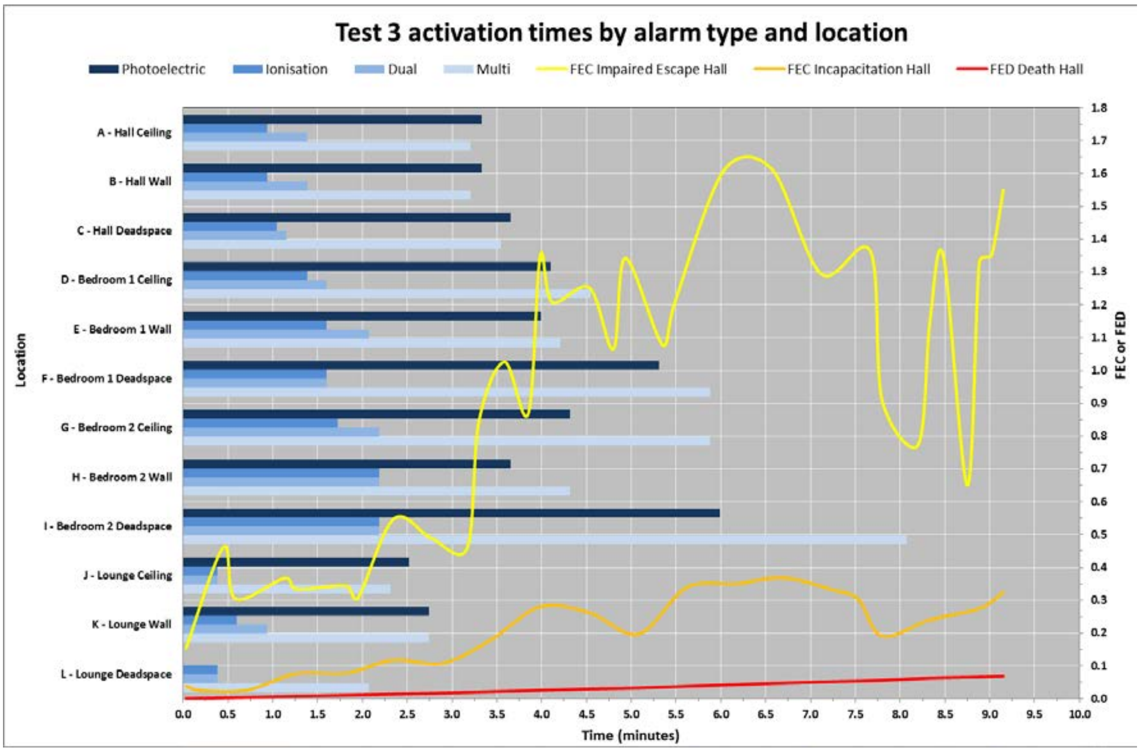

Figure 96 Scenario 15, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 53 Scenario 15 Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Hallway tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	*-0.16*	2.68	3.00	0.06	1.77	2.96	3.31	1.77	2.29	4.68	4.23	2.41
Hall Wall	0.06	3.00	3.22	0.17	1.66	3.31	3.97	0.66	2.29	4.68	4.23	2.41
Hall Dead-space	*-0.27*	3.00	3.22	*-0.37*	0.77	3.08	3.97	0.98	1.96	4.57	4.46	2.07
ROO Ceiling	3.54	5.08	3.12	3.54	4.29	6.37	5.07	4.64	3.09	5.24	5.24	3.31
ROO Wall	0.71	4.10	3.12	0.61	1.66	4.86	4.18	1.32	2.88	5.02	4.68	2.88
ROO Dead-space	*#N/A*	5.08	4.75	3.54	*#N/A*	6.27	6.27	2.53	*#N/A*	5.24	5.24	3.55

Table 54 Scenario 15 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.36	0.18	0.27
Air Temp (°C)	14.82	12.51	13.86
Rel. Humidity (%)	79.04	84.18	77.91
Air Pressure (mbar)	1024.35	1022.20	1022.01

3.14 SCENARIO 16: Flaming chair fire in lounge, bedroom doors open

In this scenario, a flaming fire was initiated on the seat pad of a timber dining chair using a butane barbeque lighter. The flame was held to the seat edge for 15 seconds and then removed. The flaming fire spread across the chair pad until the cushion is consumed and did not spread to the MDF backing or rubber wood frame. The fire self-extinguished in approximately 12 minutes.

Figure 97 Before (left) and after (right) photographs of Scenario 16, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 55 Scenario 16 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling		05:53	04:47			07:15	05:11			05:30	04:32	
Hall Wall		05:00	04:28			06:29	05:17			05:24	03:39	
Hall Dead-space		05:20	04:02			06:15	05:30			05:04	03:59	
ROO Ceiling		03:03	03:56		09:05	04:25	04:32		03:06	02:14	02:34	
ROO Wall		03:03	03:17			04:51	05:17			02:41	03:20	
ROO Dead-space		02:16	02:23			01:12	01:18			02:00	02:14	

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 1.8 ppm), formaldehyde (up to 0.7 ppm) and sulfur dioxide (up to 5.1 ppm).

The peak temperature measured at the ceiling in the Lounge room was 26.3°C.

The tenability limits for occupant incapacitation were not reached in these tests.

Table 56 Scenario 16 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3	04:57	00:08				
FEC IMPAIRED ESCAPE 1.0						
FEC INCAPACITATION 0.3						
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

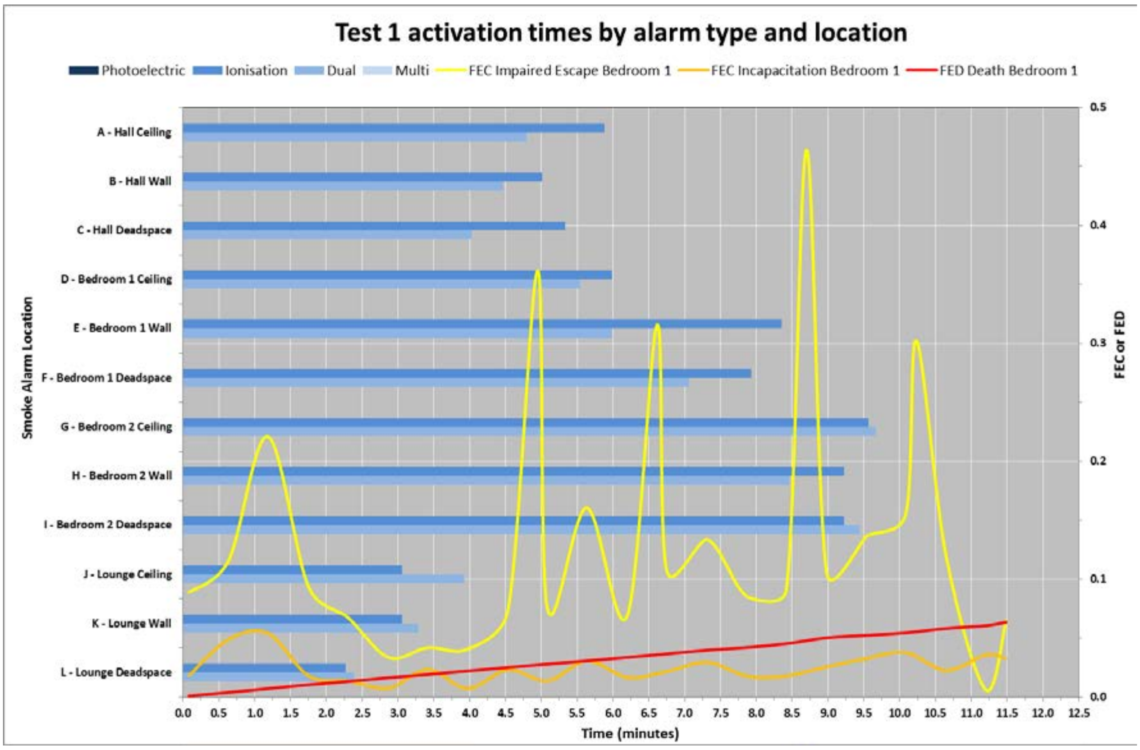

Figure 98 Scenario 16, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

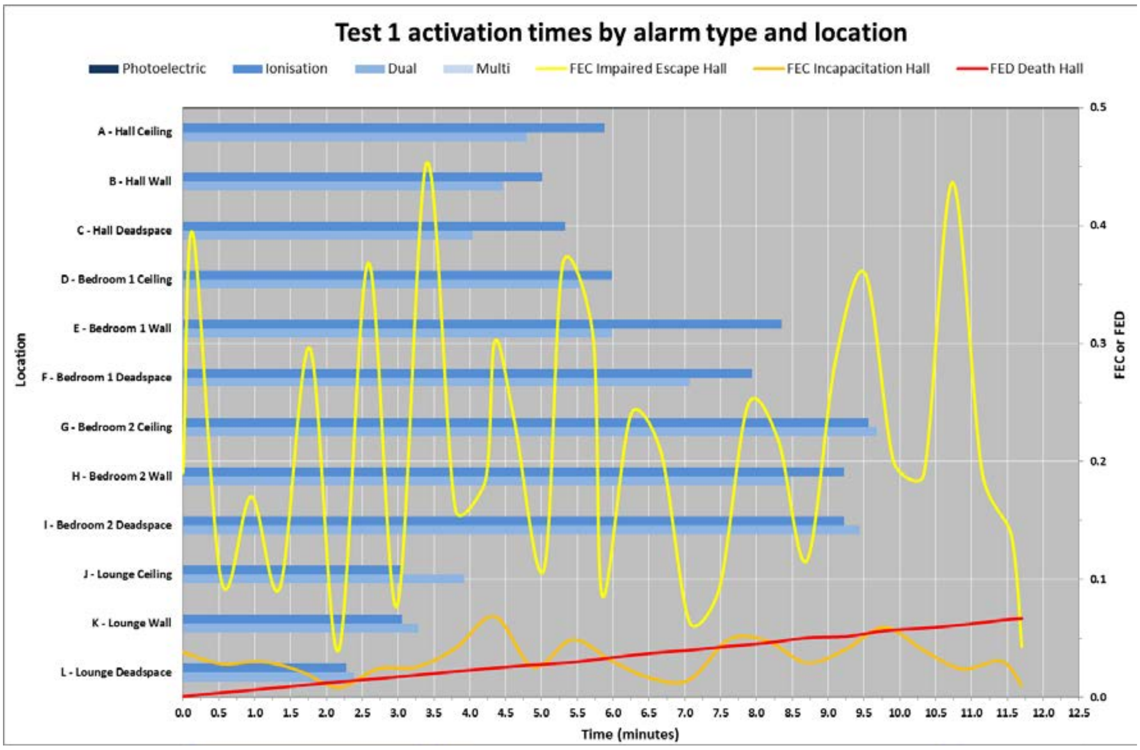

Figure 99 Scenario 16, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

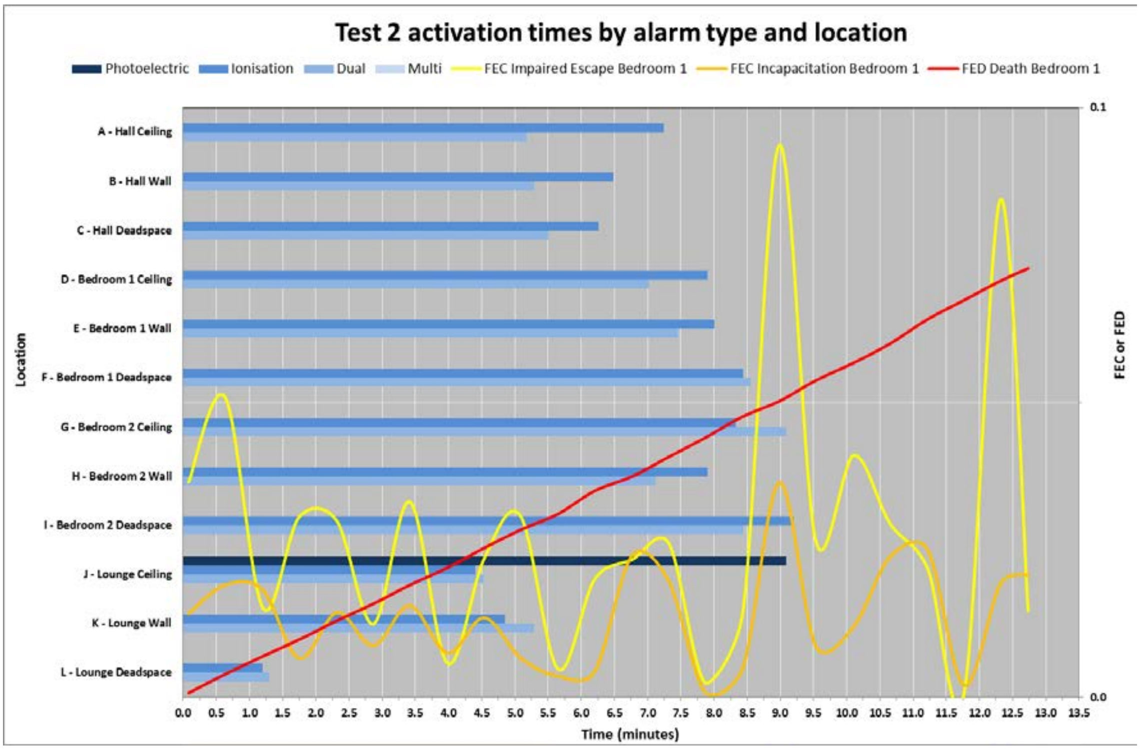

Figure 100 Scenario 16, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

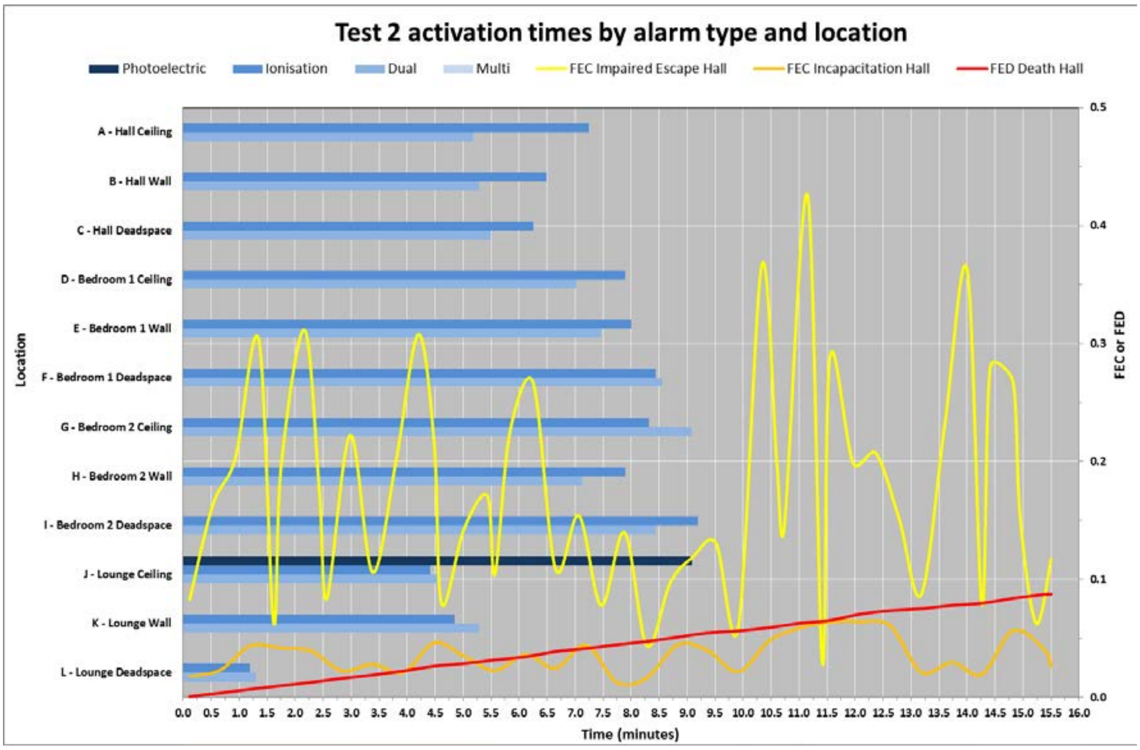

Figure 101 Scenario 16, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

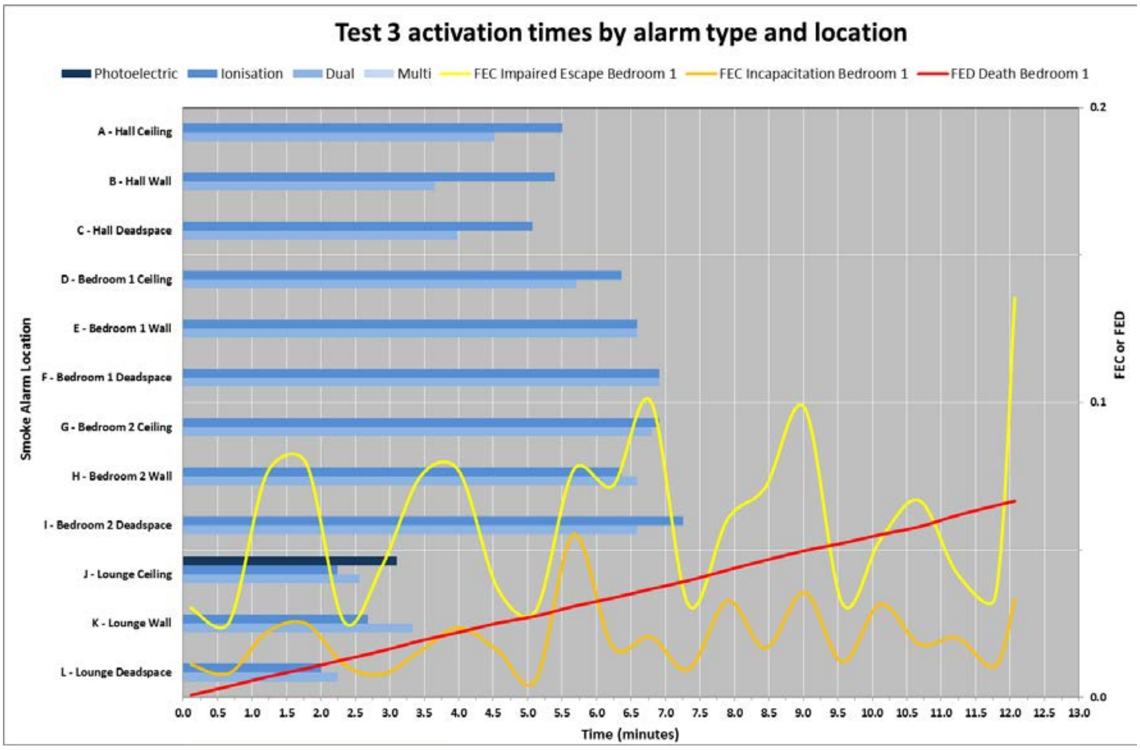

Figure 102 Scenario 16, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

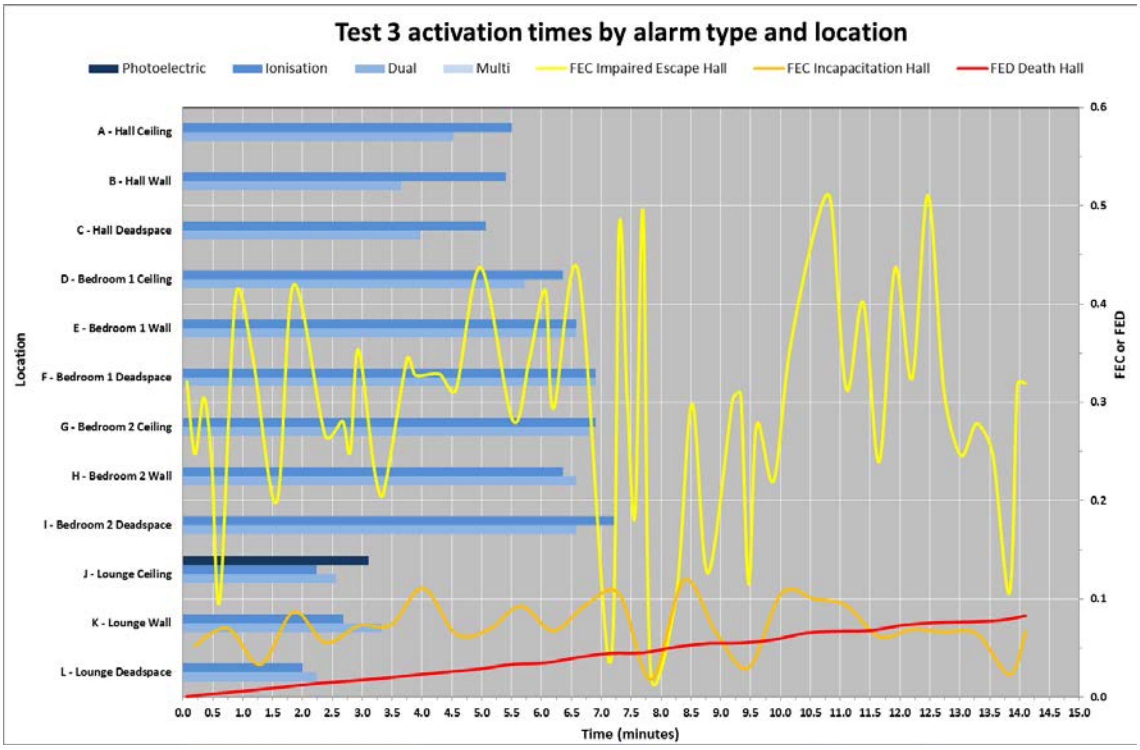

Figure 103 Scenario 16, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 57 Scenario 16 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.75	0.78	0.53
Air Temp (°C)	16.70	18.04	15.29
Rel. Humidity (%)	51.13	52.03	75.26
Air Pressure (mbar)	1024.40	1023.33	1023.79

3.15 SCENARIO 17: Flaming cooking oil fire in kitchen, bedroom doors open

In this scenario 250 ml of cooking oil (canola) is heated to flashpoint (+380°C) in a 24 cm frying pan on the stove. Flaming ignition of the cooking oil was achieved at different times for each test using a butane barbeque lighter: Test 1 at 14 minutes when the oil surface temperature was 400°C, Test 2 at 11m20s at 390°C, and Test 3 at 10m40s at 434°C.

Figure 104 Before (left) and during (right) photographs of Scenario 17, Tests 1 (top), 2 (middle) and 3 (bottom).

The majority of smoke alarms activated before the flames ignited (Table 58).

Table 58 Scenario 17 smoke alarm activation times (min:sec) in the Hallway and Lounge room

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	11:06	08:20	06:49	11:06	07:13	07:00	06:33	07:00	08:59	09:36	10:14	08:32
Hall Wall	10:53	08:07	06:09	11:00	06:46	06:33	06:40	06:40	07:54	09:30		08:20
Hall Dead-space	11:40	08:46	05:56	11:47	08:20	08:06	07:40	08:13		10:01	07:48	09:24
ROO Ceiling	09:40	05:50	04:30	09:40	05:40	06:07	05:40	05:34	05:01	05:59	04:41	05:40
ROO Wall	10:47	05:03	05:03	10:40	07:20	07:27	06:33	06:46	07:22	07:22	06:44	07:22
ROO Dead-space	14:51	10:40	10:08	12:15	10:06	05:00	05:40	08:00	09:12	10:58	11:11	09:05

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 5.5 ppm), formaldehyde (up to 0.94 ppm), and sulfur dioxide (up to 4.9 ppm).

The peak temperature measured in the kitchen was 79°C and in the Lounge room was 66.6°C, both at ceiling height in Test 1.

