Large-scale fire tests with textile membranes for building applications

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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 include their low weight, and in the case of textile membranes, their translucency and architectural flexibility. 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 Technical Note describes large-scale tests conducted with textile membranes. The purpose of the report is to give a full description of the tests, including the test set-up and test procedures. The report provides detailed notes, photographs and measurement data from the tests.

Two series of large-scale tests with textile membranes were conducted. The same general test set-up was used for both series of tests. A test building was made where the textile membrane was mounted on a metal frame. The size of this test building was identical to the size of the building used for reference tests of building products (ISO 9705). The differences between the two test series included the size and heat output of the burner, the placement of the burner in the test building and the choice of textile membranes that were tested.

The first series of tests was conducted as a proposed reference scenario test for reaction-to-fire testing of textile membranes for building applications based on the European classification system for building products, EN 13501-1. The second series of tests was conducted for the validation of mathematical simulations (CFD) of burn-trough of textile membranes.

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. En begränsning för textila material är dock deras brandegenskaper, vilket understryker vikten av en korrekt brandsäkerhets-bedömning vid användande av sådana material i byggnadskonstruktioner.

Denna arbetsrapport beskriver storskaliga brandförsök utförda med textila membran. Syftet med rapporten är att ge en detaljerad beskrivning av försöksuppställning samt testprocedurer. Rapporten innehåller detaljerade anteckningar från försöken, fotografier samt mätdata från försöken.

Två försöksserier utfördes där den huvudsakliga provuppställningen var densamma. Testbyggnaden bestod av det textila membranet som var uppspänt på en stålram. Storleken på testbyggnaden var identisk med den byggnad som används för referenstest med byggnadsprodukter (ISO 9705). Skillnaden mellan de två försöksserierna innefattade storleken på brännareffekt, placering av brännaren, samt valet av textila membran som testades.

Den första försöksserien utfördes som ett förslag på ett lämpligt referenstest av textila membran med applikation som byggnadsprodukter. Referenstestet är tänkt som en referens för textila membran till de provningar som klassificerar byggnadsprodukter enligt EN 13501-1. Den andra testserien utfördes för att ge ett försöksunderlag för validering av utförda matematisk simuleringar (CFD) av genombrinning i takapplikationer av textila membran.

1 Introduction

This report describes large-scale fire tests conducted with textile membranes within the EU-project contex-T. The purpose of the report is to give a full description of the tests, including the test set-up and test procedures. The report provides detailed notes, photographs and measurement data from the tests.

The results from the tests of the different textile membranes presented in the report are not compared to each other or assessed in any general way regarding fire safety. Assessments and discussions in the report are made only regarding technical details of the tests. The status of this report is to provide data for assessments and analyses that have been conducted separately in the project.

Two series of large-scale tests with textile membranes were conducted. The same general test set-up was used for both series of tests. A test building was made where the textile membrane was mounted on a metal frame. The size of this test building was identical to the size of the building used for reference tests of sandwich panels, ISO 13784 [1], and for reference tests of building products, ISO 9705 [2]. The differences between the two test series included the size and heat output of the burner, the placement of the burner in the test building and the choice of textile membranes that were tested.

The first series of tests was conducted as a proposed reference scenario test for reaction-to-fire testing of textile membranes for building applications based on the European classification system for building products, EN 13501-1 [3]. Textile membranes intended for building applications in Europe have been tested according to various national test standards, often German or French tests, but are today increasingly tested according to the tests described by EN 13501-1, where the SBI-test (EN 13823 [4]) is the major test, for conformance with the European Construction Products Directive. Knowledge of the validity of the SBI-test regarding prediction of the real fire behaviour of textile membranes is, however, very limited. Therefore the large-scale reference tests presented in this report were conducted with a selection of different membranes that had previously been tested in the SBI using different methods of mounting [5]. The results from the large-scale reference scenario tests will form a basis for an assessment of the link between the classification based on the EN 13501-1 tests and the fire performance in a large-scale test.

The second series of tests was conducted for the validation of mathematical simulations of burn-through of textile membranes. Computational Fluid Dynamics (CFD) simulations are an important tool for justifying performance based design solutions. One important aspect when it comes to buildings constructed using textile membranes is that such buildings allow natural smoke ventilation if a hole opens up in the membrane during a fire. This feature must therefore be included in CFD-codes to be used for simulations of textile membranes in fires. Such models have been developed in WP 3.3 of contex-T. The second test series presented in this report was made to acquire large-scale data on burn-through of PVC/Polyester membranes for the validation of the hole-opening model in the CFD code.

2 Description of tests

2.1 Test building

The tests were conducted with a room of size 3.60 m × 2.40 m × 2.40 m as specified in ISO 13784 and ISO 9705, with a door opening on one short side of 0.8 m × 2 m. The walls and the roof consisted of one layer of textile membrane. The wall on the short side with the door opening was, however, made of non-combustible mineral board (Promatect). A photo of the test building is given in Figure 1. The frame was constructed using 2 mm thick steel profiles 60 mm × 60 mm with the exception of the vertical bars in the non-door corners which were constructed using 2 mm thick 40 mm × 40 mm steel L-profiles. For clamping of the membranes, 60mm flat iron bars were used with a self-drilling screw every 300mm. Holes were predrilled in the frame and the flat bars, with slightly bigger holes in the flat bars. The membrane used for the walls was fastened at the top and bottom of the frame and on the door corners. One continuous length of membrane was used for all three walls. The membrane for the roof was mounted on a special frame for the roof. The roof frame was fastened to the walls using screws and the joint between the two frames was carefully calked using mineral wool. The mounting of the membrane is shown in Figure 2 and Figure 3.

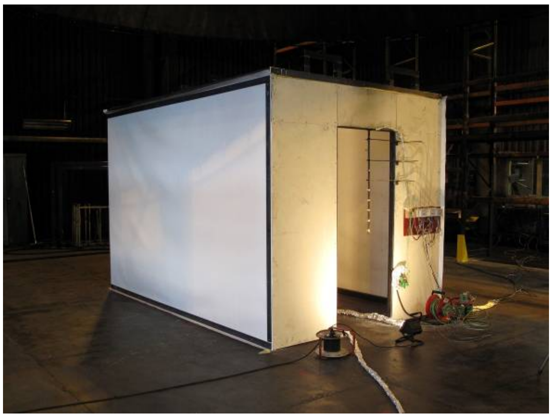

Figure 1 The test building of textile membrane on a metal frame.

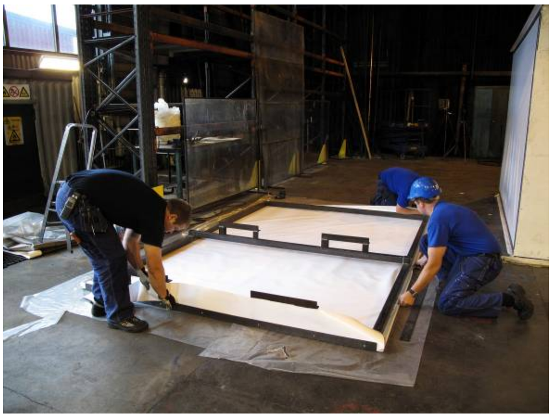

Figure 2 Mounting of membrane for the roof.

Figure 3 Mounting of roof membrane.

2.2 Burner location and heat output levels

Two series of tests were performed. The main differences between the tests series were the size and location of the fire source, which in both cases consisted of a sand-burner fuelled with propane.

In the first series of tests, a 17 cm × 17 cm burner was placed in the left hand rear corner of the room with a heat release rate (HRR) from the burner of 100 kW for 10 minutes followed by 300 kW for 10 minutes, as in the ISO 9705 room corner test [2]. The burner is seen in Figure 4. The first series of tests were conducted in order to investigate a possible reference scenario for European reaction-to-fire classification tests.

In the second series of test, a 30 cm × 30 cm burner was placed in the middle of the room. Two sets of tests with the burner located at different heights were made. In one set of test the burner was placed at a height of 45 cm with a HRR from the burner of 95 kW for 10 minutes, 140 kW for 10 minutes, followed by 300 kW for 5 minutes. In the other set of test the burner was placed at a height of 100 cm with a HRR from the burner of 95 kW for 5 minutes followed by 140 kW for 5 minutes. The burner is seen in Figure 5 and Figure 6. These test were conducted for validation of CFD modelling of hole opening in membranes during fire.

Figure 4 Burner for the reference scenario tests.

Figure 5 Burner for CFD-validation tests.

Figure 6 Placing the burner in the middle of the room in the CFD-validation tests.

2.3 Measurements in the test building

In both series of tests, temperature and velocities in the door opening were measured. The temperature at 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 cm below the soffit and velocities at 10, 30 and 50 cm below the soffit were recorded, as can be seen in Figure 7.

When the burner was placed in the corner, measurements were conducted in the middle of the room with a thermocouple (TC) tree with TCs every 10 cm. One TC was mounted against the membrane ceiling (inside the room) as seen in Figure 8 plus one TC on the membrane roof (outside the room). The TC on the membrane was mounted by means of tape only which implies that the TC could lose contact with the membrane during the tests, especially on the ceiling.

Smoke measurements were conducted at a height of 1.60 m close to the central TC tree (12 cm towards the door). In addition, a Plate thermocouple was placed on the floor with its centre 12 cm × 12 cm away from the TC tree. Markings were made on the rear wall 50 cm, 1 m, 1.5 m and 2 m away from the corner in order to follow the flame spread during each test.

When the burner was placed in the middle of the room the TC on the outside of the membrane was still placed in the middle while the thermocouple tree was placed 80 cm from the rear wall and the Plate thermocouple 15 cm × 15 cm away from the TC tree. The smoke measurement was placed 60 cm from the rear wall. Markings were made on the roof/ceiling 30 and 50 cm away from the centre to follow the hole opening during each test.

Figure 7 Velocity and temperature measurement in door opening. Smoke measurement and thermocouple tree in middle of room can also be seen.

Figure 8 Thermocouple tree and TC mounted on inside of ceiling.

2.4 Measurements of total heat production and smoke

The test room was placed under a large calorimetric hood/duct system. Heat Release Rate (HRR) and smoke production were measured in the duct. Additionally, the velocities and temperature readings in the door opening were used to estimate the convective flow of heat out of the door opening. The HRR measurement in the duct was calibrated before each test with a propane burner as shown in Figure 9.

Figure 9 Calibration of HRR measurement with propane burner.

2.5 Documentation of tests

The tests were video recorded with 2 video cameras and photos were taken from several angels during each tests, see figures 10 and 11. Detailed notes were taken during the tests (see Section 3) and the size of the hole in the membrane was measured and photo documentation made after each test.

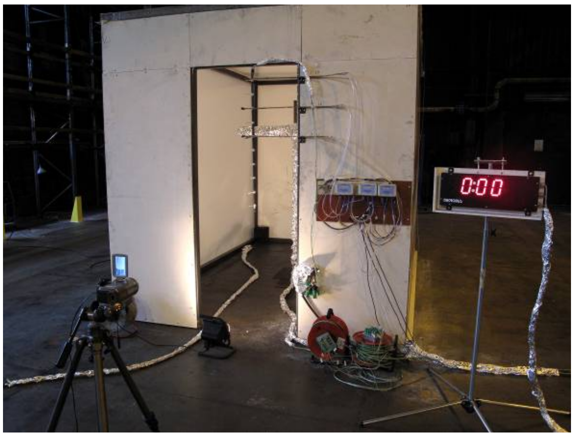

Figure 10 All test were video recorded.

Figure 11 All tests were photographed from several angles.

2.6 Textile membranes included in the tests

The textile membranes included in the tests are listed in Table 1. The Reference scenario tests (Tests 1-5) were conducted with membranes for which reaction-to-fire tests had been conducted earlier in contex-T [5], including a Silicone-Glass fibre membrane. The CFD validation tests (Tests 6-10) were made with PVC-PES membranes only, as these tests were made to study burn-through of the membrane.

Table 1 The textile membranes included in the tests.

Test number	Textile membrane	Purpose
1	Sioen B6656 / PVC-PES[1] / 1300 g.m^{-2}	Reference scenario
2	Sioen B8103 / PVC-PES / 650 g.m^{-2}	-«-
3	Atex 5000 TRL /Silicone-Glass fibre / 1270 g.m^{-2}	-«-
4	Sioen B6656 / PVC-PES / 1300 g.m^{-2}	-«-
5	Sioen B8103/ PVC-PES / 650 g.m^{-2}	-«-
6	Sioen B8103/ PVC-PES / 650 g.m^{-2}	Determine placement of burner
7	Sioen B8103/ PVC-PES / 650 g.m^{-2}	CFD validation
8	Sioen B8103/ PVC-PES / 650 g.m^{-2}	-«-
9	Sioen T3107 / PVC-PES / 1150 g.m^{-2}	-«-
10	Sioen T3107/ PVC-PES / 1150 g.m^{-2}	-«-

[1] PES = Polyester

3 Test results

3.1 Reference scenario tests

The tests conducted in the first series are listed in Table 2. Information on duct flow in the hood/duct system, burner stages during the tests (identical in all five tests), and general notes regarding burn-through are included in the table.

Notes made during tests 1-5 are presented for each test below (section 3.1.1 - 3.1.5) together with curves from the measurements and photos taken during the tests.

Table 2 Reference scenario tests conducted.

Test number	Textile membrane	Duct flow*	Burner stages	Notes on burn-trough
1	Sioen B6656 / PVC-PES / 1300 $g.m^{-2}$	110 000 m³/h	100 kW – 10 min 300 kW – 10 min	Burn-trough at 100 kW
2	Sioen B8103 / PVC-PES / 650 $g.m^{-2}$	110 000 m³/h	-„-	-„-
3	Atex 5000 TRL /Silicone-Glass fibre / 1270 $g.m^{-2}$	80 000 m³/h	-„-	No burn-trough
4	Sioen B6656 / PVC-PES / 1300 $g.m^{-2}$	60 000 m³/h	-„-	Burn trough at 100 kW
5	Sioen B8103/ PVC-PES / 650 $g.m^{-2}$	60 000 m³/h	-„-	-„-

* The Duct flow was adjusted in the experiments to give as good measurements as possible.

3.1.1 Test 1: Reference test with thick PVC-PES (B6656)

Notes made during the test are presented in Table 3. A selection of the photos taken during the test are presented in Figure 12 - Figure 16. Results from the measurements are presented in Figure 17 - Figure 24.

Table 3 Notes made during Test 1.

Time	Comment
2 minutes	Ignition of burner at 100 kW
2 minutes 20 seconds	Black smoke out of door, “leopard” pattern on outside by burner
2 minutes 27 seconds	Hole
3 minutes 15 seconds	Piece falls outwards but does not burn
3 minutes 50 seconds	Flame leans outwards
4 minutes 40 seconds	Piece falls inwards but does not burn
4 minutes 50 seconds	Burning pieces falls out
6 minutes 40 seconds	Burning piece falls outwards which continues to burn until 11 minutes, the membrane burns also a little close to the floor but no flame spread as the mounting frame prevents this.
7 minutes 40 seconds	No burning on the rim of the hole

12 minutes	Burner increased to 300 kW, flame pulsates inwards/outwards
12 minutes 20 seconds	Rim of hole burns again
12 minutes 40 seconds	Black smoke out of door until time 14 minutes
12 minutes 50 seconds	Hole reaches roof mounting
13 minutes 20 seconds	Burning pieces falling outwards
14 minutes 30 seconds	Flame leaning outwards
16 minutes 20 seconds	Only very limited burning on rim
22 minutes	Burner turned off

Comment: The hole in the membrane after the fire was estimated from photos as 0.8 m × 2 m on both sides.

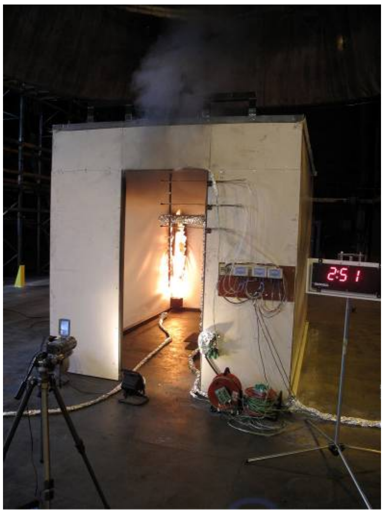

Figure 12 **Hole has recently opened up in the corner (Test 1, time 2:51).**

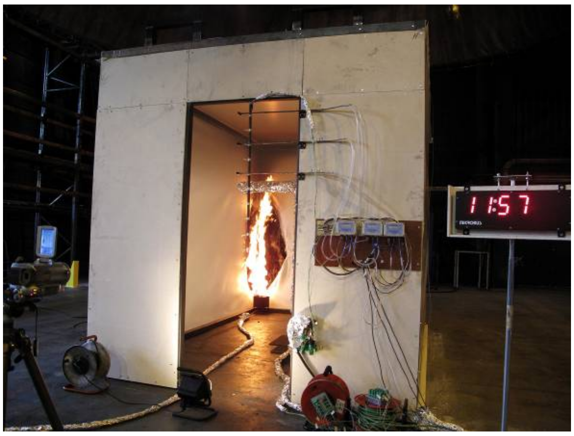

Figure 13 **Just before increasing burner output (Test 1, time 11:57).**

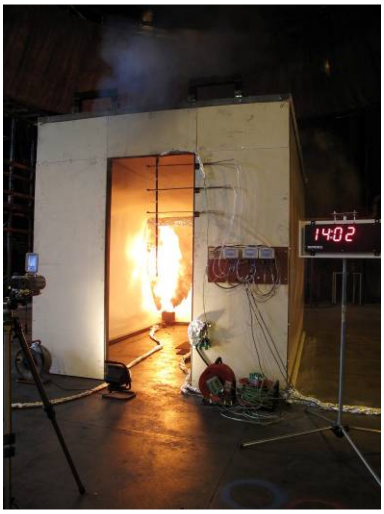

Figure 14 **Illustrative photo of fire behaviour at highest burner output (Test 1, time 14:02).**

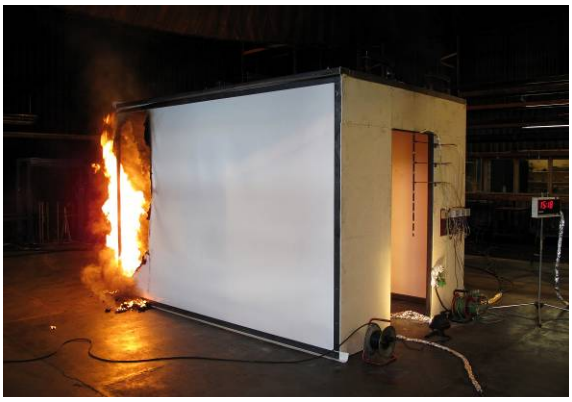

Figure 15 **View from the outside at the highest burner output (Test 1, time 15:19).**

