Fire tests with textile membranes on the market - results and method development of cone calorimeter and SBI test methods

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TEXTILE STRUCTURES AND BUILDINGS OF THE FUTURE

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Fire Technology

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Abstract

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This work has been conducted within the European project contex-T, "Textile Architecture – Textile Structures and Buildings of the Future". Contex-T is an Integrated Project dedicated to SMEs within the 6th Framework Programme and brings together a consortium of over 30 partners from 10 countries. Among the main objectives of the project is the development of new lightweight buildings using textile structures and the development of safe, healthy and economic buildings. Advantages of textile materials in buildings includes their low weight, and in the case of textile membranes, their translucency and architectural possibilities. A common disadvantage, however, is the fire properties of textile materials which highlights the importance of fire safety assessments for building application of such materials.

This report presents the results of reaction-to-fire tests conducted with textile membranes. The work includes pre-characterization tests conducted with the Cone Calorimeter (ISO 5660) and classification type tests conducted with the SBI (EN 13823), together with additional test methods required for EN 13501-1 classification.

The test were conducted with a selection of textile membranes that are typically used in buildings. The textile membranes were produced by context-T partners to be used as reference products representing materials presently available on the market. The idea was to produce a database of test results for presently available products to be used for benchmarking of the new products developed within the project.

Key words: textile membranes, fire tests, Cone Calorimeter, Single Burning Item (SBI)

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Sammanfattning

Detta arbete har utförts inom det Europeiska projektet **contex-T**, ”Textile Architecture – Textile Structures and Buildings of the Future”. Contex-T är ett ”Integrated Project” inom det 6:e ramprogrammet med ett konsortium bestående av mer än 30 partners från tio länder. Bland projektets syften ingår att utveckla nya lättviktsbyggnader av textila strukturer samt säkra, hälsosamma och ekonomiska byggnader. Fördelar med textila byggnadsmaterial inkluderar deras låga vikt och för textila membran, deras ljusgenomsläpplighet och arkitektoniska möjligheter. Men en gemensam begränsning för textila material är deras brandegenskaper, vilket understryker vikten av en korrekt brandsäkerhetsbedömning vid användande av sådana material i byggnadskonstruktioner.

Denna rapport presenterar resultatet av provningar av textila membrans brandegenskaper. Provningarna inkluderade småskaliga försök av utveckligskaraktär utförda med konkalorimeter (ISO 5660) samt provningar med SBI (EN 13823) och kompletterande metoder vilka krävs för Euroklassning enligt EN 13501-1.

Provningarna utfördes med ett urval av textila membran som används till byggnadsapplikationer. Dessa textila membran producerades av contex-T partners som referensprodukter representerande typiska produkter förekommande på marknaden. Avsikten var att ta fram en databas av testresultat för dagens produkter att ha som en jämförelse vid utvecklingen av nya produkter.

1 Introduction

Fire tests with textile membranes have been conducted at SP Fire Technology as part of WP 1.7 of contex-T. The tested membranes were representative of the most common types currently on the market. Two main test methods have been used: the Cone Calorimeter, ISO 5660 [1], which has been selected as a pre-characterization method for contex-T, and the SBI-test, EN 13823 [2], which is the most important test method in the European classification of building materials, EN 13501 [3]. The membranes were also tested according to the small-flame test, EN ISO 11925-2 [4], and the heat of combustion test, EN ISO 1716 [5], and the non-combustibility test, EN ISO 1182 [6], when relevant, in order to establish a complete indication of the classes of reaction-to-fire performance.

For both the Cone Calorimeter and the SBI, it has been necessary to investigate the appropriate testing protocols for testing textile membranes. Although the test methods used are standard methods, there is a certain freedom in the testing procedure, especially in the mounting of the sample species.

Regarding the Cone Calorimeter tests, there were two objective for conducting the tests. The first objective was to find a test procedure that is sensitive enough to distinguish between membranes with differences in fire performance. The second objective was to build up a data base of test results for membranes on the market with differences in composition and fire performance. Membranes with improved performance, developed in contex-T, could then be tested and compared to membranes in the data base as the membrane is developed, without requiring the production of large quantities of material.

For the SBI-tests the mounting of the test specimen is important for the results of the test, and consequently also for the preliminary Euroclass indicated as a result of the test. For some product groups there are mounting instructions defined in special product standards on a European level. For textile membranes in tensile structures no product standard is presently available. The mounting of the test specimen in the tests reported here was made using two alternative methods.

This report describes the methods used, together with the results obtained. The results are discussed and some conclusions and recommendation for further work are given.

Note: This report is essentially identical to the report submitted as an internal report within the contex-T project. This report has, however, been complemented with results from EN ISO 1716 and EN ISO 1182 tests with the “Silicone membrane” and the “PTFE membrane”.

2 Textile membranes investigated

The most common types of textile membranes currently found on the market were selected for the tests. Four membranes with polyester fabric and PVC coating were delivered from Sioen. The individual PVC membranes had a variety of thicknesses of the coating (PVC 1 thinnest, PVC 4 thickest).

Two different membranes with glass fibre fabric were delivered from DITF Denkendorf. One of these membranes had a silicone coating, whereas the other had a PTFE coating.

An additional membrane with glass fibre fabric and PTFE coating (PTFE - Terpolymer) was delivered from Polymage. This membrane was delivered at a later time, and only Cone Calorimeter tests were conducted with this membrane.

Data on the membranes tested, representing membranes currently found on the market, is given in Table 1.

Table 1 Data on the textile membranes included in the fire tests.

Textile membrane	Test label	Type	Fabric	Coating	Appearance	Thickness (mm)	Mass per unit area (g/m^2)*
PVC 1	a	Sioen B8103	100% PES 1100 dtex	PVC, fire retarded “M2-quality”	bright white, smooth surface, flexible	0.5	640 (650)
PVC 2	c	Sioen B9115	100% PES 1100 dtex	-"-	grey, smooth surface, flexible	0.6	720 (730)
PVC 3	b	Sioen B6101	100% PES 1100 dtex	-"-	bright white, smooth surface, flexible	0.8	1070 (1050)
PVC 4	d	Sioen B6656	100% PES 1670 dtex	-"-	bright white, smooth surface, flexible	1.1	1290 (1300)
Silicone	e	Interglas Atex 5000TRL	“glass fibre”	“silicone”	dull white, sticky surface, flexible	1.0	1270
PTFE	f	Verseidag duraskin B18089	-"-	“PTFE”	light brownish, smooth surface, rigid	0.7	1150
PTFE - Terpolymer	g	A-tex 2500 Low E	Fabric Glass EC 9 3x 68 tex / 204 tex	SOLAFLON - transparent fluoropolymer mass of coating white side ~ 50 g/sqm mass of coating alu side ~ 10 g/sqm	aluminized side and clear white side, fabric structure surface, flexible	0.3	330

* Measured on sample; nominal value from supplier in parenthesis.

NOTE: The materials were labelled in alphabetical order as they were received at SP. However, to help in the interpretation of the test results the PVC membranes has been named 1-4 in order of increasing mass per unit area.

3 Cone Calorimeter tests

3.1 Introduction

The Cone Calorimeter (ISO 5660-1)[1] has been selected as a pre-characterization method for reaction-to-fire assessment of membranes in the contex-T project. The goal is to have reference data before the introduction of new innovative materials and solutions. Such reference data should then provide the possibility to investigate the benefits of new solutions in the development phase thereby avoiding unnecessary costs for the manufacture of large amounts of material at an early stage in the development process.

The Cone Calorimeter is widely used as a tool for fire safety engineering, by industry for product development and in some areas as a product classification tool. The Cone Calorimeter has been proven to predict large-scale test results for different types of products when the test data is used as input to the correlation model Conetools [7].

The Cone Calorimeter is schematically shown in Figure 1.

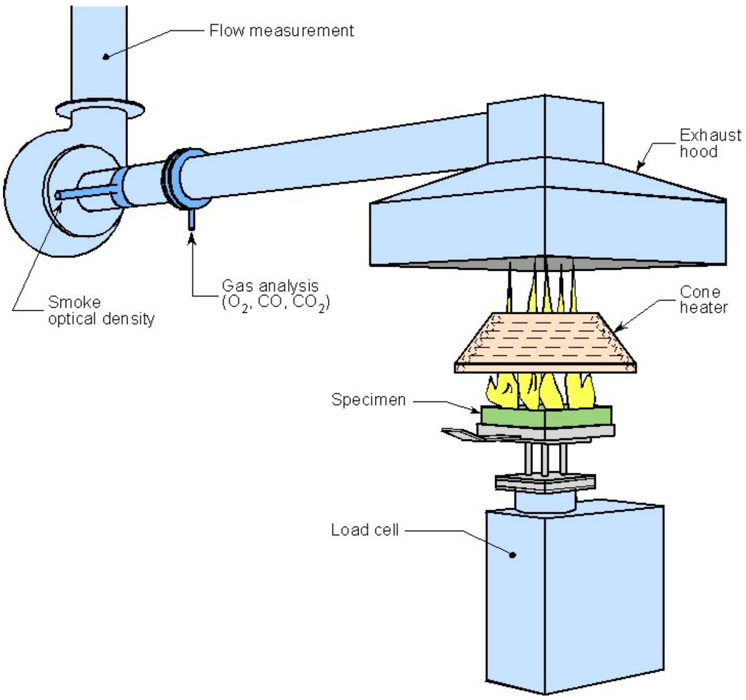


Figure 1 Schematic drawing of the Cone Calorimeter (ISO 5660-1).

In the Cone Calorimeter, sample specimens of 0.1 m × 0.1 m are exposed to controlled levels of radiant heating by a conical shaped electrical heater giving a heat flux in the range of 0-100 kW/m^2. The specimen surface is heated by the cone and an external spark ignitor ignites the pyrolysis gases from the specimen. The gases are collected by a hood and extracted by an exhaust fan. The heat release rate (HRR) is determined by measurement of the oxygen consumption, derived from the oxygen concentration and the flow rate in the exhaust duct. The specimen is placed on a load cell during testing. Important parameters determined from a Cone Calorimeter test include: time to ignition (t_{ign}), heat release rate, HRR (q), total heat produced (THR), effective heat of combustion (ΔH_c), smoke production (SPR) and total smoke production (TSP).

3.2 Test programme

The first goal for the test programme was to develop a suitable test protocol for textile membranes including a proper mounting method and appropriate heat flux levels. The main requirements for determining the suitability of the test protocol were that it should produce repeatable results and the results should discriminate between different types of membranes. A secondary goal was to produce meaningful data on membranes currently found on the market to use as a reference for comparison in pre-characterization of new materials developed within the contex-T project. The tests conducted were divided into two main series and a supplementary third series.

Test series 1 – Exploration of a proper mounting method

All tests were run at 50 kW/m^2 external radiant flux. Only the PVC membranes were available at the time for this test series. The tests were conducted in August 2007.

Test series 2 – Tests using two different mounting methods

The mounting method investigated were:

1. The sample specimen was wrapped with aluminium foil on the reverse side, placed against a non-combustible insulation material, with a metal net on top of the sample.
2. The sample was mounted with an air gap.

Duplicate tests were run with 35 kW/m^2 and 50 kW/m^2 external radiant flux. At the time for this test series both the silicone and the two types of PTFE membranes were available. The tests were conducted in November 2007.

Test series 3 – Supplementary tests with PVC 1 and PVC 4.

Sample specimen were wrapped with aluminium foil on the reverse side, placed against a non-combustible insulation material, with a metal net on top of the sample. The external radiant flux was 50 kW/m^2. The tests were conducted in April 2008.

The membrane materials often had one smooth (front) surface and a more rough (reverse) surface. The samples were, as a rule, mounted with the rough surface exposed to the incident heat flux, since the rough side would be likely to be faced inwards in a building.

3.3 Summary of test results

A summary of the results from the first series of tests is given in Table 2 and the results from the second series are given in Table 3. The supplementary tests with two of the PVC membranes are given in Table 4. Graphs on heat release (HRR) and smoke production (SPR) are given in Appendix 1.

The investigation of a proper mounting method is evaluated and discussed in Section 3.4. The results from systematic tests using the two selected mounting methods and two heat fluxes are discussed in Section 3.5.

Table 2 Results from the first series of Cone Calorimeter tests.

Test	Flux (kW/m^2)	t_{ign} (s)	q_{max} (kW/m^2)	THR (MJ/m^2)	Mounting method	Comments*
PVC 1 (B8103):						
a1	50	8	106	8.6	standard	curls and shrinks to ball
a2	50	8	114	9.3	+bars	curls over bars
a6	50	10	237	8.0	+net	shrinks moderately
a3	50	9	212	7.9	+staples	uneven surface from the insulation
a4	50	8	183	7.7	+staples -insul.	-
a5	50	8	177	7.5	+staples -insul.	-
a7	50	7	142	10.1	air gap	-
a8	50	7	151	11.5	air gap	-
PVC 2 (B9115):						
c1	50	8	215	9.2	+staples -insul.	-
c2	50	9	182	9.4	+staples -insul.	curls partly
c3	50	8	189	9.3	air gap	-
c4	50	8	151	10.8	air gap	frame collapses
c5	50	7	179	10.3	air gap	-
PVC 3 (B6101):						
b1	50	9	177	13.2	+staples -insul.	curls partly
b2	50	11	163	12.9	+staples -insul.	curls partly
b3	50	8	181	14.9	air gap	-
b4	50	8	182	15.4	air gap	-
PVC 4 (B6656):						
d1	50	11	189	14.9	standard	curls and shrinks to ball
d4	50	12	299	15.0	+net	-
d6	50	12	199	16.4	+net -insul.	-
d2	50	11	201	16.6	+staples -insul.	curls
d3	50	10	204	16.4	+staples -insul.	curls
d5	50	16	201	14.3	+staples +fold	-
d7	50	10	204	18.1	air gap	-
d8	50	9	199	19.8	air gap	-

* A test without comments performed well.

Table 3 Results from the second series of Cone Calorimeter tests.

Test	Flux (kW/m^2)	t_{ign} (s)	q_{max} (kW/m^2)	THR (MJ/m^2)	Mounting method	Comments*
PVC 1 (B8103):						
a10	35	15	167.3	8.0	standard +net	-
a11	35	14	184.6	8.1	-"-	-
a15	50	8	190.1	8.5	-"-	-
a12	35	11	91.3	7.8	air gap	-
a13	35	10	118.2	7.1	-"-	-
PVC 2 (B9115):						
c10	35	15	171.4	9.3	standard +net	-
c11	35	16	161.1	8.9	-"-	-
c15	50	8	158.4	8.7	-"-	-
c16	50	9	155.8	8.7	-"-	-
c12	35	13	123.6	10.1	air gap	membr. came off frame
c13	35	12	144.7	10.6	-"-	frame collapses
PVC 3 (B6101):						
b10	35	19	170.6	12	standard +net	-
b11	35	19	160.2	12	-"-	-
b16	50	12	188.1	12.5	-"-	-
b17	50	12	170.9	12	-"-	-
b12	35	13	105.1	14.1	air gap	frame collapses
b13	35	11	100.2	14.1	-"-	frame collapses
b14	35	15	97.3	13.8	-"-	-
PVC 4 (B6656):						
d10	35	20	193.8	15.5	standard +net	-
d11	35	19	193.8	16.1	-"-	-
d14	50	10	230.4	15.4	-"-	-
d12	35	16	141	17.9	air gap	-
d13	35	16	146.9	16.8	-"-	-
Silicone:						
e10	35	83	75.3	10.1	standard +net	-
e11	35	85	84.2	10.1	-"-	-
e16	50	36	117.7	11.3	-"-	-
e17	50	37	110	10.7	-"-	-
e12	35	104	62.8	5.5	air gap	-
e13	35	100	64.7	5.8	-"-	-
e14	50	30	110.7	8.8	-"-	-
e15	50	31	117.4	7.8	-"-	-

* A test without comments performed well.

Table 3 cont. **Results from the second series of Cone Calorimeter tests.**

Test	Flux (kW/m^2)	t_{ign} (s)	q_{max} (kW/m^2)	THR (MJ/m^2)	Mounting method	Comments*
PTFE:						
f10	35	n.i.	-	-	standard +net	-
f11	35	n.i.	-	-	-"-	-
f16	50	87	45.2	1.9	-"-	-
f17	50	84	42.7	1.7	-"-	-
f12	35	n.i.	-	-	air gap	-
f13	35	n.i.	-	-	-"-	-
f14	50	91	18.8	1.7	-"-	-
f15	50	93	27.8	1.6	-"-	-
PTFE-Terpolymer:						
g10	35	n.i.	-	-	standard +net	white surface exposed
g11	35	n.i.	-	-	-"-	-"-
g15	50	n.i.	-	-	-"-	-"-
g12	35	n.i.	-	-	air gap	aluminized surface exposed
g13	35	n.i.	-	-	-"-	white surface exposed
g14	50	n.i.	-	-	-"-	-

* A test without comments performed well.
n.i. = no ignition

Table 4 **Results from the third supplementary series of Cone Calorimeter tests.**

Test	Flux (kW/m^2)	t_{ign} (s)	q_{max} (kW/m^2)	THR (MJ/m^2)	Mounting method	Comments*
PVC 1 (B8103):						
a16	50	8	160.8	7.8	standard +net	smooth surface exposed
a17	50	8	214.4	7.7	-"-	rough surface exposed
a18	50	8	205.2	7.7	-"-	smooth surface exposed
a19	50	9	212.4	7.5	-"-	rough surface exposed
PVC 4 (B6656):						
d15	50	10	211.9	14.8	-"-	rough surface exposed
d16	50	12	238.1	14.8	-"-	-"-
d17	50	12	242.7	14.9	-"-	-"-

* A test without comments performed well.

3.4 Mounting of sample

The mounting method for the sample specimen is very important and has a large influence on the test results. One example of the importance of the mounting method is the choice of backing material placed under the sample. The use of an insulating backing material gives a short time to ignition whereas a non-insulating backing material gives a longer time. The reason is that the sample material heats up faster in the first case as less heat is dissipated into the insulating backing material.

In the work presented here, there have been two strategies used in the optimization of the mounting method.

The first method was to find a mounting/testing protocol that gave results that were as repeatable as possible. In this case, no real consideration was taken of the final application for the membrane materials tested. This method was developed from the standard mounting method normally used for building materials which includes wrapping the reverse side of the sample specimen with aluminium foil and mounting the specimen on a backing of incombustible insulating material. An advantage with following the standard mounting method as closely as possible is that the results could be compared more easily with data from other products.

The second method was to mount the sample in a configuration that resembled its final application as closely as possible. Therefore, this mounting included an air gap under the sample, as the most common application for the membranes is as a freely mounted membrane ceiling material or wall material.

The first tests were run with the lightest and the heaviest PVC membranes (PVC 1 and PVC 4) using the standard mounting method. A mounted sample is shown in Figure 2 (a) and a burning sample during a test is shown in Figure 2 (b).

(a)

(b)

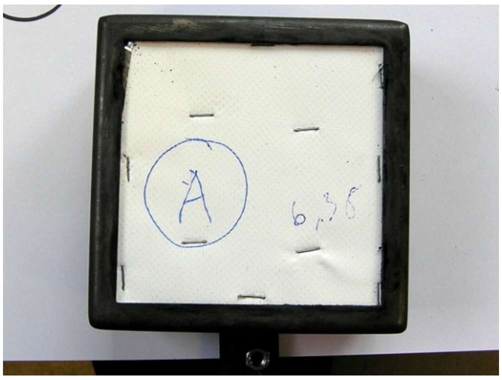
Figure 2 (a) Standard mounting of sample with frame. The sample is wrapped with aluminium foil on the reverse side and is placed on insulation material.
(b) The sample specimen curls up in a "ball" when burning in the Cone Calorimeter.

It was seen that the sample early in the test curled up from the periphery into the centre of the frame and burned like a "ball". This is not an acceptable behaviour as the burning area changes considerably and the heat release is strongly influenced by the burning area. The standard mounting method was therefore not suitable for use with textile membranes.

From the tests with the standard mounting it was concluded that the membrane material must be fixed to the backing material. The first method investigated was to fasten staples trough the membrane into the backing material. A membrane sample specimen, placed on a piece of insulated material, fixed with multiple staples to the backing is shown in Figure 3 (a). As can be seen from the figure the surface became rather uneven which is undesirable for a method that analyses a surface property (heat release per surface area) and for which the received heat flux of the sample is dependent on the distance to the radiator. If instead the membrane was placed directly on the incombustible backing material, the stapled surface became even, as can be seen in Figure 3 (b).

(a)

(b)



(c)

(d)

Figure 3 (a) Sample specimen placed on insulation and stapled to a non-combustible board.
(b) Sample specimen stapled directly on non-combustible board.
(c) As in (b) but the specimen is here mounted with the frame and ready for testing.
(d) Sample specimen mounted in the Cone Calorimeter during a test.

A sample specimen mounted by the latter method is shown in Figure 3 (c) and a burning sample during a test is shown in Figure 3 (d). It was seen that this method in some tests worked well, but in many tests, especially with the heavier membranes, one or several staples were pulled out of the backing by shrinking forces in the membrane, and the membrane eventually curled up somewhat in these cases despite the addition of staples. The mounting method with staples, therefore, did not give repeatable tests conditions between different membranes and occasionally not between repeated tests with the same type of membrane, and was not a satisfactory mounting method.

The next mounting method investigated was to use the standard mounting with aluminium foil and insulated backing and to place a metal net on top of the sample specimen. The metal net had a grid pattern with 8×8 openings on the sample surface (10 cm × 10 cm total). The disadvantage of using the metal net is that is has a certain mass that "steals" some of the heat from the external radiation, and that the ignition time for the sample (especially thin samples) can be somewhat prolonged by this in the presence of the net.

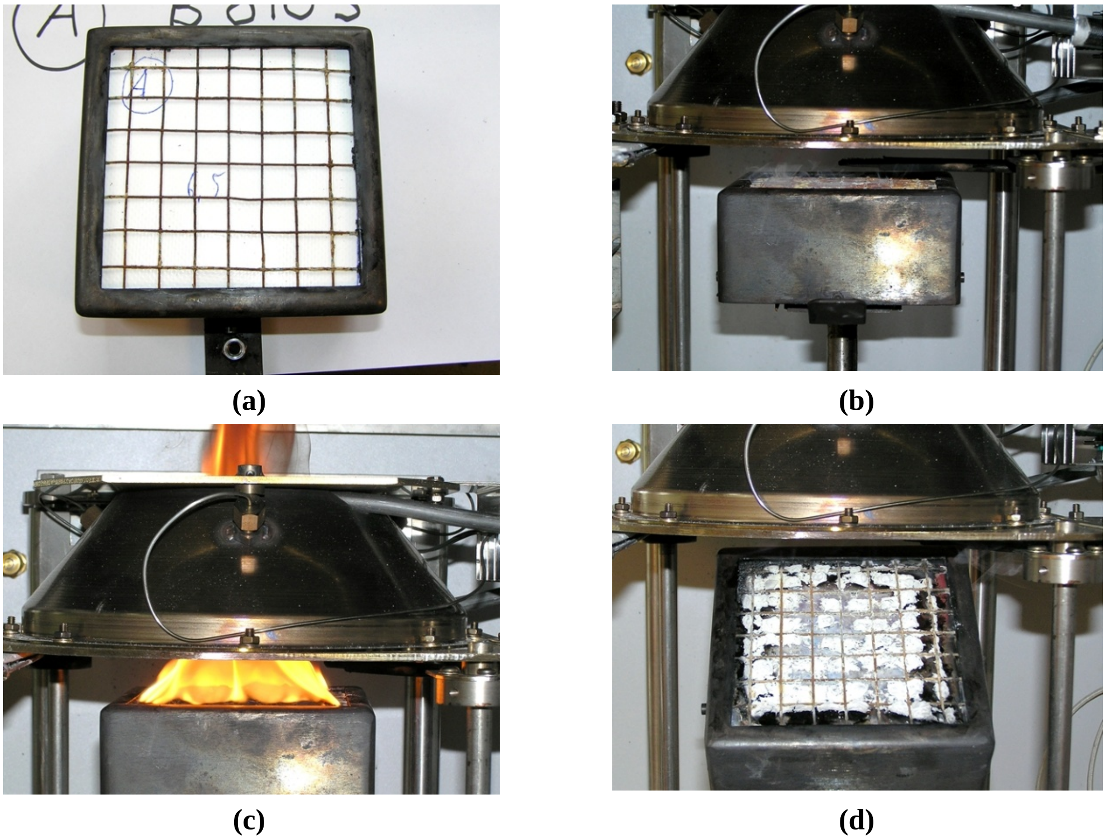


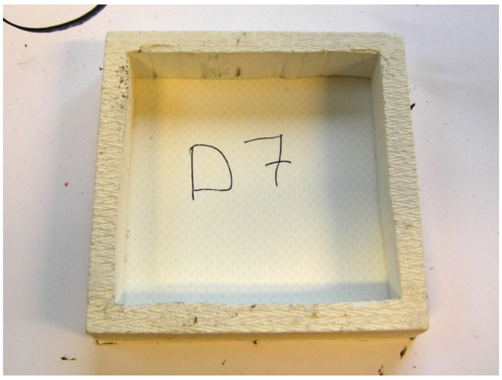
Figure 4 **(a) Standard mounting with metal net added.**
(b) Pyrolysis of sample before ignition.
(c) The sample has ignited and is burning evenly over the sample surface.
(d) Residues of the sample after the test (polyester/PVC membrane).

A sample specimen mounted with the metal net is shown in Figure 4 (a). Figure 4 (b) - Figure 4 (d) contains a series of photos showing a sample, from pyrolysis before ignition (b), through flaming combustion from the sample surface (c), to the remaining ash after completion of the test (d). Note from Figure 4 (c) that the sample was burning across the complete sample surface. This was a behaviour generally seen from this mounting method. The sample material melted before ignition and stuck to the metal net, which held the sample in place during the test.

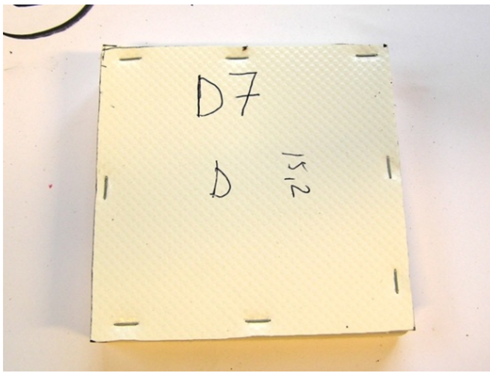
Only two tests were conducted within the first test series with the standard mounting method including a metal net. In spite of the few initial tests made, this mounting method was determined to be the best method in terms of test repeatability, as the sample surface remained rather constant throughout a test.

Duplicate tests were run with all materials using the standard mounting and metal net at both 35 kW/m^2 and 50 kW/m^2 external radiant flux (see Table 2 and Table 3). Some supplementary tests were run with two of the materials at 50 kW/m^2 (see Table 4).

The method with the sample mounted with an air gap is showed in Figure 5. A frame was consisting of non-combustible mineral board and the membrane sample was stapled to the frame. The outer dimension of the frame were 110 mm × 110 mm and the thickness was 10 mm. The mineral board had a thickness of 20 mm which was the depth of the air gap.

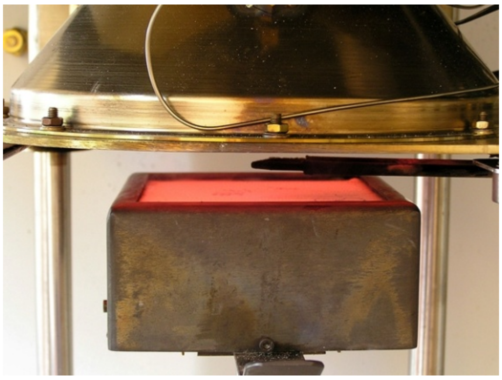


(a)

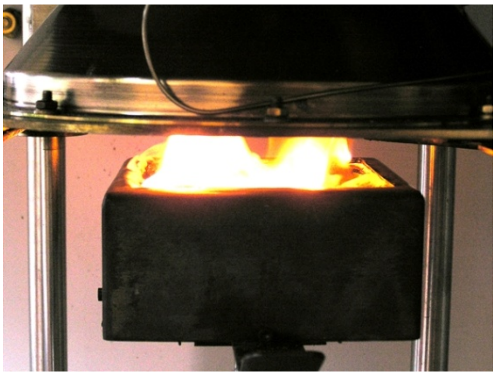


(b)

Figure 5 **(a) Sample specimen mounted on frame to get an air-gap under the membrane (turned up-side-down to show the frame). (b) Sample specimen mounted on frame.**



(a)



(b)

(c)

Figure 6 **(a) Sample specimen before ignition.**
(b) The membrane opens up just after ignition and material falls down and burns from the bottom of the air-gap.
(c) The material remaining in position close to the frame continues to burn in the end of the test.

The frame with the sample specimen was placed on alumina foil on top of insulation material and tested using a metal frame. A complete test can be seen in Figure 6 (a) – (c). The sample generally ignited and burned shortly from the sample surface before the membrane opened up and material fell down and burned at the bottom of the air gap. One disadvantage of this method is that as the material falls down and the distance to the radiator increases and consequently the heat flux received by the sample material becomes lower than specified.

Duplicate tests were run with all materials using the mounting method with an air gap both at 35 kW/m^2 and 50 kW/m^2 external radiant flux (see Table 2 and Table 3).

3.5 Discussion of test results

The test results on maximal heat release (q_{max}) from the duplicate tests made with samples mounted with insulation and metal net are shown in Figure 7 and Figure 8. The heat release is plotted versus the time to ignition (t_{ign}) to obtain a comprehensive picture of the performance in the Cone Calorimeter. Note that only sample materials that did ignite in the tests are included in the diagrams.

The results from the tests with an external radiation of 35 kW/m^2 are shown in Figure 7. As shown in the plot the PVC membranes are gathered in a group with similar values of t_{ign} and q_{max}. The silicone membrane had a considerably longer t_{ign} and evolved much less peak energy when burning (lower q_{max}). It can also be seen that none of the PTFE membranes ignited from a heat flux of 35 kW/m^2.

If studying the group of PVC membranes more closely, it can be seen that the membranes can be separated and that their performance in the test are quite logical. The two membranes with the lowest mass per unit area, PVC 1 and PVC 2 (see Table 1), have the shortest t_{ign}, and fall into one sub-group. The two membranes with considerably higher mass per unit area, PVC 3 and PVC 4, have longer t_{ign}, and fall into another sub-group. Regarding q_{max} there is no clear significant separation, except that PVC 4 gives the highest peak. A separation in heat release can, however, be seen from the total heat released during the complete test (THR). Logically THR increases with increasing mass per unit area for the PVC membranes (see Table 3) which have the same type of coating, but different thicknesses. It is also interesting to note that the silicone membrane has a relatively high THR, actually higher than the two lightest PVC membranes tested.

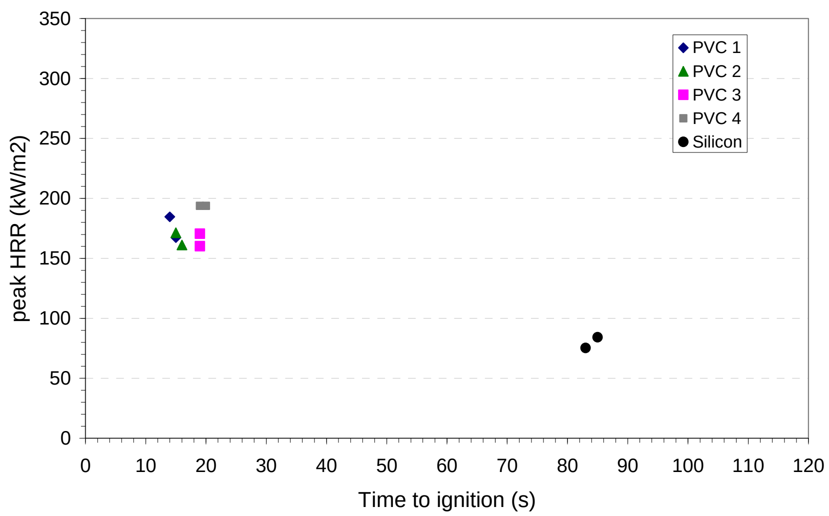


Figure 7 Results from 35 kW/m^2 Cone Calorimeter tests with the sample specimen mounted with insulated backing material and a metal net on top of the sample.

The results from the tests with an external radiation of 50 kW/m^2 are shown in Figure 8. Here the separation of the PVC membranes with respect to t_{ign} is less clear compared to the 35 kW/m^2 tests; but a separation is still present. This is expected as the ignition time is much shorter at this higher flux.

As there was a rather poor repeatability especially in q_{max} for PVC 1 and PVC 4 from the first two series of tests, repeated tests were run with these materials in a third supplementary series of tests (see Table 4). As can be seen from Figure 8 there is a significant variation in the q_{max} measured from the individual tests with these material. This variation could not be explained from observations in the tests. The results on total heat release (THR) from these materials had, however, a high repeatability as can be seen in Table 2-Table 4.

There is a very clear separation of the group of PVC membranes, the silicone membrane, and the PTFE membrane which ignited at this heat flux (see Figure 8). The silicone membrane had comparable high THR also at this heat flux, whereas the PTFE membrane gave a very low THR (see Table 3).

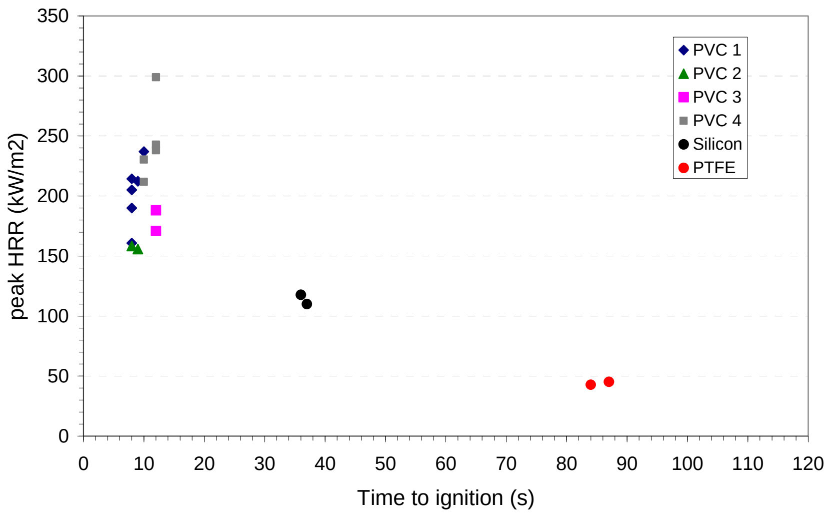


Figure 8 Results from 50 kW/m^2 Cone Calorimeter tests with the sample specimen mounted with insulated backing material and a metal net on top of the sample.

The test results concerning the maximal heat release (q_{max}) plotted versus time to ignition (t_{ign}) from the duplicate tests with samples mounted with an air gap are shown in Figure 9 and Figure 10. The most significant occurrence in the tests with an air gap, was that the PVC membranes opened up (burnt a hole) early after ignition, whereas the silicone membrane and the PTFE membranes never opened up.

There was a general problem in these tests in that the frame was easily broken by shrinking forces from the PVC membranes. The rather non-repeatable results for the PVC membranes in the tests with 35 kW/m^2, shown in Figure 9, are probably a direct result of this behaviour. There is, however, some logical separation in t_{ign} if ignoring the two tests with PVC 3 with the shortest t_{ign}. In these two tests the frame broke rather early in the test.

One can observe that while q_{max} has decreased for the PVC membranes, comparing the tests with an air gap and the tests with the metal net, q_{max} for the silicone membrane is rather constant between the two mounting methods. The reason for this is of course that the silicone membrane does not open up in the tests with an air gap while the PVC membranes do open up.

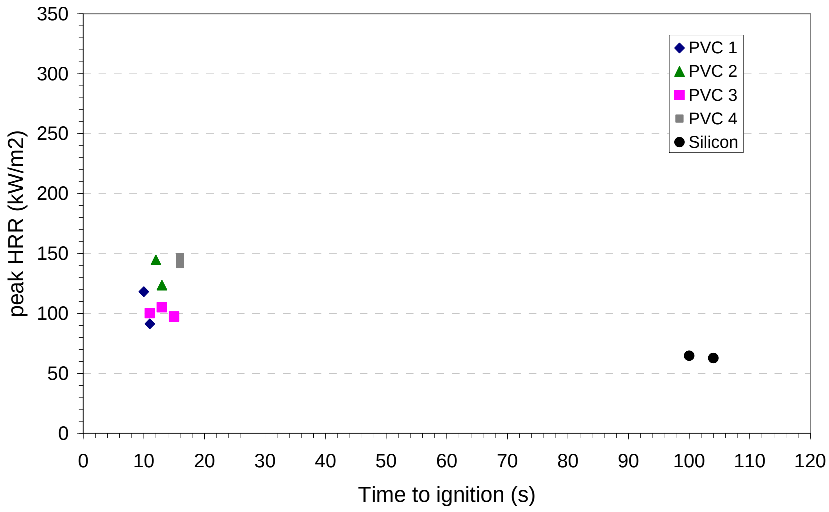


Figure 9 Results from cone calorimeter tests with 20 mm air gap sample mounting and 35 kW/m^2 external radiation.

Figure 10 shows a clear separation between the group of PVC membranes, the silicone membrane, and the PTFE membrane which ignited at the higher flux. There is a better repeatability at this heat flux between the repeated tests with the PVC membranes, and there are logical separations in both t_{ign} and q_{max}.

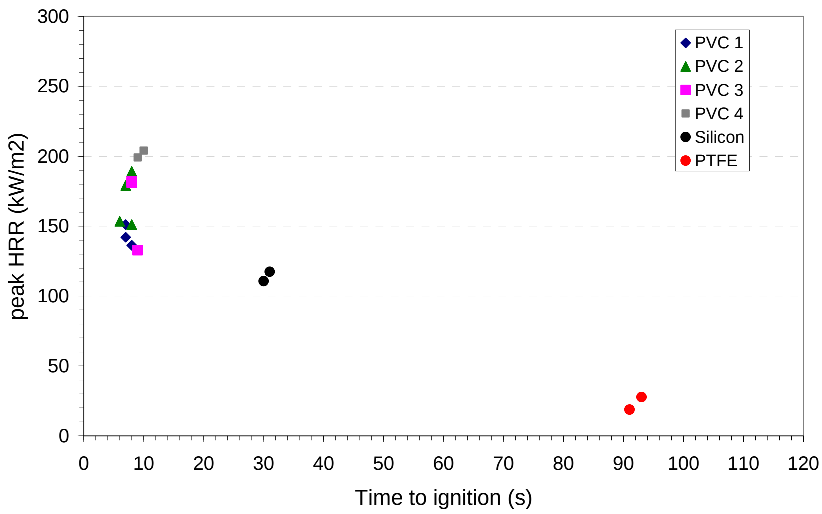


Figure 10 Results from cone calorimeter tests with 20 mm air gap sample mounting and 50 kW/m^2 external radiation.

If comparing the results for q_{max} from tests at 50 kW/m^2, with an air gap and the tests with metal net and backing, it can be seen that the results for the PVC membranes and for the silicone membrane are of the same order of magnitude between tests with the two mounting methods. The results on q_{max} for PTFE, however, are about 50% lower in the tests with an air gap.

3.6 Conclusions

Two alternative mounting methods for the sample specimen were developed in the first tests series. One of the mounting methods included placing the sample specimen on an insulating backing material and placing a metal net on top of the sample to keep it from curling up and thereby changing its exposure area during the test. This was the mounting method most closely resembling the standard mounting method for Cone Calorimeter tests. The other mounting method included mounting the sample specimen with an air gap.

These mounting methods were systematically investigated with the different types of membranes available in a second test series.

The mounting method with insulation and a metal net had most advantages. It is straight forward to mount the sample specimen; the results have the potential to be repeatable as the specimen surface stays relatively constant during a test; and, especially at 50 kW/m^2 heat flux, the results are very similar to the results from test with samples mounted with an air gap which represents the end-use condition.

The mounting method with an air-gap requires more work in mounting the sample, and at least with the present type of frame, there are problems with staples pulled out of the frame, or rupture of the frame, from tensile forces in the shrinking membrane material.

The general recommendations for further testing in the project with membrane materials are to primarily use the mounting method with insulation and a metal net, and to use a heat flux of 50 kW/m^2. If using a lower heat flux some materials might not ignite, as was the case for the PTFE membrane. However, if there is to low separation of material performance at the high heat flux, and the samples ignite at 35 kW/m^2, then 35 kW/m^2 may be used as appropriate.

4 SBI tests

4.1 Introduction

The SBI test, EN 13823, evaluates the potential contribution of a product to the development of a fire, under a fire situation, simulating a single burning item in a room corner near to that product. The SBI is the major test method for reaction-to-fire classification of linings within the European classification system for building materials, which is described in the classification standard EN 13501. The SBI-test is relevant for the Euro classes A1, A2, B, C and D. The classification requirements from EN 13501 are given in Appendix 4.

A schematic drawing of the test apparatus is shown in Figure 11. Specifications of the SBI-test are summarised in Table 5.

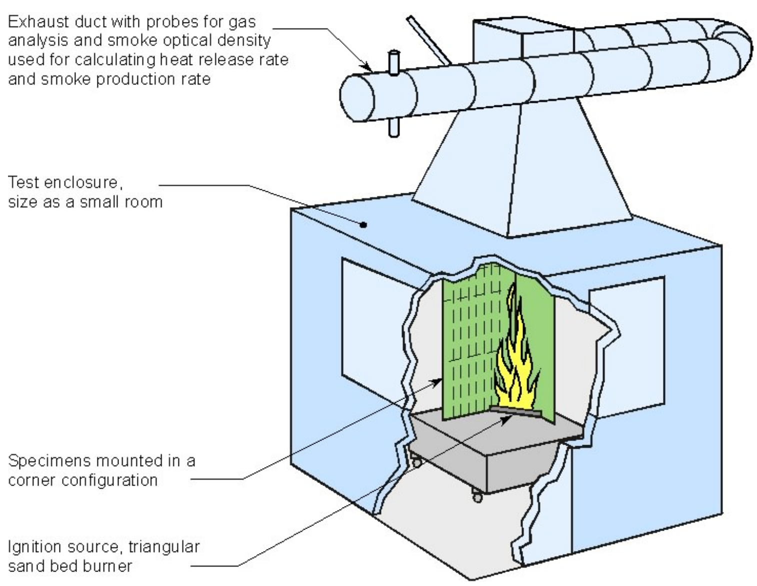


Figure 11 Schematic drawing of the SBI test apparatus.

Table 5 EN 13823 SBI test specifications.

Specimens	Samples for 3 tests. Each test requiring one sample of 0.5×1.5m and one sample of 1.0×1.5m
Specimen position	Forms a vertical corner
Ignition source	Gas burner of 30 kW heat output placed in corner
Test duration	20 min
Conclusions	Classification is based on FIGRA, THR_{600s} and maximum flame spread. Additional classification is based on SMOGRA, TSP_{600s} and droplets/particles.

The SBI is an intermediate scale test. The test samples, 0.5 m × 1.5 m and 1.0 m × 1.5 m are mounted in a corner configuration where they are exposed to a gas flame ignition source. Direct measure of fire growth (Heat Release Rate, HRR) and light obscuring smoke (Smoke Production Rate, SPR) are principal results from a test. Other properties, such as the occurrence of burning droplets/particles and maximum flame spread, are also observed.

The index FIGRA, FIre Growth RAte, is used to determine the Euroclass. The concept is to classify the product based on its tendency to support fire growth. Thus FIGRA is a measure of the biggest growth rate of the fire during an SBI test as seen from the test start. FIGRA is calculated as the maximum value of the function (heat release rate)/(elapsed test time), units are W/s. A graphical presentation is shown in Figure 12.

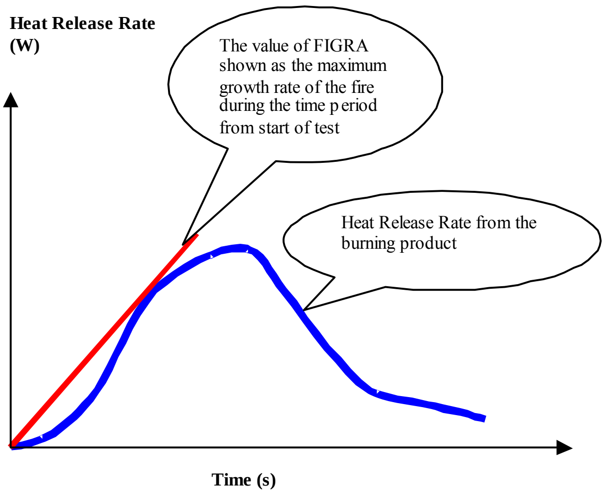


Figure 12 Graphical representation of the FIGRA index.

To minimise noise the HRR data is calculated as a 30s running average. In addition, certain threshold values of HRR and the total heat release rate must first be reached before FIGRA is calculated.

The additional classification for smoke is based on the index SMOGRA, SMOke Growth RAte. This index is based on similar principles to those for FIGRA. SMOGRA is calculated as the maximum value of the function (smoke production rate)/(elapsed test time) multiplied by 10 000. The data for the smoke production rate, SPR, is calculated as a 60s running average to minimise noise. In addition, certain threshold values of SPR and integral values of SPR must first be reached before SMOGRA is calculated.

Detailed definitions of FIGRA and SMOGRA can be found in EN 13823 (SBI).

4.2 Test programme

The first six materials in Table 1 were tested in the SBI. Two methods for mounting the sample in the SBI were investigated and at least duplicate tests were run. The samples were, as a rule, mounted with the rough surface exposed to the incident heat flux, since the rough side would be likely to be faced inwards in a building.

All tests were video filmed and photographs were taken before, during, and after the test. Summarized results of the tests are given in Section 4.3 and the test results are discussed in Section 4.4 and 4.5. Photos of selected test specimens are given in Appendix 2, and graphs with HRR and SPR results are given in Appendix 3.

4.3 Summary of test results

Table 6 Results from SBI tests.