Table 59 Scenario 17 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3	12:36	01:40	05:32	00:30	06:45	10:13
FEC IMPAIRED ESCAPE 1.0		16:23		13:25		
FEC INCAPACITATION 0.3				13:25		
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

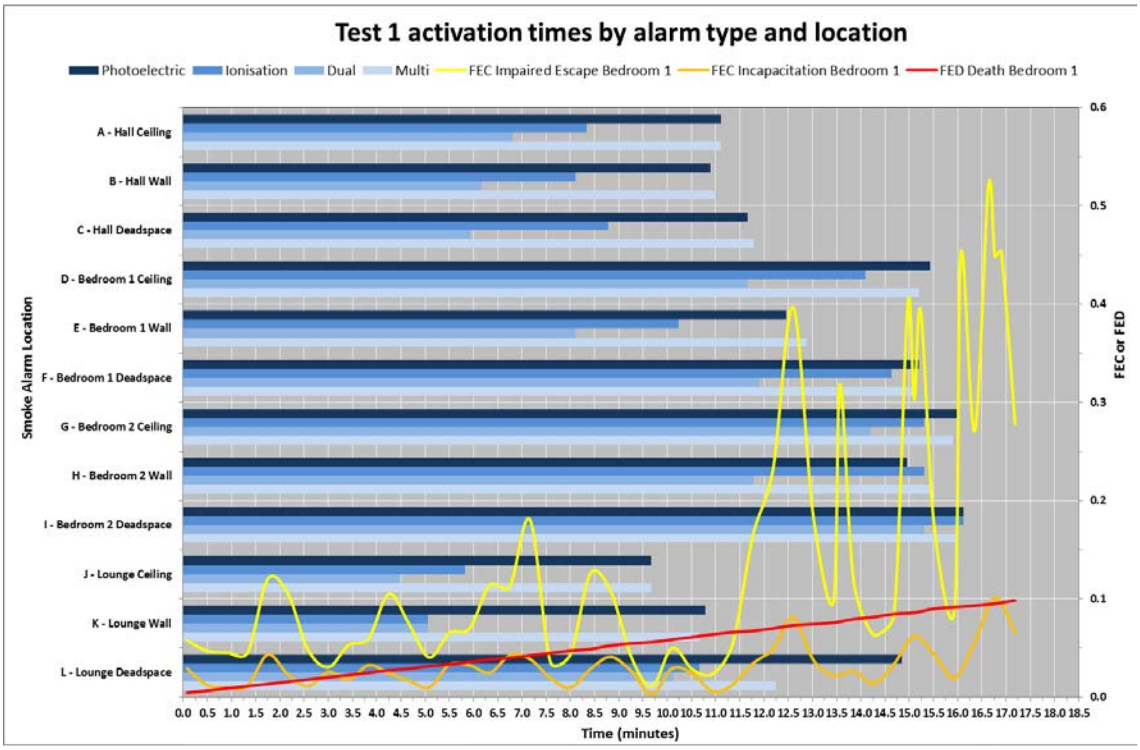

Figure 105 Scenario 17, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

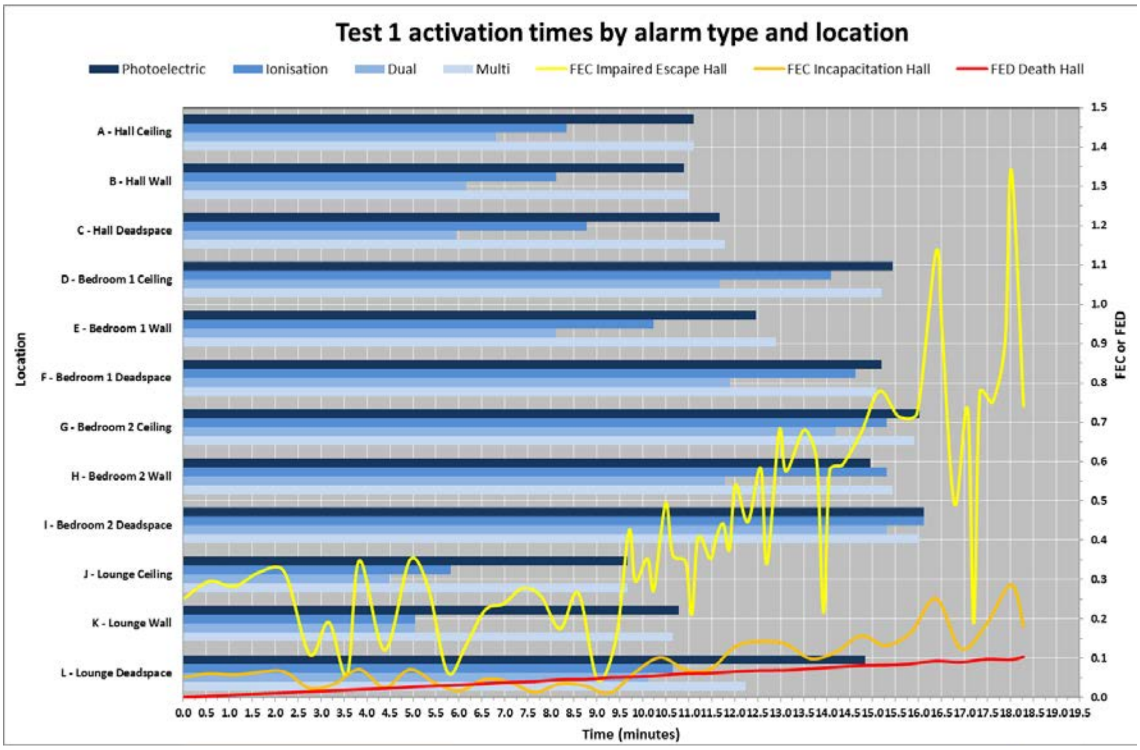

Figure 106 Scenario 17, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

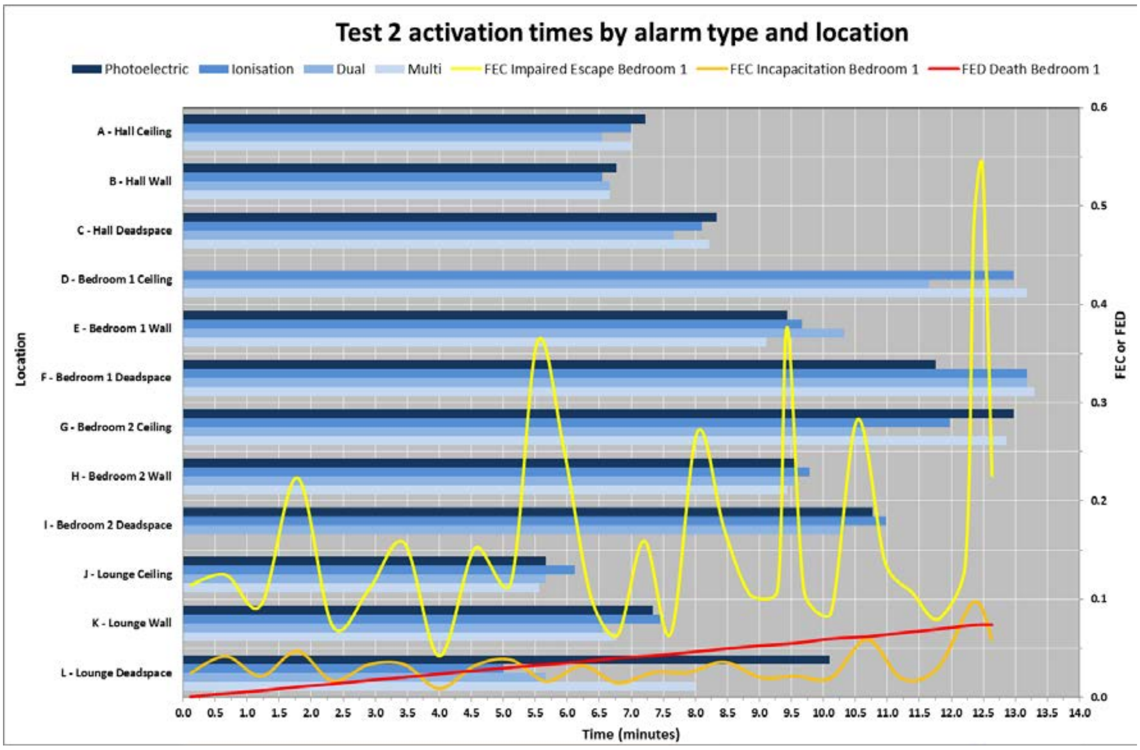

Figure 107 Scenario 17, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

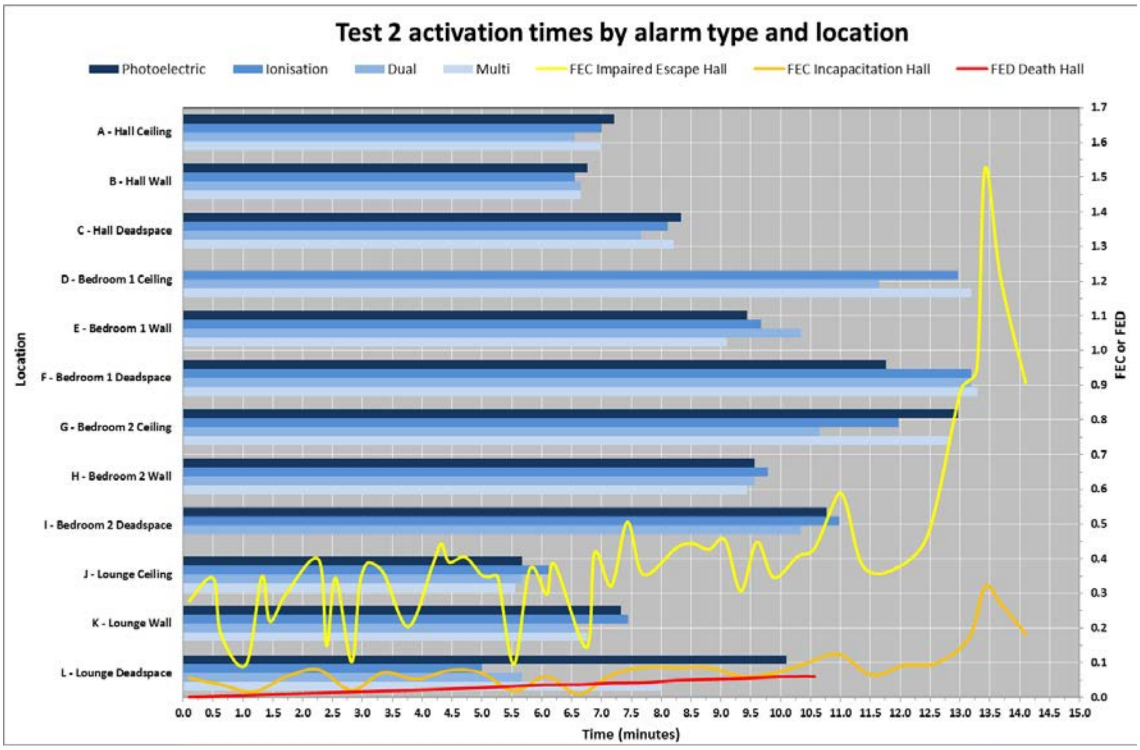

Figure 108 Scenario 317, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

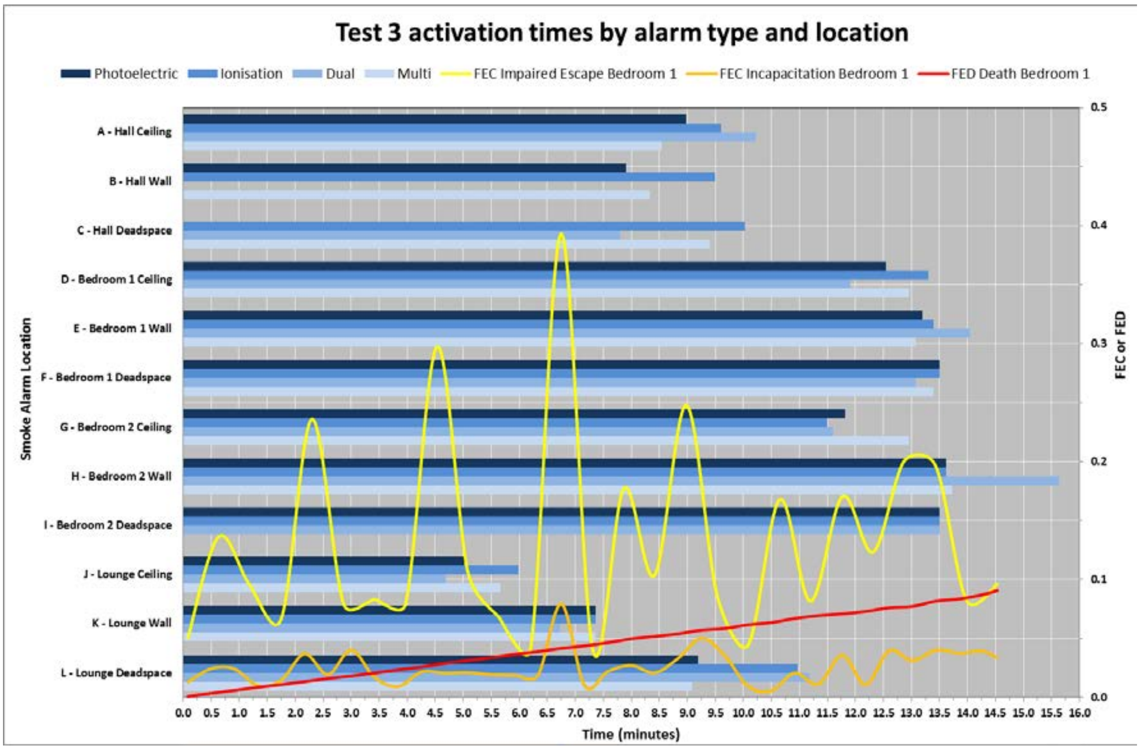

Figure 109 Scenario 17, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

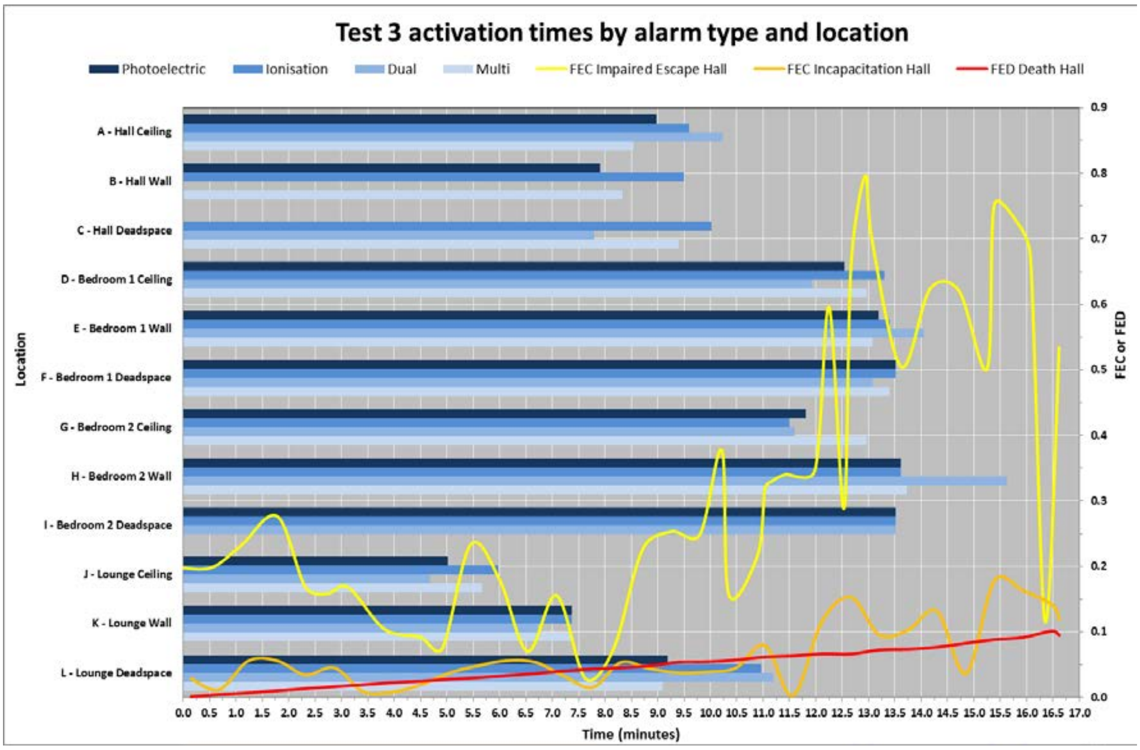

Figure 110 Scenario 17, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 60 Scenario 17 Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Hallway tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient. ROO alarms in this scenario were the lounge room alarms which were nearest to the kitchen.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	#N/A	#N/A	#N/A	#N/A	6.20	6.42	6.87	6.42	#N/A	#N/A	#N/A	#N/A
Hall Wall	#N/A	#N/A	#N/A	#N/A	6.65	6.87	6.76	6.76	#N/A	#N/A	#N/A	#N/A
Hall Dead-space	#N/A	#N/A	#N/A	#N/A	5.09	5.31	5.75	5.20	#N/A	#N/A	#N/A	#N/A
ROO Ceiling	#N/A	#N/A	#N/A	#N/A	7.75	7.30	7.75	7.86	#N/A	#N/A	#N/A	#N/A
ROO Wall	#N/A	#N/A	#N/A	#N/A	6.09	5.96	6.87	6.65	#N/A	#N/A	#N/A	#N/A
ROO Dead-space	#N/A	#N/A	#N/A	#N/A	3.32	8.42	7.75	5.42	#N/A	#N/A	#N/A	#N/A

Table 61 Scenario 17 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.51	0.46	0.89
Air Temp (°C)	20.88	20.58	16.36
Rel. Humidity (%)	27.80	43.22	42.36
Air Pressure (mbar)	1009.27	1012.55	1002.51

3.16 SCENARIO 18: Flaming tea towel fire in kitchen, bedroom doors open

In this scenario, a flaming fire was initiated in a cotton tea towel on the kitchen stove using a butane barbeque lighter. The flame was held in contact with the tea towel for 15s and then removed. The tests ended after six to seven minutes.

Figure 111 Images of Scenario 18, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 62 Scenario 18 smoke alarm activation times (min:sec) in the Hallway and Lounge room

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling		01:37	01:57		02:38	01:44	01:58	02:12	06:58	02:05	02:32	05:57
Hall Wall	06:55	02:39	02:45		02:19	01:51	01:58	02:19	05:44	02:12	02:12	05:57
Hall Dead-space		01:37	01:37		02:52	01:51	02:19	03:00	06:51	02:19	02:26	07:11
ROO Ceiling	00:22	00:22	00:16	00:22	00:57	00:50	00:50	00:57	01:32	01:38	01:38	
ROO Wall		00:43	01:17		01:44	01:17	01:10	01:44	06:58	01:38	01:59	06:37
ROO Dead-space		00:43	00:43		01:31	02:45		01:31		01:52	01:52	

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 2.9 ppm), and formaldehyde (up to 1.3 ppm).

The peak temperature measured in the kitchen was 34.7°C and in the Lounge room was 34.4°C, both at ceiling height in Test 3.

The tenability limits for occupant incapacitation in the Hallway at 1.5 metres were not reached in the tests.

Table 63 Scenario 18 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3			06:35	05:57	04:45	02:00
FEC IMPAIRED ESCAPE 1.0						
FEC INCAPACITATION 0.3						
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