Figure 16 **Damages in the corner of the room (Test 1, test completed).**

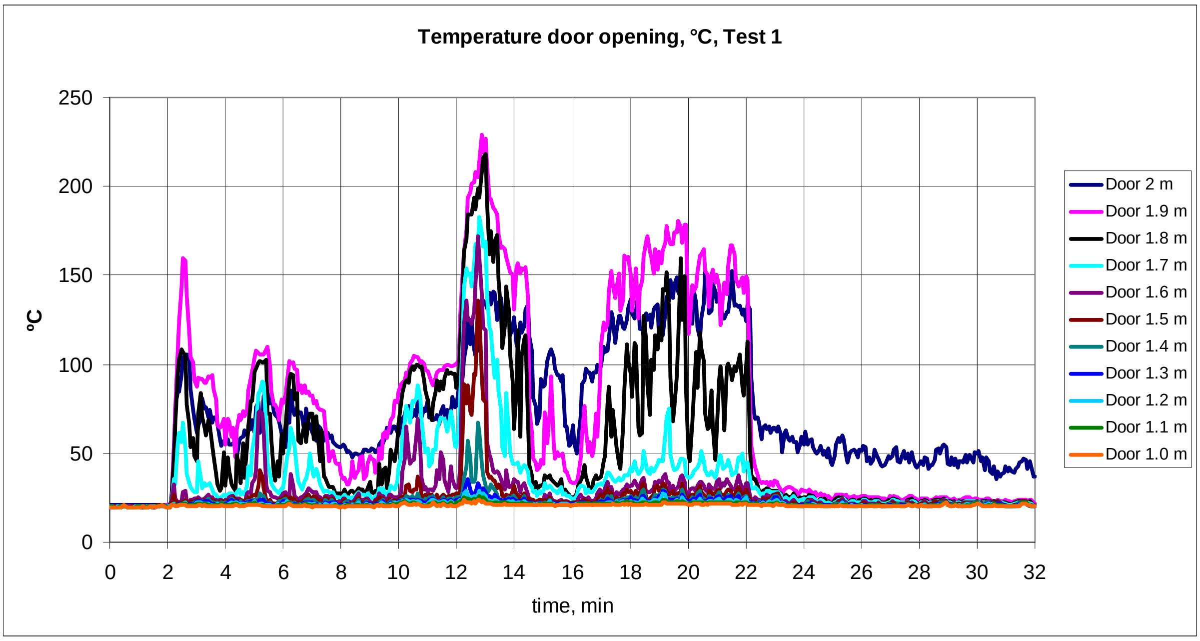

Figure 17 **Temperature readings in door opening in test 1.**

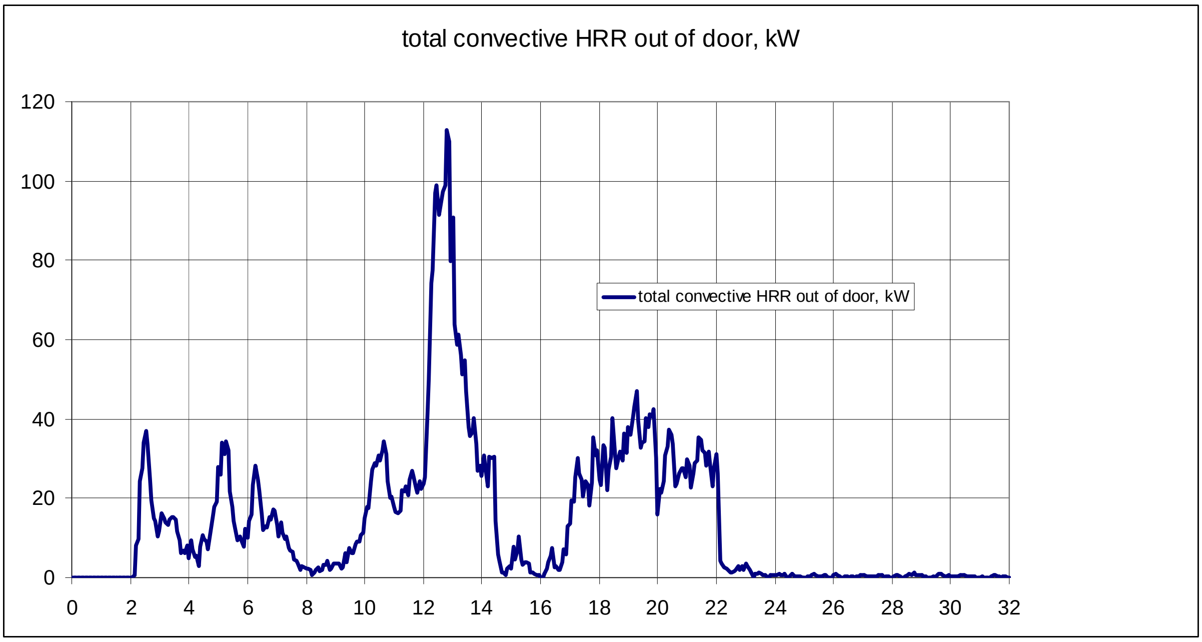

Figure 18 **Total convective HRR flow out of door opening in test 1.**

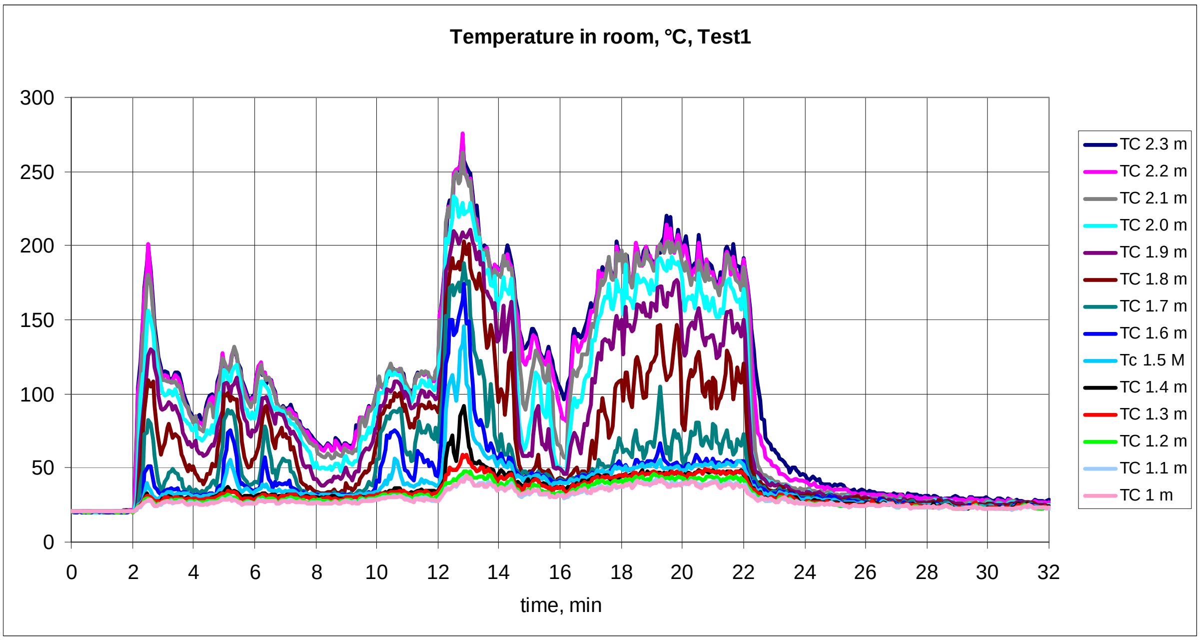

Figure 19 **Temperature readings in middle of room test 1.**

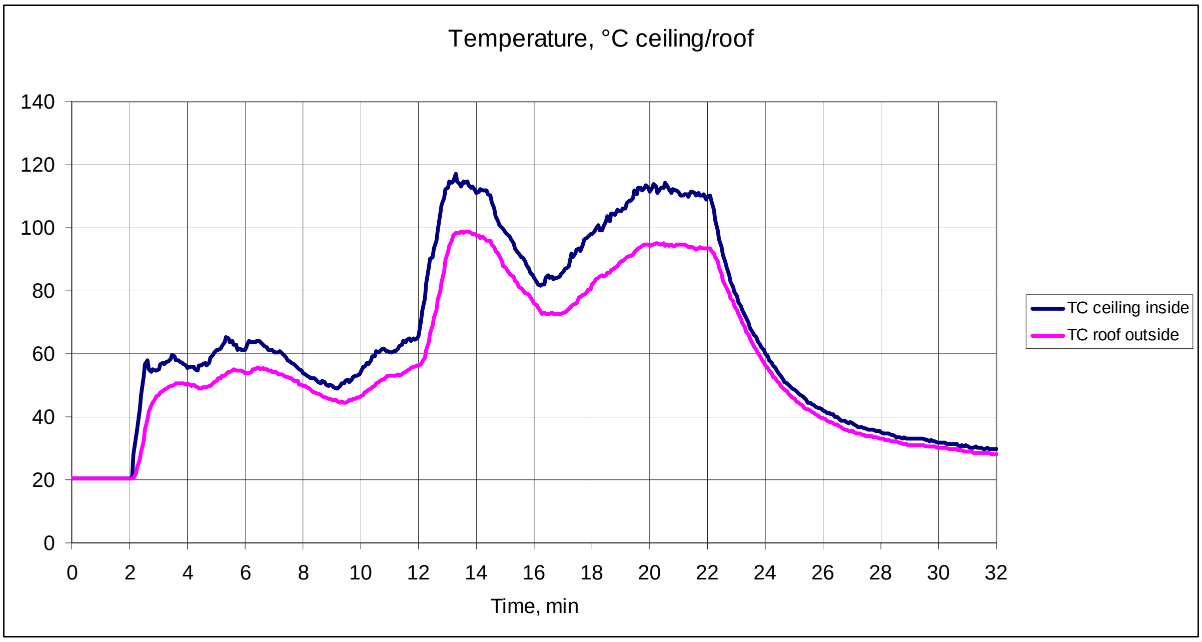

Figure 20 **Temperature readings on membrane from test 1.**

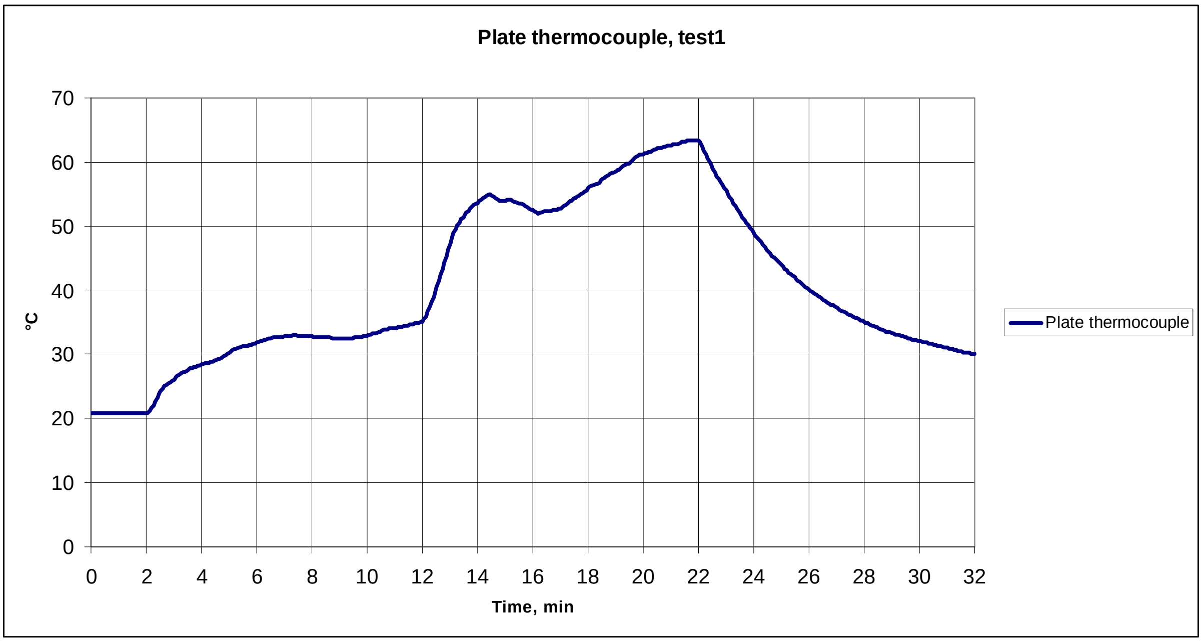

Figure 21 **Plate thermocouple readings test 1.**

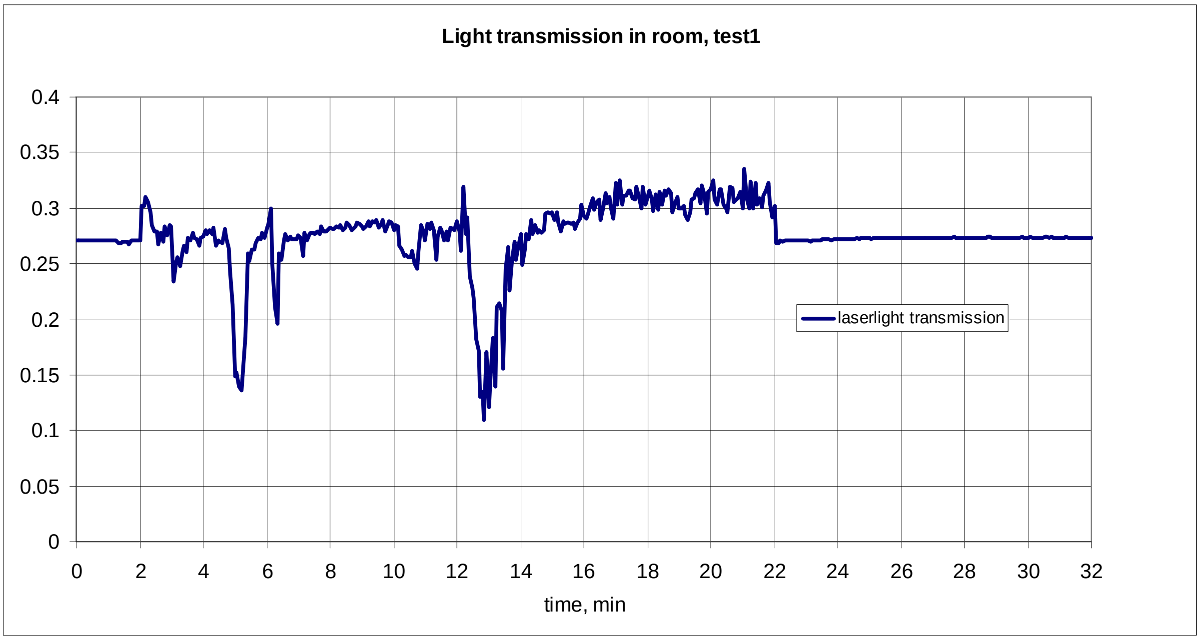

Figure 22 **Laser light transmission in room test 1. Signal has been corrected due to soot deposit.**

The light transmission was measured in a very simple way using an LED laser and a GaAsP photodiode sensitive in the range up to 800 nm which means that it is sensitive for Infrared light (IR) produced by the fire which explains the increased light when the burner is turned on as seen in Figure 22.

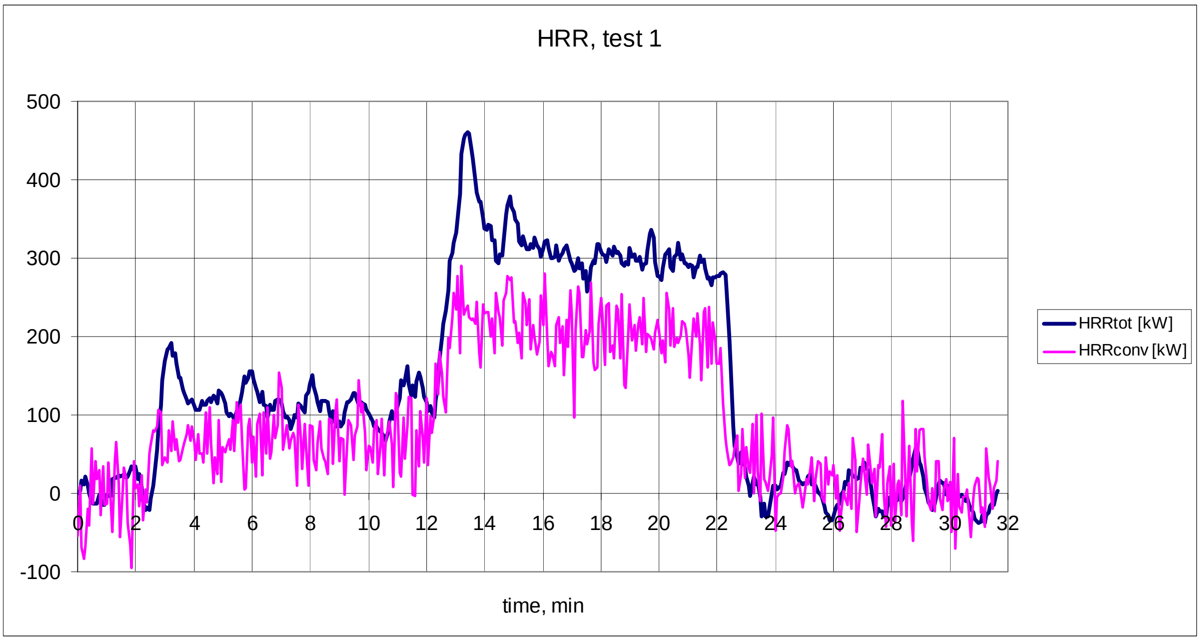

Figure 23 **Total and convective Heat Release Rate in test 1.**

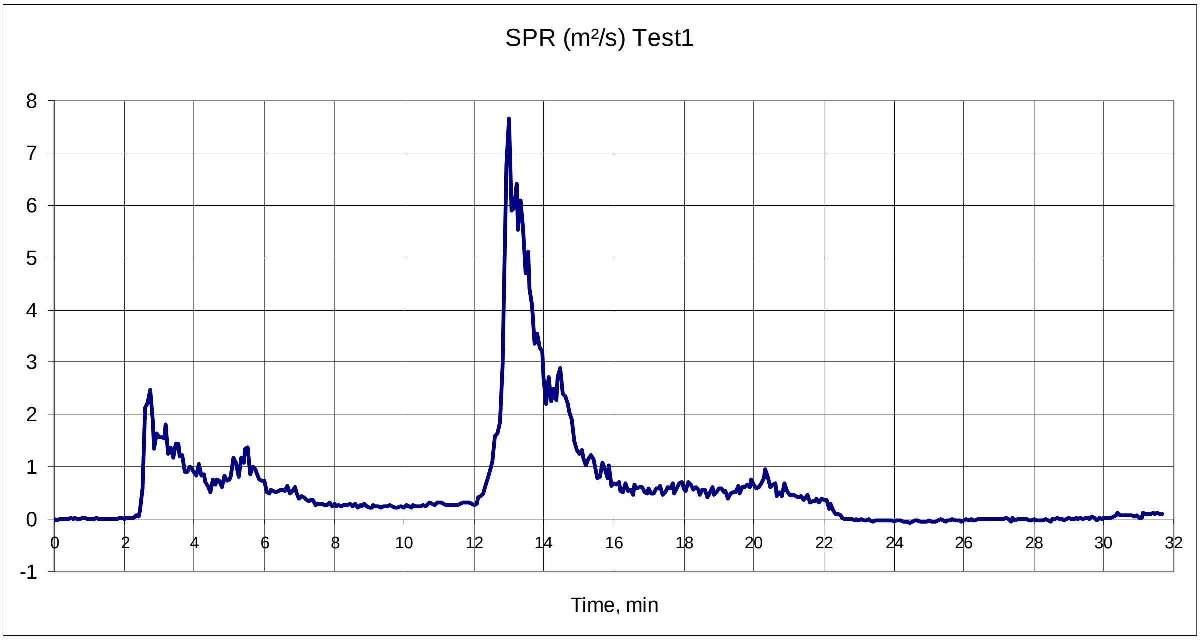

Figure 24 Smoke in duct Test 1 drift corrected.

3.1.2 Test 2: Reference test with thin PVC-PES (B8103)

Notes made during the test are presented in Table 4. Photos taken during the test are presented in Figure 25 - Figure 30 and the measurement results are presented in Figure 31 - Figure 38.

Table 4 Notes made during test 2.

Time	Comment
2 minutes	Ignition of burner at 100 kW
2 minutes 5 seconds	Flames reaches ceiling
2 minutes 13 seconds	Hole
2 minutes 25 seconds	Burning piece outwards
2 minutes 30 seconds	Burning piece also inwards stuck by burner, burns through membrane at time 2 minutes 55, extinguished at 3 minutes 20 seconds
2 minutes 40 seconds	Burning pieces falls outwards
3 minutes	Hole up to 1.6 m
4 minutes	Burning pieces falls inwards
5 minutes 20 seconds	Black smoke outwards
8 minutes 30 seconds	Smoke from the rim of the hole
12 minutes	Burner increased to 300 kW
12 minutes 13 seconds	Burns on the rim
12 minutes 20 seconds	Pieces falling, also burning inwards
12 minutes 35 seconds	Smoke becomes darker
14 minutes 20 seconds	Burning pieces floats slowly down the hole rim, extinguished before reaching floor.
15 minutes	No burning on hole rim
15 minutes 40 seconds	Reaches 50 cm flame spread line on rear wall
15 minutes 50 seconds	Hole in ceiling
16 minutes	Starts burning on hole rim again for a while
22 minutes	Burner turned off

Comment: At the end of the test the hole was 80 cm wide and 2 m high on the longer side and 60 cm wide and 2 m high on the short side. The hole in the ceiling was 40 cm × 25 cm.

