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Smoke Production and Detection

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Abstract

The smoke production from various packaging materials and electrical appliances during smouldering combustion was measured in the cone calorimeter. In addition test were performed in the EN54 room to study the sensitivity of smoke detectors to some of these fires. The experiments were simulated using Sofie. Different common ventilation systems are also discussed briefly.

Key words: smoke detection, smoke production, sensitivity of detectors, ventilation

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Preface

This report presents the results from the BRANDFORSK project "Early detection in rooms with high ceilings" nr 622-001. The BRANDFORSK sponsorship is gratefully acknowledged.

Siemens Building Technologies, Cerberus division supported the tests with detectors and other equipment. Jan Blomqvist actively took part in the tests and was assisted by Thomas Holmqvist for installation and commissioning of the detection system.

Jerker Lykke ABB Contracting gave valuable information on ventilation systems used in industries and provided us with drawings of ventilation systems. Morten Avlund and Erik Lohse, Delta are acknowledged for lending equipment and their help during the tests performed at Delta Electronics in Denmark. Lars Pettersson is acknowledged for conducting the cone calorimeter tests.

Sammanfattning

I detta delprojekt har rökproduktionen från en del förpacknings- och el-material mätts. Mätningarna utfördes i konkalorimetern. Rökproduktionen mättes med brandvärldens vanliga HeNe-laser och detektorvärldens MIREX. Tyvärr gick det inte att montera MIREXen på samma ställe på rökgaskanalen från konen som HeNe-lasern sitter utan den fick monteras en bit bort. Resultaten gav att rökproduktionen mätt med MIREXen var högre än mätt med HeNe lasern, detta stämmer inte överens med teorin. Ytterligare mätningar gjordes därför med en annan laser på MIREXens plats. Dessa gav också högre värde än den vanliga lasern, vilket visar att mätt rökproduktion antagligen beror på var man mäter denna. Detta kommer att undersökas närmre i det andra projektet.

Olika detektorers känslighet mot några av bränderna i första delen och en rökgenerator mättes i ett EN54 rum. Detektorerna löste ut i förväntad ordning dvs. de känsligaste först. I några fall löste alla ut medan i andra endast en del av detektorerna. Dessutom mättes rökproduktionen med en laser och SICK (SICK använder samma våglängd som MIREX). Dessa resultat stämde överens med teorin dvs. rök mätt med SICK var lägre än mätt med lasern. I detta fall mättes röken på samma radiella avstånd från branden. Någon ytterligare utvärdering av skillnaden mellan SICK/MIREX och laser gjordes inte i dagsläget på grund av resultatet i första delen. Dock ser man att skillnaden mellan rök vid de olika våglängderna beror på vilket material det är. Skillnaden var i storleksordningen 2 för rökgeneratorn medan det för plastmaterialen inte var någon större skillnad.

Olika ventilationssystem diskuteras kort. Det finns i princip två olika ventilationstyper, total omrörning samt deplacerande. Den deplacerande har en ganska kraftig temperaturgradient i rummet som antagligen kan ställa till problem. System med total omrörning har ofta små dysor med hög lufthastighet för att skapa omrörningen som kan ställa till problem. Båda typerna har ofta en död volym längst uppe vid tak som ej deltar i ventilationen.

I det fortsatta projektet är det tänkt att fullskaleförsök ska göras i två olika lokaler med olika ventilationstyper. Därefter görs parameterstudie med CFD.

1 Introduction

Early detection in rooms with ventilation and/or high ceilings is a difficult task. A rough estimate of how severe a fire must be in order to take control of the airflow pattern in the room is given in refernces 1 and 2. This estimate results in fires in the order of a MegaWatts (MW). A one MW fire causes severe damage in many cases and therefore smoke detectors should be placed at locations where the smoke reaches the detector at an early stage in the fire. In order to calculate when a detector will be activated one should know the smoke production from the fire. Further, we need to know how the smoke is transported and the sensitivity of the detector.

Fires in electrical equipment and packaging materials are relatively common in industries. The smoke production from these are usually not known, especially when in the beginning of the fire with smouldering combustion. There is data available in the literature[3] on smoke production from mainly pure fuels and usually from flaming combustion.

Smoke detectors are tested according to EN54[4]. In these test the detectors are tested against certain test fires and the smoke density together with an ionisation current is measured during the test. Publicly available test results on smoke detectors against other fires are very scarce.

Usually when doing smoke spread calculations a uniform temperature profile in the room is assumed together with no airflow before the fire starts. This is not the case in the reality, in rooms with high ceiling there is usually a significant temperature gradient and the air flow in the room can be rather large due to the ventilation system. There is also the problem of other heating sources in the room that causes airflows. These problems cannot be modelled in, for instance, two zone models. In general they require CFD type of simulations. Only a very limited number of simulations[2] of this kind have been published.

This report gives the results from the project "Early detection in rooms with high ceilings"-part1. This part was divided into three work packages. In the first work package the smoke production from some packaging materials and electrical equipment was measured in the cone calorimeter. The second work package included tests with some of the fires from work package 1 in a EN54 test room, in addition a CFD simulation was made of the experiments. Different types of ventilation systems were studied in work package three. No thorough analysis is made on the result since that is not within the scope of part 1. This will be included in part 2 of the project.

2 Smoke produced by smouldering package materials and electrical equipment

The smoke production from various "fires" of package materials and electrical equipment was measured in the cone calorimeter using both the conventional cone calorimeter HeNe laser and the MIREX. Materials tested included storage materials (a blue PE-box and corrugated cardboard) and electrical products (lighters for fluorescent lamps, extension cord with extra plug holes and cables). In addition the same measurements were performed for the fire denoted “TF2” in the table. In all 27 tests were conducted, which are listed in table 1. In the experiments, the material was mounted in the cone calorimeter sample holder, and the holder was placed in the cone calorimeter with the radiation shield, the measurements were started and after 30 s of pre-measuring time then the radiation shield was removed.

Table 1. Cone calorimeter tests.

File and testname	Material	Radiation	Spark igniter on	Ignition	comments
Pe1	Blue PE-box	20 kW/m²	No	No	Igniter on after 20 minutes
Pe2	Blue PE-box	20 kW/m²	No	No	
Pe3	Blue PE-box	20 kW/m²	No	No	Material melted down into the sample holder
Pe4	Blue PE-box	20 kW/m²	Yes	187 + 30s	Flashed a couple of times before ignition
Paper1	Corrugated cardboard	20 kW/m²	No	93 + 30 s	No weight measurement
Paper2	Corrugated cardboard	8.5 kW/m²	No	No	Wrong radiation level
Paper3	Corrugated cardboard	12 kW/m²	No	No	Glowing without smoke at end of test
Paper4	Corrugated cardboard	12 kW/m²	No	No	1 minute pre-measuring time
Paper5	Corrugated cardboard	12 kW/m²	No	No	
Lighter1	2 Lighters for florescent lamp	20 kW/m²	No	No	
Lighter2	2 Lighters for florescent lamp	20 kW/m²	No	No	Plastic harder than in previous test
Lighter3	Lighter for florescent lamp, one a "safety lighter"	20 kW/m²	No	No	
Safe1	2 Safety lighters for florescent lamp	20 kW/m²	No	No	
Gren1	Extra plug hole	20 kW/m²	No	1815 + 30 s	Spark added after 1830 s
Gren2	Extra plug hole	20 kW/m²	No	1238 + 30 s	Spark added after 1230 s
Gren3	Extra plug hole	20 kW/m²	No	907 + 30	Spark added after 930 s
Cable1	Ball of white single conductor	20 kW/m²	After 930 s	No	
Cable2	White single conductor mounted according to FIPEC configuration	20 kW/m²	No	No	
Cable3	White single conductor mounted according to FIPEC configuration	30 kW/m²	No	50 + 30s	

File and testname	Material	Radiation	Spark igniter on	Ignition	comments
Cable4	White single conductor	No radiation, the cable was heated from within by a to high current. Level 4.4 V	No	No	Increased to 4.5 V after 800 s
Cable 5	Red single conductor	No radiation, the cable was heated from within by a to high current. Level 6.3 V	No	No	Increased to 7.7 V after 4 minutes
Cable 6	Three conductor	No radiation, the cable was heated from within by a to high current. Level 5.5 V	No	No	Voltage switched off after 290 s
Cable7	Three conductor, mounted according to FIPEC configuration	25 kW/m²	No	755 + 30 s	Increased to 35 kW after 730 s
Foam1	madras	20 kW/m²	No		Spark added at 182 + 30 s. Radiation increased to 35 kW at 330 s.
Wood1	Particle board	35 kW/m²	No	74 + 30	
TF2a	TF2	No radiation, TF2 fire	No	730	No weight measurement
TF2b	TF2	No radiation, TF2 fire	No	735	No weight measurement

In figure 1 the Maximum extinction coefficient obtained with the HeNe laser for each of the experiments is presented together with the maximum extinction coefficient divided by the mass loss. The extinction coefficient k is calculated as $1/L*\ln(I_0/I)$ where L is the pathlength, I_0 is the intensity without smoke and I intensity with smoke. Due to the low mass loss rate there is a large uncertainty in the extinction coefficient per mass lost. Still one can identify that the smoke production is larger per gram consumed under non-flaming conditions.

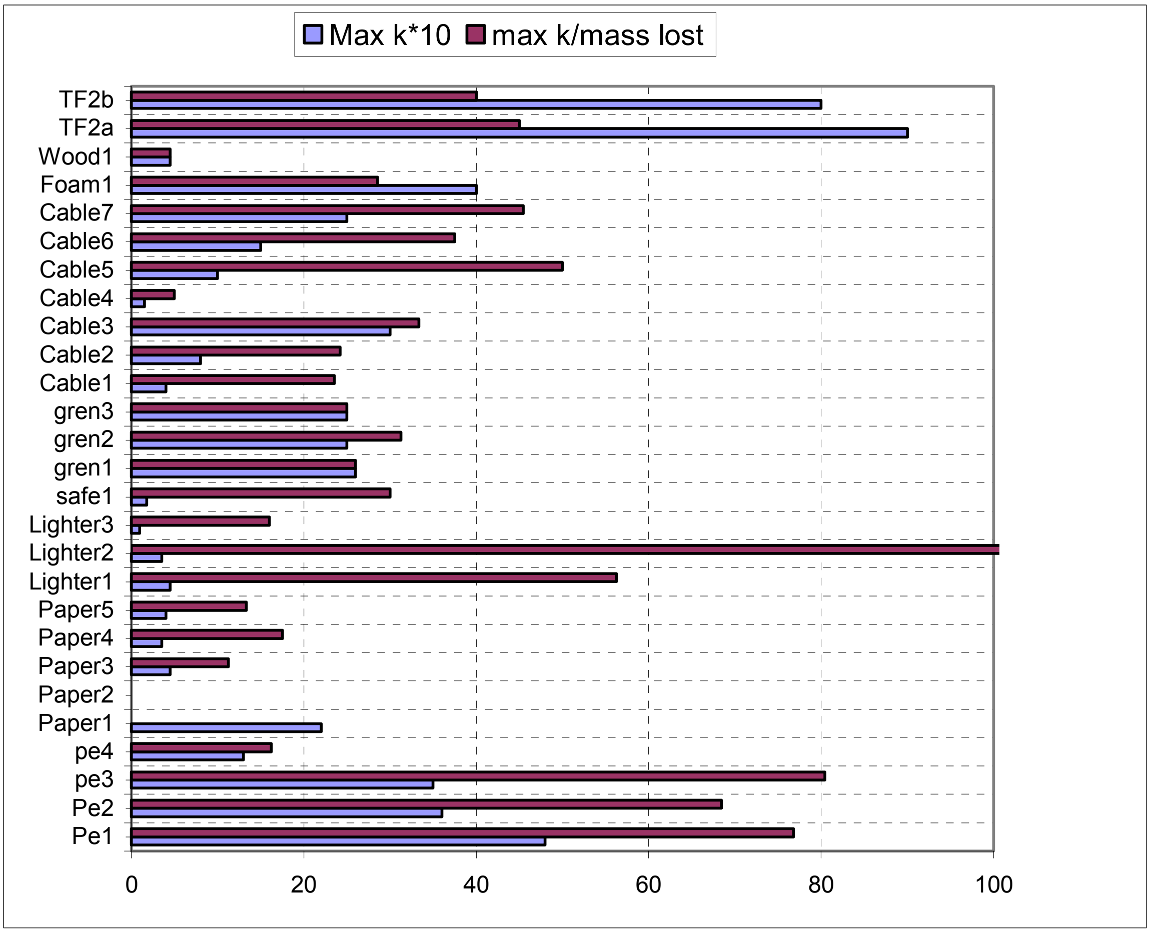

Figure 1 Maximum extinction coefficient times 10 and maximum extinction coefficient divided by mass lost (g/s).

Due to the large diameter of the MIREX beam (i.e. 4 cm) it was not possible to mount the MIREX close to the cone calorimeter measurement but the MIREX was mounted in a larger duct after the principle cone calorimeter duct. Therefore one cannot compare the extinction coefficient obtained by the MIREX and the HeNe laser directly. Instead one has to compare the Smoke Production Rate, SPR. SPR is calculated as the extinction coefficient k times the volumetric flow. A comparison is made between the two different measurements in figures 2-28 below.

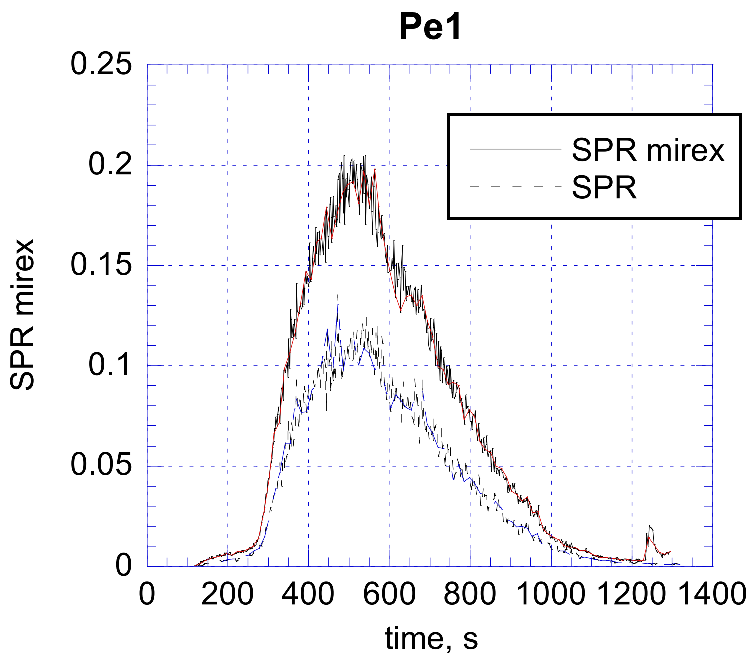

Figure 2 Comparison of SPR obtained by the MIREX and the cone calorimeter for test PE1.

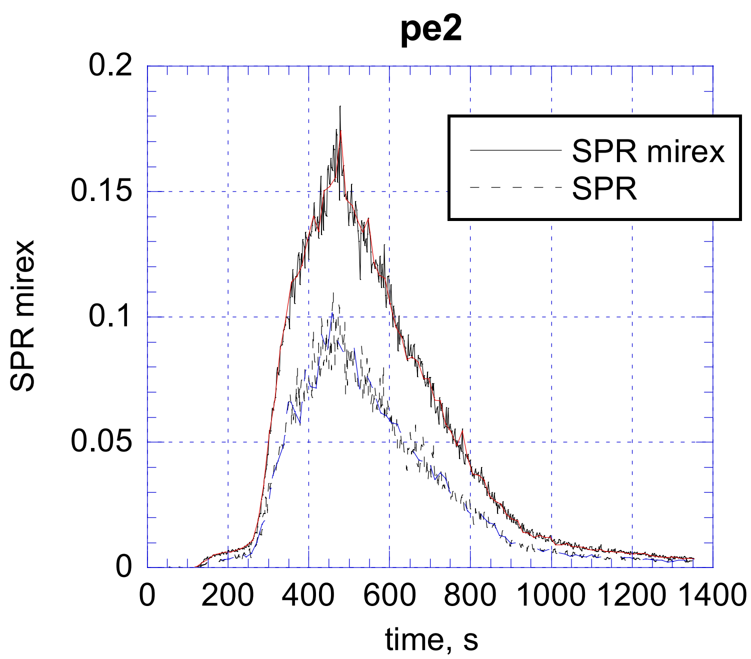

Figure 3 Comparison of SPR obtained by the MIREX and the cone calorimeter for test PE2.

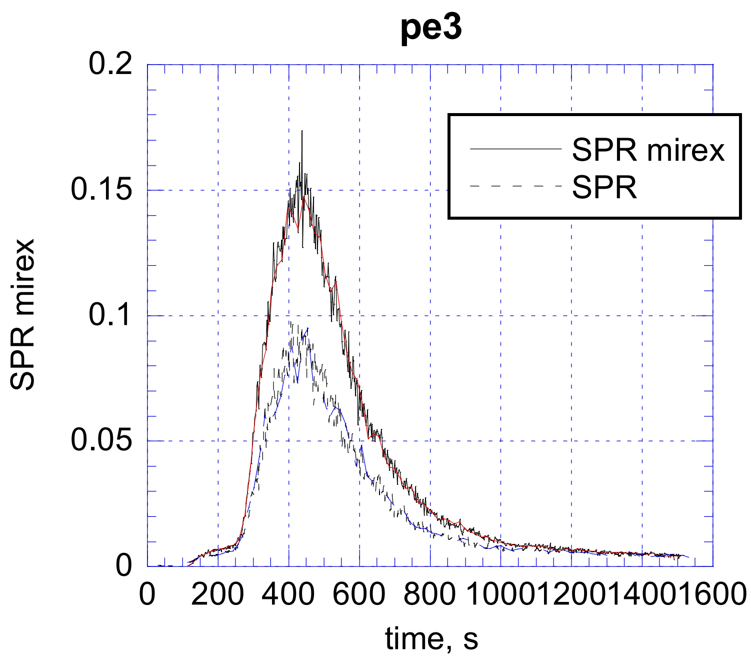

Figure 4 Comparison of SPR obtained by the MIREX and the cone calorimeter for test PE3.