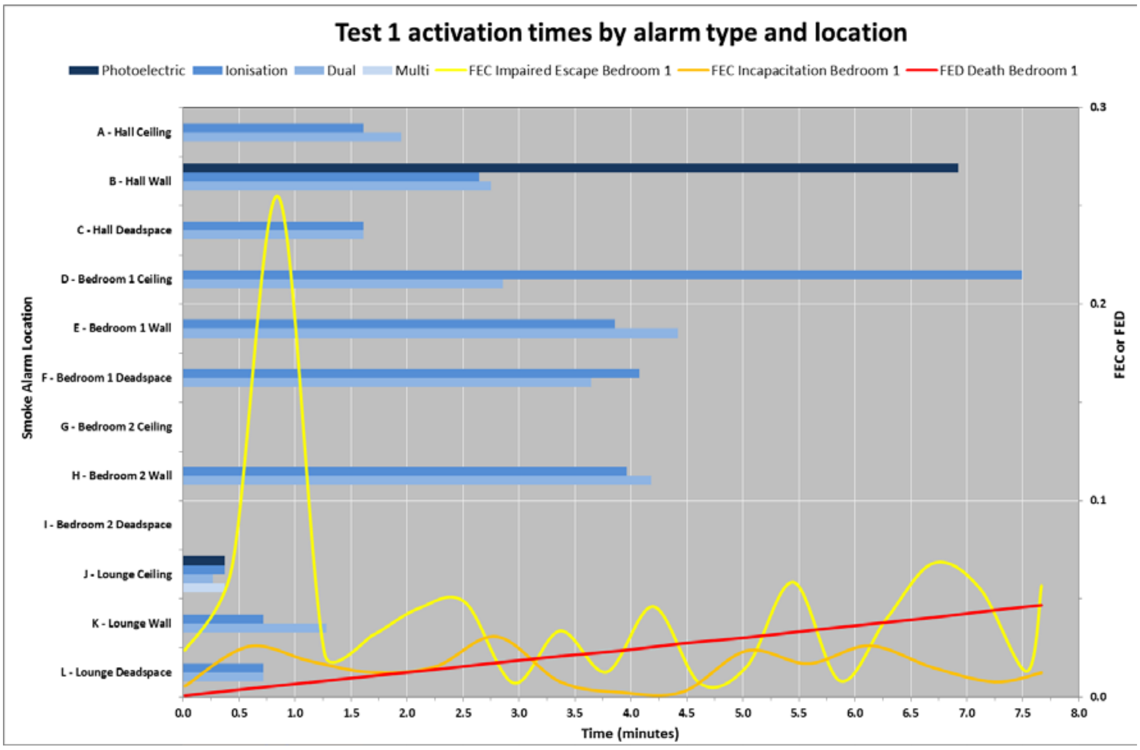

Figure 112 Scenario 18, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

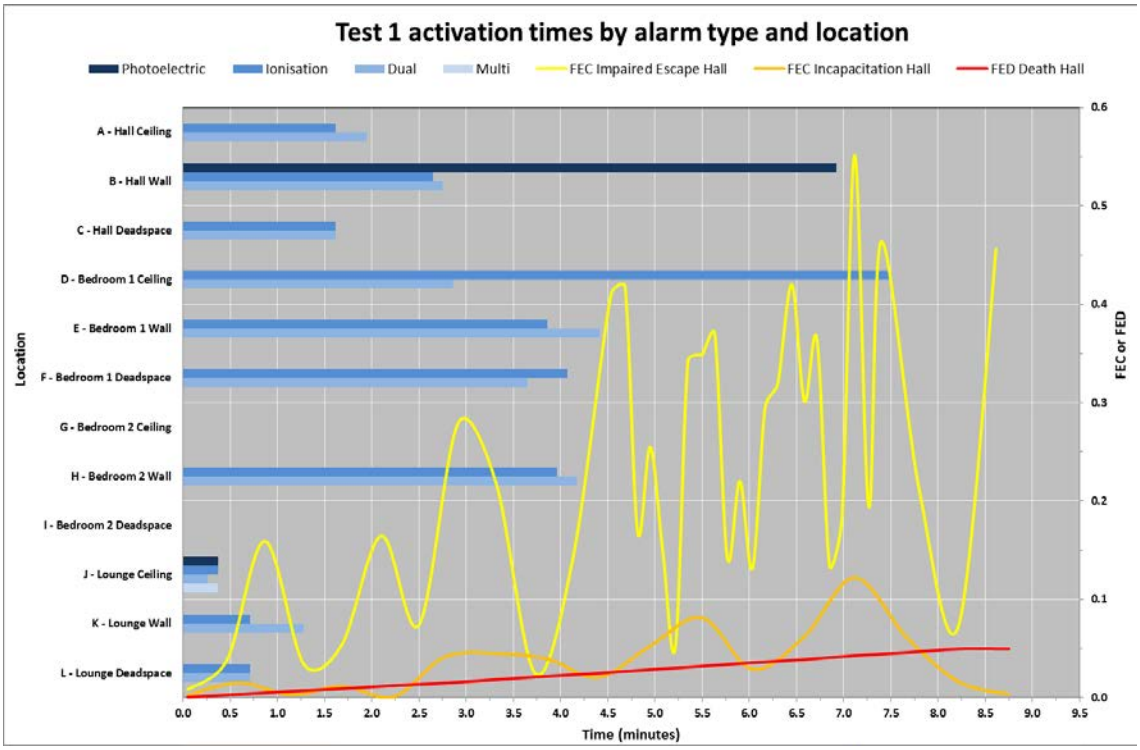

Figure 113 Scenario 18, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

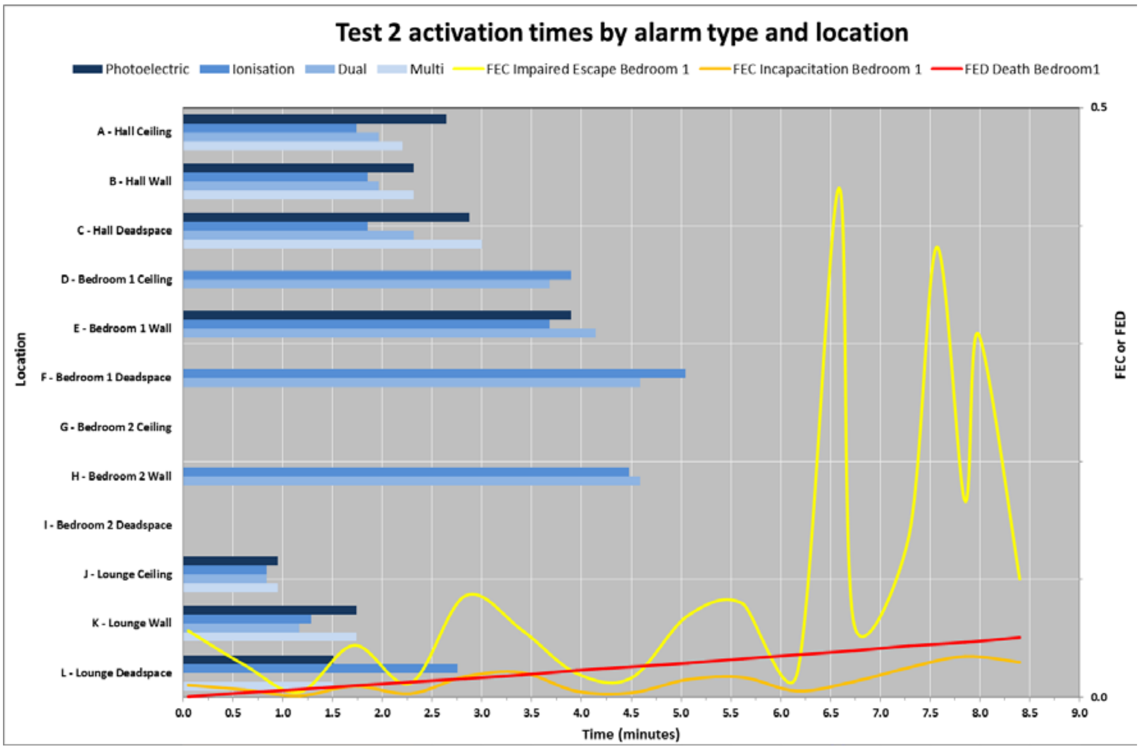

Figure 114 Scenario 18, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

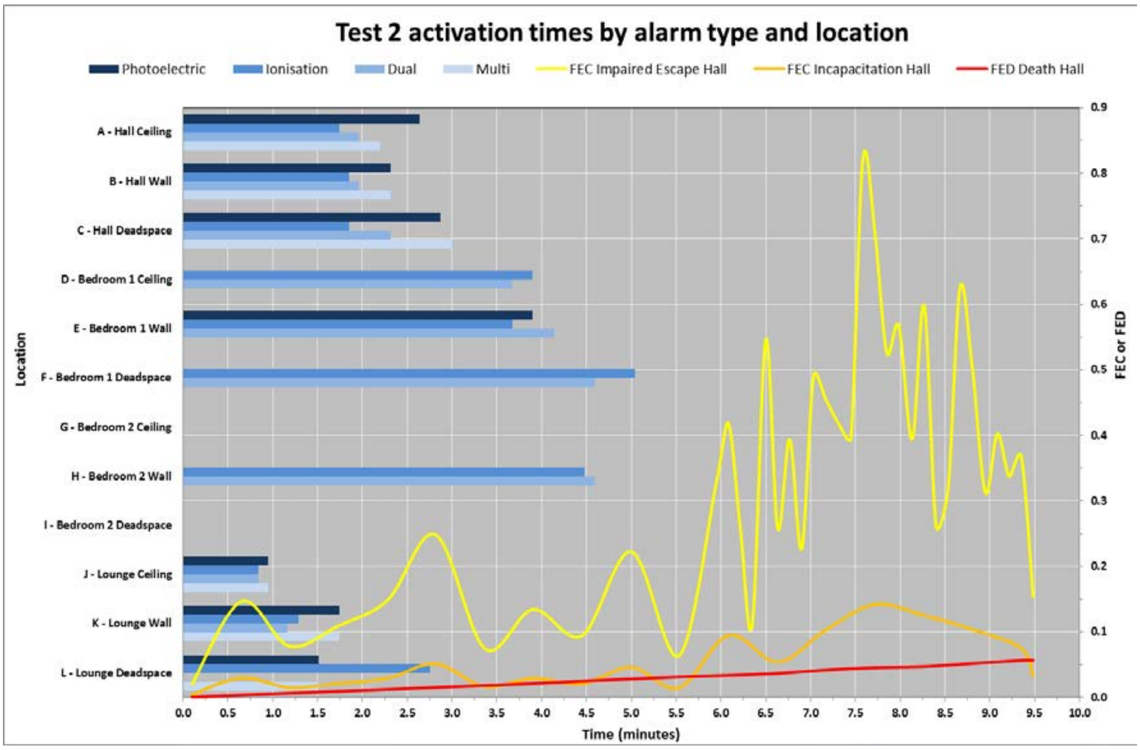

Figure 115 Scenario 18, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

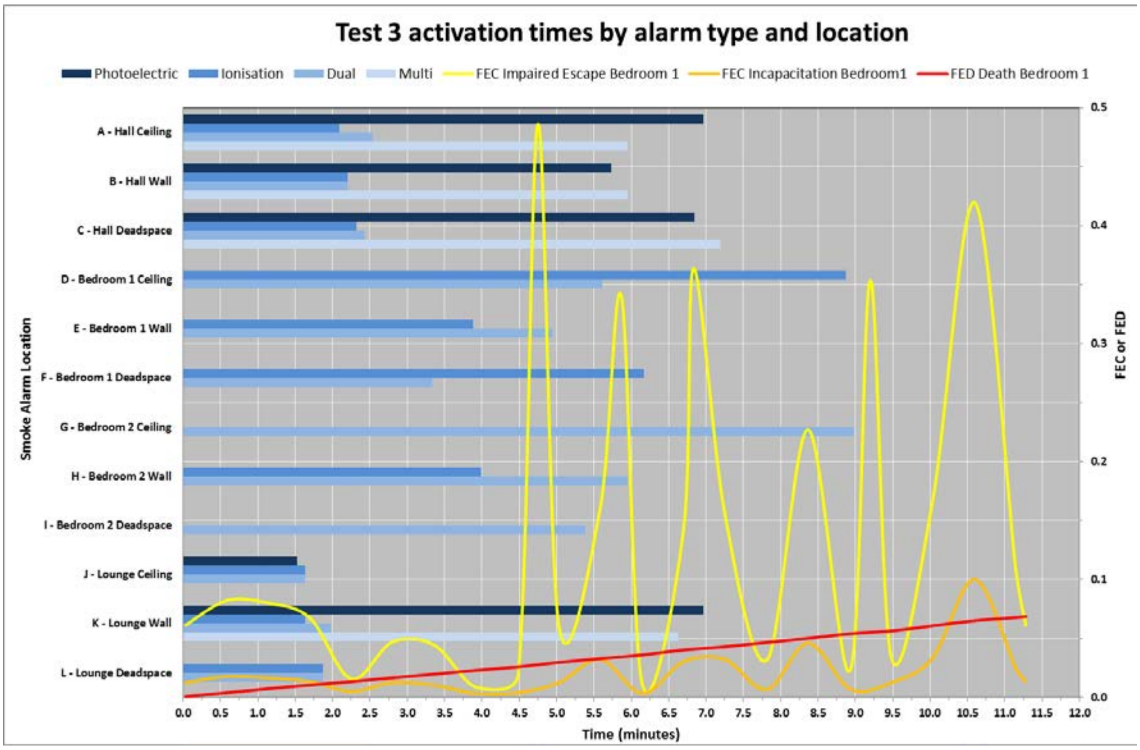

Figure 116 Scenario 18, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

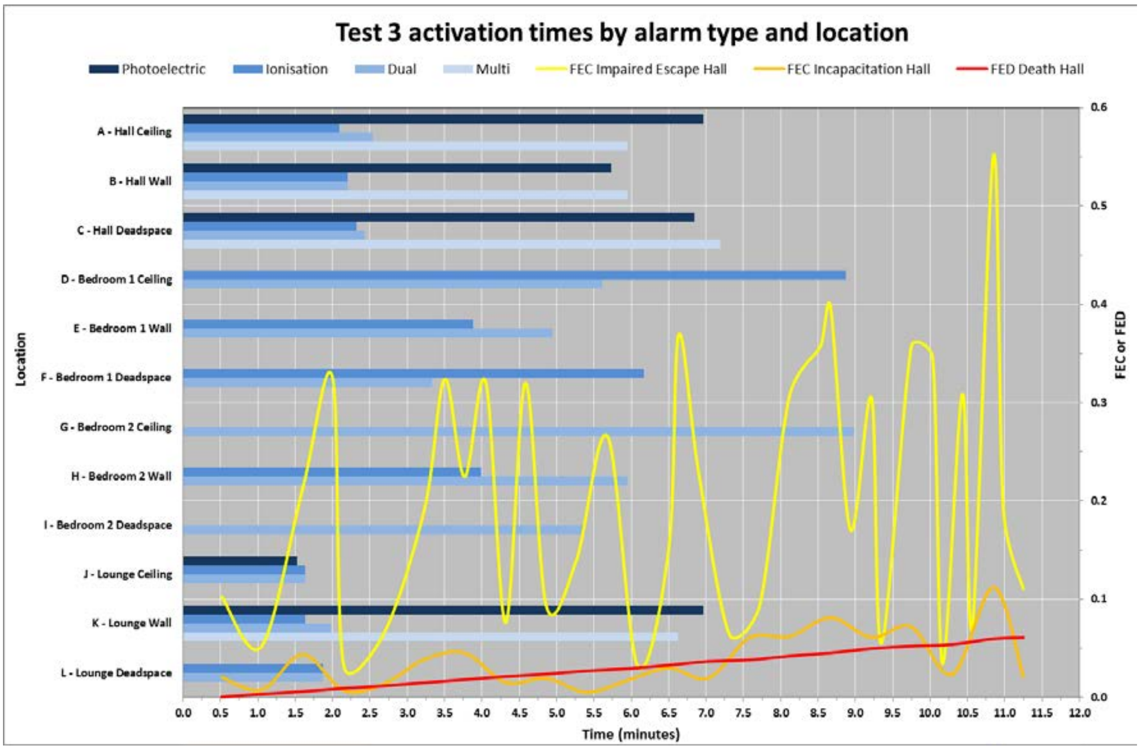

Figure 117 Scenario 18, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 64 Scenario 18 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	1.07	1.00	1.04
Air Temp (°C)	23.60	24.69	24.50
Rel. Humidity (%)	37.12	31.66	18.35
Air Pressure (mbar)	1007.69	1007.56	1008.22

3.17 SCENARIO 19: Smouldering iron in the laundry, bedroom doors open

In this scenario, a smouldering fire was initiated in the laundry/bathroom using a clothes iron which had been modified to bypass the in-built thermal cut-off. The appliance was switched on high heat and left to heat up on its own. In these three tests, the iron heats for a couple of minutes before self-igniting at 3m30s, 2m35s, and 3m15s in Test 1, 2 and 3, respectively.

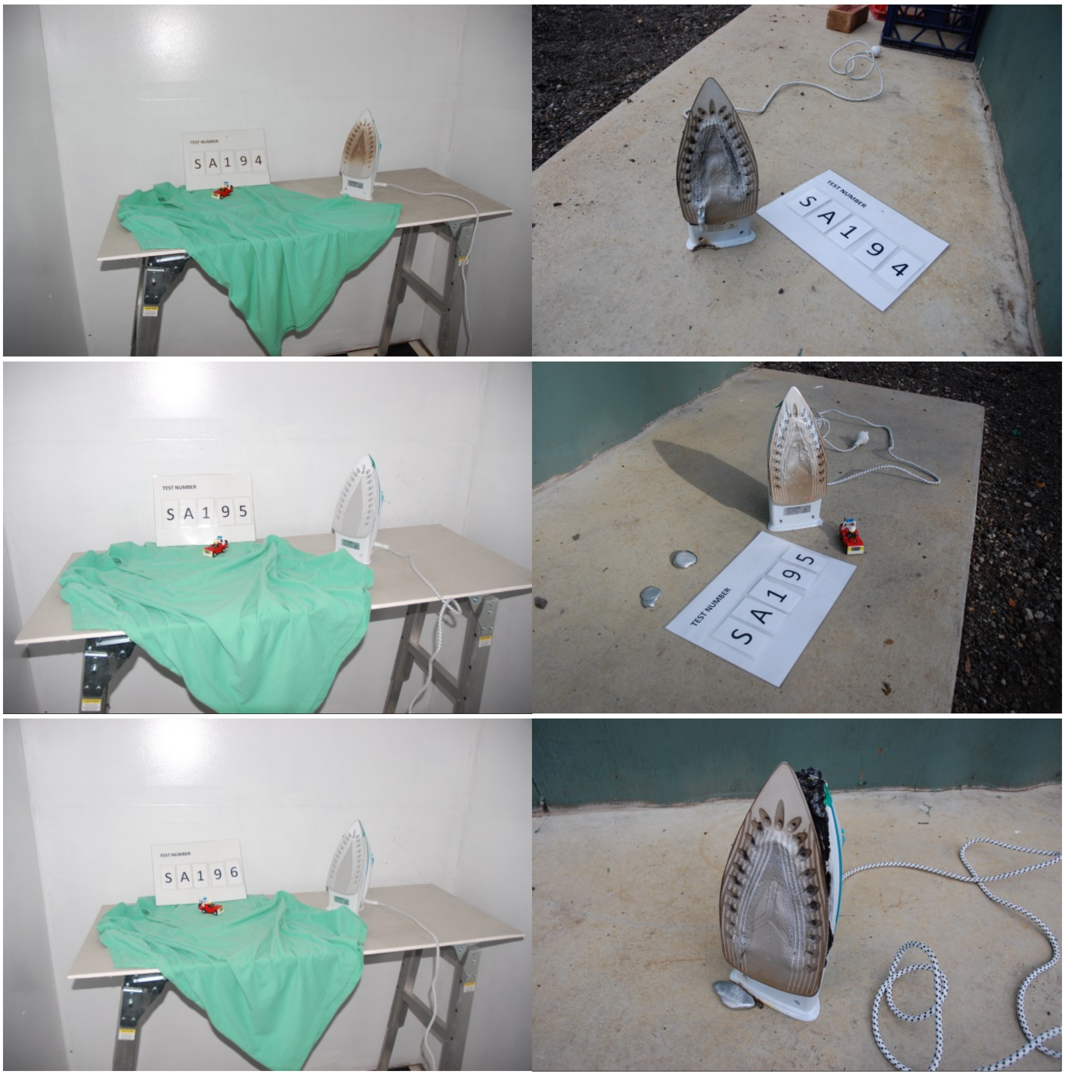

Figure 118 Before (left) and after (right) photographs of Scenario 19, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 65 Scenario 19 smoke alarm activation times (min:sec) in the Hallway and Lounge room.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling		03:54	03:08	03:22		02:35	02:35	02:35		02:40	02:20	02:54
Hall Wall	04:01	02:56	03:08	03:35	03:08	02:35	03:02	03:21	03:32	02:40	02:47	03:19
Hall Dead-space	04:07	03:48	04:20	04:26	03:53	03:34	03:15	04:07	03:51	03:06	03:19	03:51
Lounge Ceiling	07:52	04:26	04:20	08:05	04:39	03:47	04:13	05:00	04:37	04:24	05:16	04:57
Lounge Wall	06:35	04:07	04:20	05:17		04:25	04:19	06:30	07:01	04:44	05:29	06:15
Lounge Dead-space					05:26		09:44	05:26	05:49	05:29	05:36	05:29

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 2.3 ppm), formaldehyde (up to 0.73 ppm) and sulfur dioxide (up to 3.7 ppm).

The tenability limits for occupant incapacitation were not reached in the tests.

Table 66 Scenario 19 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3		01:35	03:59		06:55	00:41
FEC IMPAIRED ESCAPE 1.0						
FEC INCAPACITATION 0.3						
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

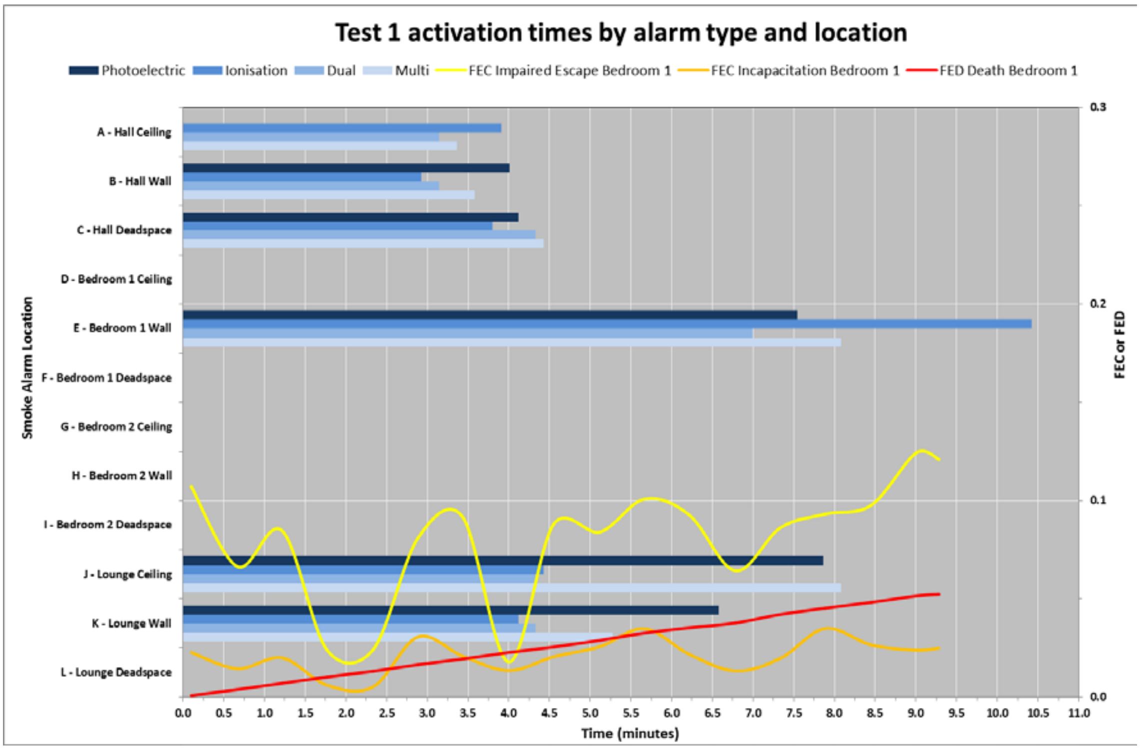

Figure 119 Scenario 19, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

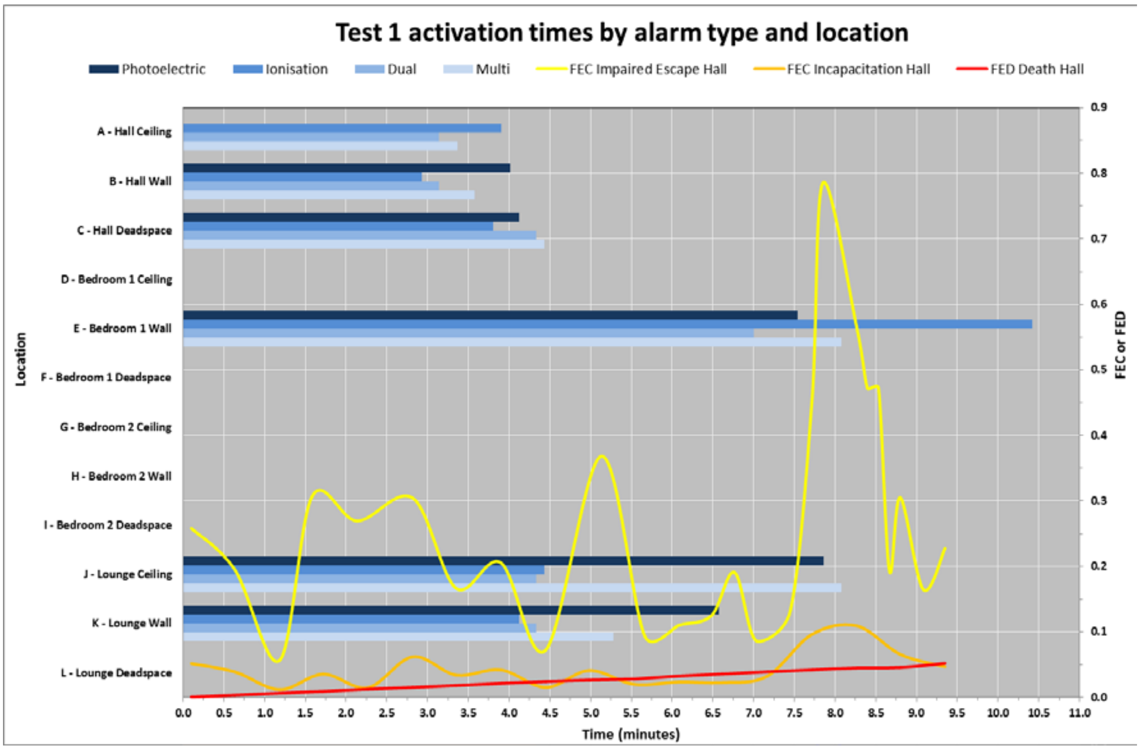

Figure 120 Scenario 19, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

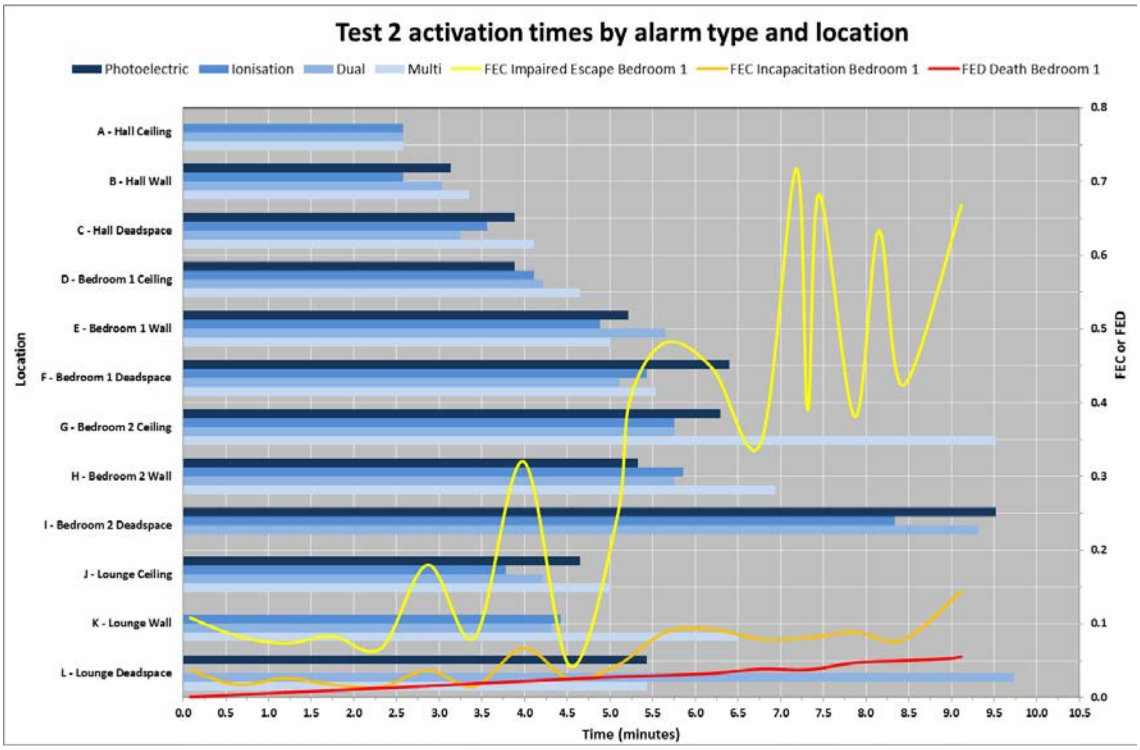

Figure 121 Scenario 19, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

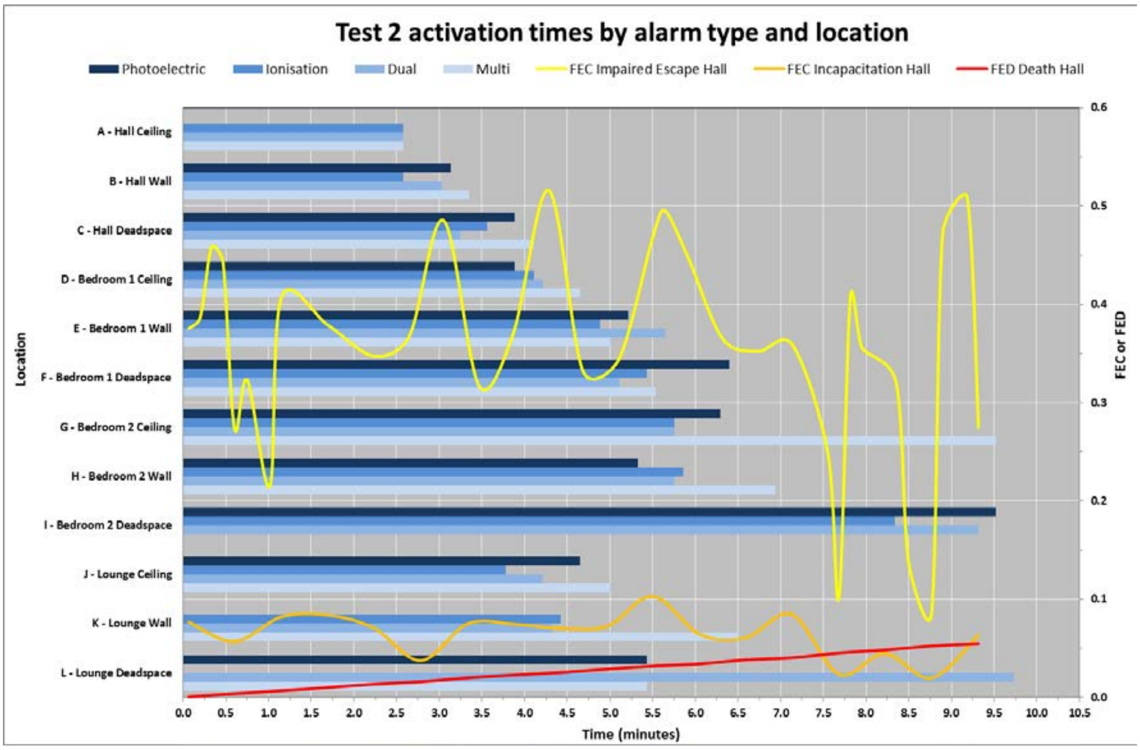

Figure 122 Scenario 317, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

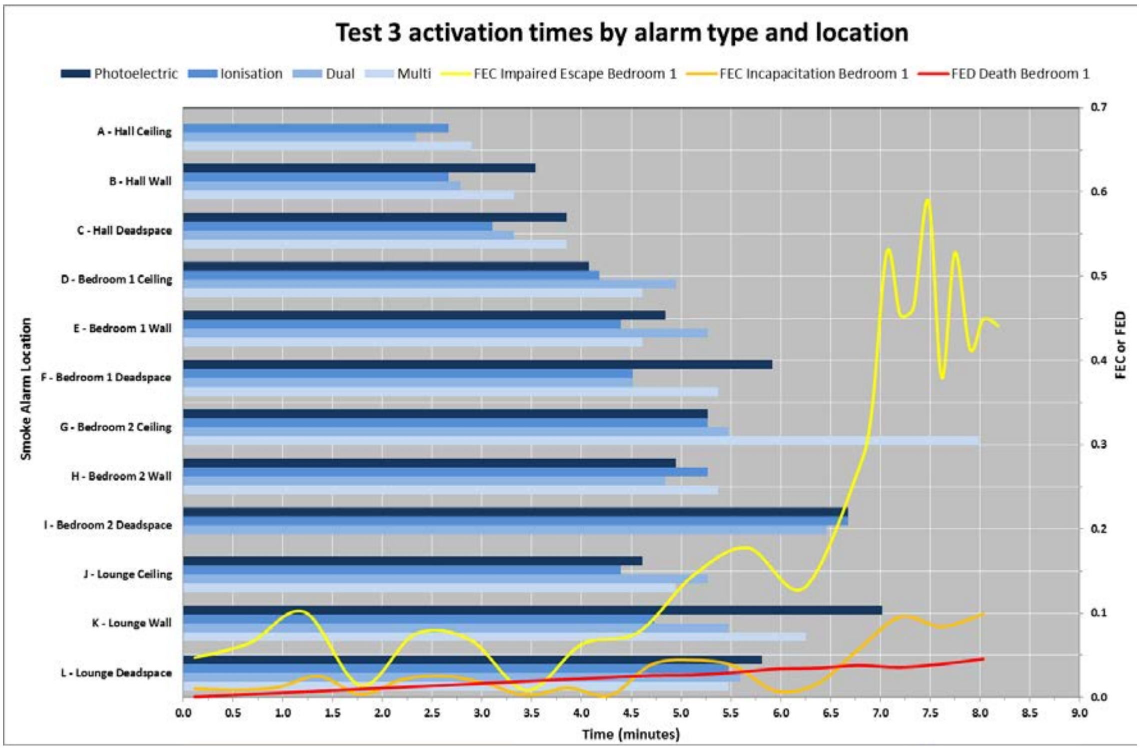

Figure 123 Scenario 19, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

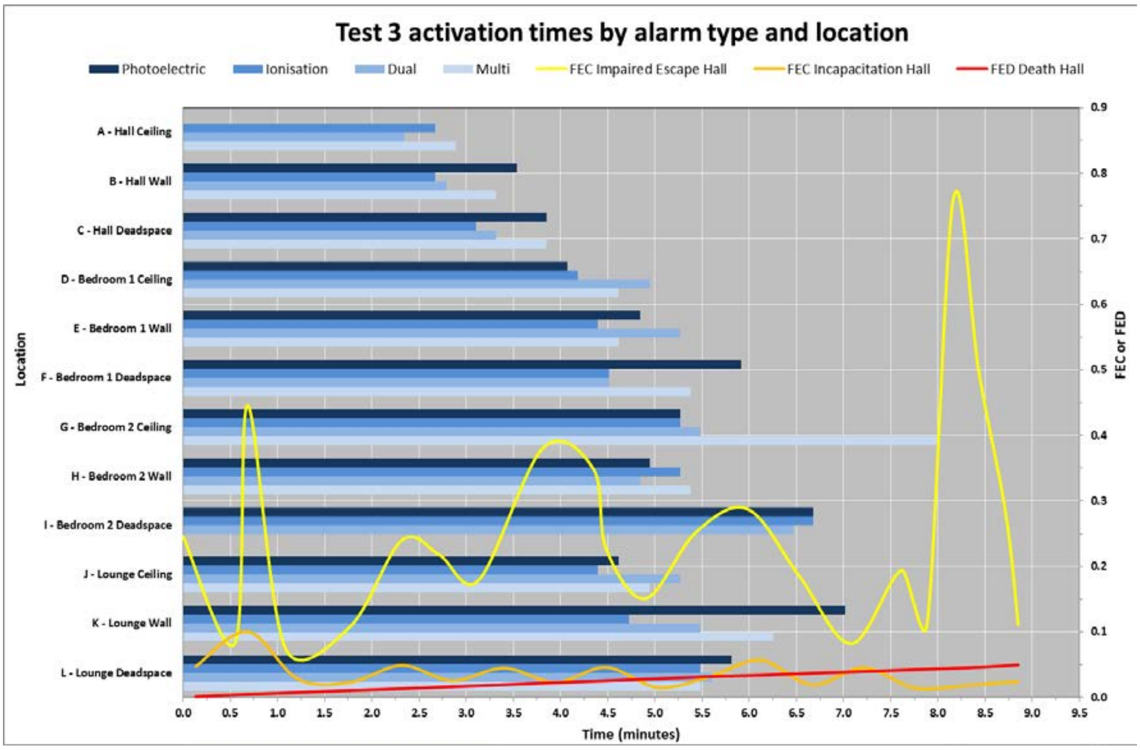

Figure 124 Scenario 19, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 67 Scenario 19 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.70	0.67	0.65
Air Temp (°C)	18.35	15.61	16.27
Rel. Humidity (%)	46.83	45.93	43.76
Air Pressure (mbar)	990.30	999.21	999.02

3.18 SCENARIO 20: Smouldering iron in the laundry, laundry door closed

In this scenario, similarly to Scenario 19, a smouldering fire was initiated in the laundry/bathroom using a clothes iron which had been modified to bypass the in-built thermal cut-off. The appliance was switched on high heat and left to heat up on its own and the sliding door to the laundry was shut. In these three tests, the iron heats for a couple of minutes before self-igniting.

