Experimental investigation of using CO sensors to detect smouldering fires in dwellings

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ABSTRACT

SP Fire Research has recently conducted a research project which demonstrated that CO sensors may be more suitable than photoelectric detectors for detecting smouldering fires at an early stage. This was done by experimentally comparing photoelectric detectors with CO sensor in simulated bedroom fires. The response times of the CO sensors were significantly faster than for the photoelectric detectors. Furthermore, whereas the levels of fire gases at the time of CO alarm activation were sub-toxic, the results indicate that the CO dose may exceed critical values before photoelectric detectors activated.

INTRODUCTION

In Norway, eight out of ten fire-related fatalities occur in dwellings [1]. It is acknowledged that smoke detectors save lives, which emphasizes the importance of every home having a functioning smoke detector. During recent decades, two predominant smoke detection technologies have been used in dwellings, namely, ionization and photoelectric detection. In recent years, the latter have demonstrated a better overall performance with regards to detecting both flame and smouldering fires [2], and in Norway this technology is recommended in dwellings. Effort has been made to increase the sensitivity of these technologies to decrease detection time, either by making the sensors more sensitive, by combining several sensors in one detector or introducing logic algorithms. Studies conclude that the latter point is important, if an undesirable increase in nuisance alarms is to be avoided [3], [4].

Several studies have shown that CO sensors are promising in detecting fires [3], [5]. Cestari, Worrell and Milke conducted a study where they compared data from CO sensors in combination with other measurements and technologies, such as temperature rise rate, ionization and photoelectric smoke alarms. One of the key findings from the study was that CO sensors detect smouldering fires earlier than photoelectric detectors, and that they provide a higher level of nuisance immunity.

There are two predominant casues of death in fires; burns and asphyxiation from fire gases. In smouldering fires, there are no flames to give burns, but there may be extensive smoke and fire gas production. It is therefore of interest to determine the gas concentrations in a room during the time period until detection. The literature presents a wide range of tenability limits and toxicity parameters of important fire gases, for which a selection is shown in Table 1.

Table 1 Tenability criteria with respect to human individuals exposed to fire effluents in terms of IC_{50} (incapacitation concentration), LC_{50} (lethal concentration), ID_{50} (incapacitation dose) and LD_{50} (lethal dose).

Gas	IC_{50} [ppm]	LC_{50} [ppm]	ID_{50} [ppm min]	LD_{50} [ppm min]
CO	1400 – 1700 [6]	4600 [7] 5500 [8] 8300 [8] 3000 [9] 2500 - 4000 [6]	35 000 – 45 000 [10]	70 000 – 135 000 [10]
CO_2	100 000 [11]	146 000 [11]		
HCN	100 – 200 [10]	110 – 160 [7] 200 [8] 135 [10]	750 – 2500 [10] 1200 – 2700 [12]	1500 – 7500 [10]
O_2		75 000 [7]		

In this study, smouldering fire experiments was performed in a test room. Response times for photoelectric detectors were compared to those of combination detectors with CO sensors. Furthermore, concentrations of toxic fire gases were measured, in order to indicate whether a person sleeping in a bedroom may be asphyxiated at the time of alarm.

METHOD AND TEST SET-UP

Test enclosure and furnishing

The tests were conducted in a room that simulated a typical room in dwellings, e.g., a bedroom, and the dimensions complied with ISO 9705 [13]. The door opening was kept closed during the tests to prevent ventilation of fire gases to ensure repeatability.