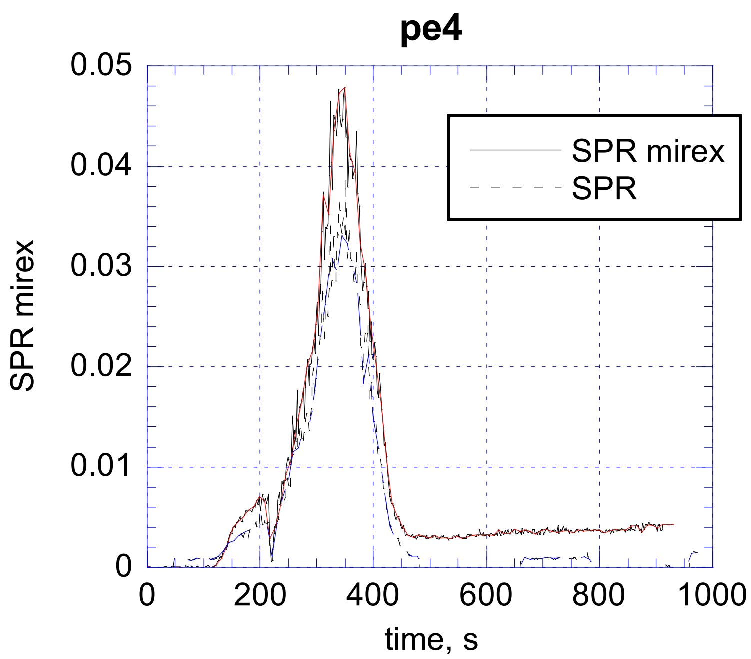

Figure 5 Comparison of SPR obtained by the MIREX and the cone calorimeter for test PE4.

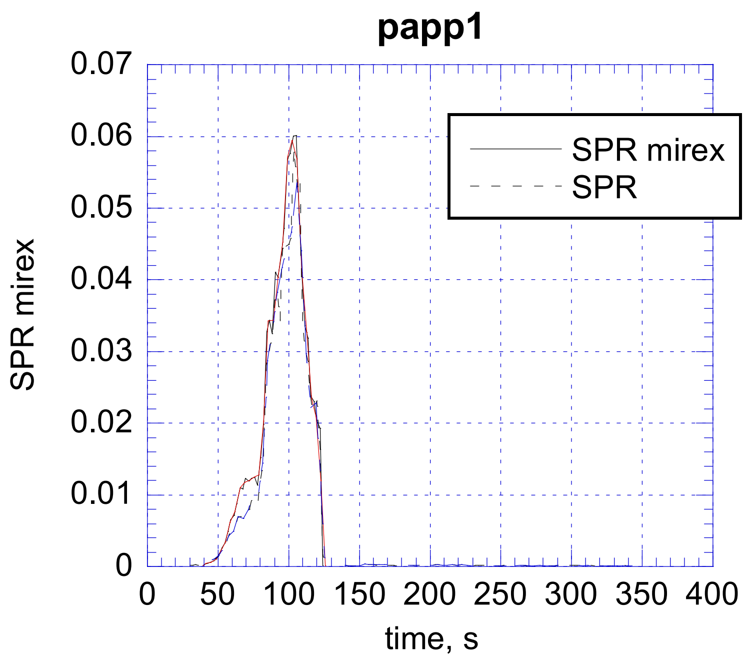

Figure 6 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Paper1.

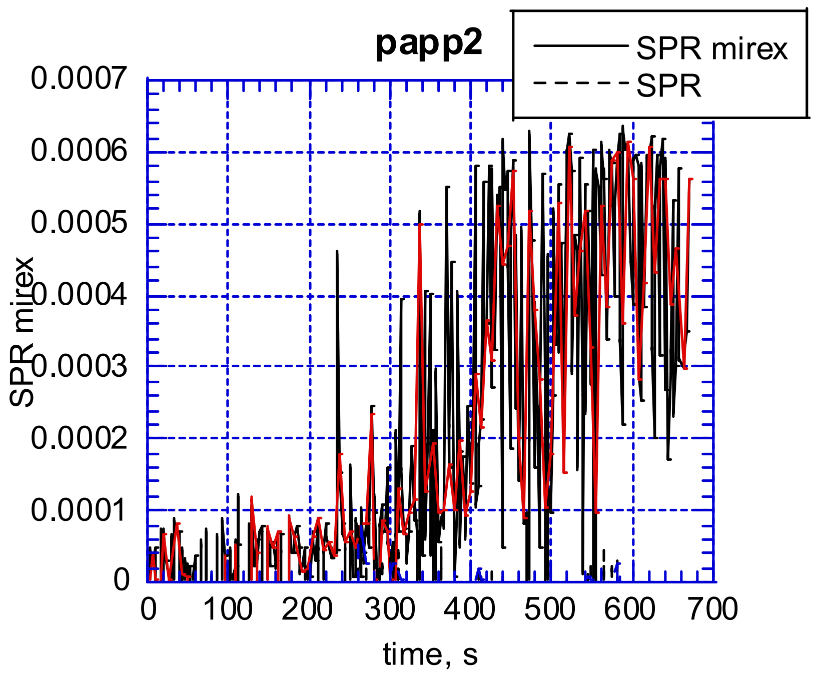

Figure 7 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Paper2.

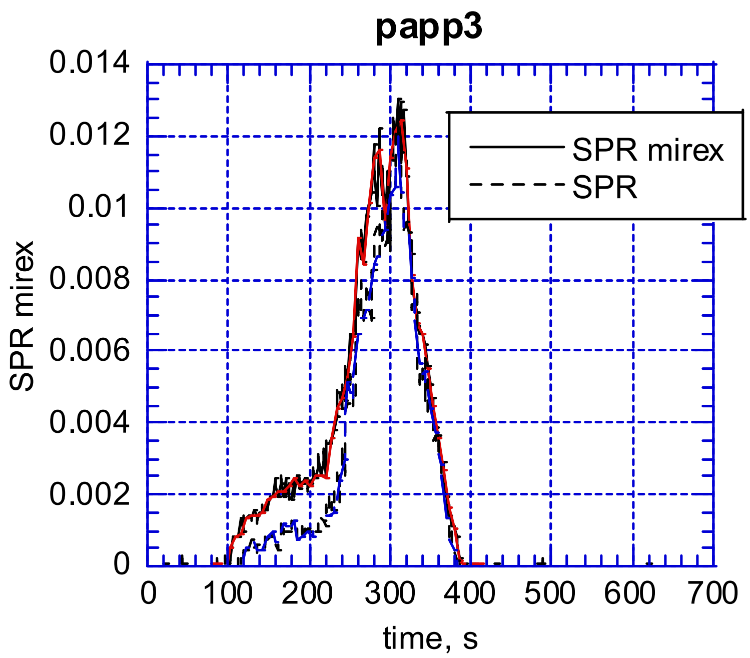

Figure 8 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Paper3.

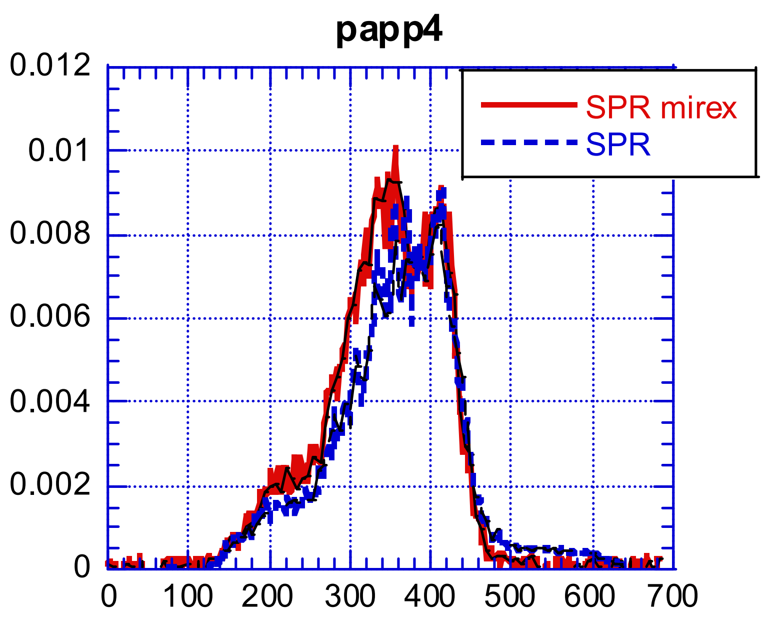

Figure 9 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Paper4.

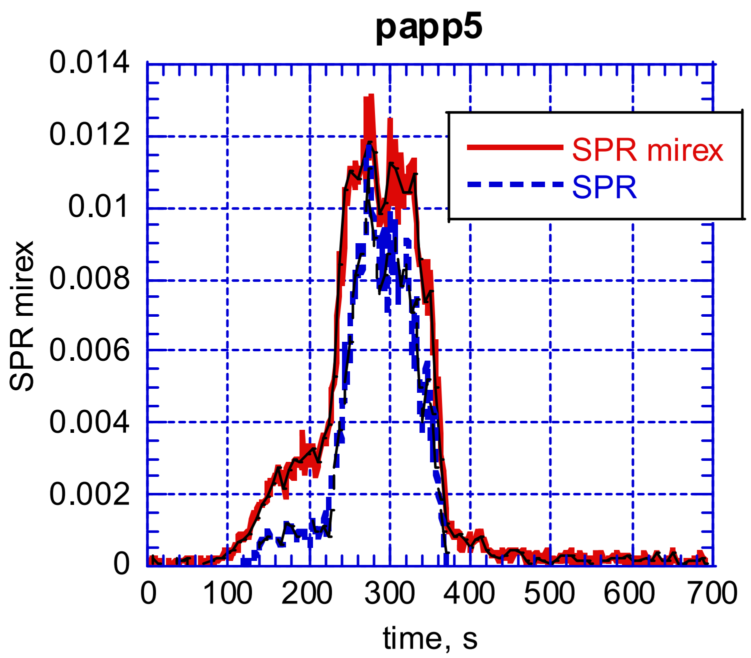

Figure 10. Comparison of SPR obtained by the MIREX and the cone calorimeter for test Paper5.

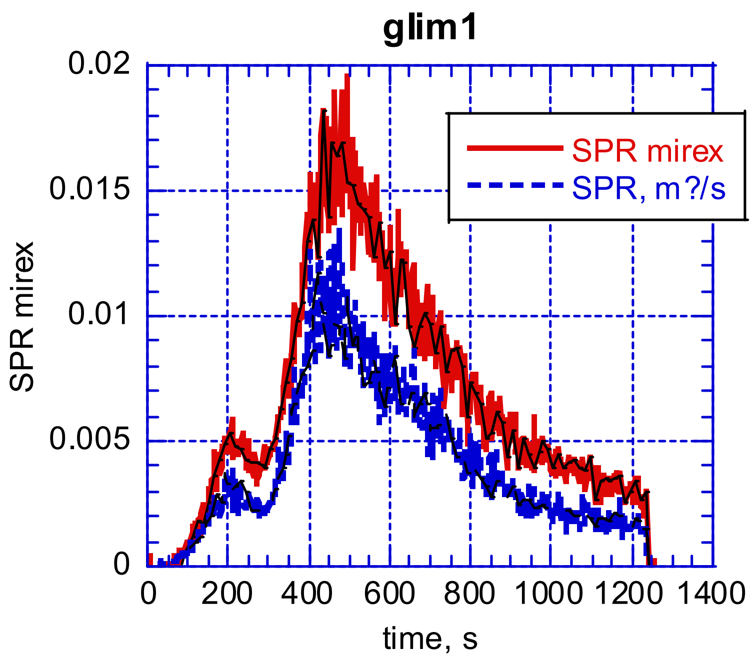

Figure 11 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Lighter1.

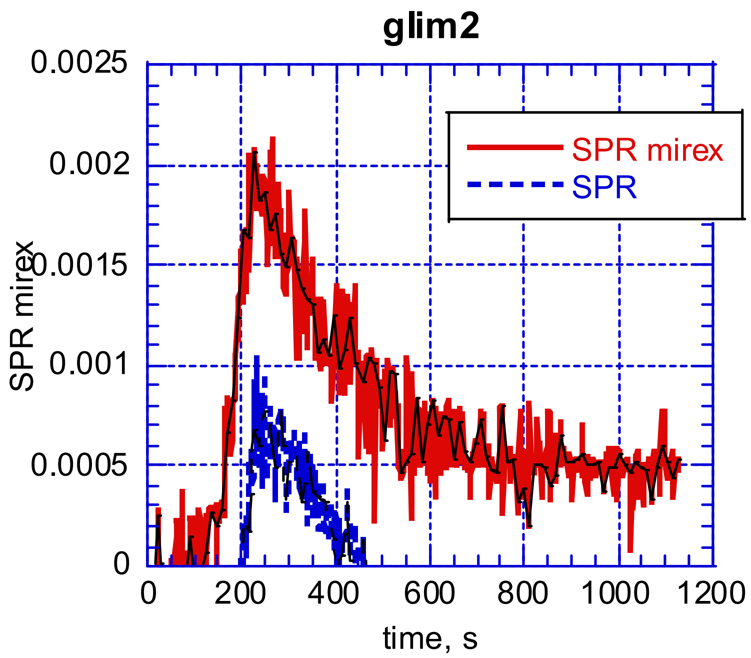

Figure 12 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Lighter2.

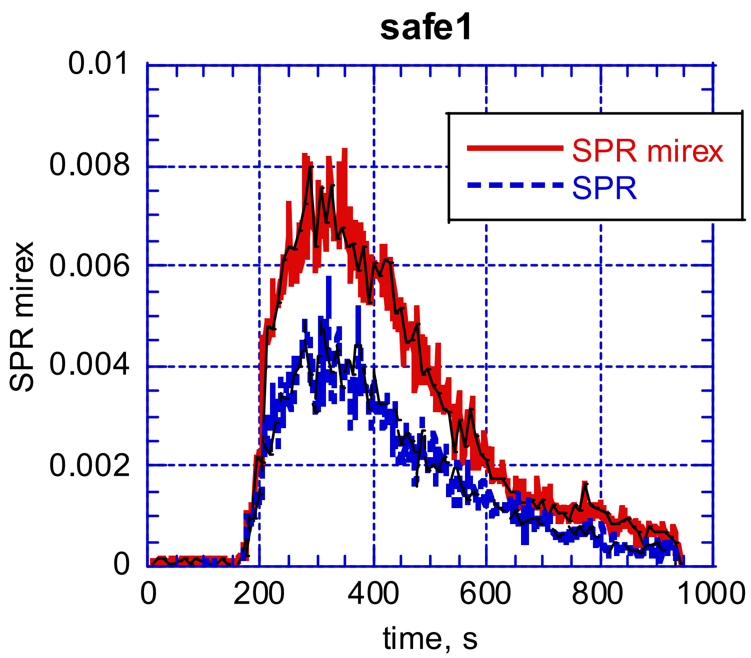

Figure 13 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Safe1.

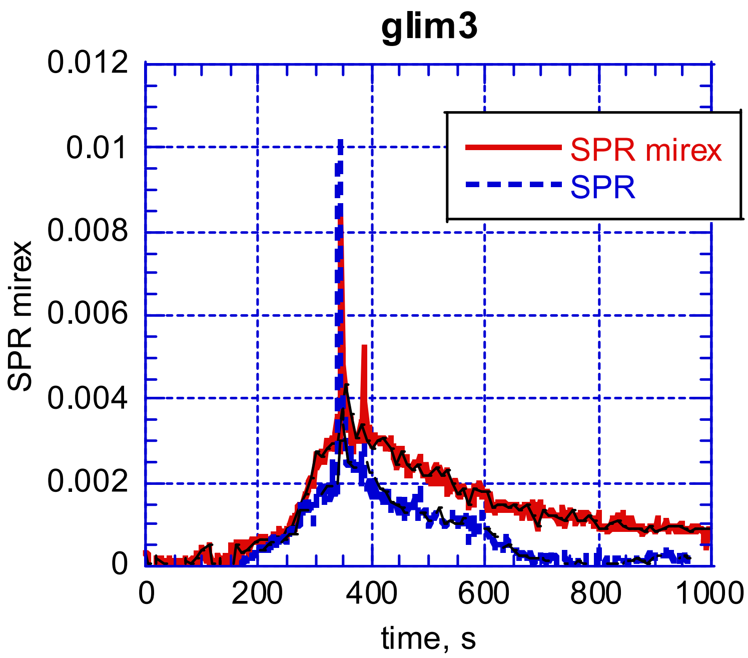

Figure 14 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Lighter3.

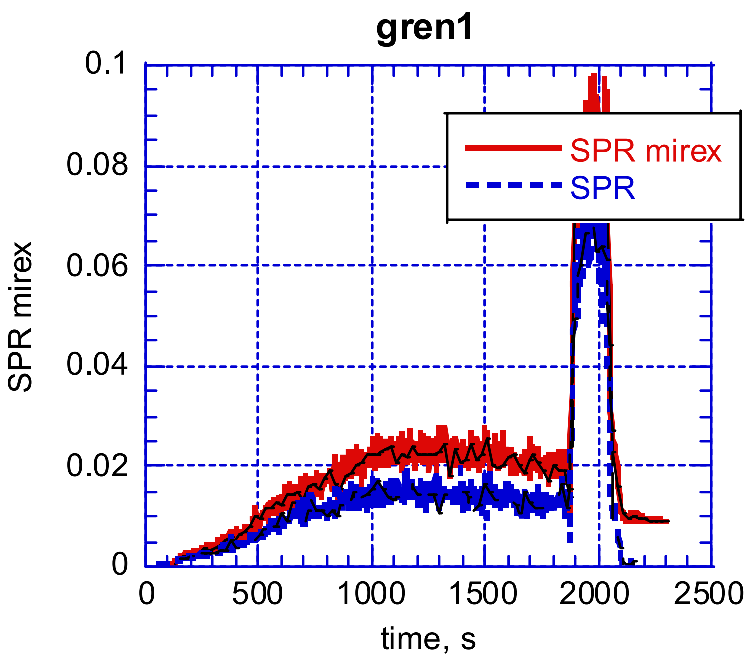

Figure 15 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Gren1.