Figure 125 Before (left) and after (right) photographs of Scenario 3, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 68 Scenario 20 smoke alarm activation times (min:sec) in the Hallway and Lounge room.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	05:54	04:30	04:42	04:36				16:11	06:10	05:57	06:03	05:57
Hall Wall	05:02	04:42	04:42	04:56	07:38		08:17	06:40	06:49	06:49		05:50
Hall Dead-space	06:07	06:33	06:19	06:00							08:04	08:43
Lounge Ceiling										09:54	09:54	09:54
Lounge Wall	06:45		06:59	06:33								
Lounge Dead-space	07:12		07:12									

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 1.1 ppm). The tenability limits for occupant incapacitation were not reached in the tests.

Table 69 Scenario 20 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3		00:14	02:19	05:32		05:33
FEC IMPAIRED ESCAPE 1.0						
FEC INCAPACITATION 0.3						
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

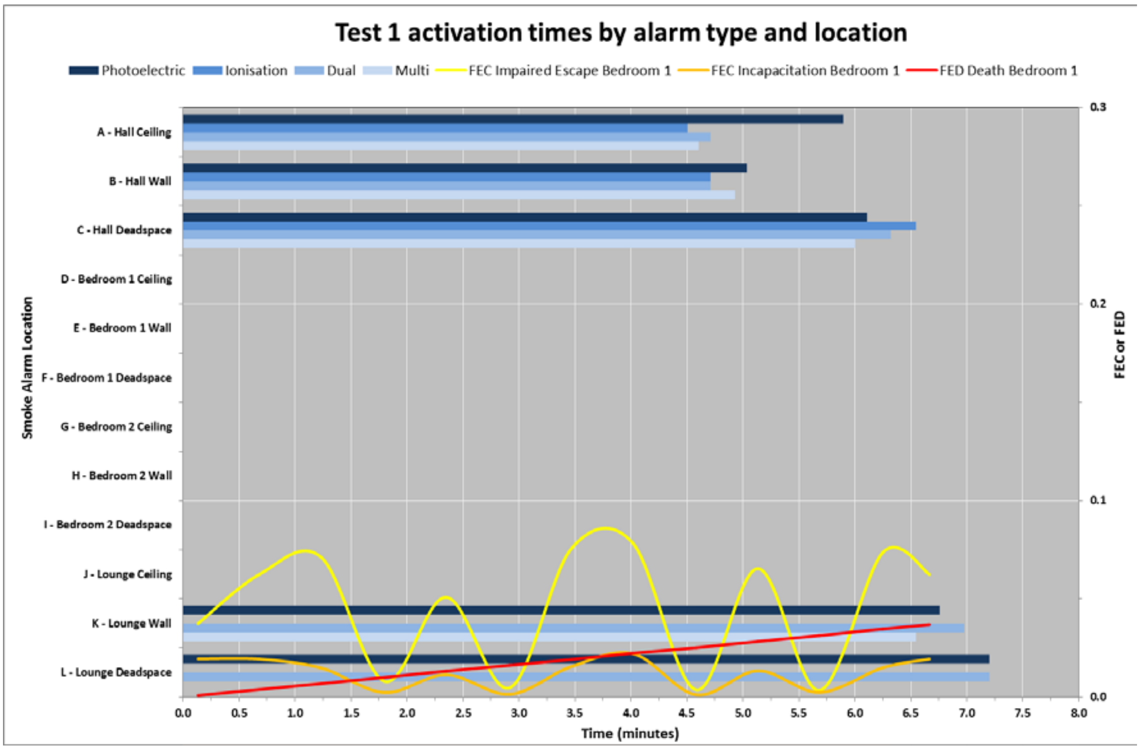

Figure 126 Scenario 20, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

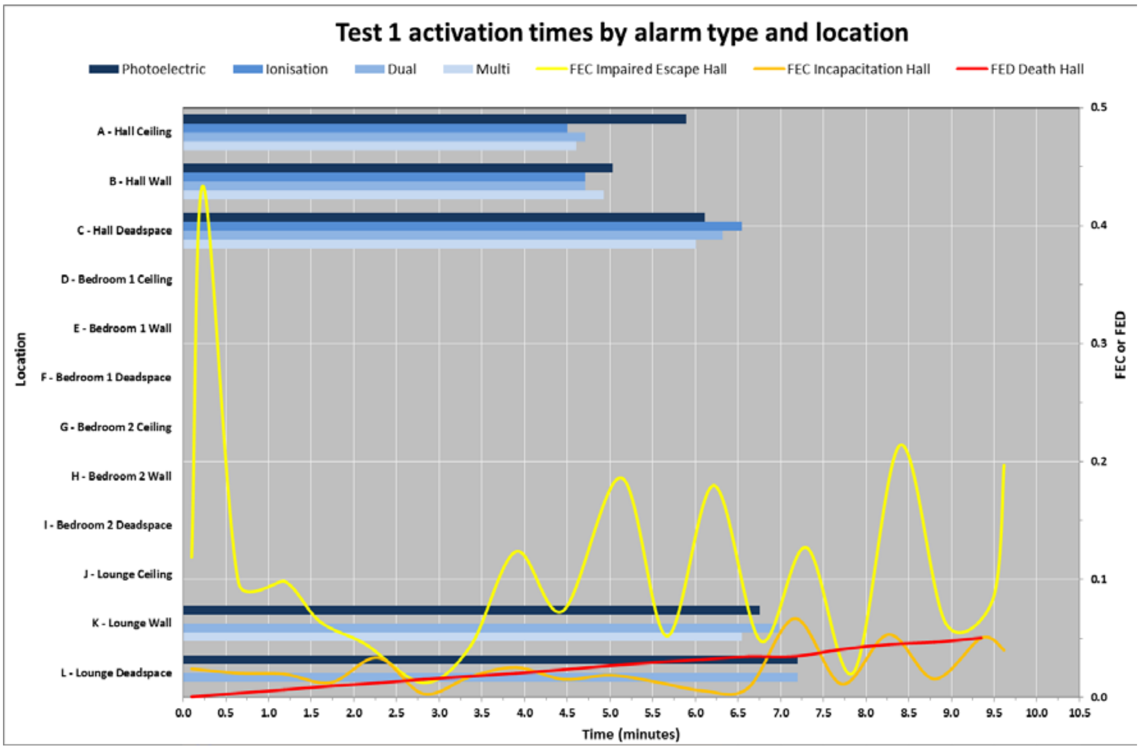

Figure 127 Scenario 20, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

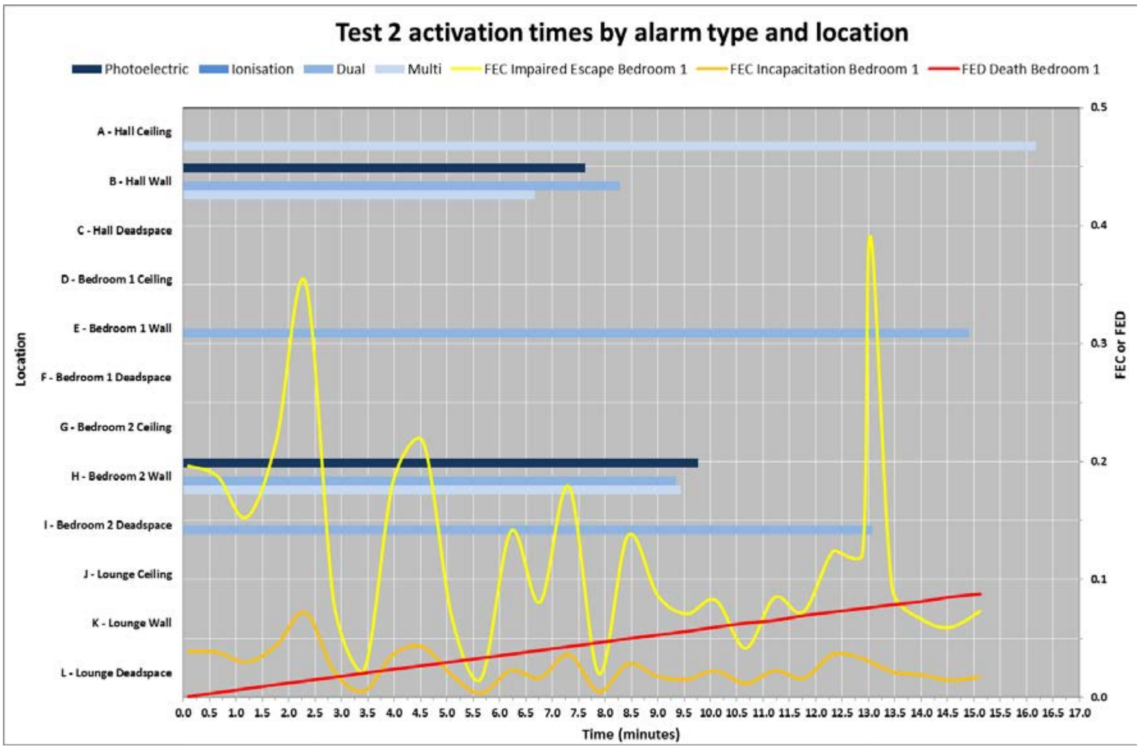

Figure 128 Scenario 20, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

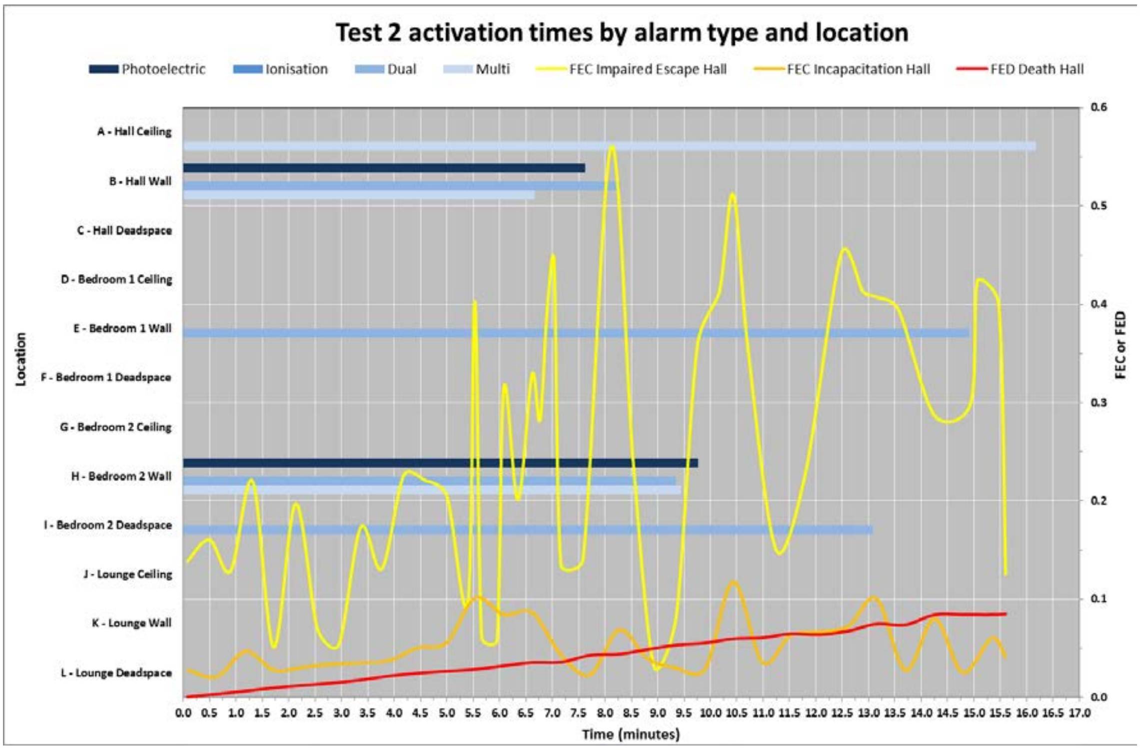

Figure 129 Scenario 317, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

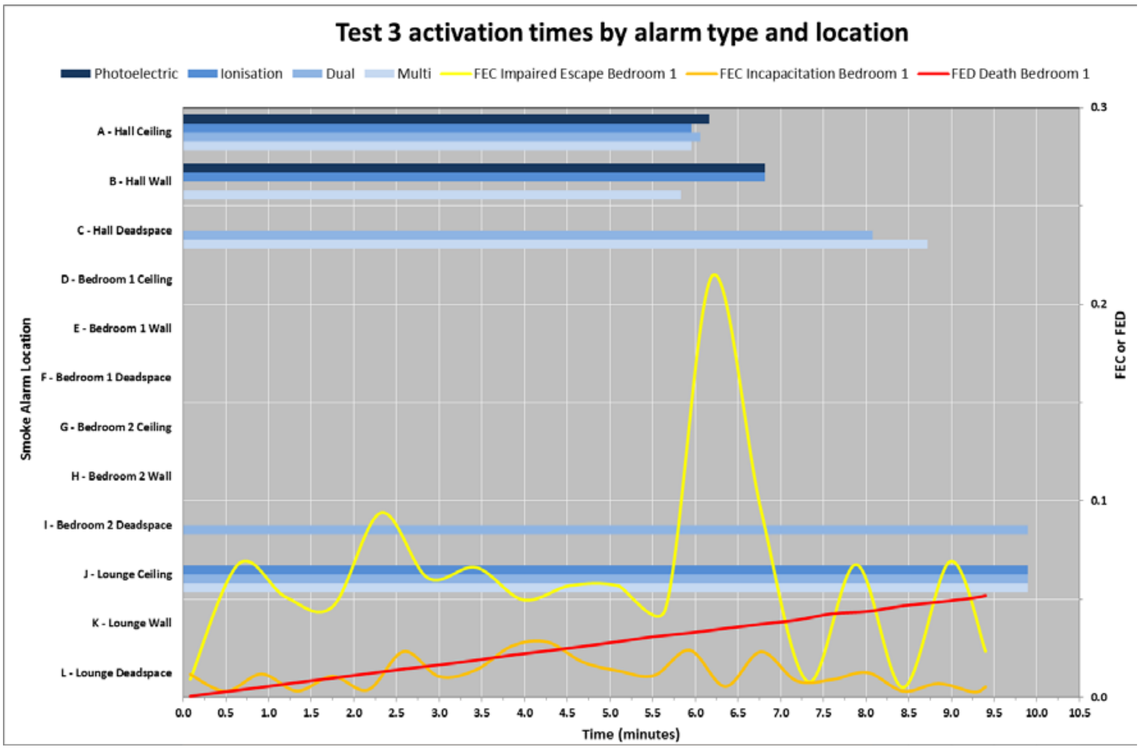

Figure 130 Scenario 20, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

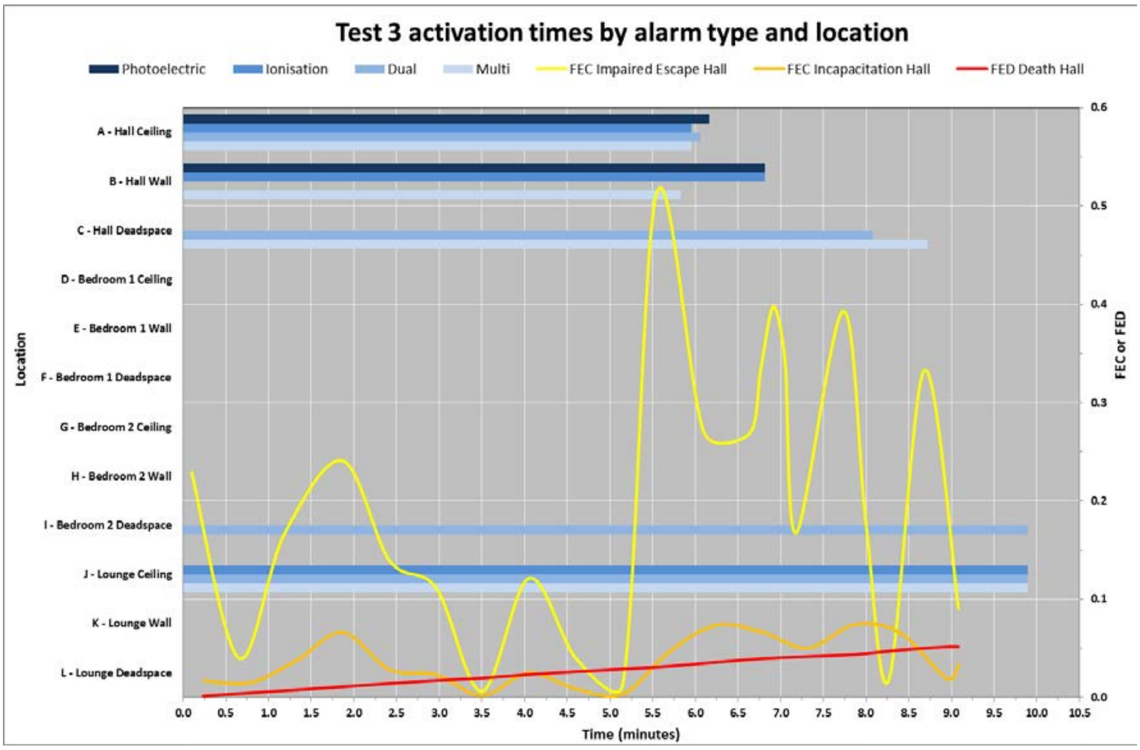

Figure 131 Scenario 20, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 70 Scenario 20 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.84	0.91	0.64
Air Temp (°C)	16.98	17.19	17.39
Rel. Humidity (%)	43.08	41.10	42.38
Air Pressure (mbar)	998.65	1001.27	1002.08

3.19 SCENARIO 22: Flaming bedding in Bedroom 1, Bedroom 1 door closed

In this scenario, a flaming fire was initiated on a pillow in Bedroom 1 using a butane barbeque lighter. The door to Bedroom 1 was closed throughout the test. The flame was held to the pillow edge for 15 seconds and then removed.

Figure 132 Images of Scenario 22, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 71 Scenario 22 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	02:36	02:17	02:29	02:36	02:33	02:13	02:07	02:19	02:32	02:13	02:19	02:19
Hall Wall	02:29	02:23	02:29	02:29	02:19	02:07	02:13	02:26	02:39	02:19	02:32	02:39
Hall Dead-space	02:29	02:10	02:29	02:23	02:19	01:54	02:58	02:07	02:25	02:06	02:39	02:13
ROO Ceiling	01:38	01:25	01:45	01:32	01:03	00:44	01:16	00:56	01:14	00:30	00:36	01:08
ROO Wall	01:38	01:13	01:38	01:38	01:09	00:56	01:22	01:22	01:21	00:49	00:49	01:21
ROO Dead-space	01:38	01:00	00:53	01:38	01:09	00:56	01:03	01:03		00:36	01:02	01:14

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 10.5 ppm), formaldehyde (up to 4.2 ppm), nitrogen dioxide (up to 20 ppm), phenol (up to 11.2 ppm) and sulfur dioxide (up to 5.5 ppm). The tenability limits for occupant incapacitation were reached only in Bedroom 1. The peak temperature measured in Bedroom 1 reached 138°C at the ceiling (Test 2).

Table 72 Scenario 22 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3	01:32	03:43	00:09	01:13	01:23	06:56
FEC IMPAIRED ESCAPE 1.0	02:13		01:07		01:40	
FEC INCAPACITATION 0.3	02:13		01:41		01:40	
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