Sample	$FIGRA_{0.2MJ}$ (W/s)	$FIGRA_{0.4MJ}$ (W/s)	THR_{600s} (MJ)	SMOGRA (m^2/s^2)	TSP_{600s} (m^2)	LFS (Y/N)	FDP (Y/N)[i]	Preliminary SBI classification	Membrane burns hole (s)	Mounting method[ii]	Comments
PVC 1 (B8103):											
a1	0.0	0.0	0.6	53.1	115.8	N	N; N	A1-B / s2 / d0	13	1	-
a2	0.0	0.0	0.6	65.6	126.9	N	N; N	A1-B / s2 / d0	13	1	Photo in Appendix 2
a3	276.1	117.7	1.6	130.9	146.0	N	N; N	C / s2 / d0	13	2	-
a4	365.1	212.6	1.4	207.2	145.8	N	N; N	C / s3 / d0	13	2	Photo in Appendix 2
PVC 2 (B9115):											
c1	59.5	0.0	0.7	87.2	130.4	N	N; N	A2-B / s2 / d0	17	1	Photo in Appendix 2
c2	0.0	0.0	0.5	86.7	115.8	N	N; N	A1-B / s2 / d0	17	1	-
c3	374.8	220.3	1.2	145.0	127.1	N	N; N	C / s2 / d0	17	2	Photo in Appendix 2
c4	306.1	200.0	1.4	144.5	145.2	N	N; N	C / s2 / d0	17	2	-
PVC 3 (B6101):											
b1	39.0	29.9	1.1	28.8	137.8	N	N; N	A2-B / s2 /d0	-	1	Test failed*
b2	23.7	23.7	1.0	69.8	162.4	N	N; Y	A2-B / s2 / d2	27	1	Burning piece of material fell down, Photo in Appendix 2
b3	215.0	79.8	2.0	81.2	191.4	N	N; N	C / s2 / d0	30	1	-
b4	238.6	191.7	1.6	88.1	135.9	N	N; N	C / s2 / d0	27	2	-
b5	244.3	182.3	1.8	97.7	163.8	N	N; N	C / s2 / d0	27	2	Photo in Appendix 2
b6	185.5	66.2	1.5	77.9	145.9	N	N; N	C / s2 / d0	27	2**	-

[i] Flaming droplets (FDP): flamimg ≤ 10s; flamimg > 10s.
[ii] Monting methods: 1 – membrane mounted with an air gap, 2 – membrane mounted with an air gap and a metal bar as support in the corner (see section 4.4).

* The sample shrinked from the heat and the strong forces pulled the sample loose from the mounting screews in the lower part of the membrane.
** Mounting method 2, but the metal bar support was placed behind the membrane and fastened to the membrane with steel wires.

Table 6 cont. Results from SBI tests.

Sample	FIGRA$_{0.2MJ}$ (W/s)	FIGRA$_{0.4MJ}$ (W/s)	THR$_{600s}$ (MJ)	SMOGRA (m^2/s^2)	TSP$_{600s}$ (m^2)	LFS (Y/N)	FDP (Y/N)[i]	Preliminary SBI classification	Membrane burns hole (s)	Mounting method[ii]	Comments
PVC 4 (B6656):											
d1	321.1	296.2	6.4	182.5	449.4	N	N; Y	D / s3 / d2	39	1	Burning piece of material fell down, Photo in Appendix 2
d2	476.2	476.2	4.1	207.6	285.7	N	N; N	D / s3 / d0	40	1	-
d3	337.8	326.9	5.0	131.8	358.3	N	N; N	D / s3 / d0	34*	2	-
d4	424.8	424.8	6.0	162.0	373.7	N	N; N	D / s3 / d0	33*	2	Burning piece of material fell down, but inside border, Photo in Appendix 2
Silicone:											
e1	40.2	0.0	0.8	18.1	36.3	N	N; N	A2-B / s1 / d0	no hole	1	Photo in Appendix 2
e2	47.5	0.0	0.9	21.8	35.6	N	N; N	A2-B / s1 / d0	-"-	1	-
e3	0.0	0.0	0.9	0.0	33.8	N	N; N	A1-B / s1 / d0	-"-	2	Photo in Appendix 2
e4	0.0	0.0	0.8	0.0	35.7	N	N; N	A1-B / s1 / d0	-"-	2	-
PTFE:											
f1	0.0	0.0	0.1	0.0	15.5	N	N; N	A1-B / s1 / d0	no hole	1	Photo in Appendix 2
f2	0.0	0.0	0.1	0.0	13.4	N	N; N	A1-B / s1 / d0	-"-	1	-
f3	0.0	0.0	0.1	0.0	12.3	N	N; N	A1-B / s1 / d0	-"-	2	Photo in Appendix 2
f4	0.0	0.0	0.1	0.0	13.4	N	N; N	A1-B / s1 / d0	-"-	2	-

[i] Flaming droplets (FDP): flamimg ≤ 10s; flamimg > 10s.
[ii] Mounting methods: 1 – membrane mounted with an air gap, 2 – membrane mounted with an air gap and a metal bar as support in the corner (see section 0).

* A small hole was formed at the base of the corner at 17 s. A major hole opened up after more than 30 s.

Table 7 Test parameter explanation SBI (EN 13823).

Parameter	**Explanation**
Test start	Start of data collection.
End of test	26:00 (min:s) after test start.
HRR_{av}, maximum, kW	Peak Heat Release Rate of material between ignition of the main burner and end of test (burner heat output excluded), as a 30 seconds running average value.
SPR_{av}, maximum, m^2/s	Peak Smoke Production Rate of material between ignition of the main burner and end of test (burner heat output excluded), as a 60 seconds running average value.
$FIGRA_{0,2MJ}$, W/s	FIre Growth RAte index is defined as the maximum of the quotient $HRR_{av}(t)/(t\text{-}300s)$, multiplied by 1000. During 300 s $\le t \le$ 1500 s, threshold value 3 kW and 0.2 MJ.
$FIGRA_{0,4MJ}$, W/s	FIre Growth RAte index is defined as the maximum of the quotient $HRR_{av}(t)/(t\text{-}300s)$, multiplied by 1000. During 300 s $\le t \le$ 1500 s, threshold value 3 kW and 0.4 MJ.
$SMOGRA$, m^2/s^2	SMOke Growth RAte index is defined as the maximum of the quotient $SPR_{av}(t)/(t\text{-}300s)$, multiplied by 10 000. During 300 s $\le t \le$ 1500 s, threshold value 0.1 m^2/s and 6 m^2.
THR_{600s}, MJ	Total heat release of the sample during 300 s $\le t \le$ 900 s
TSP_{600s}, m^2	Total smoke production of the sample during 300 s $\le t \le$ 900 s

4.4 Mounting of sample

The mounting of the sample specimen in the SBI is described in EN 13823. The mounting can be done according to two principles: 1) mounting as in the end use application, or 2) standard mounting. When products are tested using the first principle, the test results are valid only for that application. When products are tested using the standard mounting, the test results are valid for that specific end use application and can be valid for a wider range of end-use applications. For the standard mounting there are specifications given in the standard; however, the standard mounting is specifically designed for board materials.

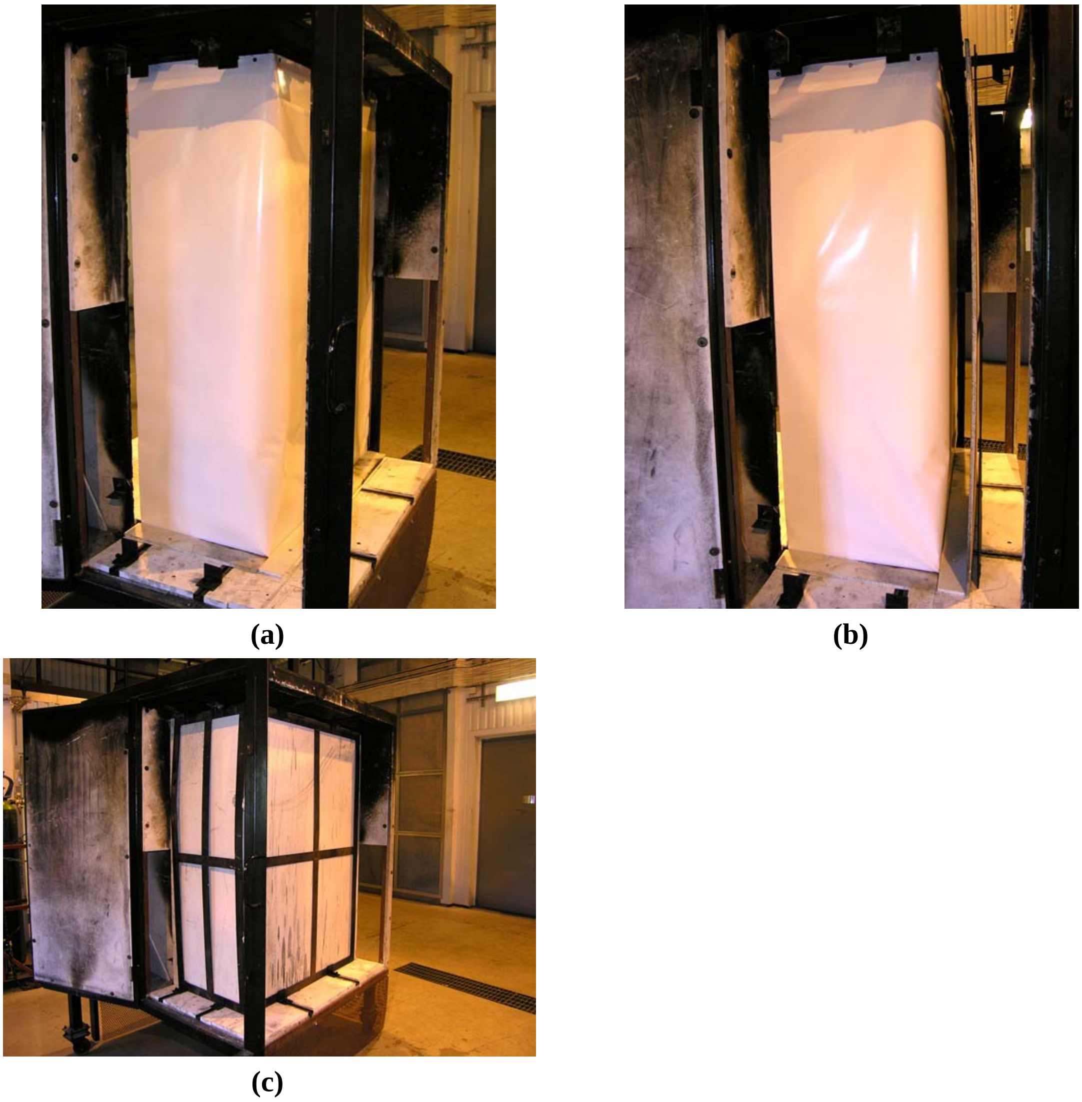


Figure 13 Photos showing details of a membrane sample material mounted in the SBI-test trolley.
(a) The membrane is fixed in the upper and lower edges.
(b) A backing board is placed behind the membrane giving an 80 mm air gap.
(c) Sample ready for testing with backing boards secured behind both flanks of the mounted membrane.

There are, therefore, no specific mounting requirements or instructions given for technical textile membranes in EN 13823. For some other groups of product, e.g., gypsum boards and sealing membranes, mounting specifications are given in special product standards; for other groups of products, e.g., pipe insulation and sandwich panels, product standards are under development.

There is, however, one product standard available for a specific application of membrane materials. This is the product standard for stretched ceilings, EN 14716:2004 [8]. In this product standard there is a detailed description of the mounting requirements for the SBI test, including a description of a test frame. This test frame was not available at the time for the tests reported here, but the mounting method referred to as “method 1” below, is in all respects very similar to the mounting requirements given in EN 14716:2004.

The standard mounting specifications have been followed as far as possible in the tests reported here. The general mounting method used is shown in Figure 13. One piece of membrane was fitted in the corner position and mechanically fixed in the upper and lower edges with metal screws. Backing boards were positioned behind the sample with an air-gap of 80 mm (mounting specification given for standard mounting in EN 13823).

(a) (b)

Figure 14 The methods used for mounting the sample specimen in the SBI; in both cases there was a 80 mm air gap behind the membrane which was fixed in the upper and lower edges.
(a) Method 1: no support in the corner.
(b) Method 2: metal profile as support in the corner.

It was seen that the mounting method described above gave non-repetitive results for some membrane materials, and a modification of the mounting method was made by fitting a metal support in the corner position. The metal support used was L-profile in steel with the dimensions 20 mm×20 mm. A sample specimen mounted without support is shown in Figure 14 (a), and the same membrane material mounted with a metal profile as support is shown in Figure 14 (b).

Duplicate tests with both mounting methods were run with all membrane materials.

4.5 Discussion

The test results are presented as bar-graphs in Figure 15 – Figure 19. Limiting values for the Euroclass classification are indicated in the figures.

Note that the classification information achieved from an SBI-test is a preliminary classification only. The final classification of a product is often given from the combined results of several tests methods, depending on the class, as described in EN 13501 (see Appendix 4). The test results of EN ISO 11925-2 are given in section 5.

Results for FIGRA $_{0.4MJ}$ are presented in Figure 15. FIGRA $_{0.4MJ}$ is the first FIGRA parameter studied when assessing the classification of a product. As can be seen from the figure, the PVC 4 membrane indicates a D class, while the other membranes have to be evaluated using the FIGRA $_{0.2MJ}$ data.

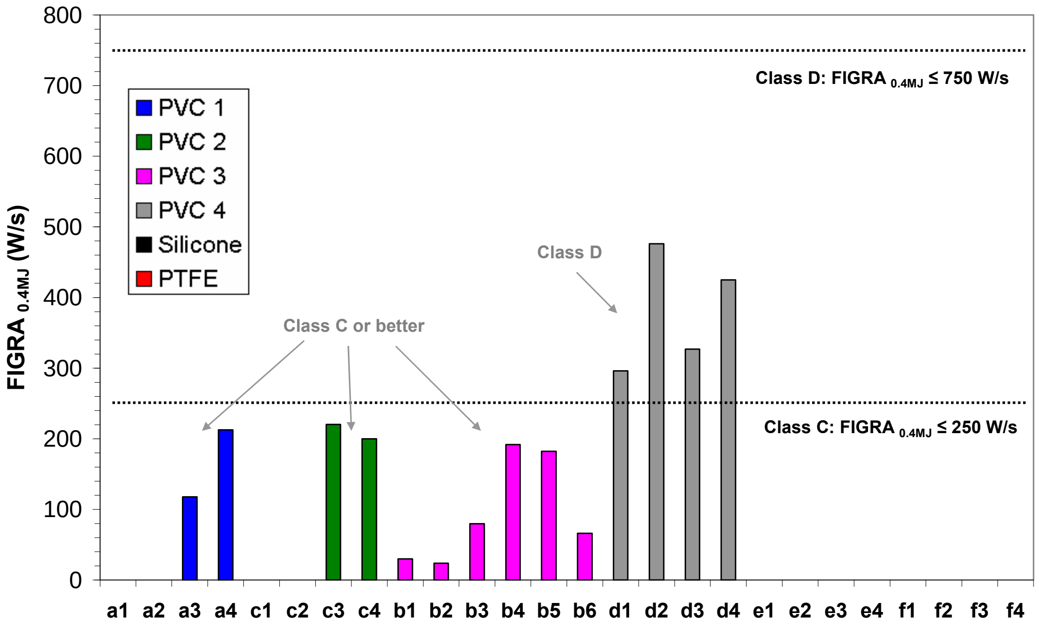


Figure 15 Fire growth rate (FIGRA $_{0.4MJ}$) from EN 13823 (SBI)-tests.

The results for FIGRA $_{0.2MJ}$ presented in Figure 16 show that the PVC 1 results indicate A1-B class for the tests without a corner support (tests a1 and a2), while the tests with a corner support (tests a3 and a4) indicate C-class. The reason for the large difference in results from tests with the two mounting methods can be seen in the photos from the tests in Appendix 2.

In the tests without a corner support, the membrane bends forward away from the flame when the flame attack has opened up a hole (Appendix 2, Figure 93). In the tests with a corner support, the material is kept in position after the membrane has opened up, which results in continued vertical flame spread (Appendix 2, Figure 94).

The tests with PVC 2 and PVC 3 show basically the same behaviour as PVC 1. Without a corner support the tests indicate A1-B or A2-B classes (material bends away from the flame), but with a corner support the test results in a C-class indication.

The silicone membrane results indicate A2-B class for mounting without corner support and A1-B class for mounting with corner support. This is the reverse behaviour compared to the PVC membranes. A reason for the slightly better class indication for the silicone membrane in the tests with a corner support could possibly be that the support bar protected some of the combustible coating from the flames. As the total amount of material combusted was low for the silicone membrane the material protected by the support bar could have had an influence in this case.

The PTFE membrane has A1-B class indication regardless of sample mounting method.

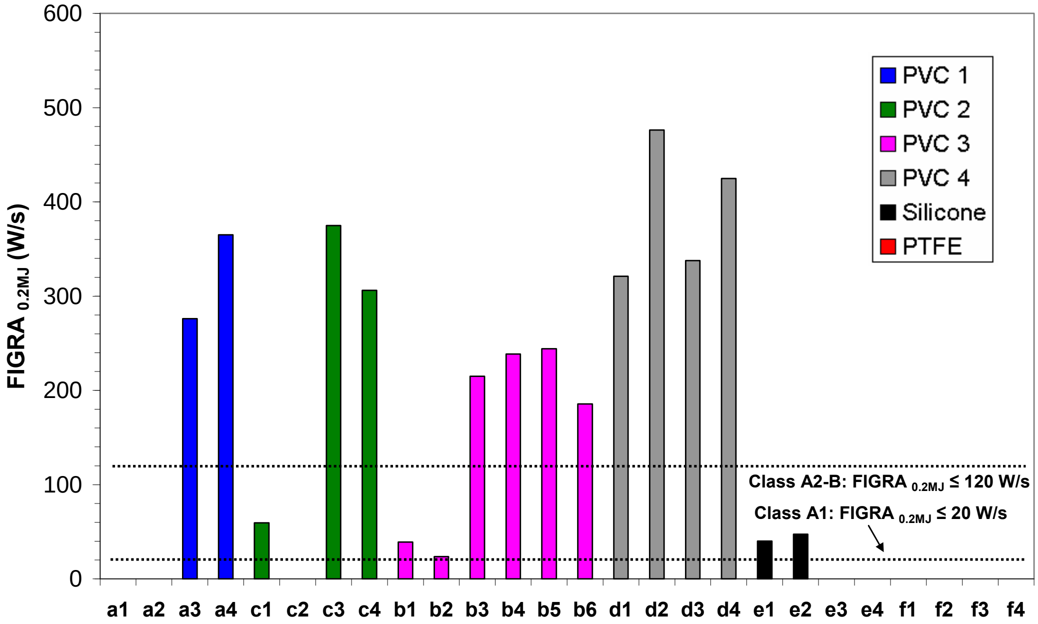


Figure 16 Fire growth rate (FIGRA $_{0.2MJ}$) from EN 13823 (SBI)-tests.

There are also criteria on THR to be met for the classification. The results on THR $_{600s}$ are given in Figure 17. It can be seen from the figure that the results on THR generally were low and that there are no changes in indicated classes from FIGRA due to high THR results.

One can note from Figure 17 that the PTFE membrane had a low but measurable THR.

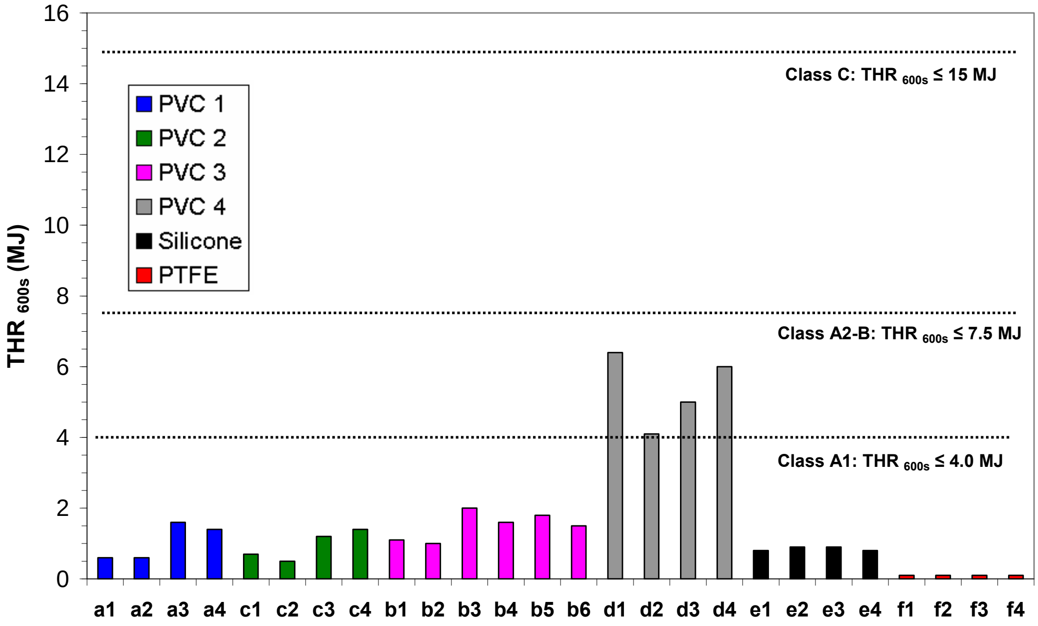


Figure 17 Total heat release (THR_{600s}) from EN 13823 (SBI)-tests.

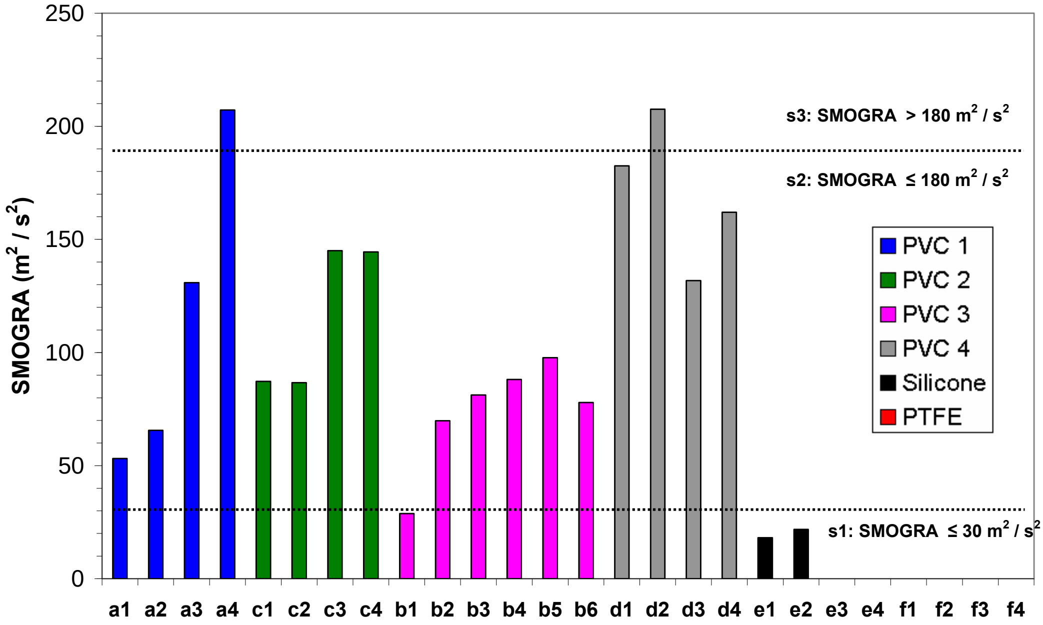


Figure 18 Smoke growth rate (SMOGRA) from EN 13823 (SBI)-tests.

Additional classification for smoke is given from SMOGRA and TSP (see Section 4.1), with results shown in Figure 18 and Figure 19, respectively. It can be seen that one of the PVC 1 tests with a corner support reach the s3-class, which all tests with PVC 4 also do (from high results on TSP). All remaining test with PVC membranes, irrespective of mounting method, reach the s2-class.

The silicone and the PTFE membrane both reach the s1-class; and the PTFE membrane is the membrane that produces the least smoke.

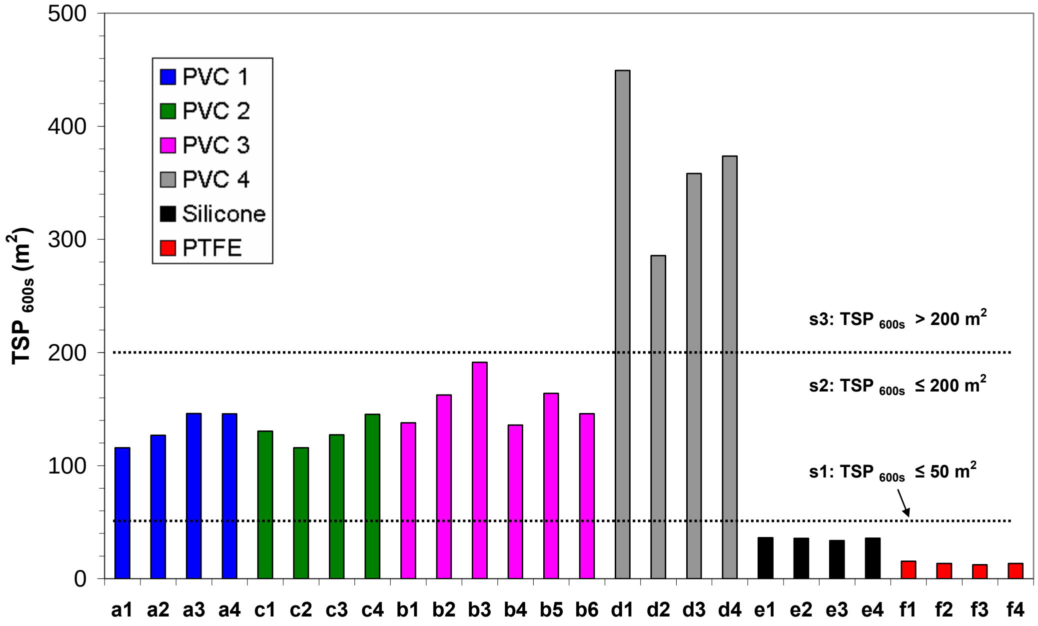


Figure 19 Total smoke production (TSP_{600s}) from EN 13823 (SBI)-tests.

4.6 Conclusions

There was a clear difference in reaction-to-fire performance between the different types of membranes tested. The PTFE membrane had the best performance and achieved a preliminary A1-B/ s1/ d0 class from the SBI. The Silicone membrane also performed well and achieved a preliminary A2-B/ s1/ d0 class or A1-B/ s1/ d0.

The PVC membranes, which included a combustible polyester fabric, showed less desirable fire performance from the criteria used in evaluating a test with the SBI. The PVC 4 membrane with the thickest coating showed flame spread and burning all the way to the top of the test specimen. This resulted in a D/ s3 / d0-d2 class, irrespectively of sample mounting method used. The PVC 1, PVC 2 and PVC 3 membranes, which had less thick coating, showed better fire behaviour compared to PVC 4, but the results of a test were strongly influenced by the sample mounting method used.

If the PVC sample was mounted without any support in the corner position, the membrane bent away from the corner after burning a hole and avoided the flames from the burner. This resulted in A1-B/ s2 / d0 or A2-B/ s2/ d0 class. If, however, a thin metal support was put in the corner position, the material was held in place after a hole had opened up, and flame spread continued. This resulted in C / s2 / d0 class, i.e. a lower class.

The fact that the mounting method used for the SBI test had such a large influence on the results for some types of membranes was an important finding.

5 Small flame tests

5.1 Introduction

EN ISO 11925-2 evaluates the ignitability of a product after exposure to a small flame. The test is relevant for the Euroclasses B, C, D and E.

A schematic drawing of the test apparatus is shown in Figure 20. Specifications of EN ISO 11925-2 are summarised in Table 8.

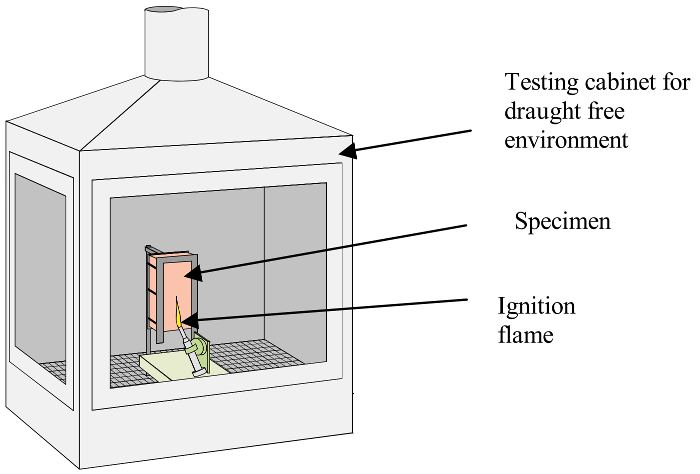


Figure 20 EN ISO 11925-2 Small flame test.

Table 8 EN ISO 11925-2 Small flame test, specifications.

Specimens	250 mm long, 90 mm wide, thickness < 60 mm
Specimen position	Vertical
Ignition source	Small burner. Flame inclined 45° and impinging either on the edge or the surface of the specimen.
Flame application	30s for Euroclass B, C and D. 15s for Euroclass E.
Conclusions	Classification is based on the time for flames to spread 150mm and occurrence of droplets/particles.

5.2 Test results

The tests were conducted using surface exposure and the time for flame exposure time was 30 seconds. It was assumed that edge exposure is not relevant for normal application of membranes in tensile structures. Results from the tests are summarised in Table 9.

Note: edge exposure is often the more severe mode of testing

Table 9 Results from EN ISO 11925-2.

Test	The sample ignited (s)	The flames reach 150 mm (s)	Burning droplets (Yes/No)	Filter paper ignited	
				Yes/No	Time (s)
PVC 1 (B8103):					
1	9	24	N	N	-
2	8	-	N	N	-
3	9	25	N	N	-
4	8	-*	N	N	-
5	9	27	N	N	-
6	9	23	N	N	-
PVC 2 (B9115):					
1	12	26	N	N	-
2	11	28	N	N	-
3	13	-*	N	N	-
4	12	27	N	N	-
5	11	-*	N	N	-
6	10	28	N	N	-
PVC 3 (B6101):					
1	11	-*	N	N	-
2	12	-*	N	N	-
3	13	-*	N	N	-
4	12	-*	N	N	-
5	14	-*	N	N	-
6	12	-*	N	N	-
PVC 4 (B6656):					
1	8	-*	N	N	-
2	9	-*	N	N	-
3	9	-*	N	N	-
4	9	-*	N	N	-
5	8	-*	N	N	-
6	10	-*	N	N	-

*Flaming ceased before the flame tip reached 150 mm.

Table 9 cont. Results from EN ISO 11925-2.

Test	Ignition (s)	Flames reaches 150mm at time (s)	Burning droplets (Yes/No)	Burning droplets ignites substrate	
				Yes/No	Time (s)
Silicone:					
1	-	-*	N	N	-
2	-	-*	N	N	-
3	-	-*	N	N	-
4	-	-*	N	N	-
5	-	-*	N	N	-
6	-	-*	N	N	-
PTFE:					
1	-	-*	N	N	-
2	-	-*	N	N	-
3	-	-*	N	N	-
4	-	-*	N	N	-
5	-	-*	N	N	-
6	-	-*	N	N	-
PTFE-Terpolymer:					
1	-	-*	N	N	-
2	-	-*	N	N	-
3	-	-*	N	N	-
4	-	-*	N	N	-
5	-	-*	N	N	-
6	-	-*	N	N	-

*Flaming ceased before the flame tip reached 150 mm.

5.3 Discussion

For the PVC 1 material and the PVC 2 material, flames reached 150 mm before 60 s. For classification according to EN 13501, this means that these materials can be classified as class E at a maximum. For E-class, positive test results from EN ISO 11925-2 with a time for flame exposure of 15 s are required (see EN 13501).

The reason for the fast flame spread for PVC 1 and PVC 2 was probably their limited thickness. In the tests the flame burned a hole in the material, and the flame spread rather quickly after that.

For the remaining materials: PVC 3, PVC 4, PTFE and PTFE-Terpolymer, the results were all very good, and fulfil the requirement for B-classification.

6 Preliminary classification from test results

The results from EN 13823 (SBI) tests and EN ISO 11925-2 (small flame) tests are used for classification of reaction-to-fire performance as described in EN 13501 (see Appendix 4). The preliminary classifications of the materials reported on here are presented in Table 10.

Note that the tests results are not sufficient for an full classification according to EN 13501 and that the classes presented in Table 10 are indicative only. For an official classification, triplicate EN 13823 test must be run. Further for classification in classes A1 and A2, materials have to pass the various criteria of EN ISO 1182 (ignitability test) and EN ISO 1716 (calorific value), see Appendix 4.

Table 10 Classification from test results of EN 13823 and EN ISO 11925-2 and resulting preliminary Euroclasses.

Membrane	EN 13823 (SBI) Mounting method 1	EN 13823 (SBI) Mounting method 2	EN ISO 11925-2 (small flame)	Preliminary Euroclass
PVC 1 (B8103)	2 tests: B	2 tests: C	E	E
PVC 2 (B9115)	2 tests: B	2 tests: C	E	E
PVC 3 (B6101)	1 test: B 1 test: C	2 tests: C	B-D	C
PVC 4 (B6656):	2 tests: D	2 tests: D	B-D	D
Silicone	2 tests: A2-B	2 tests: A1-B	B-D	B*
PTFE	2 tests: A1-B	2 tests: A1-B	B-D	B*

* Results from EN ISO 1716 and EN ISO 1182 with Silicone and PTFE showed that these products did not fulfil the requirements for classes A1-A2.

7 Conclusions and recommendations

Pre-characterization tests with the Cone Calorimeter:

The general recommendations for further testing in the project with membrane materials is to primarily use the mounting method with insulation and a metal net, and to use a heat flux of 50 kW/m^2. If using a lower heat flux some materials might not ignite, as was the case for the PTFE membrane. However, if there is to low separation with the high heat flux, and the sample ignites at 35 kW/m^2, tests at 35 kW/m^2 may be appropriate.

SBI test protocol:

From the results of the investigation made here, it is recommender to use the mounting method with a corner support for SBI testing of textile membranes (Mounting Method 2). The main objection to the mounting method without a corner support is that the test results were non-repeatable for some membranes using this method.

It is recommended that common mounting specifications are agreed and implemented in the testing of textile membranes for tensile structures. Normally such specifications are given in a product standard. Note that technical membranes can have different applications and that mounting specifications could be based on different end-user application or be general standard mounting specifications.

Prediction of SBI performance from cone calorimeter test data:

A semi-qualitative prediction can be seen by a direct comparison between the Cone Calorimeter tests made by the recommended protocol (Figure 8) and the SBI-test run with the recommended mounting method.

In the Cone Calorimeter the PVC membranes forms a group with short ignition time and relatively high peak heat release, the PVC 4 membrane shows the highest heat release. This is what is seen in the SBI-tests with D-class results for PVC 4 and C-class results for the other PVC membranes. The separation in results between PVC 4 and the better performing PVC membranes is, however, small.

The Silicon membrane and the PTFE membrane results are well separated in the Cone Calorimeter which reflects their behaviour in the SBI well.

It is recommended to investigate further whether the *Conetools* software could be used for more quantitative prediction of SBI performance of technical membranes using Cone Calorimeter input data.

8 References

[1] ISO 5660-1:2002, Reaction-to-fire tests - Heat release, smoke production and mass loss rate — Part 1: Heat release rate (cone calorimeter method).

[2] EN 13823: 2002, Reaction to fire tests for building products - Single burning item test.

[3] EN 13501-1:2007, Fire classification of construction products and building elements - Part 1: Classification using test data from reaction to fire tests.

[4] EN ISO 11925-2, Reaction to fire tests - Ignitability of building products subjected to direct impingement of flame - Part 2: single-flame source test (ISO 11925-2:2002).

[5] EN ISO 1716:2002, Reaction to fire tests for building products -- Determination of the heat of combustion.

[6] EN ISO 1182:2002, Reaction to fire tests for building products -- Non-combustibility test.

[7] P. Van Hees, T. Hertzberg, A. Steen Hansen, Development of a Screening Method for the SBI and Room Corner using the Cone Calorimeter, SP Report 2002:11, SP Swedish National Testing and Research Institute, Borås, 2002.

[8] EN 13823:2004, Stretched ceilings – Requirements and test methods.

Appendix 1 Cone Calorimeter (ISO 5660): test results

PVC 1:

Property	Name of variable	a1	a2	a3	Average value
Flashing (min:s)	t_{flash}	-	-	-	-
Ignition (min:s)	t_{ign}	00:08	00:08	00:09	00:08
All flaming ceased (min:s)	t_{ext}	03:21	01:56	01:10	02:09
Test time (min:s)	t_{test}	05:21	05:00	05:00	05:07
Heat release rate (kW/m^2)	q	See figure 20			
Peak heat release rate (kW/m^2)	q_{max}	105	114	212	144
Average heat release, 3 min (kW/m^2)	q_{180}	42	46	43	44
Average heat release, 5 min (kW/m^2)	q_{300}	28	31	26	29
Total heat produced (MJ/m^2)	THR	8.7	9.4	8.0	8.7
Smoke production rate (m^2/m^{2}s)	SPR	See figure 21			
Peak smoke production (m^2/m^{2}s)	SPR_{max}	8.04	10.40	19.95	12.80
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.0	0.1	0.0	0.1
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	480.6	575.5	561.8	539.3
Total smoke production (m^2/m^2)	TSP	481	576	562	539
Sample mass before test (g)	M_0	6.4	6.4	6.3	6.4
Sample mass at sustained flaming (g)	M_s	6.5	6.5	5.8	6.3
Sample mass after test (g)	M_f	0.3	0.0	-0.4	-0.1
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	1.7	2.7	2.2	2.2
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	4.3	6.7	10.8	7.3
Total mass loss (g/m^2)	TML	703	741	704	716
Effective heat of combustion (MJ/kg)	DH_c	12.3	12.7	11.3	12.1
Specific smoke production (m^2/kg)	SEA	684	777	798	753
Max average rate of heat emission (kW/m^2)	MARHE	73.8	86.9	138.4	99.7
Volume flow in exhaust duct (l/s)	V	24	24	24	24

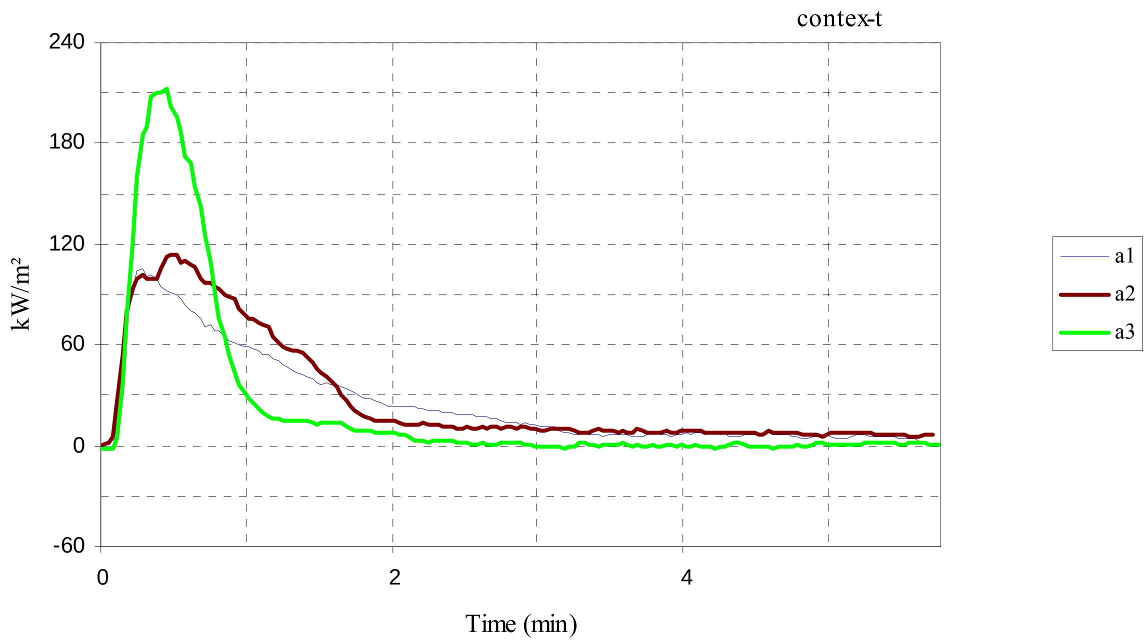


Figure 21 Heat release rate at an irradiance of 50 kW/m^2.

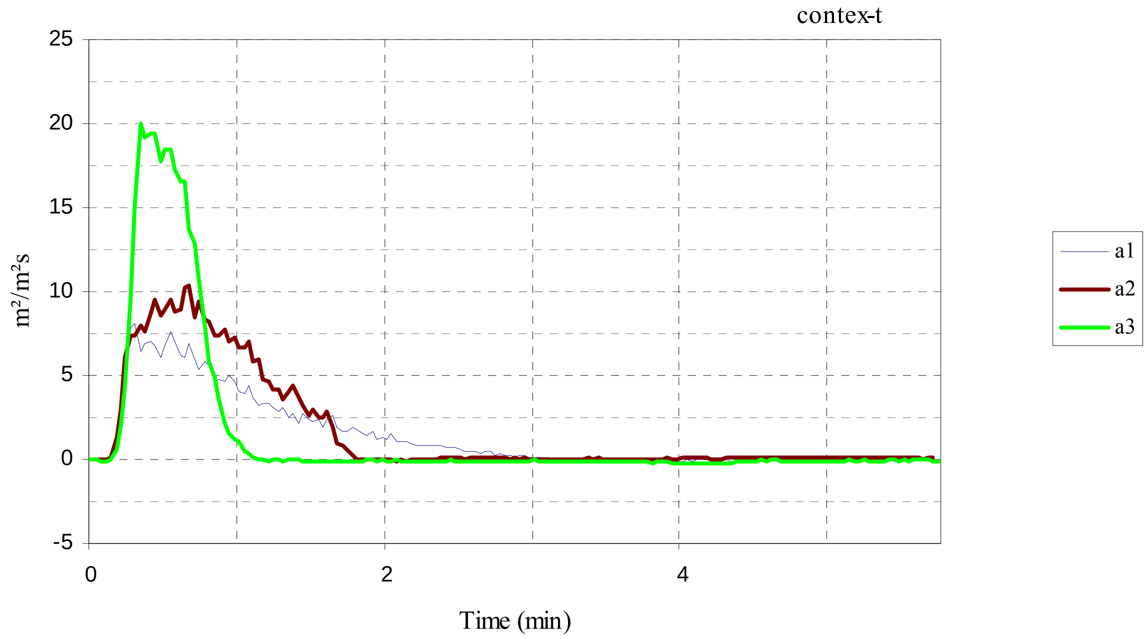


Figure 22 Smoke production rate at an irradiance of 50 kW/m^2.

PVC 1:

Property	Name of variable	a4	a5	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:08	00:08	00:08
All flaming ceased (min:s)	t_{ext}	01:18	01:30	01:24
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 22		
Peak heat release rate (kW/m^2)	q_{max}	183	177	180
Average heat release, 3 min (kW/m^2)	q_{180}	42	41	41
Average heat release, 5 min (kW/m^2)	q_{300}	25 24		25
Total heat produced (MJ/m^2)	THR	7.8	7.6	7.7
Smoke production rate (m^2/m^{2}s)	SPR	See figure 23		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	19.13	17.75	18.44
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	1.2	0.2	0.7
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	544.8	486.5	515.6
Total smoke production (m^2/m^2)	TSP	546	487	516
Sample mass before test (g)	M_0	6.4	6.4	6.4
Sample mass at sustained flaming (g)	M_s	6.7	6.3	6.5
Sample mass after test (g)	M_f	0.0	-0.4	-0.2
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	2.5	3.0	2.8
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	4.5	3.0	3.8
Total mass loss (g/m^2)	TML	756	759	757
Effective heat of combustion (MJ/kg)	DH_c	10.3	10.0	10.1
Specific smoke production (m^2/kg)	SEA	723	641	682
Max average rate of heat emission (kW/m^2)	MARHE	121.4	117.1	119.2
Volume flow in exhaust duct (l/s)	V	24	24	24

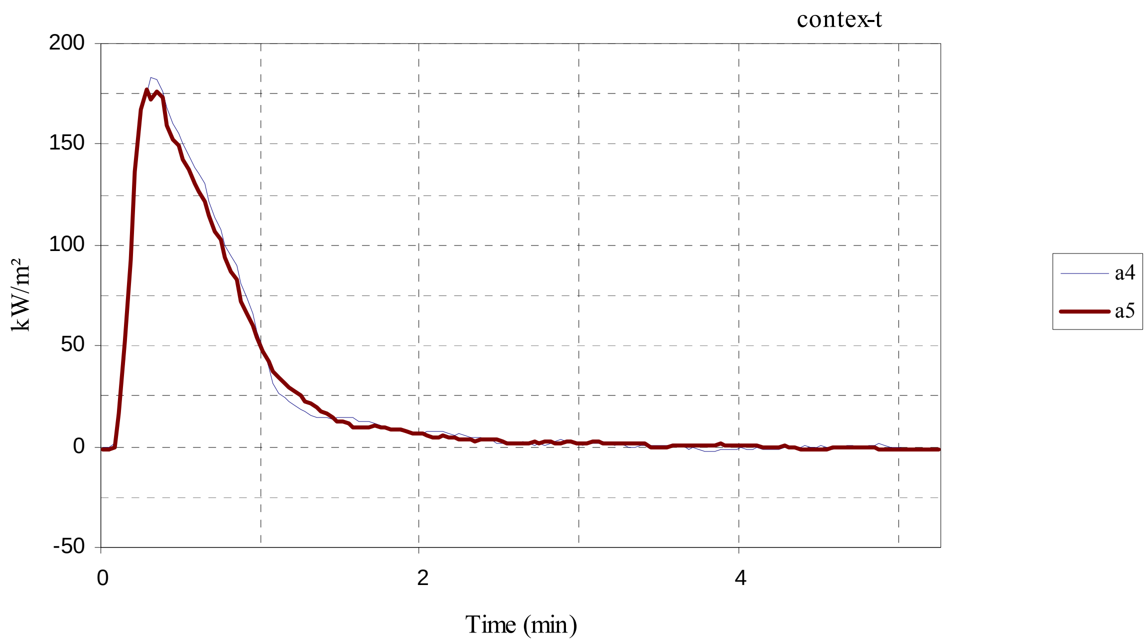


Figure 23 Heat release rate at an irradiance of 50 kW/m^2.