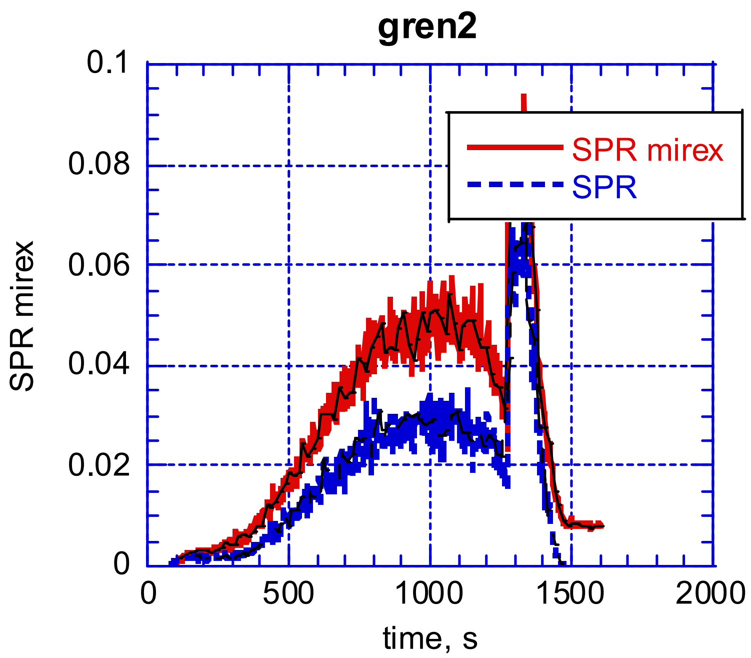

Figure 16 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Gren2.

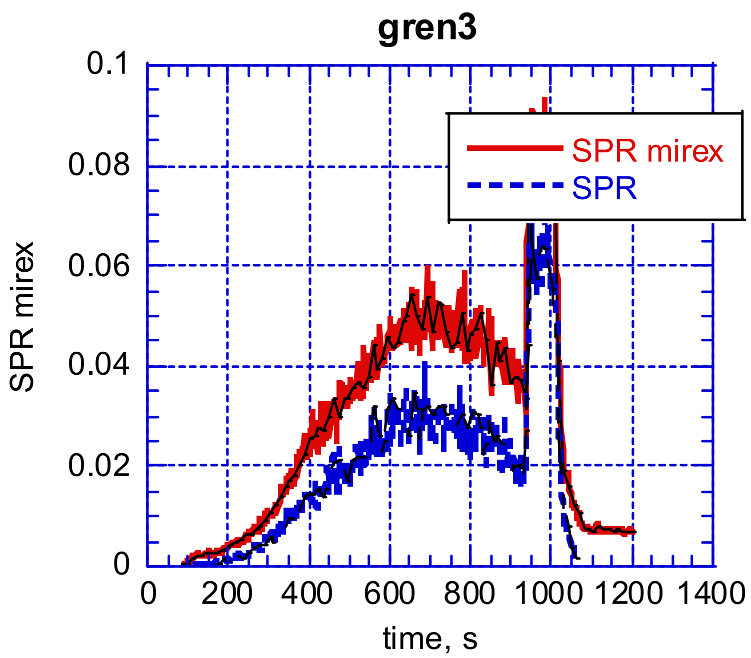

Figure 17 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Gren3.

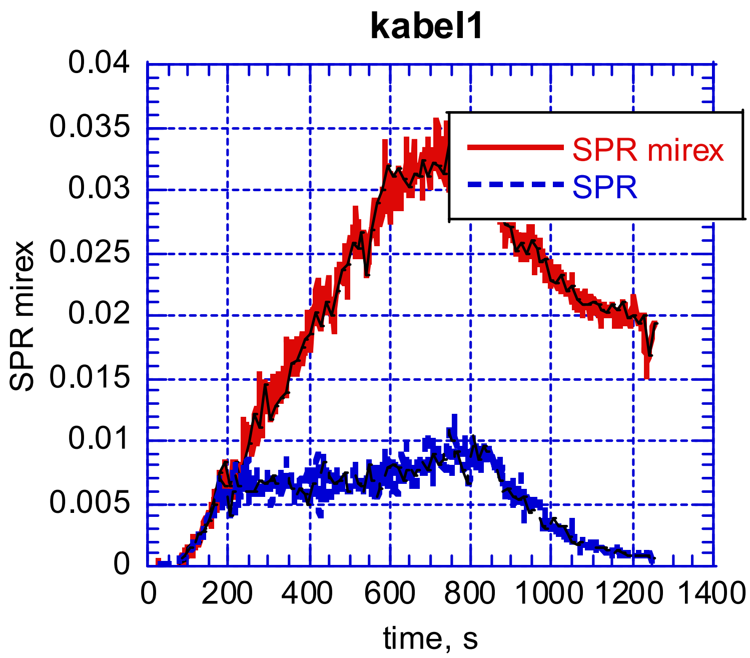

Figure 18 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Cable1.

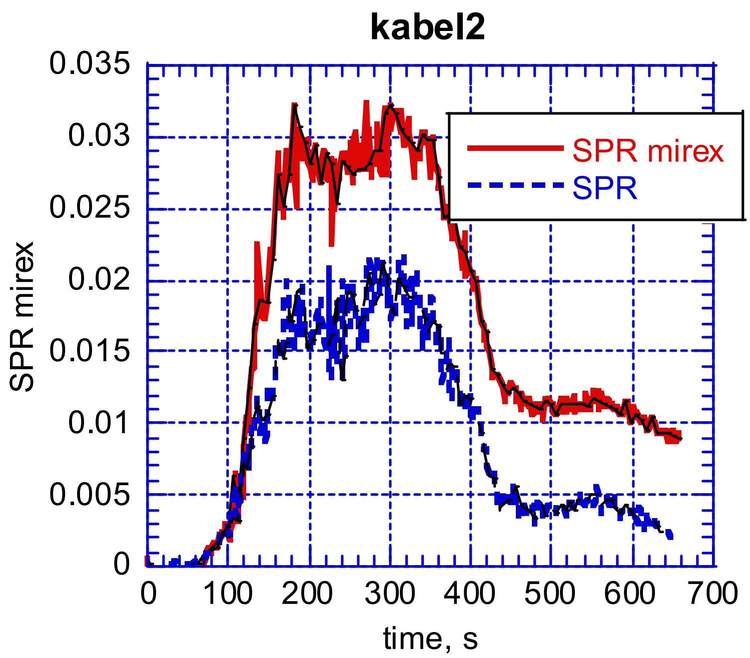

Figure 19 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Cable2.

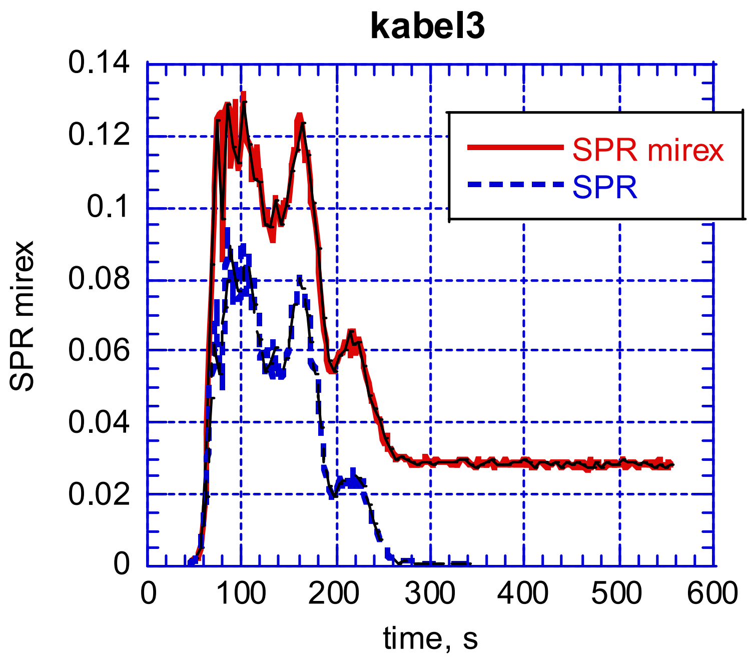

Figure 20 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Cable3.

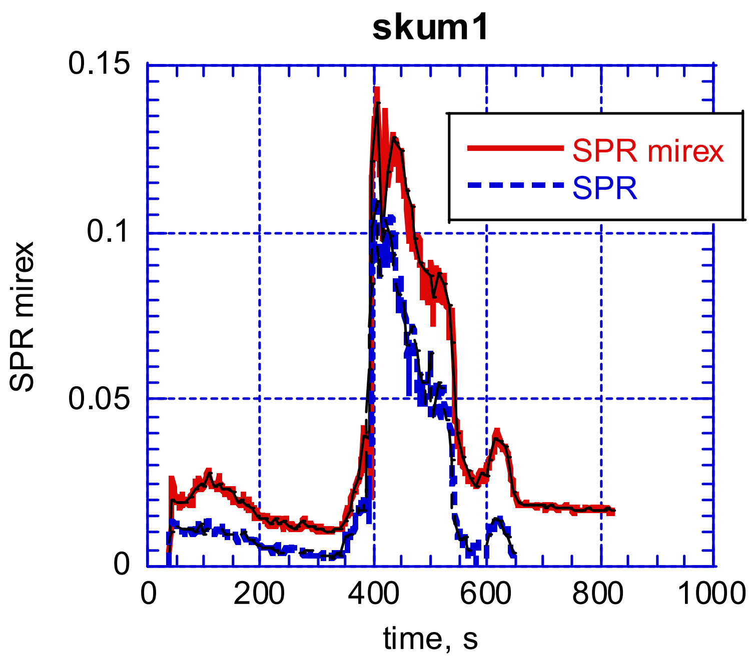

Figure 21 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Foam1.

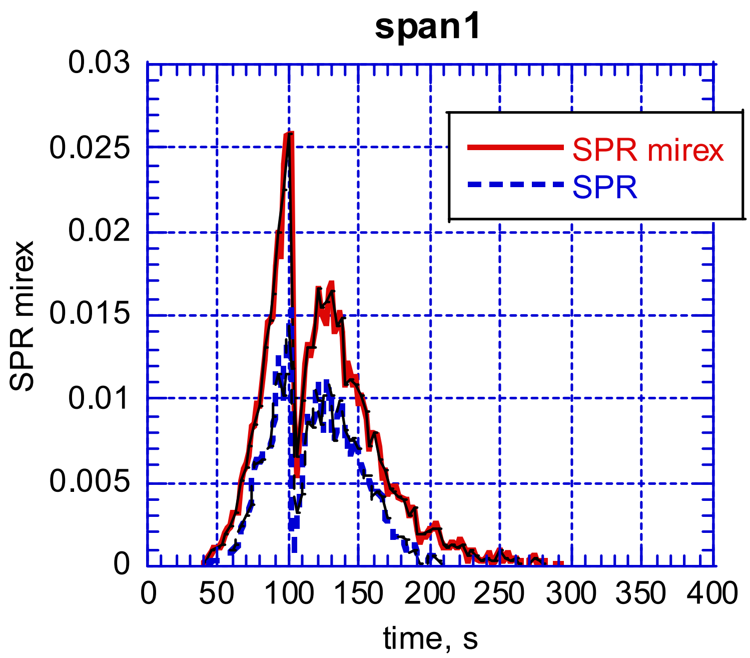

Figure 22 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Wood1.

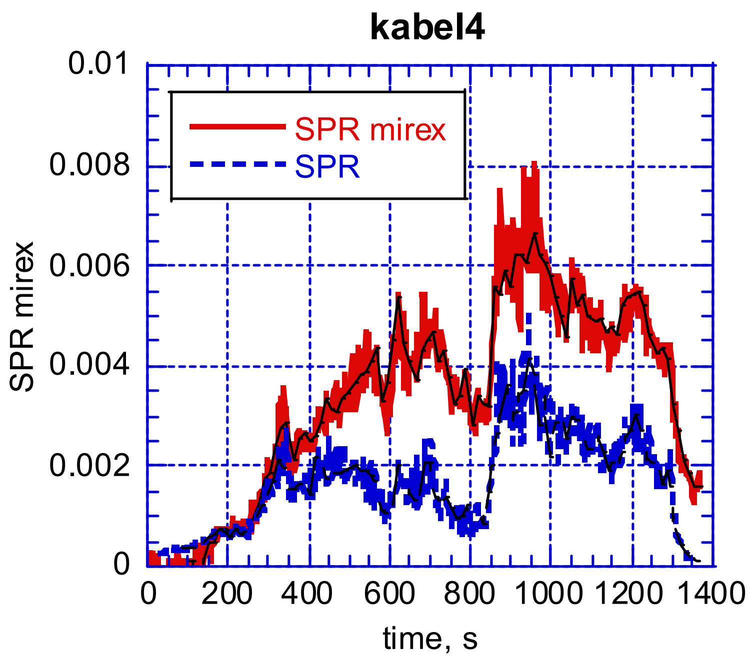

Figure 23 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Cable4.

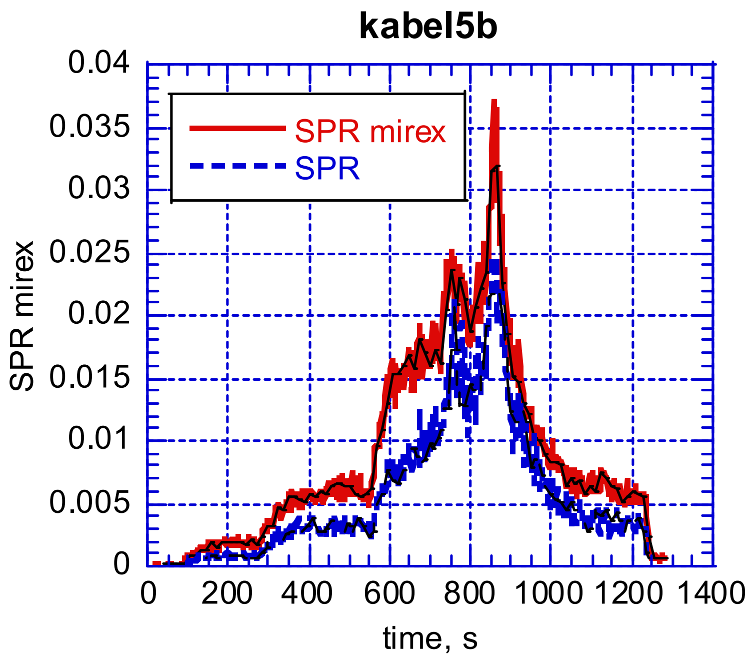

Figure 24 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Cable5.

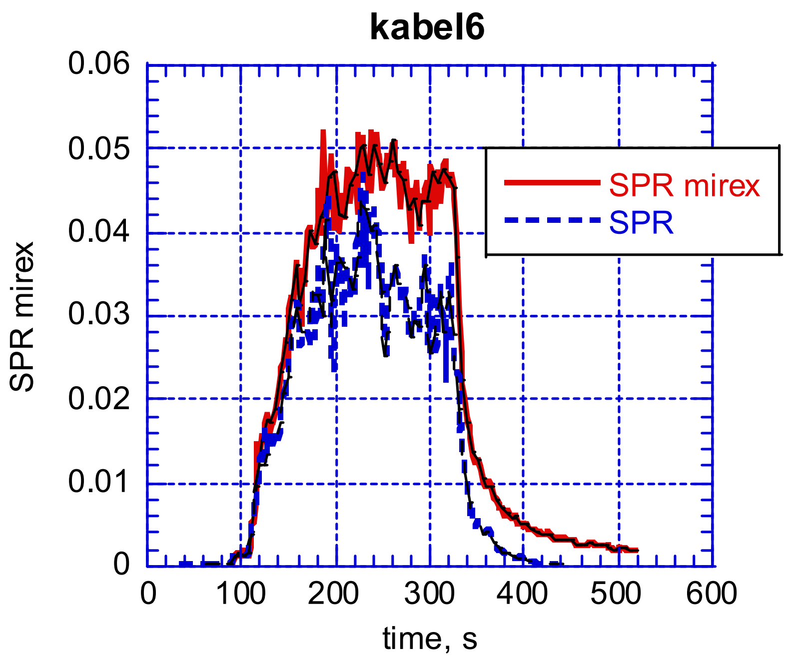

Figure 25 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Cable6.

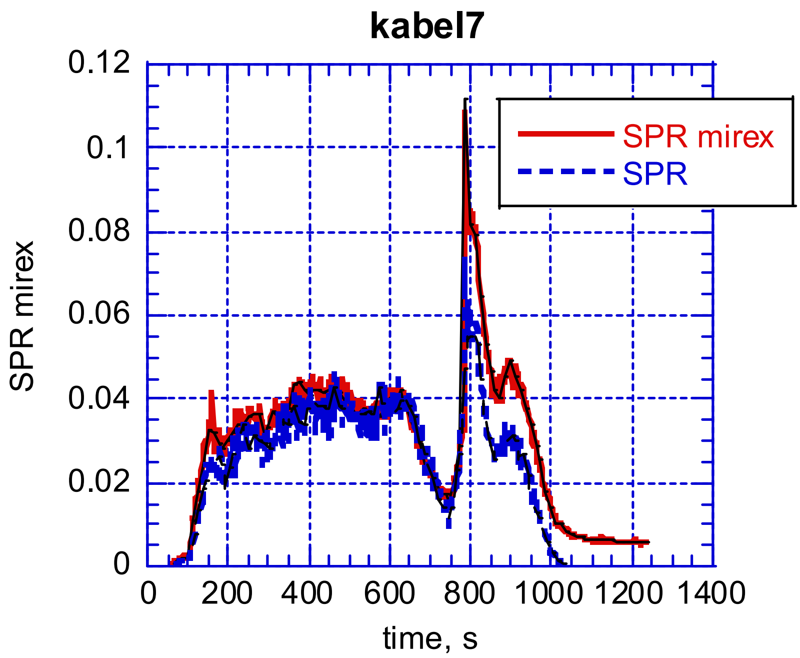

Figure 26 Comparison of SPR obtained by the MIREX and the cone calorimeter for test Cable7.