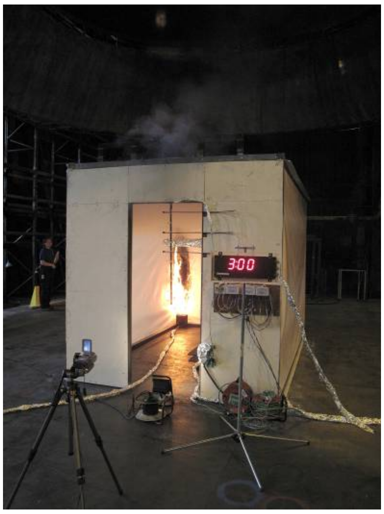

Figure 25 Hole has opened up in the corner and reached a height of 1.6 m (Test 2, time 3:00).

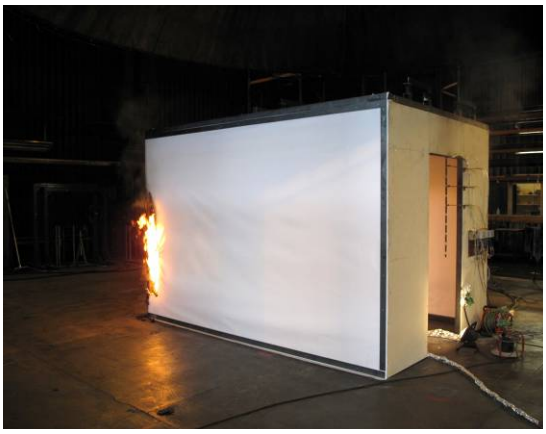

Figure 26 View from the outside of the burning corner (Test 2, time 4:05).

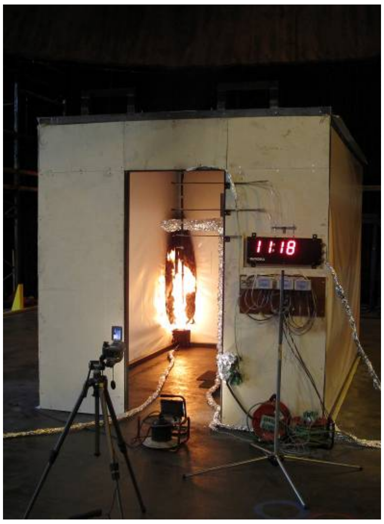

Figure 27 Hole in the corner just before increasing the burner output (Test 2, time 11:18).

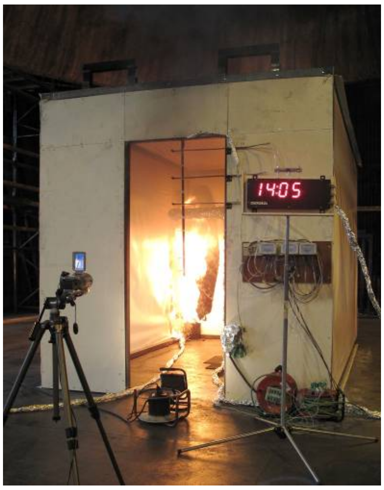

Figure 28 Illustrative photo of fire behaviour at the highest burner output (Test 2, time 14:05).

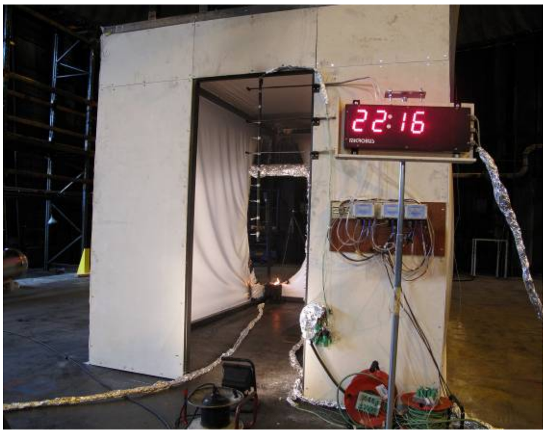

Figure 29 **Damages in the corner of the room (Test 2, test completed).**

Figure 30 **Close up of hole in the roof in the corner (Test 2, test completed).**

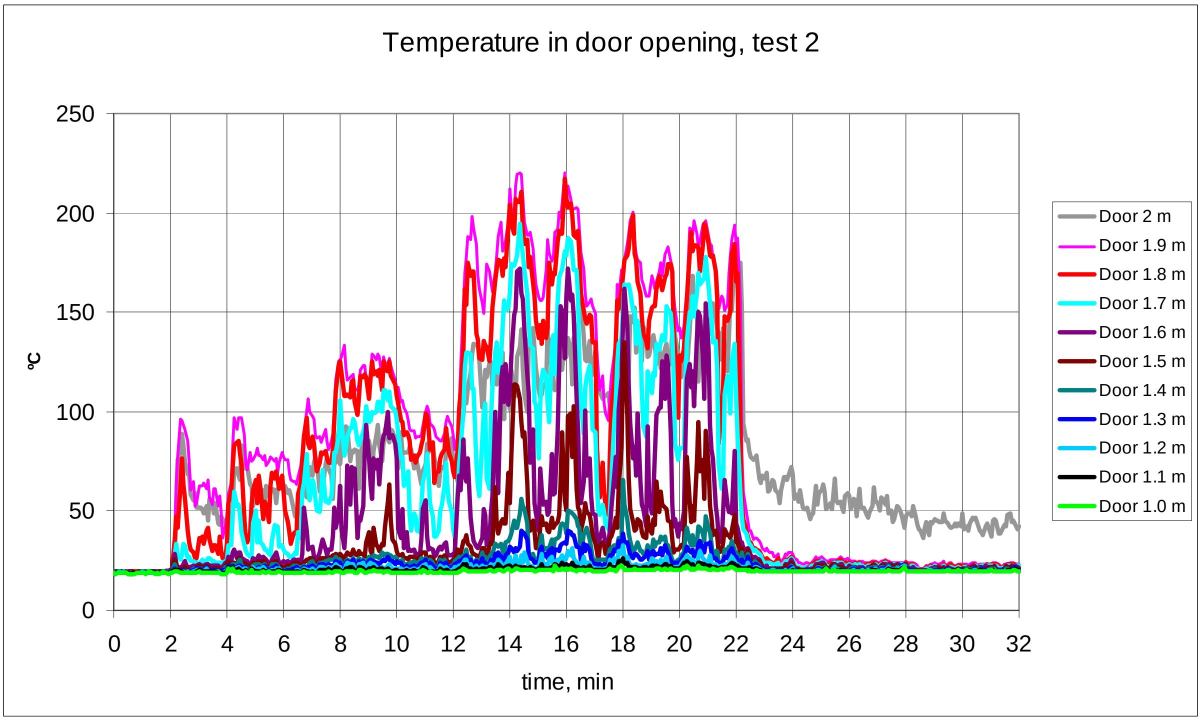

Figure 31 **Temperature readings door opening test 2.**

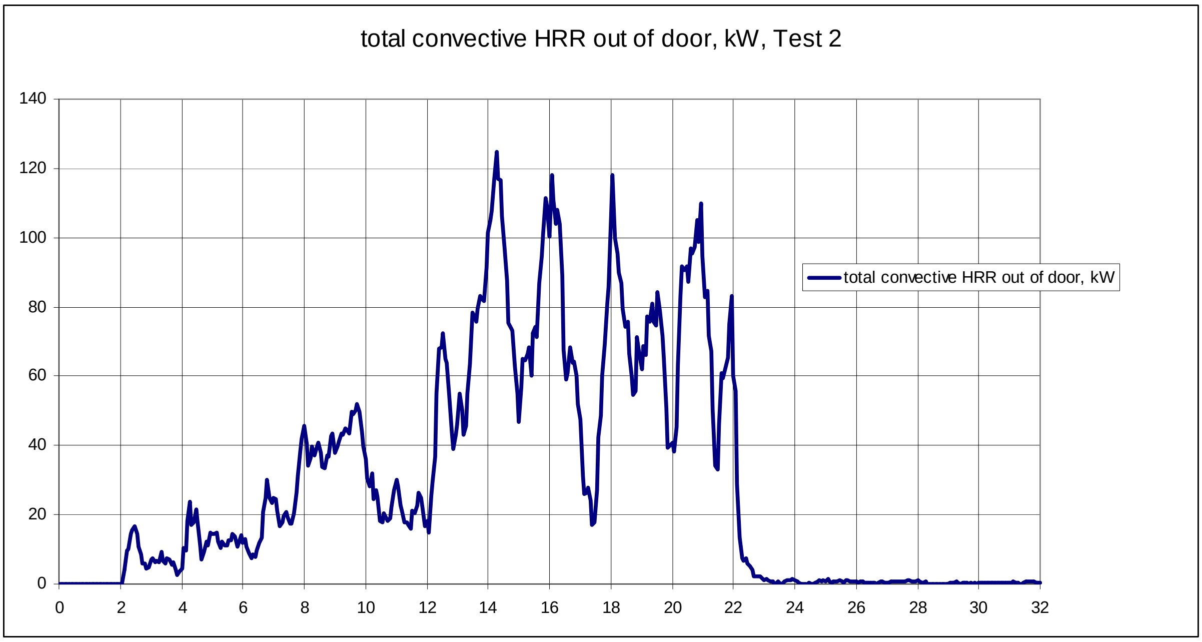

Figure 32 Total convective HRR flow out of door opening in Test 2.

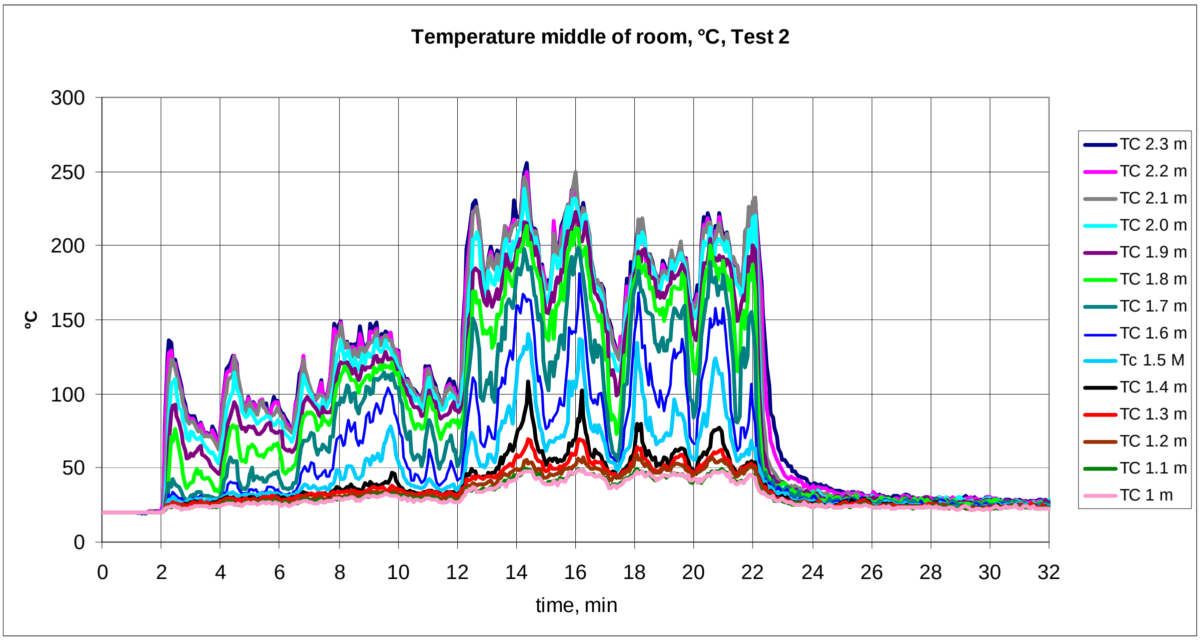

Figure 33 Temperature readings in middle of room Test 2.

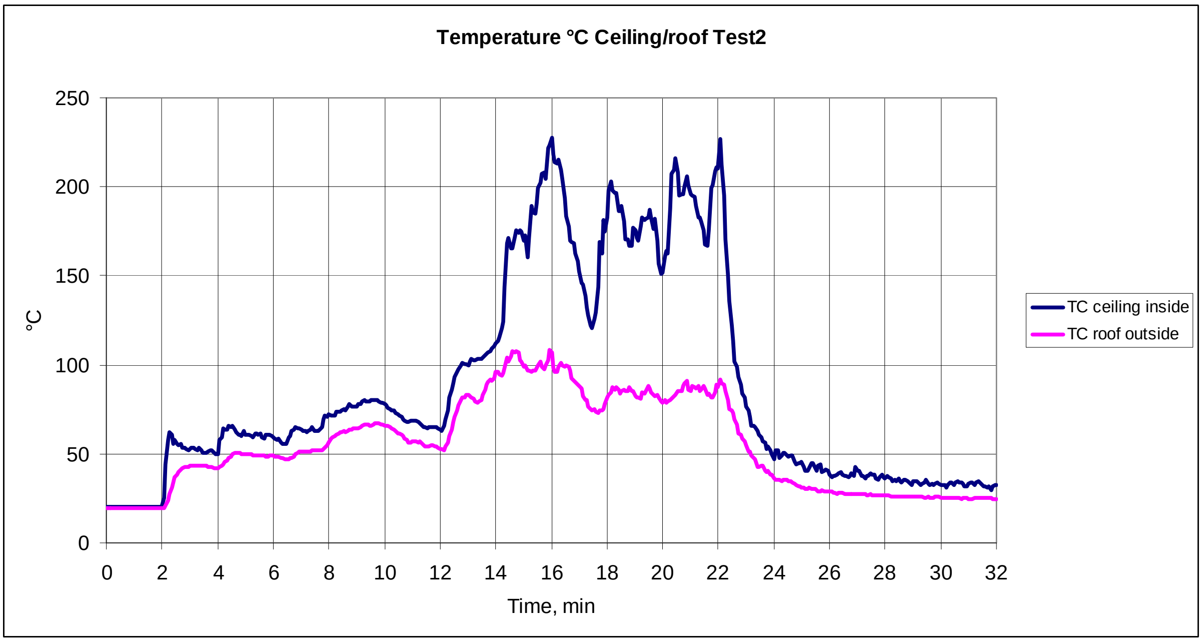

Figure 34 Temperature readings on membrane from Test 2.

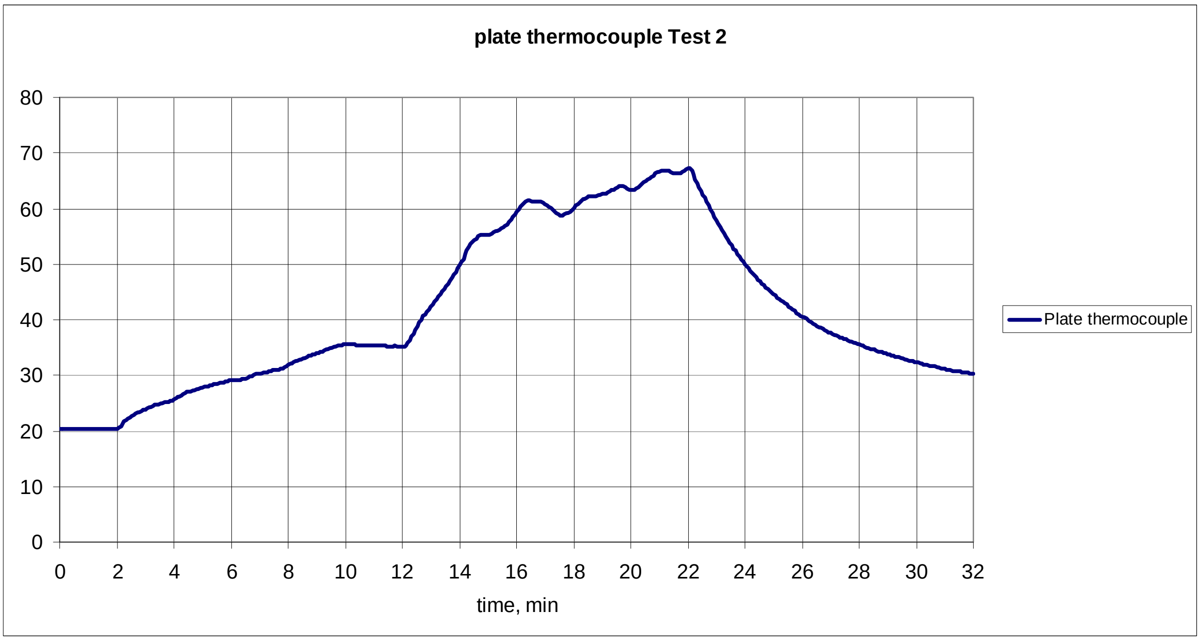

Figure 35 Plate thermocouple readings Test 2.

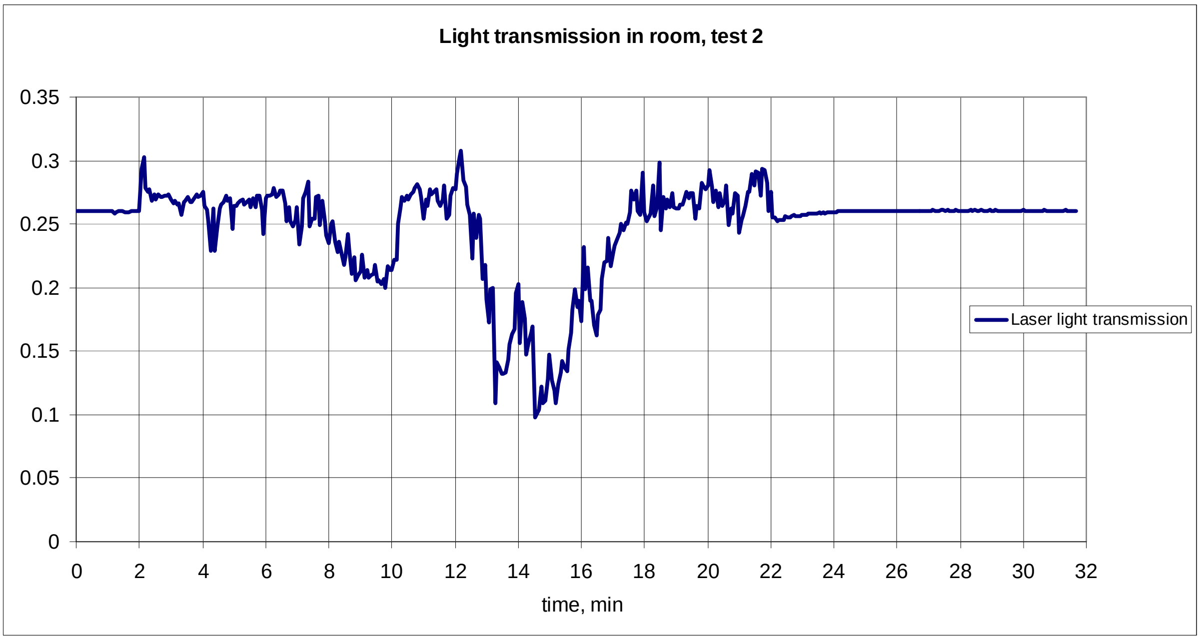

Figure 36 Laser light transmission in room Test 2 drift corrected.