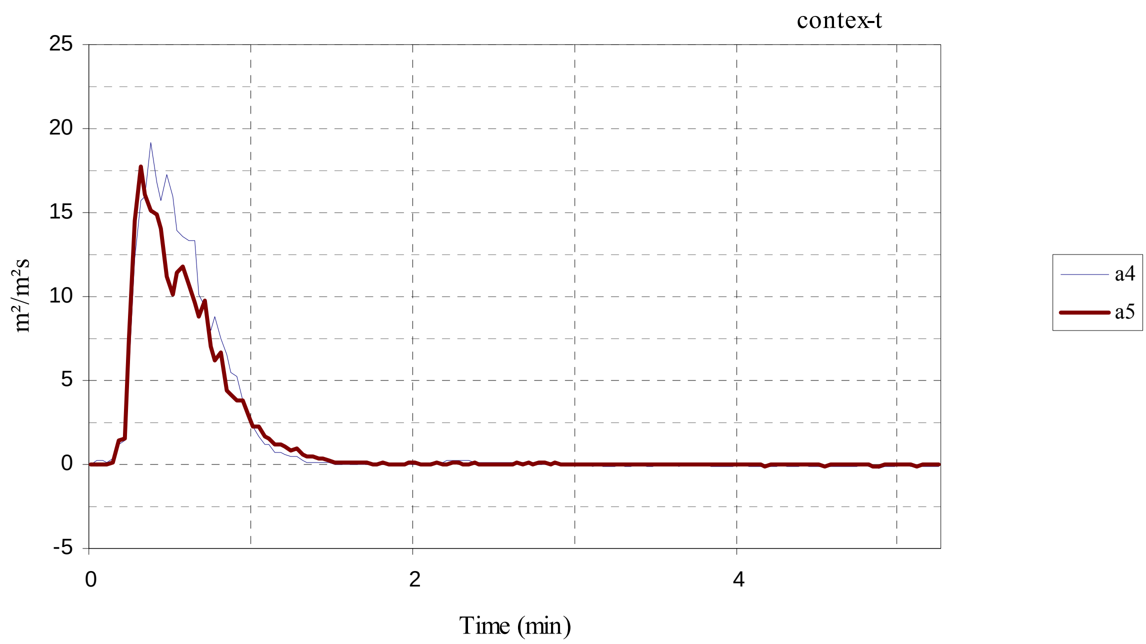


Figure 24 Smoke production rate at an irradiance of 50 kW/m^2.

PVC 1:

Property	Name of variable	a6	a15	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:10	00:08	00:09
All flaming ceased (min:s)	t_{ext}	01:00	01:07	01:04
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 24		
Peak heat release rate (kW/m^2)	q_{max}	237	190	213
Average heat release, 3 min (kW/m^2)	q_{180}	44	44	44
Average heat release, 5 min (kW/m^2)	q_{300}	26 28		27
Total heat produced (MJ/m^2)	THR	8.1	8.6	8.3
Smoke production rate (m^2/m^{2}s)	SPR	See figure 25		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	22.51	18.73	20.62
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.3	0.2	0.2
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	561.3	584.5	572.9
Total smoke production (m^2/m^2)	TSP	562	585	573
Sample mass before test (g)	M_0	6.4	6.4	6.4
Sample mass at sustained flaming (g)	M_s	6.2	6.3	6.3
Sample mass after test (g)	M_f	-0.3	0.5	0.1
Average mass loss rate (g/m^{2}s)	$MLR_{ign\text{-}end}$	3.1	2.1	2.6
Average mass loss rate (g/m^{2}s)	$MLR_{10\text{-}90}$	9.5	16.5	13.0
Total mass loss (g/m^2)	TML	734	661	698
Effective heat of combustion (MJ/kg)	DH_c	11.1	12.9	12.0
Specific smoke production (m^2/kg)	SEA	765	884	825
Max average rate of heat emission (kW/m^2)	MARHE	139.6	124.9	132.2
Volume flow in exhaust duct (l/s)	V	24	24	24

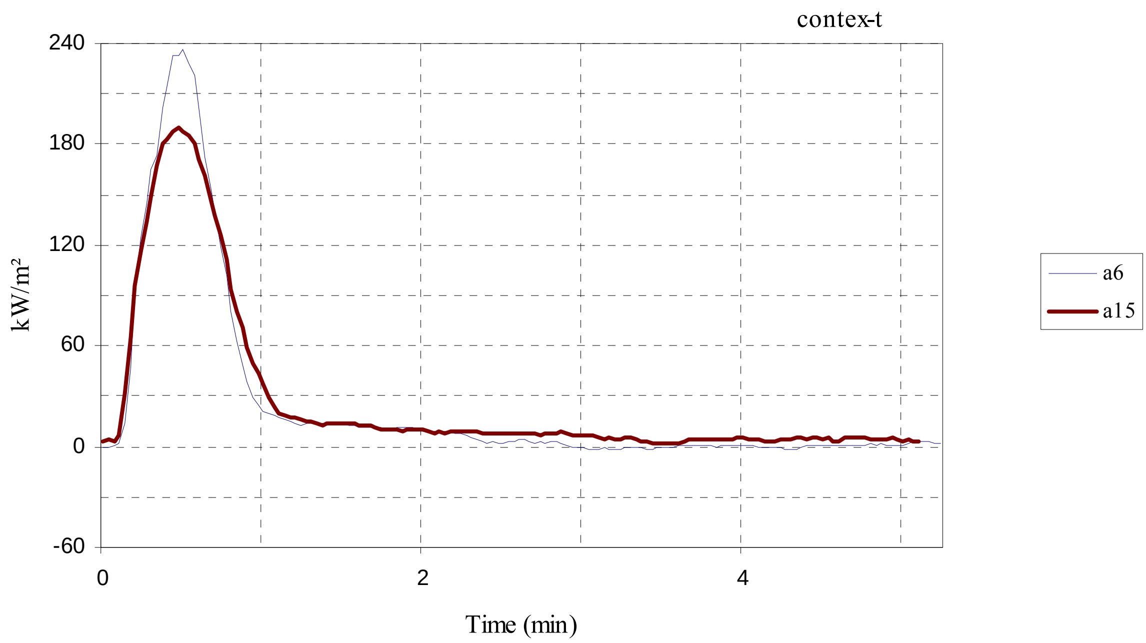


Figure 25 Heat release rate at an irradiance of 50 kW/m^2.

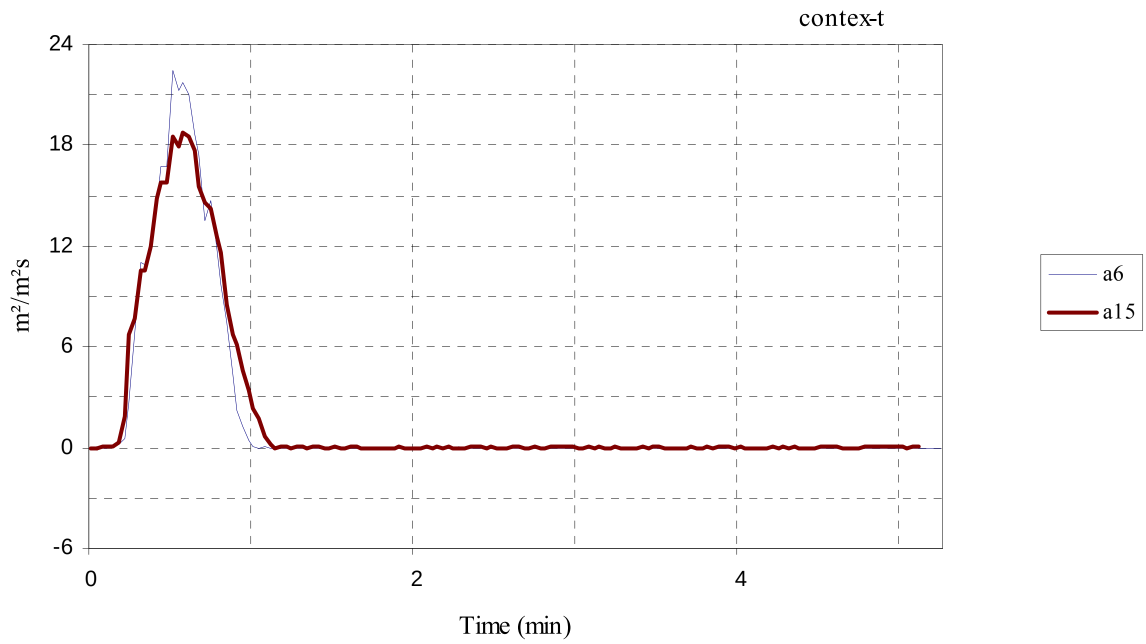


Figure 26 Smoke production rate at an irradiance of 50 kW/m^2.

PVC 1:

Property	Name of variable	a7	a8	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:07	00:07	00:07
All flaming ceased (min:s)	t_{ext}	02:08	02:27	02:18
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 26		
Peak heat release rate (kW/m^2)	q_{max}	142	151	146
Average heat release, 3 min (kW/m^2)	q_{180}	46	51	49
Average heat release, 5 min (kW/m^2)	q_{300}	35 39		37
Total heat produced (MJ/m^2)	THR	10.2	11.5	10.8
Smoke production rate (m^2/m^{2}s)	SPR	See figure 27		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	7.40	8.95	8.17
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.0	-0.2	-0.1
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	330.4	328.3	329.4
Total smoke production (m^2/m^2)	TSP	330	328	329
Sample mass before test (g)	M_0	7.9	8.0	7.9
Sample mass at sustained flaming (g)	M_s	8.1	7.4	7.8
Sample mass after test (g)	M_f	-1.2	-1.4	-1.3
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	3.5	3.4	3.4
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	4.1	3.8	4.0
Total mass loss (g/m^2)	TML	1058	997	1027
Effective heat of combustion (MJ/kg)	DH_c	9.6	11.6	10.6
Specific smoke production (m^2/kg)	SEA	312	329	321
Max average rate of heat emission (kW/m^2)	MARHE	98.6	106.5	102.5
Volume flow in exhaust duct (l/s)	V	24	24	24

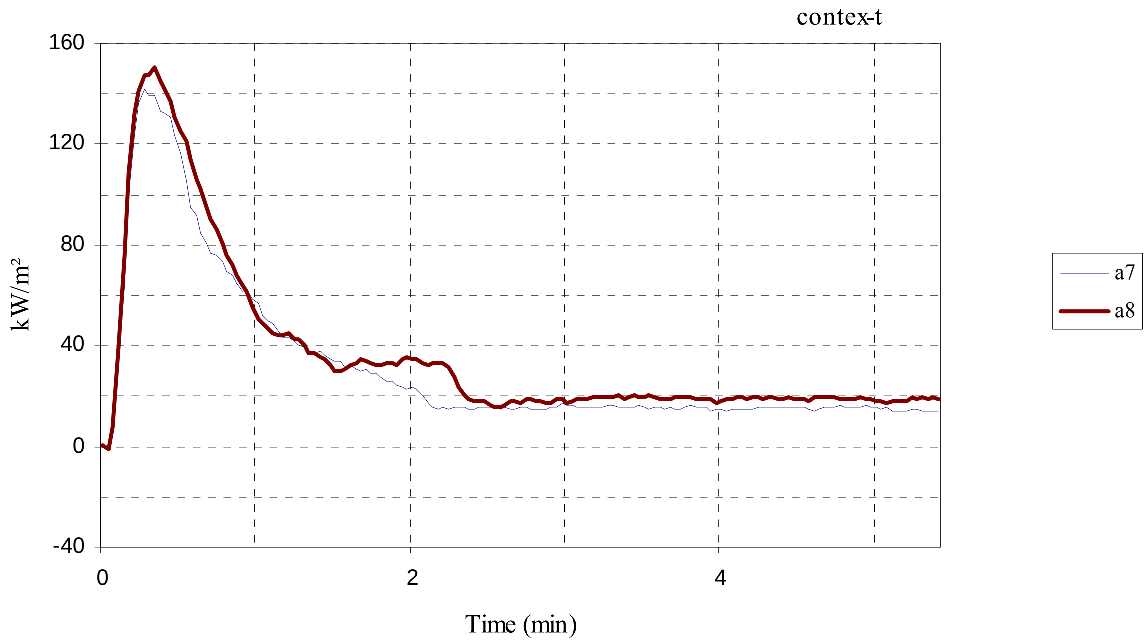


Figure 27 Heat release rate at an irradiance of 50 kW/m^2.

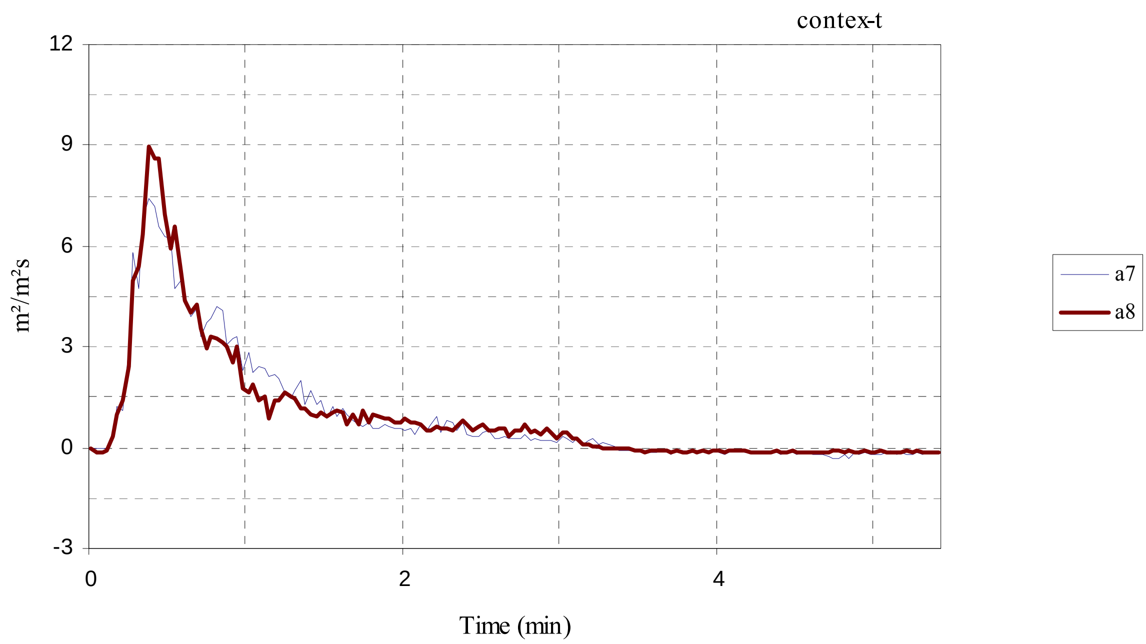


Figure 28 Smoke production rate at an irradiance of 50 kW/m^2.

PVC 1:

Property	Name of variable	a10	a11	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:15	00:14	00:15
All flaming ceased (min:s)	t_{ext}	01:22	01:19	01:20
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 28		
Peak heat release rate (kW/m^2)	q_{max}	167	185	176
Average heat release, 3 min (kW/m^2)	q_{180}	44	44	44
Average heat release, 5 min (kW/m^2)	q_{300}	26 27		26
Total heat produced (MJ/m^2)	THR	8.0	8.2	8.1
Smoke production rate (m^2/m^2s)	SPR	See figure 29		
Peak smoke production (m^2/m^2s)	SPR_{max}	16.49	17.27	16.88
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.1	0.2	0.2
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	541.9	576.1	559.0
Total smoke production (m^2/m^2)	TSP	542	576	559
Sample mass before test (g)	M_0	6.4	6.6	6.5
Sample mass at sustained flaming (g)	M_s	6.6	6.4	6.5
Sample mass after test (g)	M_f	0.4	0.2	0.3
Average mass loss rate (g/m^2s)	$MLR_{ign\text{-}end}$	2.5	2.6	2.6
Average mass loss rate (g/m^2s)	$MLR_{10\text{-}90}$	10.4	13.5	12.0
Total mass loss (g/m^2)	TML	704	709	707
Effective heat of combustion (MJ/kg)	DH_c	11.4	11.5	11.5
Specific smoke production (m^2/kg)	SEA	770	813	791
Max average rate of heat emission (kW/m^2)	MARHE	101.6	109.3	105.4
Volume flow in exhaust duct (l/s)	V	24	24	24

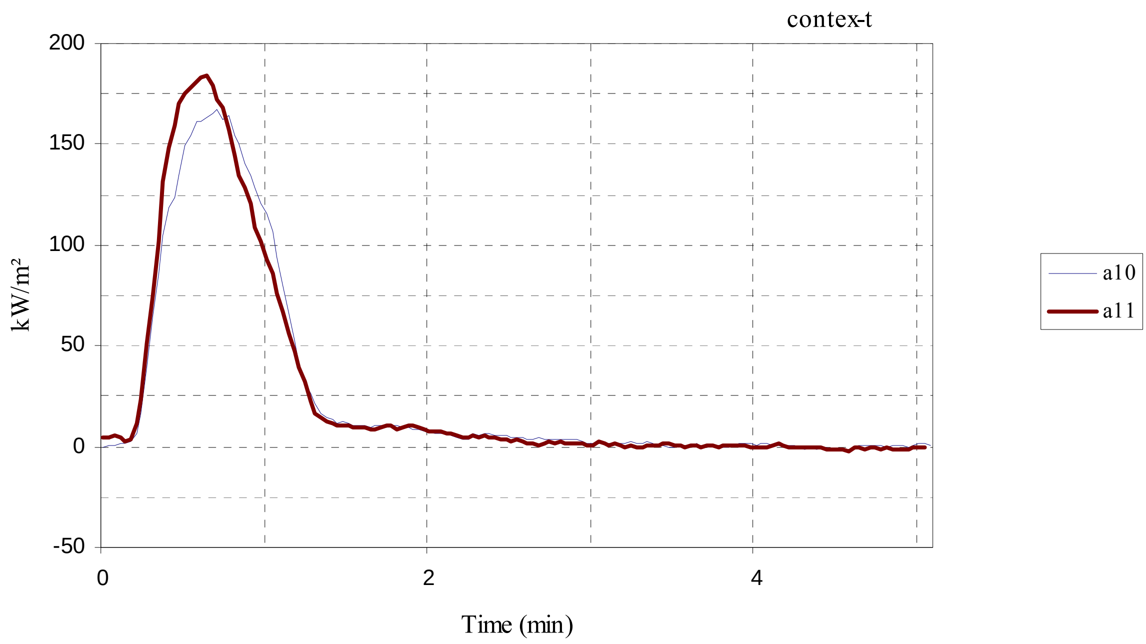


Figure 29 Heat release rate at an irradiance of 35 kW/m^2.

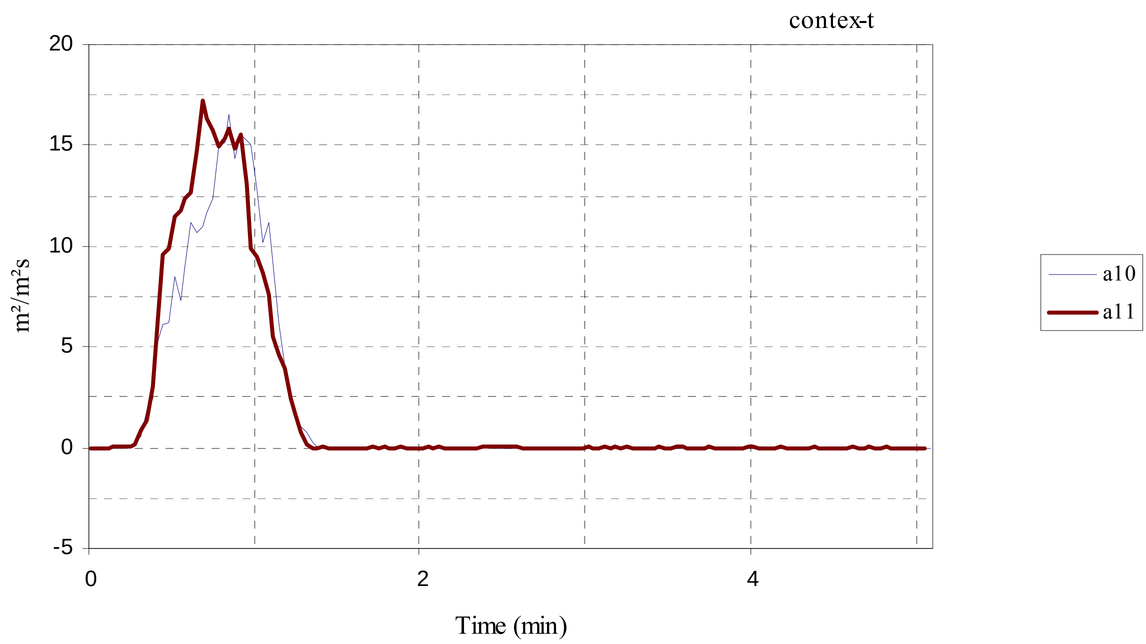


Figure 30 Smoke production rate at an irradiance of 35 kW/m^2.

PVC 1:

Property	Name of variable	a12	a13	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:11	00:10	00:11
All flaming ceased (min:s)	t_{ext}	03:45	01:33	02:39
Test time (min:s)	t_{test}	05:45 05:00		05:23
Heat release rate (kW/m^2)	q	See figure 30		
Peak heat release rate (kW/m^2)	q_{max}	91	118	105
Average heat release, 3 min (kW/m^2)	q_{180}	36	35	35
Average heat release, 5 min (kW/m^2)	q_{300}	25 24		24
Total heat produced (MJ/m^2)	THR	7.9	7.1	7.5
Smoke production rate (m^2/m^{2}s)	SPR	See figure 31		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	0.03	8.10	4.07
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.0	0.2	0.1
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	2.0	383.7	192.8
Total smoke production (m^2/m^2)	TSP	2	384	193
Sample mass before test (g)	M_0	6.4	6.4	6.4
Sample mass at sustained flaming (g)	M_s	4.8	6.7	5.7
Sample mass after test (g)	M_f	-2.0	0.1	-1.0
Average mass loss rate (g/m^{2}s)	$MLR_{ign\text{-}end}$	2.4	2.6	2.5
Average mass loss rate (g/m^{2}s)	$MLR_{10\text{-}90}$	2.9	3.2	3.1
Total mass loss (g/m^2)	TML	770	747	758
Effective heat of combustion (MJ/kg)	DH_c	10.2	9.6	9.9
Specific smoke production (m^2/kg)	SEA	3	514	258
Max average rate of heat emission (kW/m^2)	MARHE	60.4	77.4	68.9
Volume flow in exhaust duct (l/s)	V	24	24	24

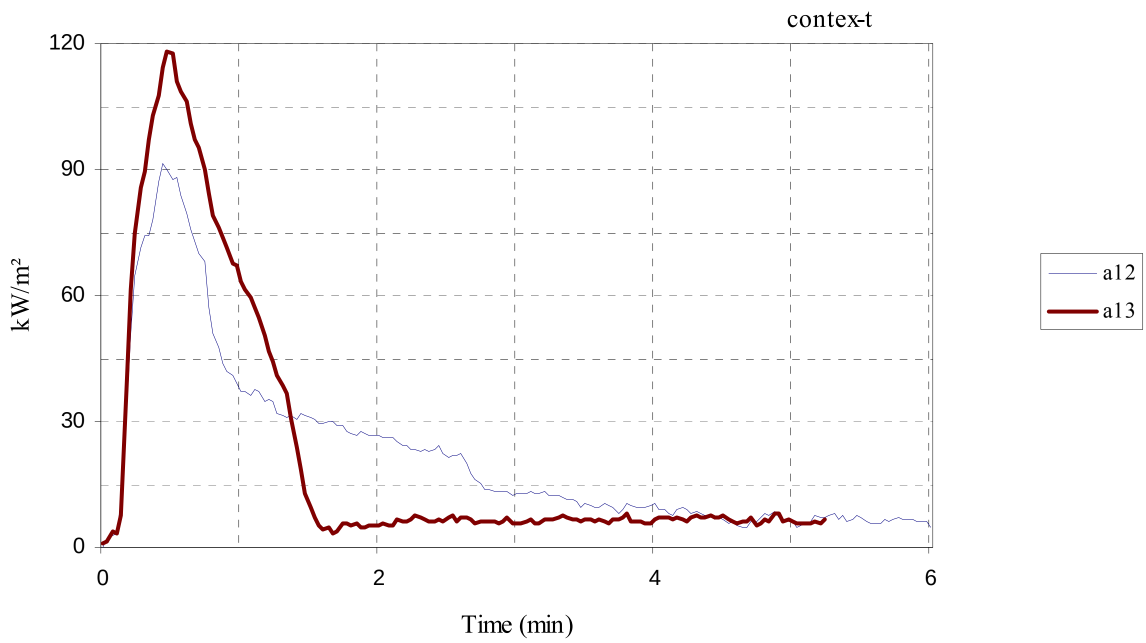


Figure 31 Heat release rate at an irradiance of 35 kW/m^2.

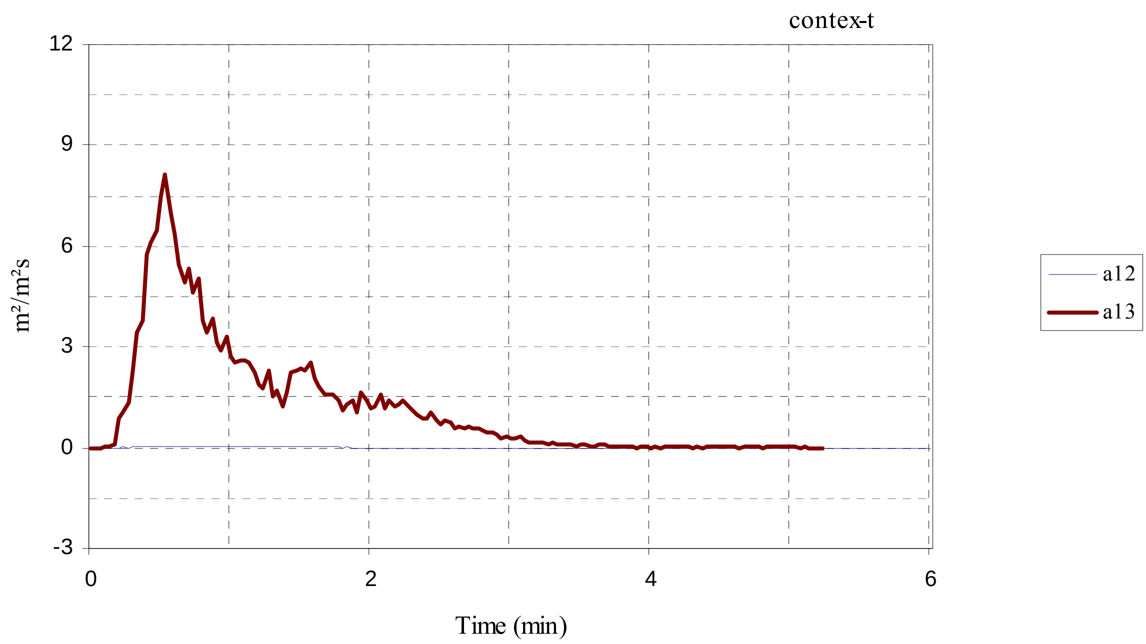


Figure 32 Smoke production rate at an irradiance of 35 kW/m^2.

PVC 1:

Property	Name of variable	A 16	A 17	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:08	00:08	00:08
All flaming ceased (min:s)	t_{ext}	01:23	01:09	01:16
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 32		
Peak heat release rate (kW/m^2)	q_{max}	161	214	188
Average heat release, 3 min (kW/m^2)	q_{180}	42	42	42
Average heat release, 5 min (kW/m^2)	q_{300}	26 25		26
Total heat produced (MJ/m^2)	THR	7.9	7.8	7.8
Smoke production rate (m^2/m^{2}s)	SPR	See figure 33		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	15.27	21.35	18.31
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.1	0.1	0.1
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	580.7	612.0	596.3
Total smoke production (m^2/m^2)	TSP	581	612	596
Sample mass before test (g)	M_0	6.4	6.3	6.3
Sample mass at sustained flaming (g)	M_s	6.5	6.5	6.5
Sample mass after test (g)	M_f	0.1	0.4	0.3
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	2.5	2.5	2.5
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	8.7	14.5	11.6
Total mass loss (g/m^2)	TML	715	690	703
Effective heat of combustion (MJ/kg)	DH_c	11.0	11.3	11.2
Specific smoke production (m^2/kg)	SEA	812	887	850
Max average rate of heat emission (kW/m^2)	MARHE	109.3	134.4	121.8
Volume flow in exhaust duct (l/s)	V	24	24	24

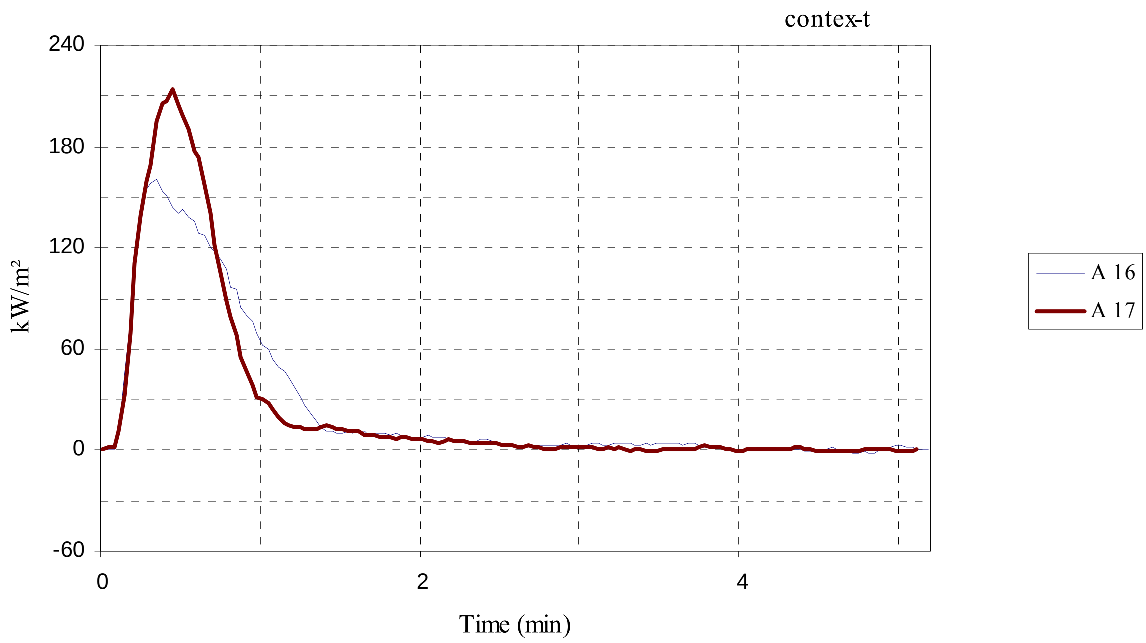


Figure 33 Heat release rate at an irradiance of 35 kW/m^2.

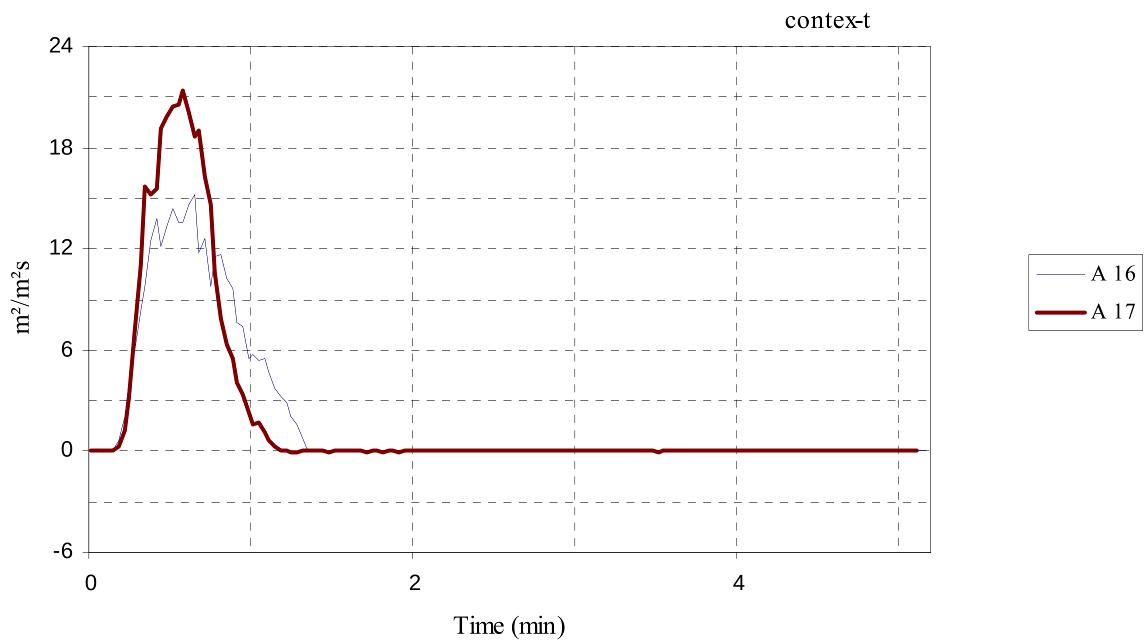


Figure 34 Smoke production rate at an irradiance of 35 kW/m^2.

PVC 1:

Property	Name of variable	A 18	A 19	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:08	00:09	00:09
All flaming ceased (min:s)	t_{ext}	01:03	01:07	01:05
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 34		
Peak heat release rate (kW/m^2)	q_{max}	205	212	209
Average heat release, 3 min (kW/m^2)	q_{180}	42	41	41
Average heat release, 5 min (kW/m^2)	q_{300}	25 24		25
Total heat produced (MJ/m^2)	THR	7.7	7.5	7.6
Smoke production rate (m^2/m^{2}s)	SPR	See figure 35		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	20.61	22.08	21.34
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.1	0.0	0.1
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	566.4	600.3	583.3
Total smoke production (m^2/m^2)	TSP	566	600	583
Sample mass before test (g)	M_0	6.4	6.5	6.4
Sample mass at sustained flaming (g)	M_s	6.6	6.5	6.5
Sample mass after test (g)	M_f	0.5	0.3	0.4
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	2.1	2.5	2.3
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	17.0	14.8	15.9
Total mass loss (g/m^2)	TML	681	703	692
Effective heat of combustion (MJ/kg)	DH_c	11.4	10.7	11.0
Specific smoke production (m^2/kg)	SEA	832	854	843
Max average rate of heat emission (kW/m^2)	MARHE	134.6	129.5	132.0
Volume flow in exhaust duct (l/s)	V	24	24	24

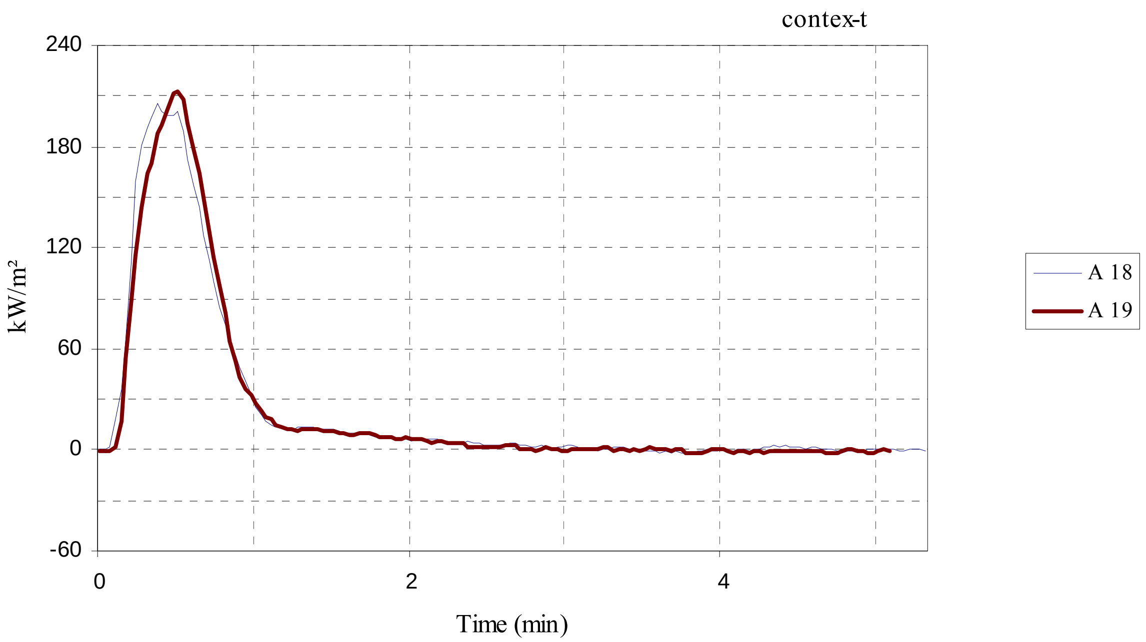


Figure 35 *Heat release rate at an irradiance of 35 kW/m^2.*

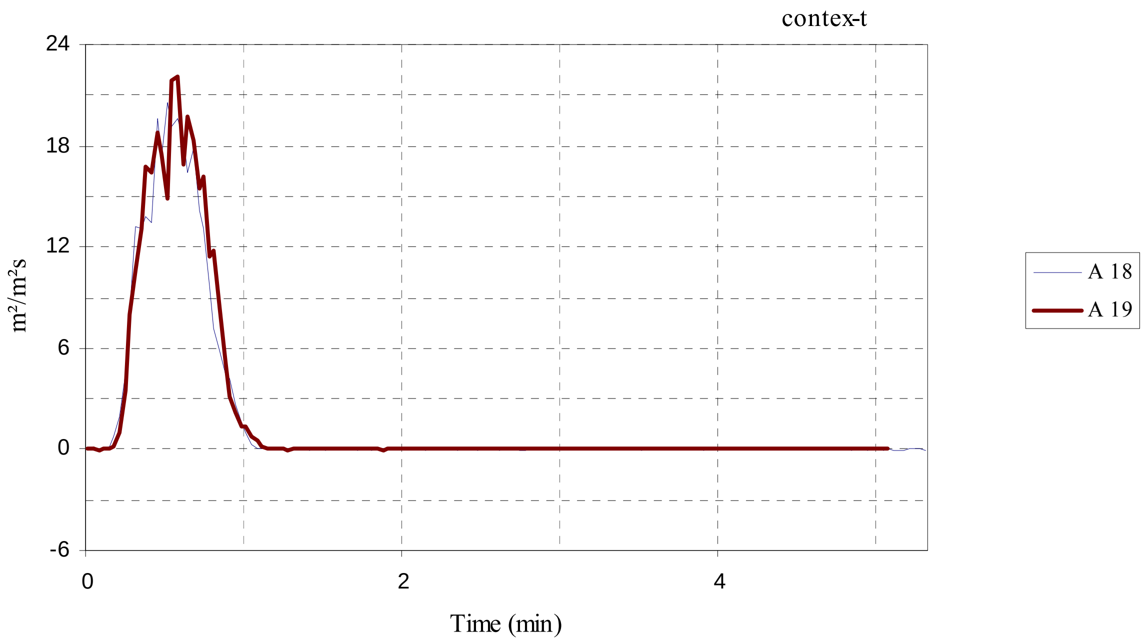


Figure 36 Smoke production rate at an irradiance of 35 kW/m^2.

PVC 3:

Property	Name of variable	b1	b2	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:09	00:11	00:10
All flaming ceased (min:s)	t_{ext}	02:13	02:17	02:15
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 36		
Peak heat release rate (kW/m^2)	q_{max}	177	163	170
Average heat release, 3 min (kW/m^2)	q_{180}	68	66	67
Average heat release, 5 min (kW/m^2)	q_{300}	44 43		43
Total heat produced (MJ/m^2)	THR	13.3	13.0	13.1
Smoke production rate (m^2/m^2s)	SPR	See figure 37		
Peak smoke production (m^2/m^2s)	SPR_{max}	14.16	14.97	14.57
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.2	1.6	0.9
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	723.5	806.2	764.8
Total smoke production (m^2/m^2)	TSP	724	808	766
Sample mass before test (g)	M_0	11.1	11.0	11.0
Sample mass at sustained flaming (g)	M_s	11.0	11.0	11.0
Sample mass after test (g)	M_f	0.5	0.3	0.4
Average mass loss rate (g/m^2s)	$MLR_{ign-end}$	3.6	4.5	4.0
Average mass loss rate (g/m^2s)	MLR_{10-90}	5.8	5.8	5.8
Total mass loss (g/m^2)	TML	1181	1203	1192
Effective heat of combustion (MJ/kg)	DH_c	11.3	10.8	11.0
Specific smoke production (m^2/kg)	SEA	613	671	642
Max average rate of heat emission (kW/m^2)	MARHE	125.8	118.7	122.3
Volume flow in exhaust duct (l/s)	V	24	24	24

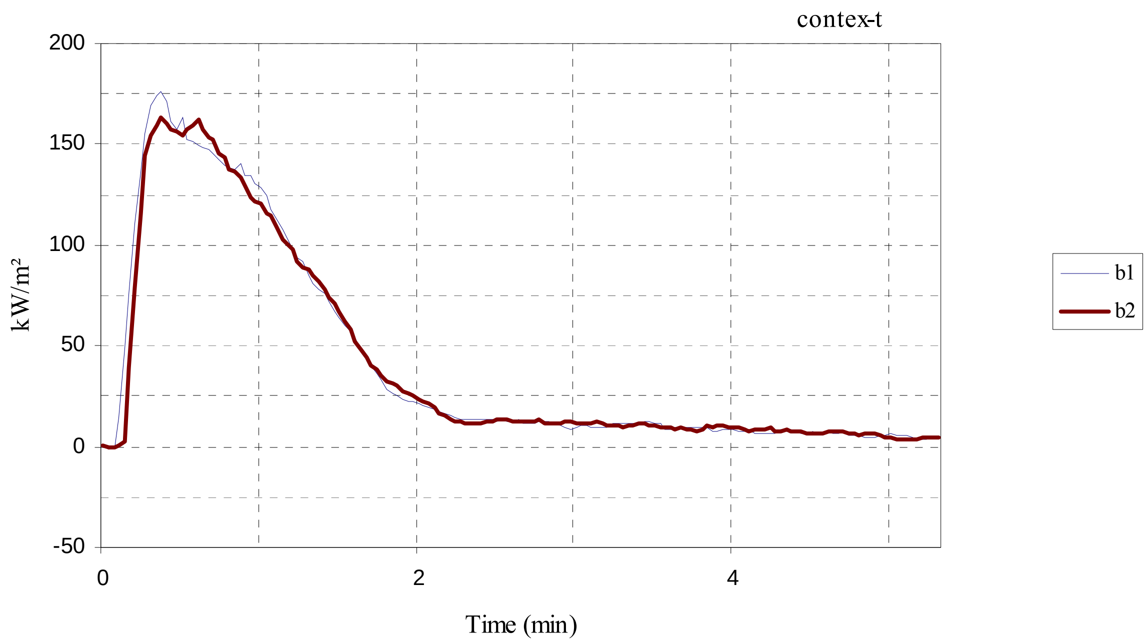


Figure 37 Heat release rate at an irradiance of 50 kW/m^2.

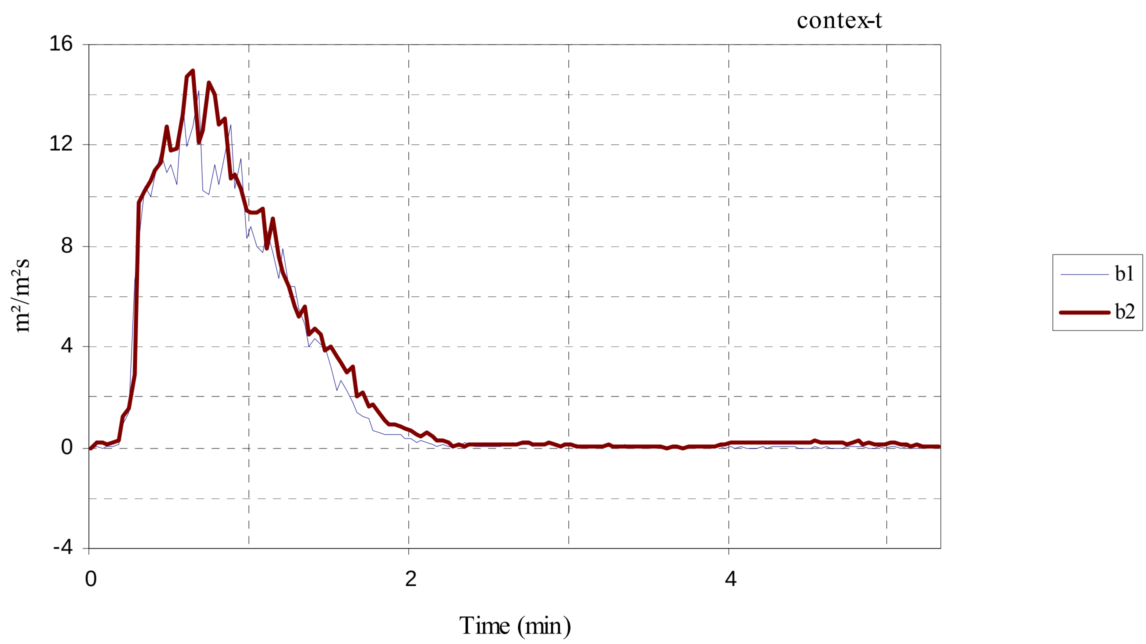


Figure 38 Smoke production rate at an irradiance of 50 kW/m^2.