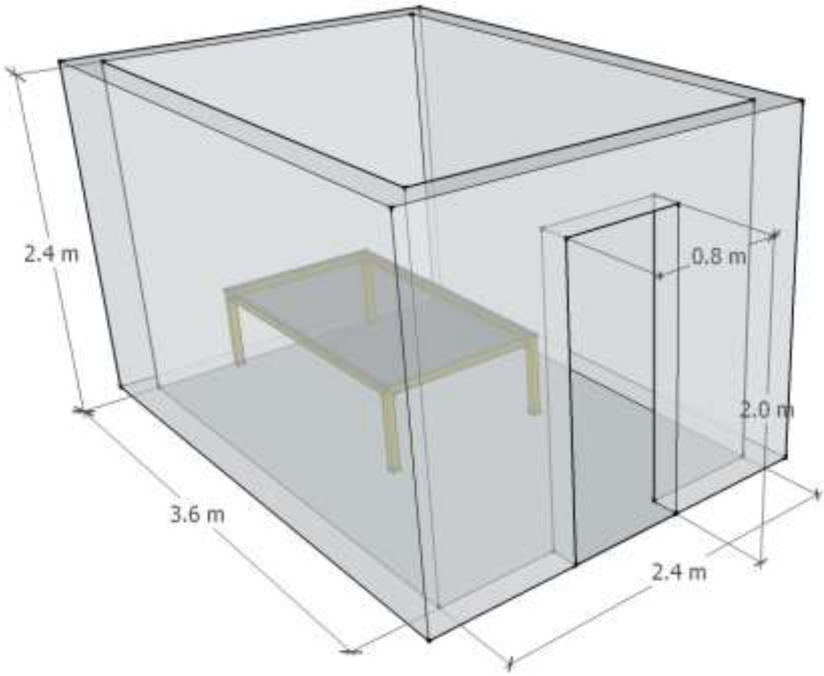

Figure 1 The test room was built according to ISO 9705 [13]. The room has a floor area of 8.6 m^2 and a volume of 20.7 m^3. At one of the end walls there is a door opening, which was kept closed during the tests. The room was furnished with a bed mock-up.

The room was furnished with a 60 cm high bed frame mock-up, which comprised a 50 mm framework and plasterboard measuring 2.2 m × 1.2 m (l × w) as a mattress substrate.

Fire load

To simulate smouldering fire in upholstered furniture, a piece of polyurethane mattress was used as the fuel load, measuring 70 cm × 50 cm × 10 cm (l × w × h). To initiate a smouldering fire, a heating device consisting of cotton, wound around a 90 cm piece of resistance wire (0.5 mm diameter, 6.88 Ω/m), which in turn was wound around a 15 cm long ceramic core, was used, see Figure 2a-b. The device was placed at the centre of the surface of the mattress. To isolate the generated heat and to increase the chances of ignition, the mattress was insulated with ceramic insulation, see Figure 2c.

Preliminary tests showed that the generated smoke would emerge from the mattress segment at different locations from test to test, which could compromise the consistency of the test results. Therefore, to ensure a fixed point of leakage, the mattress segment was placed in a wooden box, with a 51 mm diameter aperture on the top face, see Figure 2d.

In the main series of ten tests, the wooden box with the mattress segment was positioned on top of the mock-up at the foot-end (test no. 1-4), underneath the mock-up (test no. 5-7) and on the floor, in the corner by the door opening (test no. 8-10).