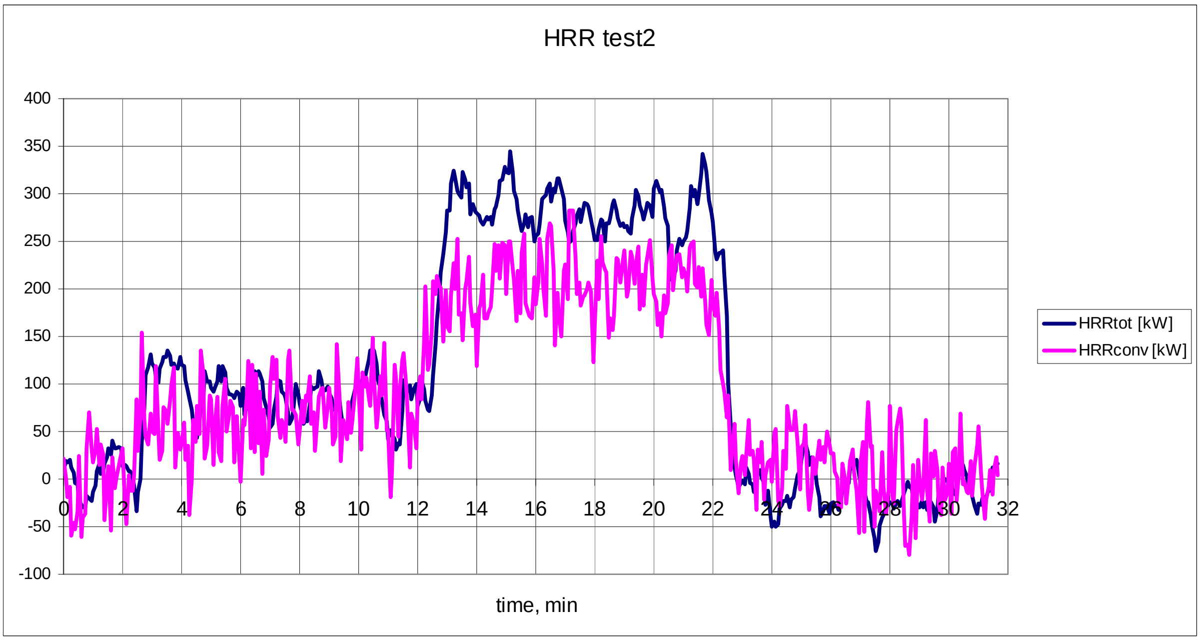

Figure 37 Total and convective Heat Release Rate in Test 2.

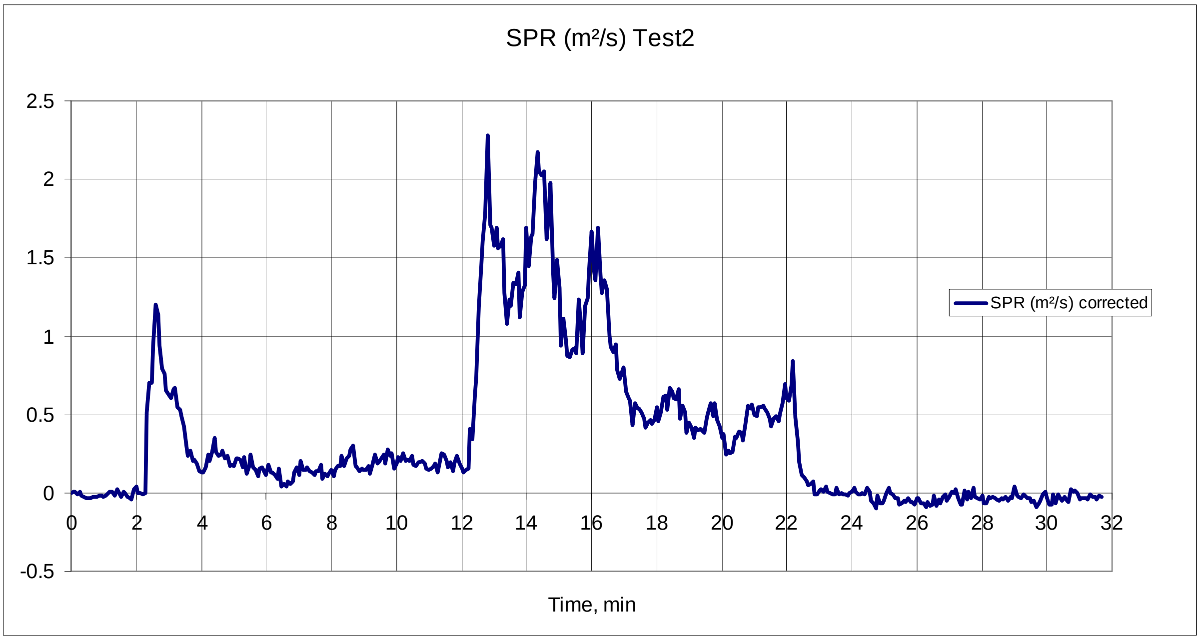

Figure 38 **Smoke in duct Test 2 corrected for drift.**

3.1.3 Test 3: Reference test with silicone-GF (Atex 5000 TRL)

Notes made during the test are presented in Table 5. Photos taken during the test are presented in Figure 39 - Figure 44 and results from the measurements in Figure 45 - Figure 52.

Table 5 Notes made during test 3.

Time	Comment
2 minutes	Ignition of burner at 100 kW
2 minutes 10 seconds	Smoke coming out from rear
2 minutes 50 seconds	White smoke gas layer
12 minutes	Burner increased to 300 kW
12 minutes 10 seconds	Flames reaches ceiling
12 minutes 20 seconds	Smoke produced
12 minutes 45 seconds	Smoke layer established
14 minutes	Smoke layer disappear
22 minutes	Burner turned off

Comment: No hole opened during the test.

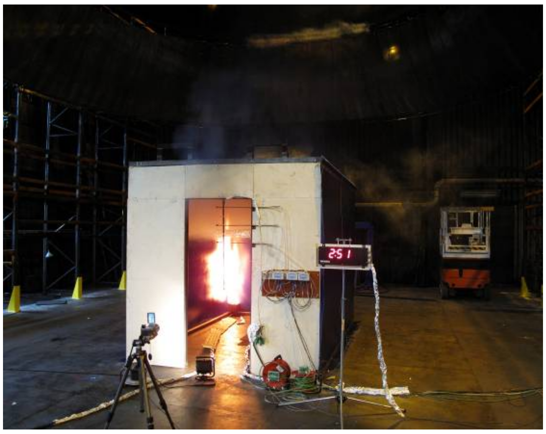

Figure 39 View of burner in corner of room shortly after ignition of burner (Test 3, time: 2:51).

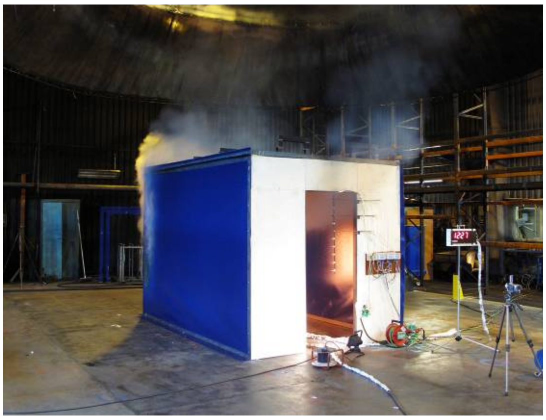

Figure 40 View of the corner from the outside, highest burner output (Test 3, time: 12:27).

Figure 41 Illustrative photo of fire behaviour at highest burner output (Test 3, time: 13:18).

Figure 42 Smoke layer in room and decomposition/evaporation of coating material (Test 3, time:

13:34).

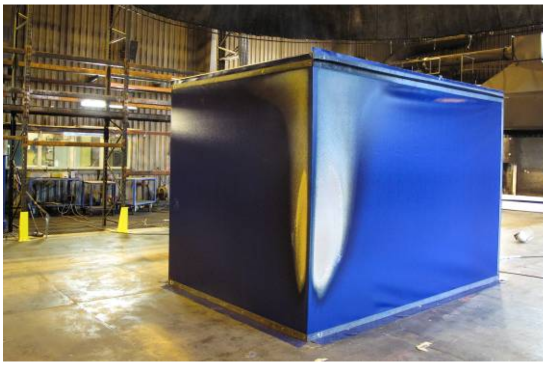

Figure 43 Damages in corner, glass fibre backing material intact (Test 3, test completed).

Figure 44 Close up on damages in corner (Test 3, test completed).

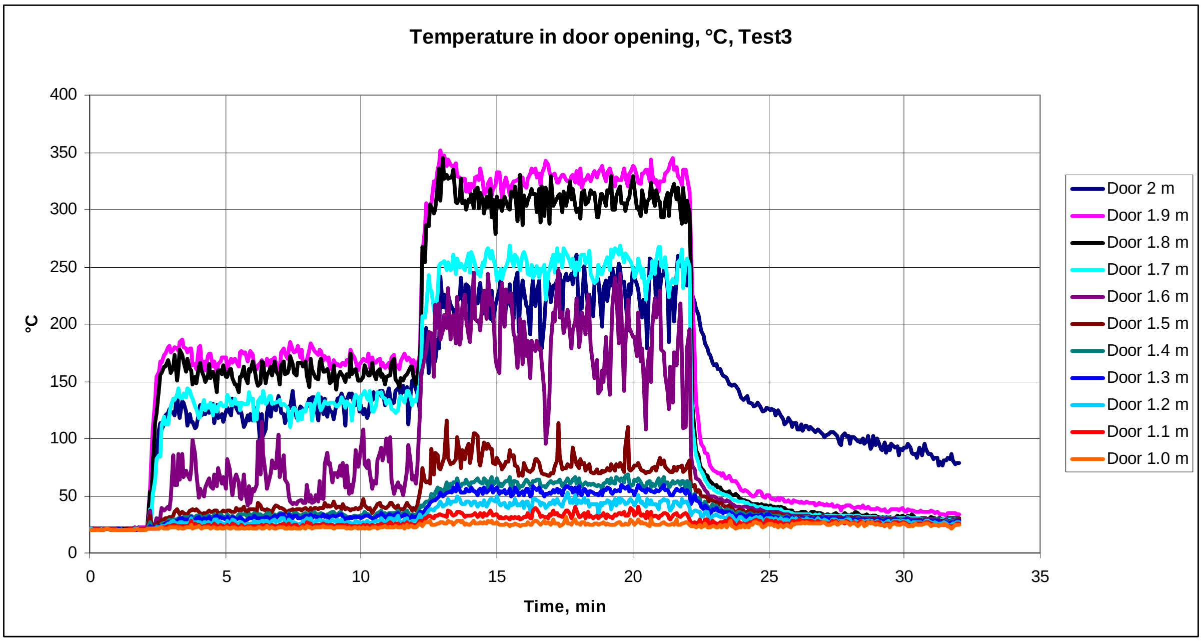

Figure 45 Temperature readings in door opening in Test 3.

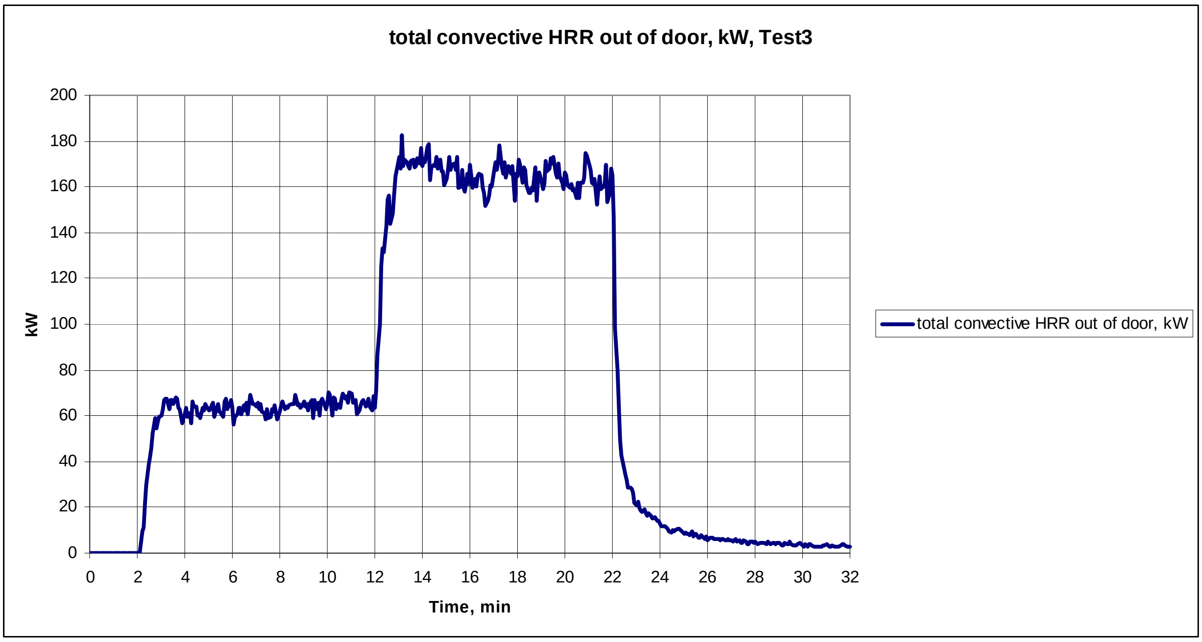

Figure 46 Total convective HRR flow out of door opening in Test 3.

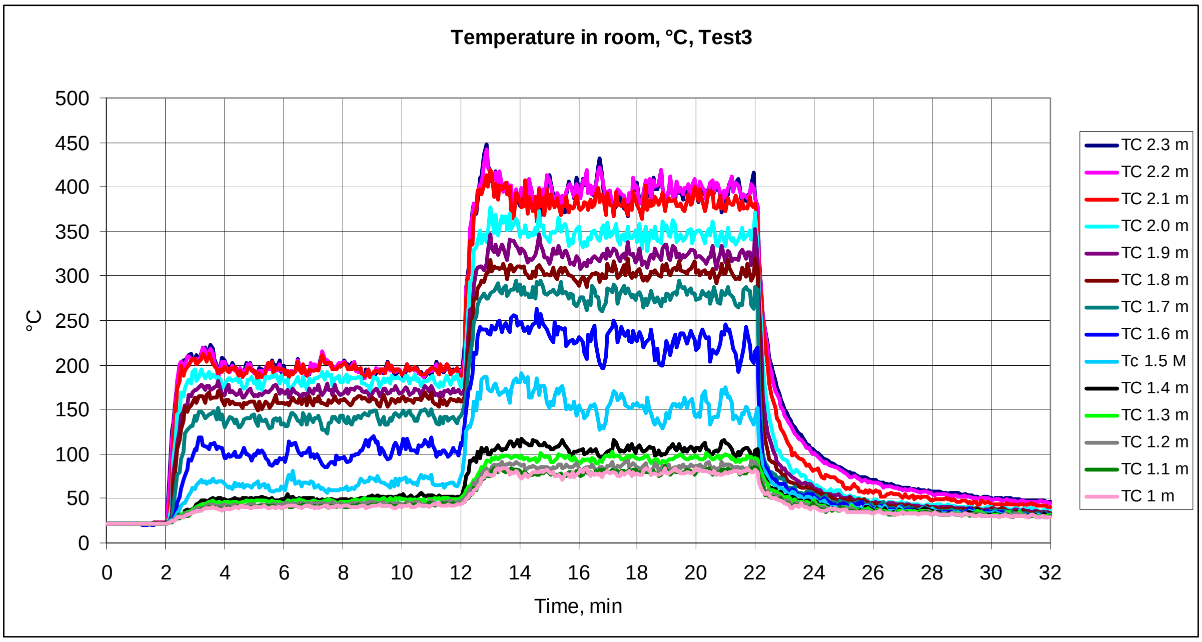

Figure 47 Temperature readings in middle of room Test 3.

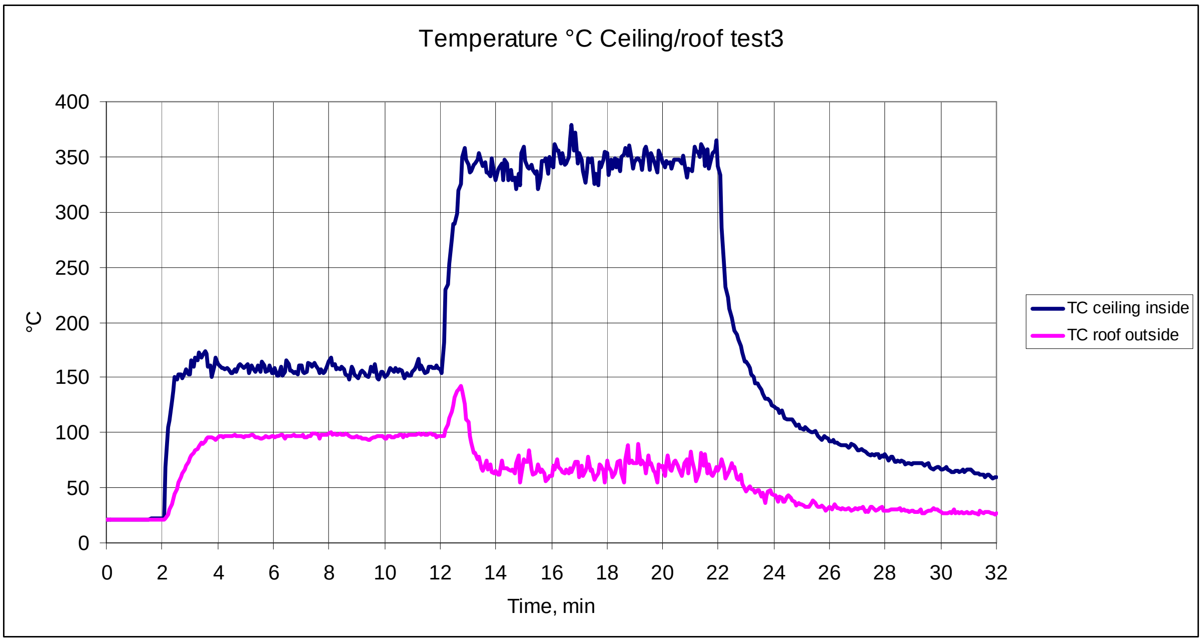

Figure 48 Temperature readings on membrane from Test 3.

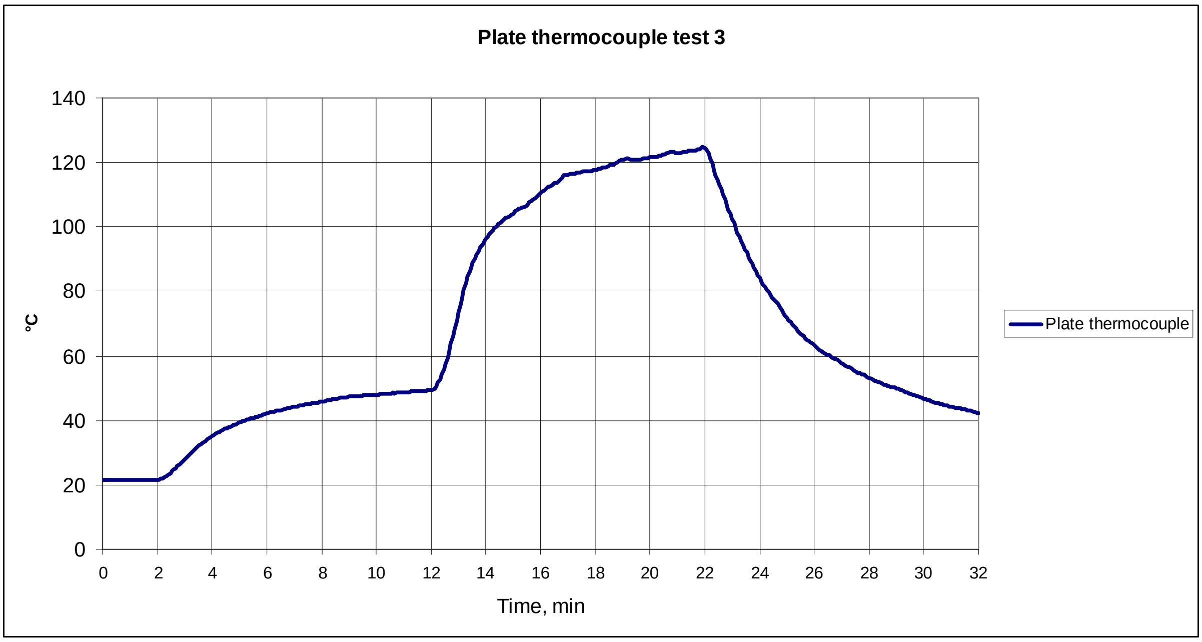

Figure 49 Plate thermocouple readings Test 3.