PVC 3:

Property	Name of variable	b3	b4	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:08	00:08	00:08
All flaming ceased (min:s)	t_{ext}	02:44	02:43	02:44
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 38		
Peak heat release rate (kW/m^2)	q_{max}	181	182	182
Average heat release, 3 min (kW/m^2)	q_{180}	75	78	76
Average heat release, 5 min (kW/m^2)	q_{300}	50 51		51
Total heat produced (MJ/m^2)	THR	15.0	15.5	15.2
Smoke production rate (m^2/m^2s)	SPR	See figure 39		
Peak smoke production (m^2/m^2s)	SPR_{max}	10.37	11.01	10.69
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.0	0.0	0.0
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	614.7	636.6	625.6
Total smoke production (m^2/m^2)	TSP	615	637	626
Sample mass before test (g)	M_0	13.1	13.1	13.1
Sample mass at sustained flaming (g)	M_s	12.9	13.2	13.1
Sample mass after test (g)	M_f	0.6	0.8	0.7
Average mass loss rate (g/m^2s)	$MLR_{ign-end}$	4.8	4.8	4.8
Average mass loss rate (g/m^2s)	MLR_{10-90}	6.7	6.8	6.8
Total mass loss (g/m^2)	TML	1392	1410	1401
Effective heat of combustion (MJ/kg)	DH_c	10.7	11.0	10.9
Specific smoke production (m^2/kg)	SEA	441	452	447
Max average rate of heat emission (kW/m^2)	MARHE	120.4	122.8	121.6
Volume flow in exhaust duct (l/s)	V	24	24	24

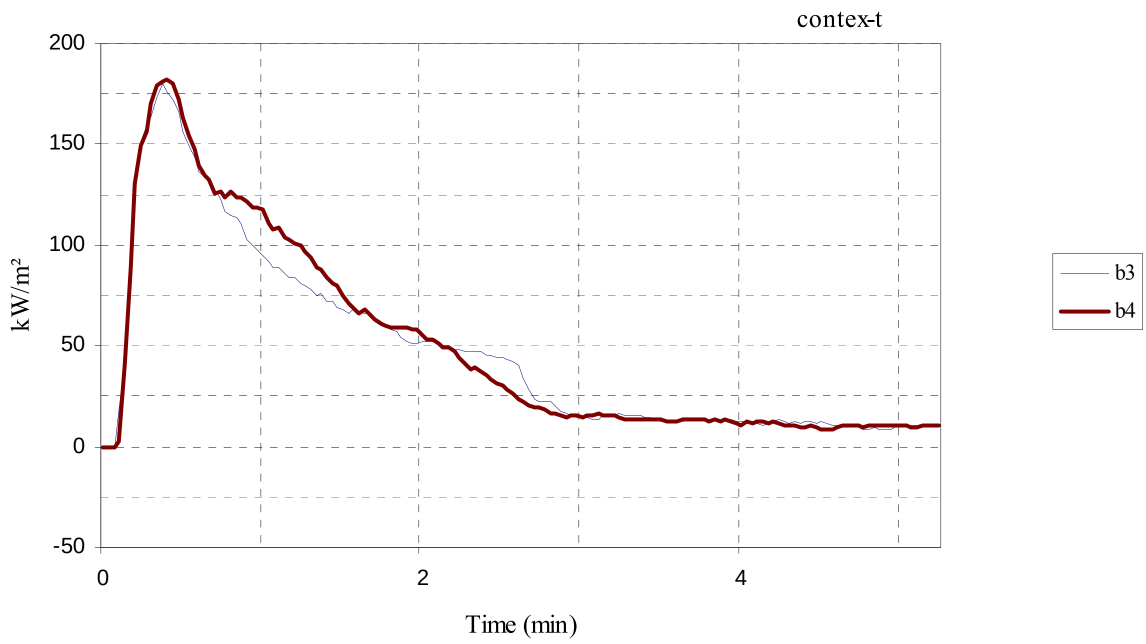


Figure 39 Heat release rate at an irradiance of 50 kW/m^2.

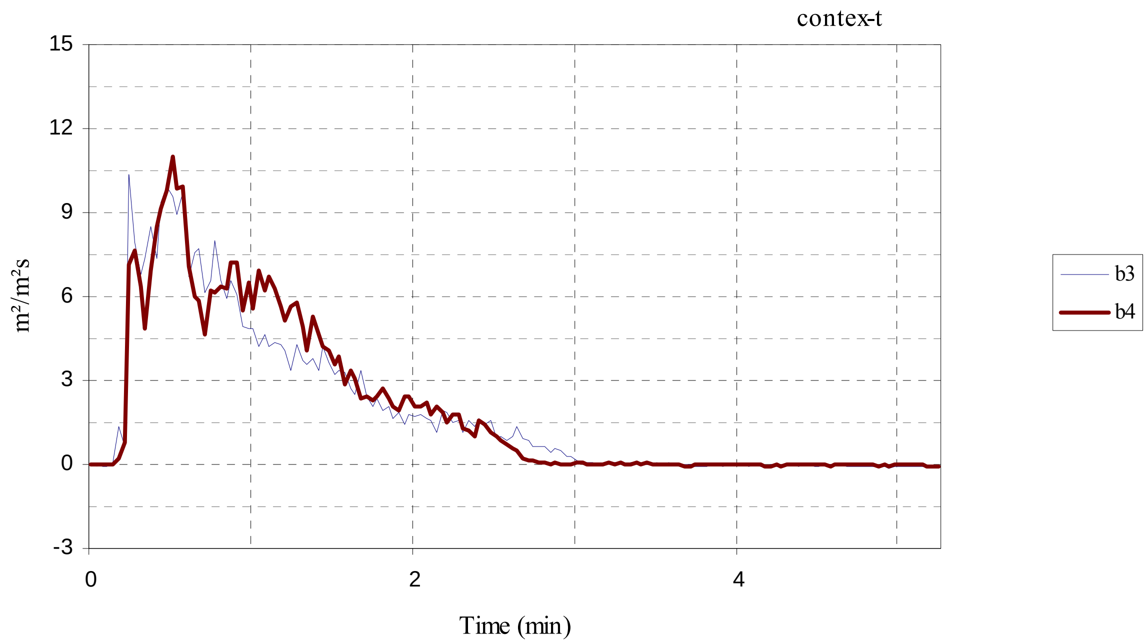


Figure 40 Smoke production rate at an irradiance of 50 kW/m^2.

PVC 3:

Property	Name of variable	b10	b11	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:19	00:19	00:19
All flaming ceased (min:s)	t_{ext}	01:48	01:48	01:48
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 40		
Peak heat release rate (kW/m^2)	q_{max}	169	160	165
Average heat release, 3 min (kW/m^2)	q_{180}	64	63	64
Average heat release, 5 min (kW/m^2)	q_{300}	40 40		40
Total heat produced (MJ/m^2)	THR	12.1	12.0	12.0
Smoke production rate (m^2/m^{2}s)	SPR	See figure 41		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	17.95	17.92	17.94
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.3	0.1	0.2
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	881.9	884.1	883.0
Total smoke production (m^2/m^2)	TSP	882	884	883
Sample mass before test (g)	M_0	10.7	10.6	10.6
Sample mass at sustained flaming (g)	M_s	10.3	11.0	10.7
Sample mass after test (g)	M_f	0.5	1.2	0.9
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	3.9	4.0	4.0
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	13.9	14.8	14.4
Total mass loss (g/m^2)	TML	1111	1113	1112
Effective heat of combustion (MJ/kg)	DH_c	10.9	10.8	10.8
Specific smoke production (m^2/kg)	SEA	794	794	794
Max average rate of heat emission (kW/m^2)	MARHE	107.9	106.2	107.0
Volume flow in exhaust duct (l/s)	V	24	24	24

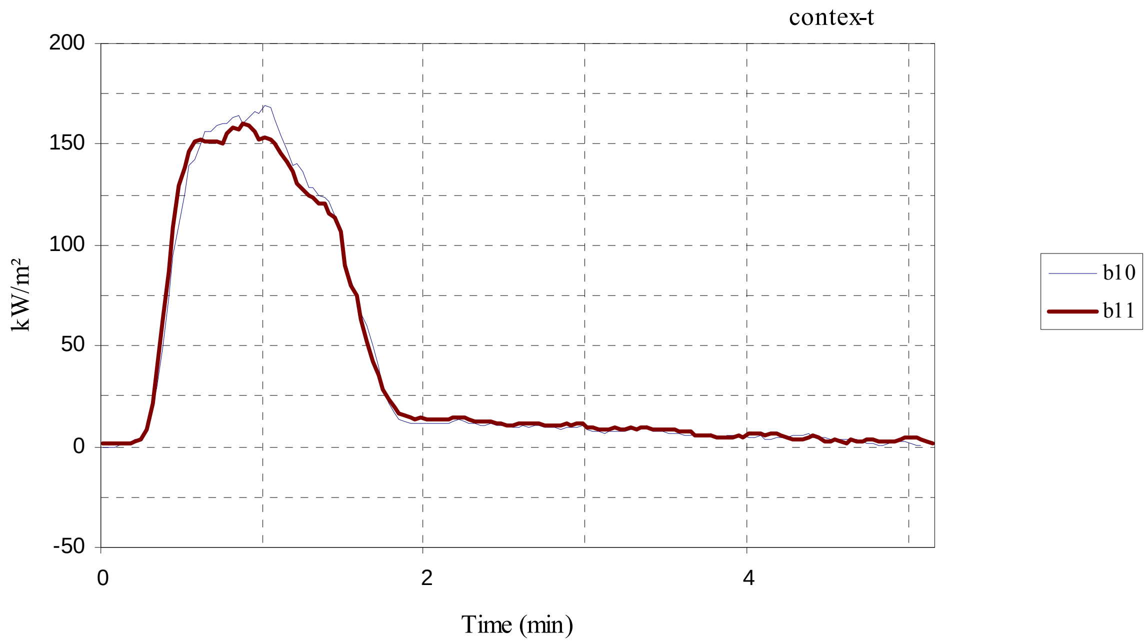


Figure 41 Heat release rate at an irradiance of 35 kW/m^2.

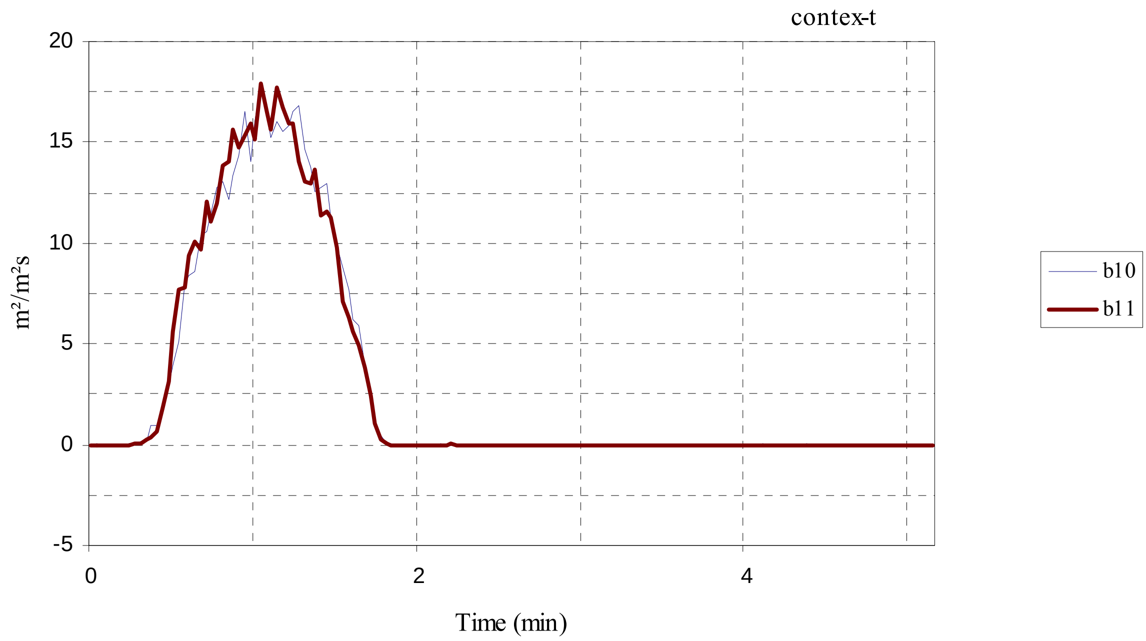


Figure 42 Smoke production rate at an irradiance of 35 kW/m^2.

PVC 3:

Property	Name of variable	b12	b13	b14	Average value
Flashing (min:s)	t_{flash}	-	-	-	-
Ignition (min:s)	t_{ign}	00:13	00:11	00:15	00:13
All flaming ceased (min:s)	t_{ext}	03:46	03:52	03:27	03:42
Test time (min:s)	t_{test}	05:46	05:52	05:27	05:42
Heat release rate (kW/m^2)	q	See figure 42			
Peak heat release rate (kW/m^2)	q_{max}	105	100	97	101
Average heat release, 3 min (kW/m^2)	q_{180}	66	63	68	66
Average heat release, 5 min (kW/m^2)	q_{300}	46	46	45	46
Total heat produced (MJ/m^2)	THR	14.1	14.2	13.8	14.1
Smoke production rate (m^2/m^{2}s)	SPR	See figure 43			
Peak smoke production (m^2/m^{2}s)	SPR_{max}	6.24	5.46	6.08	5.93
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.1	0.1	0.4	0.2
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	646.7	665.0	561.5	624.4
Total smoke production (m^2/m^2)	TSP	647	665	562	625
Sample mass before test (g)	M_0	10.7	10.8	10.7	10.7
Sample mass at sustained flaming (g)	M_s	14.2	10.7	10.5	11.8
Sample mass after test (g)	M_f	3.2	-0.2	0.0	1.0
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	3.5	3.7	3.8	3.6
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	5.6	5.5	6.0	5.7
Total mass loss (g/m^2)	TML	1247	1233	1192	1224
Effective heat of combustion (MJ/kg)	DH_c	11.3	11.5	11.6	11.5
Specific smoke production (m^2/kg)	SEA	519	540	471	510
Max average rate of heat emission (kW/m^2)	MARHE	71.0	63.8	71.2	68.7
Volume flow in exhaust duct (l/s)	V	24	24	24	24

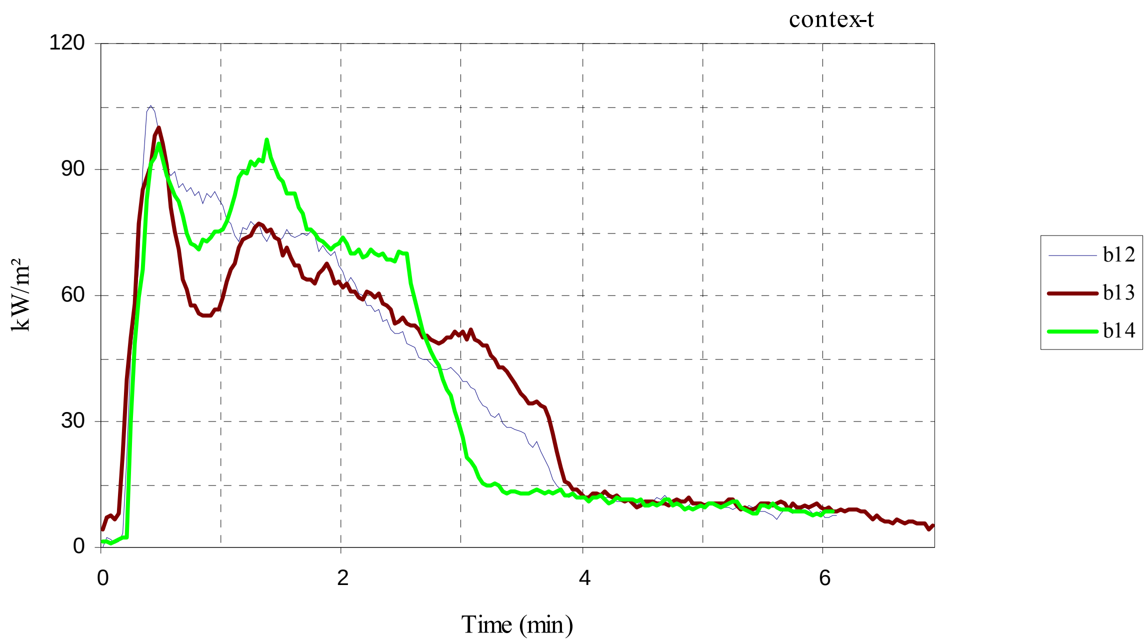


Figure 43 Heat release rate at an irradiance of 35 kW/m^2.

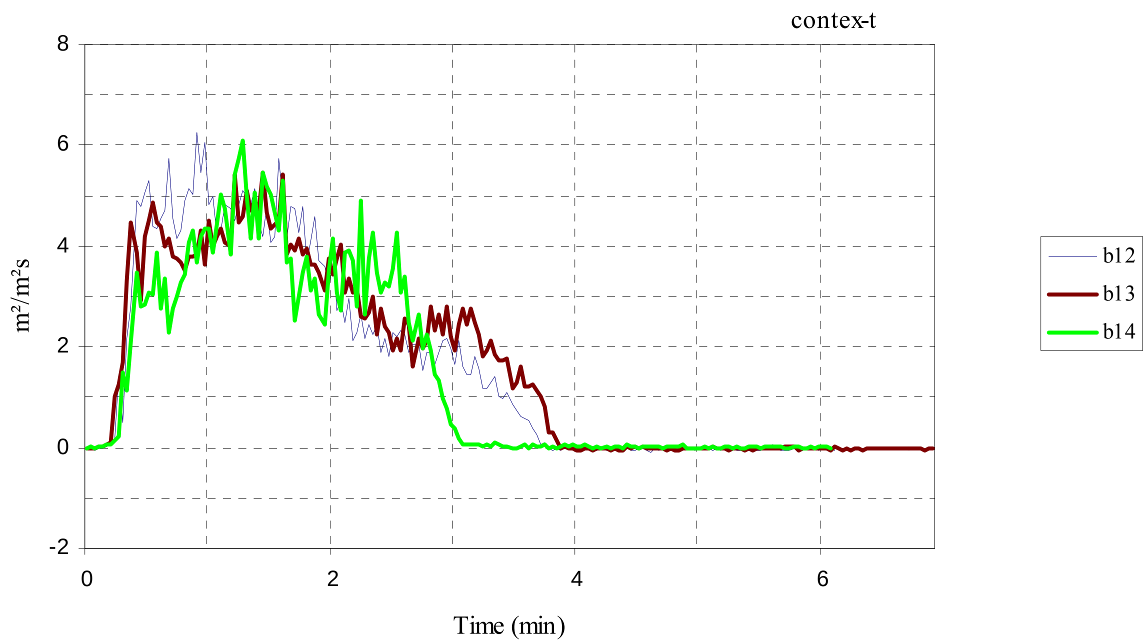


Figure 44 Smoke production rate at an irradiance of 35 kW/m^2.

PVC 3:

Property	Name of variable	b16	b17	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:12	00:12	00:12
All flaming ceased (min:s)	t_{ext}	01:29	01:44	01:37
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 44		
Peak heat release rate (kW/m^2)	q_{max}	188	171	180
Average heat release, 3 min (kW/m^2)	q_{180}	65	62	64
Average heat release, 5 min (kW/m^2)	q_{300}	41 40		41
Total heat produced (MJ/m^2)	THR	12.6	12.1	12.4
Smoke production rate (m^2/m^2s)	SPR	See figure 45		
Peak smoke production (m^2/m^2s)	SPR_{max}	22.75	17.60	20.17
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.2	0.5	0.4
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	955.0	855.4	905.2
Total smoke production (m^2/m^2)	TSP	955	856	906
Sample mass before test (g)	M_0	11.0	10.8	10.9
Sample mass at sustained flaming (g)	M_s	9.8	10.7	10.2
Sample mass after test (g)	M_f	-0.4	0.5	0.1
Average mass loss rate (g/m^2s)	$MLR_{ign-end}$	4.0	4.0	4.0
Average mass loss rate (g/m^2s)	MLR_{10-90}	18.5	12.4	15.5
Total mass loss (g/m^2)	TML	1157	1146	1152
Effective heat of combustion (MJ/kg)	DH_c	10.9	10.6	10.7
Specific smoke production (m^2/kg)	SEA	825	747	786
Max average rate of heat emission (kW/m^2)	MARHE	135.7	115.7	125.7
Volume flow in exhaust duct (l/s)	V	24	24	24

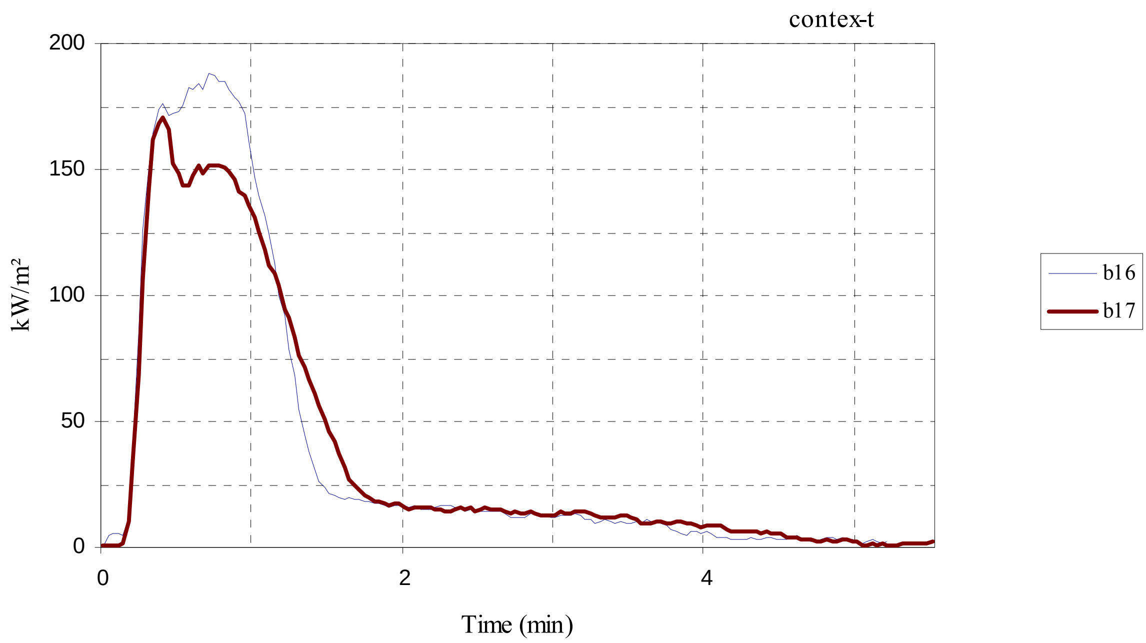


Figure 45 Heat release rate at an irradiance of 50 kW/m^2.

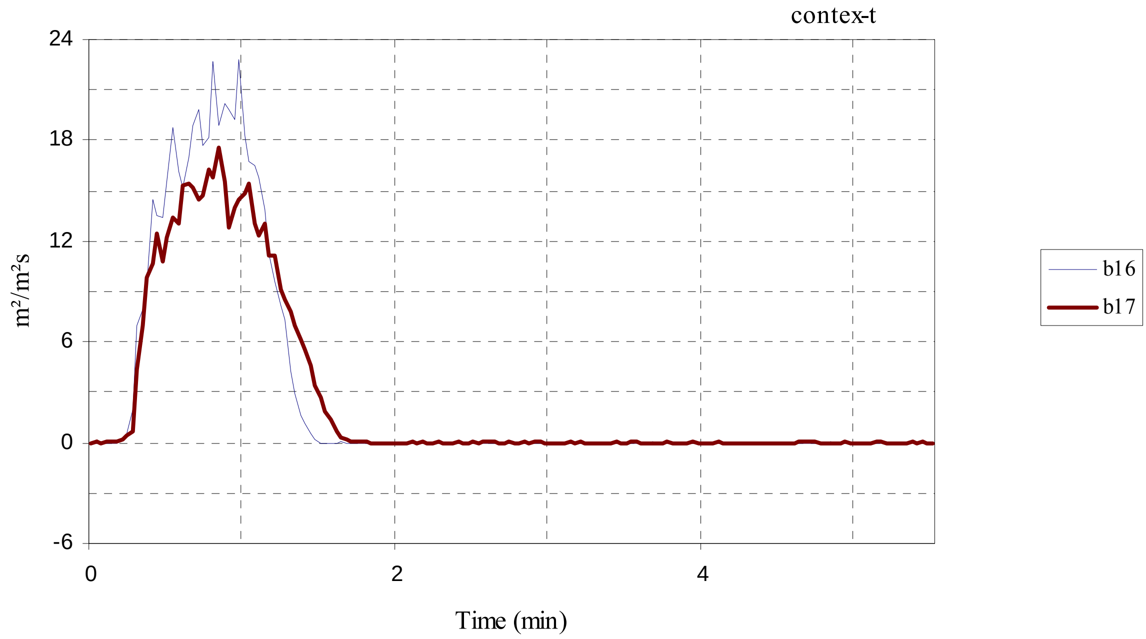


Figure 46 Smoke production rate at an irradiance of 50 kW/m^2.

PVC 2:

Property	Name of variable	c1	c2	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:08	00:09	00:09
All flaming ceased (min:s)	t_{ext}	01:27	01:48	01:37
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 46		
Peak heat release rate (kW/m^2)	q_{max}	215	182	199
Average heat release, 3 min (kW/m^2)	q_{180}	49	49	49
Average heat release, 5 min (kW/m^2)	q_{300}	30 31		31
Total heat produced (MJ/m^2)	THR	9.3	9.4	9.4
Smoke production rate (m^2/m^{2}s)	SPR	See figure 47		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	17.01	17.71	17.36
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	-0.3	0.5	0.1
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	526.1	625.8	576.0
Total smoke production (m^2/m^2)	TSP	526	626	576
Sample mass before test (g)	M_0	7.4	7.2	7.3
Sample mass at sustained flaming (g)	M_s	7.4	6.5	6.9
Sample mass after test (g)	M_f	0.0	-1.2	-0.6
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	2.8	2.9	2.9
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	4.7	3.9	4.3
Total mass loss (g/m^2)	TML	828	869	848
Effective heat of combustion (MJ/kg)	DH_c	11.3	10.9	11.1
Specific smoke production (m^2/kg)	SEA	635	721	678
Max average rate of heat emission (kW/m^2)	MARHE	135.9	119.7	127.8
Volume flow in exhaust duct (l/s)	V	24	24	24

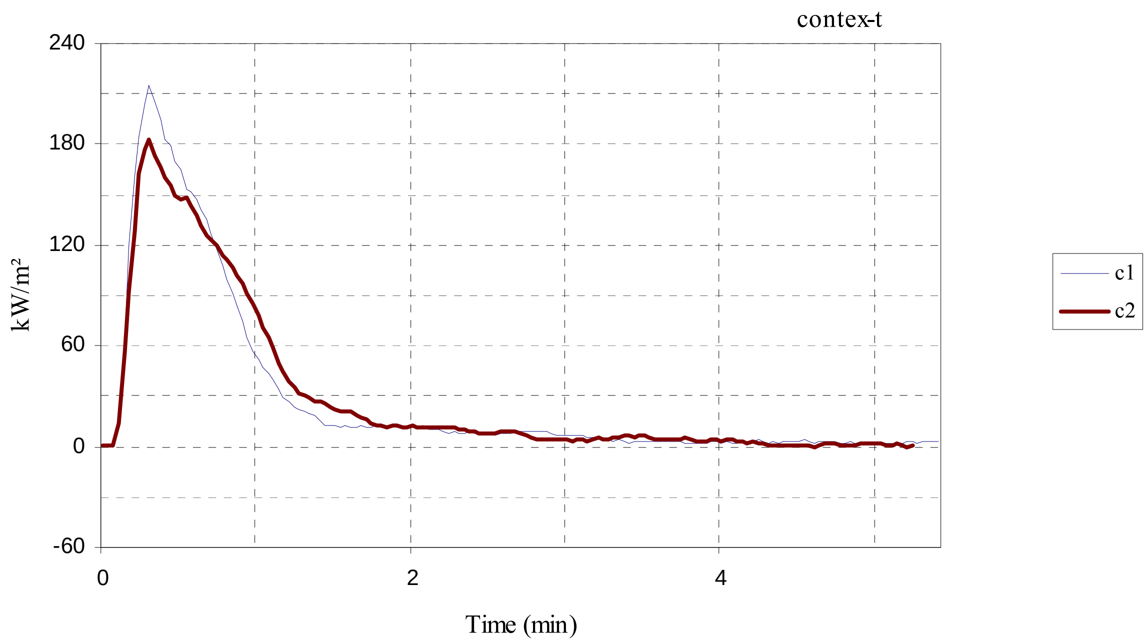


Figure 47 Heat release rate at an irradiance of 50 kW/m^2.

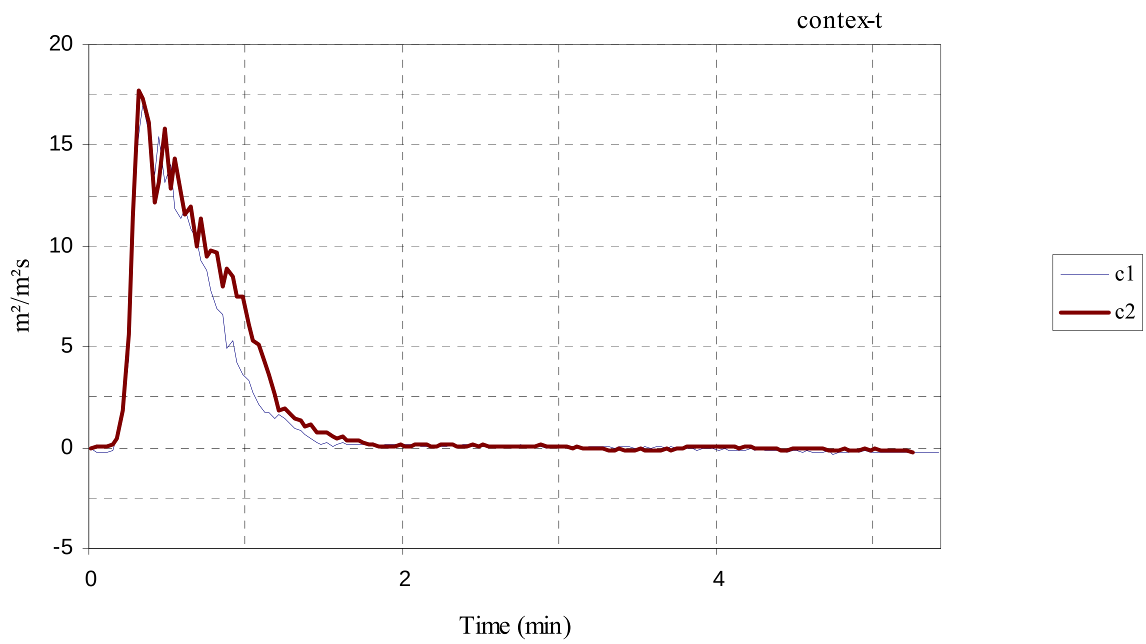


Figure 48 Smoke production at an irradiance of 50 kW/m^2.

PVC 2:

Property	Name of variable	c3	c4	c5	Average value
Flashing (min:s)	t_{flash}	-	-	-	-
Ignition (min:s)	t_{ign}	00:08	00:08	00:07	00:08
All flaming ceased (min:s)	t_{ext}	02:12	02:51	02:55	02:39
Test time (min:s)	t_{test}	05:00	05:00	05:00	05:00
Heat release rate (kW/m^2)	q	See figure 48			
Peak heat release rate (kW/m^2)	q_{max}	189	151	179	173
Average heat release, 3 min (kW/m^2)	q_{180}	46	55	54	52
Average heat release, 5 min (kW/m^2)	q_{300}	31	36	36	34
Total heat produced (MJ/m^2)	THR	9.5	11.0	10.6	10.4
Smoke production rate (m^2/m^2s)	SPR	See figure 49			
Peak smoke production (m^2/m^2s)	SPR_{max}	15.34	9.69	12.39	12.48
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.4	0.1	0.0	0.2
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	431.9	539.5	460.7	477.4
Total smoke production (m^2/m^2)	TSP	432	540	461	478
Sample mass before test (g)	M_0	8.7	8.8	8.7	8.8
Sample mass at sustained flaming (g)	M_s	8.7	8.5	8.4	8.5
Sample mass after test (g)	M_f	-1.4	-1.4	-0.2	-1.0
Average mass loss rate (g/m^2s)	$MLR_{ign-end}$	4.0	3.8	3.3	3.7
Average mass loss rate (g/m^2s)	MLR_{10-90}	4.6	5.7	4.8	5.0
Total mass loss (g/m^2)	TML	1145	1118	971	1078
Effective heat of combustion (MJ/kg)	DH_c	8.3	9.8	11.0	9.7
Specific smoke production (m^2/kg)	SEA	377	483	474	445
Max average rate of heat emission (kW/m^2)	MARHE	123.9	106.0	122.0	117.3
Volume flow in exhaust duct (l/s)	V	24	24	24	24

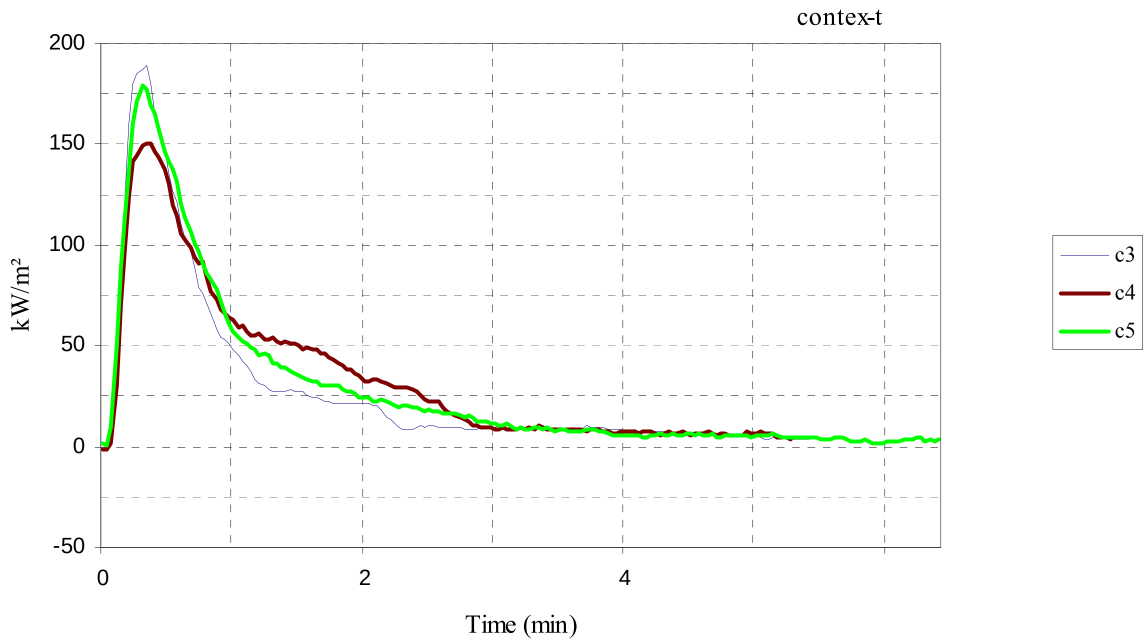


Figure 49 Heat release rate at an irradiance of 50 kW/m^2.

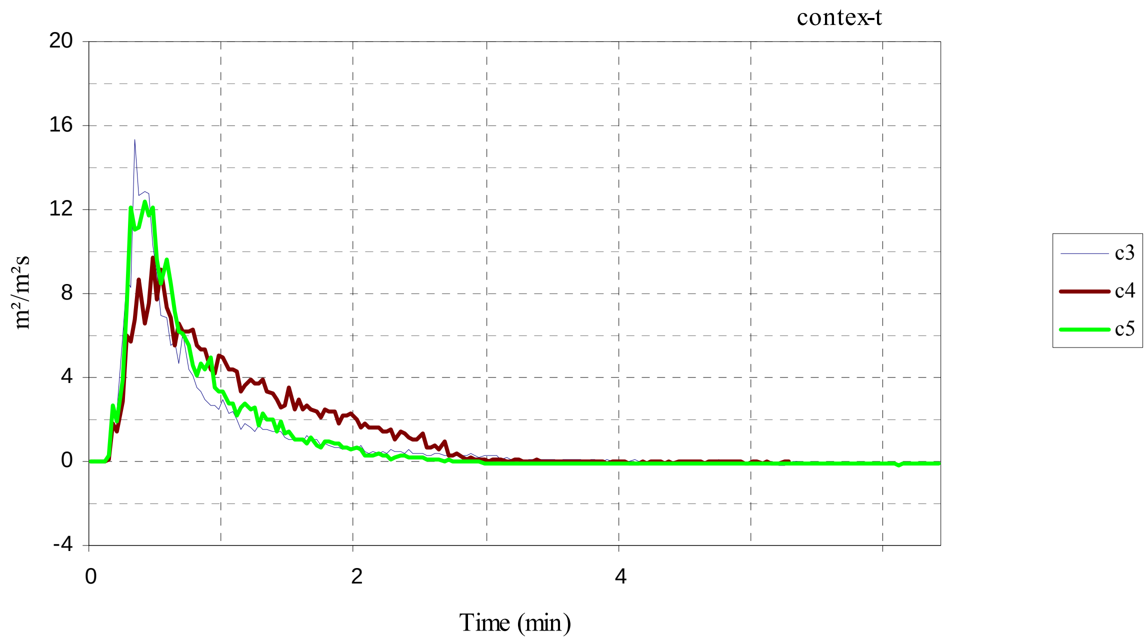


Figure 50 Smoke production rate at an irradiance of 50 kW/m^2.

PVC 2:

Property	Name of variable	c10	c11	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:15	00:16	00:16
All flaming ceased (min:s)	t_{ext}	01:26	01:28	01:27
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 50		
Peak heat release rate (kW/m^2)	q_{max}	171	161	166
Average heat release, 3 min (kW/m^2)	q_{180}	50	48	49
Average heat release, 5 min (kW/m^2)	q_{300}	31 29		30
Total heat produced (MJ/m^2)	THR	9.3	8.9	9.1
Smoke production rate (m^2/m^{2}s)	SPR	See figure 51		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	18.05	17.27	17.66
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.2	0.4	0.3
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	634.7	643.0	638.9
Total smoke production (m^2/m^2)	TSP	635	643	639
Sample mass before test (g)	M_0	7.3	7.2	7.3
Sample mass at sustained flaming (g)	M_s	7.5	6.8	7.2
Sample mass after test (g)	M_f	0.6	0.1	0.3
Average mass loss rate (g/m^{2}s)	$MLR_{ign\text{-}end}$	2.7	2.5	2.6
Average mass loss rate (g/m^{2}s)	$MLR_{10\text{-}90}$	14.2	13.2	13.7
Total mass loss (g/m^2)	TML	783	760	771
Effective heat of combustion (MJ/kg)	DH_c	11.9	11.7	11.8
Specific smoke production (m^2/kg)	SEA	811	847	829
Max average rate of heat emission (kW/m^2)	MARHE	108.8	100.9	104.8
Volume flow in exhaust duct (l/s)	V	24	24	24

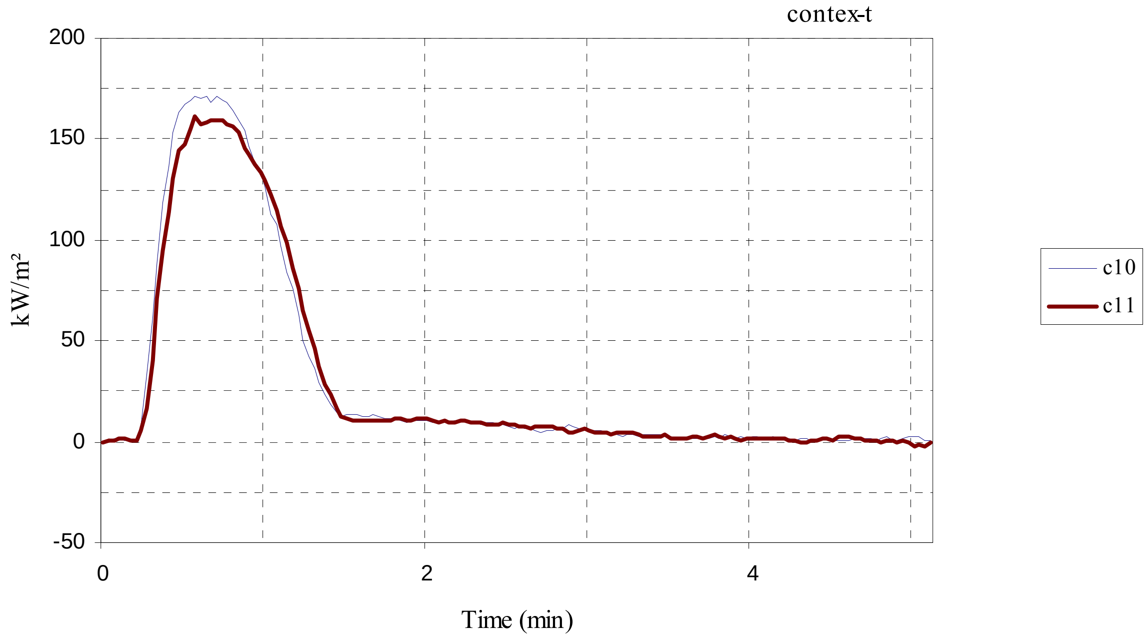


Figure 51 Heat release rate at an irradiance of 35 kW/m^2.

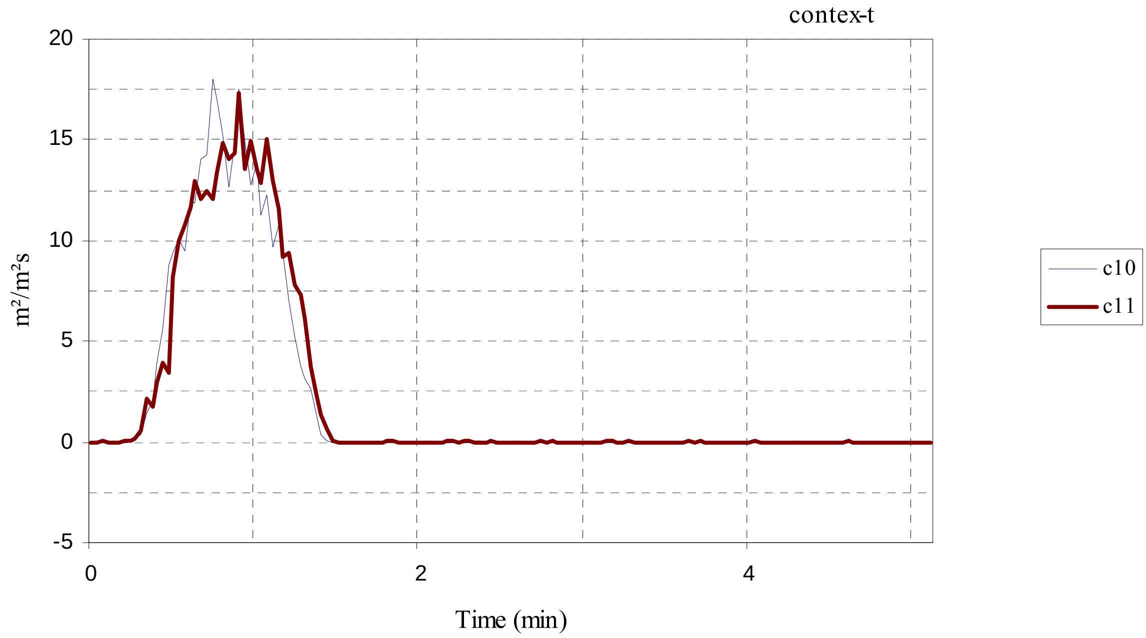


Figure 52 Smoke production rate at an irradiance of 35 kW/m^2.

PVC 2:

Property	Name of variable	c12	c13	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:13	00:12	00:12
All flaming ceased (min:s)	t_{ext}	02:15	02:16	02:15
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 52		
Peak heat release rate (kW/m^2)	q_{max}	124	145	134
Average heat release, 3 min (kW/m^2)	q_{180}	51	54	52
Average heat release, 5 min (kW/m^2)	q_{300}	33 35		34
Total heat produced (MJ/m^2)	THR	10.2	10.7	10.4
Smoke production rate (m^2/m^{2}s)	SPR	See figure 53		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	9.50	8.91	9.21
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.3	0.2	0.3
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	397.2	453.5	425.4
Total smoke production (m^2/m^2)	TSP	398	454	426
Sample mass before test (g)	M_0	7.3	7.4	7.3
Sample mass at sustained flaming (g)	M_s	7.1	7.6	7.3
Sample mass after test (g)	M_f	-0.9	-0.8	-0.8
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	3.2	2.9	3.1
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	4.4	5.2	4.8
Total mass loss (g/m^2)	TML	897	947	922
Effective heat of combustion (MJ/kg)	DH_c	11.3	11.3	11.3
Specific smoke production (m^2/kg)	SEA	443	479	461
Max average rate of heat emission (kW/m^2)	MARHE	90.1	96.0	93.1
Volume flow in exhaust duct (l/s)	V	24	24	24

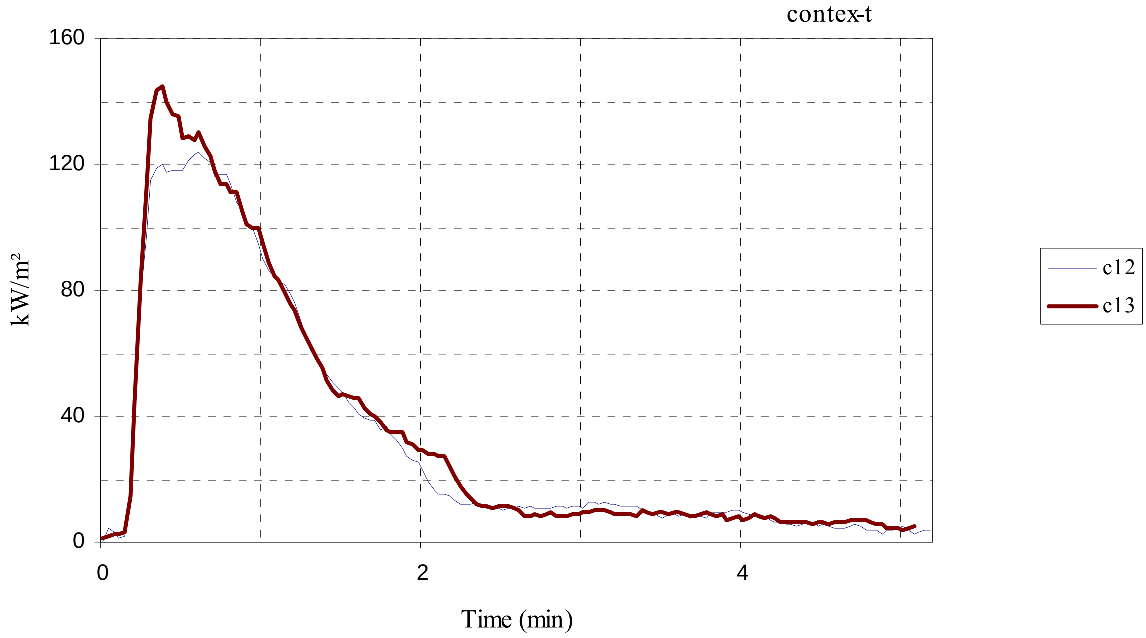


Figure 53 Heat release rate at an irradiance of 35 kW/m^2.