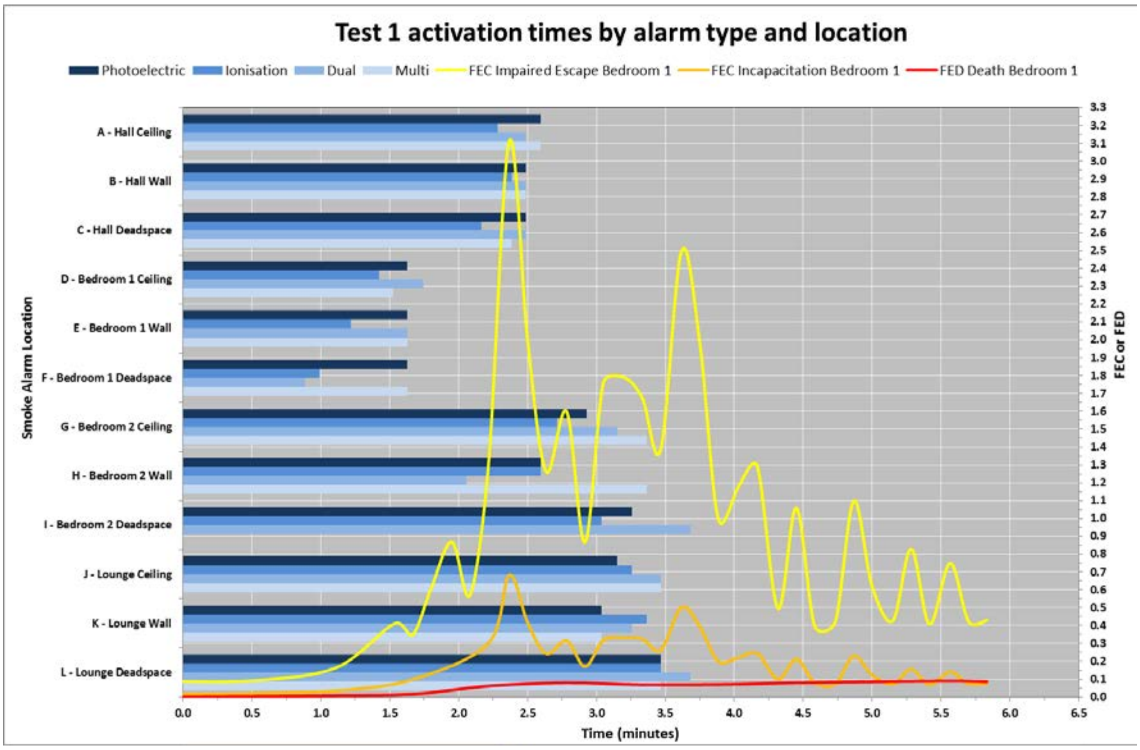

Figure 133 Scenario 22, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

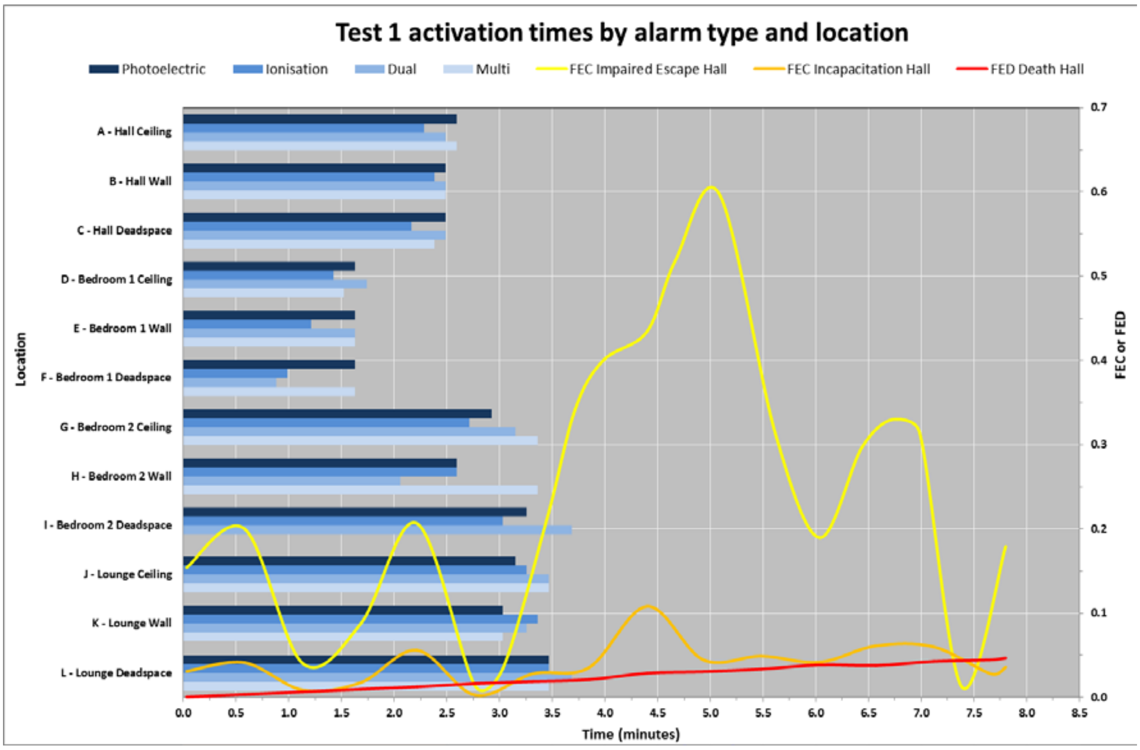

Figure 134 Scenario 22, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

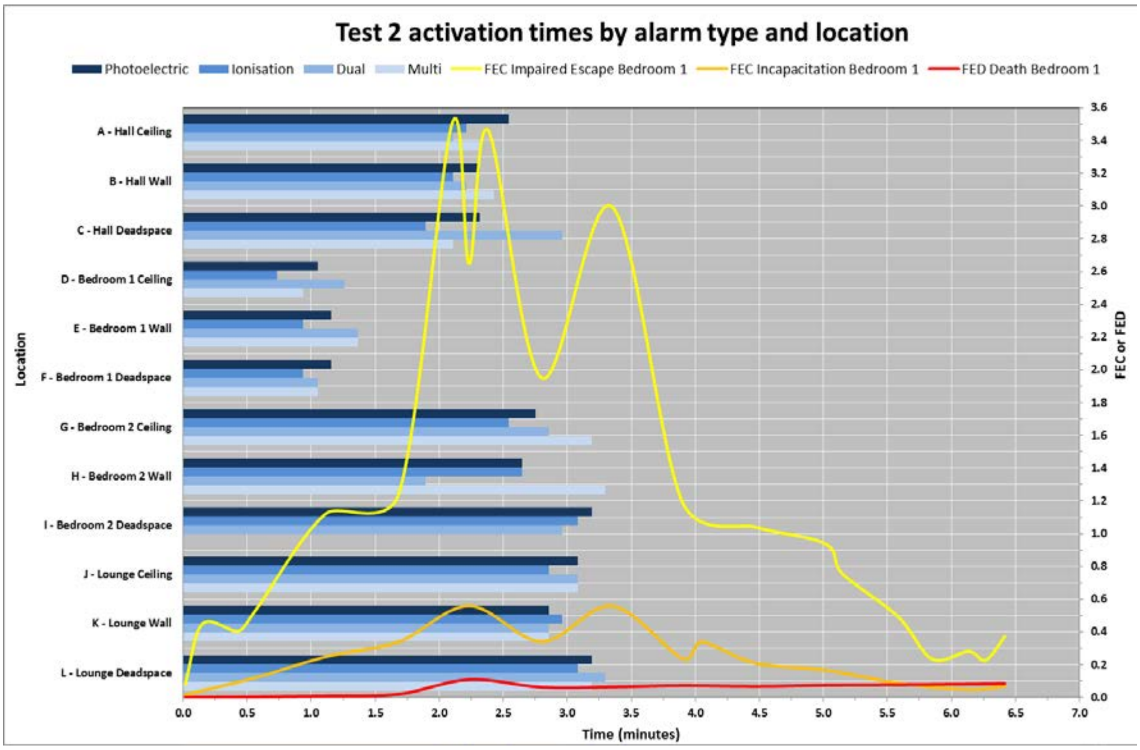

Figure 135 Scenario 22, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

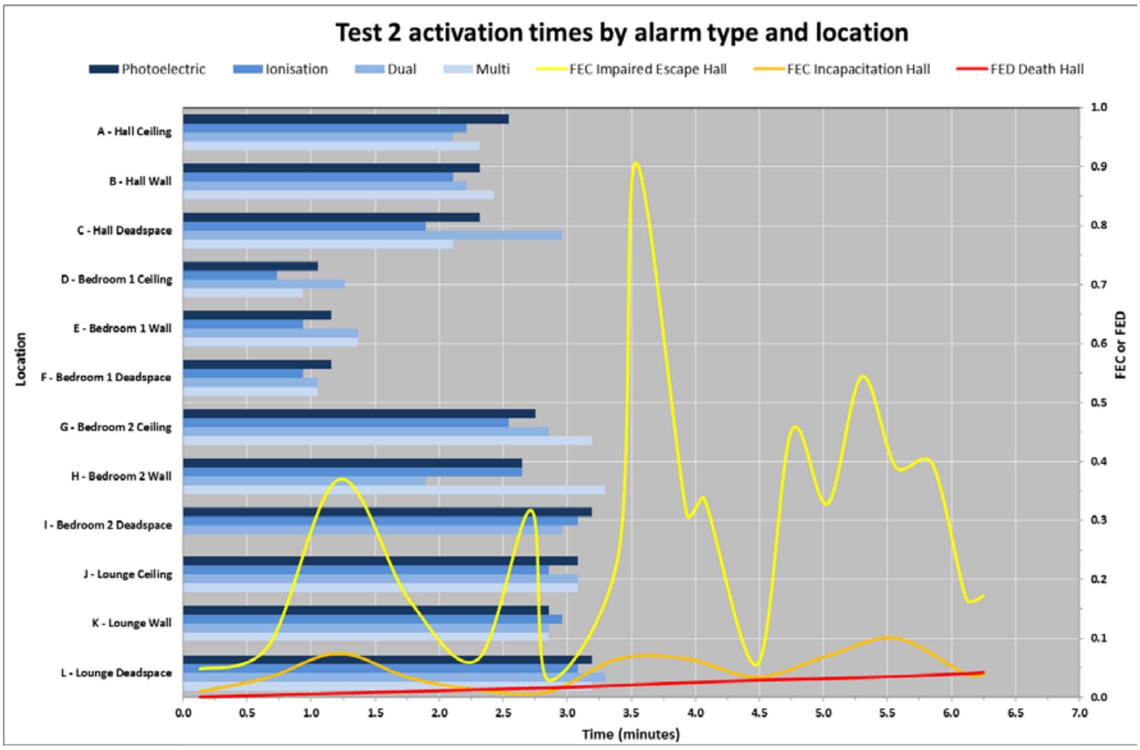

Figure 136 Scenario 22, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

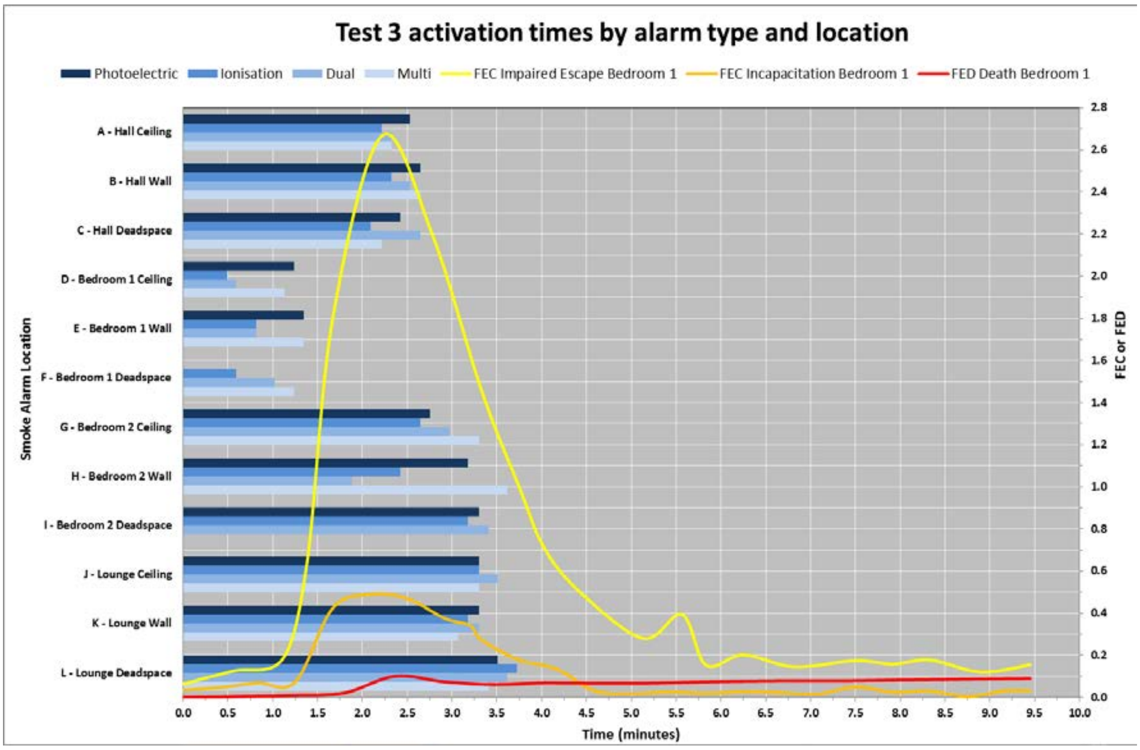

Figure 137 Scenario 22, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

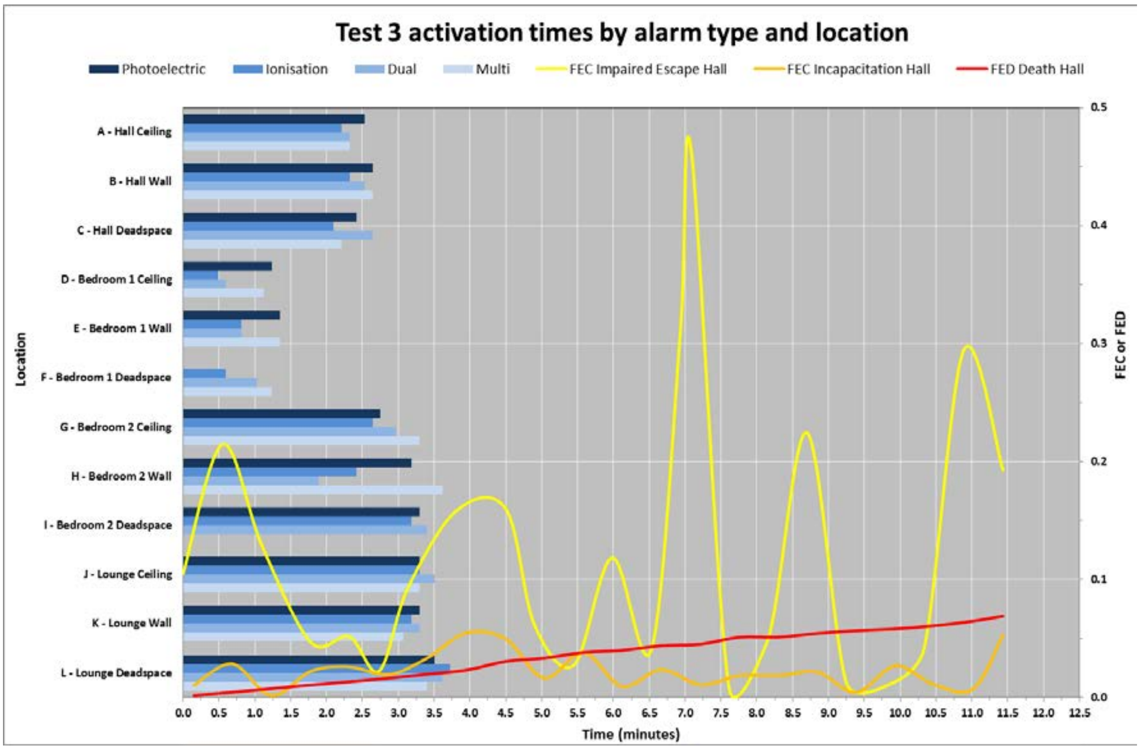

Figure 138 Scenario 22, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 73 Scenario 22 Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Hallway tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	*-0.38*	*-0.07*	*-0.27*	*-0.38*	*-0.86*	*-0.53*	*-0.43*	*-0.64*	*-0.86*	*-0.55*	*-0.65*	*-0.65*
Hall Wall	*-0.27*	*-0.17*	*-0.27*	*-0.27*	*-0.64*	*-0.43*	*-0.53*	*-0.74*	*-0.98*	*-0.65*	*-0.86*	*-0.98*
Hall Dead-space	*-0.27*	0.05	*-0.27*	*-0.17*	*-0.64*	*-0.21*	*-1.28*	*-0.43*	*-0.76*	*-0.43*	*-0.98*	*-0.55*
ROO Ceiling	0.59	0.79	0.47	0.69	0.63	0.95	0.42	0.75	0.43	1.17	1.07	0.54
ROO Wall	0.59	1.00	0.59	0.59	0.53	0.75	0.32	0.32	0.32	0.85	0.85	0.32
ROO Dead-space	0.59	1.22	1.33	0.59	0.53	0.75	0.63	0.63	*#N/A*	1.07	0.64	0.43

Table 74 Scenario 22 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.73	0.99	0.71
Air Temp (°C)	18.50	18.87	18.20
Rel. Humidity (%)	39.29	38.58	39.24
Air Pressure (mbar)	1000.71	1000.71	1001.19

3.20 SCENARIO 23: Flaming paper fire in Bedroom 2, bedroom doors open

In this scenario, a flaming fire was initiated in a waste bin containing 20 sheets of scrunched copy paper using the butane barbeque lighter. The flame is left in contact with the paper for 15 seconds and then removed. The fires continued to burn for two to three minutes and self-extinguished after all the paper had burned.

Figure 139 Images of Scenario 23, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 75 Scenario 23 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling		00:48	01:14			01:08	01:15			01:23	01:16	
Hall Wall		00:41	01:07			01:08	01:15			01:08	01:16	
Hall Dead-space		00:41	00:48			01:02	01:15			01:08	01:29	
ROO Ceiling		00:08	00:28			00:35	00:42			00:35	00:42	
ROO Wall		00:14	00:41			00:42	00:49			00:35	00:42	
ROO Dead-space		00:08	00:21			00:42	00:55	00:55		00:28	00:42	

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 2.7 ppm) and formaldehyde (1.4 ppm). The tenability limits for occupant incapacitation were not reached in the tests. The temperatures measured in the Hallway peaked at 32.7°C at the ceiling (Test 3), from 19°C at the start of the test.

Table 76 Scenario 23 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	ROO	Hall	ROO	Hall	ROO	Hall
FEC IMPAIRED ESCAPE 0.3	00:10		00:26		00:31	03:35
FEC IMPAIRED ESCAPE 1.0						
FEC INCAPACITATION 0.3						
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

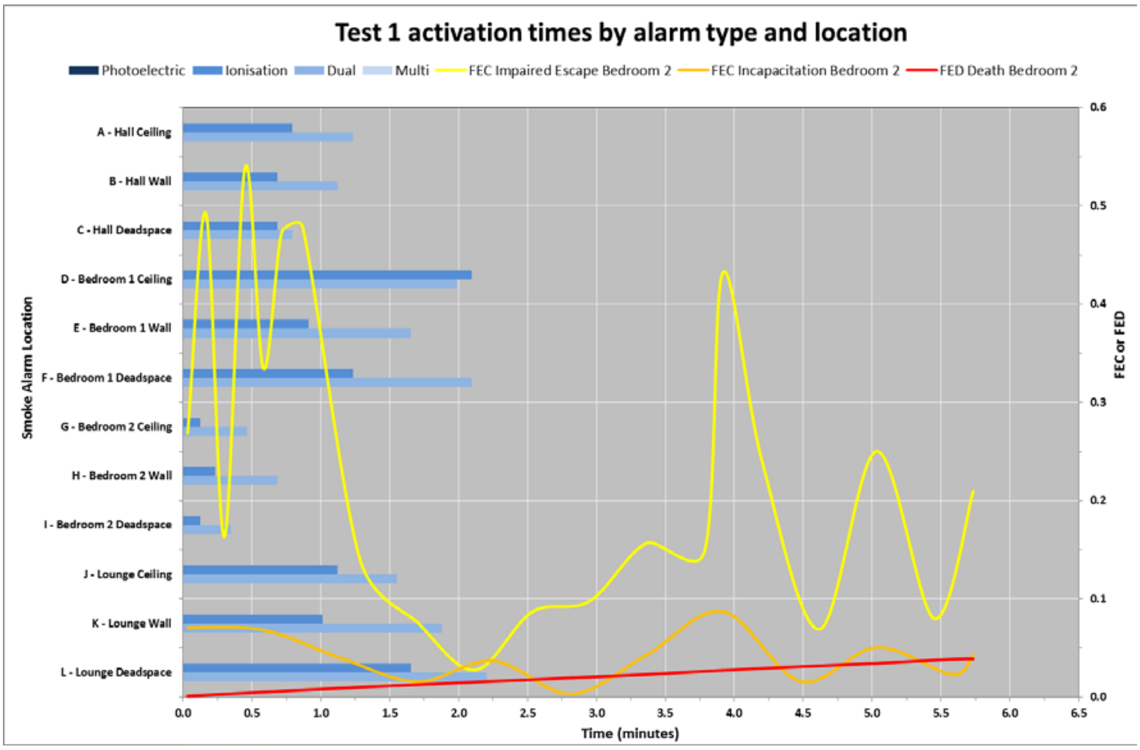

Figure 140 Scenario 23, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

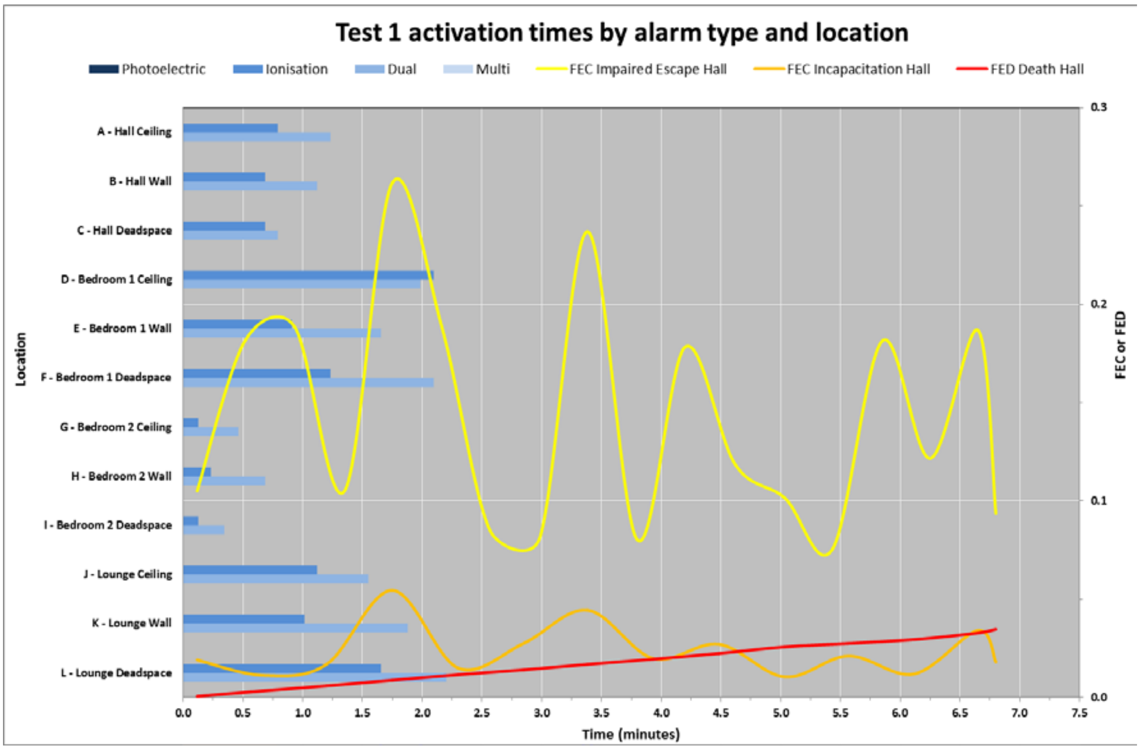

Figure 141 Scenario 23, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

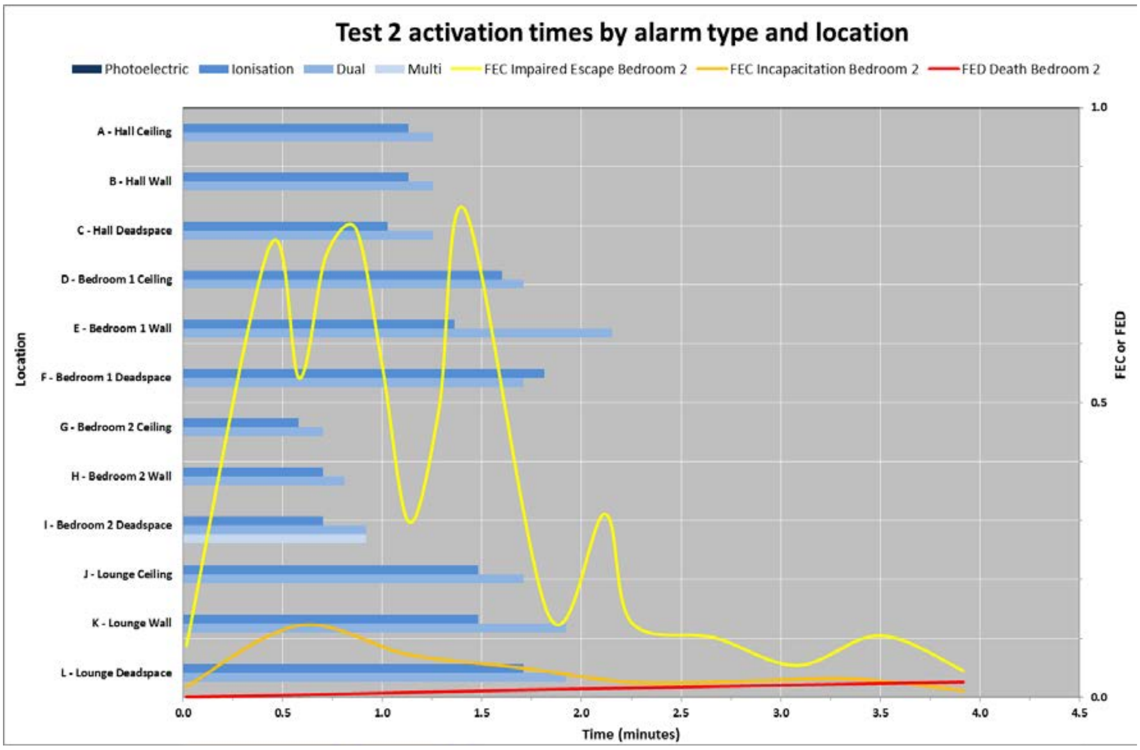

Figure 142 Scenario 23, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

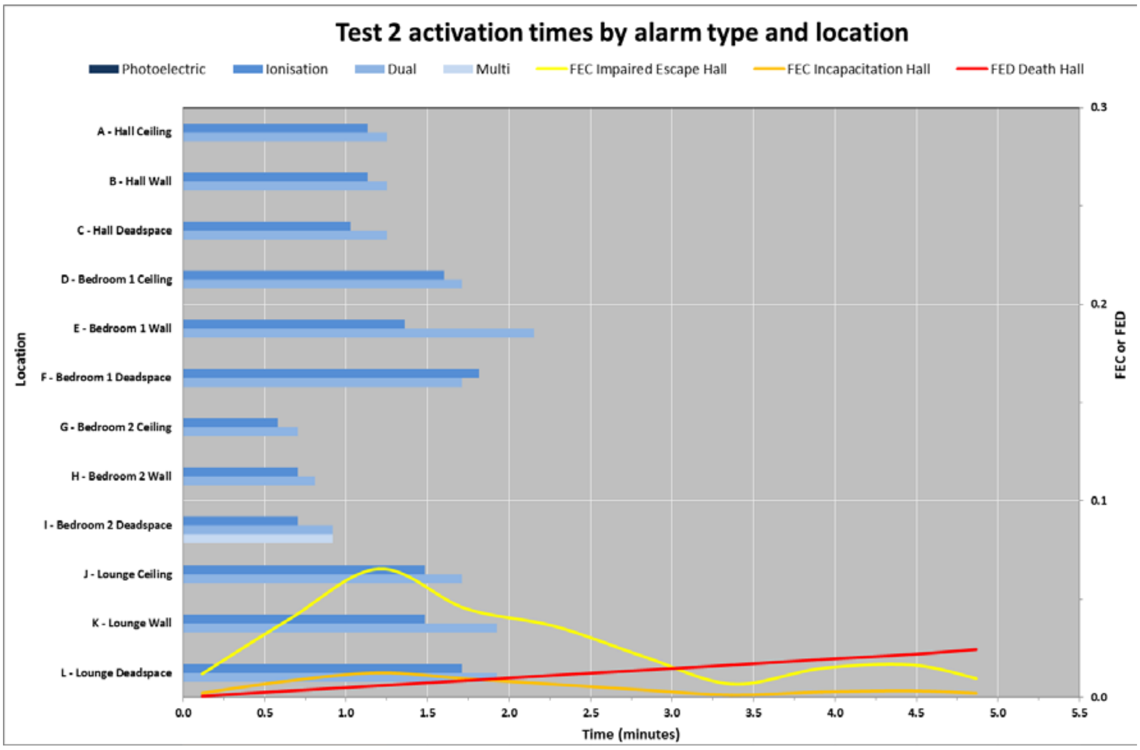

Figure 143 Scenario 23, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

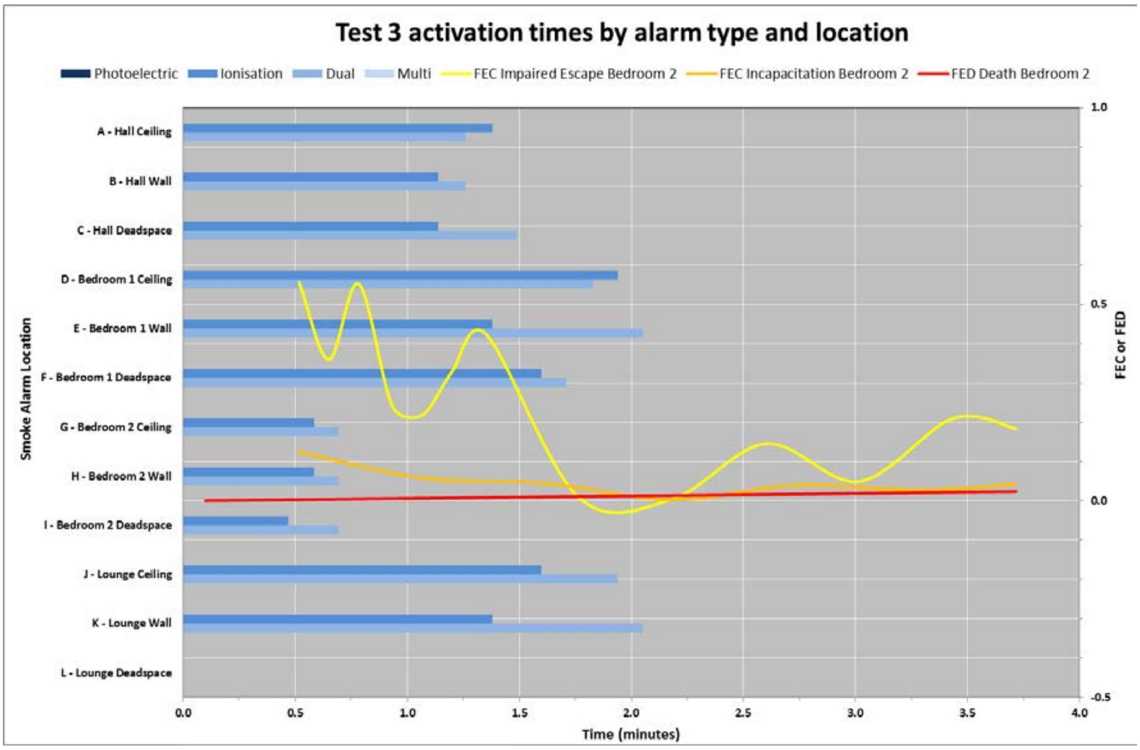

Figure 144 Scenario 23, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

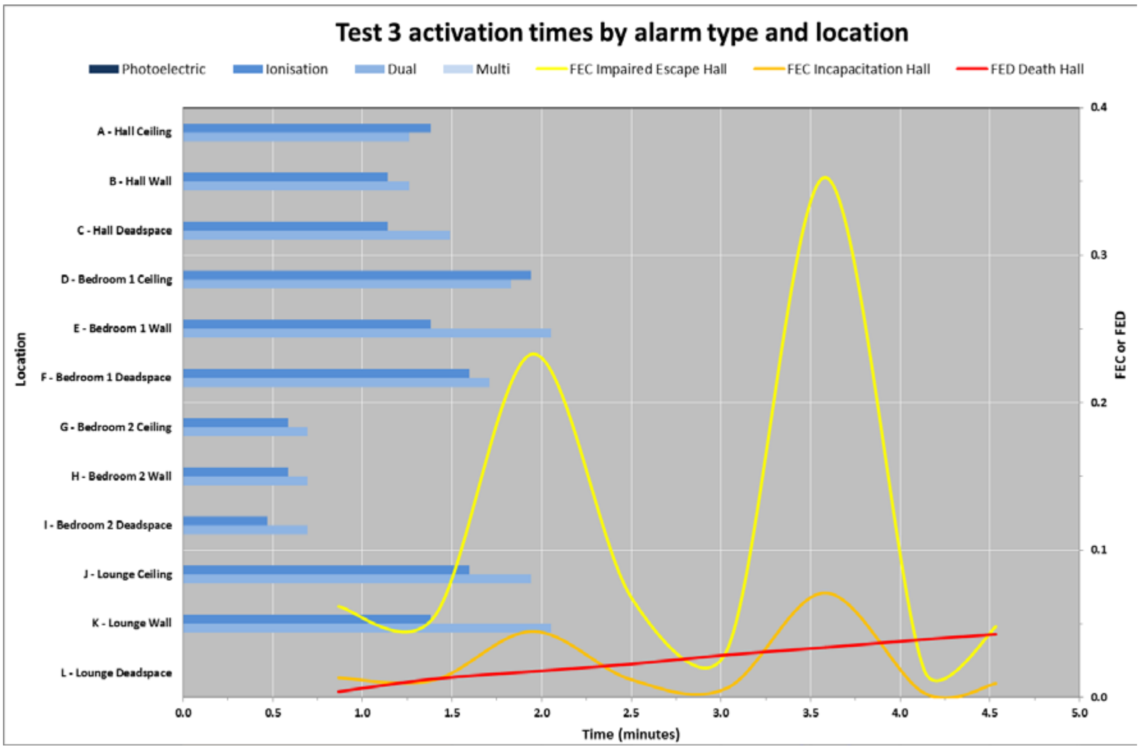

Figure 145 Scenario 23, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 77 Scenario 23 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.47	0.59	1.00
Air Temp (°C)	21.93	23.17	24.16
Rel. Humidity (%)	30.17	28.73	24.86
Air Pressure (mbar)	1010.23	1009.59	1008.98

3.21 SCENARIO 24: Flaming paper fire in Bedroom 2, Bedroom 1 closed

In this scenario, similarly to Scenario 23, a flaming fire was initiated in a waste bin containing 20 sheets of scrunched copy paper using the butane barbeque lighter. The flame was left in contact with the paper for 15 seconds and then removed. The fires continued to burn for two to three minutes and self-extinguished after all the paper had burned. The door to Bedroom 1 was closed throughout the test.