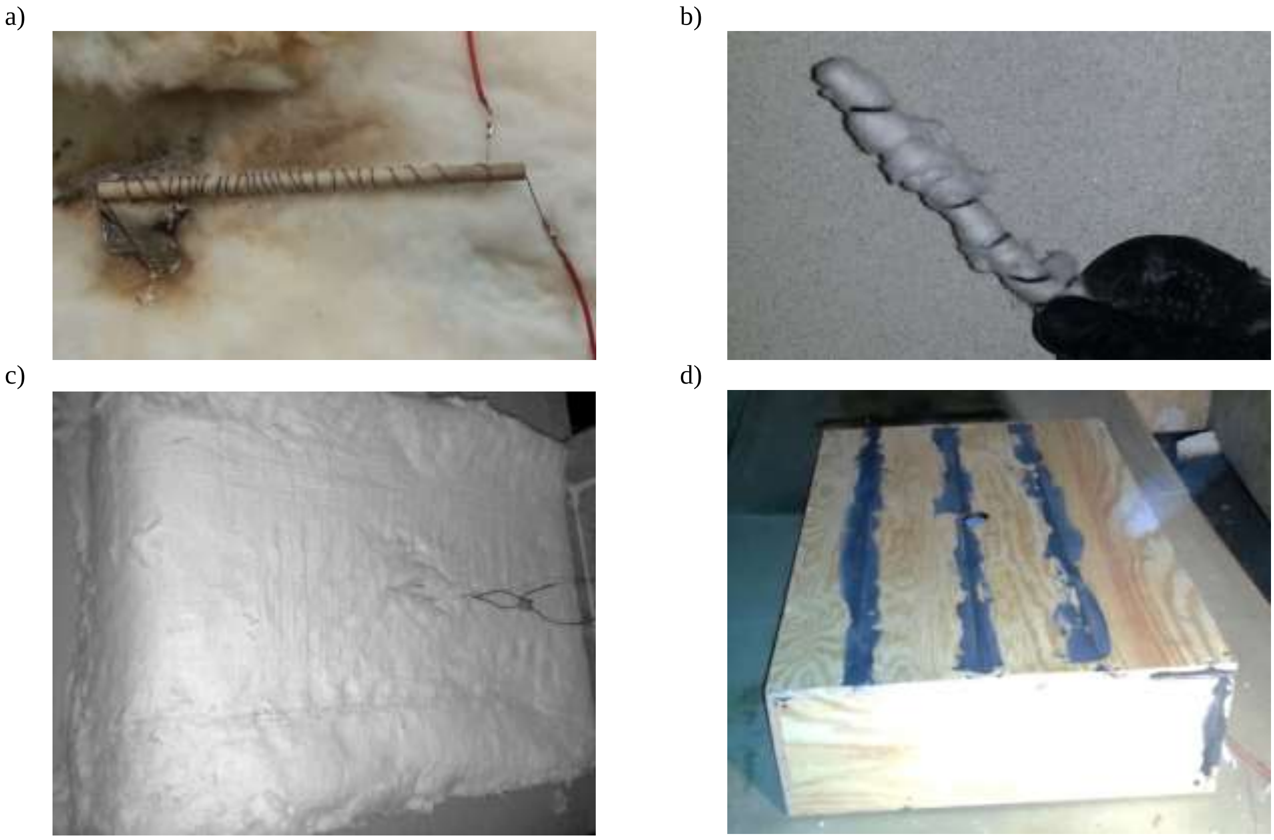

Figure 2 a) Resistance wire wound around ceramic core. b) Cotton wound around resistance wire. c) Heating device placed in mattress segment and insulated with ceramic fibre. d) Box in which the mattress segment was placed.

Instrumentation and measurements

Figure 3 shows the positions of the fire detectors in the room. A total of nine photoelectric smoke detectors of three different types were installed in a circle around the centre of the ceiling. These detectors were purchased at a local building materials supplier. In addition, a total of 21 combination detectors with sensors measuring CO concentration, light attenuation and temperature, were installed. Seven of the combination detectors were installed in the ceiling, four were installed on each wall (except the wall with the door opening) and two were installed on the floor underneath the mock-up. The positions of the combination detectors served multiple purposes; investigation of the response time for the CO sensors, investigation of the distribution of CO in the room, and investigation of the effect of dead-air space on response time. The latter is not addressed in this paper. The combination detectors provided continuous measurements for each of the three integrated sensors, whereas the photoelectric detectors provided a binary (alarm/not alarm) signal.

In order to determine the level of toxic fire gases which a sleeping person in a bedroom may be exposed to during a smouldering fire, gas was extracted 20 cm above the mock-up at the head-end, and measured by calibrated gas analysers and Fourier Transform Infrared Spectroscopy (FTIR).