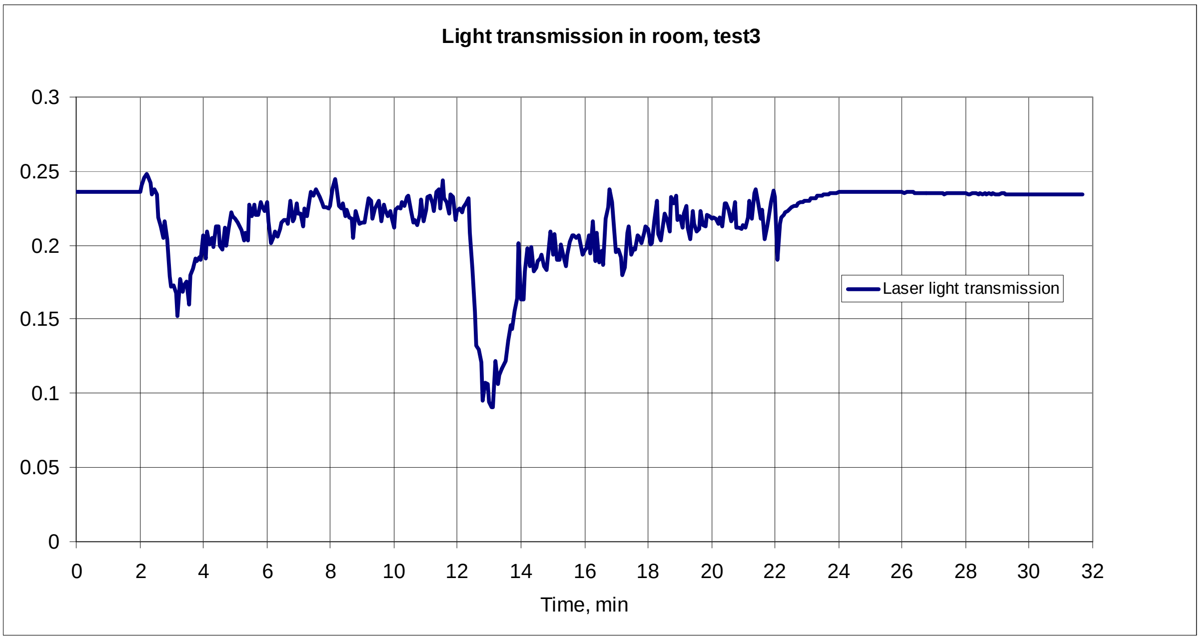

Figure 50 **Laser light transmission in room Test 3 drift corrected.**

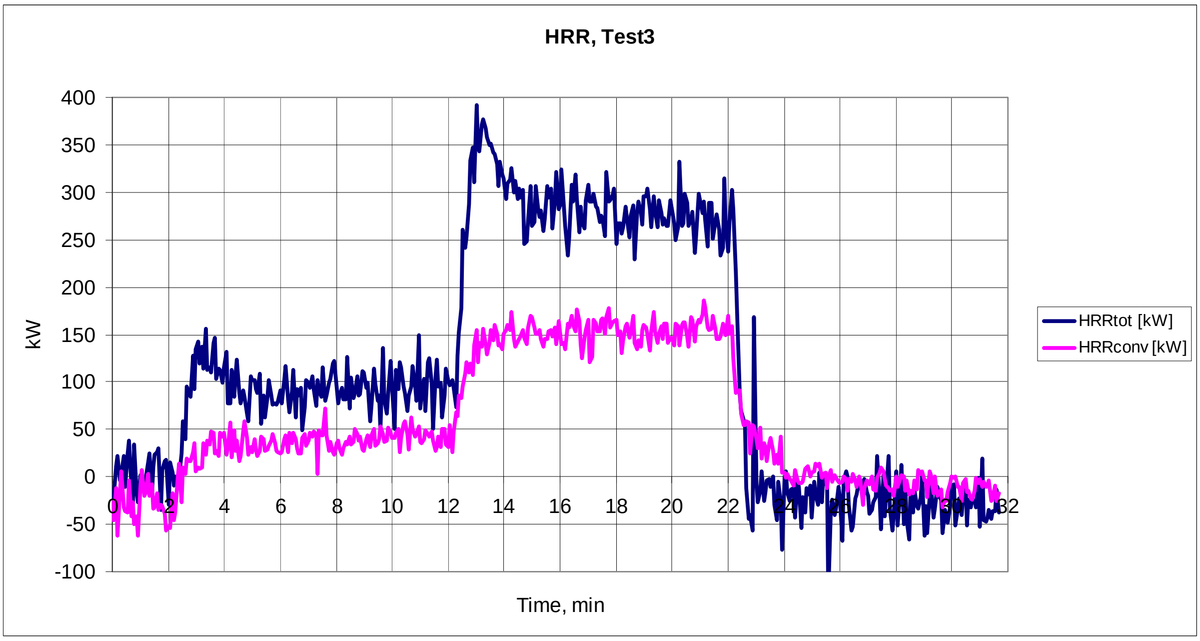

Figure 51 **Total and convective Heat Release Rate in Test 3.**

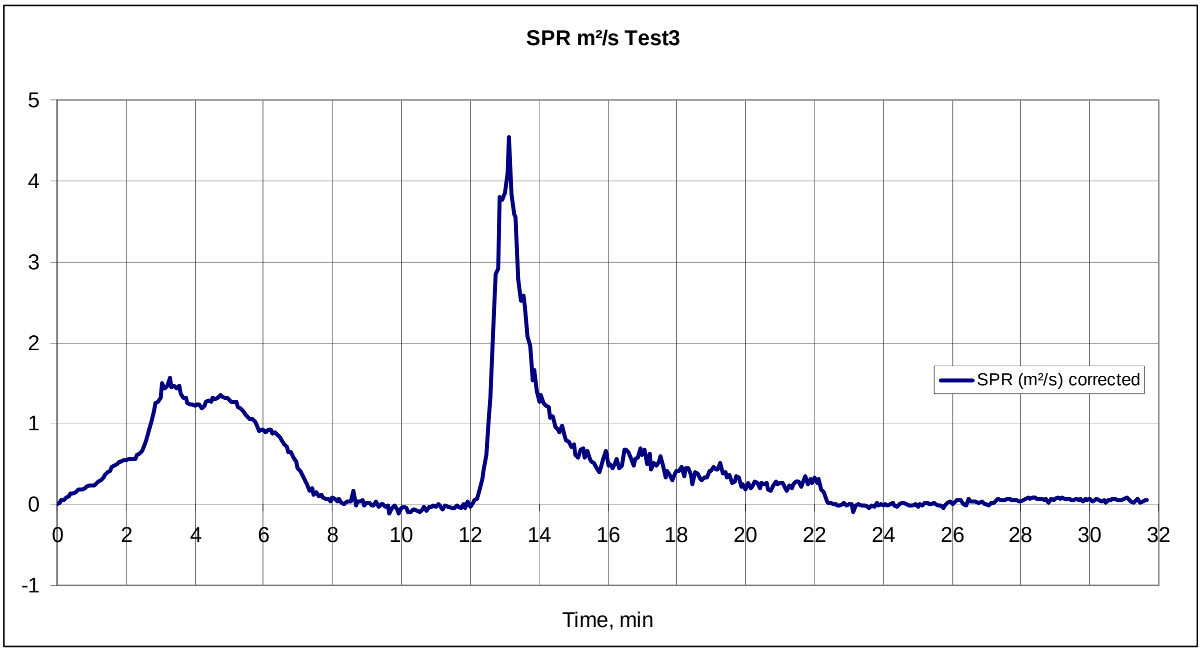

Figure 52 Smoke in duct Test 3.

3.1.4 Test 4: Reference test with thick PVC-PES (B6656)

Notes made during test 4 are presented in Table 6. Photos taken during the test are presented in Figure 53 - Figure 58 and the results from the measurements are presented in Figure 59 - Figure 66.

Table 6 Notes made during test 4.

Time	Comment
2 minutes	Ignition of burner at 100 kW
2 minutes 6 seconds	Flames reaches ceiling
2 minutes 20 seconds	Black smoke
2 minutes 30 seconds	Hole
2 minutes 40 seconds	Smoke layer developed
3 minutes	Smoke layer in vicinity of laser, pulsating
7 minutes	Burning piece falls inwards continues to burn until 9 minutes
11 minutes 20 seconds	Flames leaning out of hole
12 minutes	Burner increased to 300 kW, flames leans inwards/outwards
13 minutes 10 seconds	Pieces falling outwards, Black smoke from rear
13 minutes 20 seconds	Burns all the way up on wall
13 minutes 30 seconds	Black gaslayer, burning pieces that continous to burn
14 minutes	Small fire in membrane due to burning pieces
14 minutes 12 seconds	Glowing at ceiling
14 minutes 20 seconds	Flame leaning outwards
22 minutes	Burner turned off, membrane still burns
23 minutes 9 seconds	Fire goes out

Comment: The hole after the test measured 1 m × 2.4 m and 0.75 m × 2.2 m respectively.

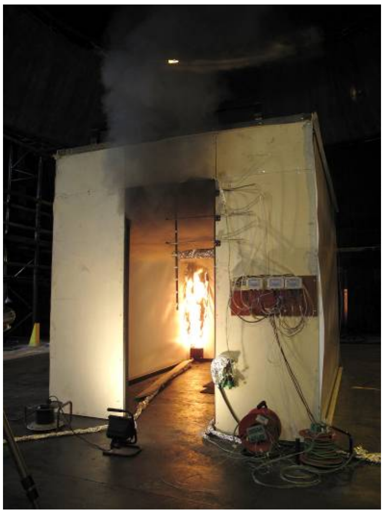

Figure 53 Black smoke out from the door opening, hole has opened in the corner (Test 4, time 2:52).

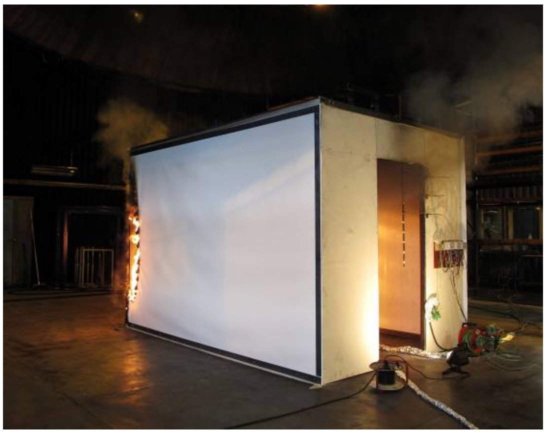

Figure 54 View from the outside of the burning corner (Test 4, time 3:13).

Figure 55 Close up of hole in corner at lowest burner output (Test 4, time 7:02).

Figure 56 Close up of hole in corner at highest burner output (Test 4, time 13:33).

Figure 57 The corner with the burner in the end of the test (Test 4, time 15:19).

Figure 58 Damages in the corner of the room (Test 4, test completed).

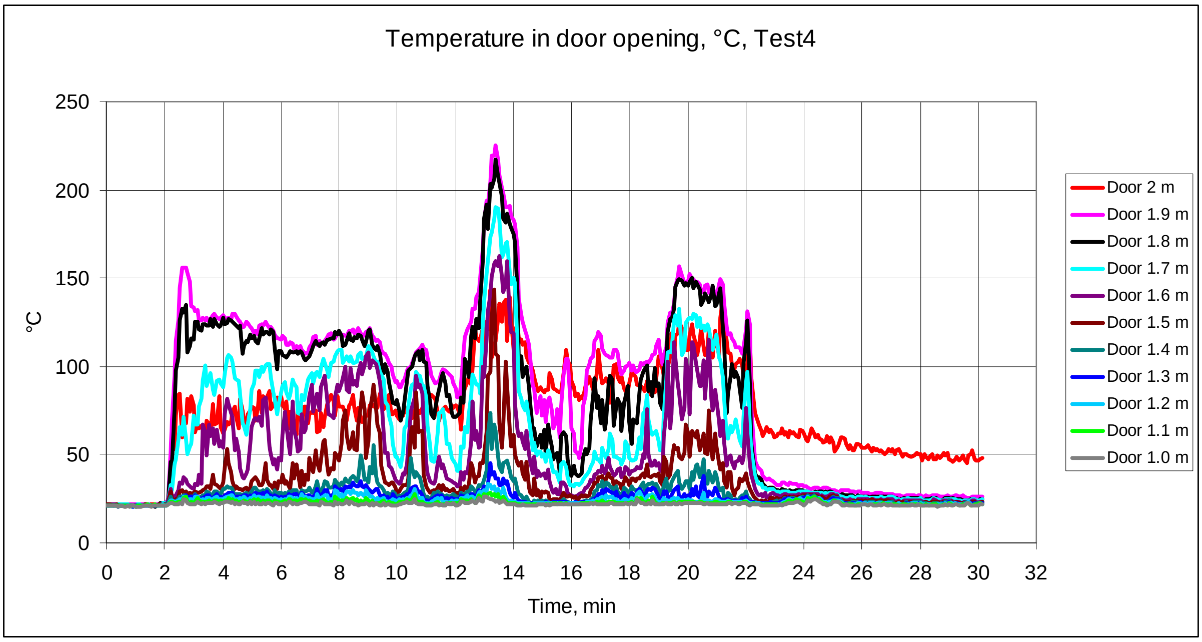

Figure 59 Temperature readings in door opening in Test 4.

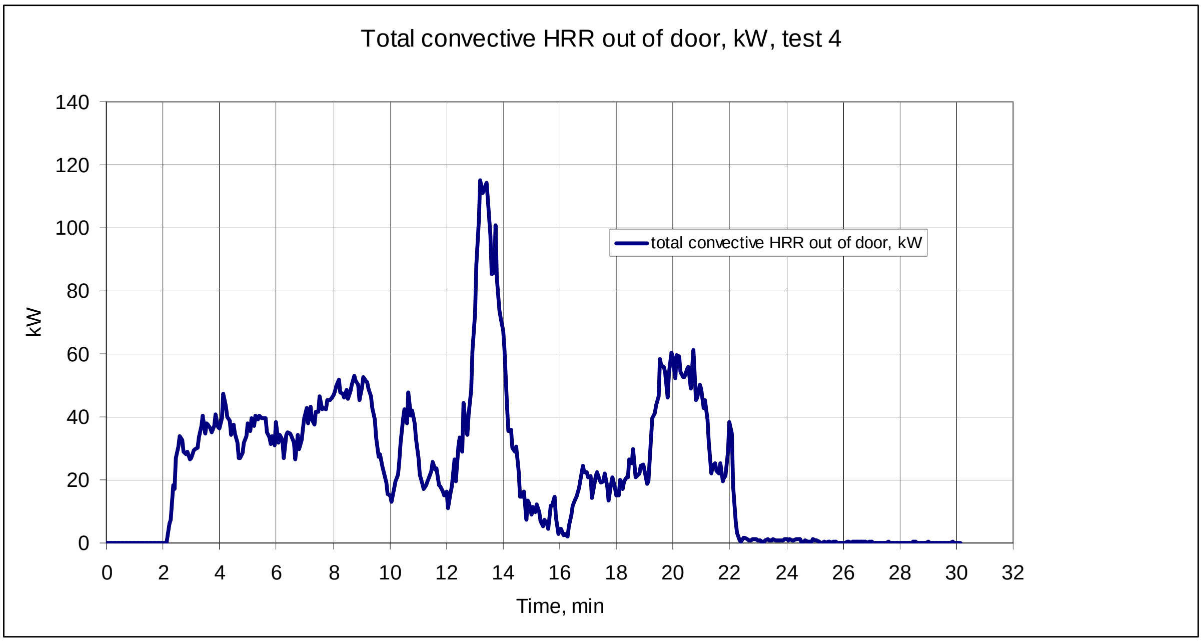

Figure 60 Total convective HRR flow out of door opening in Test 4.

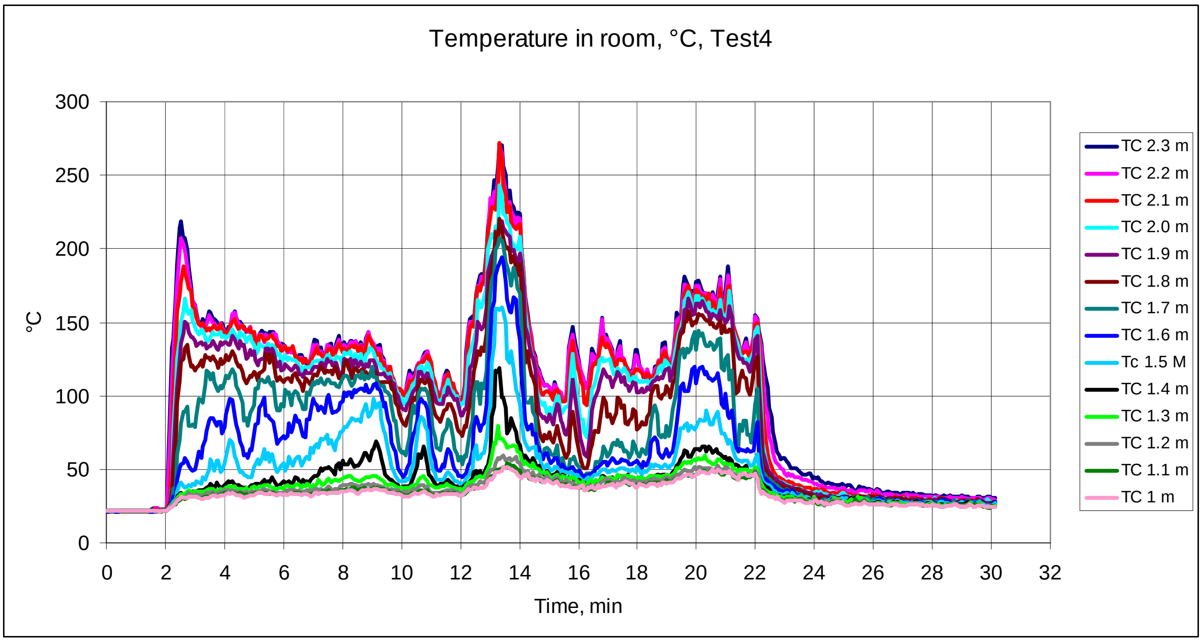

Figure 61 Temperature readings in middle of room Test 4.

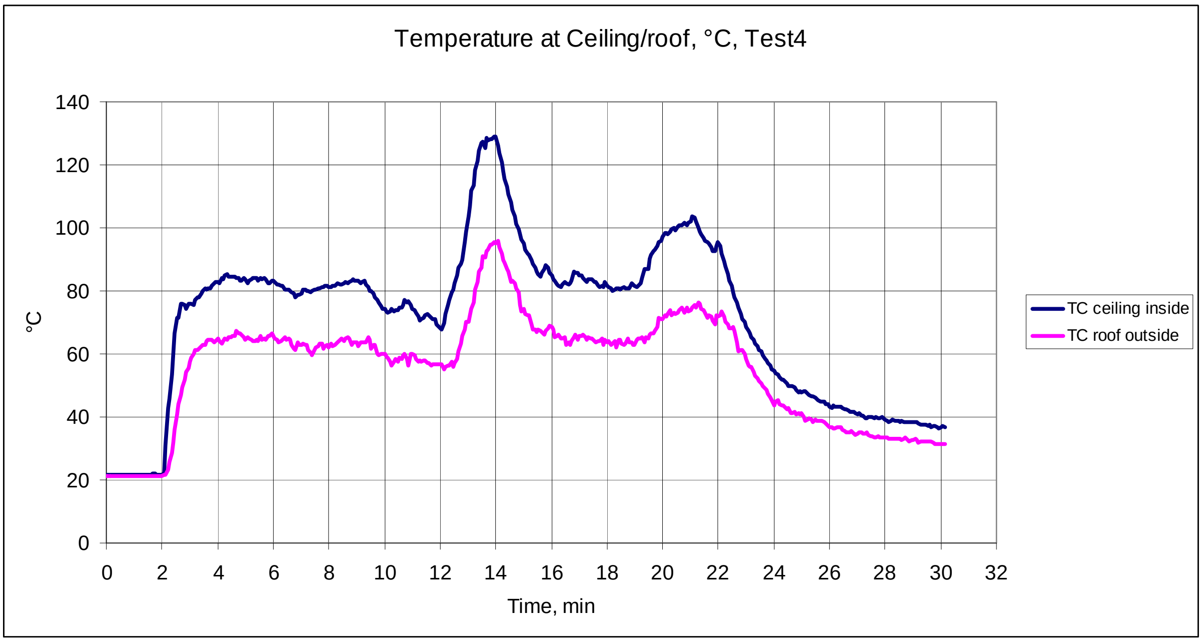

Figure 62 Temperature readings on membrane from Test 4.