Figure 146 Images of Scenario 24, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 78 Scenario 24 smoke alarm activation times (min:sec) in the Hallway and Bedroom 2

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling		01:13	01:20			00:46	01:06			00:47	00:41	
Hall Wall		01:07	01:07			00:46	00:46			00:54	00:41	
Hall Dead-space		01:07	01:13			00:46	01:06			00:35	00:41	01:00
ROO Ceiling		00:40	01:07			00:19	00:19			00:15	00:28	00:35
ROO Wall		00:40	00:47			00:19	00:38			00:28	00:28	00:47
ROO Dead-space		00:40	00:47			00:13	00:25	00:38	00:47	00:15	00:21	00:28

The irritant gases detected in Bedroom 2 included significant amounts of acrolein (up to 2.4 ppm), formaldehyde (3 ppm) and sulfur dioxide (up to 7.2 ppm). The tenability limits for occupant incapacitation were not reached in the tests. The temperatures measured in Bedroom 2 peaked at 27.9°C, rising from an initial 20°C (Test 2).

Table 79 Scenario 24 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	ROO	Hall	ROO	Hall	ROO	Hall
FEC IMPAIRED ESCAPE 0.3	00:39		00:03	03:37	00:04	03:11
FEC IMPAIRED ESCAPE 1.0						
FEC INCAPACITATION 0.3						
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

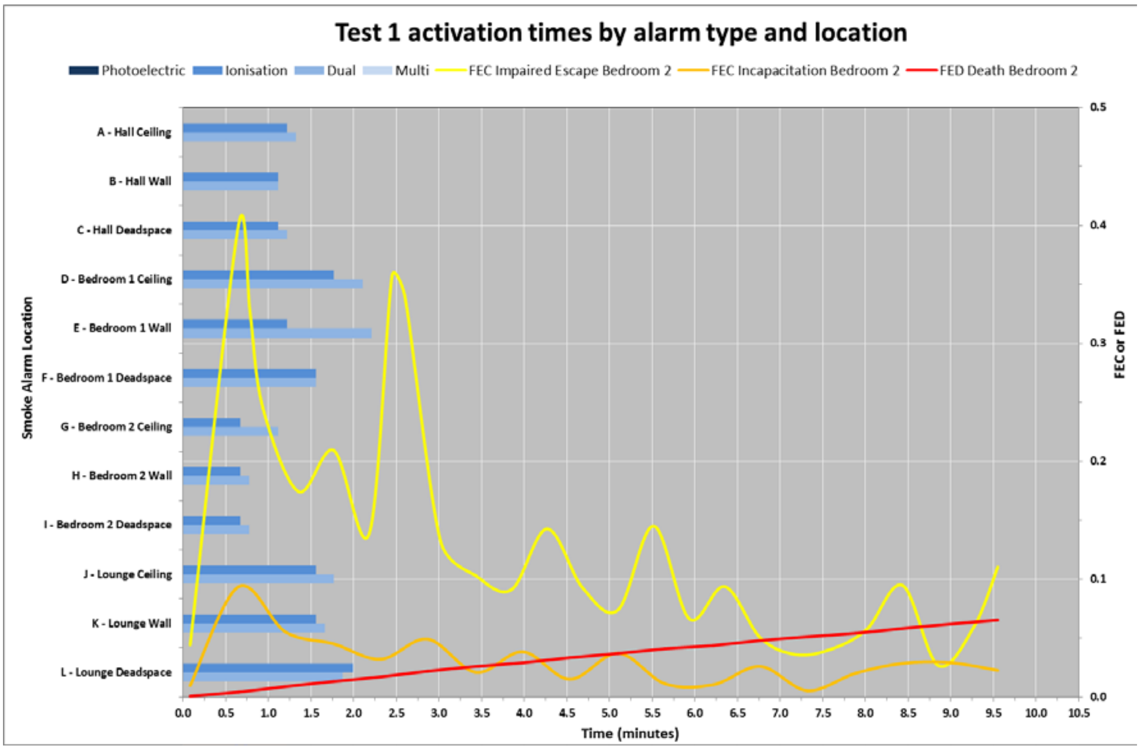

Figure 147 Scenario 24, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

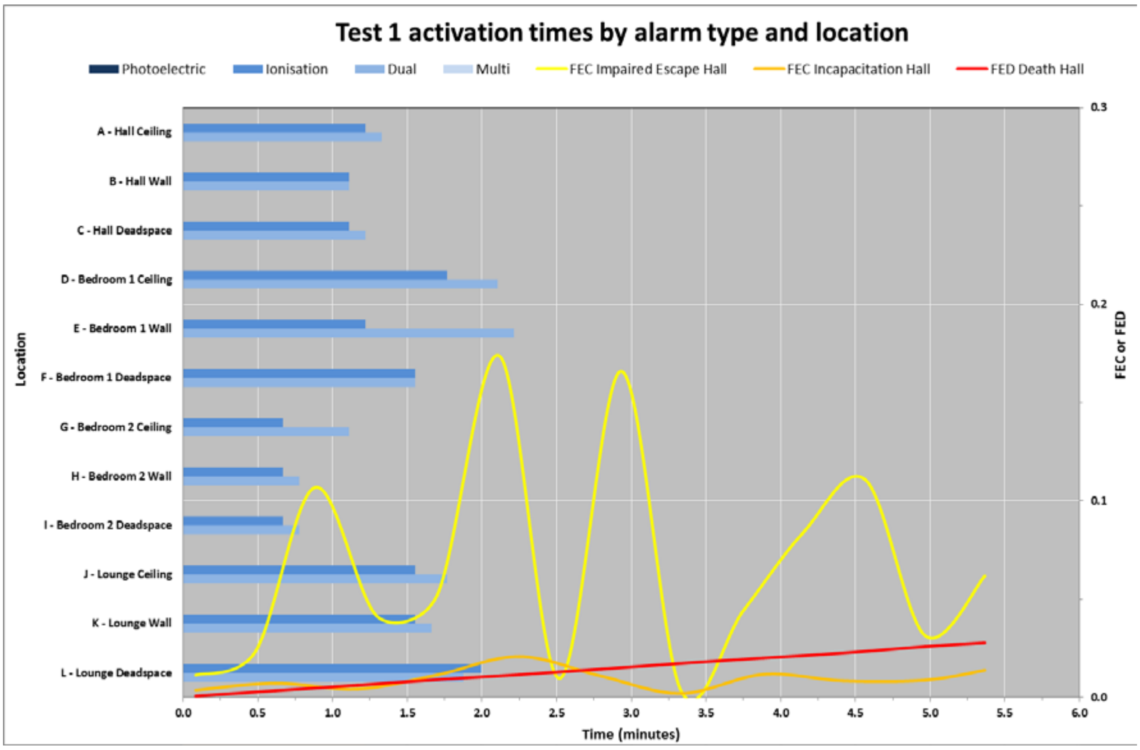

Figure 148 Scenario 24, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

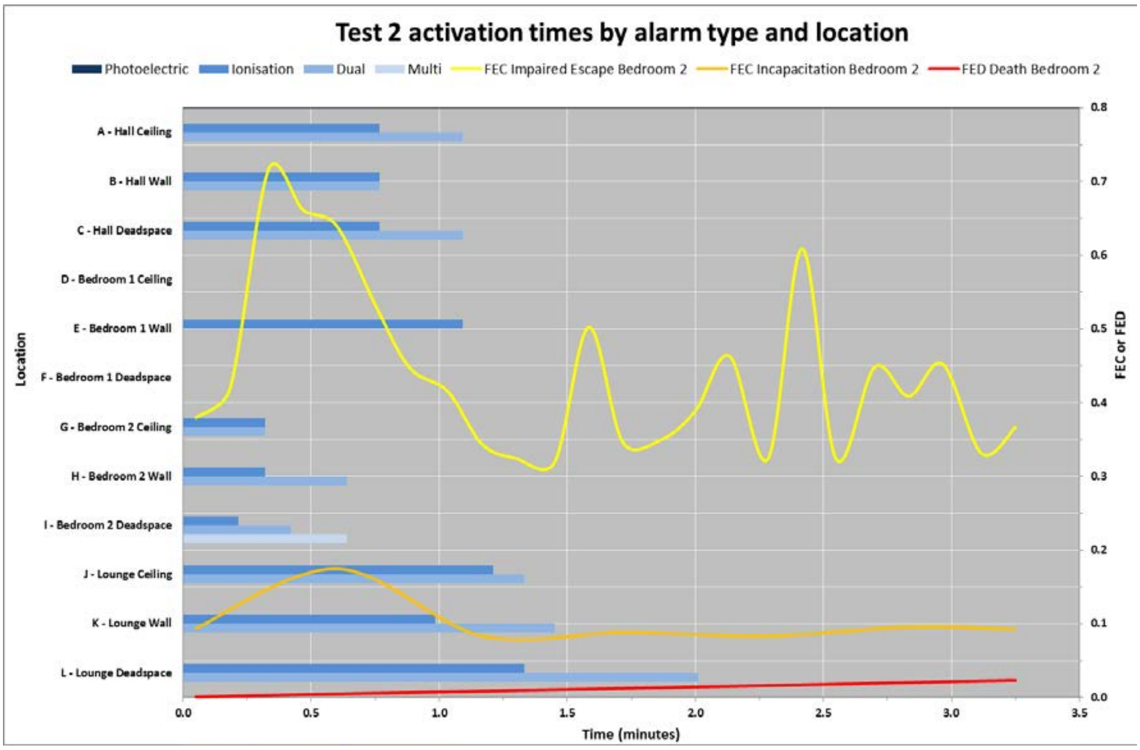

Figure 149 Scenario 24, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

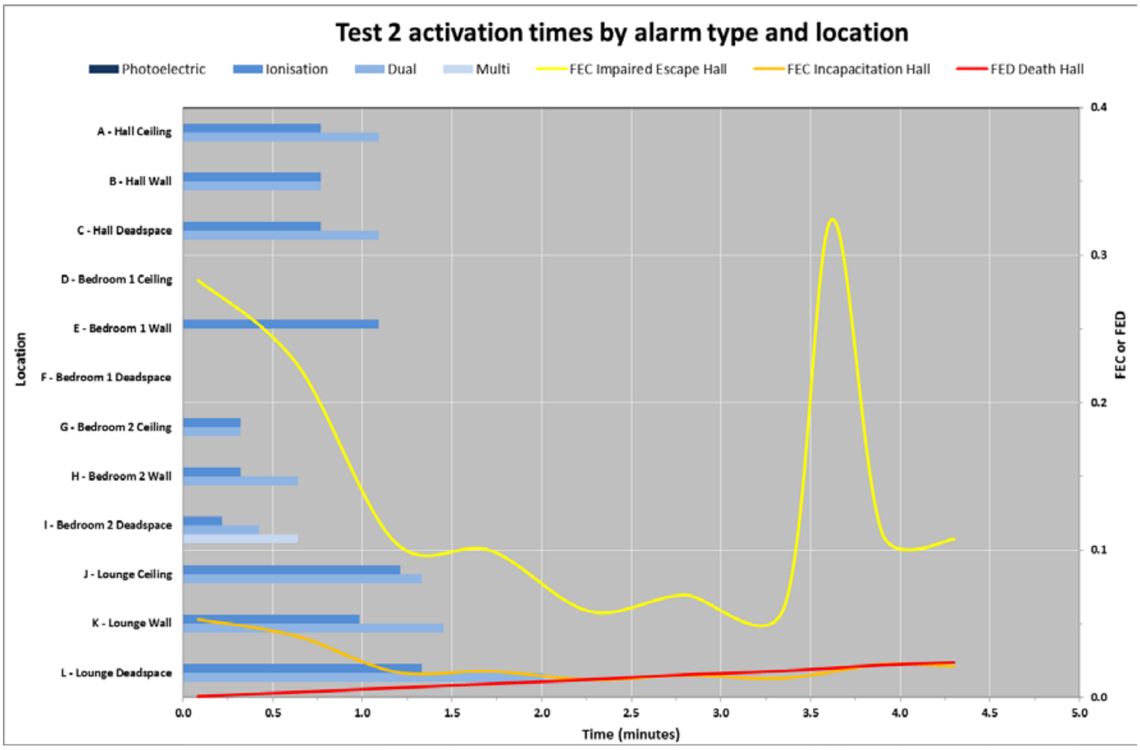

Figure 150 Scenario 24, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

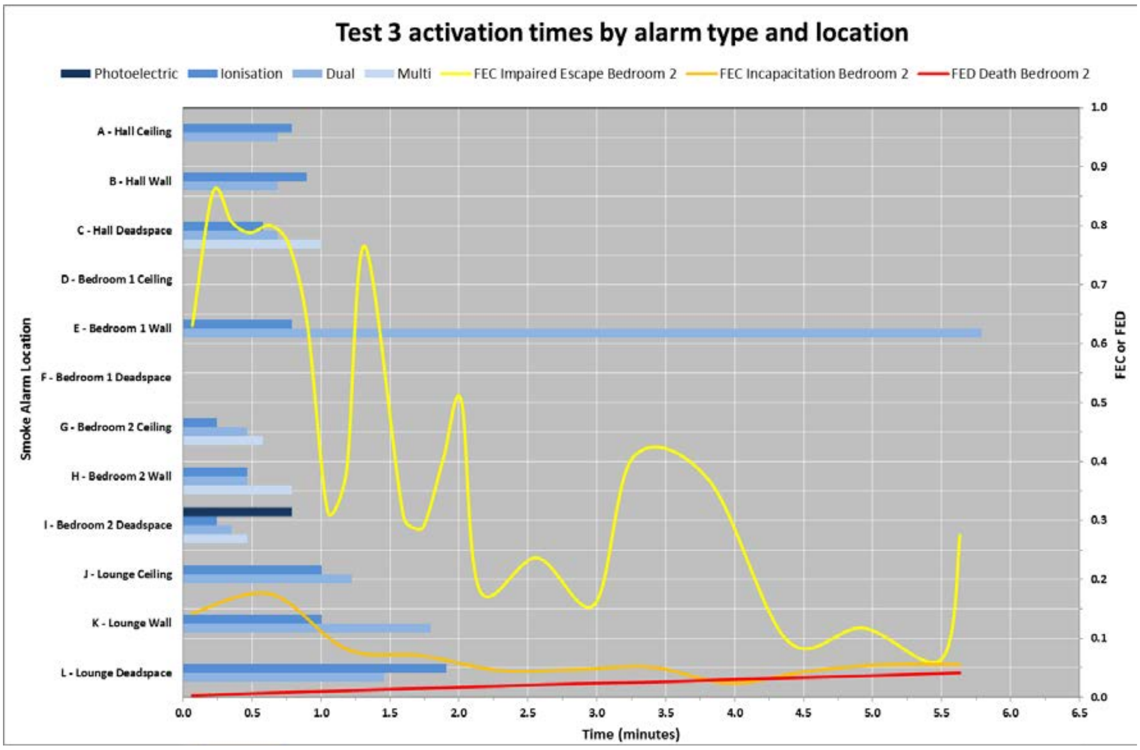

Figure 151 Scenario 24, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

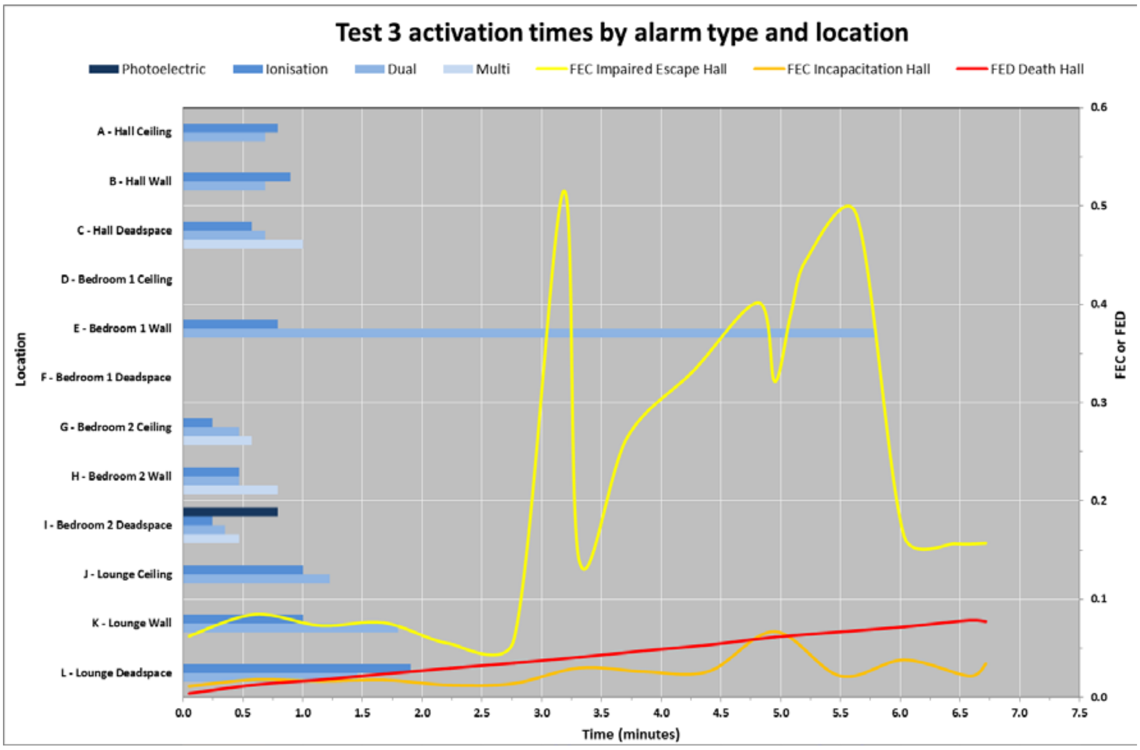

Figure 152 Scenario 24, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 80 Scenario 24 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.41	0.55	0.65
Air Temp (°C)	20.94	23.44	24.33
Rel. Humidity (%)	40.96	35.29	32.24
Air Pressure (mbar)	1016.07	1015.03	1014.39

3.22 SCENARIO 25: Flaming chair in hallway, bedroom doors open

In this scenario, a flaming fire was initiated on the pad of a timber dining chair placed in the Hallway using a butane barbeque lighter. The flame was held in contact with the chair pad for 15 seconds and then removed. The chair pad continued to burn for approximately 12 minutes and self-extinguished when it was fully consumed. The flame did not spread to the MDF backing or the rubber wood chair frame.

Figure 153 Images of Scenario 25, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 81 Scenario 25 smoke alarm activation times (min:sec) in the Hallway and Lounge room

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling		4.04	2.93			2.98	2.42			4.52	2.75	
Hall Wall		3.59	2.93			2.86	2.64			3.74	4.30	
Hall Dead-space		3.71	2.68			2.98	2.53			4.07	3.30	
Lounge Ceiling		3.82	2.57			4.61	2.53		5.94	4.63	3.53	
Lounge Wall		3.05	3.93			2.53	3.74			3.30	4.74	
Lounge Dead-space	6.88	4.14	4.37			4.73	4.95			6.71	5.39	

The irritant gases detected in the Hallway included significant amounts of acrolein (up to 1.9 ppm) and formaldehyde (0.8 ppm). The tenability limits for occupant incapacitation were not reached in the tests. The temperatures measured in the Hallway peaked at 29°C at the ceiling from an initial 16.5°C (Test 2).

Table 82 Scenario 25 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	Hall	Bed1	Hall	Bed1	Hall
FEC IMPAIRED ESCAPE 0.3	02:01	01:07		00:16		
FEC IMPAIRED ESCAPE 1.0						
FEC INCAPACITATION 0.3						
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