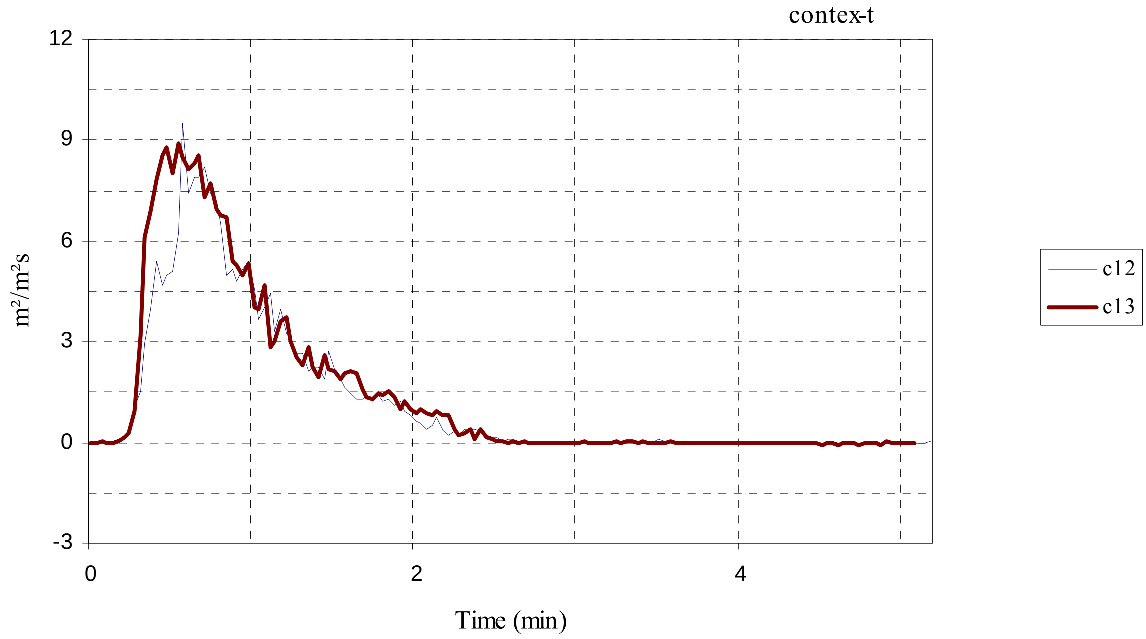


Figure 54 Smoke production rate at an irradiance of 35 kW/m^2.

PVC 2:

Property	Name of variable	c15	c16	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:08	00:09	00:09
All flaming ceased (min:s)	t_{ext}	01:17	01:19	01:18
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 54		
Peak heat release rate (kW/m^2)	q_{max}	158	156	157
Average heat release, 3 min (kW/m^2)	q_{180}	47	47	47
Average heat release, 5 min (kW/m^2)	q_{300}	29 29		29
Total heat produced (MJ/m^2)	THR	8.7	8.7	8.7
Smoke production rate (m^2/m^{2}s)	SPR	See figure 55		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	17.39	16.23	16.81
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.0	0.0	0.0
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	634.4	657.8	646.1
Total smoke production (m^2/m^2)	TSP	634	658	646
Sample mass before test (g)	M_0	7.4	7.3	7.3
Sample mass at sustained flaming (g)	M_s	7.1	7.5	7.3
Sample mass after test (g)	M_f	-0.1	0.5	0.2
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	2.7	2.6	2.6
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	8.1	10.4	9.2
Total mass loss (g/m^2)	TML	811	802	806
Effective heat of combustion (MJ/kg)	DH_c	10.8	10.8	10.8
Specific smoke production (m^2/kg)	SEA	783	820	801
Max average rate of heat emission (kW/m^2)	MARHE	115.9	113.8	114.8
Volume flow in exhaust duct (l/s)	V	24	24	24

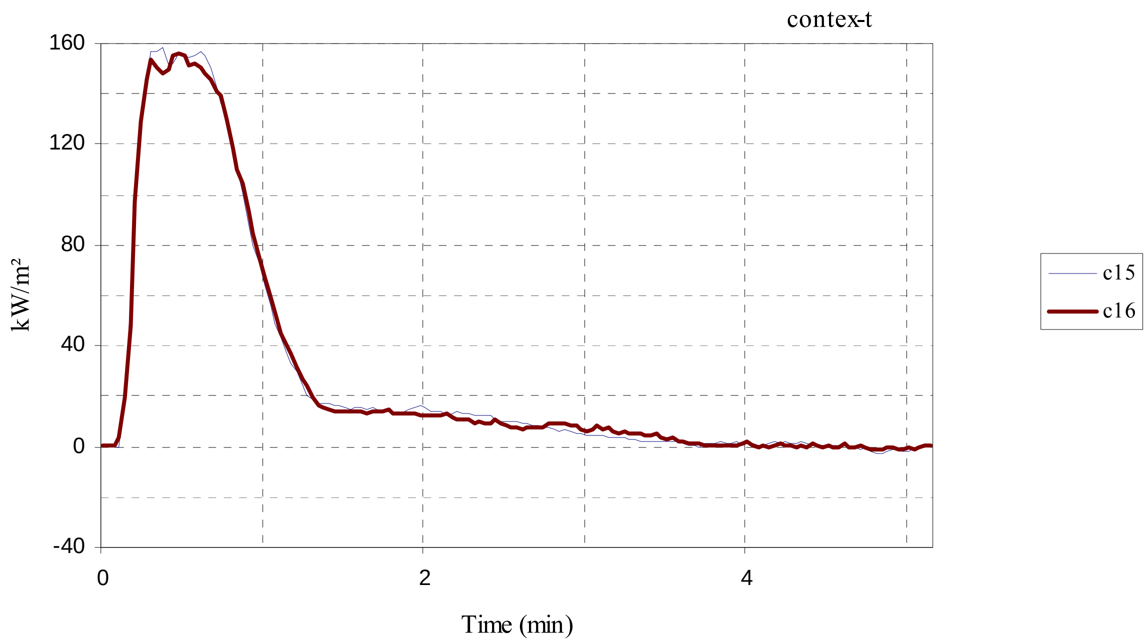


Figure 55 Heat release rate at an irradiance of 50 kW/m^2.

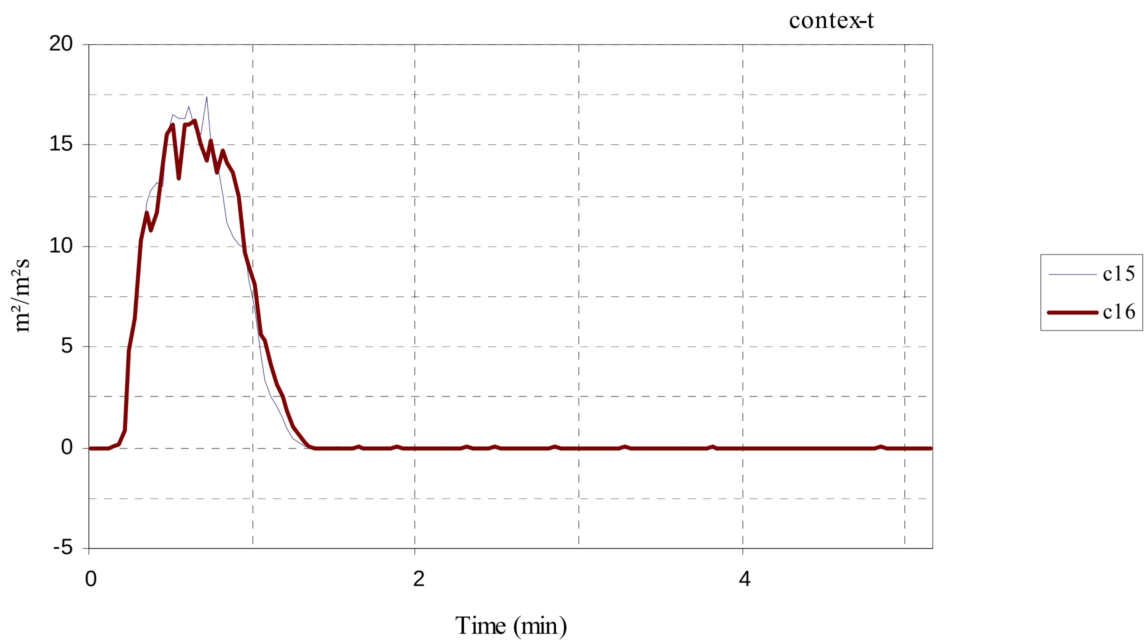


Figure 56 Smoke production at an irradiance of 50 kW/m^2.

PVC 4:

Property	Name of variable	d1	d6	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:11	00:12	00:11
All flaming ceased (min:s)	t_{ext}	03:00	01:53	02:27
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 56		
Peak heat release rate (kW/m^2)	q_{max}	189	199	194
Average heat release, 3 min (kW/m^2)	q_{180}	78	82	80
Average heat release, 5 min (kW/m^2)	q_{300}	49 55		52
Total heat produced (MJ/m^2)	THR	15.0	16.5	15.8
Smoke production rate (m^2/m^2s)	SPR	See figure 57		
Peak smoke production (m^2/m^2s)	SPR_{max}	17.37	19.37	18.37
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.2	0.5	0.3
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	1042.1	1060.2	1051.2
Total smoke production (m^2/m^2)	TSP	1042	1061	1051
Sample mass before test (g)	M_0	12.6	12.5	12.6
Sample mass at sustained flaming (g)	M_s	12.5	12.5	12.5
Sample mass after test (g)	M_f	1.0	-1.3	-0.2
Average mass loss rate (g/m^2s)	$MLR_{ign-end}$	4.8	5.4	5.1
Average mass loss rate (g/m^2s)	MLR_{10-90}	9.5	7.0	8.3
Total mass loss (g/m^2)	TML	1304	1563	1434
Effective heat of combustion (MJ/kg)	DH_c	11.5	10.5	11.0
Specific smoke production (m^2/kg)	SEA	799	678	739
Max average rate of heat emission (kW/m^2)	MARHE	128.9	145.4	137.2
Volume flow in exhaust duct (l/s)	V	24	24	24

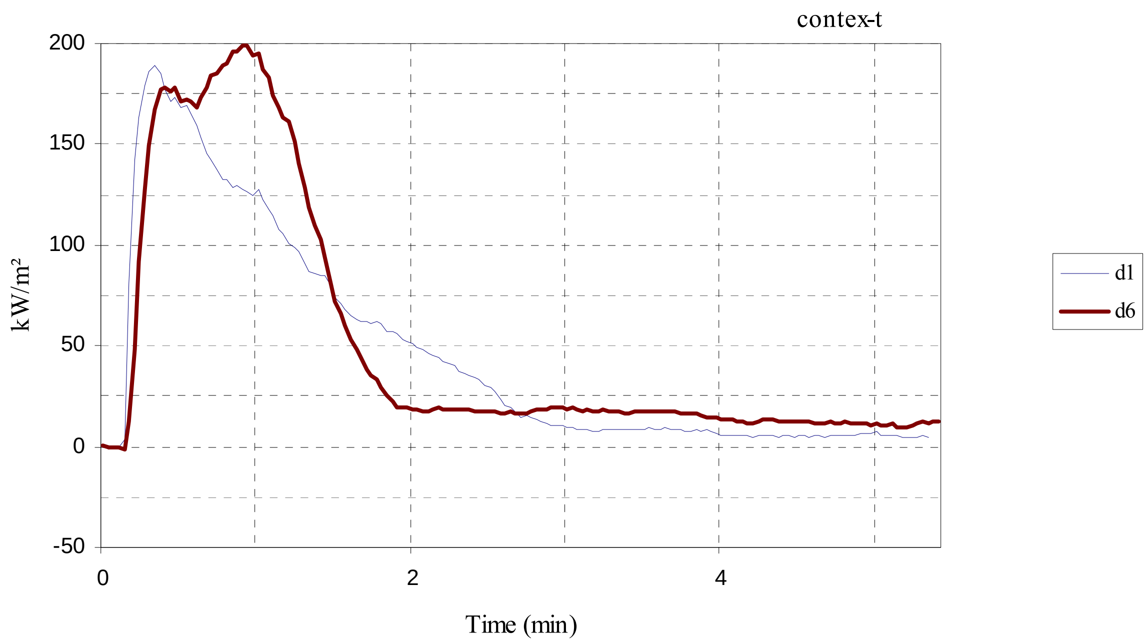


Figure 57 Heat release rate at an irradiance of 50 kW/m^2.

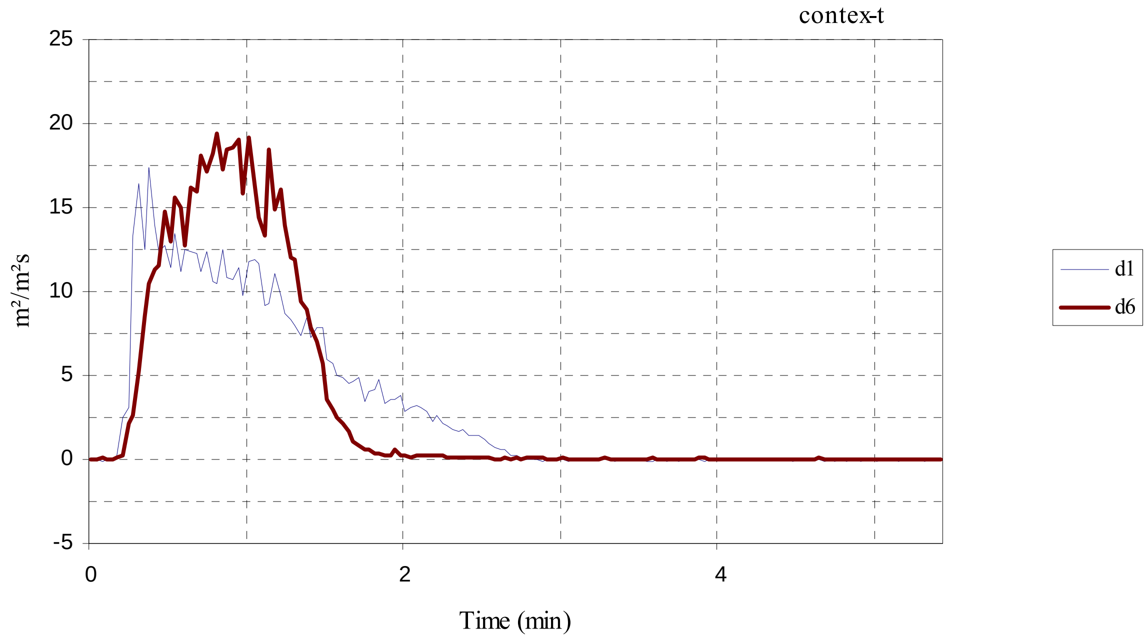


Figure 58 Smoke production at an irradiance of 50 kW/m^2.

PVC 4:

Property	Name of variable	d2	d3	d5	Average value
Flashing (min:s)	t_{flash}	-	-	-	-
Ignition (min:s)	t_{ign}	00:11	00:10	00:16	00:12
All flaming ceased (min:s)	t_{ext}	02:34	02:43	02:20	02:32
Test time (min:s)	t_{test}	05:00	05:00	05:00	05:00
Heat release rate (kW/m^2)	q	See figure 58			
Peak heat release rate (kW/m^2)	q_{max}	201	204	201	202
Average heat release, 3 min (kW/m^2)	q_{180}	85	84	72	81
Average heat release, 5 min (kW/m^2)	q_{300}	55	55	47	53
Total heat produced (MJ/m^2)	THR	16.8	16.6	15.1	16.2
Smoke production rate (m^2/m^{2}s)	SPR	See figure 59			
Peak smoke production (m^2/m^{2}s)	SPR_{max}	17.15	19.15	18.34	18.22
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.1	0.5	17.6	6.0
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	1023.9	1038.2	894.2	985.4
Total smoke production (m^2/m^2)	TSP	1024	1039	912	991
Sample mass before test (g)	M_0	12.6	12.4	25.9	17.0
Sample mass at sustained flaming (g)	M_s	12.5	12.0	26.1	16.9
Sample mass after test (g)	M_f	0.5	-0.1	14.4	4.9
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	4.4	5.0	4.6	4.7
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	10.0	9.0	5.5	8.2
Total mass loss (g/m^2)	TML	1353	1374	1332	1353
Effective heat of combustion (MJ/kg)	DH_c	12.4	12.1	11.4	12.0
Specific smoke production (m^2/kg)	SEA	757	756	685	732
Max average rate of heat emission (kW/m^2)	MARHE	142.8	140.4	139.1	140.7
Volume flow in exhaust duct (l/s)	V	24	24	24	24

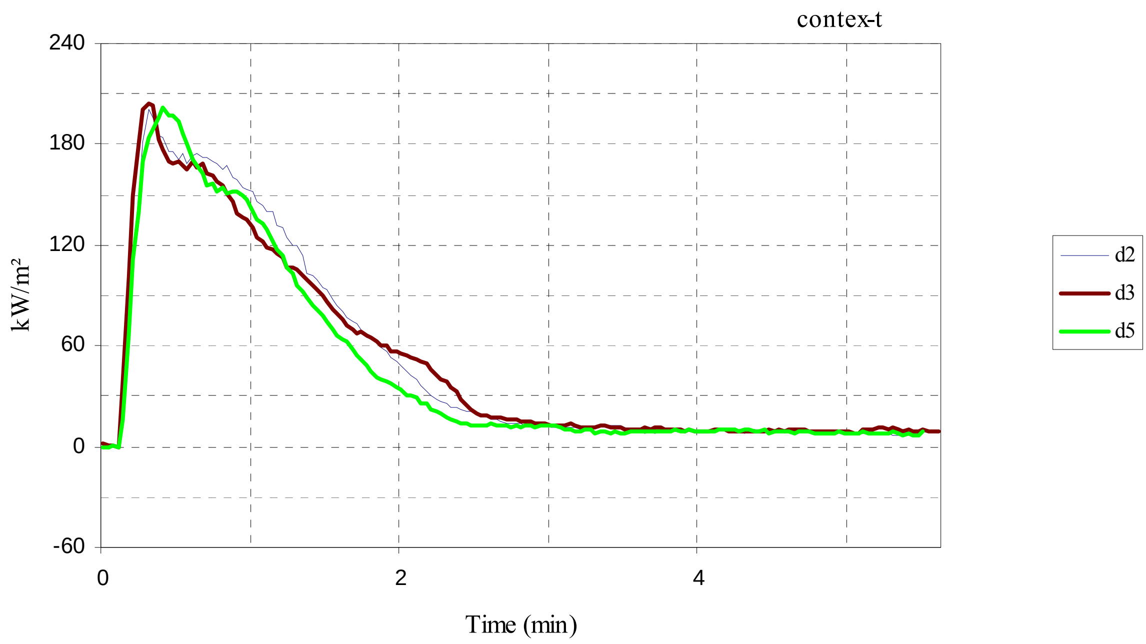


Figure 59 Heat release rate at an irradiance of 50 kW/m^2.

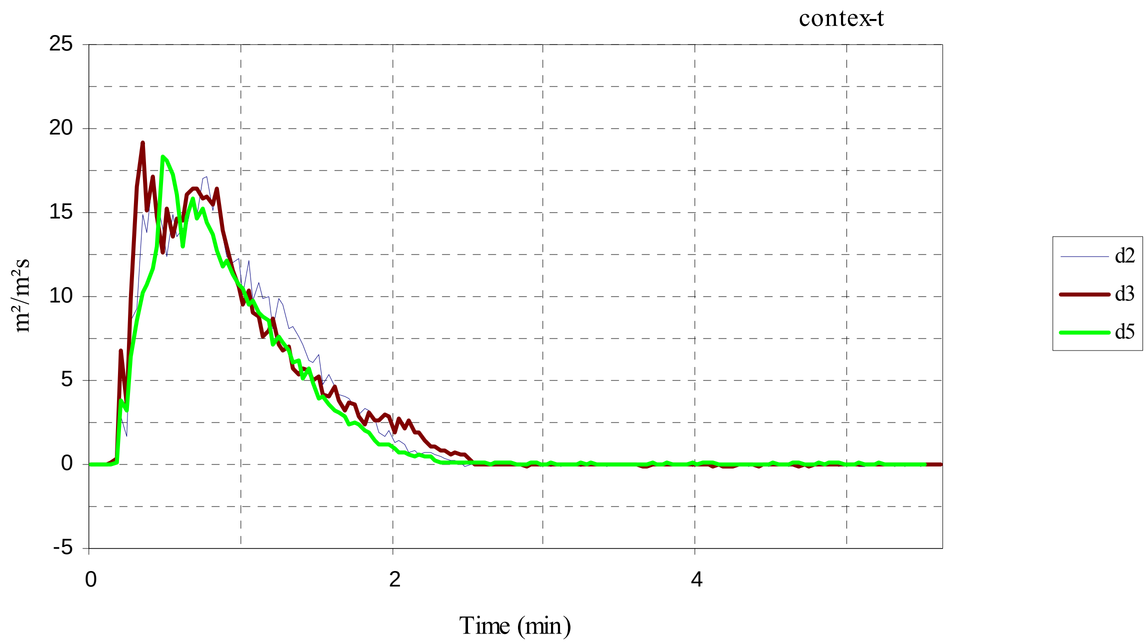


Figure 60 Smoke production at an irradiance of 50 kW/m^2.

PVC 4:

Property	Name of variable	d4	d14	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:12	00:10	00:11
All flaming ceased (min:s)	t_{ext}	01:31	01:42	01:37
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 60		
Peak heat release rate (kW/m^2)	q_{max}	299	230	265
Average heat release, 3 min (kW/m^2)	q_{180}	81	82	81
Average heat release, 5 min (kW/m^2)	q_{300}	49 51		50
Total heat produced (MJ/m^2)	THR	15.1	15.4	15.3
Smoke production rate (m^2/m^{2}s)	SPR	See figure 61		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	29.04	25.68	27.36
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.3	0.1	0.2
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	1138.0	1215.6	1176.8
Total smoke production (m^2/m^2)	TSP	1138	1216	1177
Sample mass before test (g)	M_0	12.7	12.7	12.7
Sample mass at sustained flaming (g)	M_s	13.0	11.2	12.1
Sample mass after test (g)	M_f	0.9	-0.7	0.1
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	4.7	4.5	4.6
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	22.7	18.6	20.7
Total mass loss (g/m^2)	TML	1365	1348	1356
Effective heat of combustion (MJ/kg)	DH_c	11.1	11.4	11.3
Specific smoke production (m^2/kg)	SEA	834	902	868
Max average rate of heat emission (kW/m^2)	MARHE	187.1	158.3	172.7
Volume flow in exhaust duct (l/s)	V	24	24	24

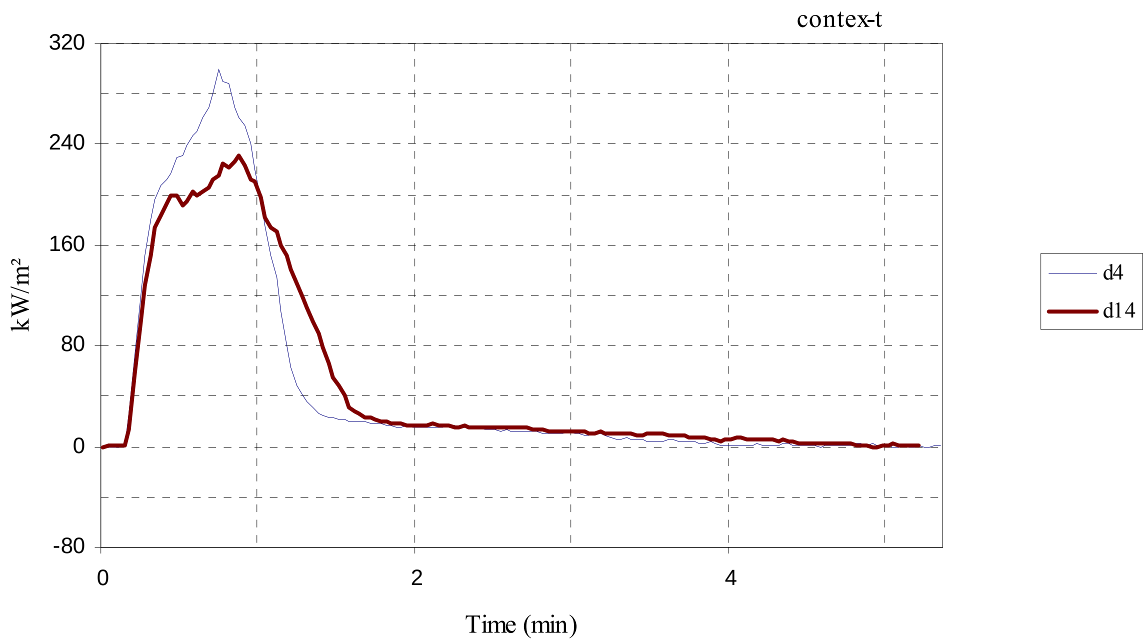


Figure 61 Heat release rate at an irradiance of 50 kW/m^2.

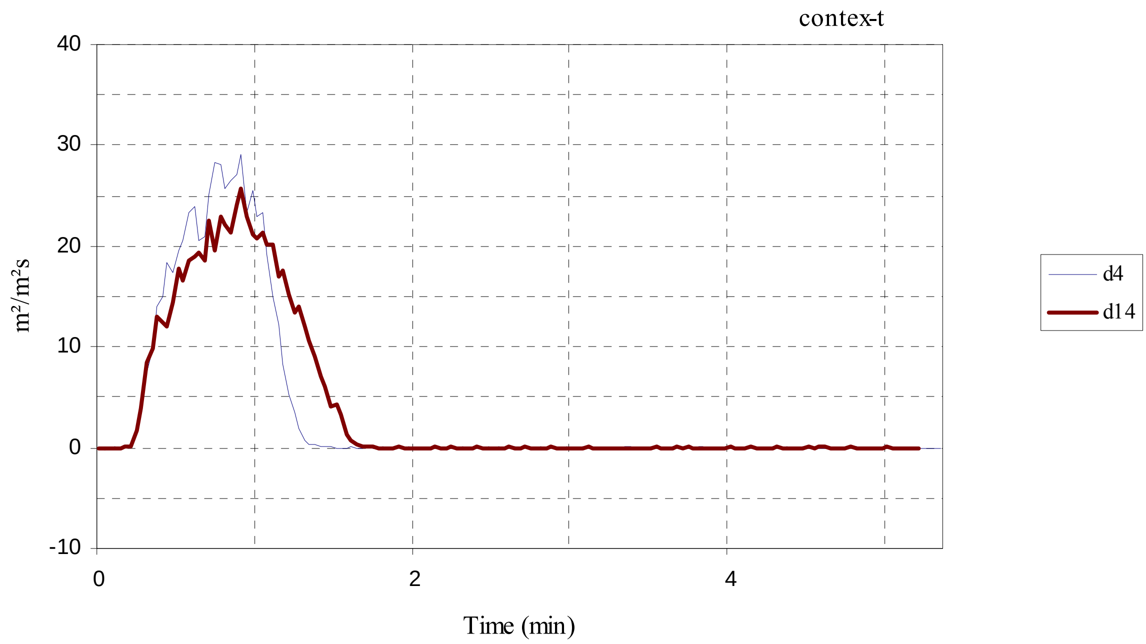


Figure 62 Smoke production at an irradiance of 50 kW/m^2.

PVC 4:

Property	Name of variable	d7	d8	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:10	00:09	00:10
All flaming ceased (min:s)	t_{ext}	03:37	03:55	03:46
Test time (min:s)	t_{test}	05:37 05:55		05:46
Heat release rate (kW/m^2)	q	See figure 62		
Peak heat release rate (kW/m^2)	q_{max}	204	199	201
Average heat release, 3 min (kW/m^2)	q_{180}	86	89	88
Average heat release, 5 min (kW/m^2)	q_{300}	58 63		61
Total heat produced (MJ/m^2)	THR	18.3	19.9	19.1
Smoke production rate (m^2/m^{2}s)	SPR	See figure 63		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	16.05	14.95	15.50
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.3	0.0	0.2
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	827.9	804.1	816.0
Total smoke production (m^2/m^2)	TSP	828	804	816
Sample mass before test (g)	M_0	15.2	15.3	15.2
Sample mass at sustained flaming (g)	M_s	15.4	15.2	15.3
Sample mass after test (g)	M_f	0.0	0.6	0.3
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	5.1	4.6	4.9
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	6.6	6.2	6.4
Total mass loss (g/m^2)	TML	1737	1647	1692
Effective heat of combustion (MJ/kg)	DH_c	10.5	12.1	11.3
Specific smoke production (m^2/kg)	SEA	477	488	483
Max average rate of heat emission (kW/m^2)	MARHE	132.8	130.3	131.6
Volume flow in exhaust duct (l/s)	V	24	24	24

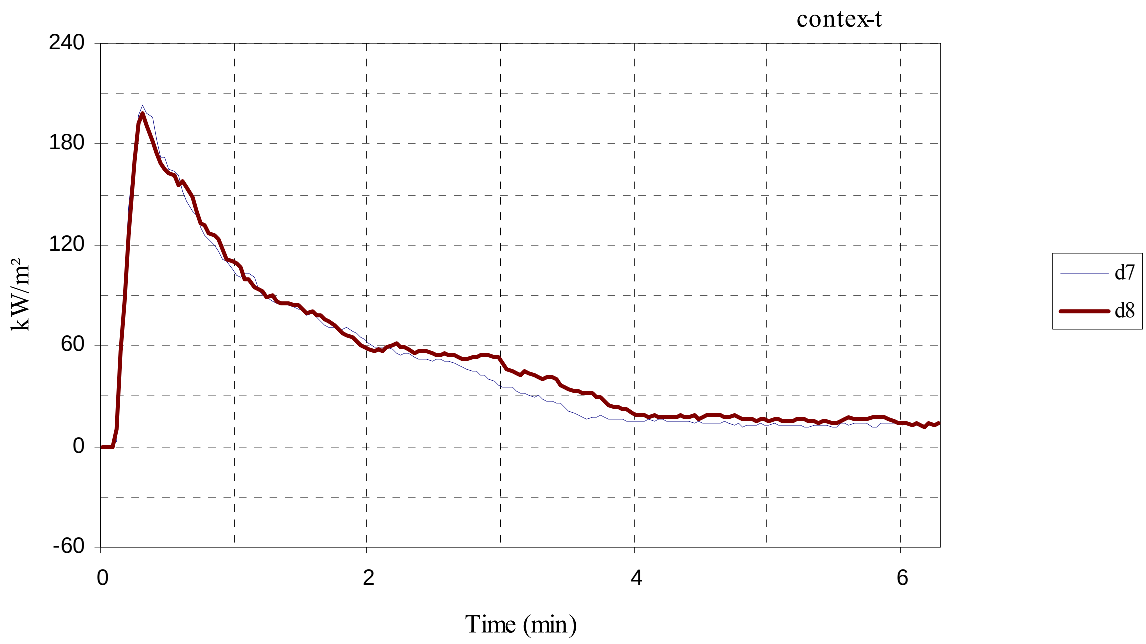


Figure 63 Heat release rate at an irradiance of 50 kW/m^2.

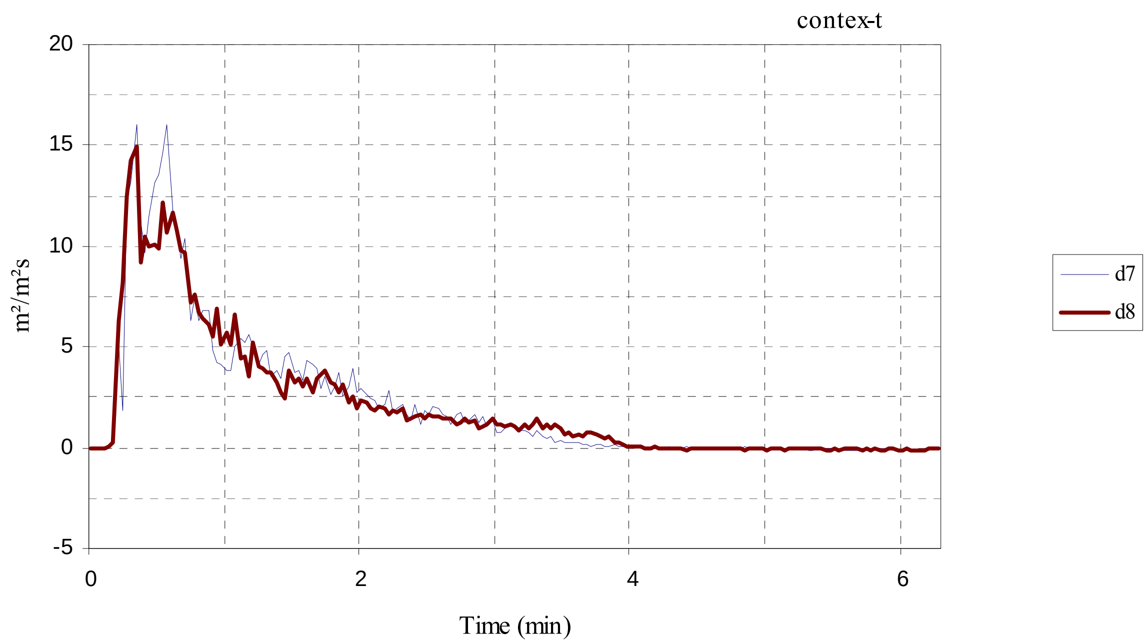


Figure 64 Smoke production rate at an irradiance of 50 kW/m^2.

PVC 4:

Property	Name of variable	d10	d11	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:20	00:19	00:20
All flaming ceased (min:s)	t_{ext}	01:56	01:58	01:57
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 64		
Peak heat release rate (kW/m^2)	q_{max}	194	194	194
Average heat release, 3 min (kW/m^2)	q_{180}	81	83	82
Average heat release, 5 min (kW/m^2)	q_{300}	51 53		52
Total heat produced (MJ/m^2)	THR	15.6	16.1	15.9
Smoke production rate (m^2/m^2s)	SPR	See figure 65		
Peak smoke production (m^2/m^2s)	SPR_{max}	22.02	21.75	21.89
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.7	0.6	0.7
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	1171.6	1191.8	1181.7
Total smoke production (m^2/m^2)	TSP	1172	1192	1182
Sample mass before test (g)	M_0	12.6	12.9	12.7
Sample mass at sustained flaming (g)	M_s	12.7	12.9	12.8
Sample mass after test (g)	M_f	1.0	1.0	1.0
Average mass loss rate (g/m^2s)	$MLR_{ign-end}$	4.6	4.6	4.6
Average mass loss rate (g/m^2s)	MLR_{10-90}	16.4	16.4	16.4
Total mass loss (g/m^2)	TML	1315	1353	1334
Effective heat of combustion (MJ/kg)	DH_c	11.9	11.9	11.9
Specific smoke production (m^2/kg)	SEA	891	881	886
Max average rate of heat emission (kW/m^2)	MARHE	130.9	130.1	130.5
Volume flow in exhaust duct (l/s)	V	24	24	24

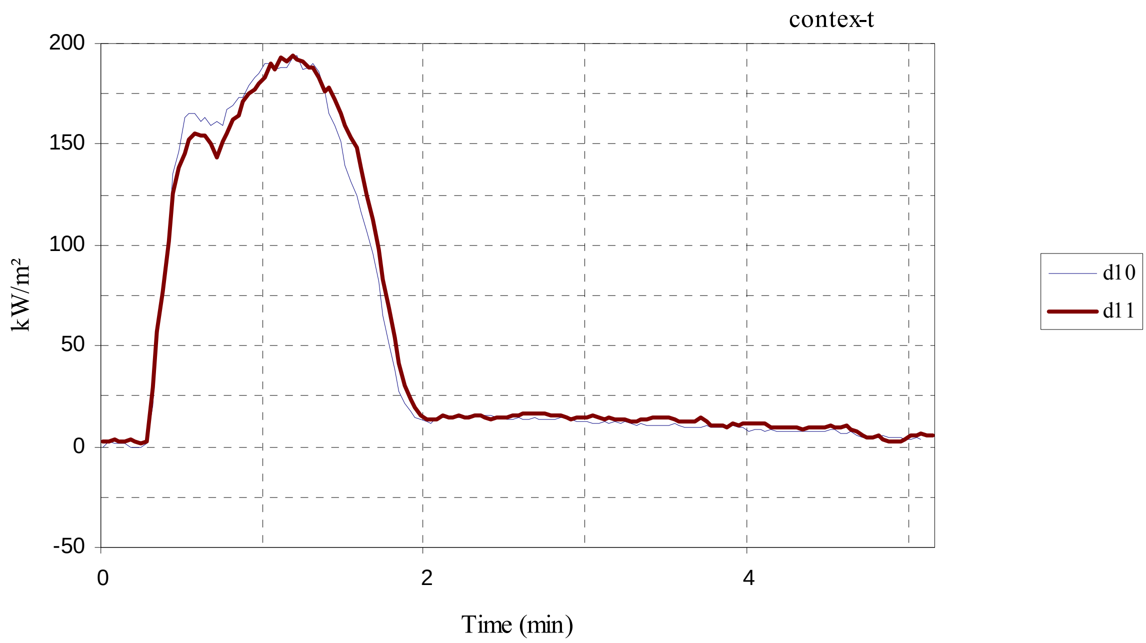


Figure 65 Heat release rate at an irradiance of 35 kW/m^2.

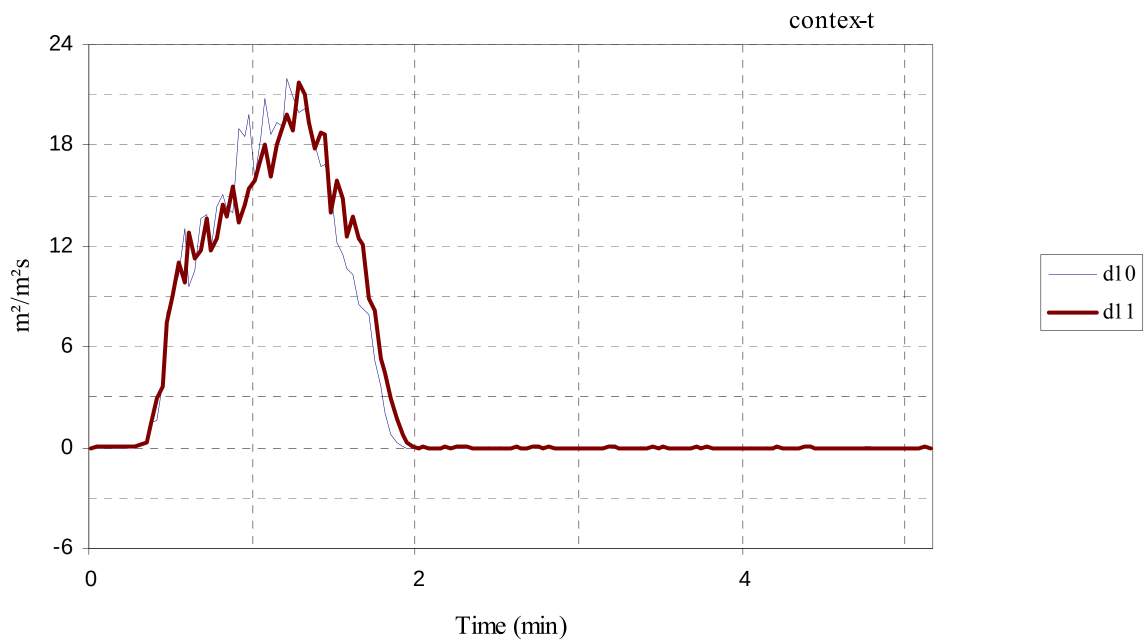


Figure 66 Smoke production rate at an irradiance of 35 kW/m^2.

PVC 4:

Property	Name of variable	d12	d13	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:16	00:16	00:16
All flaming ceased (min:s)	t_{ext}	04:17	03:46	04:02
		06:17		
Test time (min:s)	t_{test}	05:46		06:01
		See figure		
Heat release rate (kW/m^2)	q	66		
Peak heat release rate (kW/m^2)	q_{max}	141	147	144
Average heat release, 3 min (kW/m^2)	q_{180}	81	83	82
		57		
Average heat release, 5 min (kW/m^2)	q_{300}	55		56
Total heat produced (MJ/m^2)	THR	18.1	16.9	17.5
		See figure		
Smoke production rate (m^2/m^{2}s)	SPR	67		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	11.78	9.83	10.81
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.5	0.5	0.5
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	767.6	788.1	777.8
Total smoke production (m^2/m^2)	TSP	768	789	778
Sample mass before test (g)	M_0	12.7	12.5	12.6
Sample mass at sustained flaming (g)	M_s	13.4	12.5	13.0
Sample mass after test (g)	M_f	0.4	-0.2	0.1
Average mass loss rate (g/m^{2}s)	$MLR_{ign\text{-}end}$	4.2	4.2	4.2
Average mass loss rate (g/m^{2}s)	$MLR_{10\text{-}90}$	5.6	6.5	6.0
Total mass loss (g/m^2)	TML	1479	1436	1457
Effective heat of combustion (MJ/kg)	DH_c	12.2	11.8	12.0
Specific smoke production (m^2/kg)	SEA	519	549	534
Max average rate of heat emission (kW/m^2)	MARHE	86.0	89.5	87.7
Volume flow in exhaust duct (l/s)	V	24	24	24

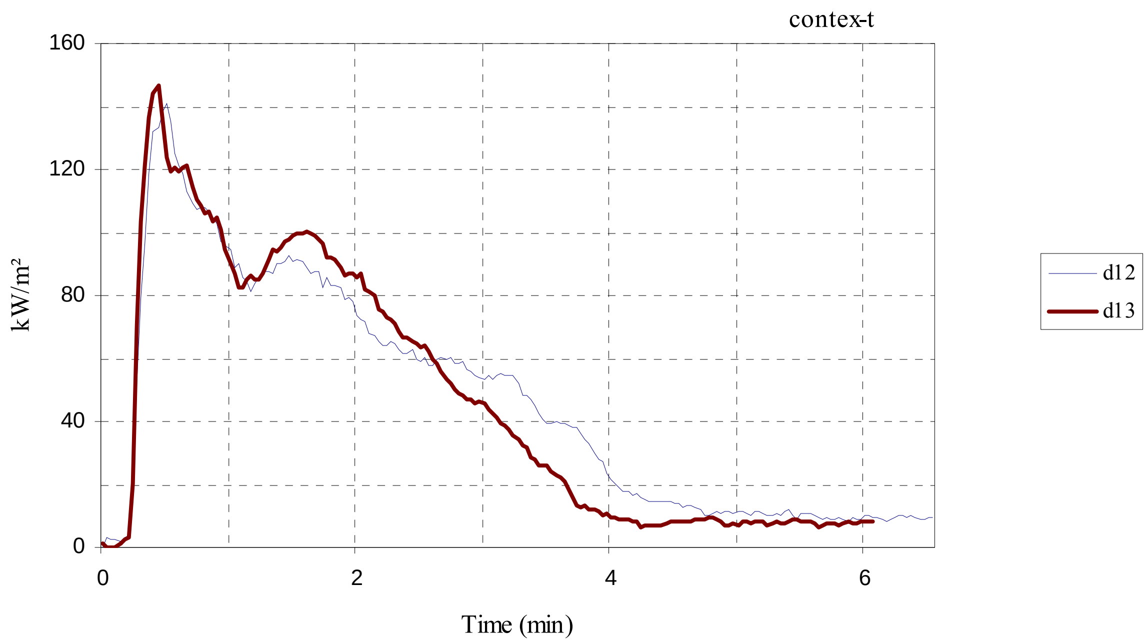


Figure 67 Heat release rate at an irradiance of 35 kW/m^2.

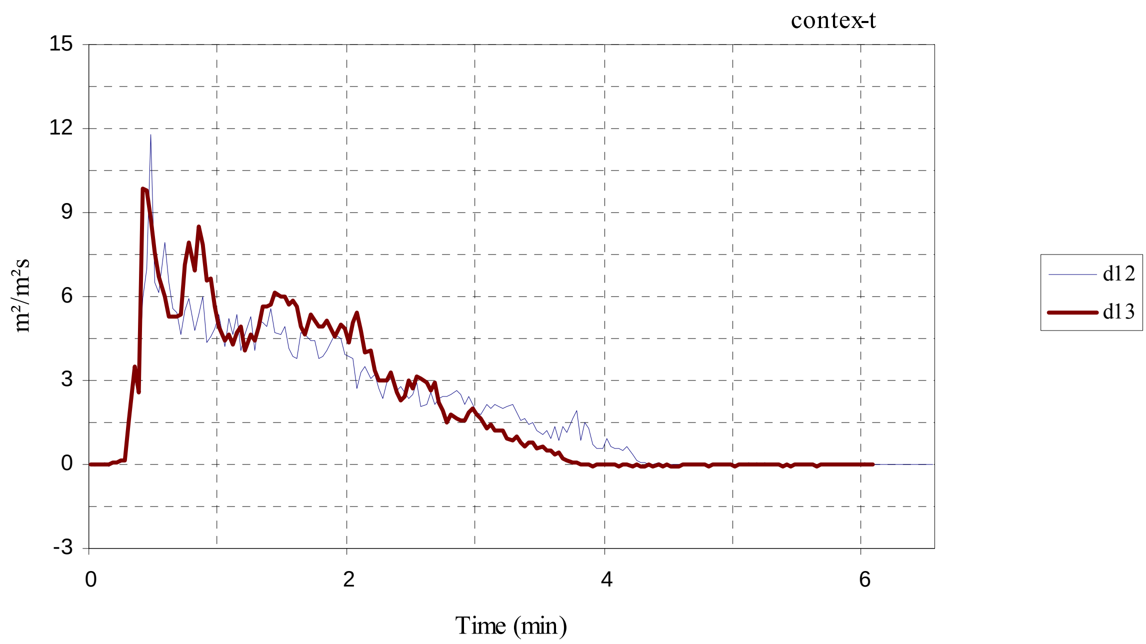


Figure 68 Smoke production rate at an irradiance of 35 kW/m^2.