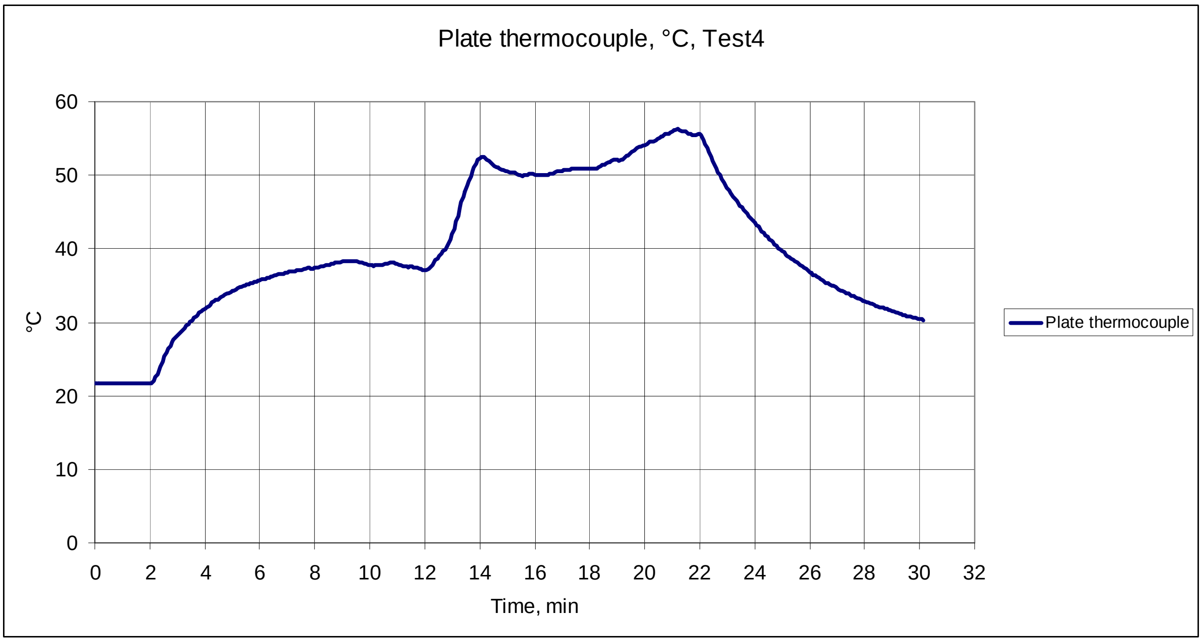

Figure 63 Plate thermocouple readings Test 4.

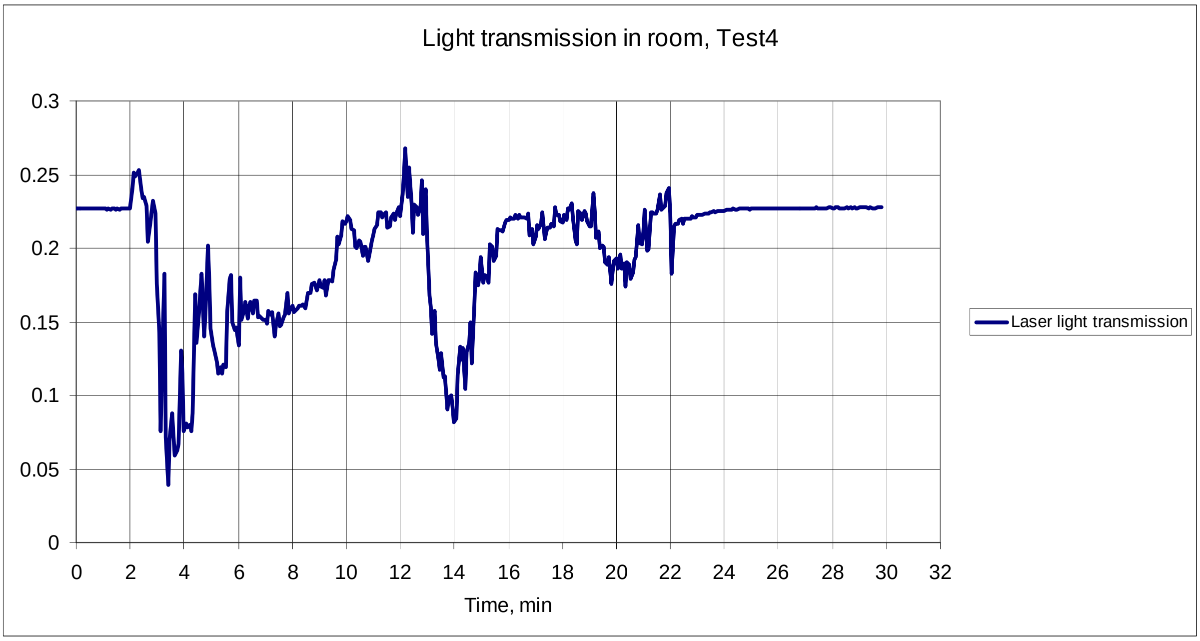

Figure 64 Laser light transmission in room Test 4 corrected for drift.

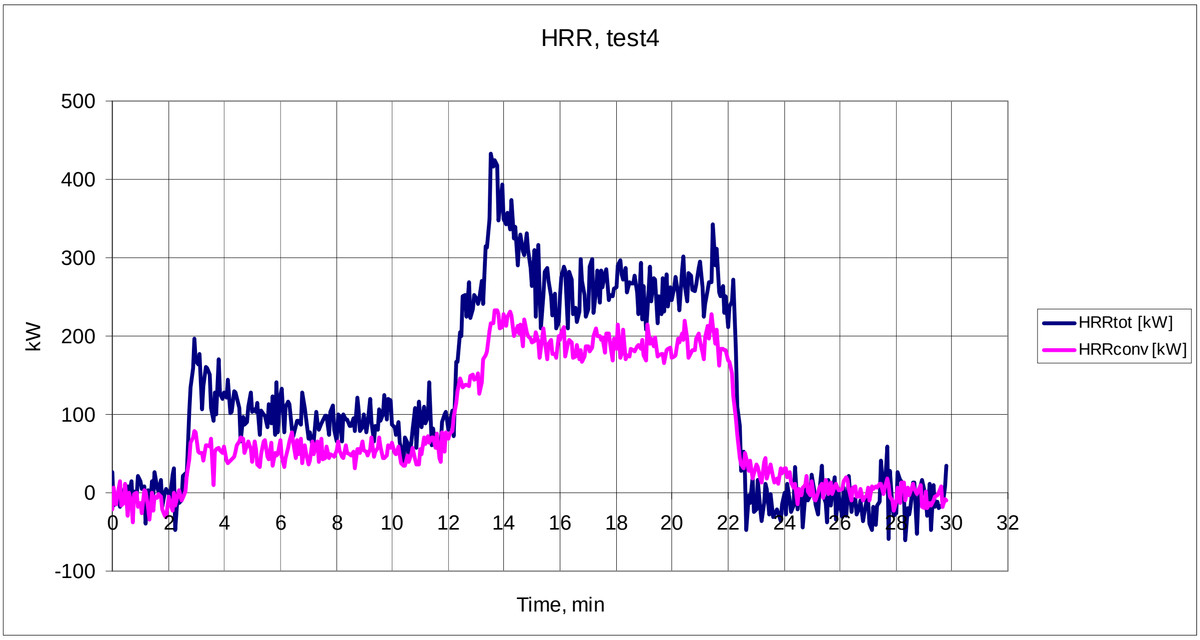

Figure 65 Total and convective Heat Release Rate in Test 4.

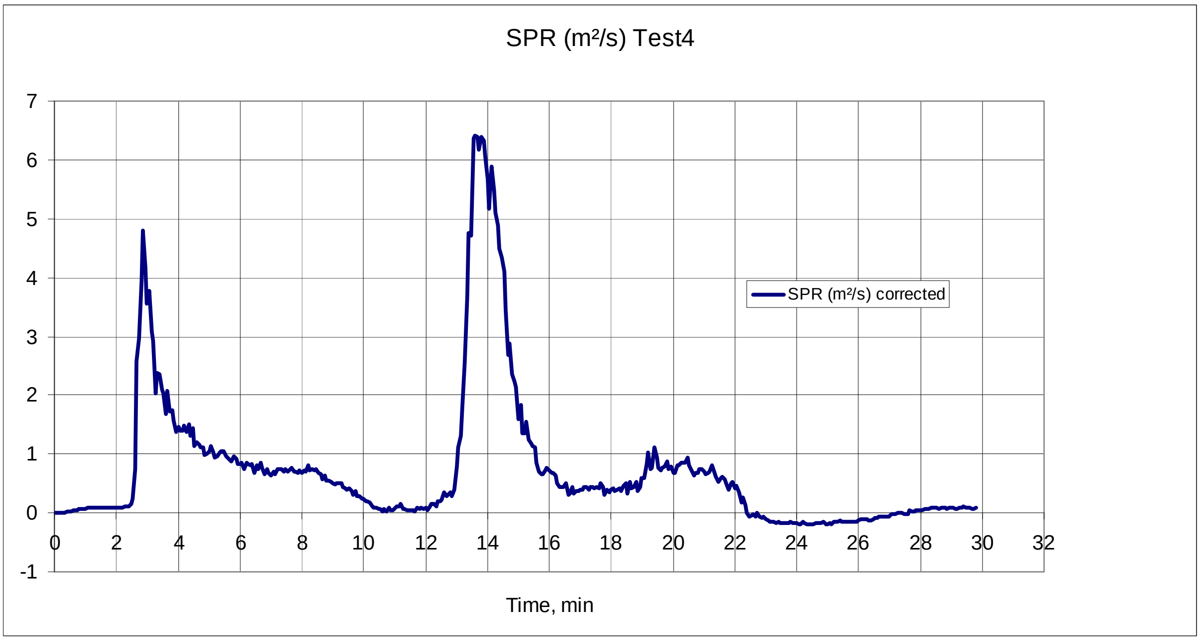

Figure 66 Smoke in duct Test 4.

3.1.5 Test 5: Reference test with thin PVC-PES (B8103)

Notes made during test 5 are presented in Table 7. Photos taken during the test are presented in Figure 67 - Figure 71 and the results from the measurements are presented in Figure 72 - Figure 79.

Table 7 Notes made during test 5.

Time	Comment
2 minutes	Ignition of burner at 100 kW
2 minutes 10 seconds	Leopard pattern
2 minutes 15 seconds	Hole, bunring pieces
2 minutes 30 seconds	Burning pieces
2 minutes 40 seconds	Dark smoke
2 minutes 50 seconds	Smoke layer developed down to about laser
5 minutes	Smoke plume out of room reaches 1,5 m
6 minutes	Smoke layer disappeared
12 minutes	Burner increased to 300 kW
12 minutes 20 seconds	Hole has reached 50 cm on short side
12 minutes 30 seconds	Dark smoke
13 minutes	Burning pieces
13 minutes 20 seconds	Burning piece get stuck a bit further down on the membrane
22 minutes	Burner turned off, membrane still burns
22 minutes 30 seconds	Fire goes out

Comment: The hole was measured as 0.7 m × 2.2 m on the long wall side, 0.8 m × 2 m on the short wall side and 15 cm × 2 cm ceiling.

Figure 67 Hole has opened up in the corner (Test 5, time 2:58).

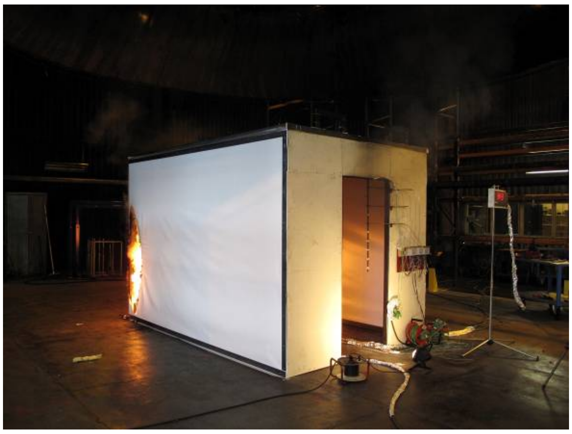

Figure 68 View from the outside of the burning corner (Test 5, time 3:43).

Figure 69 Hole in the corner after increasing to the highest burner output (Test 5, time 12:47).

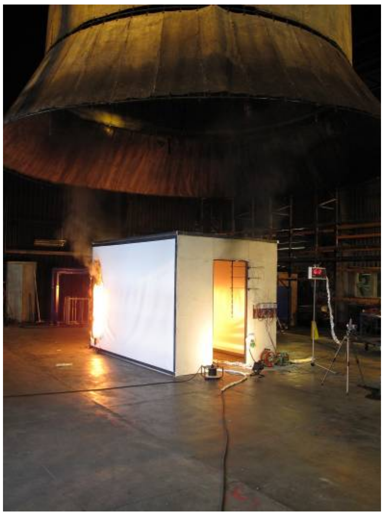

Figure 70 View from the outside of the burning corner (Test 5, time 16:12).

Figure 71 Damages in the corner of the room (Test 5, test completed).

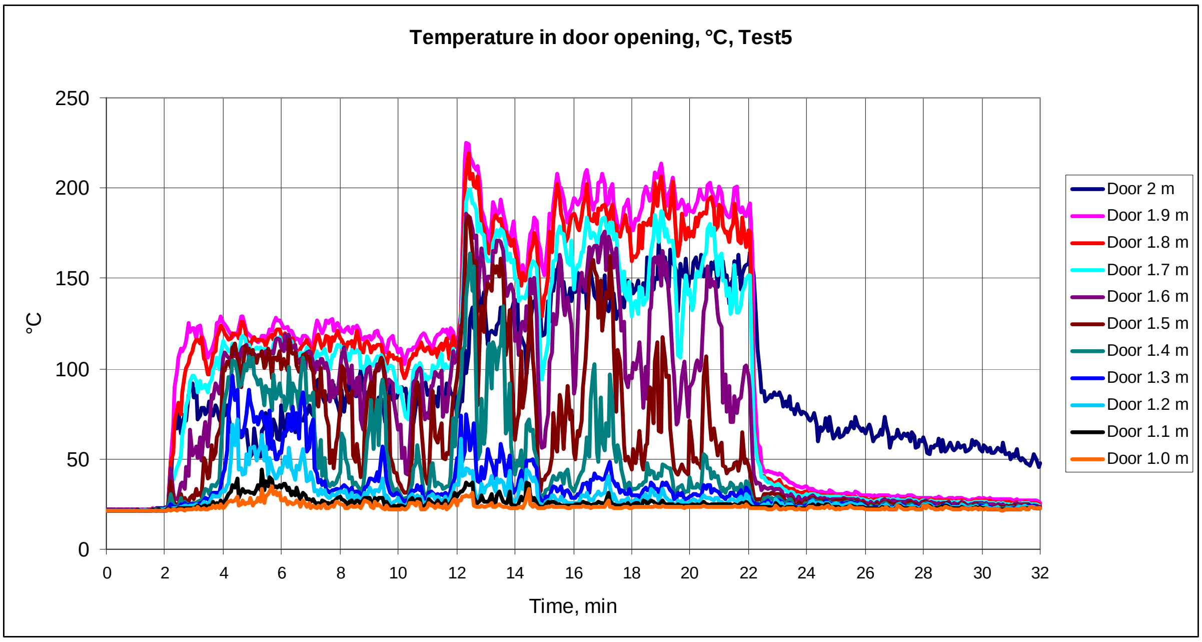

Figure 72 Temperature readings in door opening in Test 5.

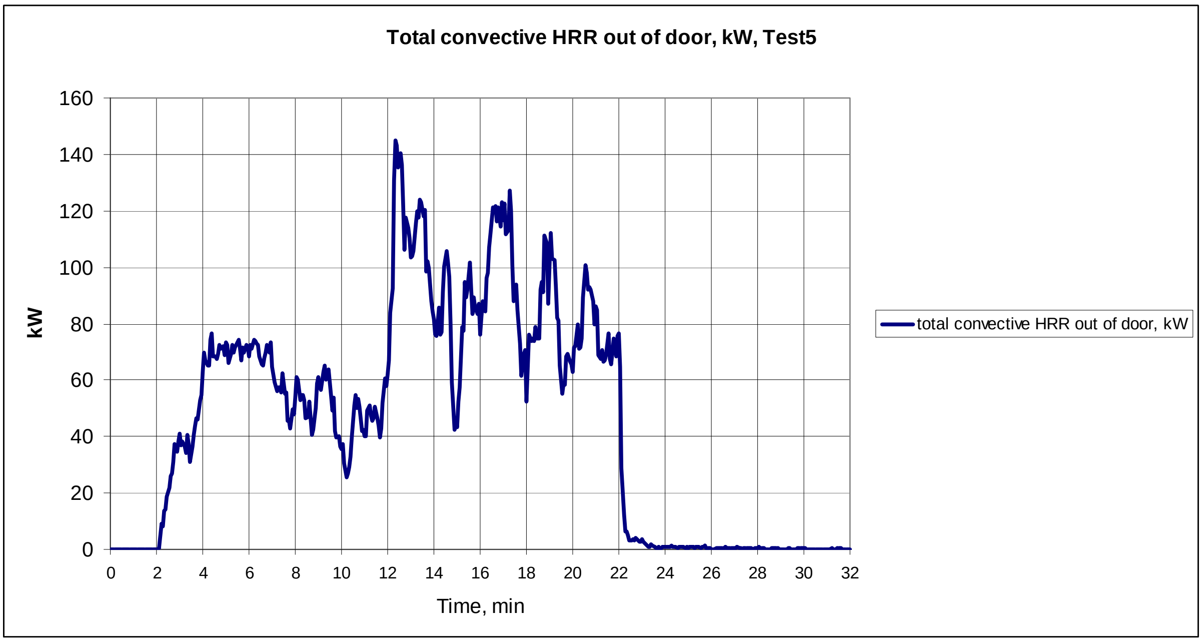

Figure 73 Total convective HRR flow out of door opening in Test 5.

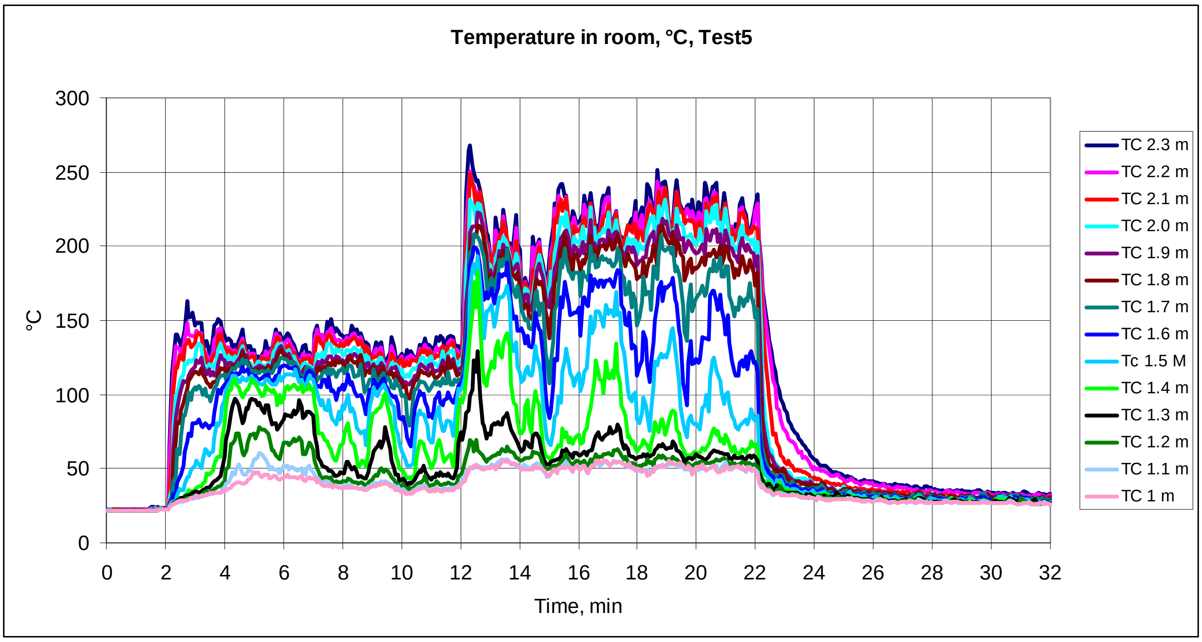

Figure 74 Temperature readings in middle of room Test 5.