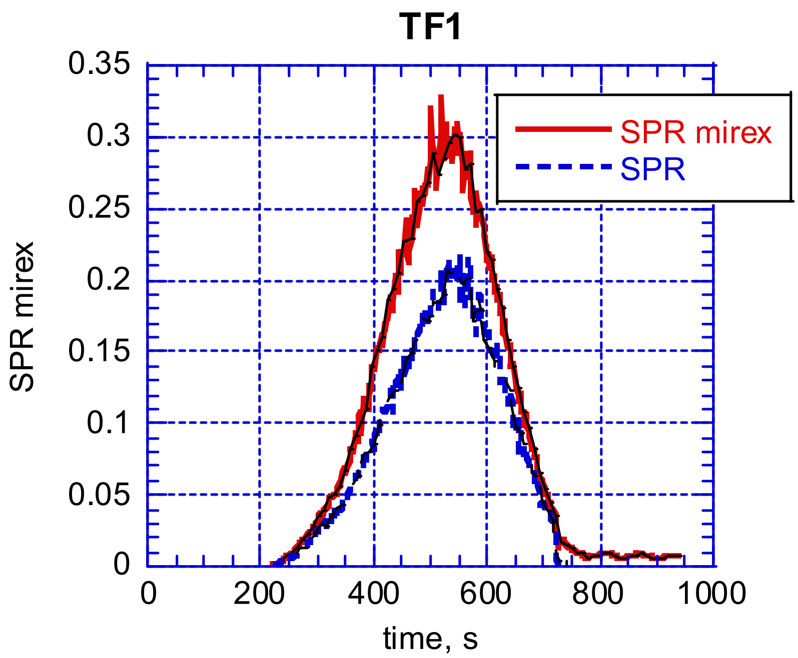

Figure 27 Comparison of SPR obtained by the MIREX and the cone calorimeter for test TF2a.

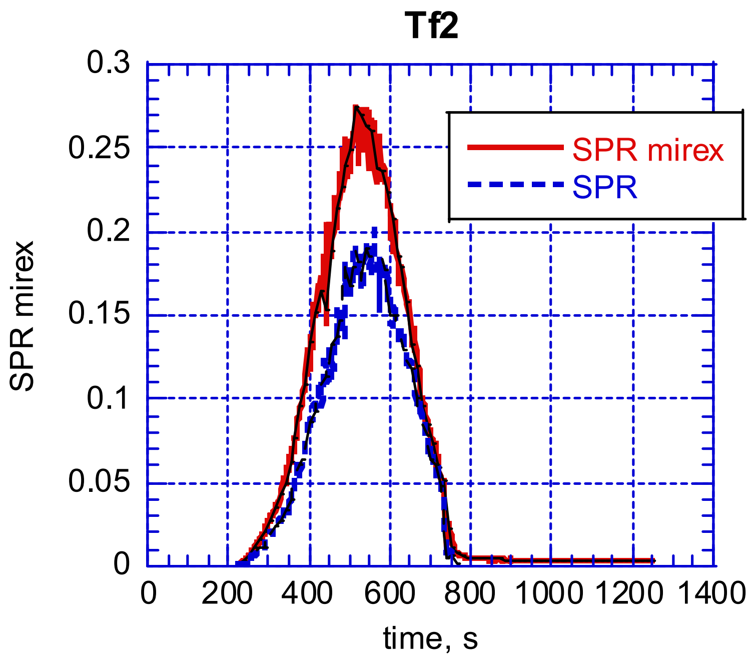

Figure 28 Comparison of SPR obtained by the MIREX and the cone calorimeter for test TF2b.

Some investigators have studied the smoke density or production measured using different wavelengths, however none of these provide an answer to how the smoke density varies relative to the measuring wavelength. The results from Coppa and La Malfa[5] are difficult to interpret since the measurements with the different wavelengths were not performed at the same time. Tewarson[3] has reported single values for smoke production measured at three different wavelengths, however the results from Andersson[2] indicate that the ratio between the smoke density measured at the different wavelengths varies during the fire scenario.

In this investigation, the SPR measured with the MIREX was higher than the SPR measured with the HeNe laser. According to theory[6] and other investigators[2,5,3] it should be the other way around. Therefore an additional measurement was performed using a 670 nm diode laser at the MIREX measuring point. This extra measurement indicated that the SPR measured at the MIREX measuring point was higher than at the HeNe-laser measuring point. The uncertainty of this measurement was however high and therefore this measurement is not reported here, but additional measurements will be performed in other projects in order to clarify this issue.

3 Smoke Detector sensitivity

Smoke detectors are usually tested against the EN54 standard[4]. According to the standard the detector are tested against 5 different test fires. Data on detectors performance against other fires is, however, not publicly available.

In this project different types of detectors were tested in an EN54 room against some of the fires tested in the cone calorimeter and against a SG3000 smoke generator. The detectors tested were supplied and mounted by Siemens Cerberus according to the EN54 standard, i.e. the detectors were mounted 3 m from the fire circle with 20 cm between each detector. The MIC and the detectors were placed on a 3 m radius from the centre. The distance between each detector was 20 cm and the distance between the MIC and detector 1 and 2 was 30 cm. The SICK was placed 3.35 m from the centre. The Line detector was placed 2.5 m from the centre of the room with 8 m between detector and reflector. The placement of the detectors is indicated in figure 29 below. The detectors and sensitivity settings used are listed in table 2 below. In all 17 tests were performed as listed in table 3 below. The sensitivities and types of the detectors were chosen to represent typical sensitive detectors used in industries today.

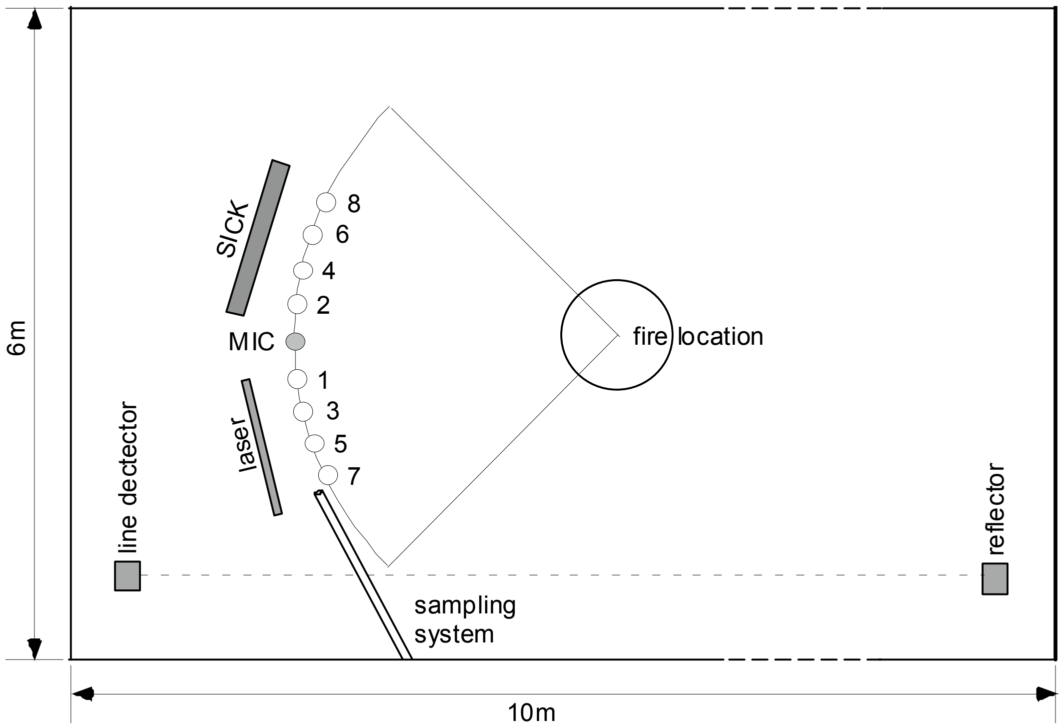

Figure 29 Placement of detectors in the EN54 room at Delta Electronics.

Table 2 Detectors used for the tests.

Position (in Fig 29)	Detector and setting	Nominal aerosol density at alarm (EN54-7 smoke tunnel test)	Meets EN54-7	Comment
1	DOT1151A, APS007	m = 3 %/m	Yes	Multisensor detector, optical smoke and heat.
2	DOT1151A, APS006	m = 6 %/m	Yes	Multisensor detector, optical smoke and heat.
3	DO1151A, APS006	m = 3 %/m	Yes	Optical smoke detector
4	DO1151A, APS005	m = 3 %/m	Yes	Optical smoke detector (slower signal evaluation than APS006)
5	DO1151A, APS007	m = 1.5 %/m	Yes	Optical smoke detector
6	F910, Sens 1 (-), small smoke entry,short integration)	y = 1.3	Yes	Ionisation smoke detector
7	DO1153A, APS072SH	m = 0.5 %/m		Optical detector, normal use in air sampling systems
8	F910, Sens 2, big smoke entry, short integration	y = 0.9	Yes	Ionisation smoke detector
Beam	DLO1191, alarm at 50% obscuration			Optical beam detector operated at a medium sensitivity
Sampling	DO1161A (in a Titanus 3000, setting for full scale 0.25%/m),	m = 0.25 %/m (at full scale)		The three different alarm levels are at 33, 66 and 100% of full scale.

Table 3 Tests performed in the EN54 room

Filename	Fire	Comments
SG30001	Smoke generator SG3000	
SG30002	Smoke generator SG3000	
SG30003	Smoke generator SG3000	Detector6 and 8 were not reset before start of test
SG30004	Smoke generator SG3000	
Paper1	Corrugated cardboard in portable cone, 12 kW/m²	Flashed at end
Paper2	Corrugated cardboard in portable cone, 12 kW/m²	No CO/CO_2 measurement
Paper3	2 pieces of corrugated cardboard, 12 kW/m²	
Gren1	Extra plug hole in cone, 20 kW/m²	
Gren2	Extra plug hole in cone, 20 kW/m², but distnce between material and cone changed so therefore the radiation is higher	Radiation start 20 s after measurement start
Cotton	TF3	
Paper4	Corrugated cardboard in portable cone, 20 kW/m², two pieces of paper	Radiation start 14 s after measuring start. Did not ignite. Probably problem with CO/CO_2 measurement
PE1	Blue PE-box 20 kW/m²	Radiation start 21 s after measurement start, some measurements were started after the radiation
PE2	Blue PE-box 20 kW/m²	Radiation start 17 s after measurement start. Probably problem with CO/CO_2 measurement. Steady burning after 2 min.
PE3	Blue PE-box 20 kW/m²	Radiation start 18 s after measurement start. Probably problem with CO/CO_2 measurement
Paper5	Corrugated Cardboard, 3 pieces. 20 kW/m² plus match	Fire start 30 s after measuring start
TF2a	TF2	No CO/CO_2 measurement
TF2b	TF2	Probably problem with CO/CO_2 measurement

The time to warning and alarm are presented in tables 4 and 5 below. Empty places means that no warning respectively alarm was registered during the experiment. For the sampling detector level 2 is used as warning and level 3 for alarm. The ionisation detectors at positions 6 and 8 only gave an alarm.

Table 4 Time to warning (s) from start of fire.

	sampling	detector7	line	detector5	detector3	detector1	detector2	detector4	detector8	detector6
gren1	113	146	236	196	226	270	282	270	NA	NA
gren2	178	362	566	494	578	590	694	596	NA	NA
PE1	149	224	292	288	324	336	354	356	NA	NA
PE2	189	232	248						NA	NA
PE3	204	230	306	312	332	332	366	360	NA	NA
TF2a	183	238	192	246	252	248	270	290	NA	NA
TF2b	172	218	174	220	230	220	234	250	NA	NA
Paper1	147	168		206	220	206			NA	NA
Paper2	149	220		232					NA	NA
Paper3	209	238	258	264	282	288	336	332	NA	NA
Paper4	89	94	104	102	114	120	122	144	NA	NA
cotton	82	136	58	146	132	140	160	204	NA	NA
SG3001	43	56	36	60	50	58	68	88	NA	NA
SG3002	51	62	14	68	62	66	58	90	NA	NA
SG3003	53	50	16	52	54	58	68	78	NA	NA
SG3004	50	58	22	60	66	68	74	90	NA	NA

Table 5 Time to alarm (s) from start of fire.

	sampling	line	detector7	detector5	detector1	detector3	detector6	detector2	detector4	detector8
gren1	123	250	154	198	272	264		288	292	296
gren2	221	602	412	542	622	594	1005	700	620	592
PE1	161	300	226	296	336	330		360	382	477
PE2	201		234							244
PE3	216	314	270	326	334	336		388	380	488
TF2a	195	200	242	244	248	252	359	272	314	315
TF2b	187	180	222	222	224	232	354	234	272	273
Paper1	157		174	214		230				
Paper2	165		224							
Paper3	224	272	242	268	288	282			356	342
Paper4	101		96	108	120	114		126	164	118
Cotton	92	94	134	146	140	130	167	168	224	144
SG3001	55	54	56	60	58	52	73	94	108	59
SG3002	64	54	62	66	64	60	69	68	112	52
SG3003	65	18	54	52	56	54		68	100	
SG3004	62	76	58	60	68	66	83	84	108	39

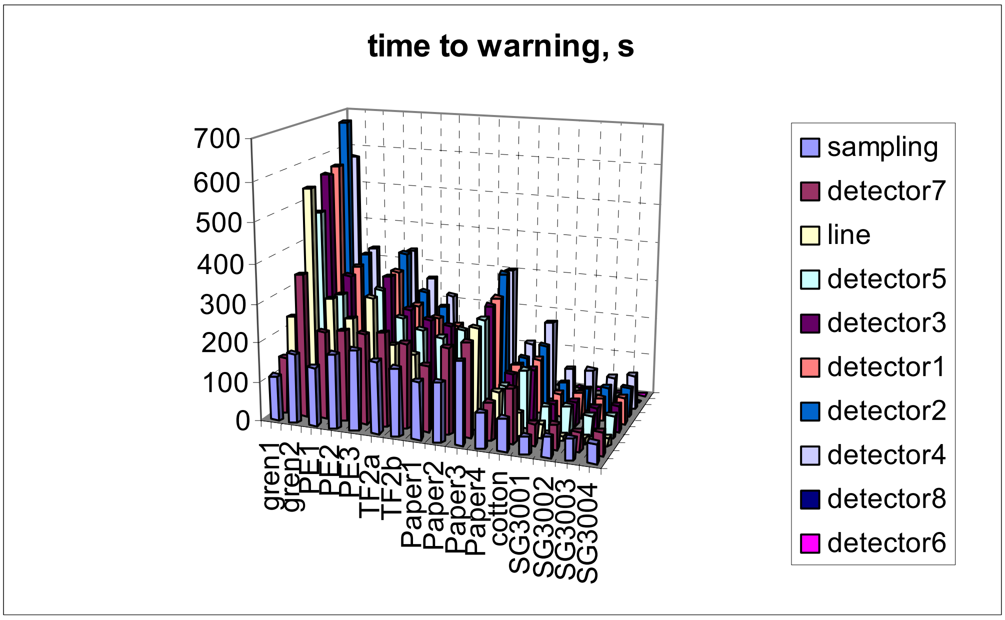

Figure 30 Time to warning for the different tests and detectors. For the ionisation detectors time to alarm was used as time to warning. For the sampling system the second level was used as time to warning.

In tables 6-8 below is the smoke obscuration m, dB/m and the parameter y at the time for warning presented. The parameter y is calculated as

$$y = \frac{i_0}{i} - \frac{i}{i_0}$$

where i_0 is the ionisation current without smoke and i the ionisation current with smoke. In table 9-11 the smoke obscuration and ionisation current are presented at time of alarm.

Table 6. Ionisation current y at the time of warning.

	sampling	detector7	line	detector5	detector3	detector1	detector2	detector4	detector8	detector6
gren1	0,14	,19	,45	,3	,42	,64	,61	,64	NA	NA
gren2	,08	,33	,64	,64	,73	,7	,79	,73	NA	NA
PE1	,1	,26	,28	,28	,37	,37	,5	,53	NA	NA
PE2	,45	,58	,7						NA	NA
PE3	,12	,19	,23	,28	,37	,37	,37	,37	NA	NA
TF2a	,02	,08	,02	,1	,15	,1	,67	,79	NA	NA
TF2b	,04	,12	,04	,17	,33	,17	,42	,67	NA	NA
Paper1	,06	,06		,17	,33	,17			NA	NA
Paper2	,06	,17		,28					NA	NA
Paper3	,02	0	,15	,15	,23	,26	,73	,67	NA	NA
Paper4	,28	,33	,58	,53	,96	,82	,76	,73	NA	NA
cotton	1	1,6	,19	1,96	1,31	1,96	1,83	1,77	NA	NA
SG3001	1,4	,99	,82	,99	1,36	,99	1,55	2,1	NA	NA
SG3002	,9	1,55	0	1,66	1,55	1,66	1,55	2,7	NA	NA
SG3003	1,6	1,18	0	1,3	1,6	1,66	1,9	1,83	NA	NA
SG3004	1,4	1,83	,17	1,6	1,45	1,45	1,66	1,9	NA	NA

NA Not Applicable

Table 7 Smoke obscuration m (dB/m) at time of warning measured with SICK.

	sampling	detector7	line	detector5	detector3	detector1	detector2	detector4	detector8	detector6
gren1	,025	,05	,175	,15	,15	,425	,425	,425	NA	NA
gren2	,025	,05	,125	,1	,125	,2	,325	,2	NA	NA
PE1	0	,05	,15	,1	,275	,4	,6	,575	NA	NA
PE2	,05	,1	,175						NA	NA
PE3	,025	,05	,1	,1	,275	,275	,475	,425	NA	NA
TF2a	,11	,65	,175	,65	,77	,675	1,275	1,475	NA	NA
TF2b	,1	,725	,175	,75	,8	,75	,8	1,325	NA	NA
Paper1	,025	,025		,15	,15	,15			NA	NA
Paper2	,025	,075		,05					NA	NA
Paper3	,025	,05	,1	,125	,175	,2	,225	,25	NA	NA
Paper4	,125	,15	,175	,15	,225	,175	,175	,125	NA	NA
cotton	,125	,275	,05	,3	,225	,3	,425	,425	NA	NA
SG3001	,1	,175	,1	,15	,175	,175	,2	,275	NA	NA
SG3002	,15	,25	0	,225	,25	,2	,275	,35	NA	NA
SG3003	,2	,125	,025	,125	,2	,225	,225	,275	NA	NA
SG3004	,225	,2	,1	,275	,25	,25	,25	,3	NA	NA

Table 8 Smoke obscuration m (dB/m) measured with HeNe laser at time of warning.