PVC 4:

Property	Name of variable	d 15	d 16	d 17	Average value
Flashing (min:s)	t_{flash}	-	-	-	-
Ignition (min:s)	t_{ign}	00:10	00:12	00:12	00:11
All flaming ceased (min:s)	t_{ext}	01:47	01:34	01:40	01:40
Test time (min:s)	t_{test}	05:00	05:00	05:00	05:00
Heat release rate (kW/m^2)	q	See figure 68			
Peak heat release rate (kW/m^2)	q_{max}	212	238	243	231
Average heat release, 3 min (kW/m^2)	q_{180}	77	79	79	78
Average heat release, 5 min (kW/m^2)	q_{300}	49	49	49	49
Total heat produced (MJ/m^2)	THR	14.9	14.9	15.0	15.0
Smoke production rate (m^2/m^{2}s)	SPR	See figure 69			
Peak smoke production (m^2/m^{2}s)	SPR_{max}	21.72	25.10	26.79	24.54
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	0.1	0.1	0.4	0.2
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	1126.0	1190.7	1215.7	1177.4
Total smoke production (m^2/m^2)	TSP	1126	1191	1216	1178
Sample mass before test (g)	M_0	12.0	12.0	12.2	12.1
Sample mass at sustained flaming (g)	M_s	11.8	12.3	12.3	12.2
Sample mass after test (g)	M_f	0.7	0.8	1.0	0.8
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	4.4	4.7	4.1	4.4
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	14.0	18.6	19.0	17.2
Total mass loss (g/m^2)	TML	1257	1302	1284	1281
Effective heat of combustion (MJ/kg)	DH_c	11.9	11.5	11.7	11.7
Specific smoke production (m^2/kg)	SEA	896	915	947	919
Max average rate of heat emission (kW/m^2)	MARHE	148.7	162.7	164.7	158.7
Volume flow in exhaust duct (l/s)	V	24	24	24	24

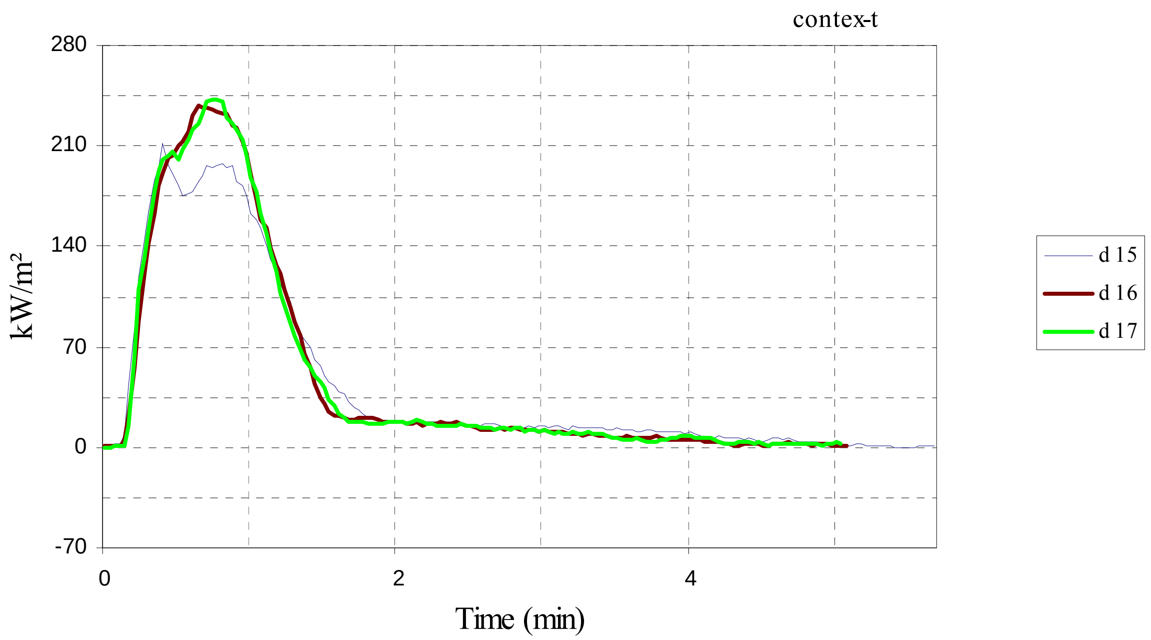


Figure 69 Heat release rate at an irradiance of 35 kW/m^2.

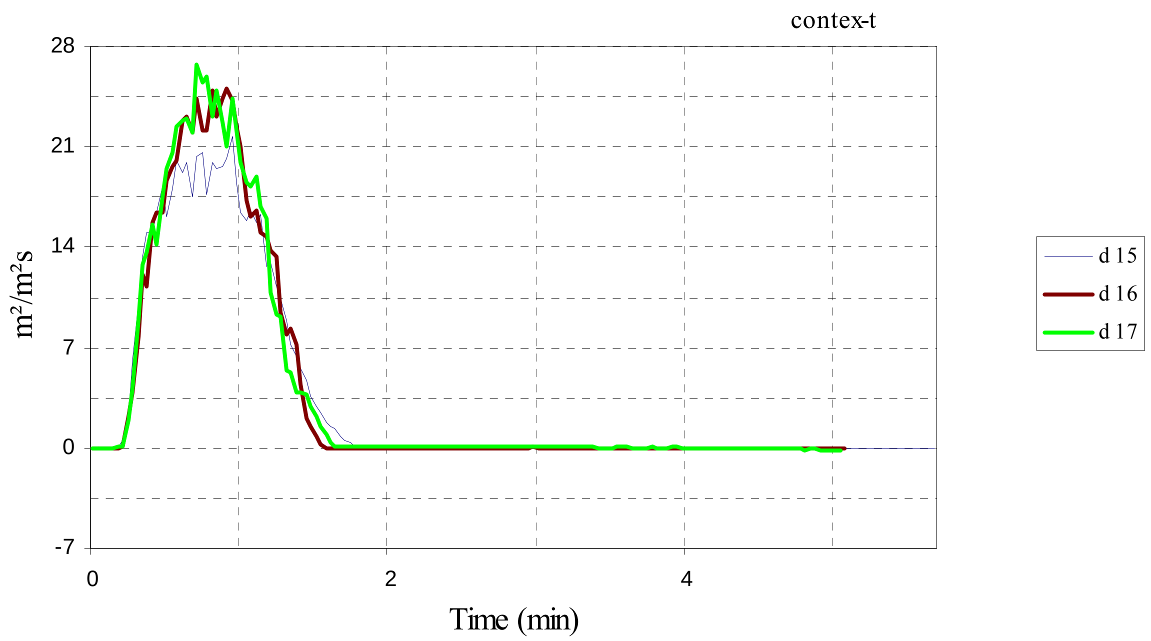


Figure 70 Smoke production rate at an irradiance of 35 kW/m^2.

Silicone:

Property	Name of variable	e10	e11	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	01:23	01:25	01:24
All flaming ceased (min:s)	t_{ext}	04:42	04:15	04:29
Test time (min:s)	t_{test}	06:42 06:15		06:29
Heat release rate (kW/m^2)	q	See figure 70		
Peak heat release rate (kW/m^2)	q_{max}	76	84	80
Average heat release, 3 min (kW/m^2)	q_{180}	49	52	51
Average heat release, 5 min (kW/m^2)	q_{300}	33 36		35
Total heat produced (MJ/m^2)	THR	10.4	11.1	10.8
Smoke production rate (m^2/m^2s)	SPR	See figure 71		
Peak smoke production (m^2/m^2s)	SPR_{max}	1.85	2.41	2.13
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	9.7	14.7	12.2
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	109.3	118.3	113.8
Total smoke production (m^2/m^2)	TSP	119	133	126
Sample mass before test (g)	M_0	12.7	12.5	12.6
Sample mass at sustained flaming (g)	M_s	12.6	12.1	12.3
Sample mass after test (g)	M_f	10.5	9.9	10.2
Average mass loss rate (g/m^2s)	$MLR_{ign-end}$	0.4	0.8	0.6
Average mass loss rate (g/m^2s)	MLR_{10-90}	1.2	1.0	1.1
Total mass loss (g/m^2)	TML	229	249	239
Effective heat of combustion (MJ/kg)	DH_c	45.3	44.7	45.0
Specific smoke production (m^2/kg)	SEA	519	534	527
Max average rate of heat emission (kW/m^2)	MARHE	36.6	38.4	37.5
Volume flow in exhaust duct (l/s)	V	24	24	24

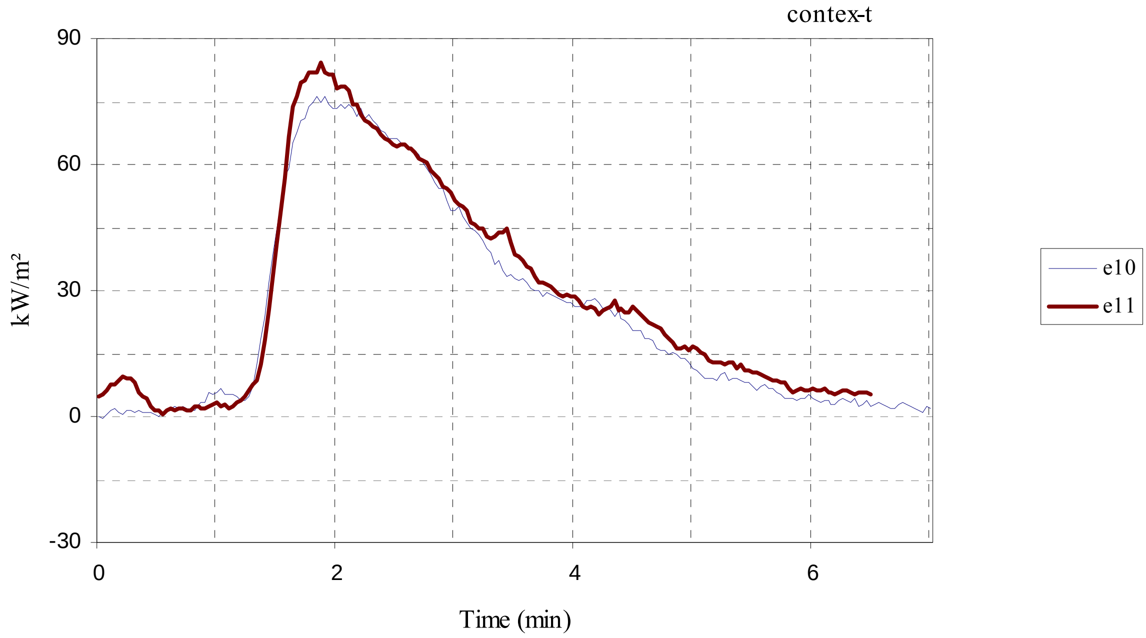


Figure 71 Heat release rate at an irradiance of 35 kW/m^2.

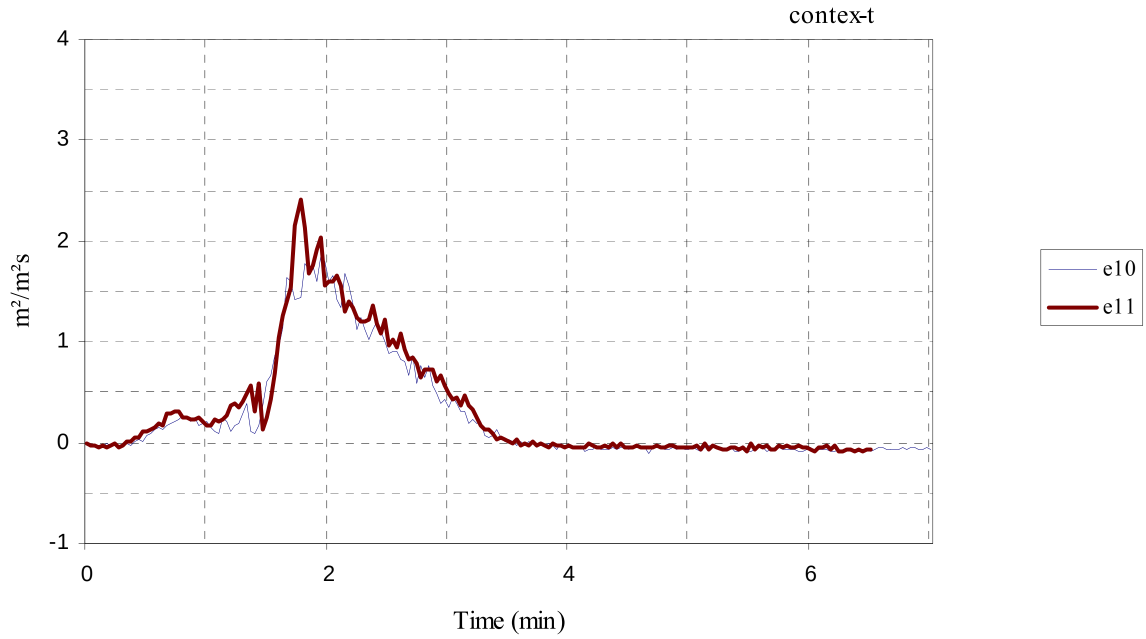


Figure 72 Smoke production rate at an irradiance of 35 kW/m^2.

Silicone:

Property	Name of variable	e12	e13	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	01:44	01:40	01:42
All flaming ceased (min:s)	t_{ext}	03:59	03:55	03:57
Test time (min:s)	t_{test}	05:59 05:55		05:57
Heat release rate (kW/m^2)	q	See figure 72		
Peak heat release rate (kW/m^2)	q_{max}	63	65	64
Average heat release, 3 min (kW/m^2)	q_{180}	29	30	29
Average heat release, 5 min (kW/m^2)	q_{300}	19 20		19
Total heat produced (MJ/m^2)	THR	5.9	6.0	5.9
Smoke production rate (m^2/m^{2}s)	SPR	See figure 73		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	1.68	1.73	1.70
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	13.7	13.3	13.5
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	60.3	69.1	64.7
Total smoke production (m^2/m^2)	TSP	74	82	78
Sample mass before test (g)	M_0	12.7	12.5	12.6
Sample mass at sustained flaming (g)	M_s	12.2	10.3	11.2
Sample mass after test (g)	M_f	10.1	7.9	9.0
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	1.0	0.9	0.9
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	1.1	1.2	1.2
Total mass loss (g/m^2)	TML	236	272	254
Effective heat of combustion (MJ/kg)	DH_c	24.8	21.9	23.4
Specific smoke production (m^2/kg)	SEA	313	303	308
Max average rate of heat emission (kW/m^2)	MARHE	22.0	22.3	22.2
Volume flow in exhaust duct (l/s)	V	24	24	24

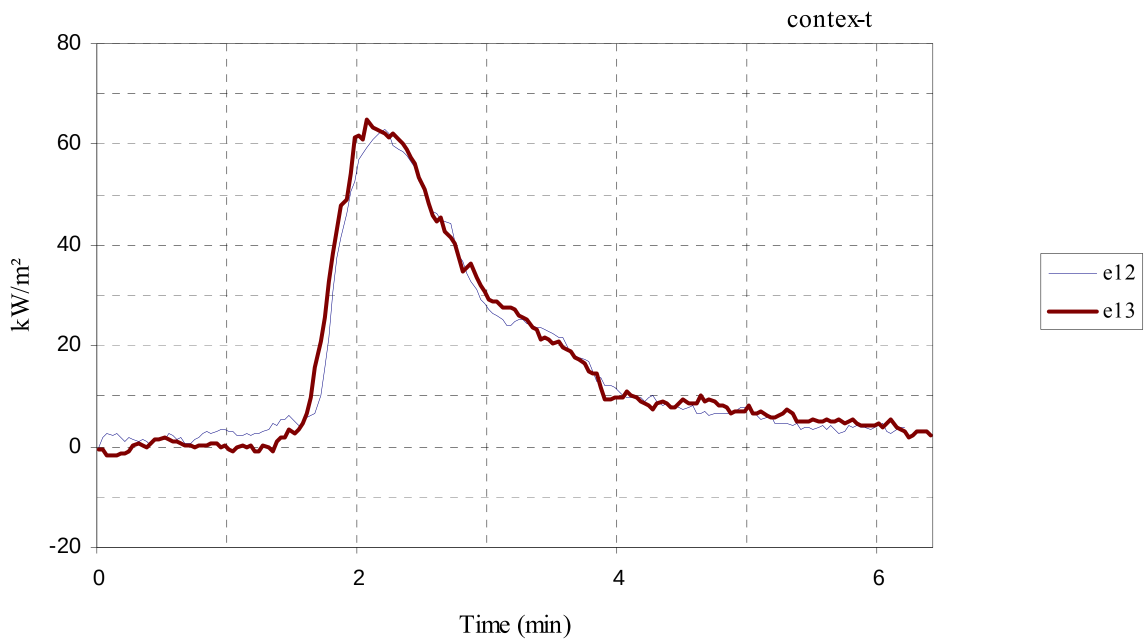


Figure 73 Heat release rate at an irradiance of 35 kW/m^2.

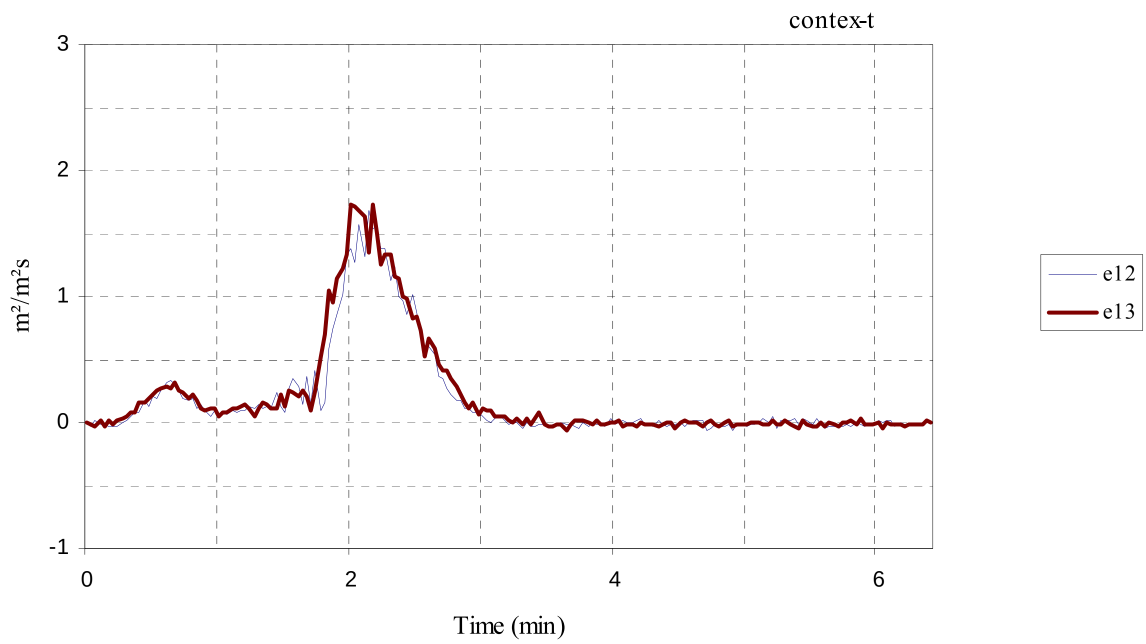


Figure 74 Smoke production rate at an irradiance of 35 kW/m^2.

Silicone:

Property	Name of variable	e14	e15	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:30	00:31	00:31
All flaming ceased (min:s)	t_{ext}	01:47	01:34	01:40
		05:00		
Test time (min:s)	t_{test}	05:00		05:00
Heat release rate (kW/m^2)	q	See figure 74		
Peak heat release rate (kW/m^2)	q_{max}	111	117	114
Average heat release, 3 min (kW/m^2)	q_{180}	44	40	42
		30		
Average heat release, 5 min (kW/m^2)	q_{300}	26		28
Total heat produced (MJ/m^2)	THR	8.9	7.9	8.4
Smoke production rate (m^2/m^{2}s)	SPR	See figure 75		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	4.82	6.53	5.67
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	5.3	5.1	5.2
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	151.9	160.6	156.3
Total smoke production (m^2/m^2)	TSP	157	166	161
Sample mass before test (g)	M_0	12.5	13.1	12.8
Sample mass at sustained flaming (g)	M_s	12.7	13.3	13.0
Sample mass after test (g)	M_f	8.9	9.9	9.4
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	1.5	1.1	1.3
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	1.6	1.5	1.6
Total mass loss (g/m^2)	TML	433	373	403
Effective heat of combustion (MJ/kg)	DH_c	20.6	21.1	20.8
Specific smoke production (m^2/kg)	SEA	363	444	403
Max average rate of heat emission (kW/m^2)	MARHE	61.3	54.2	57.7
Volume flow in exhaust duct (l/s)	V	24	24	24

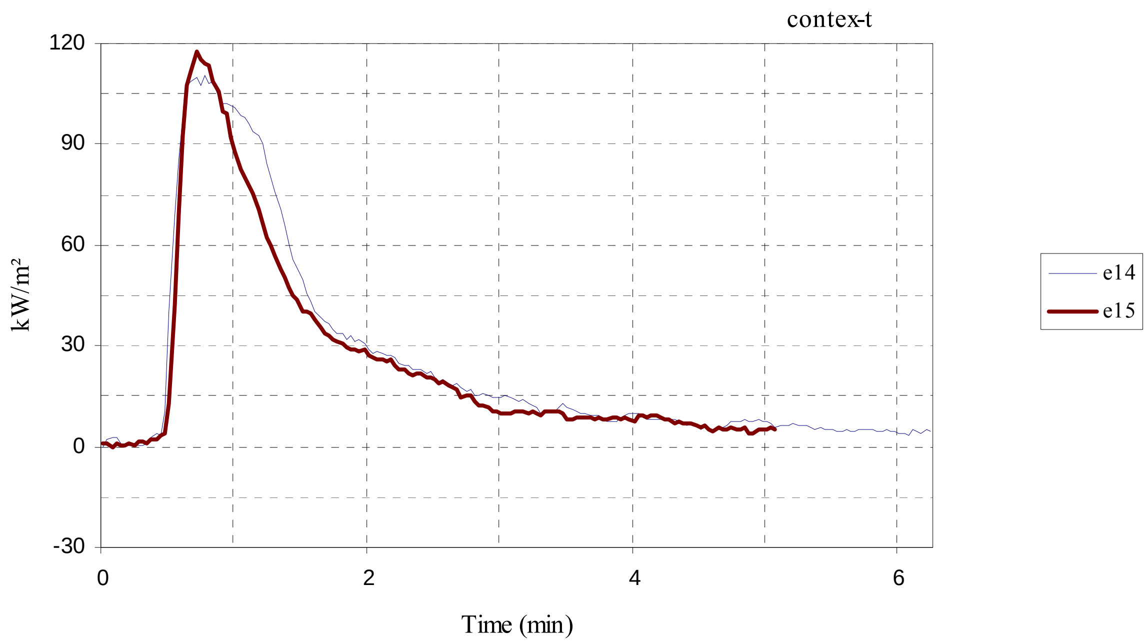


Figure 75 Heat release rate at an irradiance of 50 kW/m^2.

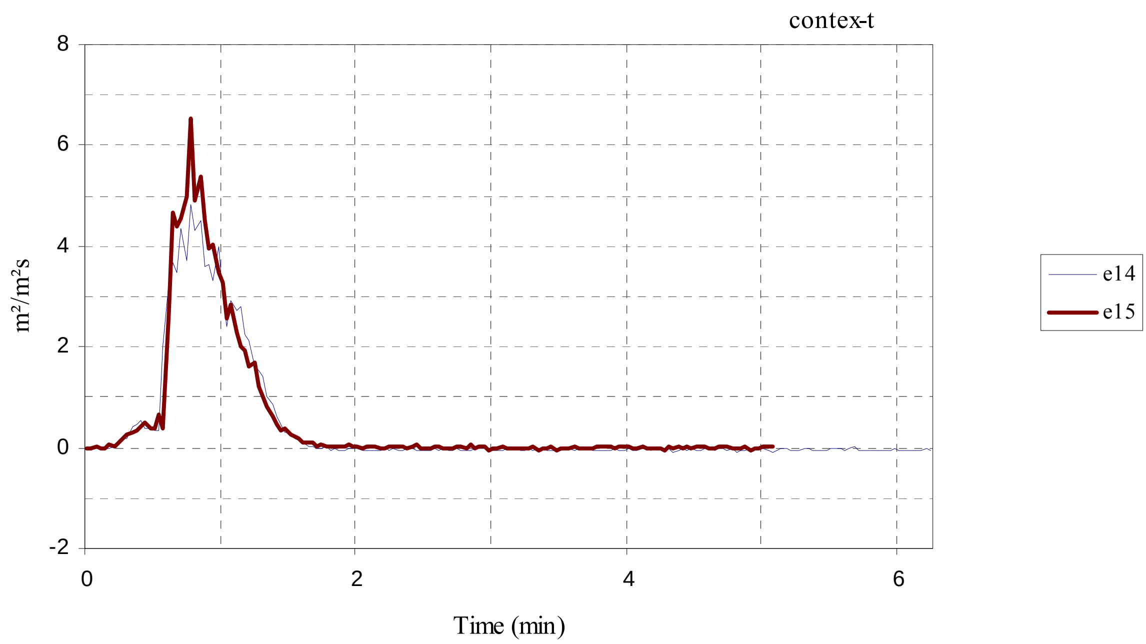


Figure 76 Smoke production rate at an irradiance of 50 kW/m^2.

Silicone:

Property	Name of variable	e16	e17	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	00:36	00:37	00:37
All flaming ceased (min:s)	t_{ext}	02:32	02:28	02:30
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 76		
Peak heat release rate (kW/m^2)	q_{max}	118	110	114
Average heat release, 3 min (kW/m^2)	q_{180}	59	55	57
Average heat release, 5 min (kW/m^2)	q_{300}	37 36		37
Total heat produced (MJ/m^2)	THR	11.3	10.8	11.0
Smoke production rate (m^2/m^{2}s)	SPR	See figure 77		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	5.32	4.46	4.89
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	5.1	5.4	5.3
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	215.7	184.3	200.0
Total smoke production (m^2/m^2)	TSP	221	190	205
Sample mass before test (g)	M_0	13.1	12.8	12.9
Sample mass at sustained flaming (g)	M_s	12.7	12.3	12.5
Sample mass after test (g)	M_f	10.1	9.9	10.0
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	1.0	1.1	1.0
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	1.4	1.8	1.6
Total mass loss (g/m^2)	TML	295	272	284
Effective heat of combustion (MJ/kg)	DH_c	38.3	39.5	38.9
Specific smoke production (m^2/kg)	SEA	748	696	722
Max average rate of heat emission (kW/m^2)	MARHE	61.7	58.8	60.2
Volume flow in exhaust duct (l/s)	V	24	24	24

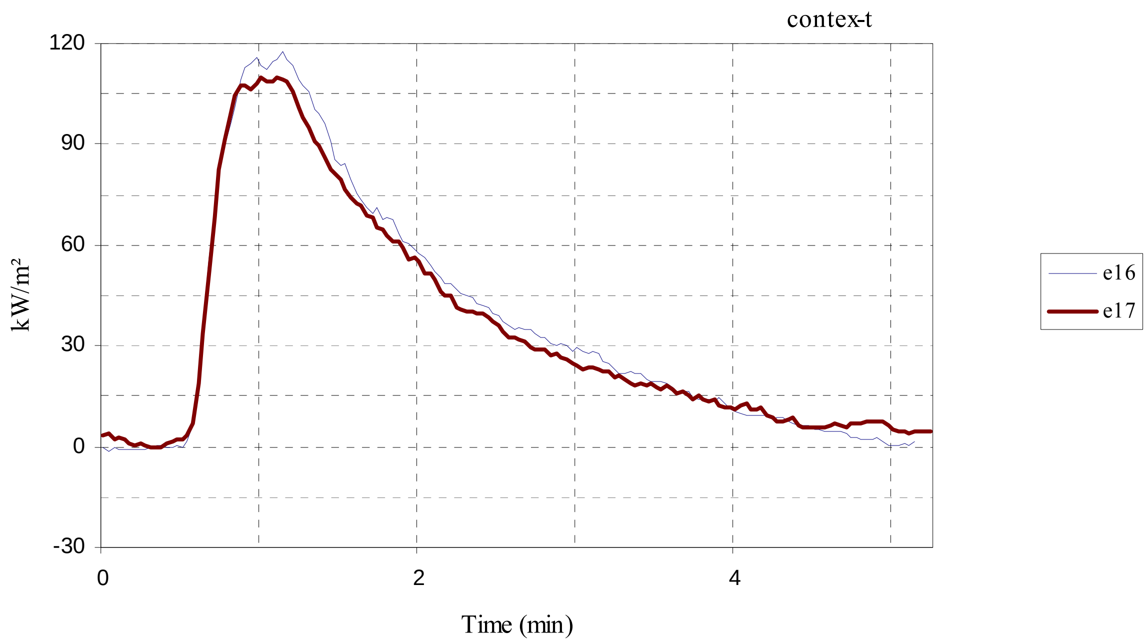


Figure 77 Heat release rate at an irradiance of 50 kW/m^2.

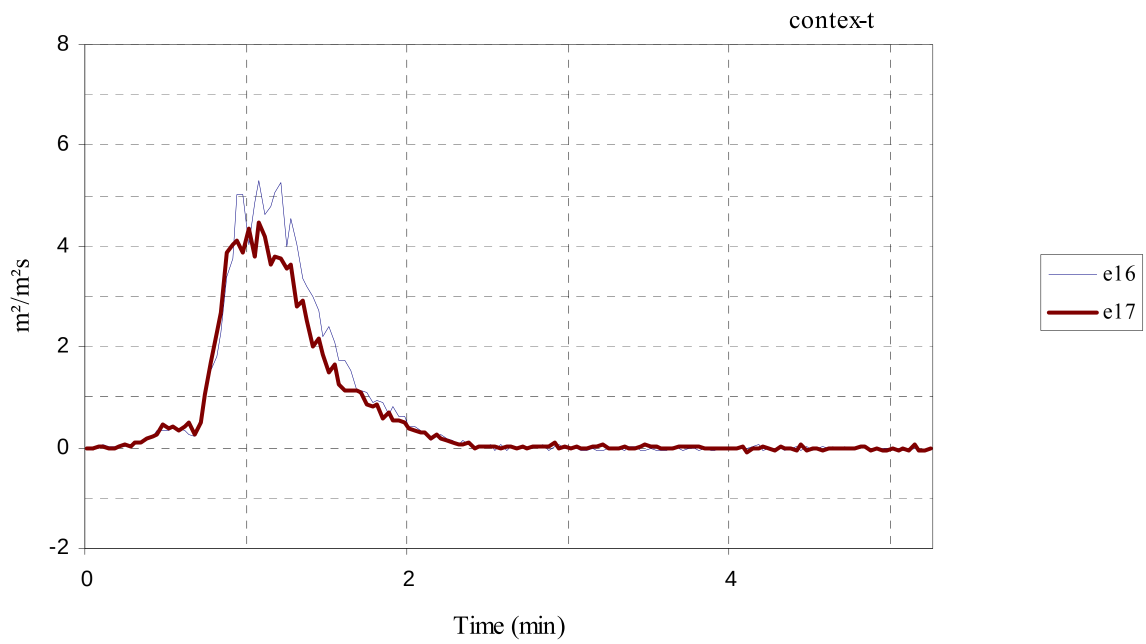


Figure 78 Smoke production rate at an irradiance of 50 kW/m^2.

PTFE:

Property	Name of variable	f10	f11	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	-	-	-
All flaming ceased (min:s)	t_{ext}	-	-	-
Test time (min:s)	t_{test}	10:00 10:00		10:00
Heat release rate (kW/m^2)	q	See figure 78		
Peak heat release rate (kW/m^2)	q_{max}	5	4	5
Average heat release, 3 min (kW/m^2)	q_{180}	-	-	-
Average heat release, 5 min (kW/m^2)	q_{300}	- -		-
Total heat produced (MJ/m^2)	THR	0.3	0.3	0.3
Smoke production rate (m^2/m^2s)	SPR	See figure 79		
Peak smoke production (m^2/m^2s)	SPR_{max}	0.68	0.47	0.57
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	-	-	-
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	-	-	-
Total smoke production (m^2/m^2)	TSP	0	0	0
Sample mass before test (g)	M_0	11.4	11.4	11.4
Sample mass at sustained flaming (g)	M_s	-	-	-
Sample mass after test (g)	M_f	7.1	7.9	7.5
Average mass loss rate (g/m^2s)	$MLR_{ign-end}$	-	-	-
Average mass loss rate (g/m^2s)	MLR_{10-90}	1.3	1.1	1.2
Total mass loss (g/m^2)	TML	-	-	-
Effective heat of combustion (MJ/kg)	DH_c	-	-	-
Specific smoke production (m^2/kg)	SEA	-	-	-
Max average rate of heat emission (kW/m^2)	MARHE	2.1	1.7	1.9
Volume flow in exhaust duct (l/s)	V	24	24	24

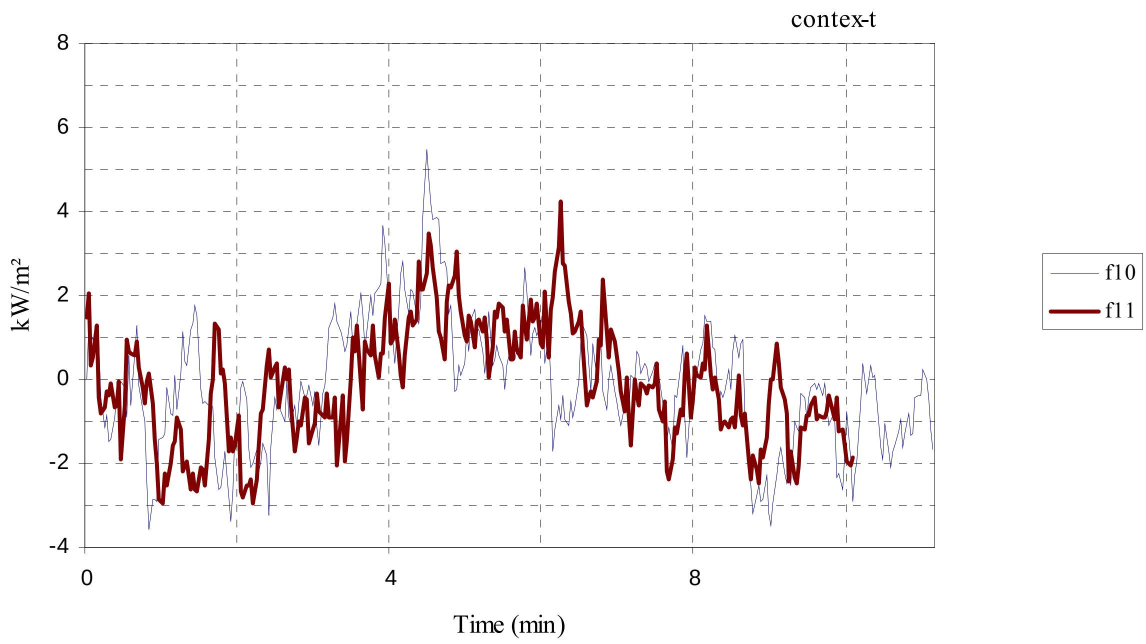


Figure 79 Heat release rate at an irradiance of 35 kW/m^2.

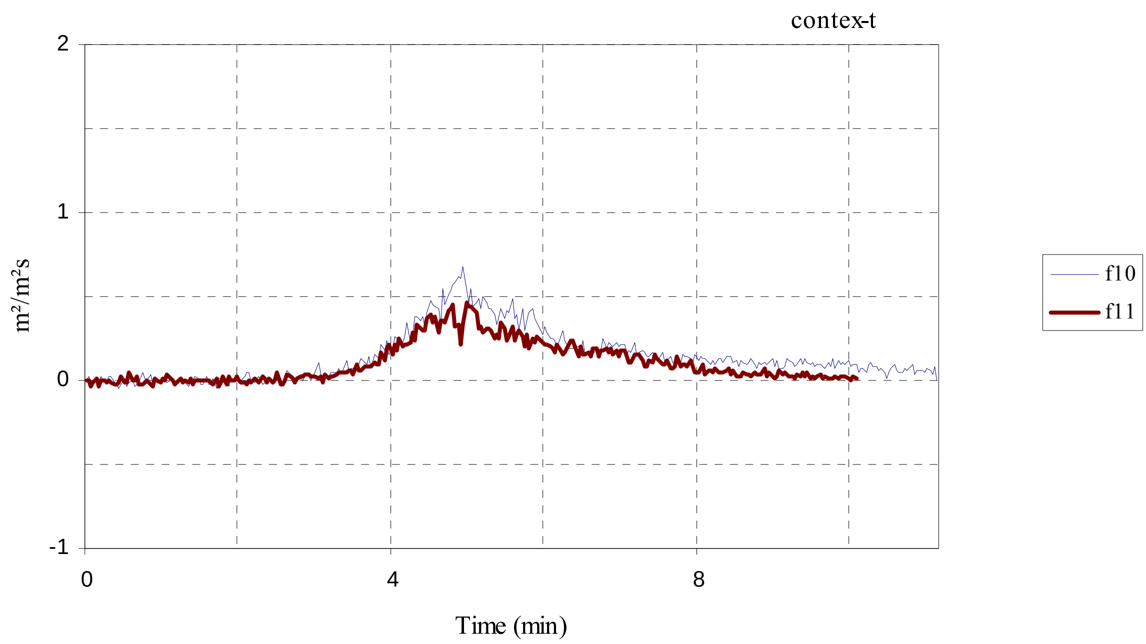


Figure 80 Smoke production rate at an irradiance of 35 kW/m^2.

PTFE:

Property	Name of variable	f12
Flashing (min:s)	t_{flash}	-
Ignition (min:s)	t_{ign}	-
All flaming ceased (min:s)	t_{ext}	-
Test time (min:s)	t_{test}	00:10:00
Heat release rate (kW/m^2)	q	See figure 80
Peak heat release rate (kW/m^2)	q_{max}	5
Average heat release, 3 min (kW/m^2)	q_{180}	-
Average heat release, 5 min (kW/m^2)	q_{300}	-
Total heat produced (MJ/m^2)	THR	0.7
Smoke production rate (m^2/m^{2}s)	SPR	See figure 81
Peak smoke production (m^2/m^{2}s)	SPR_{max}	0.23
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	-
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	-
Total smoke production (m^2/m^2)	TSP	0
Sample mass before test (g)	M_0	11.4
Sample mass at sustained flaming (g)	M_s	-
Sample mass after test (g)	M_f	8.4
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	-
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	0.7
Total mass loss (g/m^2)	TML	-
Effective heat of combustion (MJ/kg)	DH_c	-
Specific smoke production (m^2/kg)	SEA	-
Max average rate of heat emission (kW/m^2)	MARHE	1.2
Volume flow in exhaust duct (l/s)	V	24

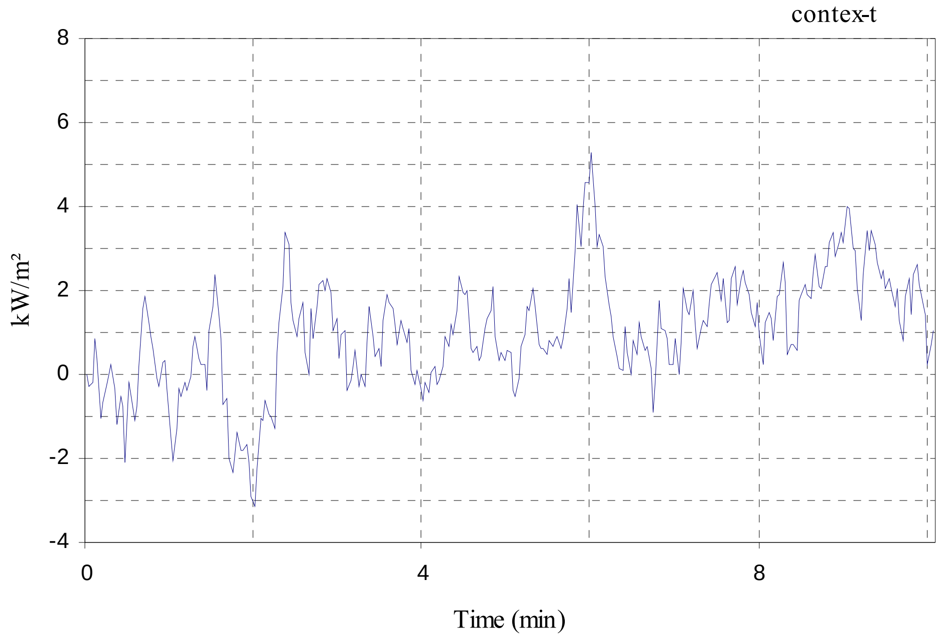


Figure 81 f12 - Heat release rate at an irradiance of 35 kW/m^2.

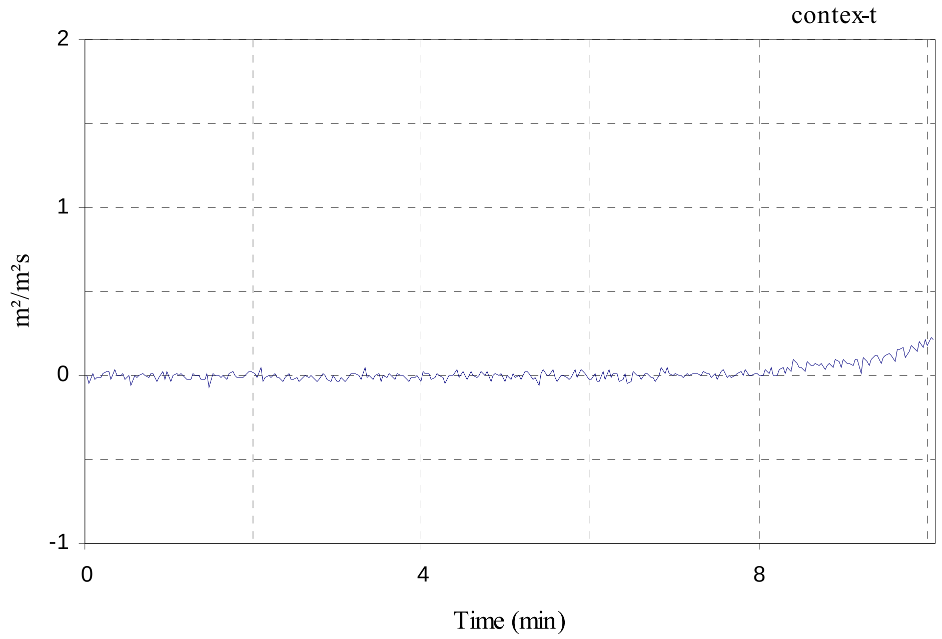


Figure 82 f12 - Smoke production rate at an irradiance of 35 kW/m^2.

PTFE:

Property	Name of variable	f14	f15	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	01:31	01:33	01:32
All flaming ceased (min:s)	t_{ext}	02:27	02:29	02:28
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 82		
Peak heat release rate (kW/m^2)	q_{max}	19	28	23
Average heat release, 3 min (kW/m^2)	q_{180}	9	8	9
Average heat release, 5 min (kW/m^2)	q_{300}	6 5		6
Total heat produced (MJ/m^2)	THR	2.0	1.8	1.9
Smoke production rate (m^2/m^{2}s)	SPR	See figure 83		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	0.45	0.51	0.48
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	5.2	2.9	4.0
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	39.9	33.4	36.7
Total smoke production (m^2/m^2)	TSP	45	36	41
Sample mass before test (g)	M_0	11.4	11.5	11.5
Sample mass at sustained flaming (g)	M_s	11.1	10.9	11.0
Sample mass after test (g)	M_f	6.3	5.4	5.9
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	2.7	2.9	2.8
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	3.2	3.2	3.2
Total mass loss (g/m^2)	TML	545	616	580
Effective heat of combustion (MJ/kg)	DH_c	3.7	2.9	3.3
Specific smoke production (m^2/kg)	SEA	83	59	71
Max average rate of heat emission (kW/m^2)	MARHE	7.8	7.5	7.7
Volume flow in exhaust duct (l/s)	V	24	24	24

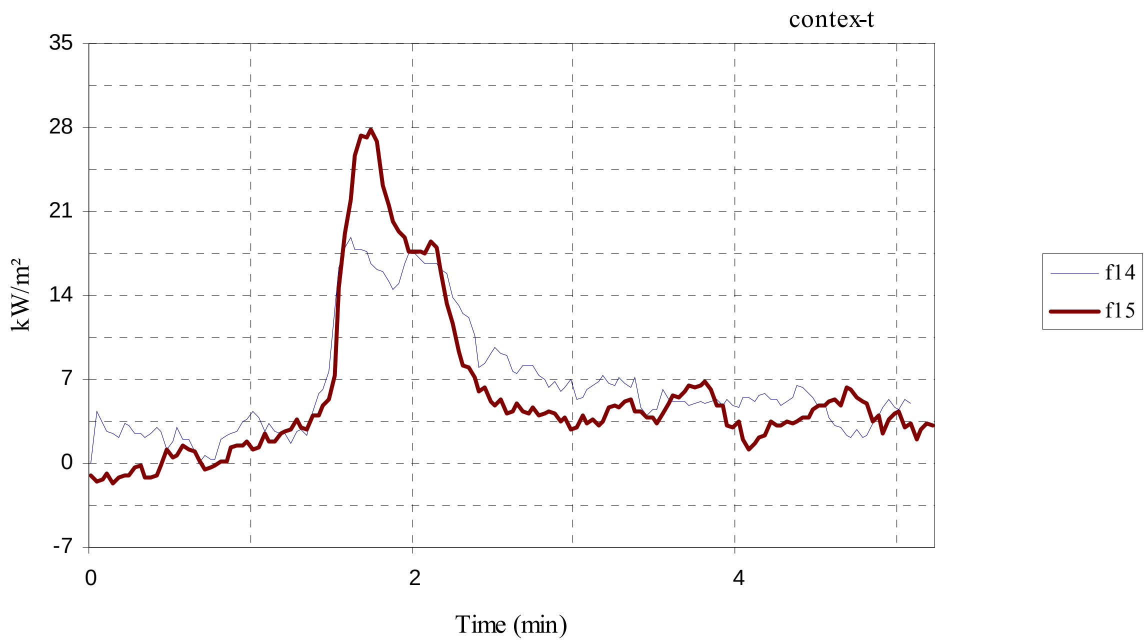


Figure 83 Heat release rate at an irradiance of 50 kW/m^2.

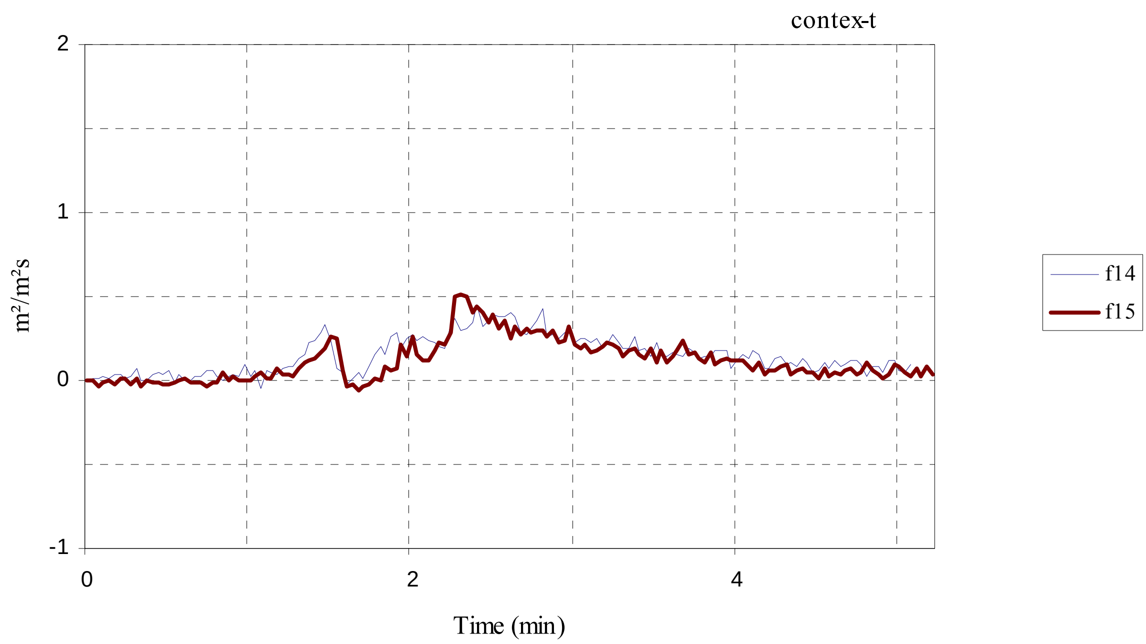


Figure 84 Smoke production rate at an irradiance of 50 kW/m^2.