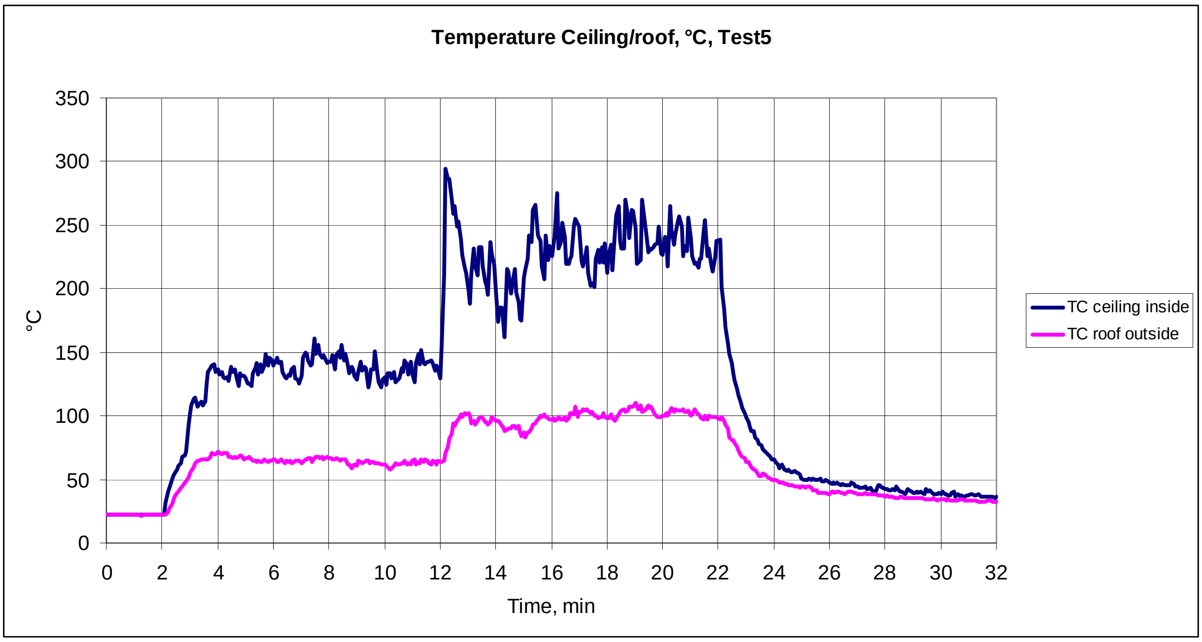

Figure 75 Temperature readings on membrane from Test 5.

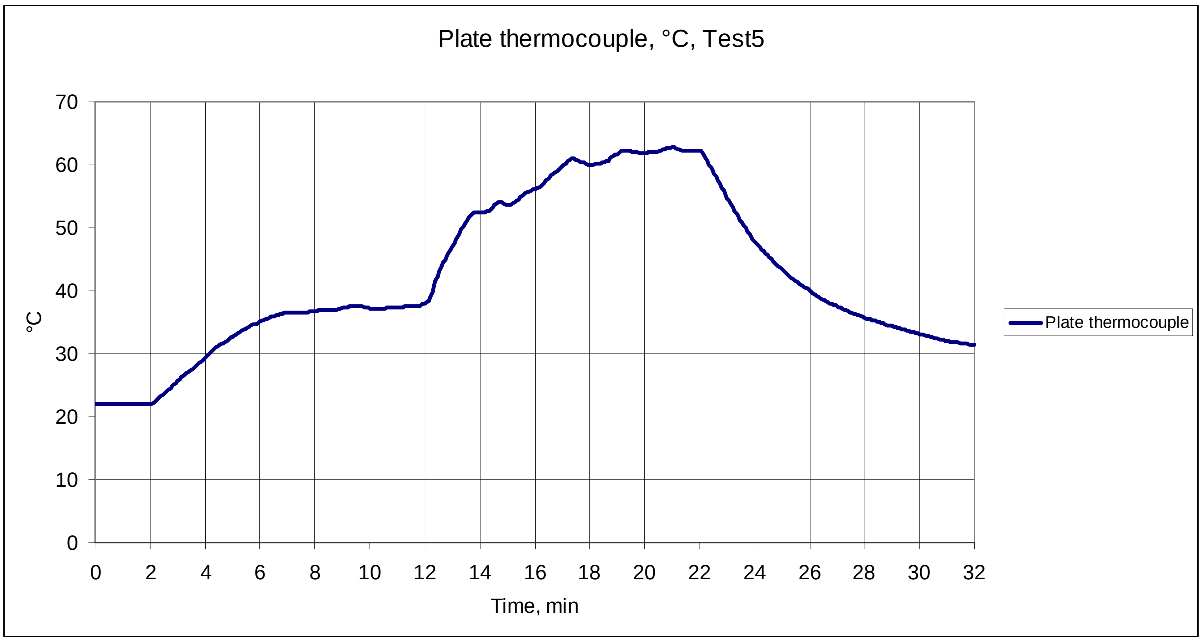

Figure 76 Plate thermocouple readings Test 5.

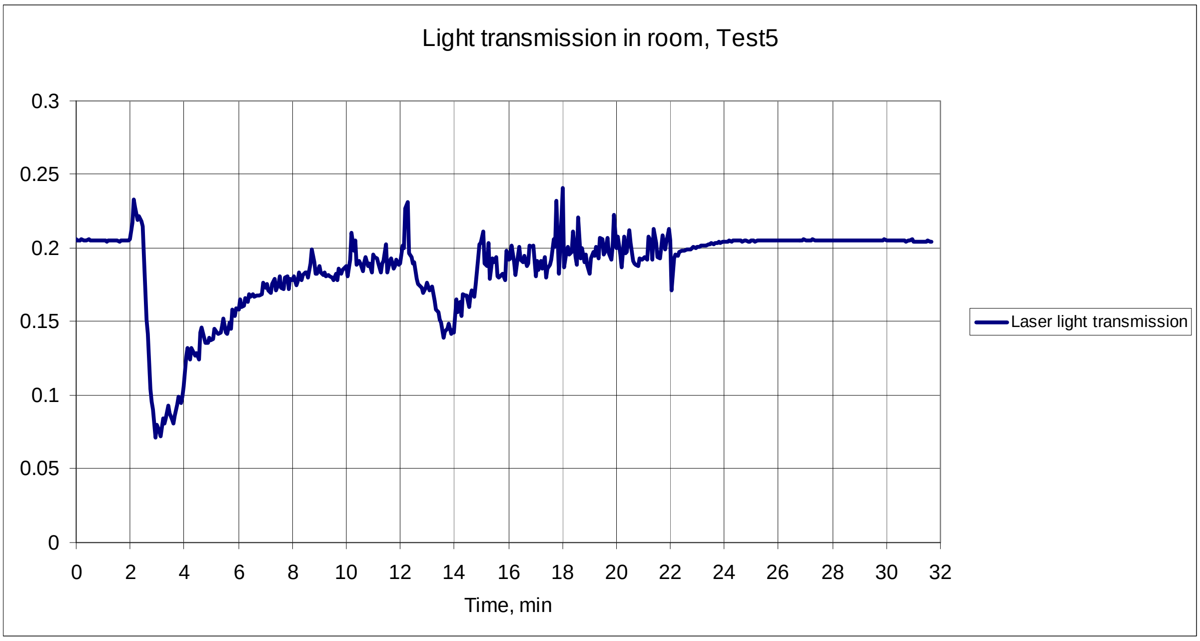

Figure 77 Laser light transmission in room Test 5.

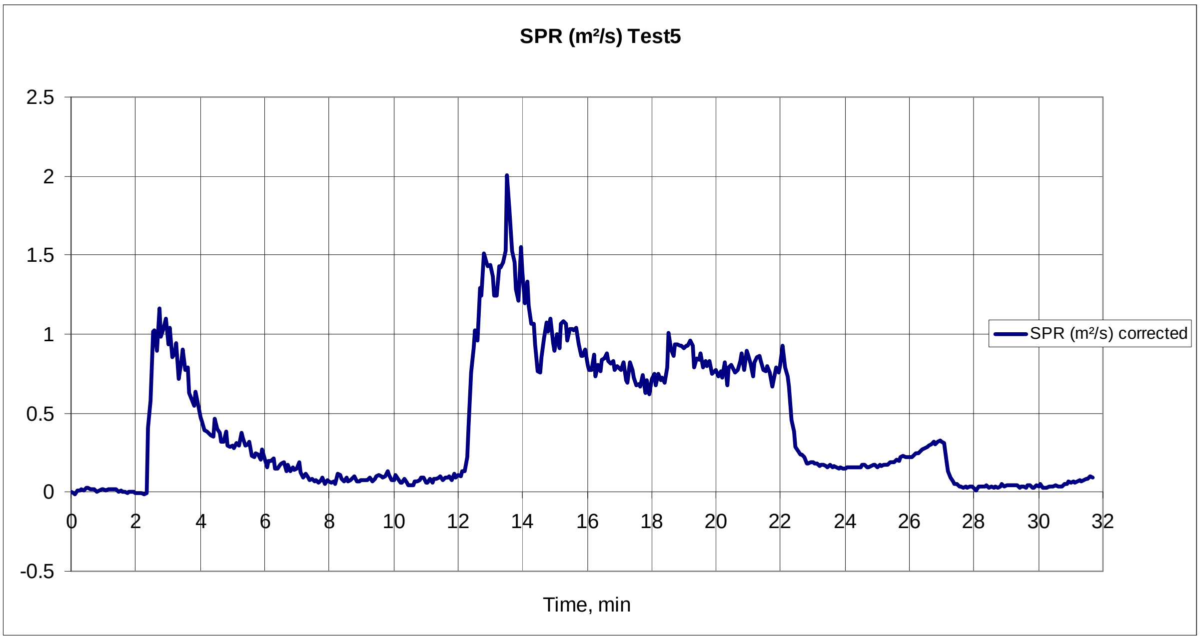

Figure 78 Smoke in duct Test 5 corrected for drift.

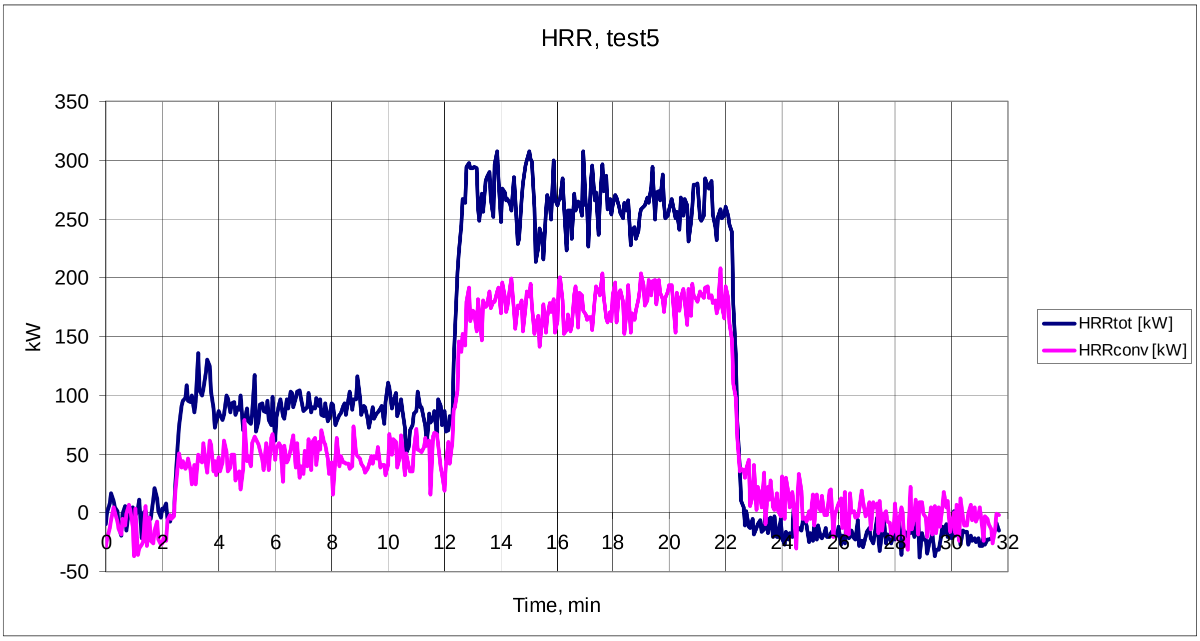

Figure 79 Total and convective Heat Release Rate in Test 5.

3.2 CFD validation tests

The tests conducted in the second series are listed in Table 8. Information concerning burner location, burner stages during the tests, and general notes regarding burn-through are included in the table. The duct flow was 60 000 m³/h in tests 6-10.

Detailed notes made during tests 7-10 are presented for each test below (section 3.2.2 - 3.2.5) together with curves from the measurements and photos taken during the tests.

Table 8 CFD validation tests conducted.

Test number	Textile membrane	Burner location	Burner stages	Notes on burn-trough
6	Sioen B8103/ PVC-PES / 650 g.m^{-2}	Test to determine location of burner	-	-
7	Sioen B8103/ PVC-PES / 650 g.m^{-2}	Centrally 1.0 m above floor level	95 kW – 5 min 140 kW – 5 min	Burn-trough during 95 kW exposure
8	Sioen B8103/ PVC-PES / 650 g.m^{-2}	Centrally 0.45 m above floor level	95 kW – 10 min 140 kW – 10 min 300 kW – 5 min	Burn-trough during 300 kW exposure
9	Sioen T3107 / PVC-PES / 1150 g.m^{-2}	Centrally 1.0 m above floor level	95 kW – 5 min 140 kW – 5 min	Burn-trough during 95 kW exposure
10	Sioen T3107/ PVC-PES / 1150 g.m^{-2}	Centrally 0.45 m above floor level	95 kW – 10 min 140 kW – 10 min 300 kW – 5 min	Burn-trough during 300 kW exposure

3.2.1 Test 6: Burner placement test

Test to determine location of burner for the CFD validation tests. The burner was placed at floor level and 1 m above the floor. The flame was more stable when the burner was placed 1 m above the floor.

3.2.2 Test 7: CFD validation test with thin PVC-PES (B8103)

The ceiling was not completely flat, but hung down approximately 6 cm in the centre of the room. The burner was placed in the middle of the room, 1 m above ground. Notes made during the test are presented in Table 9. Photos taken during the test are presented in Figure 80 - Figure 89 and measurements are presented in Figure 90 - Figure 97.

Table 9 Notes made during test 7.

Time	Comment
2 minutes	Ignition of burner at 95 kW
2 minutes 6 seconds	Flames reaches ceiling
2 minutes 33 seconds	Shrinks in ceiling, smoke coming from ceiling
2 minutes 50 seconds	Hole
7 minutes	Burner increased to 140 kW
7 minutes 25 seconds	Hole becomes bigger is about 40 cm
7 minutes 45 seconds	Piece falls down but does not burn
12 minutes	Burner turned off

Comment: The hole after the test was 0.65 m × 0.65m.

Figure 80 The textile room before the test (Test 7, prior to test).

Figure 81 Early in the test with the burner at the lower heat output (Test 7, time 02:20).

Figure 82 Hole is starting to open up (Test 7, time 02:59).

Figure 83 Hole in ceiling (Test 7, time 03:00).

Figure 84 Hole in ceiling (Test 7, time 03:18).

Figure 85 Hole in ceiling (Test 7, time 03:41).

Figure 86 Close up of hole in ceiling (Test 7, time 04:38).

Figure 87 The burner at the higher heat output (Test 7, time 06:13).

Figure 88 The hole in the ceiling at the higher heat output (Test 7, time 07:41).

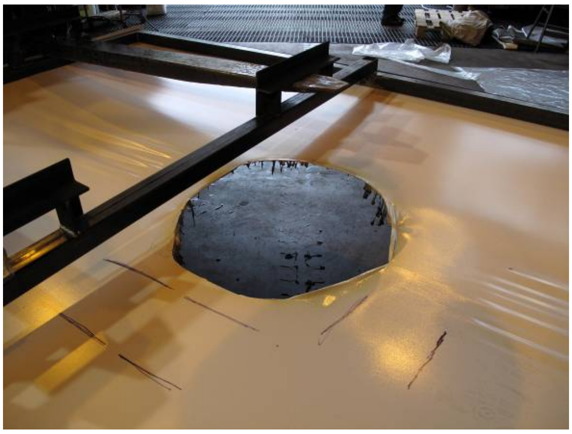

Figure 89 The size of the hole after the test (Test 7, test completed).

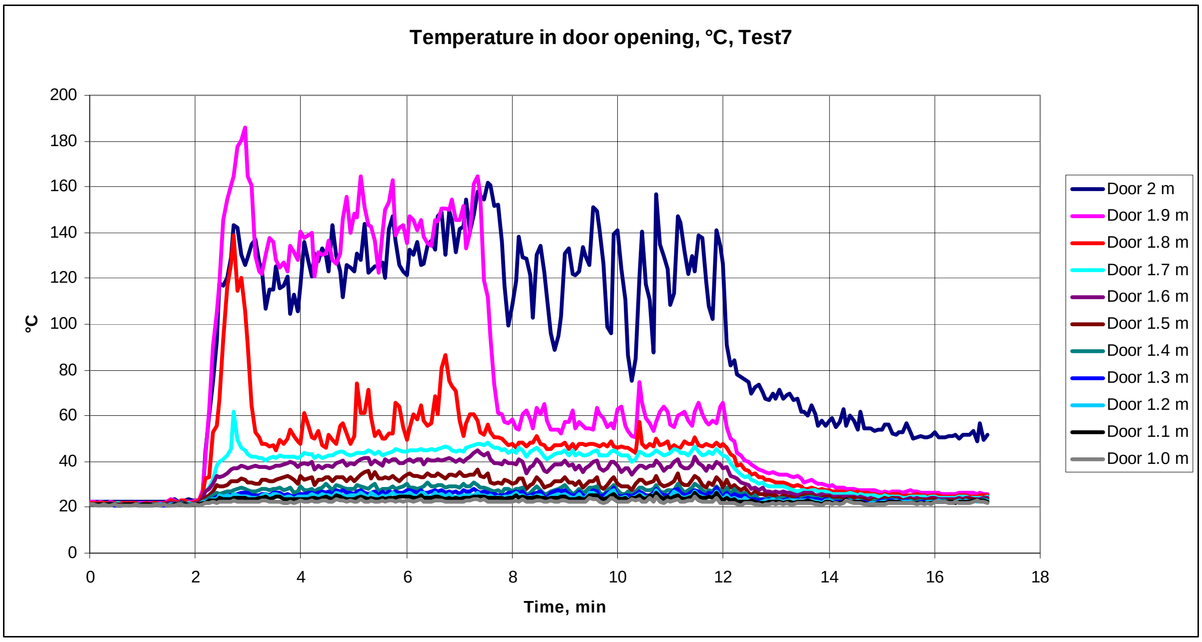

Figure 90 Temperature readings in door opening in Test 7.