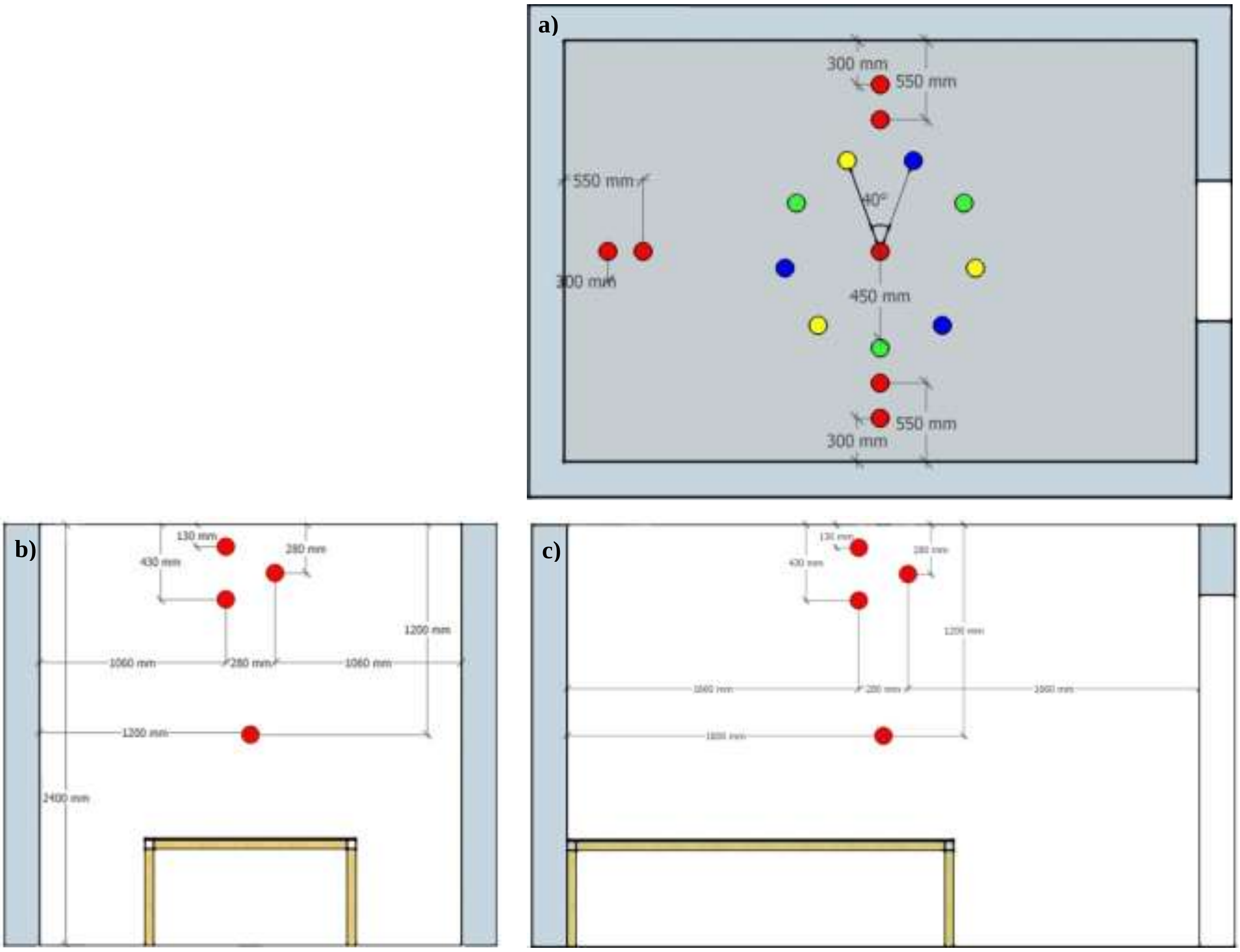

Figure 3 a) Detector positions in the ceiling: nine photoelectric detectors (blue, green and yellow markers) and 7 combination detectors (red markers). b) Four combination detectors on the short wall. c) Four combination detectors on each of the long walls.

Test procedure

A total of ten tests were conducted. The only variables in the test series were the position of the mattress segment, and the initial room temperature, which on average was 17.0 °C ± 3.2 °C. The gas analysers were calibrated before all tests.

To start the test, the heating device output was set to approximately 23 W. The heating device remained active for 10 minutes before it was switched off. By monitoring a thermocouple embedded in the mattress segment, it was decided whether or not ignition had occurred. If ignition was unsuccessful, the mattress segment was allowed to cool before a new attempt was made. At successful ignition, the fire was allowed to smoulder until all fire detectors had alarmed, or until it died out.