	sampling	detector7	line	detector5	detector3	detector1	detector2	detector4	detector8	detector6
gren1	,01	,037	,17	,11	,13	,36	,7	,36	NA	NA
gren2	,01	,02	,16	,085	,22	,18	,42	,22	NA	NA
PE1	,024	,071	,31	,26	,62	,5	,41	,94	NA	NA
PE2	,085	,18	,22						NA	NA
PE3	,032	,043	,12	,18	,26	,26	,59	,46	NA	NA
TF2a	,052	,64	,12	,81	1,1	,41	1,45	2,3	NA	NA
TF2b	,195	,99	,20	1,04	1,15	1,04	1,41	1,66	NA	NA
Paper1	,015	,075		,22	,22	,22			NA	NA
Paper2	,0058	,1		,088					NA	NA
Paper3	,023	,093	,21	,28	,36	,36	,36	,36	NA	NA
Paper4	,128	,092	,36	,21	,31	,36	,31	,26	NA	NA
cotton	,27	,73	,28	,66	,86	,59	1,05	1,05	NA	NA
SG3001	,23	,49	,54	,37	,29	,45	,49	,82	NA	NA
SG3002	,35	,48	,003	,38	,48	,41	,66	,68	NA	NA
SG3003	,48	,48	0	,51	,42	,6	,5	,68	NA	NA
SG3004	,5	,52	,001	,41	,5	,53	,4	,47	NA	NA

Table 9 Ionisation current y at time of alarm

	sampling	line	detector7	detector5	detector1	detector3	detector6	detector2	detector4	detector8
gren1	,14	,5	,21	,33	,64	,64		,67	,67	,69
gren2	,1	,76	,37	,67	,88	,7	1	,79	,88	,7
PE1	,15	,28	,26	,28	,37	,42		,5	,52	,73
PE2	,4		,58							,67
PE3	,17	,28	,19	,35	,37	,4		,42	,42	,67
TF2a	,02	,02	,1	,1	,1	,15	1,5	,69	1,1	1,1
TF2b	,06	,06	,23	,23	,26	,35	1,6	,42	,7	,7
Paper1	,06		,06	,28		,33				
Paper2	,05		,19							
Paper3	,02	,3	,02	,2	,26	,23			,67	,67
Paper4	,5		,37	,79	,82	,96		,64	,82	,88
Cotton	1,1	1,1	1,5	2	1,9	1,2	2	2,1	1,8	2
SG3001	1,1	1,1	1	1	1	1,2	1,6	2,7	2,3	1
SG3002	1,6	1,4	1,5	1,7	1,6	1,6	1,7	1,7	2,4	1
SG3003	1,9	0	1,6	1,2	1,6	1,6		1,9	2,1	
SG3004	1,6	1,6	1,8	1,6	1,5	1,5	1,7	1,8	2,1	1

Table 10 Smoke obscuration m (dB/m) at time of alarm measured with SICK.

	sampling	line	detector7	detector5	detector1	detector3	detector6	detector2	detector4	detector8
gren1	,05	,225	,05	,1	,425	,375		,525	,5	,625
gren2	,025	,2	,05	,125	,25	,2	1,225	,35	,25	,2
PE1	0	,15	,05	,15	,4	,35		,525	,75	1,05
PE2	,075		,15							,15
PE3	,05	,125	,05	,2	,3	,275		,45	,5	1
TF2a	,225	,25	,575	,625	,675	,775	2,07	1,27	1,77	1,8
TF2b	,2	,2	,72	,72	,75	,8	2,1	,8	1,4	1,4
Paper1	,02		,06	,15		,1				
Paper2	,025		,075							
Paper3	,025	,15	,05	,175	,2	,175			,125	,2
Paper4	,15		,15	,175	,175	,225		,175	,1	,225
Cotton	0,175	,175	,275	,3	,3	,225	,5	,5	,475	,3
SG3001	,2	,2	,2	,15	,2	,2	,175	,325	,325	,15
SG3002	,225	,2	,25	,2	,225	,275	,25	,225	,325	,2
SG3003	,25	,025	,2	,125	,225	,2		,225	,5	
SG3004	,25	,25	,2	,275	,25	,25	,3	,3	,35	,15

Table 11 Smoke obscuration m (dB/m) measured with HeNe laser at time of alarm.

	sampling	line	detector7	detector5	detector1	detector3	detector6	detector2	detector4	detector8
gren1	,019	,28	,04	,12	,4	,39		,59	,53	,57
gren2	,004	,24	,039	,13	,31	,18	1,53	,51	,31	,18
PE1	0,016	,41	,076	,44	,5	,54		,77	,89	1,07
PE2	,08		,18							,23
PE3	,05	,18	,077	,3	,24	,27		,71	,56	1,04
TF2a	,22	,31	,65	,6	,91	1,1	3,1	1,38	2,3	2,3
TF2b	,25	,26	1	1	1,1	1,1	2,7	1,4	2,1	2
Paper1	,026		,076	,17		,176				
Paper2	,013		,087							
Paper3	,05	,37	,076	,49	,36	,36			,21	,32
Paper4	,2		,16	,31	,36	,31		,32	,151	,36
Cotton	0,36	,38	,81	,66	,59	,85	1,01	,96	1,02	,67
SG3001	,35	,35	,49	,37	,45	,28	,7	,61	,39	,39
SG3002	,45	,4	,48	,41	,45	,5	,36	,38	,36	,36
SG3003	,43	0	,42	,51	,49	,42		,5	,83	
SG3004	,36	,39	,52	,41	,53	,5	,66	,63	,61	,2

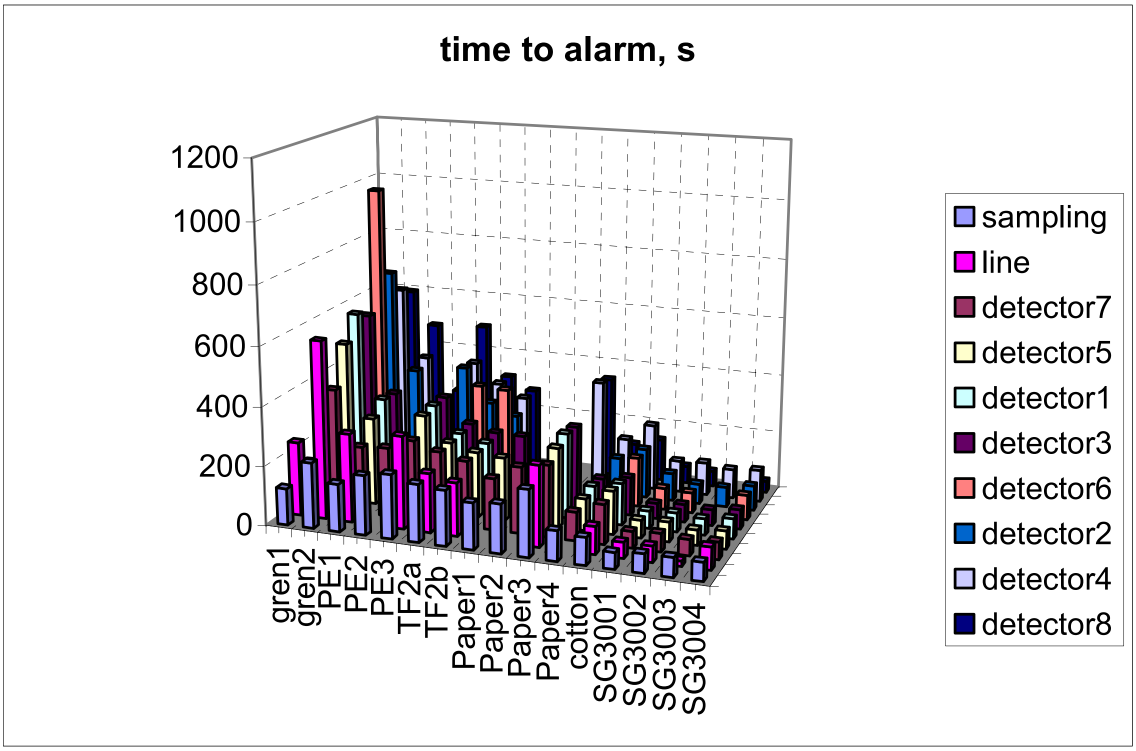

Figure 31 Time to alarm for the different tests and detectors. For the Sampling system level 3 was used as time to alarm.

The smoke density was measured during the test using a diode laser with a wavelength of 670nm and the SICK which uses an IR wavelength (the same as MIREX), a comparison between the two different measuring methods is presented in figures 31-47 below. In addition the CO and CO_2 concentration was measured during the test together with the temperature. However no significant CO concentration was detected during the tests.

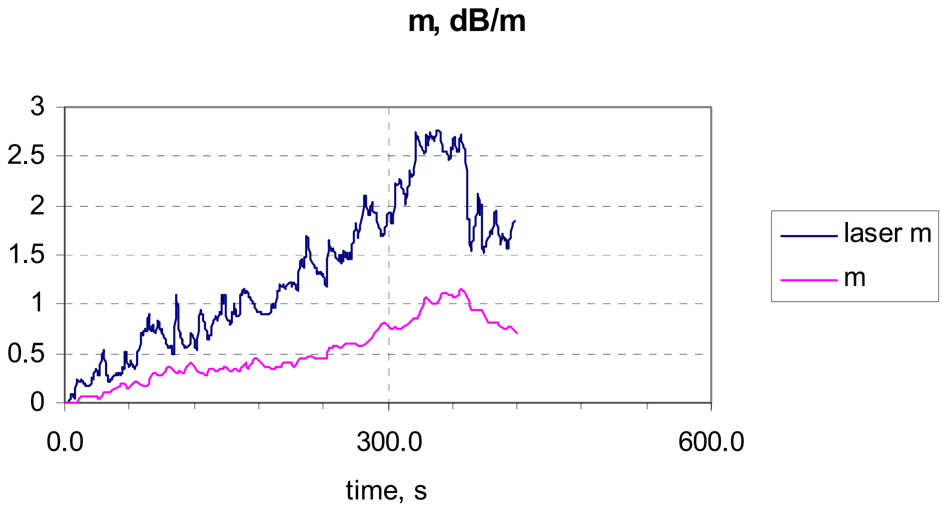

Figure 31 Smoke obscuration measured using a diode laser and the SICK for test SG3001.

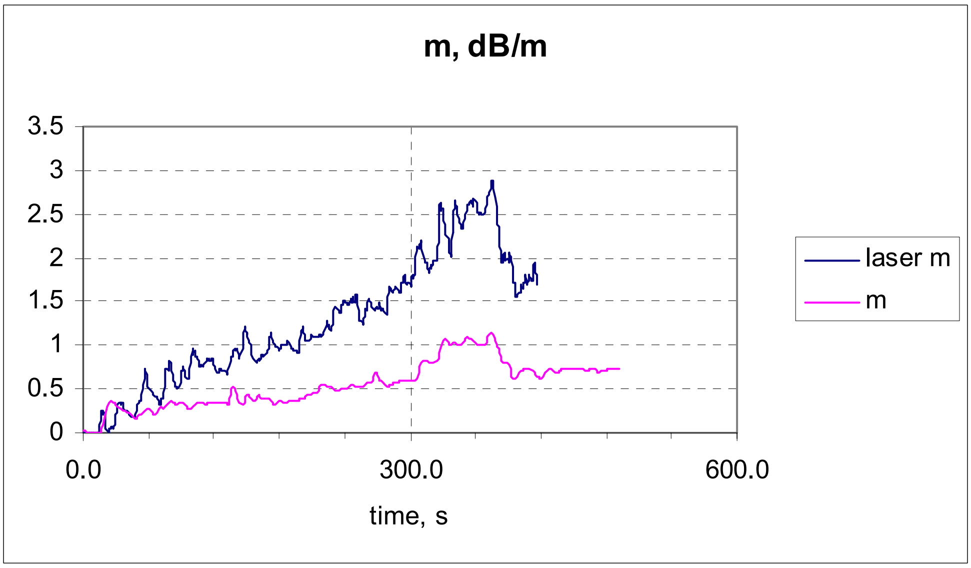

Figure 32 Smoke obscuration measured using a diode laser and the SICK for test SG3002.

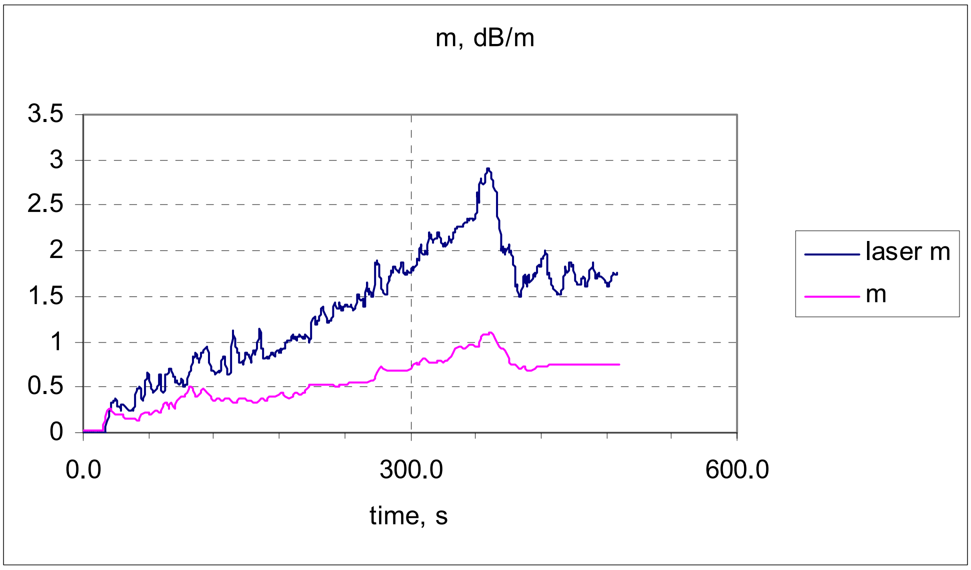

Figure 33 Smoke obscuration measured using a diode laser and the SICK for test SG3003.

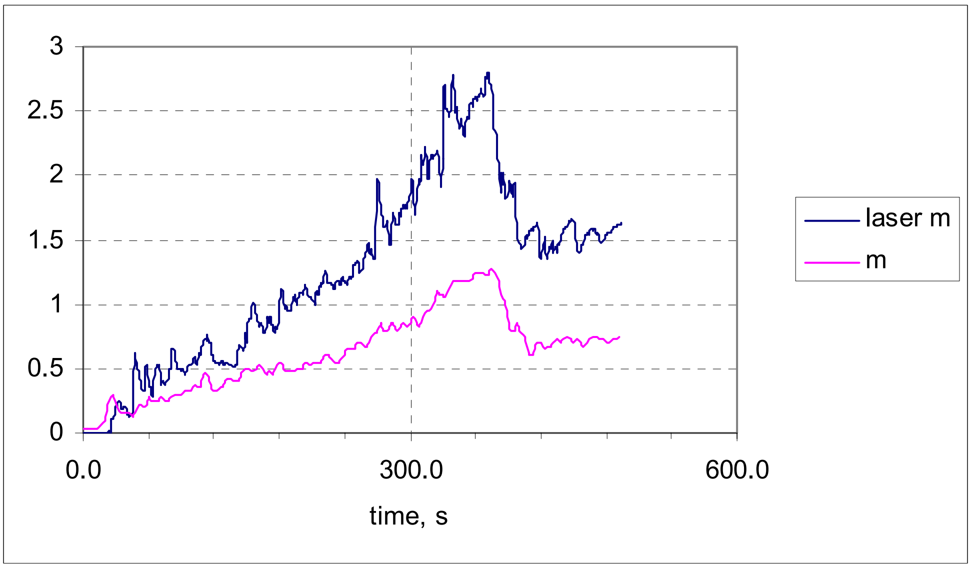

Figure 34 Smoke obscuration measured using a diode laser and the SICK for test SG3004.

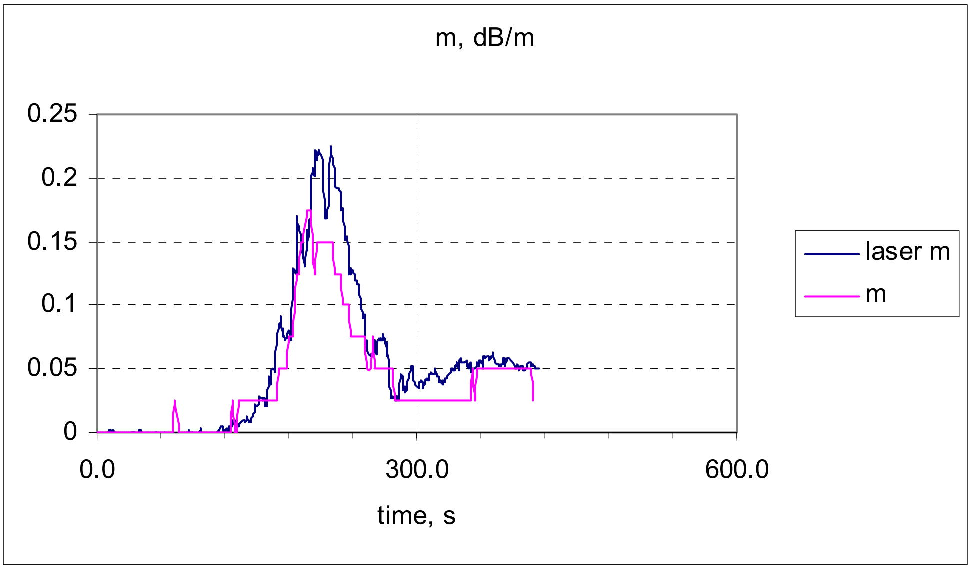

Figure 35 Smoke obscuration measured using a diode laser and the SICK for test Paper1.