PTFE:

Property	Name of variable	f16	f17	Average value
Flashing (min:s)	t_{flash}	-	-	-
Ignition (min:s)	t_{ign}	01:27	01:24	01:25
All flaming ceased (min:s)	t_{ext}	02:18	02:14	02:16
Test time (min:s)	t_{test}	05:00 05:00		05:00
Heat release rate (kW/m^2)	q	See figure 84		
Peak heat release rate (kW/m^2)	q_{max}	45	43	44
Average heat release, 3 min (kW/m^2)	q_{180}	10	9	10
Average heat release, 5 min (kW/m^2)	q_{300}	6 5		6
Total heat produced (MJ/m^2)	THR	2.1	1.8	2.0
Smoke production rate (m^2/m^{2}s)	SPR	See figure 85		
Peak smoke production (m^2/m^{2}s)	SPR_{max}	0.58	0.38	0.48
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	5.8	4.8	5.3
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	11.0	20.7	15.8
Total smoke production (m^2/m^2)	TSP	17	26	21
Sample mass before test (g)	M_0	11.6	11.5	11.5
Sample mass at sustained flaming (g)	M_s	11.2	11.3	11.3
Sample mass after test (g)	M_f	6.4	6.4	6.4
Average mass loss rate (g/m^{2}s)	$MLR_{ign\text{-}end}$	2.6	2.4	2.5
Average mass loss rate (g/m^{2}s)	$MLR_{10\text{-}90}$	4.5	3.9	4.2
Total mass loss (g/m^2)	TML	545	559	552
Effective heat of combustion (MJ/kg)	DH_c	3.9	3.2	3.6
Specific smoke production (m^2/kg)	SEA	31	46	38
Max average rate of heat emission (kW/m^2)	MARHE	12.7	12.0	12.3
Volume flow in exhaust duct (l/s)	V	24	24	24

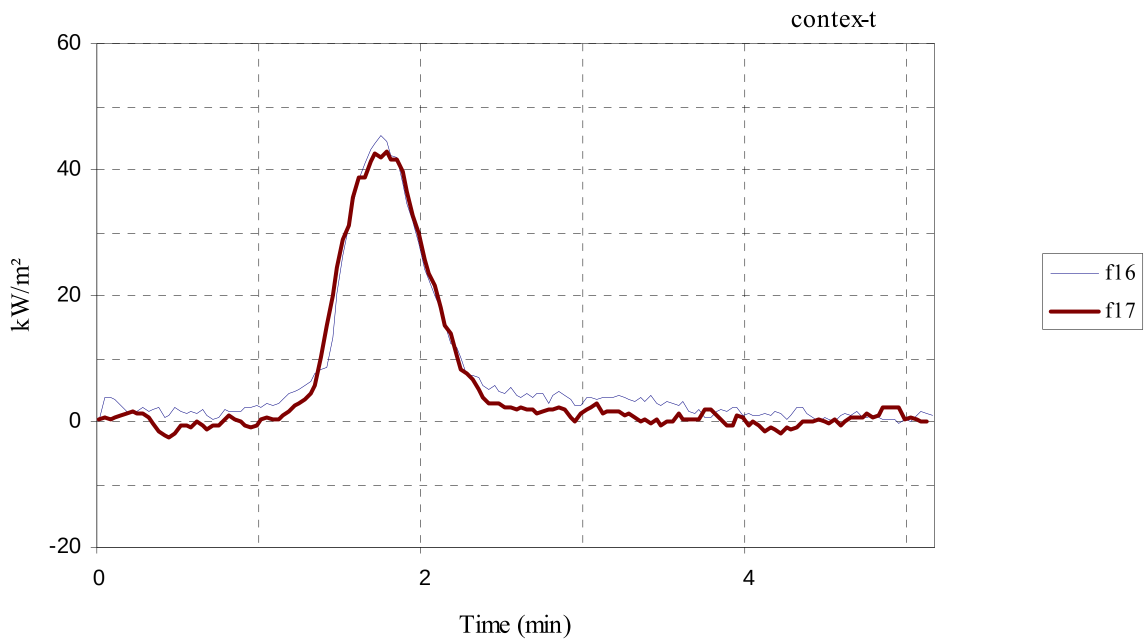


Figure 85 Heat release rate at an irradiance of 50 kW/m^2.

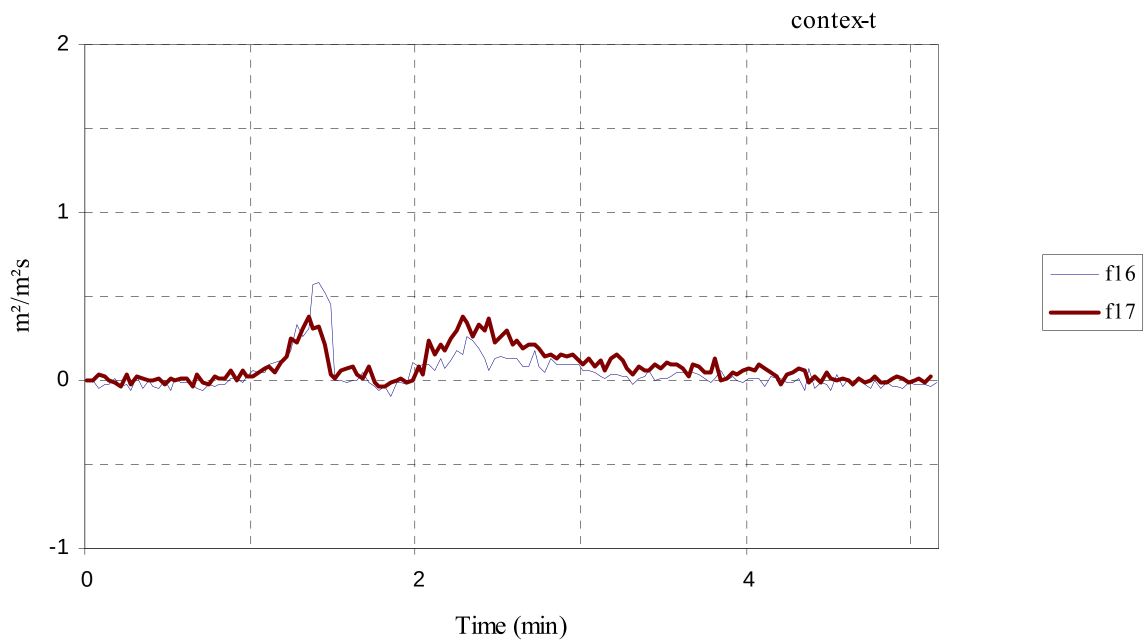


Figure 86 Smoke production at an irradiance of 50 kW/m^2.

PTFE-Terpolymer:

Property	Name of variable	g11
Flashing (min:s)	t_{flash}	-
Ignition (min:s)	t_{ign}	-
All flaming ceased (min:s)	t_{ext}	-
Test time (min:s)	t_{test}	00:10:00
Heat release rate (kW/m^2)	q	See figure 86
Peak heat release rate (kW/m^2)	q_{max}	5
Average heat release, 3 min (kW/m^2)	q_{180}	-
Average heat release, 5 min (kW/m^2)	q_{300}	-
Total heat produced (MJ/m^2)	THR	0.1
Smoke production rate (m^2/m^{2}s)	SPR	See figure 87
Peak smoke production (m^2/m^{2}s)	SPR_{max}	0.55
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	-
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	-
Total smoke production (m^2/m^2)	TSP	0
Sample mass before test (g)	M_0	3.3
Sample mass at sustained flaming (g)	M_s	-
Sample mass after test (g)	M_f	2.2
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	-
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	0.3
Total mass loss (g/m^2)	TML	-
Effective heat of combustion (MJ/kg)	DH_c	-
Specific smoke production (m^2/kg)	SEA	-
Max average rate of heat emission (kW/m^2)	MARHE	1.3
Volume flow in exhaust duct (l/s)	V	24

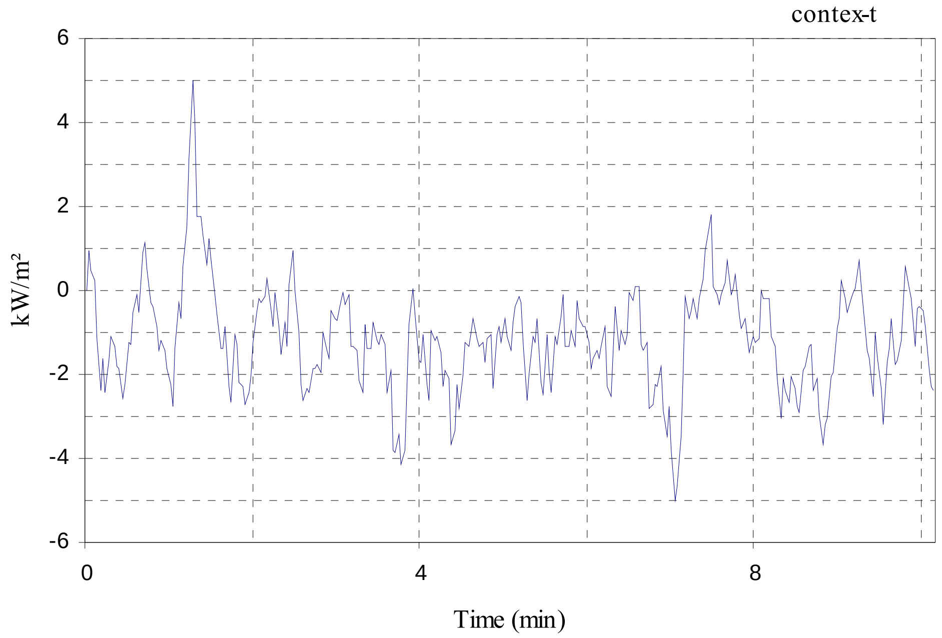


Figure 87 g11 - Heat release rate at an irradiance of 35 kW/m^2.

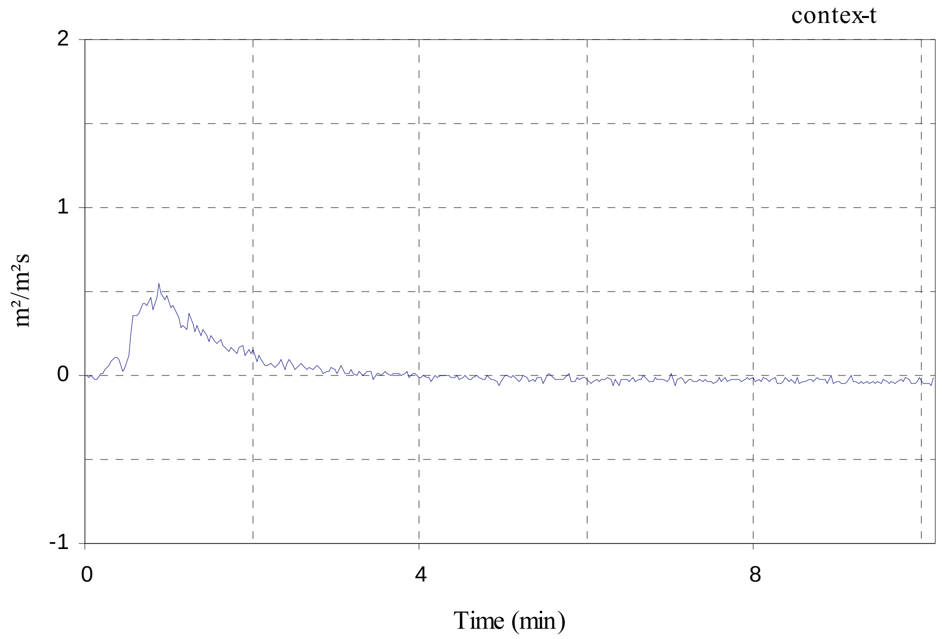


Figure 88 g11 - Smoke production rate at an irradiance of 35 kW/m^2.

PTFE-Terpolymer:

Property	Name of variable	g15
Flashing (min:s)	t_{flash}	-
Ignition (min:s)	t_{ign}	-
All flaming ceased (min:s)	t_{ext}	-
Test time (min:s)	t_{test}	00:10:00
Heat release rate (kW/m^2)	q	See figure 88
Peak heat release rate (kW/m^2)	q_{max}	7
Average heat release, 3 min (kW/m^2)	q_{180}	-
Average heat release, 5 min (kW/m^2)	q_{300}	-
Total heat produced (MJ/m^2)	THR	0.4
Smoke production rate (m^2/m^{2}s)	SPR	See figure 89
Peak smoke production (m^2/m^{2}s)	SPR_{max}	1.19
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	-
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	-
Total smoke production (m^2/m^2)	TSP	0
Sample mass before test (g)	M_0	3.3
Sample mass at sustained flaming (g)	M_s	-
Sample mass after test (g)	M_f	2.2
Average mass loss rate (g/m^{2}s)	$MLR_{ign-end}$	-
Average mass loss rate (g/m^{2}s)	MLR_{10-90}	0.8
Total mass loss (g/m^2)	TML	-
Effective heat of combustion (MJ/kg)	DH_c	-
Specific smoke production (m^2/kg)	SEA	-
Max average rate of heat emission (kW/m^2)	MARHE	6.9
Volume flow in exhaust duct (l/s)	V	24

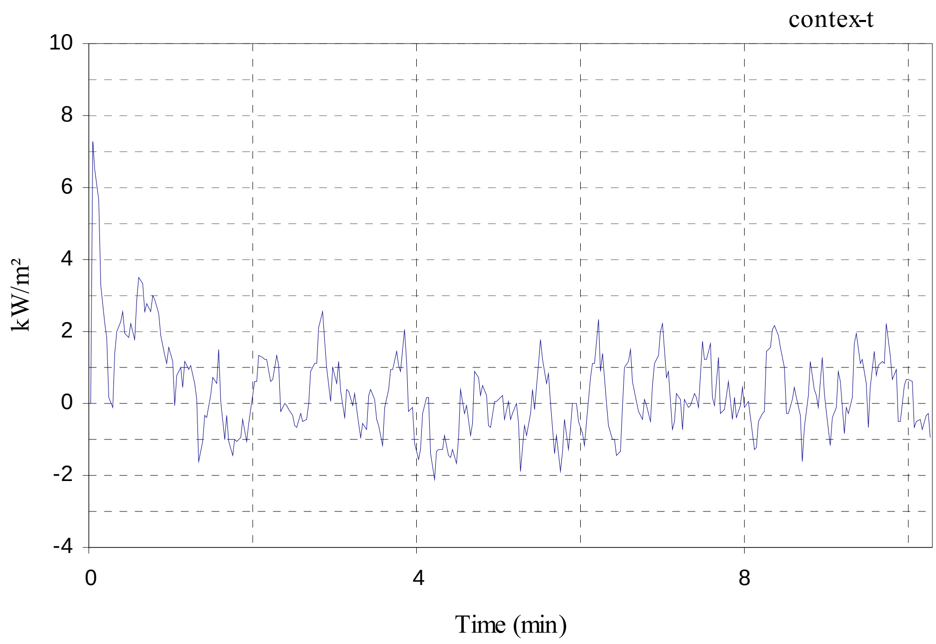


Figure 89 Heat release rate at an irradiance of 50 kW/m^2.

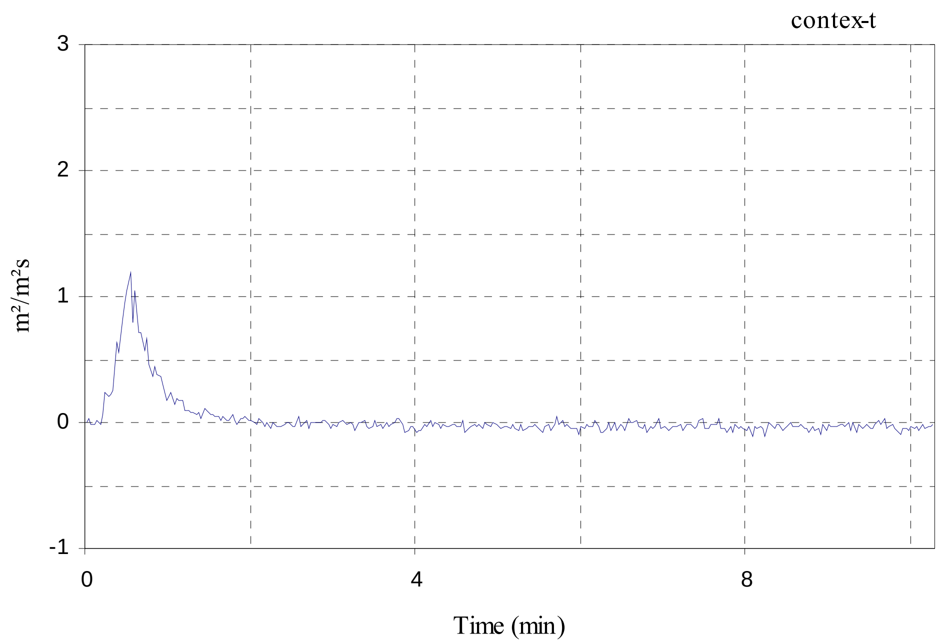


Figure 90 Smoke production rate at an irradiance of 50 kW/m^2.

PTFE-Terpolymer:

Property	Name of variable	g12	g13	g14	Average value
Flashing (min:s)	t_{flash}	-	-	-	-
Ignition (min:s)	t_{ign}	-	-	-	-
All flaming ceased (min:s)	t_{ext}	-	-	-	-
Test time (min:s)	t_{test}	10:00	10:00	10:00	10:00
Heat release rate (kW/m^2)	q	See figure 90			
Peak heat release rate (kW/m^2)	q_{max}	5	3	5	4
Average heat release, 3 min (kW/m^2)	q_{180}	-	-	-	-
Average heat release, 5 min (kW/m^2)	q_{300}	-	-	-	-
Total heat produced (MJ/m^2)	THR	0.5	0.1	0.3	0.3
Smoke production rate (m^2/m^{2}s)	SPR	See figure 91			
Peak smoke production (m^2/m^{2}s)	SPR_{max}	0.15	0.41	0.79	0.45
Total smoke production over the non-flaming phase (m^2/m^2)	TSP_{nonfl}	-	-	-	-
Total smoke production over the flaming phase (m^2/m^2)	TSP_{fl}	-	-	-	-
Total smoke production (m^2/m^2)	TSP	0	0	0	0
Sample mass before test (g)	M_0	3.3	3.2	3.3	3.3
Sample mass at sustained flaming (g)	M_s	-	-	-	-
Sample mass after test (g)	M_f	1.2	0.6	0.5	0.8
Average mass loss rate (g/m^{2}s)	$MLR_{ign\text{-}end}$	-	-	-	-
Average mass loss rate (g/m^{2}s)	$MLR_{10\text{-}90}$	0.4	0.5	0.6	0.5
Total mass loss (g/m^2)	TML	-	-	-	-
Effective heat of combustion (MJ/kg)	DH_c	-	-	-	-
Specific smoke production (m^2/kg)	SEA	-	-	-	-
Max average rate of heat emission (kW/m^2)	MARHE	1.3	0.4	1.4	1.0
Volume flow in exhaust duct (l/s)	V	24	24	24	24

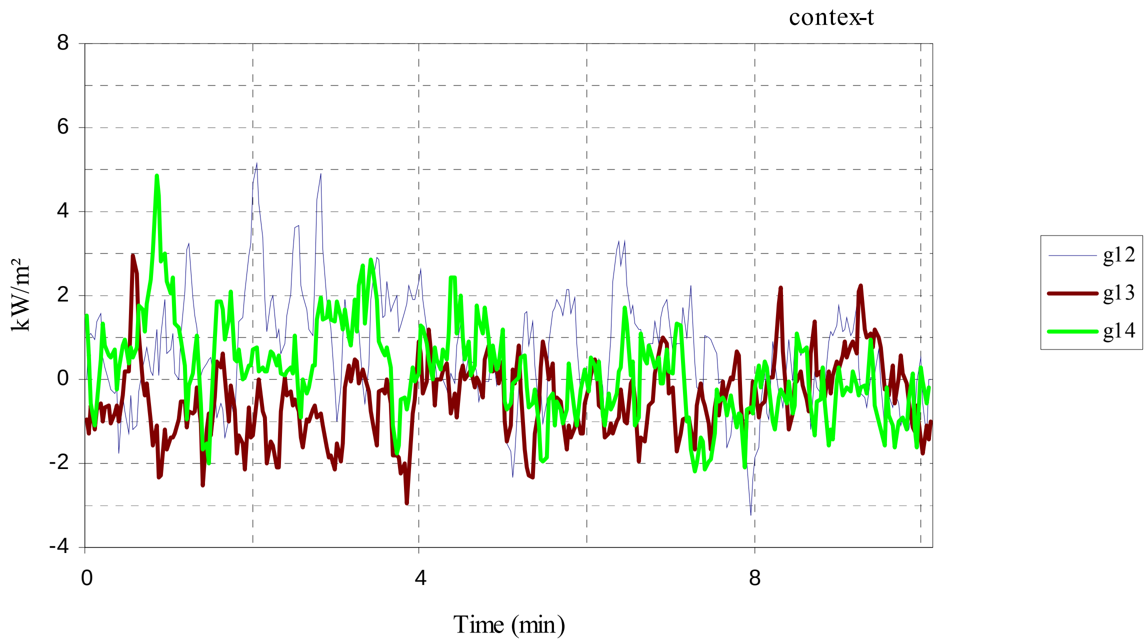


Figure 91 **g12,g13 - Heat release rate at an irradiance of 35 kW/m^2.**
g14 - Heat release rate at an irradiance of 50 kW/m^2.

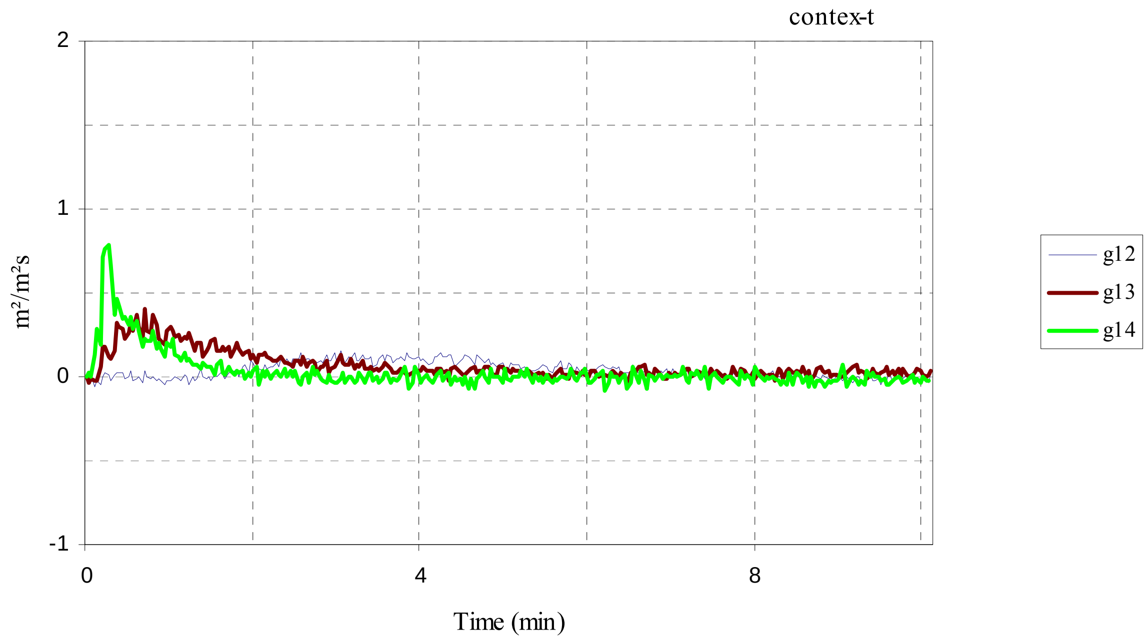


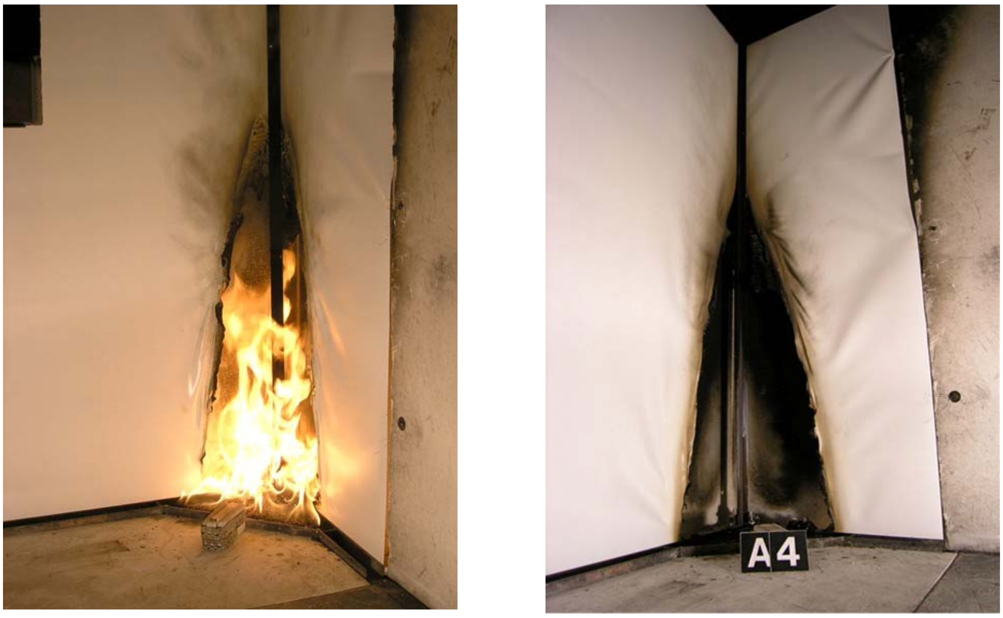
Figure 92 **g12,g13 - Smoke production rate at an irradiance of 35 kW/m^2.**
g14 - Smoke production rate at an irradiance of 50 kW/m^2.

Parameter	Explanation
Test start	The test specimen is subjected to the irradiance and the clock is started.
t_{flash}	Time from test start until flames with shorter duration than 1 s.
t_{ign}	Time from test start until sustained flaming with duration more than 10 s.
T_{ext}	Time from test start until the flames have died out.
End of test	Defined as the time when both, the product has been extinguished for 2 minutes, and the mass loss is less than 150 g/m^2 during 1 minute.
T_{test}	Test time. From test start until end of test.
q_{max}	Peak heat release rate during the entire test.
q_{180}	Average heat release rate during 3 minutes from ignition. If the test is terminated before, the heat release rate is taken as 0 from the end of test.
q_{300}	Average heat release rate during 5 minutes from ignition. If the test is terminated before, the heat release rate is taken as 0 from the end of test.
THR	Total Heat Released from test start until end of test.
SPR_{max}	Peak Smoke Production Rate from test start until end of test.
TSP	Total Smoke Produced from test start until end of test.
M_0	Mass of specimen.
M_s	Mass of specimen at sustained flaming.
M_f	Mass of specimen at the end of the test.
$MLR_{ign\text{-}end}$	Mass Loss Rate. Average mass loss rate from ignition until end of test.
$MLR_{10\text{-}90}$	Mass Loss Rate. Average mass loss rate between 10% and 90% of mass loss.
TML	Total mass loss from ignition until end of test.
ΔH_c	Effective heat of combustion calculated as the ratio between total energy released and total mass loss calculated from ignition until end of test.
SEA	Specific Extinction Area defined as the ratio between total smoke released and total mass loss calculated from test start until end of test.
MARHE	Maximum Average Rate of Heat Emission defined as the maximum of the function (cumulative heat release between t = 0 and time = t) divided by (time = t).
V	Volume flow rate in exhaust duct. Average during the test.

Appendix 2 Photographs from SBI-tests

(a) **(b)**

Figure 93 SBI-tests with “PVC 1” membrane. Sample mounting by ”method 1”.
(a) After the membrane opens up the material moves out from the corner and the flame.
(b) Burn pattern after completion of the test.



(a) **(b)**

Figure 94 SBI-tests with “PVC 1” membrane. Sample mounting by ”method 2”.
(a) The metal support holds the material in the corner position after the membrane has opened up from the flame attack.
(b) Burn pattern after completion of the test.

(a) **(b)**

Figure 95 **SBI-tests with “PVC 2” membrane. Sample mounting by ”method 1”.**
(a) After the membrane opens up the material moves out from the corner and the flame.
(b) Burn pattern after completion of the test.

(a) **(b)**

Figure 96 **SBI-tests with “PVC 2” membrane. Sample mounting by ”method 2”.**
(a) The metal support holds the material in the corner position.
(b) Burn pattern after completion of the test.

(a) (b)

Figure 97 SBI-tests with “PVC 3” membrane. Sample mounting by ”method 1”.
(a) After the membrane opens up the material moves out from the corner and the flame.
(b) Burn pattern after completion of the test.

(a) (b)

Figure 98 SBI-tests with “PVC 3” membrane. Sample mounting by ”method 2”.
(a) The metal support holds the material in the corner position.
(b) Burn pattern after completion of the test.

(a) (b)

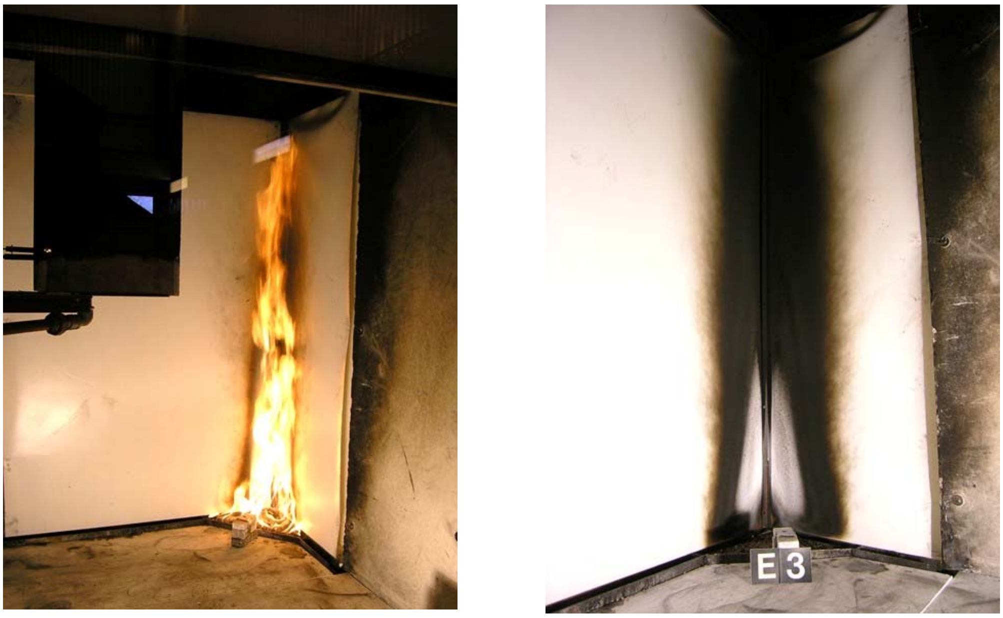
Figure 99 SBI-tests with "PVC 4" membrane. Sample mounting by "method 1".
(a) Flame spread up to the top in the corner.
(b) Burn pattern after completion of the test.

(a) (b)

Figure 100 SBI-tests with "PVC 4" membrane. Sample mounting by "method 2".
(a) Flame spread up to the top in the corner.
(b) Burn pattern after completion of the test.

(a) (b)

Figure 101 SBI-tests with “Silicone” membrane. Sample mounting by ”method 1”.
(a) The membrane does not open up from the flame attack.
(b) Burn pattern after completion of the test.



(a) (b)

Figure 102 SBI-tests with “Silicone” membrane. Sample mounting by ”method 2”.
(a) Limited influence from the corner support.
(b) Burn pattern after completion of the test.

(a) **(b)**

Figure 103 SBI-tests with “PTFE” membrane. Sample mounting by ”method 1”.
(a) The membrane does not open up from the flame attack.
(b) Burn pattern after completion of the test.

(a) **(b)**

Figure 104 SBI-tests with “PTFE” membrane. Sample mounting by ”method 2”.
(a) Limited influence from the corner support.
(b) Burn pattern after completion of the test.

Appendix 3 SBI (EN 13823): graphs of HRR and SPR

PVC 1:

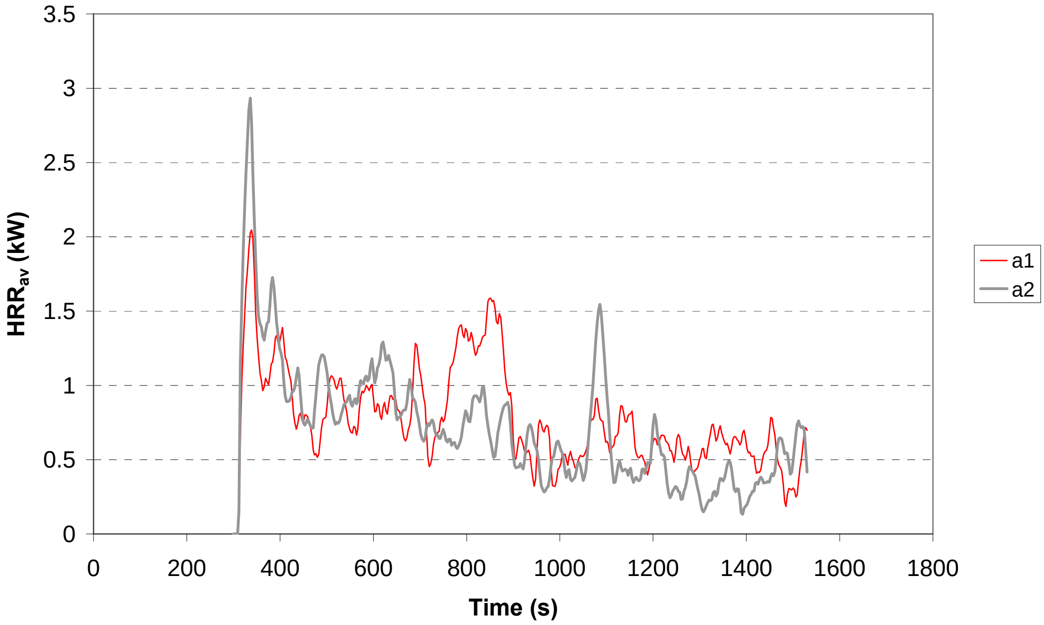


Figure 105 Graphs of heat release rate (HRR).

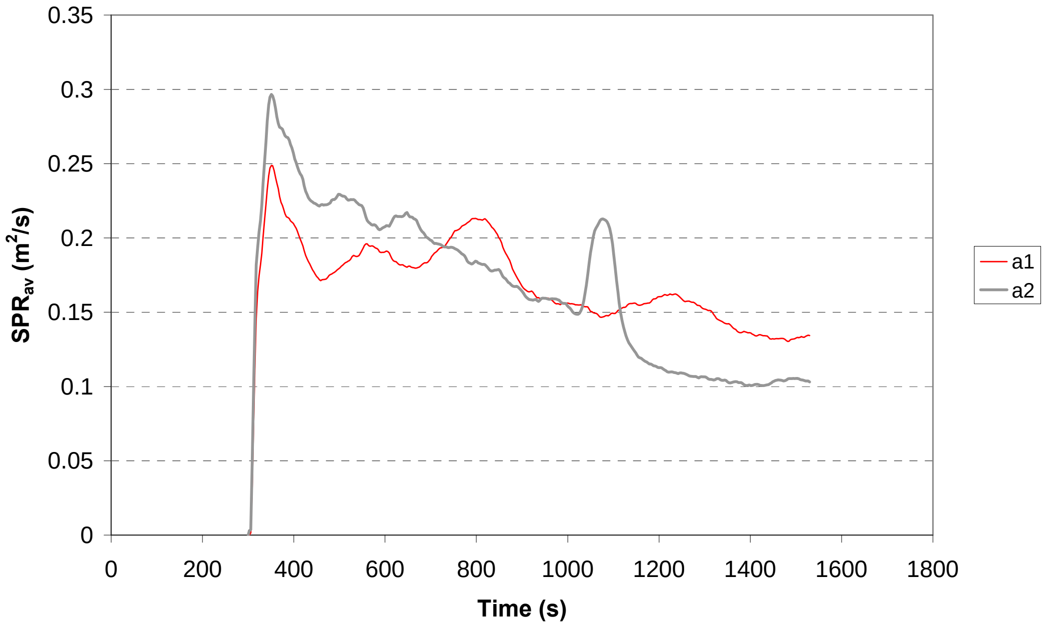


Figure 106 Graphs of smoke production rate (SPR).

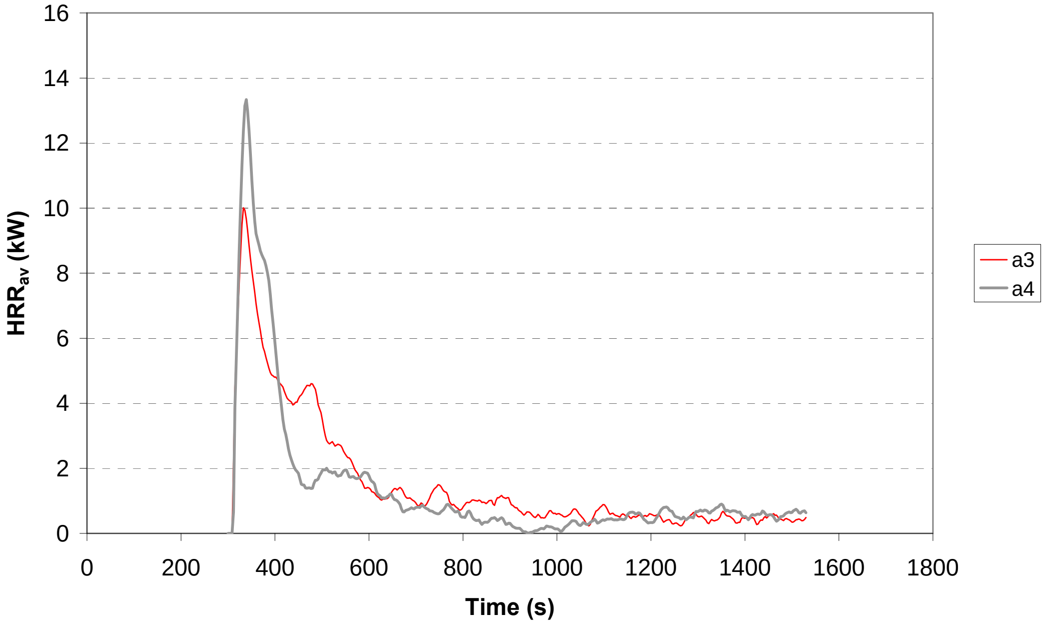


Figure 107 Graphs of heat release rate (HRR).

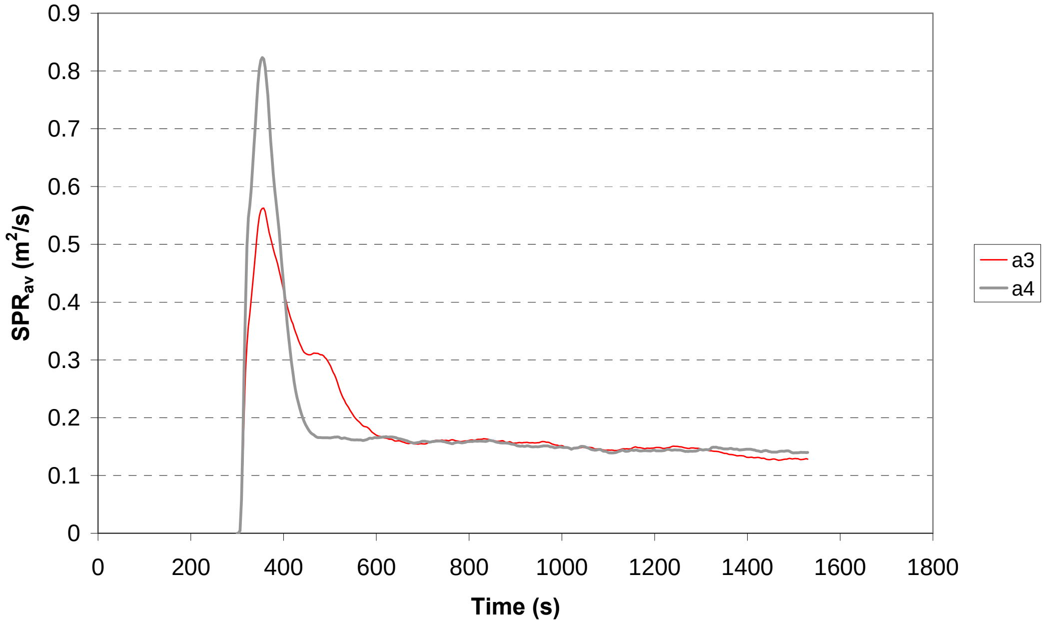


Figure 108 Graphs of smoke production rate (SPR).

PVC 3:

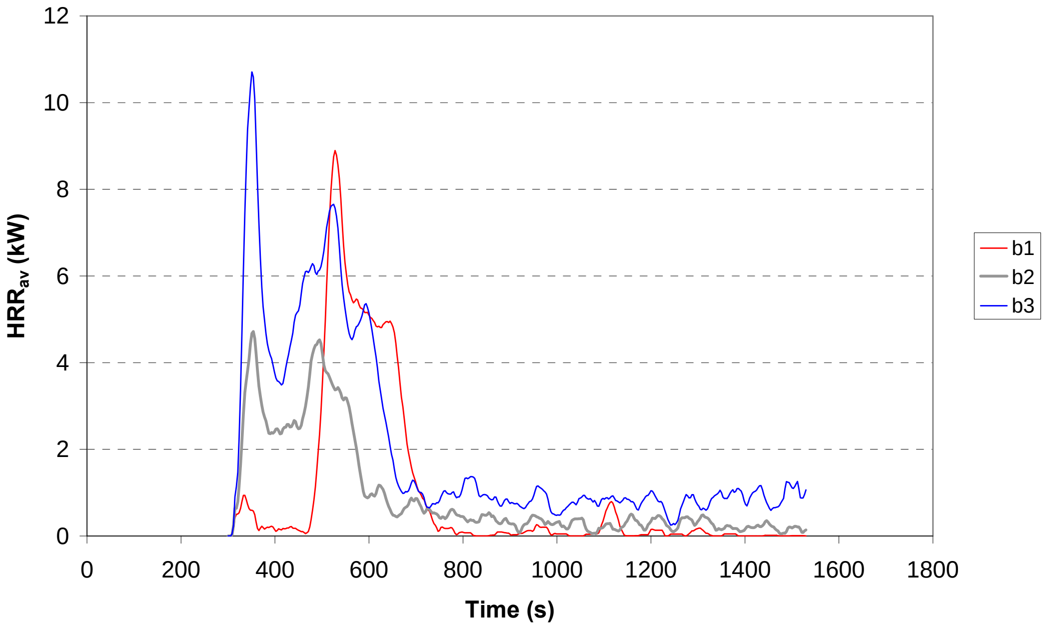


Figure 109 Graphs of heat release rate (HRR).

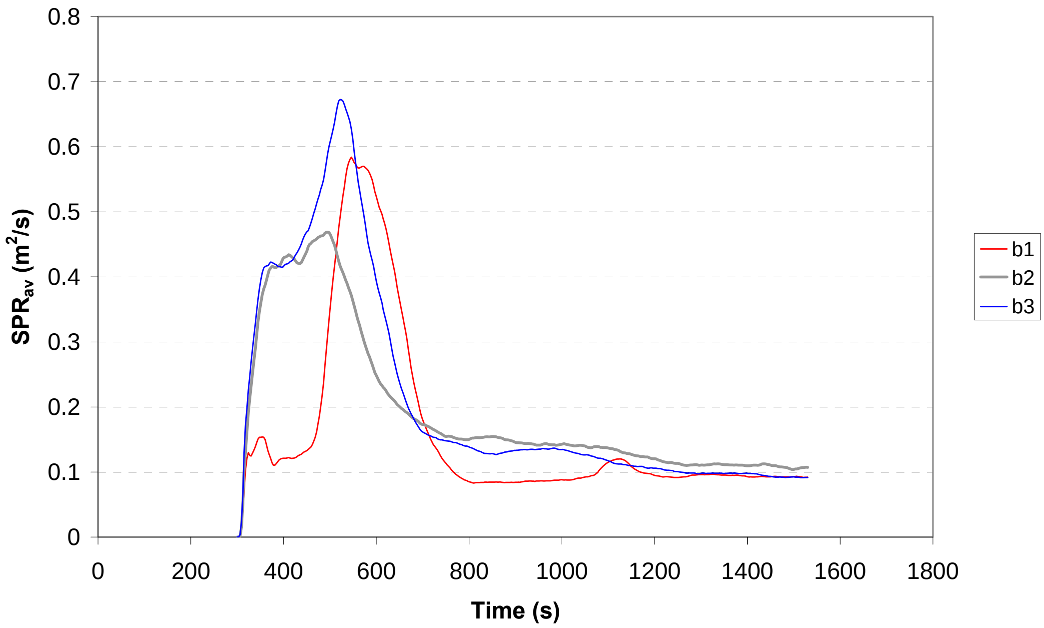


Figure 110 Graphs of smoke production rate (SPR).