RESULTS

Smouldering fire was observed throughout the test time in nine tests. In one test (test no. 5) there was transition into a flaming fire, and it was therefore excluded from further analyses.

Response time

Figure 4 presents average response times for the photoelectric detectors and the combination detectors.

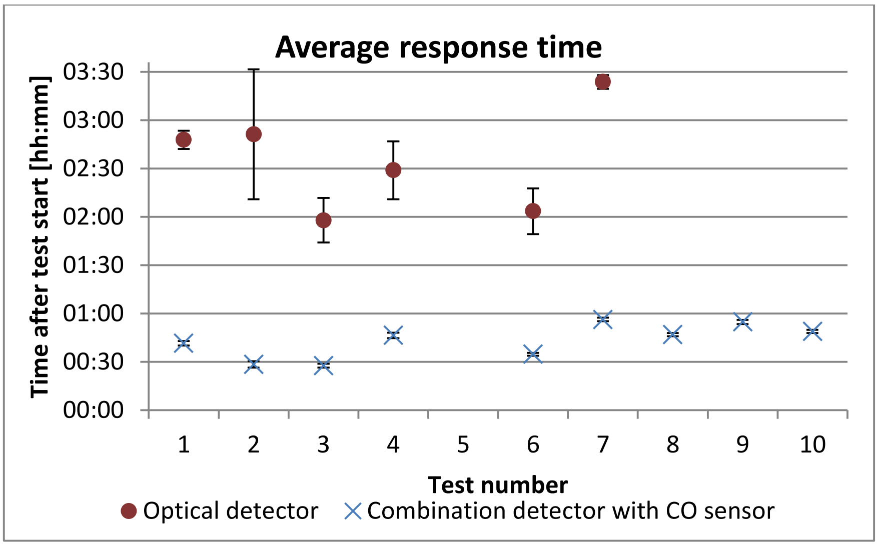

Figure 4 Average response time for photoelectric detectors (n = 9, red dots) and combination detectors with CO sensors (n = 4, blue crosses). The standard deviation is represented by error bars.

On average, the photoelectric detectors were triggered after 02:29 ± 00:31 [hh:mm] (n = 6 tests) and the combination detectors were triggered after 00:43 ± 00:10 [hh:mm] (n = 9 tests), a difference of 01:49 ± 00:26 [hh:mm] (n = 6 tests).

For the combination detectors, it was also observed that the alarm was triggered by the CO sensor before the integrated optical light attenuation sensor detected sufficient amounts of smoke to be triggered.

Gas concentrations

The gas concentrations and doses measured at the head-end of the bed in each test, at minimum and average response times for the two detector types, are presented in Table 2.

Table 2 Gas concentrations and doses at times of response for each test. Test no. 5 was excluded due to transition from smouldering to flaming fire. In tests no 8 - 10, none of the photoelectric detectors alarmed.

Time for measurement	**Test no.**	**Gas concentration / dose**				
		O_2 [%]	CO_2 [ppm]	CO [ppm]	CO dose [ppm min]	HCN [ppm]
Photoelectric detector; minimum response time	1	20.6	1465	576	30859	n/a
	2	20.5	1792	733	31384	n/a
	3	20.6	1431	502	17855	n/a
	4	20.5	1868	639	22690	n/a
	6	20.6	1630	643	18985	n/a
	7	20.4	2095	993	**57893***	n/a
Photoelectric detector; average response time	1	20.5	1565	664	**37593***	n/a
	2	20.2	2705	1453	**63957***	n/a
	3	20.5	1722	638	24371	n/a
	4	20.4	2275	907	**39325***	n/a
	6	20.5	2063	933	32547	n/a
	7	20.4	2163	1075	**64184***	n/a
Combination detector; minimum response time	1	20.8	565	25	587	n/a
	2	20.8	509	38	425	n/a
	3	20.8	446	53	1121	n/a
	4	20.8	472	52	802	n/a
	6	20.8	561	35	276	n/a
	7	20.8	633	36	515	n/a
	8	20.8	588	44	965	n/a
	9	20.8	522	30	437	n/a
	10	20.8	585	47	902	n/a
Combination detector; average response time	1	20.8	581	35	875	n/a
	2	20.8	514	42	766	n/a
	3	20.8	457	62	1236	n/a
	4	20.8	493	61	965	n/a
	6	20.8	569	35	315	n/a
	7	20.8	641	37	554	n/a
	8	20.8	591	46	1019	n/a
	9	20.8	524	36	489	n/a
	10	20.8	580	46	960	n/a