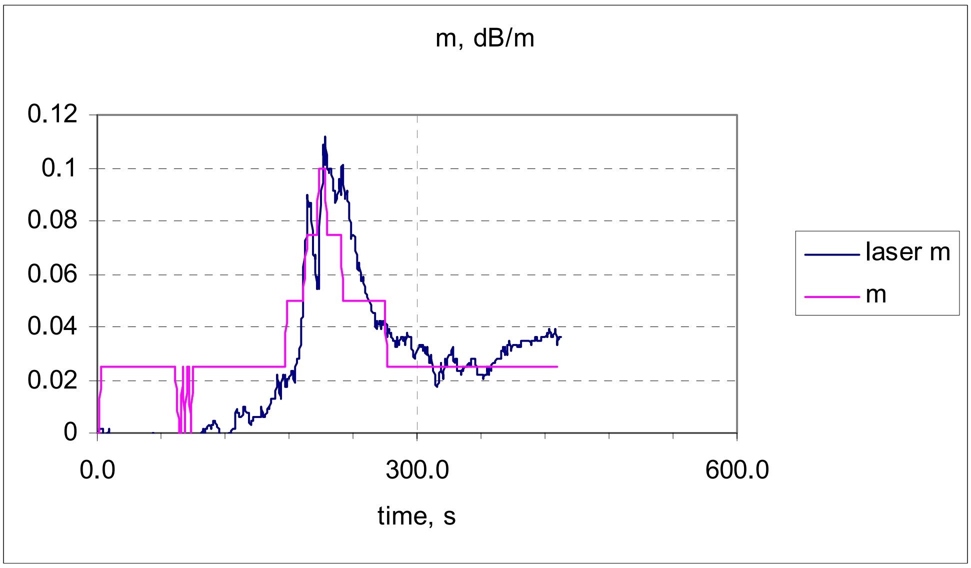

Figure 36 Smoke obscuration measured using a diode laser and the SICK for test Paper2.

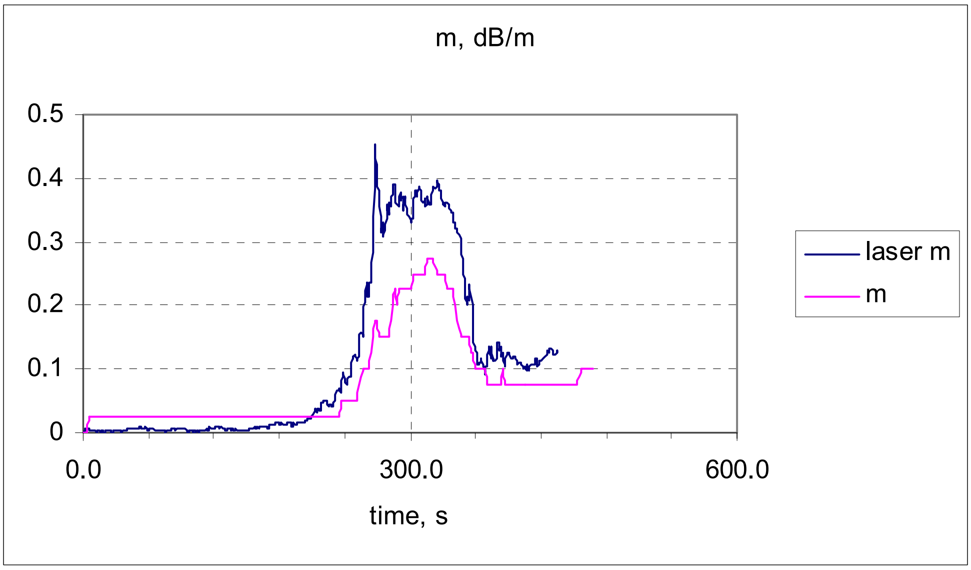

Figure 37 Smoke obscuration measured using a diode laser and the SICK for test Paper3.

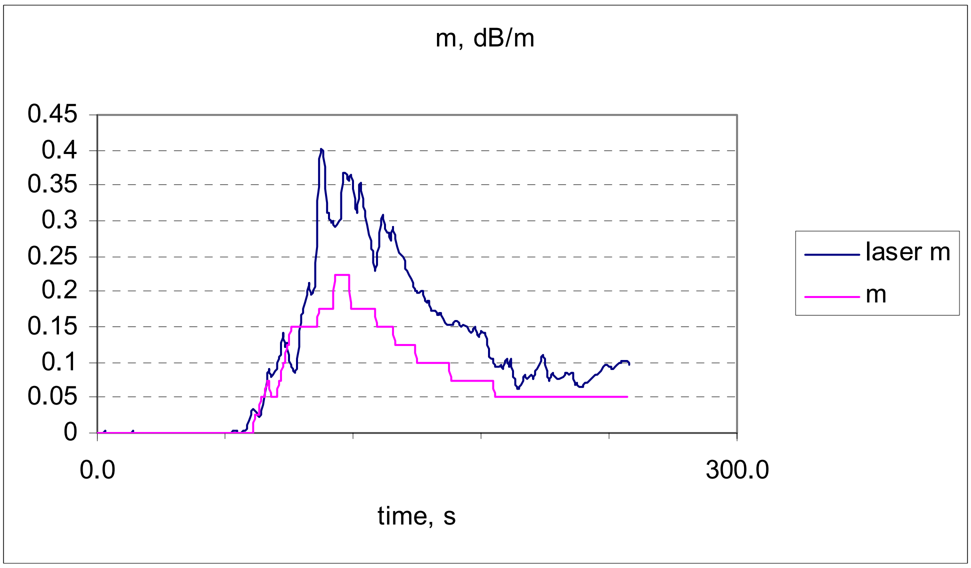

Figure 38 Smoke obscuration measured using a diode laser and the SICK for test Paper4.

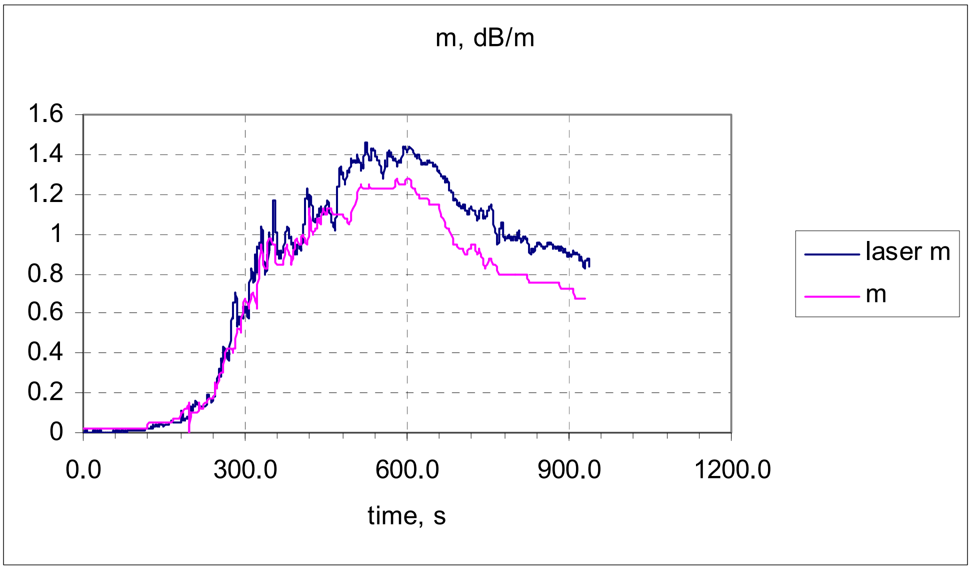

Figure 39 Smoke obscuration measured using a diode laser and the SICK for test Gren1.

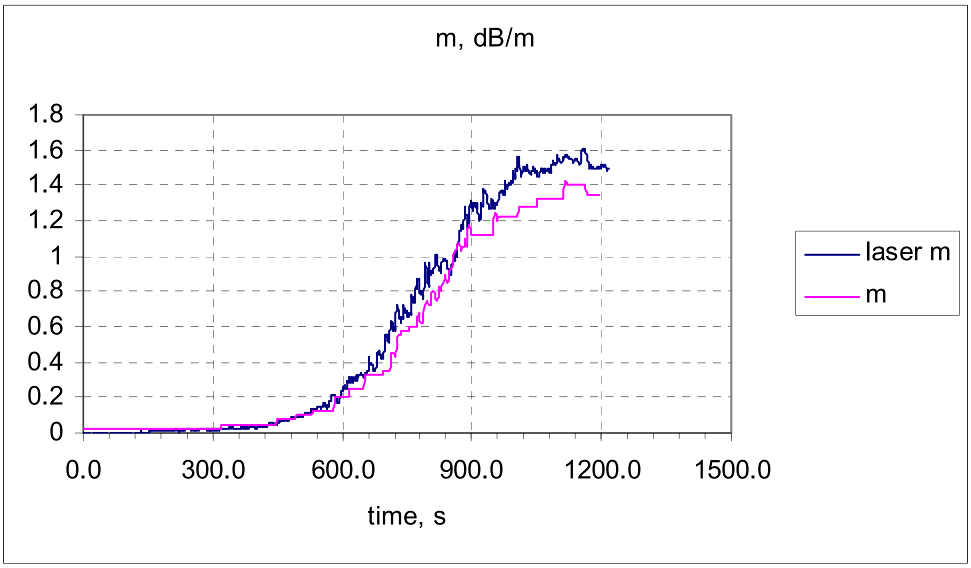

Figure 40 Smoke obscuration measured using a diode laser and the SICK for test Gren2.

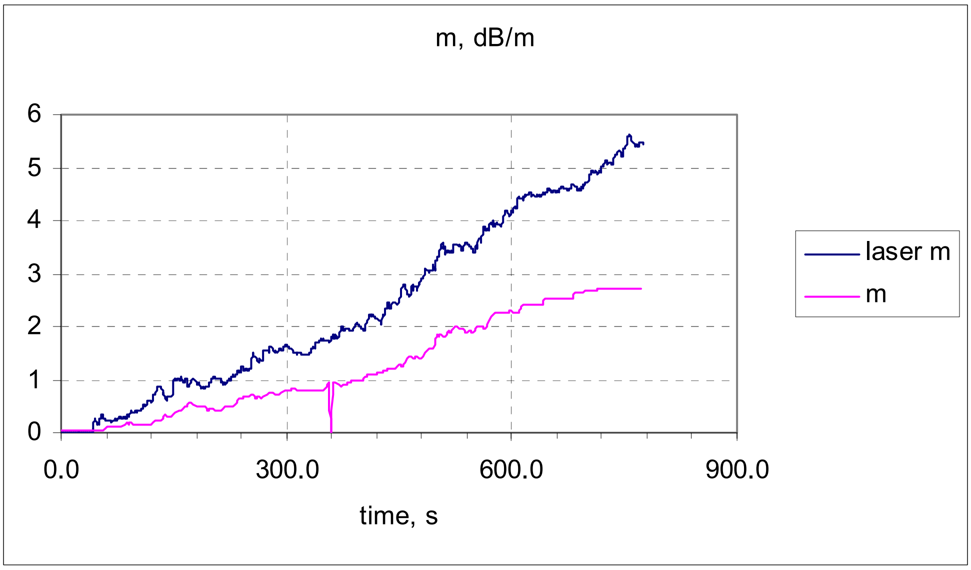

Figure 41 Smoke obscuration measured using a diode laser and the SICK for test Cotton1.

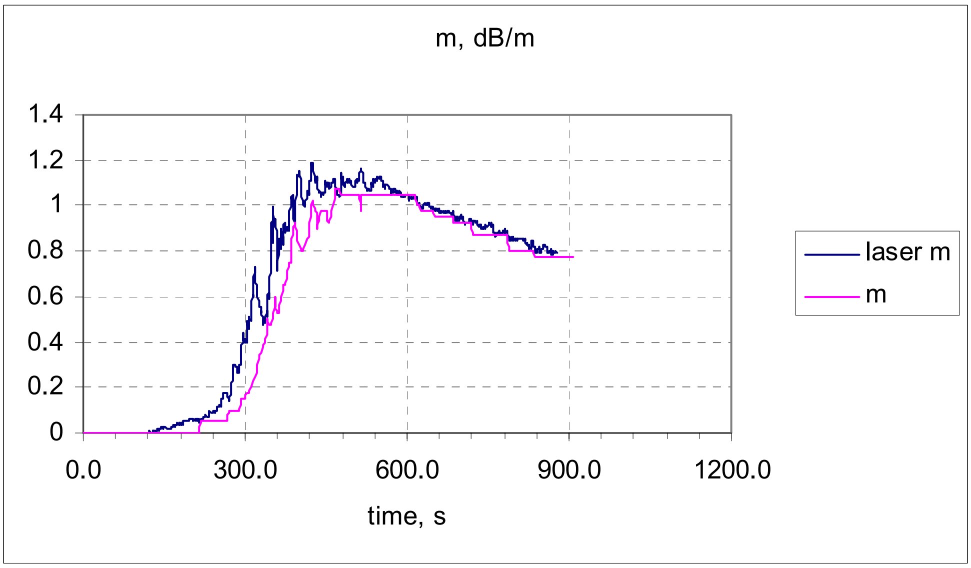

Figure 42 Smoke obscuration measured using a diode laser and the SICK for test PE1.

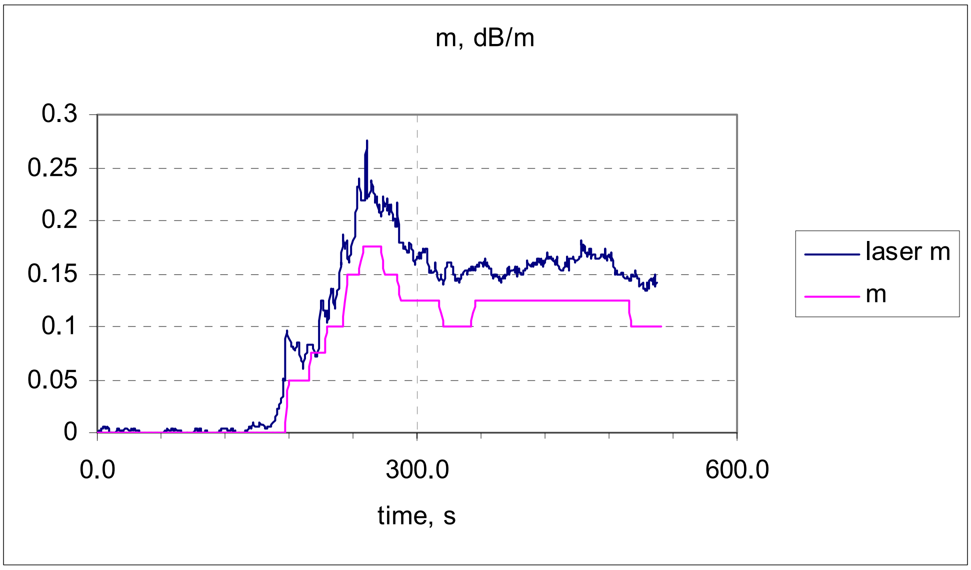

Figure 43 Smoke obscuration measured using a diode laser and the SICK for test PE2.

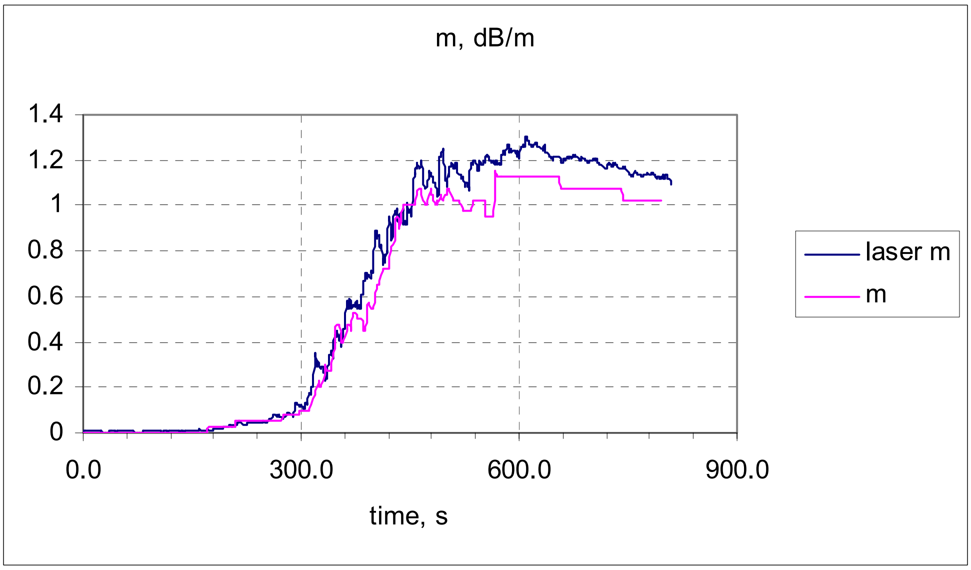

Figure 44 Smoke obscuration measured using a diode laser and the SICK for test PE3.

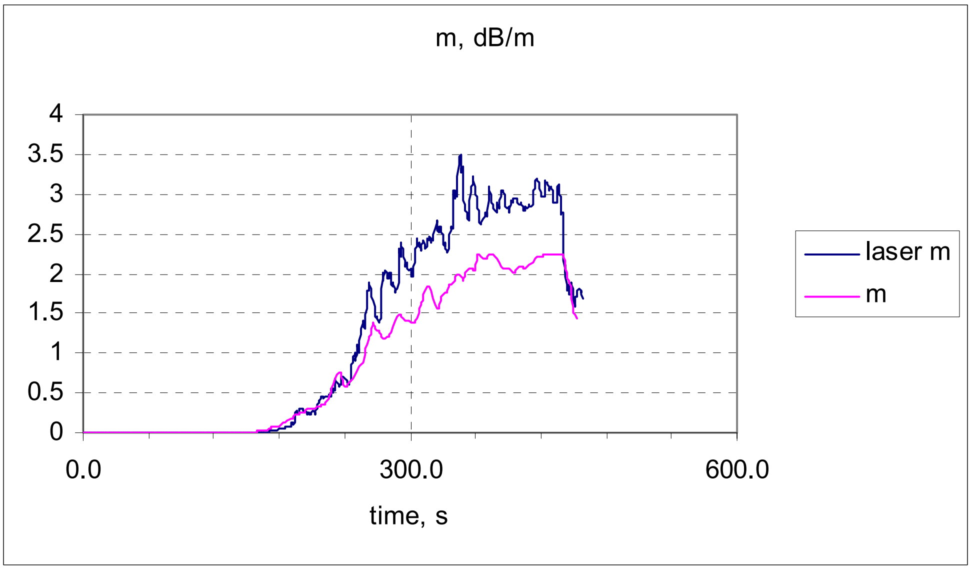

Figure 45 Smoke obscuration measured using a diode laser and the SICK for test TF2a.