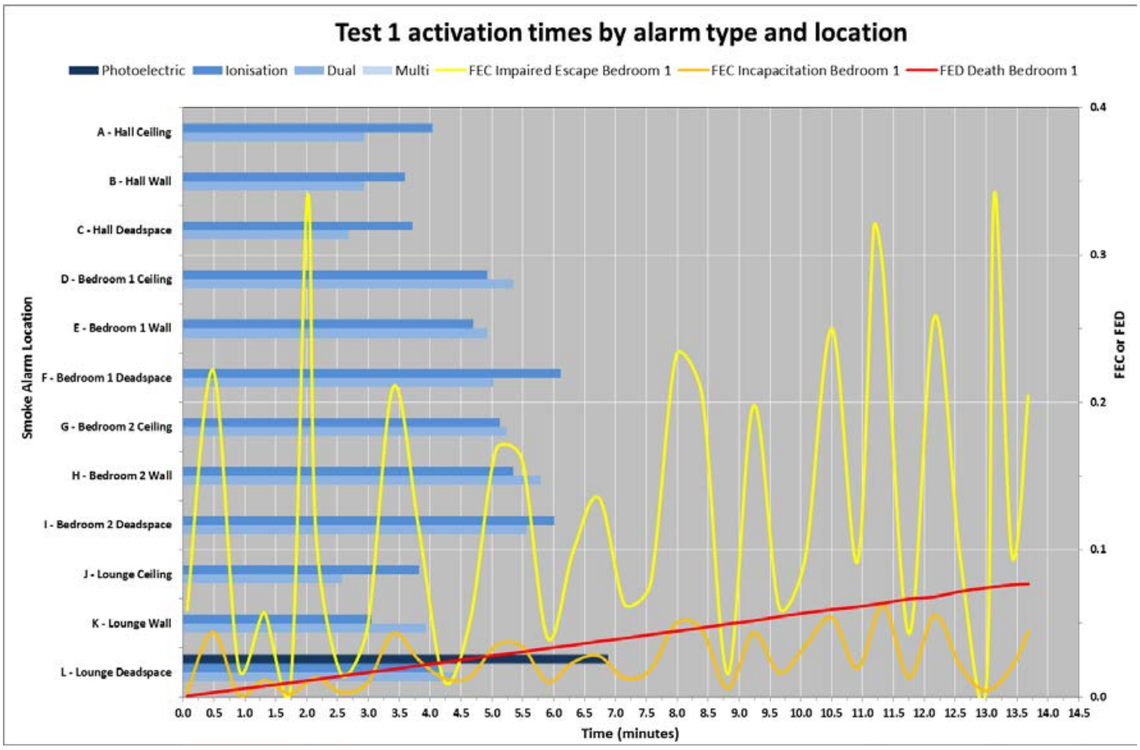

Figure 154 Scenario 25, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

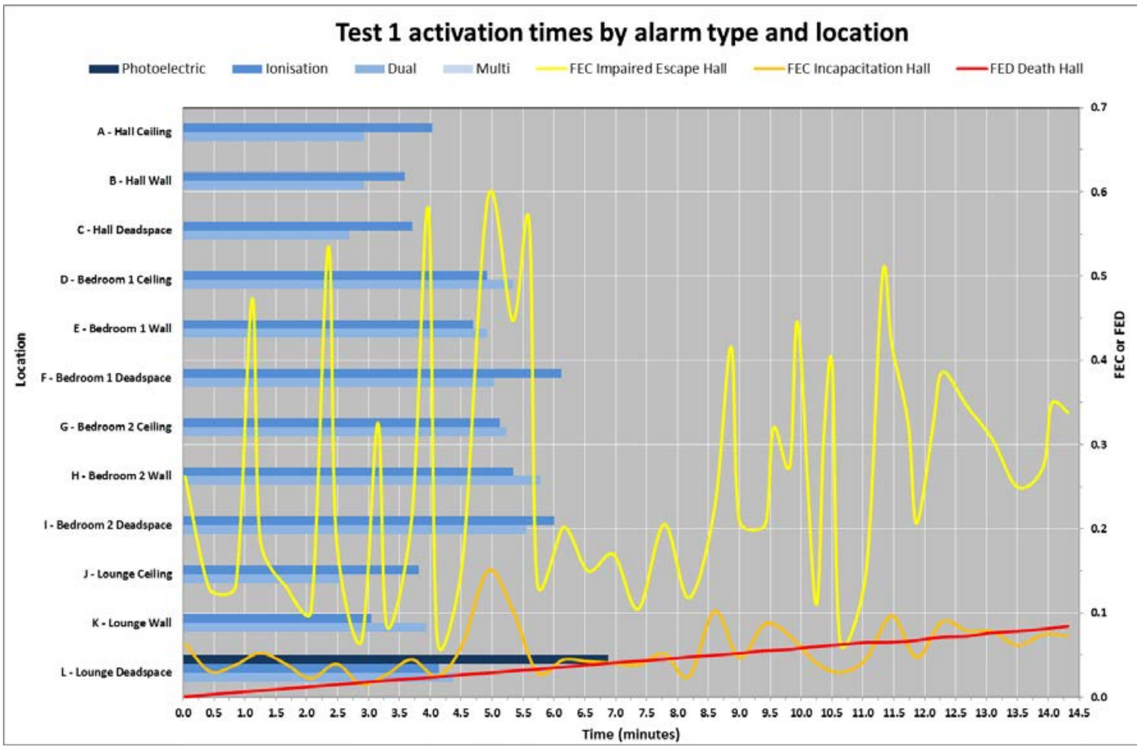

Figure 155 Scenario 25, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

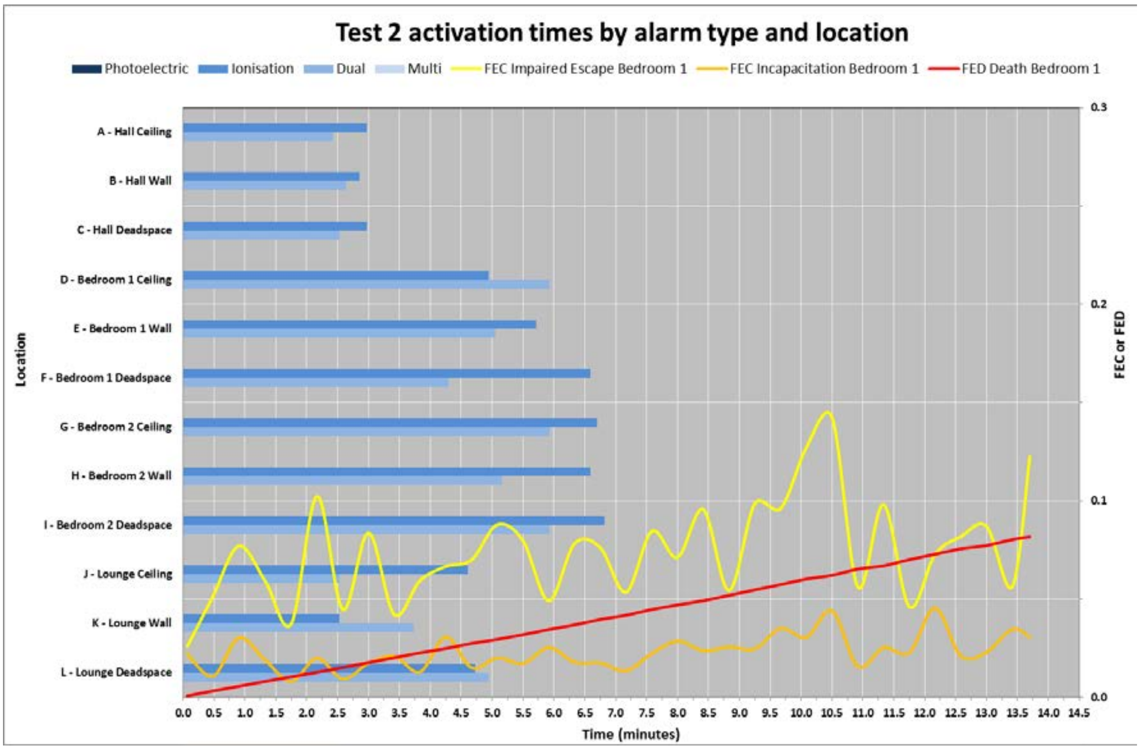

Figure 156 Scenario 25, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

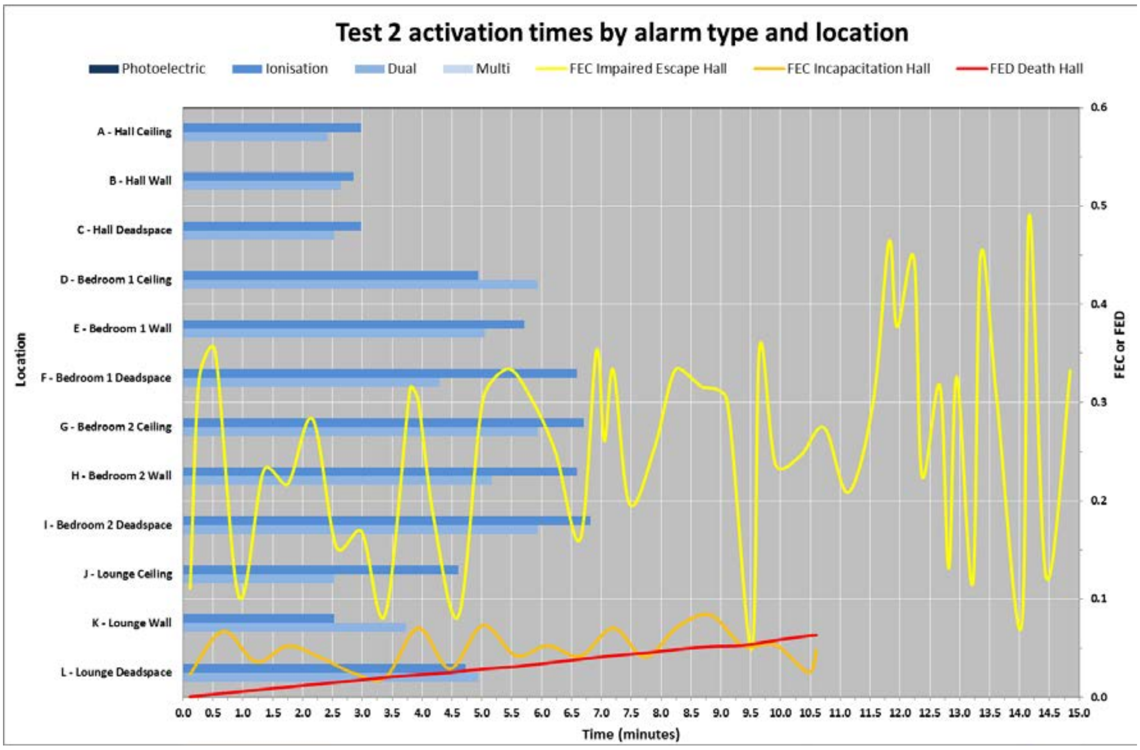

Figure 157 Scenario 25, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

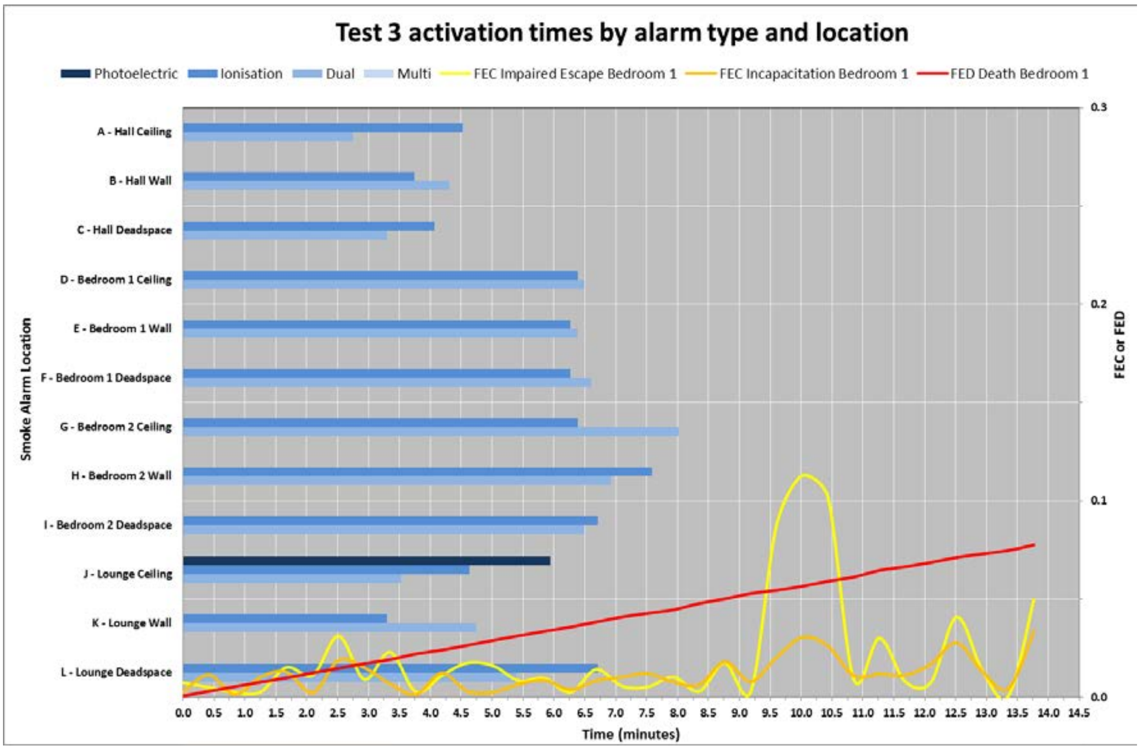

Figure 158 Scenario 25, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

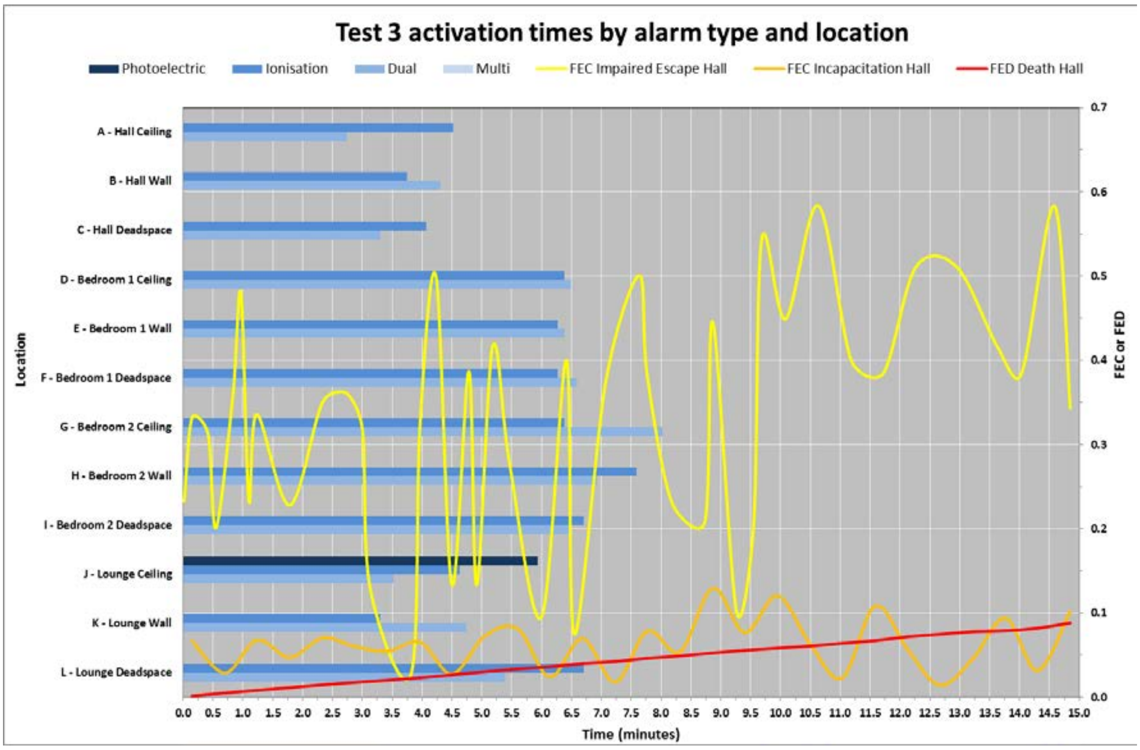

Figure 159 Scenario 25, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 83 Scenario 25 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.64	0.72	1.15
Air Temp (°C)	16.60	18.05	16.72
Rel. Humidity (%)	54.95	50.08	31.29
Air Pressure (mbar)	998.88	998.29	999.00

3.23 SCENARIO 26: Smouldering upholstered chair in hallway, bedroom doors open

In this scenario, a smouldering fire was initiated on an upholstered chair placed in the Hallway using the soldering iron heated to 350°C. The element was left in contact with three cotton batting sheets for six minutes and then removed. The smoulder continued for some 15 minutes before self-extinguishing.

Figure 160 Images of Scenario 26, Tests 1 (top), 2 (middle) and 3 (bottom).

Table 84 Scenario 26 smoke alarm activation times (min:sec) in the Hallway and Lounge room

	TEST 1				TEST 2				TEST 3			
POSITION	**Photo-electric**	**Ionisation**	**Dual**	**Multi**	**Photo-electric**	**Ionisation**	**Dual**	**Multi**	**Photo-electric**	**Ionisation**	**Dual**	**Multi**
Hall Ceiling	05:55	07:08	05:22	05:49	06:13	06:33	06:06	06:00	05:43	06:03	05:30	05:36
Hall Wall	05:15	06:48	05:55	04:49	06:26	06:52	06:06	06:00	05:49	06:03	06:16	05:23
Hall Dead-space	05:49	06:21	05:29	05:42	06:52	07:32	06:26	06:39	06:10	06:29	06:03	06:03
Lounge Ceiling			11:39				08:51		13:24		10:59	15:10
Lounge Wall	11:25	07:15	07:28	06:55	07:53	07:19	07:26	07:32	06:29	06:10	06:29	06:23
Lounge Dead-space	14:36		18:07		13:35		16:20		11:05		11:32	13:04

The irritants detected in the Hallway included significant amounts of acrolein (up to 6.2 ppm) and formaldehyde (up to 3.5 ppm).

Table 85 Scenario 26 Time after ignition (min:sec) at which tenability limits were reached 1.5 metres

	TEST 1		TEST 2		TEST 3	
	Bed1	**Hall**	**Bed1**	**Hall**	**Bed1**	**Hall**
FEC IMPAIRED ESCAPE 0.3	07:04	00:12	08:27	00:23	07:13	01:01
FEC IMPAIRED ESCAPE 1.0		03:52	09:59	10:03	12:47	06:36
FEC INCAPACITATION 0.3		03:52		11:33		06:52
FEC INCAPACITATION 1.0						
FED ASPHYXIATION 0.3						
FED ASPHYXIATION 1.0						

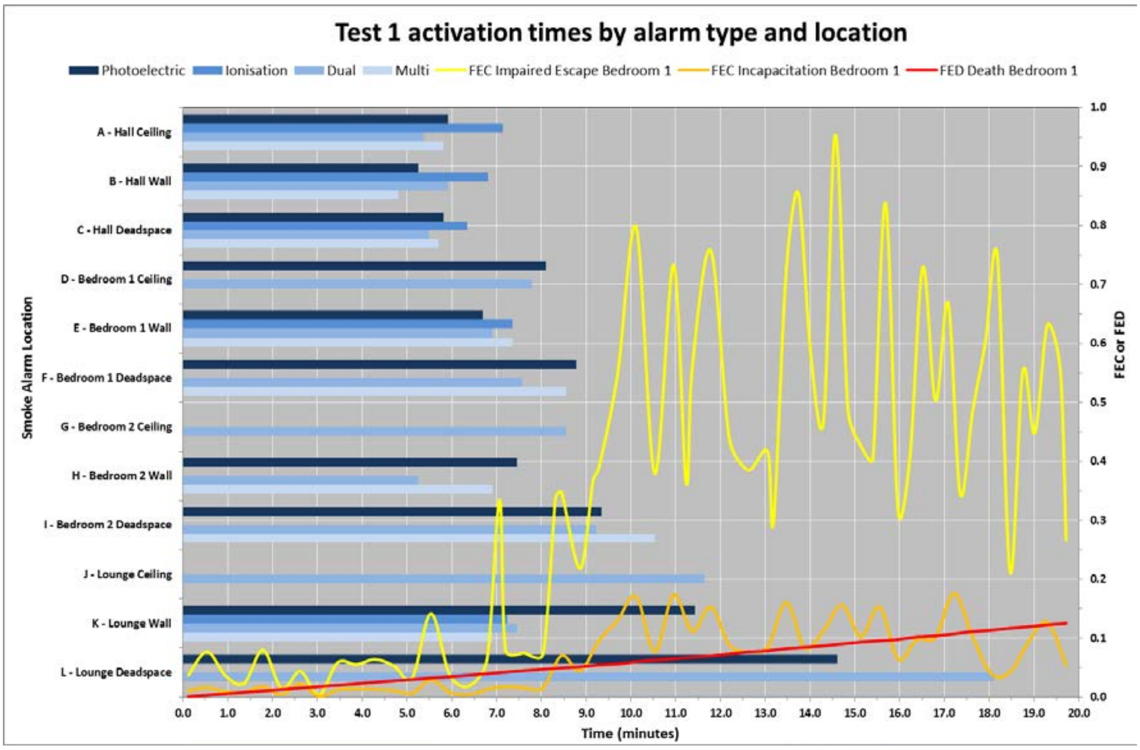

Figure 161 Scenario 26, Test 1 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

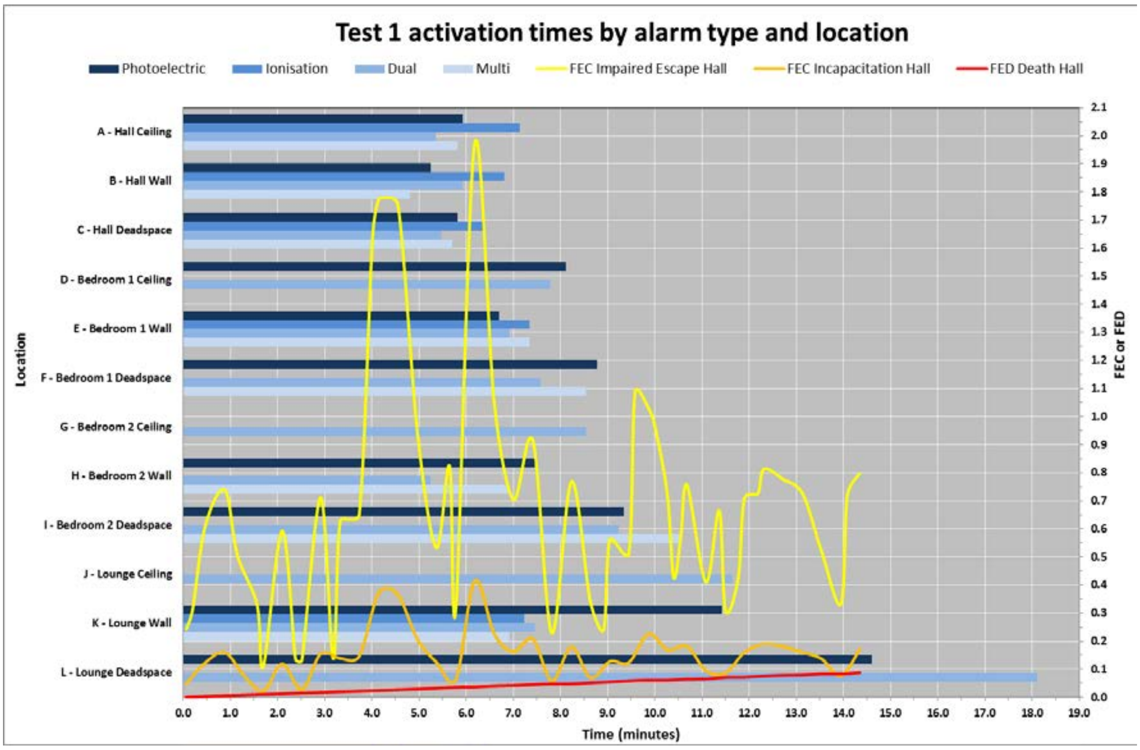

Figure 162 Scenario 26, Test 1 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

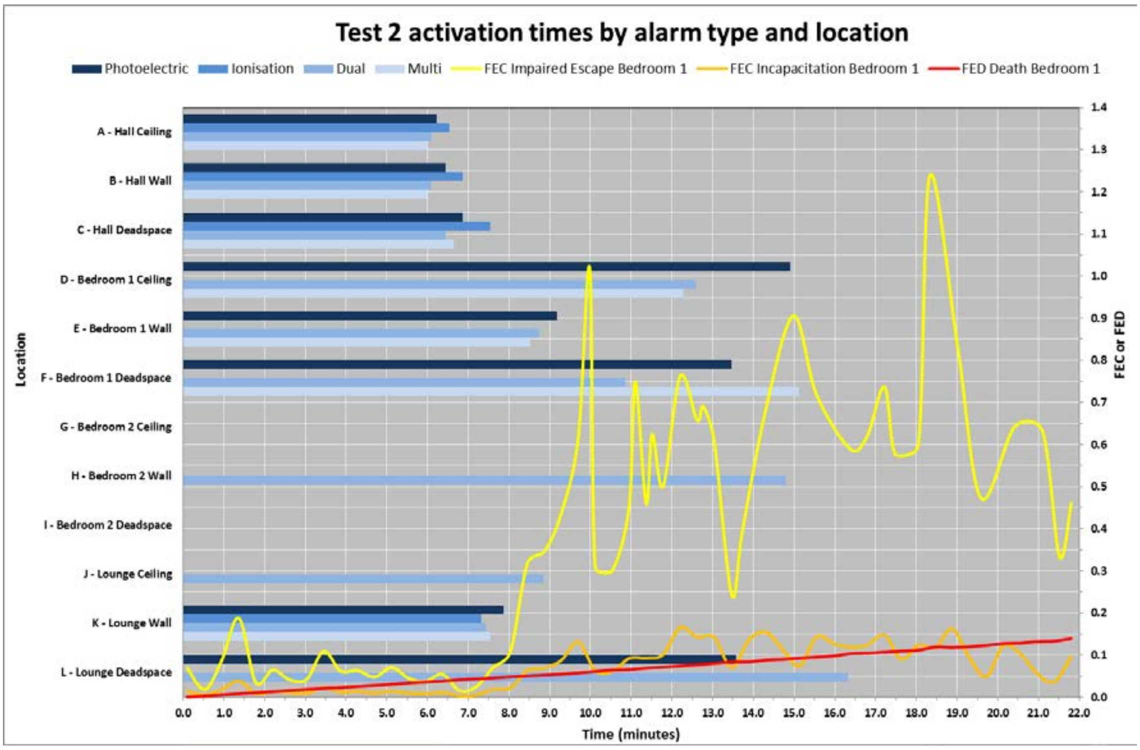

Figure 163 Scenario 26, Test 2 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

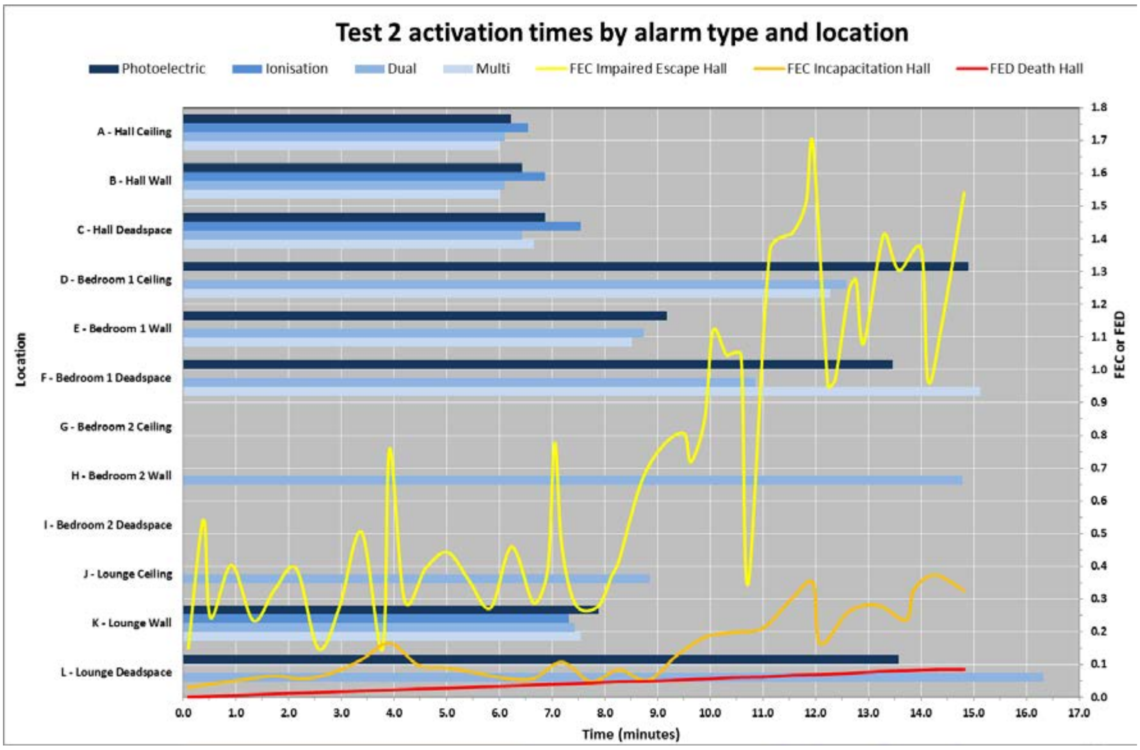

Figure 164 Scenario 26, Test 2 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

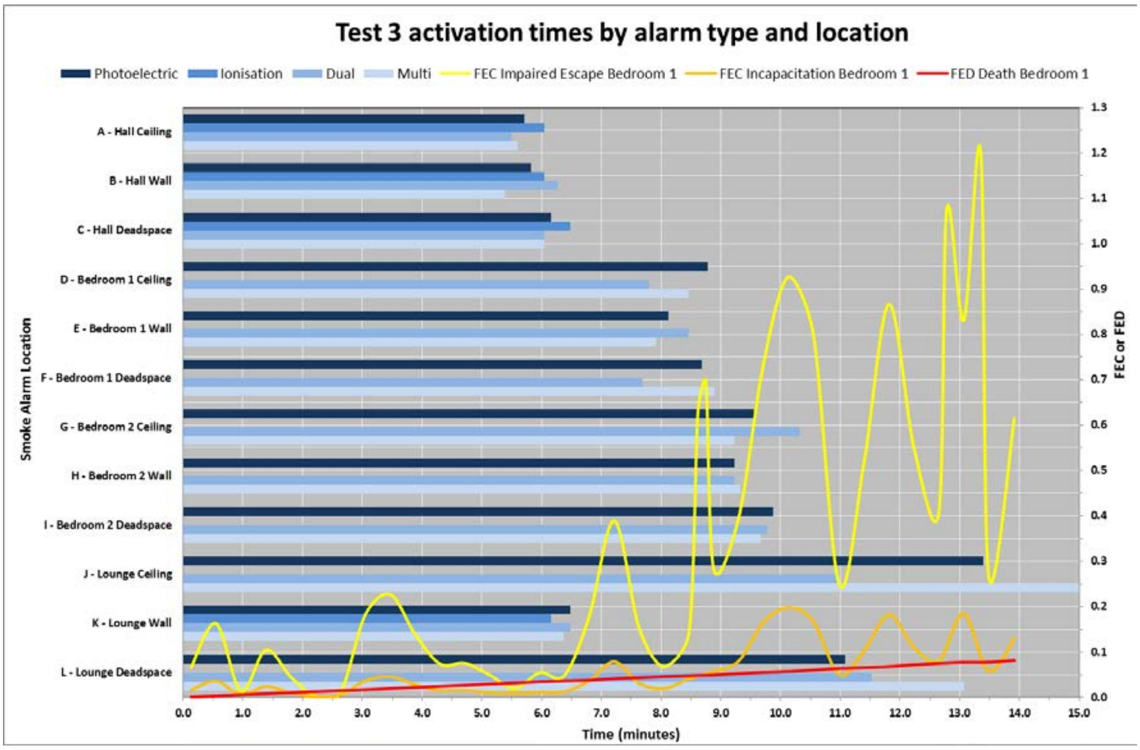

Figure 165 Scenario 26, Test 3 smoke alarm activation times by type in comparison with calculated Bedroom 1 FECs for impaired escape and incapacitation, and asphyxiation FED.

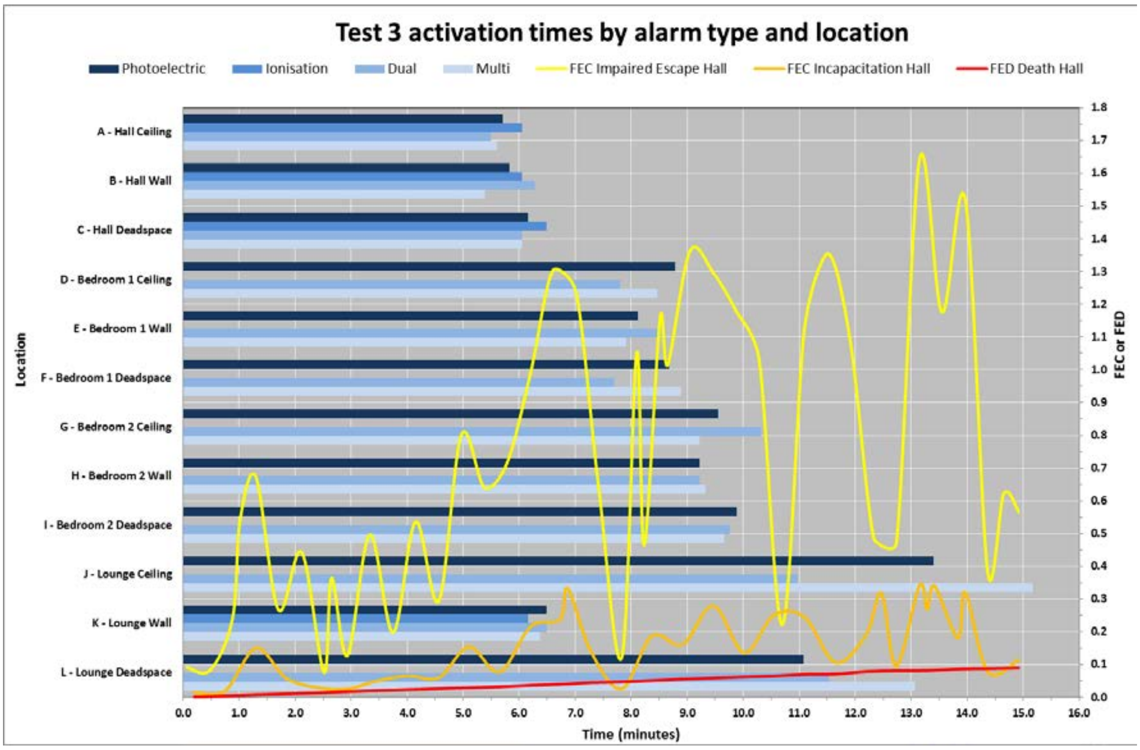

Figure 166 Scenario 26, Test 3 smoke alarm activation times by type in comparison with calculated Hallway FECs for impaired escape and incapacitation, and asphyxiation FED.