In one test (test no.7), the CO dose in the test enclosure had exceeded ID_{50} when the first photoelectrical smoke detector alarmed. At the average response time of the photoelectric detectors, the CO dose exceeded ID_{50} in four out of six valid tests. In comparison, the CO doses measured at the combination detectors' average response time was < 1236 ppm × min, and thus well below the tenability limits. The absolute gas concentrations (ppm) were non-critical at the times of alarm for both detector types

CO measurements from the 21 combination detectors in the the room were very consistent, and also in good agreement with the CO measurements at the head-end of the mock-up. This indicates that the CO was distributed evenly in the room. This is also reflected in the standard error for the response times of the combination detectors, as represented by the error bars in **Figure 4**.

DISCUSSION

This study has shown that photoelectric smoke detectors may not be safe in a smouldering fire, because a sleeping person may be asphyxiated by CO before the alarm triggers. CO sensors, on the other hand, had shorter response times, which in turn increases a person's chances of survival. In addition, early detection may reduce the notification time for the fire brigade's, which enables lives to be saved and reduced property damage.

These tests represent a scenario without ventilation in the room. In a room with ventilation, the smoke and fire gases may be diluted, resulting in longer time to reach toxic CO doses. It may also cause a longer response time for both CO and photoelectric detectors, and the time difference between the two may be different than has been revealed in this study.

One drawback of conventional detectors, which can be addressed with CO sensors, is nuisance alarms since they react to cooking smoke, steam and dust. CO sensors will only react to CO. This is likely to reduce the number of nuisance alarms substantially.

One of the counter-arguments against using CO sensors to detect fires has been their short service life. However, in recent years the technology has matured, and several manufacturers now ensure a 10 year service life for their products. This is the same lifespan claimed by manufacturers of photoelectric smoke detectors, as well as the replacement time recommended by the Norwegian authorities. Another counter-argument is that CO sensors are more expensive than conventional photoelectric smoke detectors. Anecdotal evidence suggests that stand-alone CO sensors (without smoke detection) cost 3-4 times a conventional photoelectric detector, whereas the more sophisicated detectors are 10 times the price. It is necessary to conduct a cost benefit analysis to see if the increased costs can be justified by the increased level of safety. However, it is likely that the price for such detectors (with CO sensors) will decrease as the technology matures and more manufacturers enter the market and the competition increases.

The CO measurements in this study demonstrated an even distribution of CO in the room. This indicates that in the case of smouldering fires in rooms with low degree of ventilation, the placement of the CO sensor is of minor importance. However, in flaming fires, there is a lower degree of CO production than in smouldering fires. There is also higher thermal buoyancy which may lead smoke particles to the smoke detector quicker than the CO molecules diffusing throughout the room, especially in larger rooms. Hence, smoke detectors, irrelevant of technology, should be installed in the ceiling, as is currently the case.

CONCLUSIONS

In this specific test setup, combination detectors that included CO sensors have proved able to detect and warn about an ongoing smouldering fire several hours before conventional smoke alarms. It was also shown that the CO doses a sleeping person would be exposed to in the time period before detection by the combination detectors were sub-toxic. For comparison; in four out of six valid tests, the CO doses had exceeded ID_{50} by the time the photoelectric detectors alarmed. By utilizing CO detection technology in fire detection, one may decrease time to detection and hence increase chance for egress and survival.

ACKNOWLEDGEMENTS

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