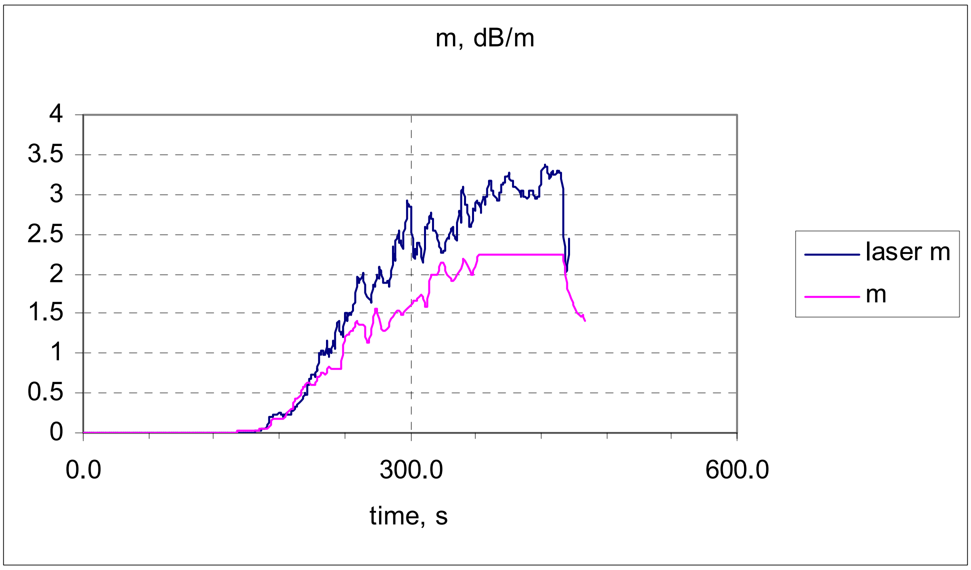

Figure 46 Smoke obscuration measured using a diode laser and the SICK for test TF2b.

As seen in figures 31-46 above the laser obscuration is higher than the SICK obscuration which complies better with theory. It is also clearly seen that the ratio between the two measurements differs for different fuels. No further analysis of the differences for the different fuels is made at this state due to the results achieved in the cone calorimeter.

In addition an experiment in the Delta room was simulated using the CFD-code Sofie. The smoke was let in into the room at a constant rate as a passive scalar with a velocity of 0.5 m/s through a surface with a temperature of 600ºC. The results are presented in figures 47-56 below for each minute. Unfortunately the colour scale differs between the figures, thus care must be taken when interpreting the results.

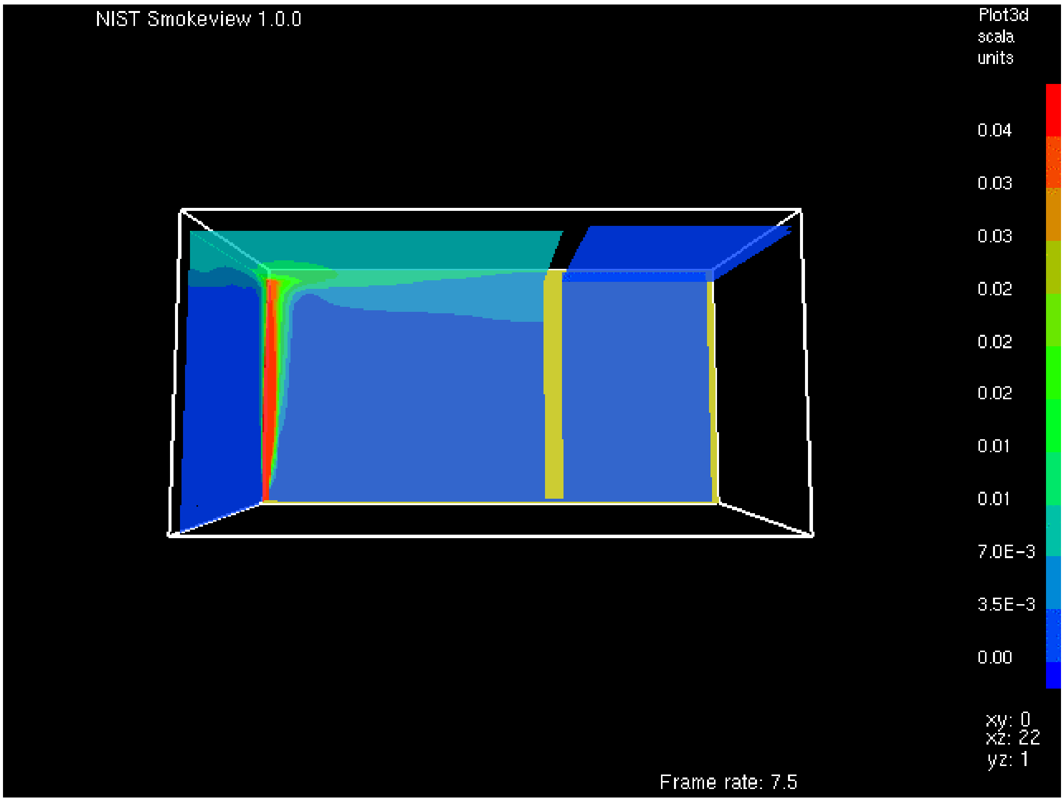

Figure 47 Smoke field after 1 minute.

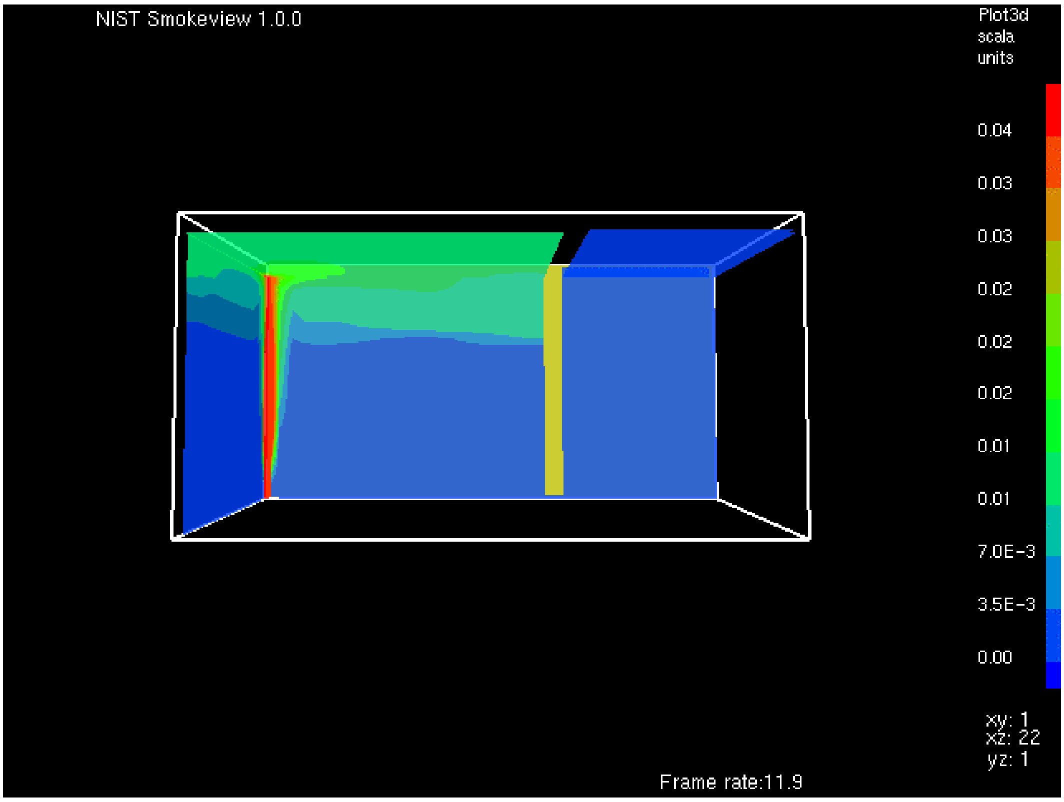

Figure 48 Smoke field after 2 minutes.

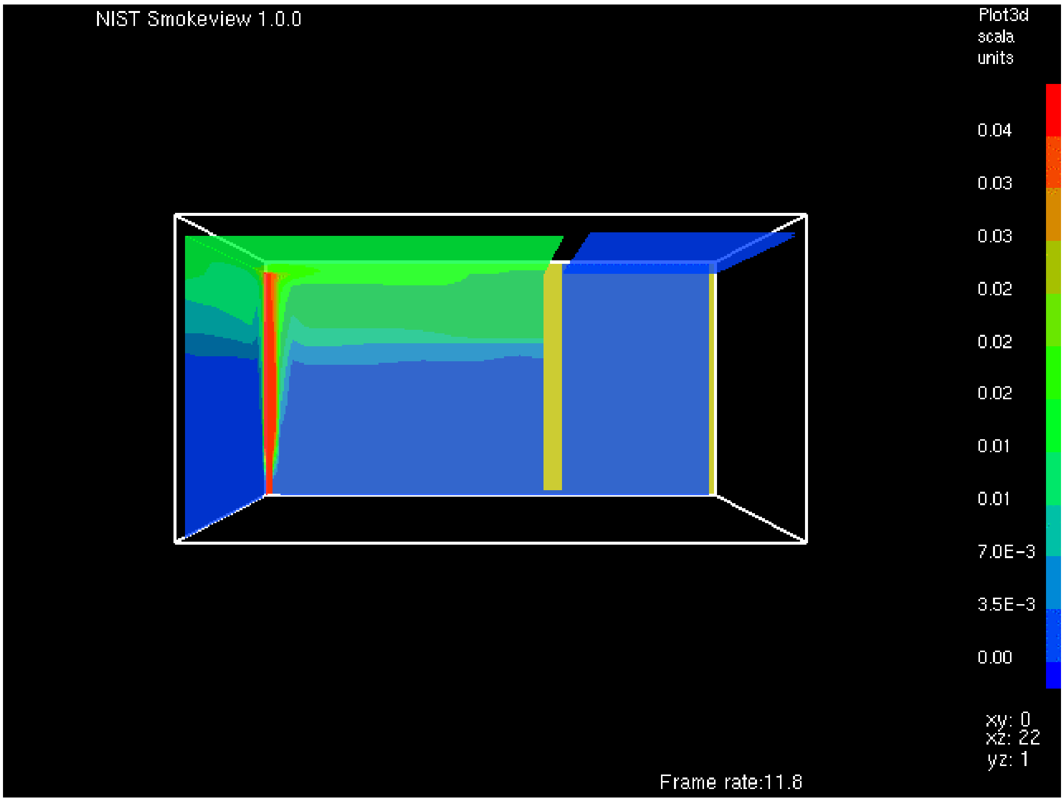

Figure 49 Smoke field after 3 minutes.

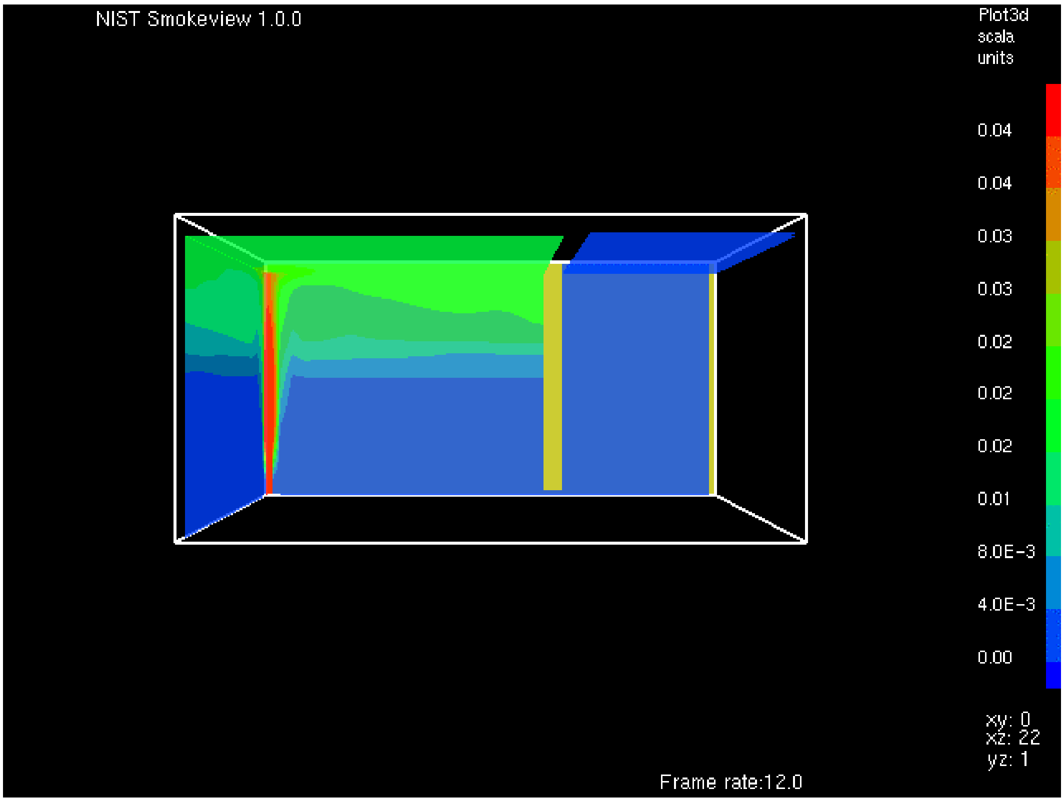

Figure 50 Smoke field after 4 minutes.

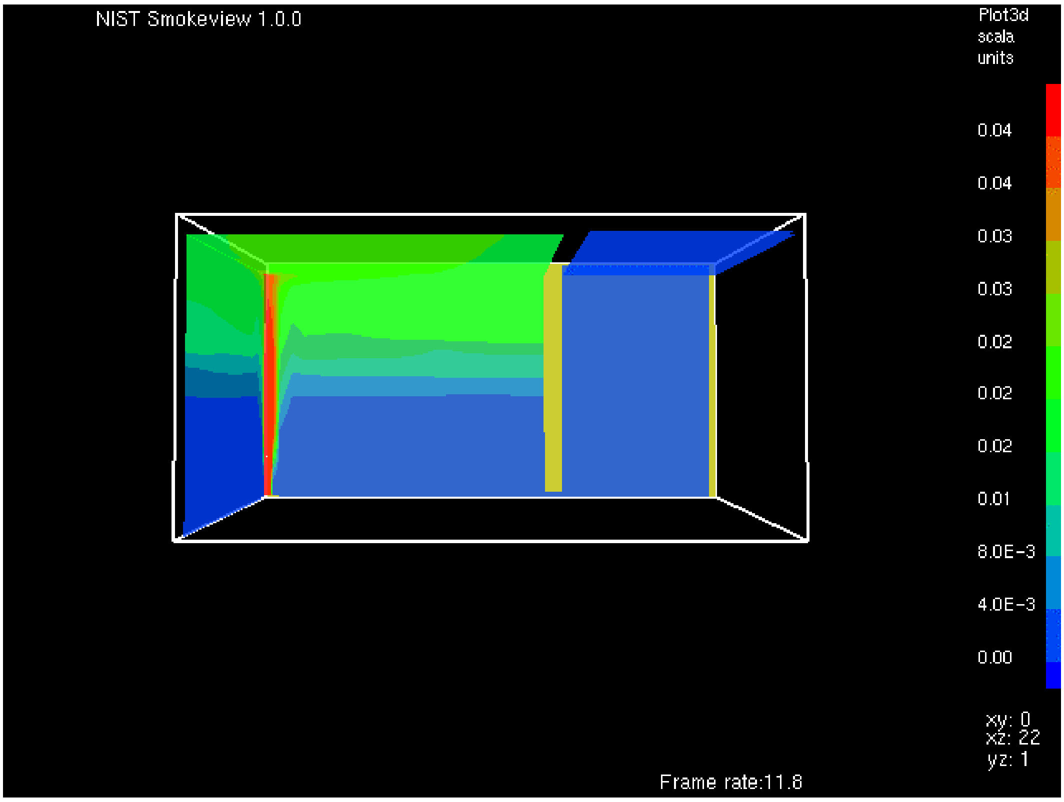

Figure 51 Smoke field after 5 minutes.

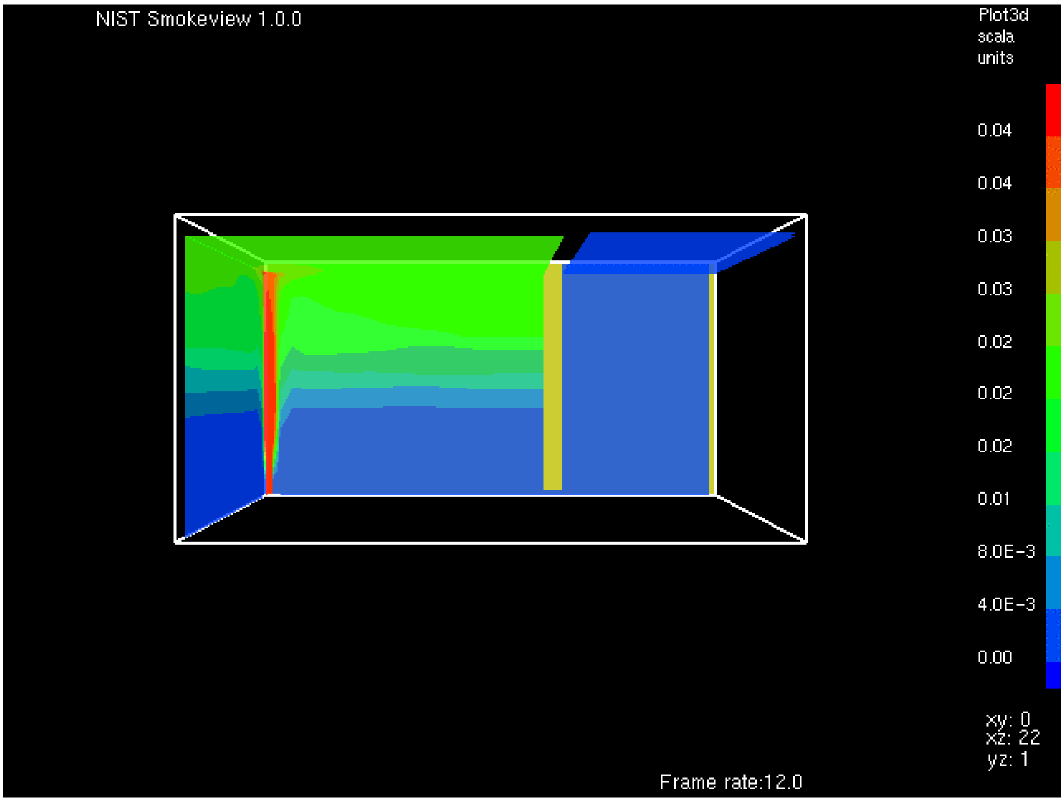

Figure 52 Smoke field after 6 minutes.