Table 86 Scenario 26 Available Safe Egress Times (ASETs) in minutes for individual smoke alarms according to Hallway tenability limits. Note: ASET≤0 is no ASET, 0<ASET<2.25 is insufficient, ASET≥2.25 is sufficient.

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling	-2.06	-3.27	-1.50	-1.95	5.33	5.01	5.45	5.56	1.15	0.81	1.37	1.26
Hall Wall	-1.39	-2.94	-2.06	-0.94	5.11	4.68	5.45	5.56	1.04	0.81	0.59	1.48
Hall Dead-space	-1.95	-2.48	-1.61	-1.84	4.68	4.01	5.11	4.90	0.70	0.38	0.81	0.81
Lounge Ceiling	#N/A	#N/A	-7.78	#N/A	#N/A	#N/A	2.69	#N/A	-6.53	#N/A	-4.11	-8.30
Lounge Wall	-7.56	-3.38	-3.59	-3.05	3.67	4.23	4.12	4.01	0.38	0.70	0.38	0.49
Lounge Dead-space	-10.74	#N/A	-14.25	#N/A	-2.03	#N/A	-4.78	#N/A	-4.22	#N/A	-4.66	-6.20

Table 87 Scenario 26 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	1.18	1.25	1.29
Air Temp (°C)	18.87	19.08	18.89
Rel. Humidity (%)	26.97	25.65	25.93
Air Pressure (mbar)	998.32	997.70	997.71

3.24 SCENARIO 27: Nuisance test - Burnt toast in the kitchen

In this scenario, four slices of bread were placed in a portable grill in the kitchen and toasted on high heat for approximately 15 minutes. The door of the grill was left ajar to allow any smoke to escape.

Figure 167 Scenario 27 set up and result (Test 1)

Smoke alarms activated include ionisation and dual alarms in the Lounge and Hallway and some duals in the bedrooms (Table 88).

Table 88 Scenario 27 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling		12.21	12.73			13.59	12.82			13.06	11.85	
Hall Wall		12.21	12.52			13.37	12.27			12.73	10.86	
Hall Dead-space		13.27	12.21				12.05			13.28	11.42	
Lounge Ceiling		15.97	15.87			11.38	9.84			10.97	9.22	
Lounge Wall		10.35	9.46			10.73	9.51			10.00	9.11	
Lounge Dead-space												
Bedroom 1 Ceiling												
Bedroom 1 Wall			14.23									
Bedroom 1 Deadspace							14.26				14.87	
Bedroom 2 Ceiling												
Bedroom 2 Wall			15.32									
Bedroom 2 Deadspace												

Table 89 Scenario 27 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.57	0.42	0.44
Air Temp (°C)	25.78	25.74	24.49
Rel. Humidity (%)	30.37	30.66	33.81

Air Pressure (mbar)	1015.06	1014.98	1014.86

3.25 SCENARIO 28: Nuisance test - Steam from the bathroom

In this scenario, a hot water urn was used to generate steam in the bathroom to simulate the steam from a shower. The test began when the sliding door to the bathroom was opened and the steam was released into the Hallway.

Figure 168 Scenario 28 set up

The only alarms to activate during these tests were the photoelectric alarms in the ceiling position in the hallway.

Table 90 Scenario 28 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	**Photo-electric**	**Ionisation**	**Dual**	**Multi**	**Photo-electric**	**Ionisation**	**Dual**	**Multi**	**Photo-electric**	**Ionisation**	**Dual**	**Multi**
Hall Ceiling	02:54				03:21				01:53			
Hall Wall												
Hall Dead-space												
Lounge Ceiling												
Lounge Wall												
Lounge Dead-space												
Bedroom 1 Ceiling												
Bedroom 1 Wall												
Bedroom 1 Deadspace												
Bedroom 2 Ceiling												
Bedroom 2 Wall												
Bedroom 2 Deadspace												

Table 91 Scenario 28 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	1.01	1.20	0.80

Air Temp (°C)	22.20	21.93	21.89
Rel. Humidity (%)	32.50	32.18	33.12
Air Pressure (mbar)	1001.30	1001.40	1001.42

3.26 SCENARIO 29: Nuisance test – Cigarettes in the Lounge room

In this scenario, two cigarettes are lit and left to smoulder in an ashtray placed on the coffee table in the Lounge.

Figure 169 Scenario 29 set up

In all tests, the cigarettes continued to smoulder for nine to 12 minutes. No smoke alarms activated in the tests.

Table 92 Scenario 29 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.37	0.57	0.75
Air Temp (°C)	23.36	25.87	27.93
Rel. Humidity (%)	40.21	32.82	26.42
Air Pressure (mbar)	1012.44	1011.49	1010.32

3.27 SCENARIO 30: Nuisance test – Incense candles in the Lounge

In this scenario, three incense candles are lit and left to burn in a holder placed on the coffee table in the Lounge.

Figure 170 Scenario 30 set up

Table 93 Scenario 30 smoke alarm activation times (min:sec)

	TEST 1				TEST 2				TEST 3			
POSITION	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi	Photo-electric	Ionisation	Dual	Multi
Hall Ceiling												
Hall Wall												
Hall Dead-space												
Lounge Ceiling			00:51							08:27	09:07	
Lounge Wall												
Lounge Dead-space												
Bedroom 1 Ceiling												
Bedroom 1 Wall												
Bedroom 1 Deadspace												
Bedroom 2 Ceiling		07:26										
Bedroom 2 Wall												
Bedroom 2 Deadspace												

Table 94 Scenario 30 atmospheric conditions

	Test 1	Test 2	Test 3
Wind Speed (km/h)	0.68	0.75	0.61
Air Temp (°C)	24.34	24.24	25.45
Rel. Humidity (%)	40.25	38.64	34.13
Air Pressure (mbar)	1012.85	1012.58	1011.80

4. Analysis and Discussion

4.1 Activation times by alarm type

In the evaluation of smoke alarm performance, as can be seen from the results presented in Section 3, a multitude of factors may contribute to variations between tests. A non-dimensional analysis technique was proposed by Milarcik, Elenick, & Roby (2008) whereby the activation time for a particular smoke detector in a specific test is normalised (or weighted) based on the activation time of the first alarm in that location. This technique eliminates the test-specific variables related to fire type and intensity, fire development, and smoke travel and allows the direct comparison of the detector technologies and sensitivities.

Milarcik et al. (2008) compared smoke alarm responses using the Common Language Effect Size (CLES) statistic, which measures the extent of overlap of two population distributions with a continuous dependent variable (normalised activation times). The CLES method assumes that the independent samples follow a normal distribution. For the comparison of non-parametric and dissimilar distributions, as in our case, the Kruskal-Wallis H test can be used to compare mean ranks of normalised activation times across multiple categories (alarm types). Using this method, the technology with the lowest mean rank has the lowest activation time, i.e. is the quickest.

When we take into account all 48 of the alarms installed in the unit and a possible 3,888 activations, the Kruskal-Wallis H test showed a statistically significant difference in normalised activation times between the different alarm types, $\chi^2(3) = 336.796$, $p < .05$, with a mean rank of 2254.00 for photoelectric alarms, 1799.79 for ionisation alarms, 1488.39 for dual alarms and 2235.82 for multi alarms. Post-hoc tests revealed significant differences between the dual alarms and ionisation alarms, $\chi^2(1) = 311.406$, $p < .05$, dual and multi alarms, $\chi^2(1) = -747.436$, $p < .05$, dual and photoelectric alarms, $\chi^2(1) = 765.609$, $p < .05$, ionisation and multi alarms, $\chi^2(1) = -436.030$, $p < .05$, and ionisation and photoelectric alarms, $\chi^2(1) = 454.203$, $p < .05$.

Excluding the nuisance tests, the Kruskal-Wallis H test on the 3,312 activations showed similar results, with a statistically significant difference in normalised activation times between the different alarm types, $\chi^2(3) = 381.524$, $p < .05$, with a mean rank of 1973.70 for photoelectric alarms, 1499.81 for ionisation alarms, 1210.75 for dual alarms and 1941.74 for multi alarms. Post-hoc tests revealed significant differences between the dual alarms and ionisation alarms, $\chi^2(1) = 289.059$, $p < .05$, dual and multi alarms, $\chi^2(1) = -730.986$, $p < .05$, dual and photoelectric alarms, $\chi^2(1) = 762.944$, $p < .05$, ionisation and multi alarms, $\chi^2(1) = -441.927$, $p < .05$, and ionisation and photoelectric alarms, $\chi^2(1) = 473.885$, $p < .05$.

4.2 Smoke alarm activations in smouldering tests

In smouldering tests (1,584 possible activations), the Kruskal-Wallis H test showed a statistically significant difference in normalised activation times between the different alarm types, $\chi^2(3) = 207.189$, $p < .05$, with a mean rank of 829.41 for photoelectric alarms, 1,000.00 for ionisation alarms, 548.28 for dual alarms and 792.31 for multi alarms. Post-hoc tests revealed significant differences between the dual alarms and multi alarms, $\chi^2(1) = -244.035$, $p < .05$, dual and photoelectric alarms, $\chi^2(1) = 281.133$, $p < .05$, dual and ionisation alarms, $\chi^2(1) = 451.721$, $p < .05$, multi and ionisation alarms, $\chi^2(1) = 207.686$, $p < .05$, and photoelectric and ionisation alarms, $\chi^2(1) = -170.588$, $p < .05$.

Paired samples t-tests showed significant differences between activation times for five of the six different smoke alarm pairs in smouldering fires. There was a significant difference between activation times for photoelectric alarms ($M = 9.55$, $SD = 6.85$) and ionisation alarms ($M = 10.05$, $SD = 6.91$); $t(179) = -2.585$, $p < .05$, with photoelectric alarms on average 29.9 seconds faster than ionisation alarms. Dual alarms ($M = 8.99$, $SD = 6.51$) were significantly faster than ionisation alarms ($M = 10.04$, $SD = 6.95$); $t(189) = 7.044$, $p < .05$, by an average of 63.0 seconds. Multi alarms ($M = 9.27$, $SD = 6.85$) were significantly faster than ionisation alarms ($M = 10.04$, $SD = 7.02$); $t(185) = 4.711$, $p < .05$, by an average of 46.3 seconds. It was also found that dual alarms ($M = 11.35$, $SD = 7.41$) were significantly faster than photoelectric alarms ($M = 12.33$, $SD = 8.84$); $t(272) = 4.397$, $p < .05$ by an average of 58.6 seconds. When compared with multi-criteria alarms ($M = 11.63$, $SD = 8.42$), dual alarms ($M = 10.85$, $SD = 7.17$) were faster by an average of 47.3 seconds; $t(267) = -3.753$, $p < .05$. There were no significant differences between activation times for photoelectric and multi-criteria alarms in smouldering fires.

4.3 Smoke alarm activations in flaming tests

In flaming tests (1,728 possible activations), the Kruskal-Wallis H test showed a statistically significant difference in normalised activation times between the different alarm types, $\chi^2(3) = 641.198$, $p < .05$, with a mean rank of 1,154.80 for photoelectric alarms, 484.87 for ionisation alarms, 659.56 for dual alarms and 1158.78 for multi alarms. Post-hoc tests revealed significant differences between the ionisation alarms and dual alarms, $\chi^2(1) = -174.686$, $p < .05$, ionisation and photoelectric alarms, $\chi^2(1) = 669.926$, $p < .05$, ionisation and multi alarms, $\chi^2(1) = -673.911$, $p < .05$, dual and photoelectric alarms, $\chi^2(1) = 495.240$, $p < .05$, and dual and multi alarms, $\chi^2(1) = -499.225$, $p < .05$.

Paired samples t-tests showed significant differences between activation times for four of the six different smoke alarm pairs in flaming fires. There was a significant difference between activation times for photoelectric alarms ($M = 4.22$, $SD = 3.35$) and ionisation alarms ($M = 3.50$, $SD = 3.20$); $t(259) = 9.157$, $p < .05$, with ionisation alarms on average 43.1 seconds faster than photoelectric alarms. Ionisation alarms ($M = 3.40$, $SD = 3.24$) were significantly faster than multi-criteria alarms ($M = 4.14$, $SD = 3.42$); $t(258) = -9.095$, $p < .05$, by an average of 44.8 seconds. Dual alarms ($M = 3.50$, $SD = 2.93$) were significantly faster than photoelectric alarms ($M = 4.21$, $SD = 3.36$); $t(257) = 8.277$, $p < .05$, by an average of 52.9 seconds. Dual alarms ($M = 3.38$, $SD = 2.94$) were significantly faster than multi-criteria alarms ($M = 4.14$, $SD = 3.42$); $t(256) = -8.352$, $p < .05$, by an average of 45.2 seconds. There were no significant differences between activation times for ionisation and dual alarms, and between photoelectric and multi-criteria alarms in flaming fires.

4.4 Non-activations and nuisance alarms

The factor that significantly affected the results of photoelectric and multi-criteria alarms was the non-activations, especially in flaming fires, which were included in the analysis. Non-activations had been removed by Milarcik et al. (2008) in their study. The flaming fires in this test series were small scale and did not produce enough large smoke particles to trigger the photoelectric sensors.

Of a possible 828 ROO alarm activations (nuisance tests excluded), there were 100 (12%) non-activations recorded in the testing. Table 95 below shows the breakdown by alarm type.

Table 95 Smoke alarm non-activation (rate) by alarm type

NON-ACTIVATIONS	PHOTOELECTRIC	IONISATION	DUAL	MULTI
ROO	51 (24.6%)	9 (4.3%)	4 (1.9%)	36 (17.4%)
Hall	63 (30.4%)	33 (15.9%)	14 (6.8%)	60 (29.0%)

One-way between subjects ANOVA was conducted to compare non-activations for photoelectric, ionisation, dual and multi alarms. There was a significant difference between non-activation rates for the four alarm types [$F(3, 824) = 24.563$, $p < .05$]. Post hoc comparisons using the Tukey HSD test indicated that the photoelectric alarms (24.6%) and multi alarms (17.4%) had significantly more ROO non-activations than the ionisation (*M* = 4.3%) and dual alarms (*M* = 1.9%).

Hallway alarms had similar results with 20.5% non-activations and one-way ANOVA also indicating significant differences between the four alarm types [$F(3, 824) = 16.989$, $p < .05$]. Post hoc comparisons found that the photoelectric alarms (*M* = 30.4%, *SD* = 46.1%) and multi alarms (*M* = 29.0%, *SD* = 45.5%) had significantly more Hallway non-activations than the ionisation (*M* = 15.9%, *SD* = 36.7%) and dual alarms (*M* = 6.8%, *SD* = 25.2%).

The nuisance tests found that ionisation alarms and dual alarms were most likely to activate due to nuisance sources, while multi alarms did not activate at all. Of a possible 144 alarm activations in the room of origin, there were 15 (10.4%) activations. One-way ANOVA found a significant difference between activation rates for the four alarm types [$F(3, 140) = 3.638$, $p < .05$]. Post hoc comparisons showed that dual alarms had significantly more nuisance activations than multi alarms.

Nuisance alarms are a major cause of smoke alarms being deactivated in homes by the occupants (Fazzini, Perkins, & Grossman, 2000). The four nuisance scenarios investigated in this series produced few activations, which were dependent on the source, the vicinity of the alarm, and the atmospheric conditions at the time of the test.

Scenario 27, which involved burning toast/sandwiches under a grill, resulted in activation of the ionisation and dual-type alarms located in the Lounge and Hall, and a scattering of dual-type alarms in the Bedrooms. The alarms activated after at least nine minutes of cooking, at which time, while there was little visible smoke, the smell of burnt toast was present. There were no activations of photoelectric or multi-criteria alarms in this Scenario.

Scenario 28, which involved steam from the bathroom, produced only activations from the nearest photoelectric alarm at the Hallway ceiling. The activations occurred after the door to the bathroom had been opened for about two or three minutes.

Scenario 29 involved smoke from a couple of cigarettes left burning in an ashtray on the coffee table in the Lounge room. While no alarms activated in all three tests, it was observed during trials that activation of alarms did occur when the smoke was able to reach them. Due to the warm outside ambient temperatures, the temperature gradients within the unit (up to 6.4 degrees C difference between temperatures measured at 0.5 metres from the floor and ceiling height in this Scenario) and the low heat release of the cigarette smoke, stratification of the smoke plume occurs, which prevents smoke from reaching the smoke alarms. It was noted that five of the six cigarettes used continued to burn for their entire lengths, while one stopped at approximately one centimetre from the butt (filter). Note that the mandatory standard for reduced fire risk cigarettes (Trade Practices (*Consumer Product Safety Standard)(Reduced Fire Risk Cigarettes*) Regulations 2008), which applies to all cigarettes sold in Australia from 23 September 2010, requires that at least 75% of the cigarettes that are tested (in accordance with AS 4830 (Standards Australia, 2007)) in a test trial must fail to achieve full length burns" (ACCC, 2010). In the smouldering tests using a lit cigarette (Scenarios 7b and 14b), all cigarettes used were successful in causing a sustained smoulder when left on a pile of cotton batting.

4.5 Toxic tenability

A comparison was made of smoke alarm activation times with the times at which tenability limits were reached in the Bedrooms and the Hallway. The available safe egress time (ASET) is the time between smoke alarm activation and the time at which the calculated fractional effective concentration (FEC) for occupant incapacitation reaches 0.3. The ASET is deemed adequate if it is greater than the required safe egress time (RSET) of 135 seconds.

Smouldering fires involved an assortment of materials including cotton, polyester, polypropylene, polyurethane, polyvinyl chloride and polyethylene, which produced smoke containing significant levels of acrolein, formaldehyde, phenol and sulfur dioxide. In the bedroom fires, tenability limits in the ROO were reached typically in around ten to 12 minutes whether the door was open or closed. When tenability limits were reached in the bedroom, it was found that only 35.7% of alarms provided sufficient ASET. When tenability limits were reached in the hallway, 54.8% of alarms provided sufficient. Table 96 and Table 97 below summarise smoke alarm performance in terms of calculated ASETs before Bedroom and Hallway tenability limits are reached. All room of origin and Hallway alarms were included except for those installed in the dead space positions.

Table 96 Smoke alarm ASET before tenability limit is reached in the Bedroom

	PHOTOELECTRIC		IONISATION		DUAL		MULTI	
	Smouldering	Flaming	Smouldering	Flaming	Smouldering	Flaming	Smouldering	Flaming
Adequate (ASET > RSET)	36.4%	0.0%	34.6%	0.0%	30.0%	0.0%	41.9%	0.0%
Inadequate (ASET < RSET)	12.1%	75.0%	23.1%	75.0%	15.0%	75.0%	12.9%	75.0%
None (ASET < 0)	51.5%	25.0%	42.3%	25.0%	55.0%	25.0%	45.2%	25.0%

Table 97 Smoke alarm ASET before tenability limit is reached in the Hallway

	PHOTOELECTRIC		IONISATION		DUAL		MULTI	
	Smouldering	Flaming	Smouldering	Flaming	Smouldering	Flaming	Smouldering	Flaming
Adequate (ASET > RSET)	54.8%	45.5%	48.1%	90.9%	56.3%	86.4%	60.0%	45.5%
Inadequate (ASET < RSET)	12.9%	50.0%	14.8%	9.1%	15.6%	13.6%	13.3%	54.5%
None (ASET < 0)	32.3%	4.5%	37.0%	0.0%	28.1%	0.0%	26.7%	0.0%

Analysis of the levels of toxic gases in the bedrooms and along the path of egress revealed that overall smoke alarm performance was poor in terms of the provision of adequate warning for the safe egress of occupants. This is in agreement with prior research (Engelsman, 2015). In the Bedroom, smoke alarms provided inadequate to no egress time for occupants during flaming fires, and were only adequate in up to 42% of smouldering fires in which the tenability limit was reached.

The poor performance of current smoke alarm technologies in terms of toxicity tenability is a cause for concern. The results indicate that current technologies are incapable of providing sufficient warning in flaming fires and require improvement for smouldering fires. There is a need to include in the smoke alarm standards a means to assess performance in terms of available safe egress times.

5. Conclusions and Recommendations

In this comprehensive study on smoke alarm activations in residential fires it was found that of the four alarm types tested, dual photoelectric/ionisation alarms were overall the quickest to activate, while only ionisation alarms activated earlier than dual alarms in fast flaming fires only.

Testing revealed that non-activation rates were high for photoelectric and multi-criteria alarms, while ionisation and dual-type alarms were more likely to activate due to nuisance sources such as cooking fumes, cigarette smoke, and burning incense.

Analysis of the levels of toxic gases in the bedrooms and along the path of egress revealed that overall smoke alarm performance was poor in terms of the provision of adequate warning for the safe egress of occupants. It was found that often tenability limits were reached in the room of origin before hallway alarms were activated. Hallway alarms did not activate at all when the door to the room of origin was closed. This reinforces the recommendations by FRNSW in Stage 1, that smoke alarms be required in all hallways, bedrooms and living spaces, and should be interconnected (Engelsman, 2015).

Smoke alarms are an essential component in a suite of fire safety measures used to protect occupants from residential fires. The results indicate that current technologies are incapable of providing sufficient warning in flaming fires and that there is a need to improve tenability performance of smoke alarms in smouldering fires where smoke alarms have the potential to provide notification for the safe egress of occupants.

Considering the findings of the study, FRNSW notes a number of measures that can be implemented to improve fire safety in residential settings:

- Smoke alarms required in every living space, bedroom and hallway
- All smoke alarms within a residence to be interconnected
- Improvement of smoke alarm performance by including toxic tenability performance requirements in the standards, and
- The use of automated fire suppression systems (home sprinklers) to be used to mitigate fast flaming fires in residences.

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APPENDIX A Furnishing materials used in testing

Table A1. Furnishing materials

Item	Materials
Double beds	Aluminium frame, timber slats (pine)
Mattresses	Polyurethane foam, polyester cover
Pillows and quilts	100% polypropylene outer, 100% polyester fill
Pillow cases and quilt covers	52% polyester, 48% cotton
Two-seater sofa	Polyester cover, polyurethane foam inner, timber frame
Sofa cushions	100% polyester outer and fill
Chairs	Timber laminate, chipboard, polyurethane foam padding, polyester cover
Waste bins	Steel mesh
Tea towels	100% cotton

APPENDIX B Tenability Criteria

Table B1. Tenability limits used in gas calculations

	Effective concentration for Escape Impairment (ppm) [REF]	Effective concentration for Incapacitation (ppm) [REF]	Lethal Effective Dose (ppm.min) [REF]
1,3 Butanediol	-	-	-
1,3-Butadiene C4H6	6700 [AEGL]	27000 [AEGL]	810000 [AEGL]
Acetaldehyde C2H4O	340 [AEGL]	1100 [AEGL]	33000 [AEGL]
Acetic acid C2H4O2 (Ethanoic acid)	-	-	-
Acetone C3H6O	9300 [AEGL]	8600 [AEGL]	258000 [AEGL]
Acetylene C2H2	-	-	-
Acrolein C3H4O	4 [SFPE]	20 [SFPE]	4500 [SFPE]
Ammonia NH3	220 [AEGL]	1600 [AEGL]	48000 [AEGL]
Benzene C5H6	2000 [AEGL]	5600 [AEGL]	168000 [AEGL]
Carbon dioxide CO2	-	-	-
Carbon monoxide CO	420 [AEGL]	600 [AEGL]	18000 [AEGL]
Carbonyl sulfide COS	69 [AEGL]	190 [AEGL]	5700 [AEGL]
Chlorobenzene C6H5Cl	430 [AEGL]	800 [AEGL]	24000 [AEGL]
Ethane C2H6	-	-	-
Ethanol C2H6O	-	-	-
Ethyl benzene C8H10	2900 [AEGL]	2600 [AEGL]	78000 [AEGL]
Ethylene C2H4	-	-	-
Formaldehyde CH2O	6 [SFPE]	30 [SFPE]	22500 [SFPE]
Formic acid CH2O	-	-	-
Hexane C6H14	4000 [AEGL]	8600 [AEGL]	258000 [AEGL]
Hydrogen bromide HBr	200 [SFPE]	900 [SFPE]	114000 [SFPE]
Hydrogen chloride HCl	200 [SFPE]	900 [SFPE]	114000 [SFPE]
Hydrogen cyanide HCN	-	-	-
Hydrogen fluoride HF	200 [SFPE]	900 [SFPE]	87000 [SFPE]
Methane CH4	-	-	-
Methanol CH4O	11000 [AEGL]	14000 [AEGL]	420000 [AEGL]
Methyl ethyl ketone (2-Butanone)	4900 [AEGL]	10000 [AEGL]	300000 [AEGL]
m-Xylene C8H10	2500 [AEGL]	3600 [AEGL]	108000 [AEGL]
Nitrogen dioxide NO2	70 [SFPE]	350 [SFPE]	1900 [SFPE]
Nitrogen monoxide NO	-	1000 [SFPE]	-
Nitrous oxide N2O	-	-	-
Octane C8H18	-	-	-
o-Xylene C8H10	2500 [AEGL]	3600 [AEGL]	108000 [AEGL]

SFPE (National Fire Protection Association. & Society of Fire Protection Engineers., 2002)
AEGL (US Environmental Protection Agency, 2016)

Table B1. Tenability limits used in gas calculations – cont.

	Effective concentration for Escape Impairment (ppm) [REF]		Effective concentration for Incapacitation (ppm) [REF]		Lethal Effective Dose (ppm.min) [REF]	
Phenol C6H5OH	29	[AEGL]	-		-	
Propane C3H8	17000	[AEGL]	33000	[AEGL]	990000	[AEGL]
Propene C3H6	-		-		-	
p-Xylene C8H10	2500	[AEGL]	3600	[AEGL]	108000	[AEGL]
Styrene C8H8	230	[AEGL]	1900	[AEGL]	57000	[AEGL]
Sulfur dioxide SO2	24	[SFPE]	120	[SFPE]	12000	[SFPE]
Toluene C7H8	1400	[AEGL]	5200	[AEGL]	156000	[AEGL]

APPENDIX C CSIRO Smoke Alarm Verification Test Reports

The tests reported in XF3033/R1 and XF3033/R3 were conducted by CSIRO Infrastructure Technologies to pre-qualify the alarm response threshold (sensitivity) and directional dependence of smoke alarms used in this research. The results were used to verify that all alarms used in the study were operable prior to installation in real fire test scenarios.

XF3033/R1 Test Report 1

XF3033/R3 Test Report 2