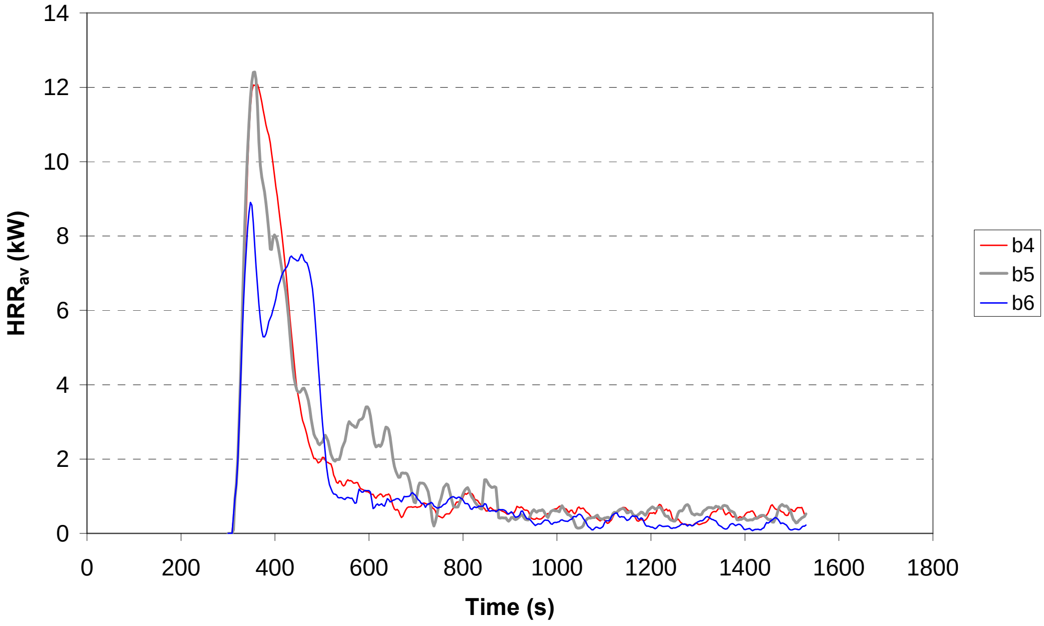


Figure 111 Graphs of heat release rate (HRR).

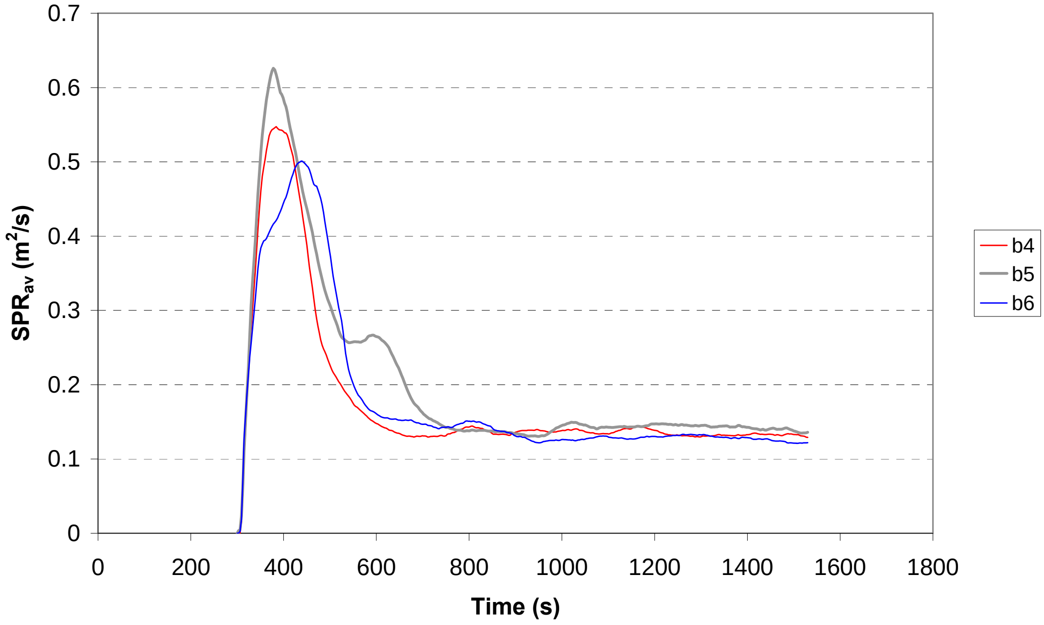


Figure 112 Graphs of smoke production rate (SPR).

PVC 2:

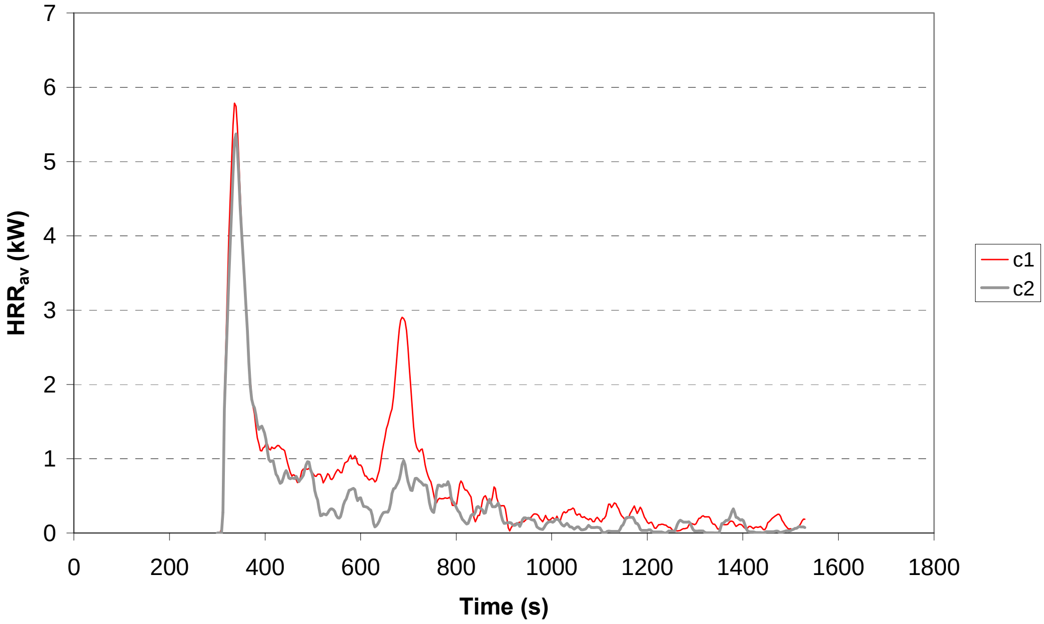


Figure 113 Graphs of heat release rate (HRR).

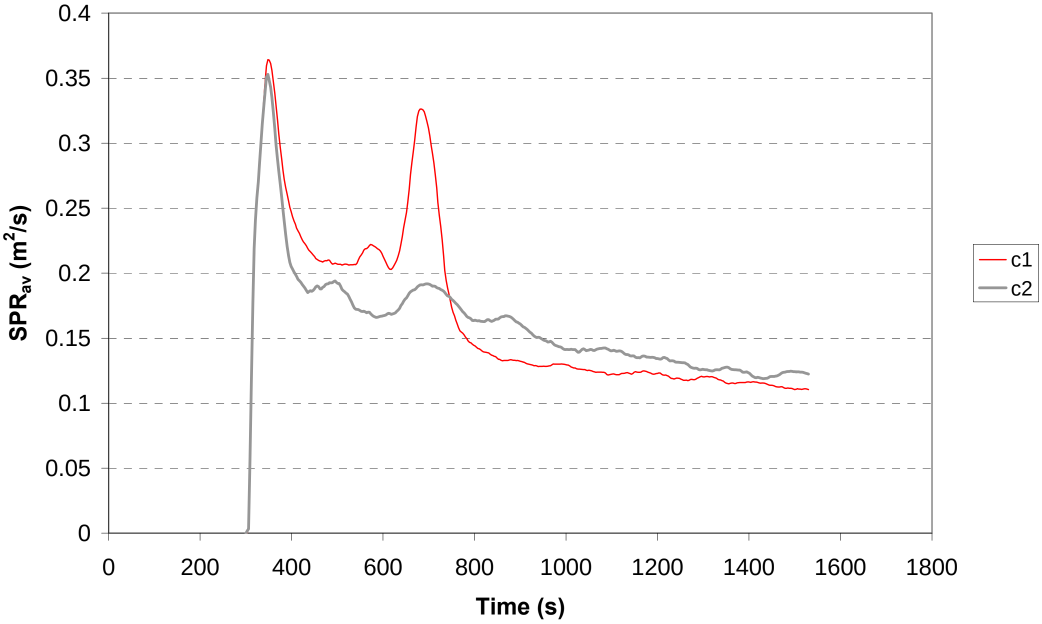


Figure 114 Graphs of smoke production rate (SPR).

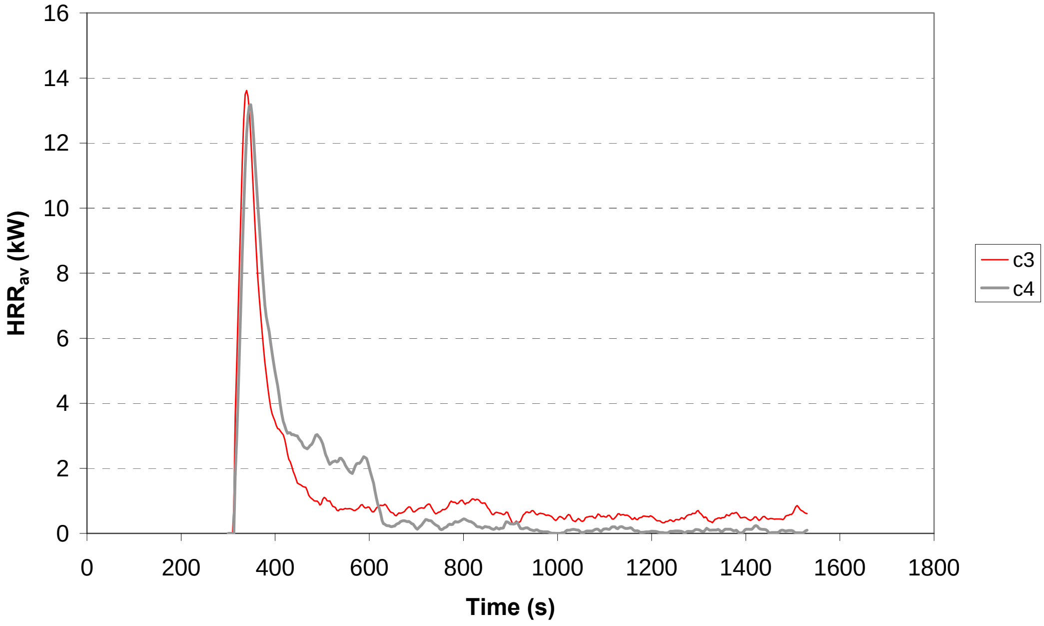


Figure 115 Graphs of heat release rate (HRR).

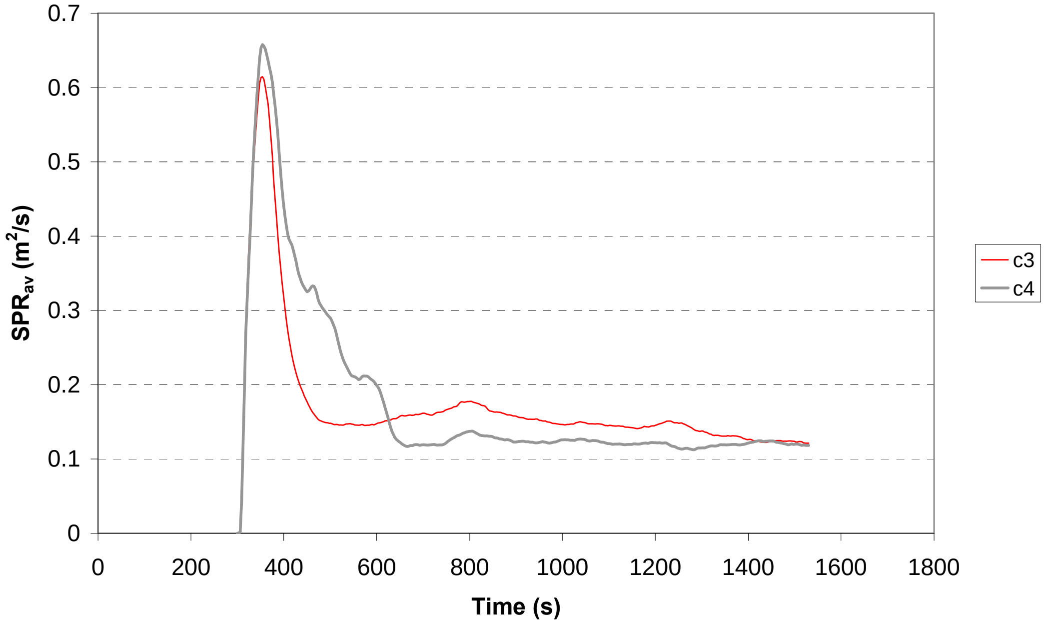


Figure 116 Graphs of smoke production rate (SPR).

PVC 4:

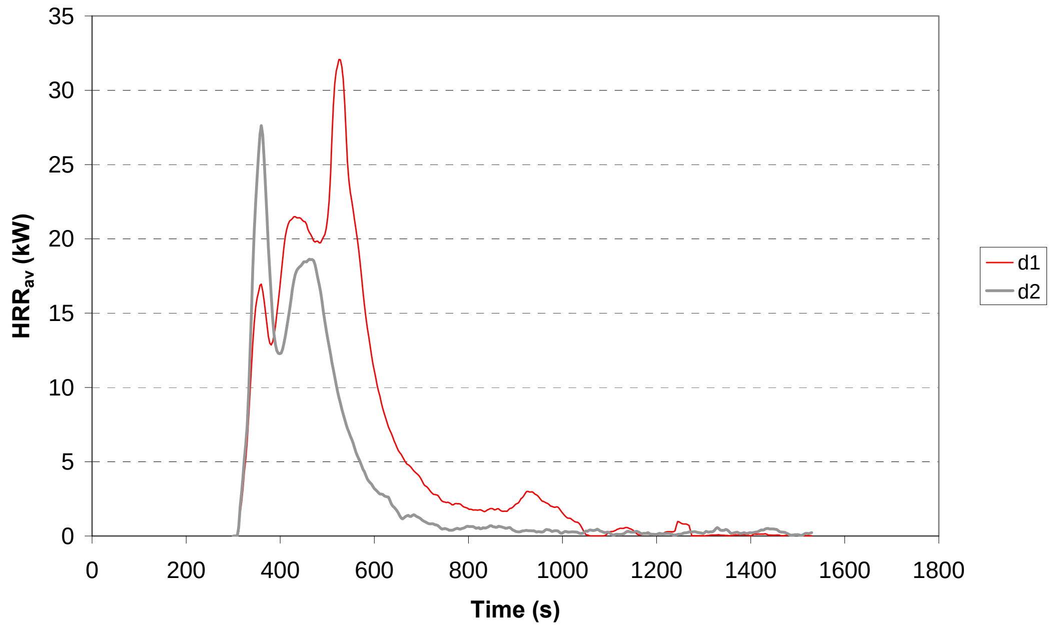


Figure 117 Graphs of heat release rate (HRR).

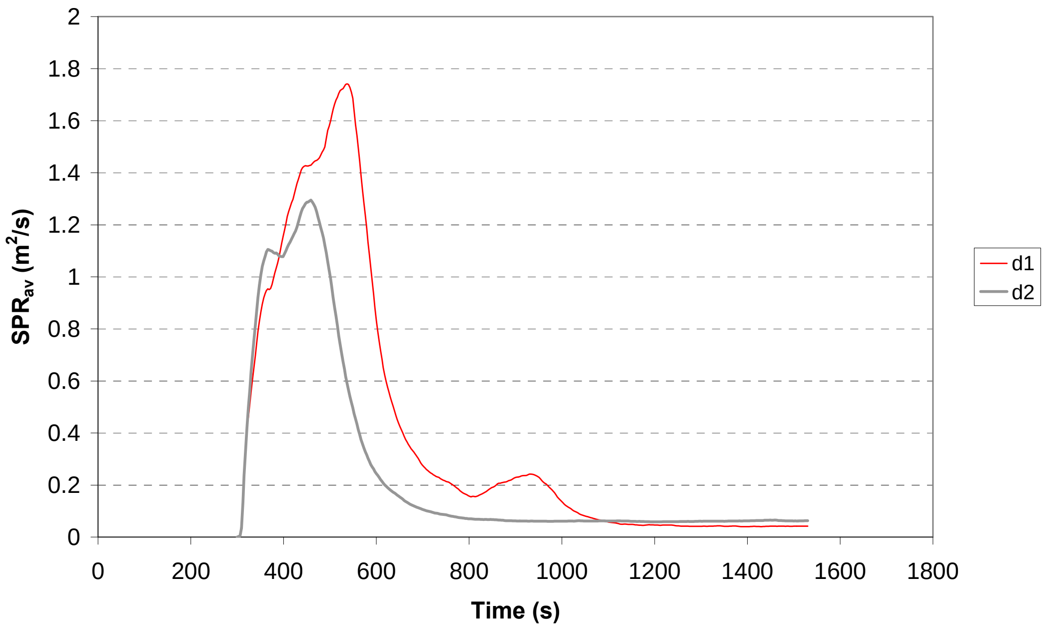


Figure 118 Graphs of smoke production rate (SPR).

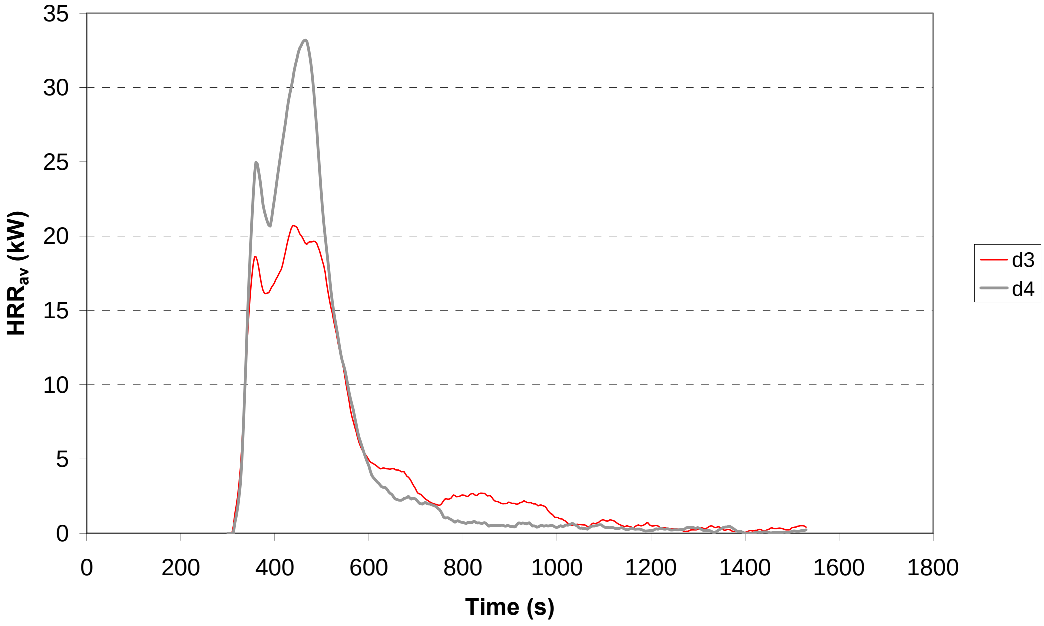


Figure 119 Graphs of heat release rate (HRR).

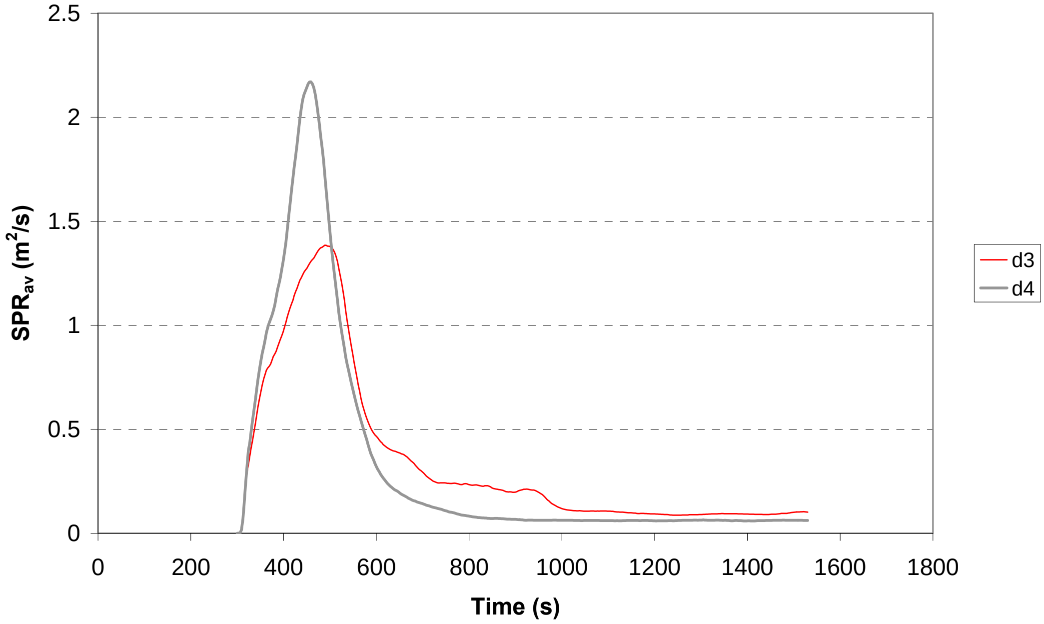


Figure 120 Graphs of smoke production rate (SPR).

Silicone:

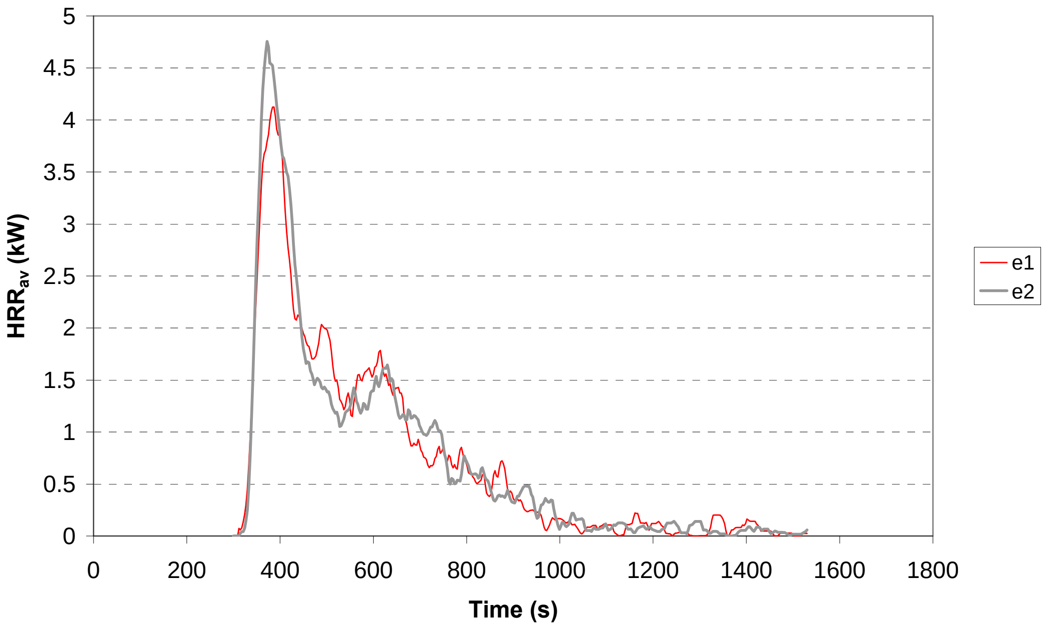


Figure 121 Graphs of heat release rate (HRR).

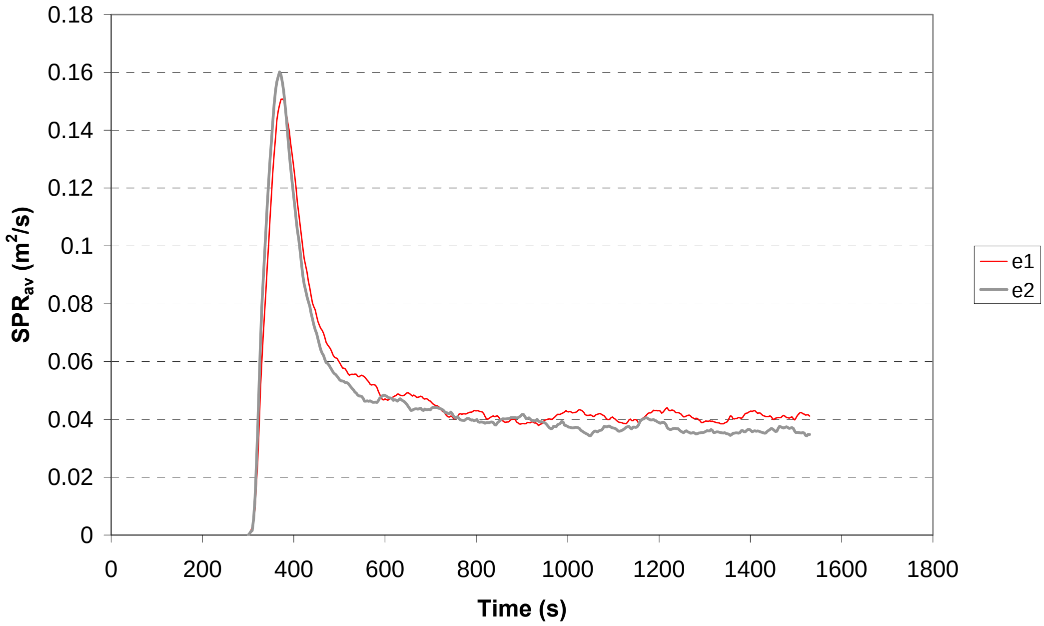


Figure 122 Graphs of smoke production rate (SPR).

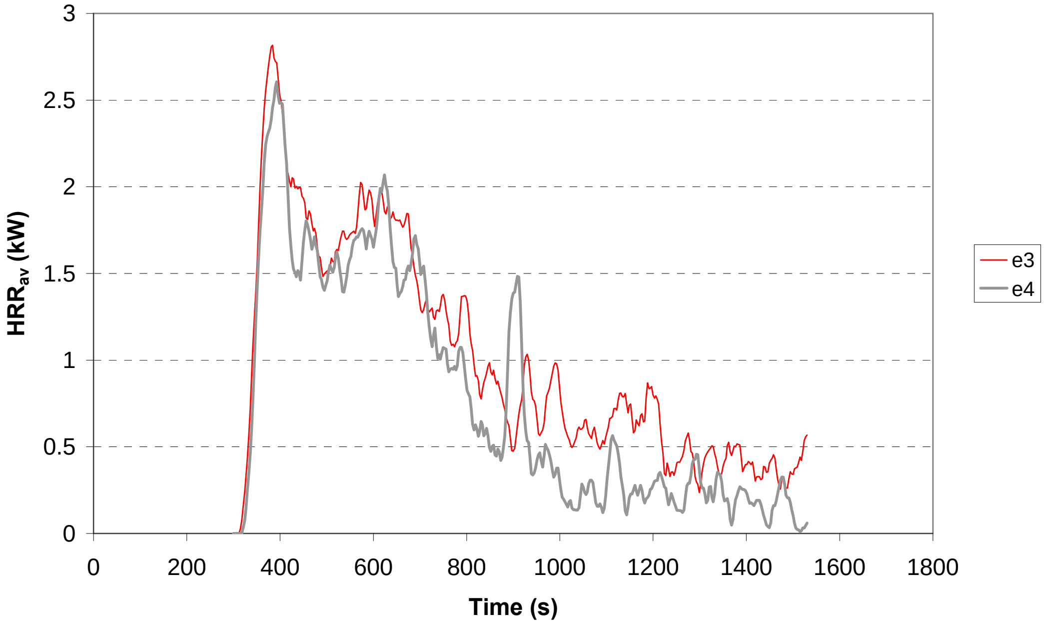


Figure 123 Graphs of heat release rate (HRR).

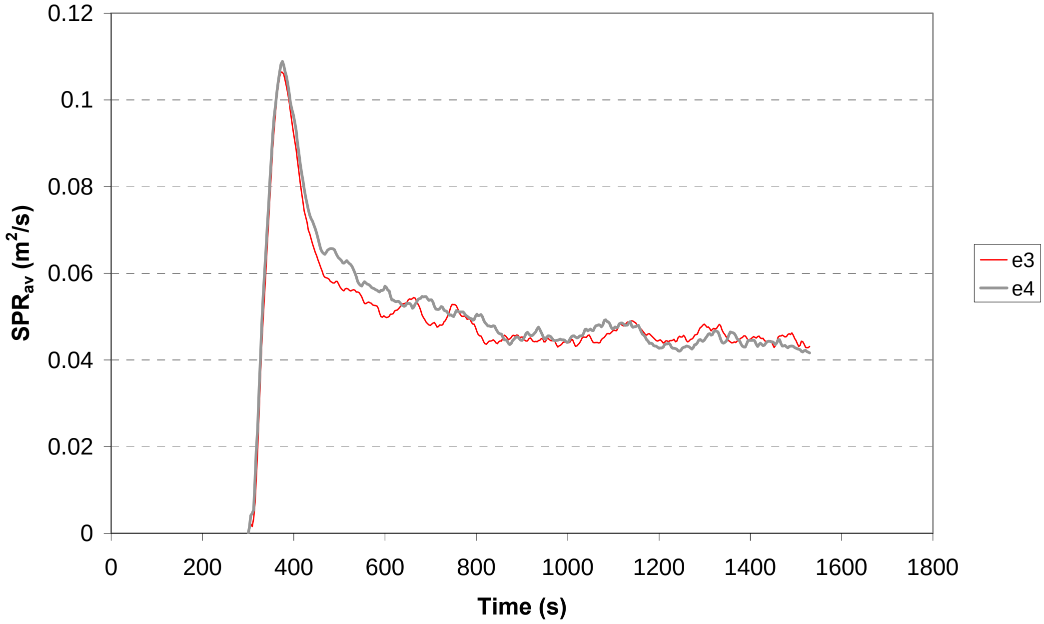


Figure 124 Graphs of smoke production rate (SPR).

PTFE:

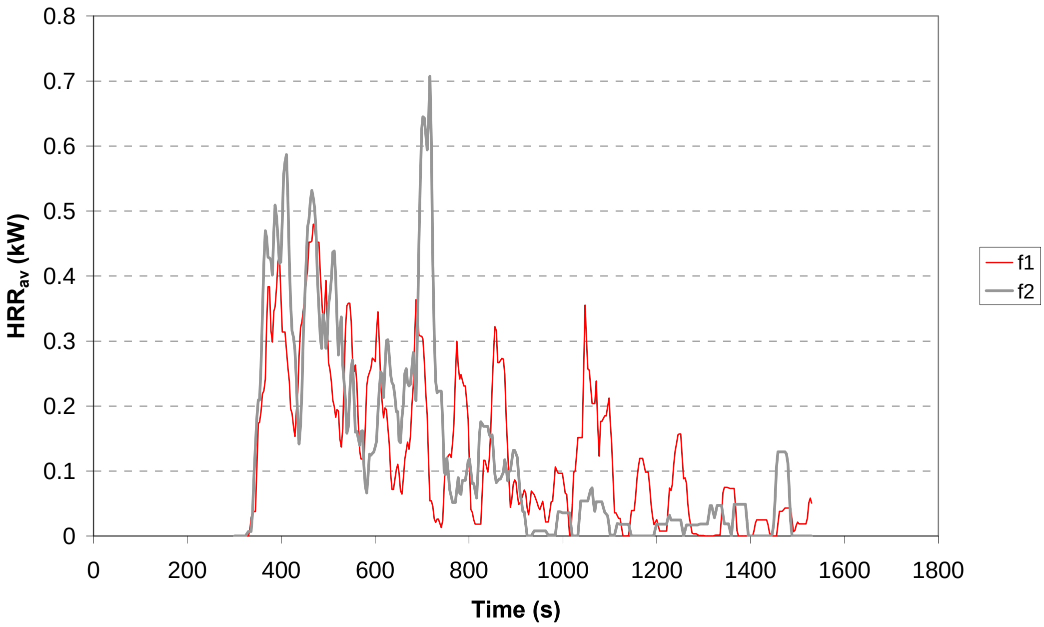


Figure 125 Graphs of heat release rate (HRR).

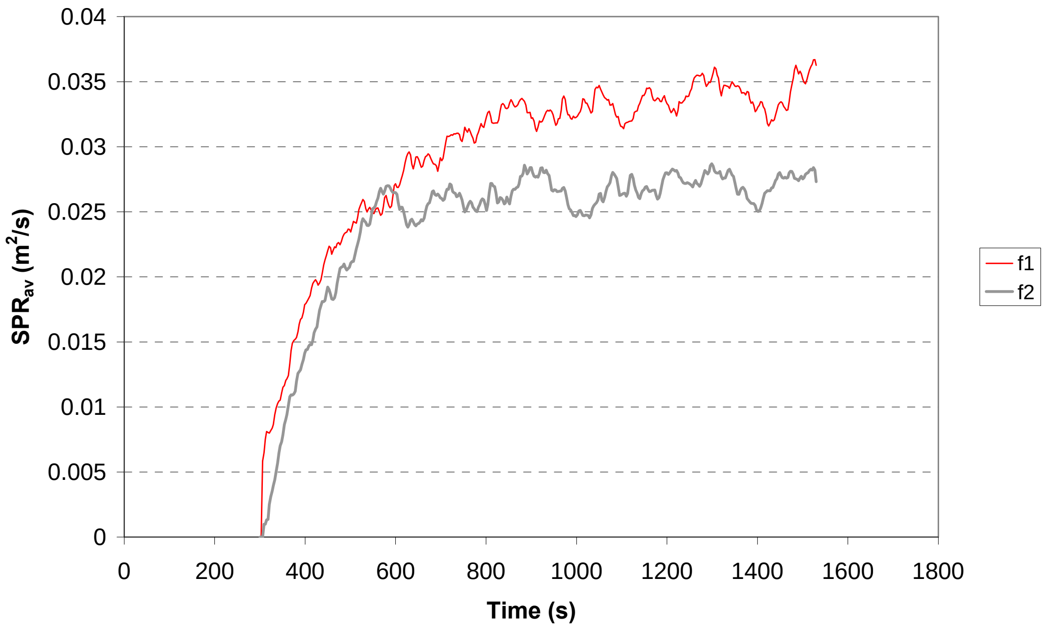


Figure 126 Graphs of smoke production rate (SPR).

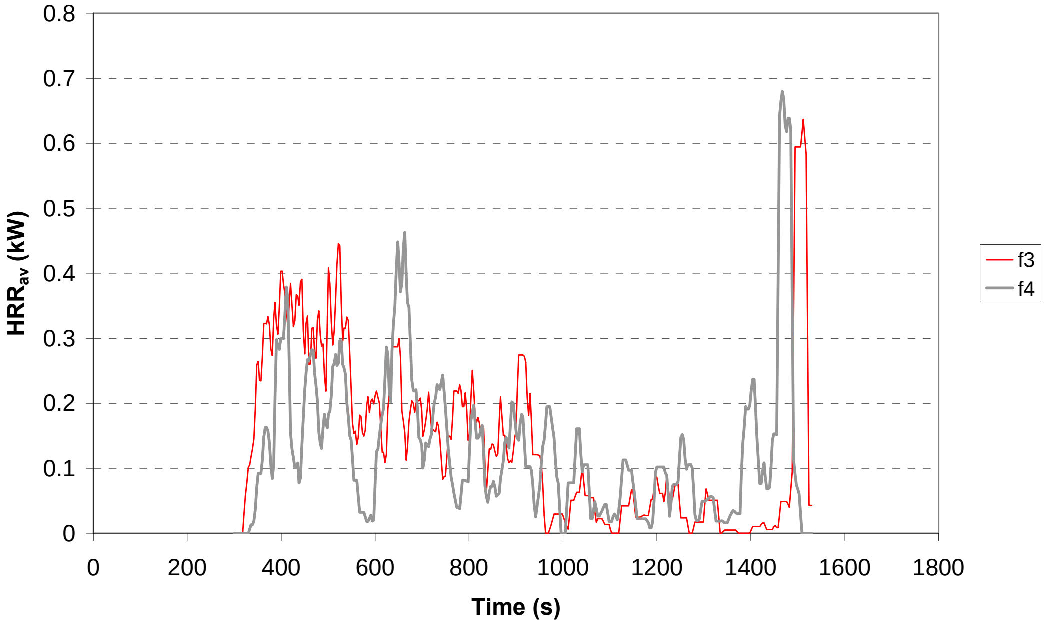


Figure 127 Graphs of heat release rate (HRR).

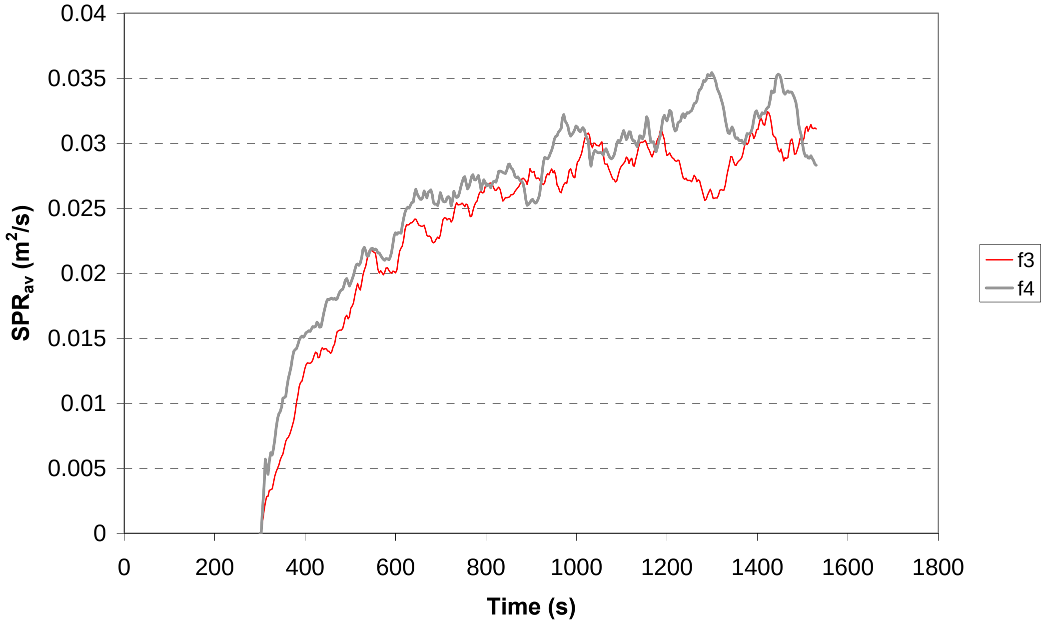


Figure 128 Graphs of smoke production rate (SPR).

Appendix 4 Classes of reaction to fire performance from EN 13501

Table 11 Classes of reaction to fire performance for construction products excluding floorings.

Class	Test method(s)	Classification criteria	Additional classification
A1	EN ISO 1182 (1); *And*	$\Delta T \leq 30°C$; *and* $\Delta m \leq 50\%$; *and* $t_f = 0$ (i.e. no sustained flaming)	-
	EN ISO 1716	PCS ≤ 2.0 $MJ.kg^{-1}$ (1); *and* PCS ≤ 2.0 $MJ.kg^{-1}$ (2) (2a); *and* PCS ≤ 1.4 $MJ.m^{-2}$ (3); *and* PCS ≤ 2.0 $MJ.kg^{-1}$ (4)	-
A2	EN ISO 1182 (1); *Or*	$\Delta T \leq 50°C$; *and* $\Delta m \leq 50\%$; *and* $t_f \leq 20s$	-
	EN ISO 1716; *and*	PCS ≤ 3.0 $MJ.kg^{-1}$ (1); *and* PCS ≤ 4.0 $MJ.m^{-2}$ (2); *and* PCS ≤ 4.0 $MJ.m^{-2}$ (3); *and* PCS ≤ 3.0 $MJ.kg^{-1}$ (4)	-
	EN 13823 (SBI)	FIGRA ≤ 120 $W.s^{-1}$; *and* LFS < edge of specimen; *and* $THR_{600s} \leq 7.5$ MJ	Smoke production(5); *and* Flaming droplets/ particles (6)
B	EN 13823 (SBI); *And*	FIGRA ≤ 120 $W.s^{-1}$; *and* LFS < edge of specimen; *and* $THR_{600s} \leq 7.5$ MJ	Smoke production(5); *and* Flaming droplets/ particles (6)
	EN ISO 11925-2(8): *Exposure = 30s*	Fs ≤ 150mm within 60s	
C	EN 13823 (SBI); *And*	FIGRA ≤ 250 $W.s^{-1}$; *and* LFS < edge of specimen; *and* $THR_{600s} \leq 15$ MJ	Smoke production(5); *and* Flaming droplets/ particles (6)
	EN ISO 11925-2(8): *Exposure = 30s*	Fs ≤ 150mm within 60s	
D	EN 13823 (SBI); *And*	FIGRA ≤ 750 $W.s^{-1}$	Smoke production(5); *and* Flaming droplets/ particles (6)
	EN ISO 11925-2(8): *Exposure = 30s*	Fs ≤ 150mm within 60s	
E	EN ISO 11925-2(8): *Exposure = 15s*	Fs ≤ 150mm within 20s	Flaming droplets/ particles (7)
F	No performance determined		

(*) The treatment of some families of products, e.g. linear products (pipes, ducts, cables etc.), is still under review and may necessitate an amendment to this decision.

(1) For homogeneous products and substantial components of non-homogeneous products.

(2) For any external non-substantial component of non-homogeneous products.

(2a) Alternatively, any external non-substantial component having a PCS ≤ 2.0 $MJ.m^{-2}$, provided that the product satisfies the following criteria of EN 13823(SBI) : FIGRA ≤ 20 $W.s^{-1}$; *and* LFS < edge of specimen; *and* THR_{600s} ≤ 4.0 MJ; *and* s1; *and* d0.

(3) For any internal non-substantial component of non-homogeneous products.

(4) For the product as a whole.

(5) **s1** = SMOGRA ≤ $30m^2.s^{-2}$ *and* TSP_{600s} ≤ $50m^2$; **s2** = SMOGRA ≤ $180m^2.s^{-2}$ *and* TSP_{600s} ≤ $200m^2$; **s3** = not s1 or s2.

(6) **d0** = No flaming droplets/ particles in EN13823 (SBI) within 600s; **d1** = No flaming droplets/ particles persisting longer than 10s in EN13823 (SBI) within 600s; **d2** = not d0 or d1; Ignition of the paper in EN ISO 11925-2 results in a d2 classification.

(7) Pass = no ignition of the paper (no classification); Fail = ignition of the paper (**d2** classification).

(8) Under conditions of surface flame attack and, if appropriate to end–use application of product, edge flame attack.

Symbols: The characteristics are defined with respect to the appropriate test method.

ΔT	temperature rise
Δm	mass loss
t_f	duration of flaming
PCS	gross calorific potential
FIGRA	fire growth rate
THR_{600s}	total heat release
LFS	lateral flame spread
SMOGRA	smoke growth rate
TSP_{600s}	total smoke production
Fs	flame spread

Definitions

Material: A single basic substance or uniformly dispersed mixture of substances, e.g. metal, stone, timber, concrete, mineral wool with uniformly dispersed binder, polymers.

Homogeneous product: A product consisting of a single material, of uniform density and composition throughout the product.

Non-homogeneous product: A product that does not satisfy the requirements of a homogeneous product. It is a product composed of one or more components, substantial and/or non-substantial.

Substantial component: A material that constitutes a significant part of a non-homogeneous product. A layer with a mass per unit area ≥ 1.0 kg/m^2 or a thickness ≥ 1.0 mm is considered to be a substantial component.

Non-substantial component: A material that does not constitute a significant part of a non-homogeneous product. A layer with a mass per unit area < 1.0 kg/m^2 and a thickness < 1.0 mm is considered to be a non-substantial component.

Two or more non-substantial layers that are adjacent to each other (i.e. with no substantial component(s) in-between the layers) are regarded as one non-substantial component and, therefore, must altogether comply with the requirements for a layer being a non-substantial component.

For non-substantial components, distinction is made between internal non-substantial components and external non-substantial components, as follows:

Internal non-substantial component: A non-substantial component that is covered on both sides by at least one substantial component.

External non-substantial component: A non-substantial component that is not covered on one side by a substantial component.

A Euroclass is intended to be declared as for example **Bd1s2**. **B** stands for the main class, **d1** stands for droplets/particles class no 1 and **s2** stands for smoke class no 2. This gives theoretically a total of about 40 classes of linings and 11 classes of floor coverings to choose from. However, each country is expected only to use a very small fraction of the possible combinations.

SP Technical Research Institute of Sweden

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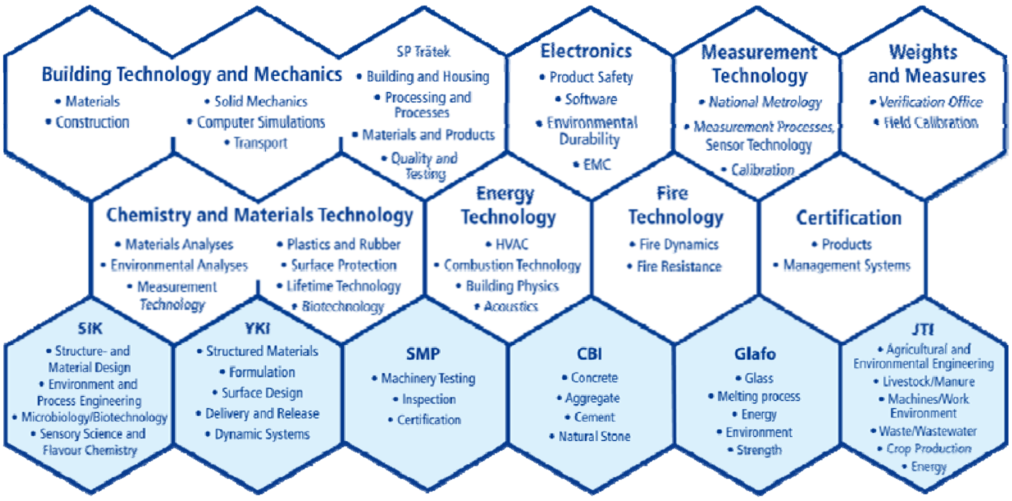

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