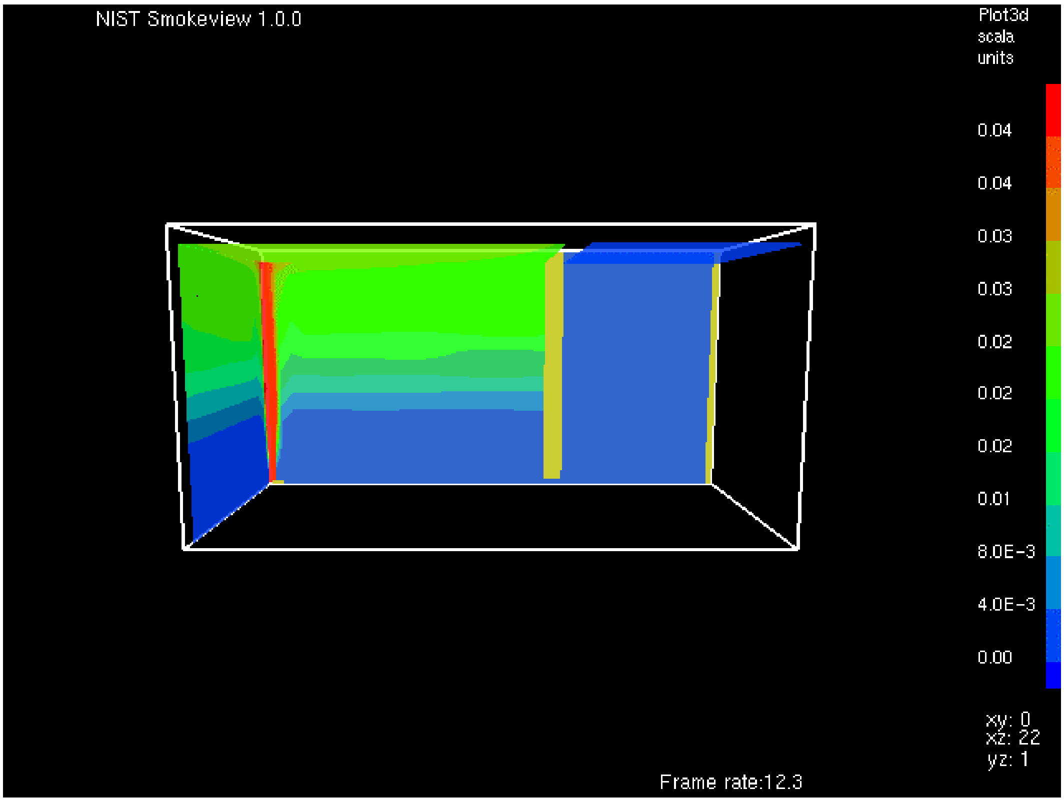

Figure 53 Smoke field after 7 minutes.

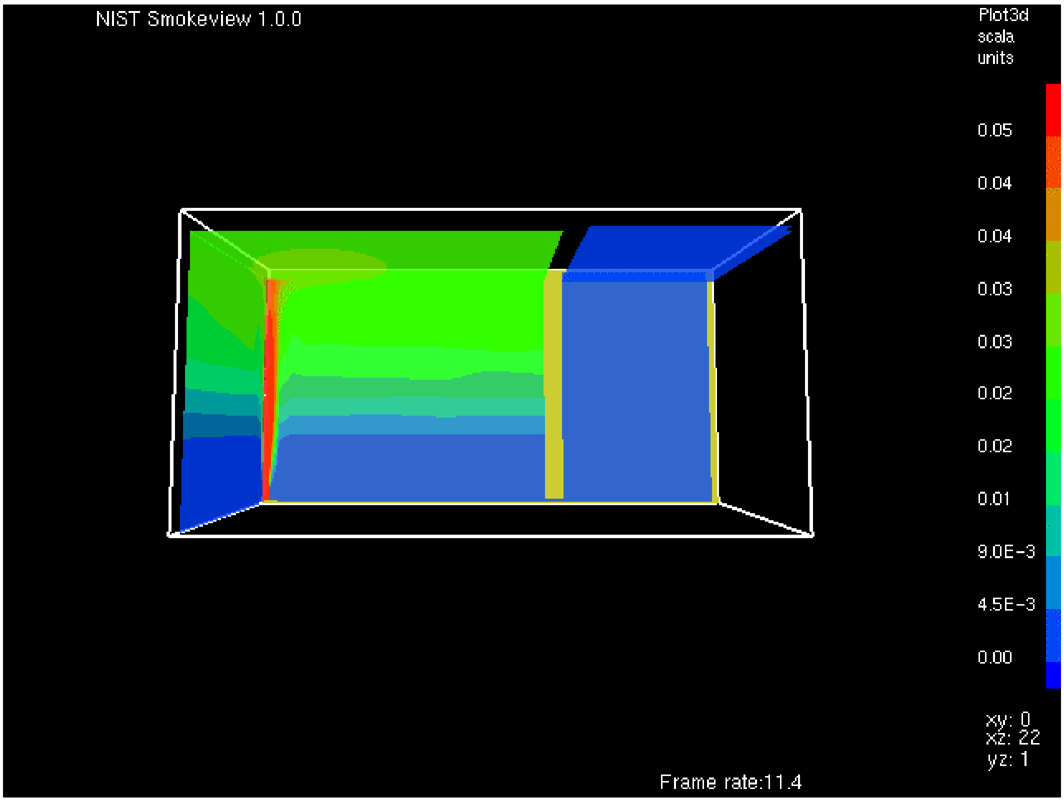

Figure 54 Smoke field after 8 minutes.

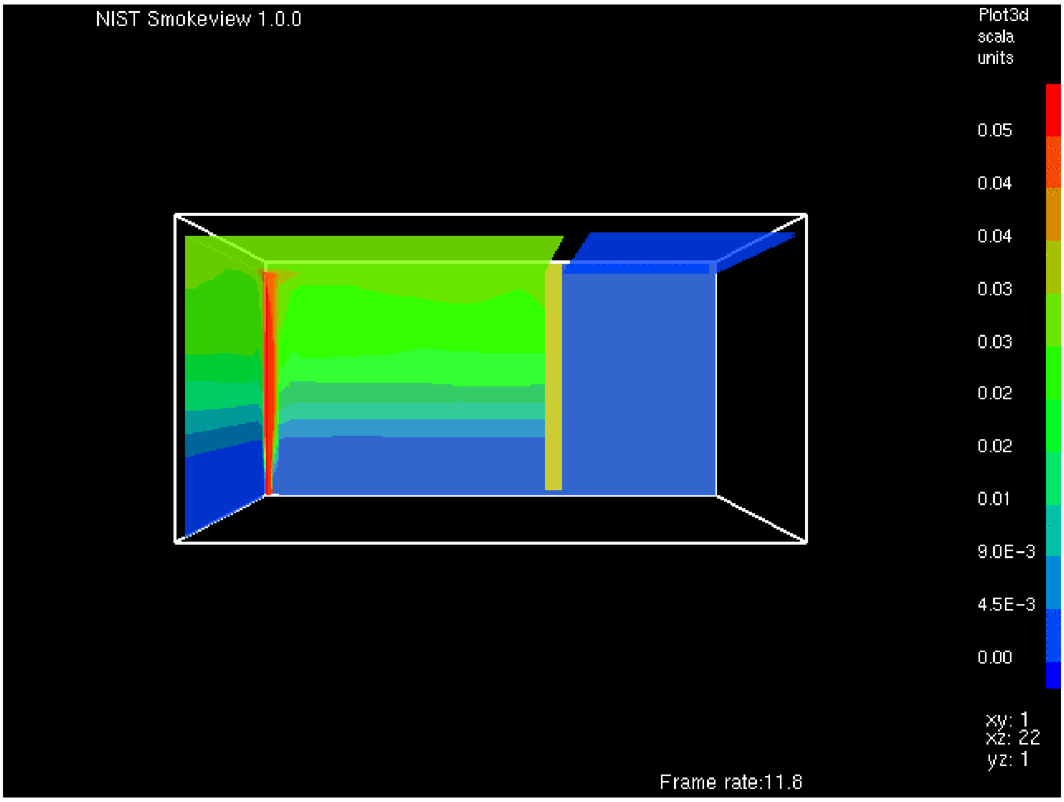

Figure 55 Smoke field after 9 minutes.

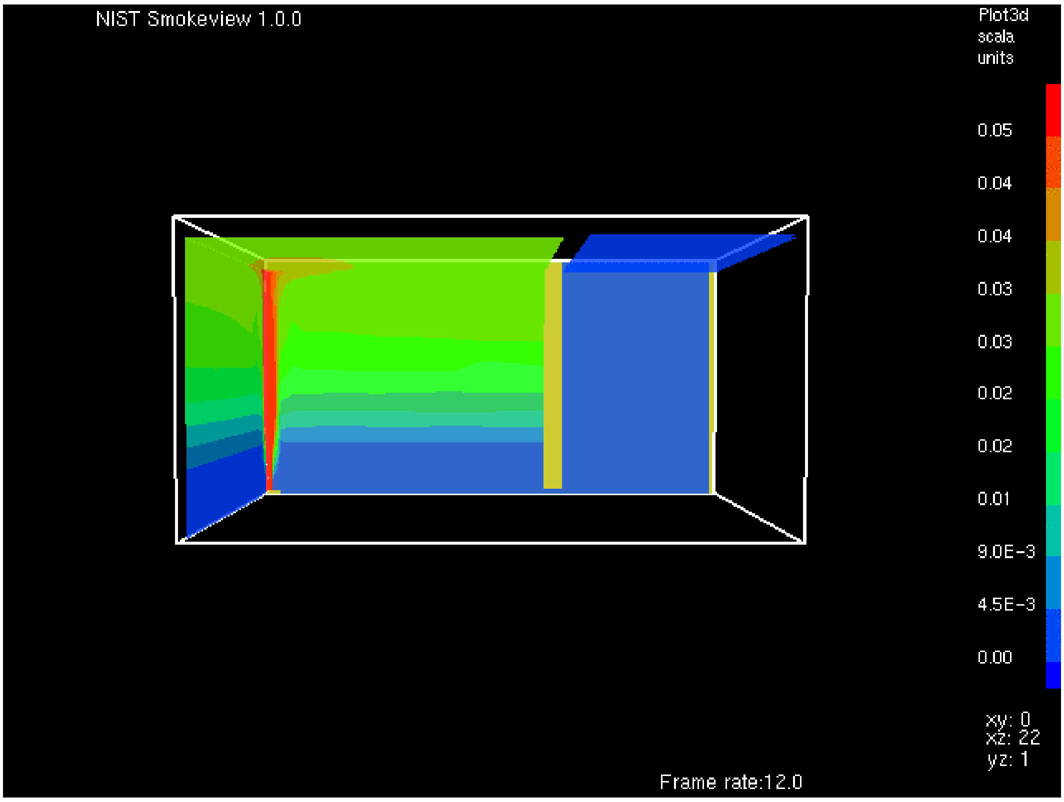

Figure 56 Smoke field after 10 minutes.

After 10 minutes the scalar equals 0.03 which means 0.3 dB/m if one lets in 10 dB/m and assumes that the optical properties of the smoke does not change during the dilution process. However, looking at test PE1 and PE3 the obscuration is 1 dB/m, i.e. it differs a factor of 3 between the simulation and the experiments. However, as seen from comparing the results from the cone calorimeter tests and the Delta tests it is doubtful that the optical properties of the smoke does not change during the dilution.

4 Different types of ventilation systems

The ventilation systems used in industries can be divided into two different types, i.e. mixing systems, see figure 57, which is a "well stirred reactor" type of system were the temperature is the same in the whole room and displacement systems, see figure 58 where a temperature gradient is maintained in the room with high temperatures close to the ceiling. The velocities close to the air supplies can be substantial in the former case while the temperature gradient causes problem in the latter case. It is also common with mixtures of the two different types of ventilation in a room as described in figure 59. In most cases there is also a dead volume close to the ceiling that does not take part in the ventilation flow.

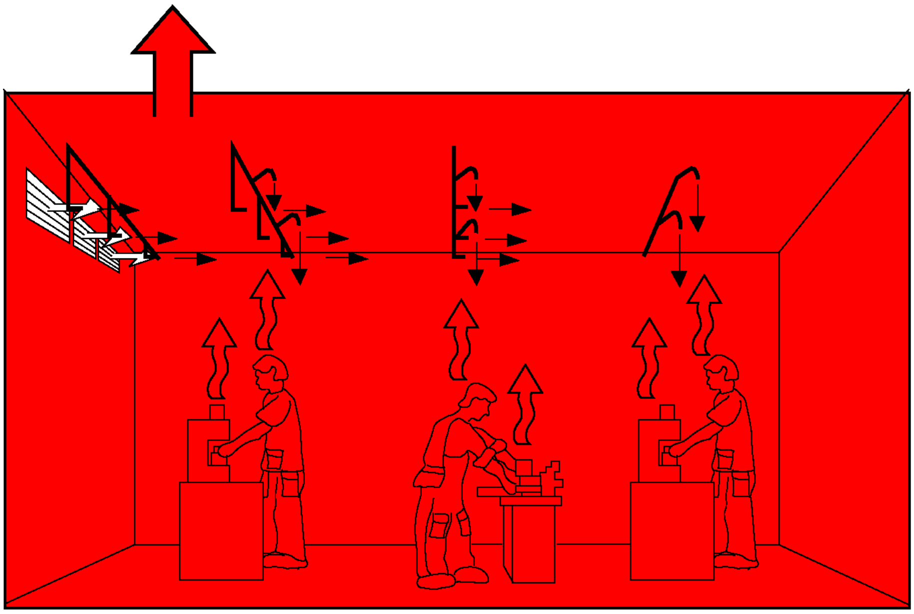

Figure 57 A total mixing system, the temperature profile is uniform within the room.

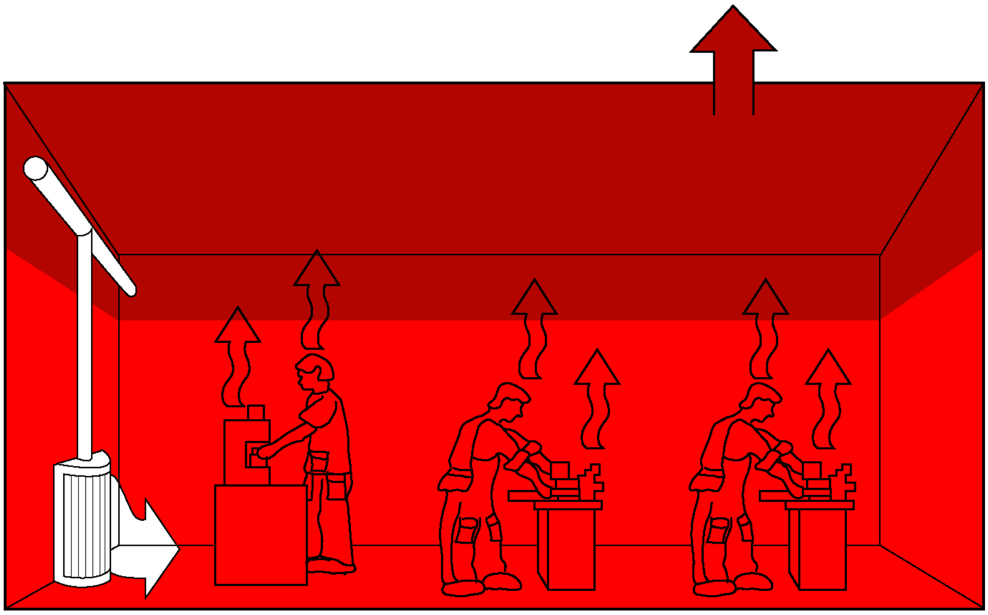

Figure 58 Displacement system, a temperature gradient is maintained in the room, with cold air close to the floor and hot at the ceiling.

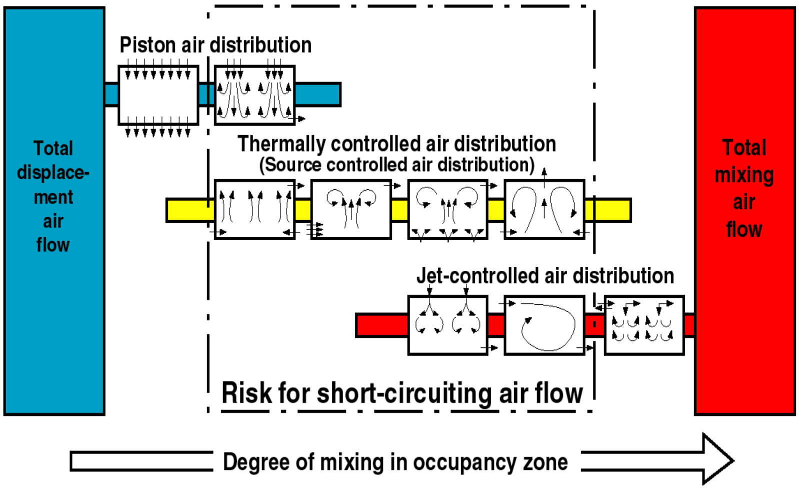

Figure 59 The range between total displacement and total mixing airflow.

5 Future work

This project aims for a better understanding of where to place detectors in order to get an early detection in rooms with high ceilings. Part 1 has studied the smoke production from different packaging materials and electrical equipment. The sensitivity of different types of detectors was also studied in an EN54 room. The next part of the project will study smoke movement in different rooms with high ceilings with different types of ventilation. Before the tests a ventilation expert will try to predict how the smoke will travel and the tests will aim to verify this. The temperature profile and velocities in the room should be measured before the smoke is let into the room. The smoke will probably be produced by the SG3000.

This report is a working report with a quick presentation of the data achieved. The data presented needs further evaluation in order to draw further conclusions on smoke production and detector sensitivity. This will e done in the final report for the whole project.

In addition further investigations on the smoke measuring problem using light will be performed in other projects.

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