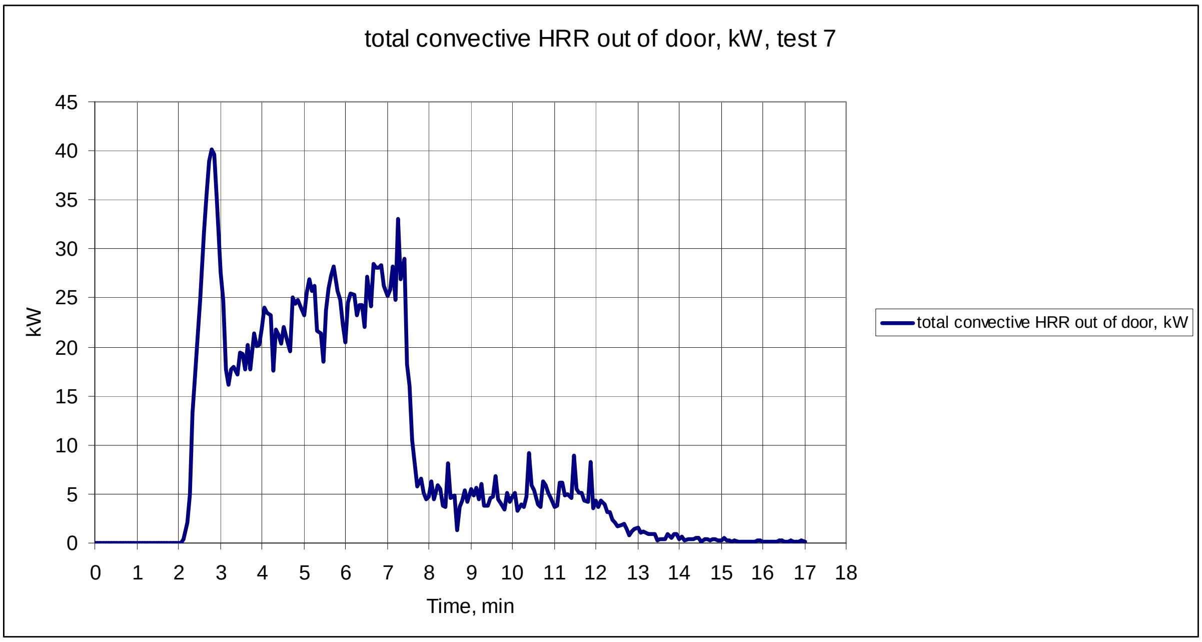

Figure 91 Total convective HRR flow out of door opening in Test 7.

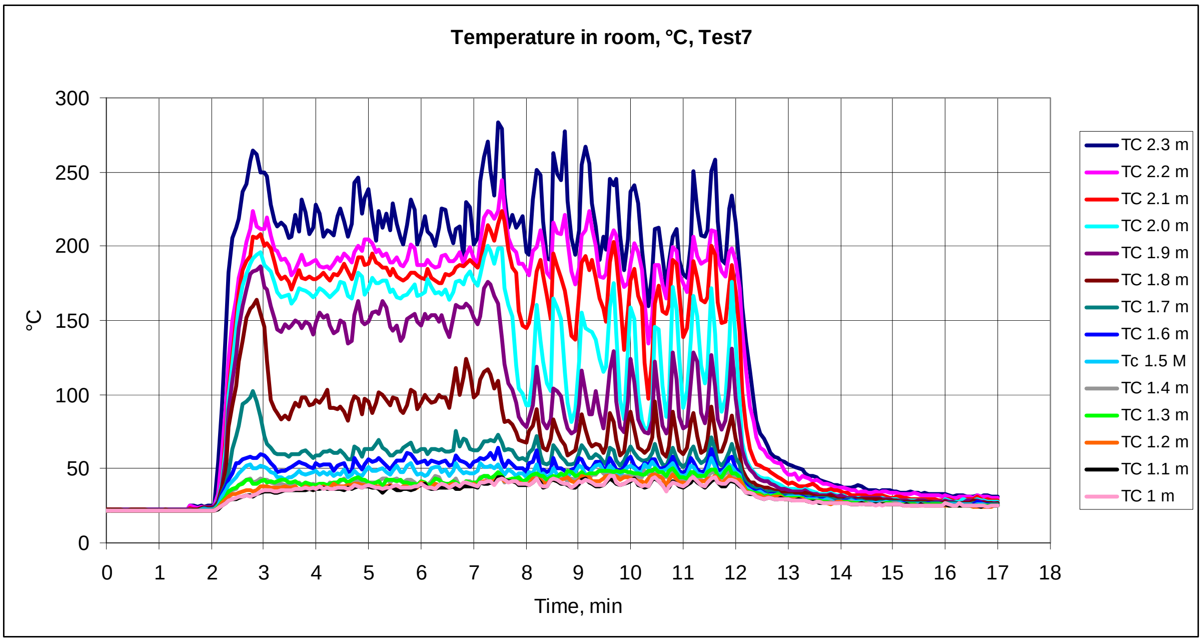

Figure 92 Temperature readings in middle of room Test 7.

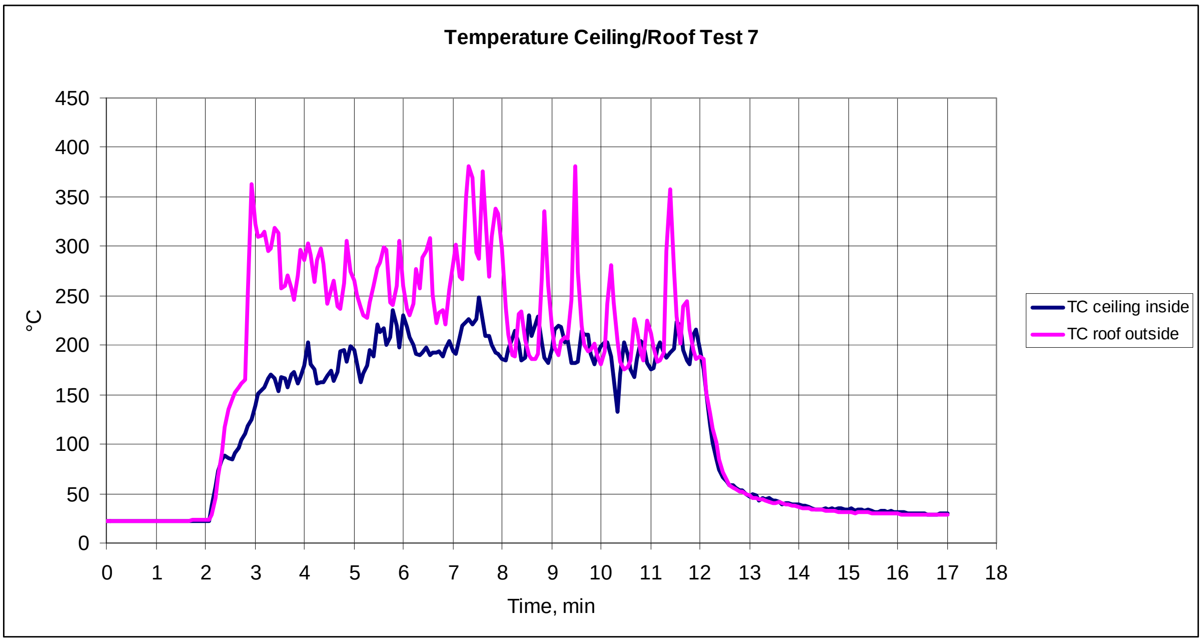

Figure 93 Temperature readings on membrane from Test 7.

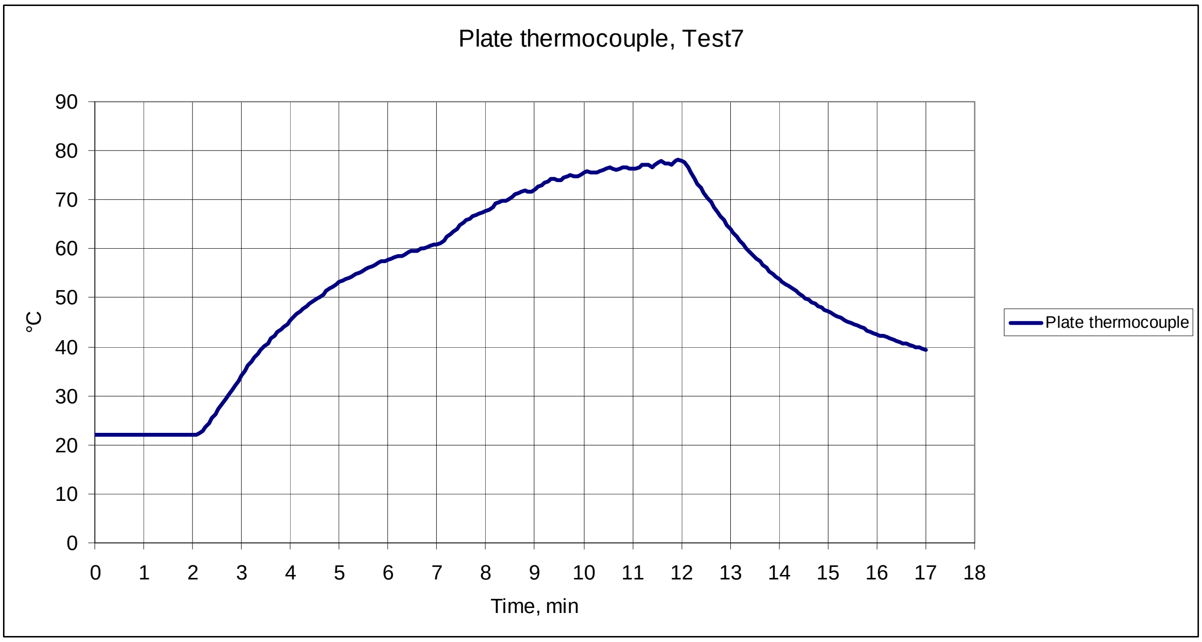

Figure 94 Plate thermocouple readings Test 7.

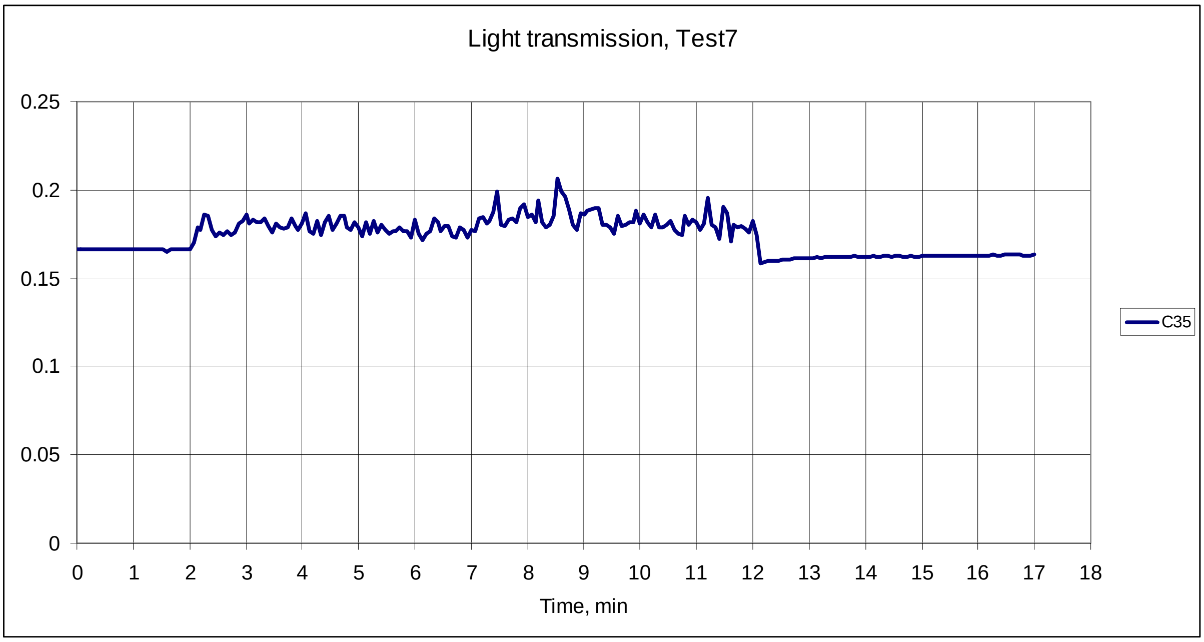

Figure 95 Laser light transmission in room Test 7.

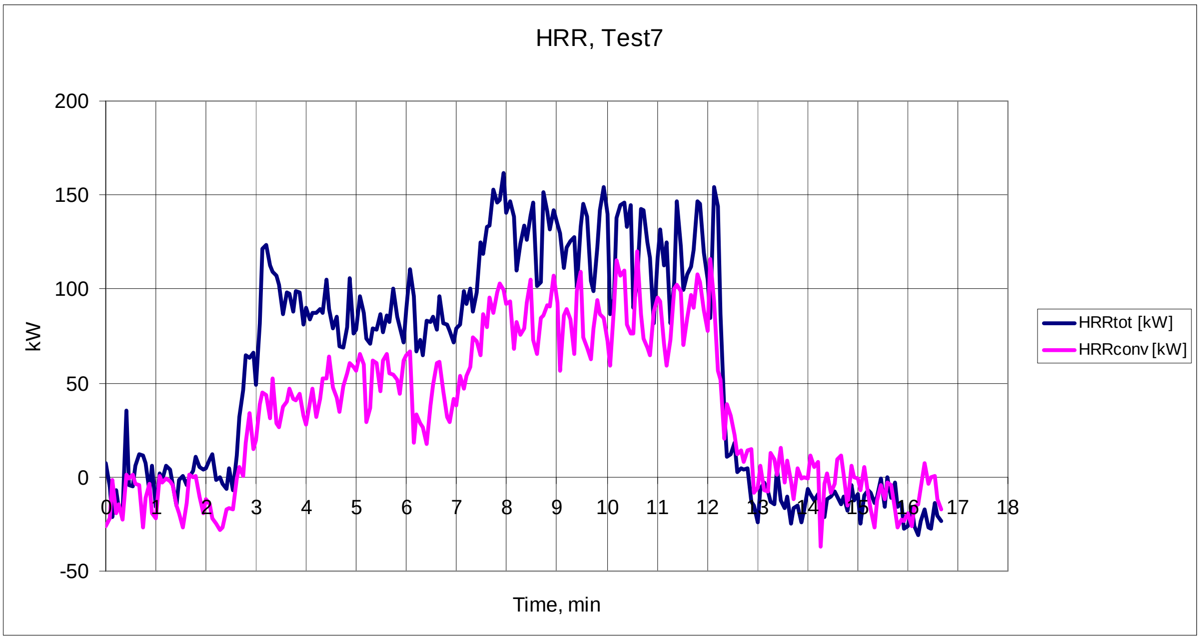

Figure 96 **Total and convective Heat Release Rate in Test 7.**

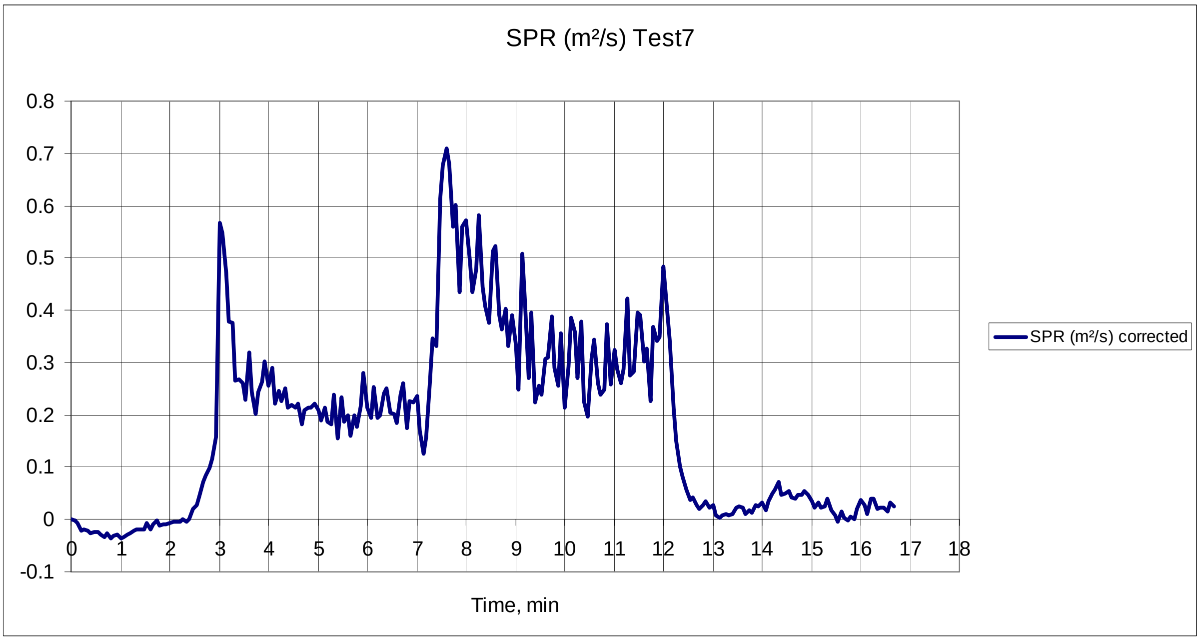

Figure 97 **Smoke in duct Test 7 corrected for drift.**

3.2.3 Test 8: CFD validation test with thin PVC-PES (B8103)

The burner was placed in the middle of the room, 45 cm above ground. The burner start was delayed due to the fact that the main gas switch had been turned off. Notes made during the test are presented in Table 10. Photos taken during the tests are presented in Figure 98 - Figure 103 while measurement results are presented in Figure 104 - Figure 111.

Table 10 Notes made during test 8.

Time	Comment
6 minutes	Ignition of burner at 95 kW
16 minutes	Burner increased to 140 kW
26 minutes	Burner increased to 300 kW
26 minutes 28 seconds	Hole
26 minutes 35 seconds	Burns on rim, hole opens up more and reach full size within 10 seconds
31 minutes	Burner turned off

Comment: The hole was measured to 0.95 cm × 1 m afterward the test.

Figure 98 The burner at the lowest heat output (95 kW) before hole opening (Test 8, time 06:38).

Figure 99 The burner at the highest heat output (300 kW) at the time of hole opening (Test 8, time 26:28).

Figure 100 Hole has opened up more and dripping from rim of hole (Test 8, time 26:36).

Figure 101 Size of hole after test (Test 8, test completed).

Figure 102 View from above of hole opening (Test 8, time 26:28).

Figure 103 View from above of dripping from rim of hole (Test 8, time 26:34).

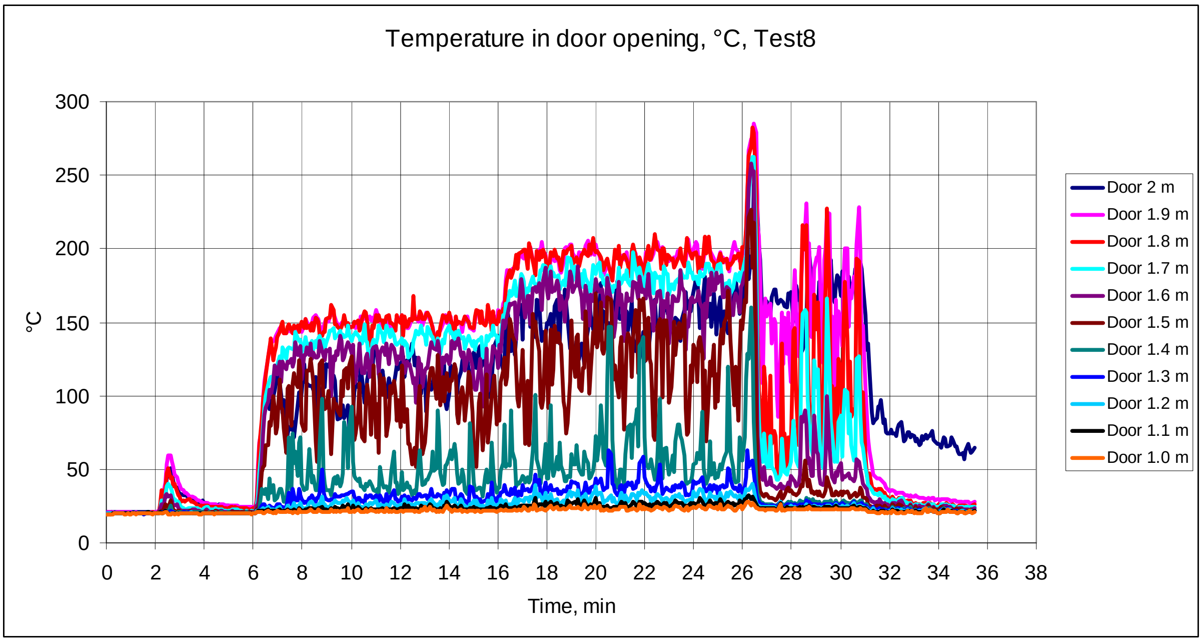

Figure 104 Temperature readings in door opening in Test 8.

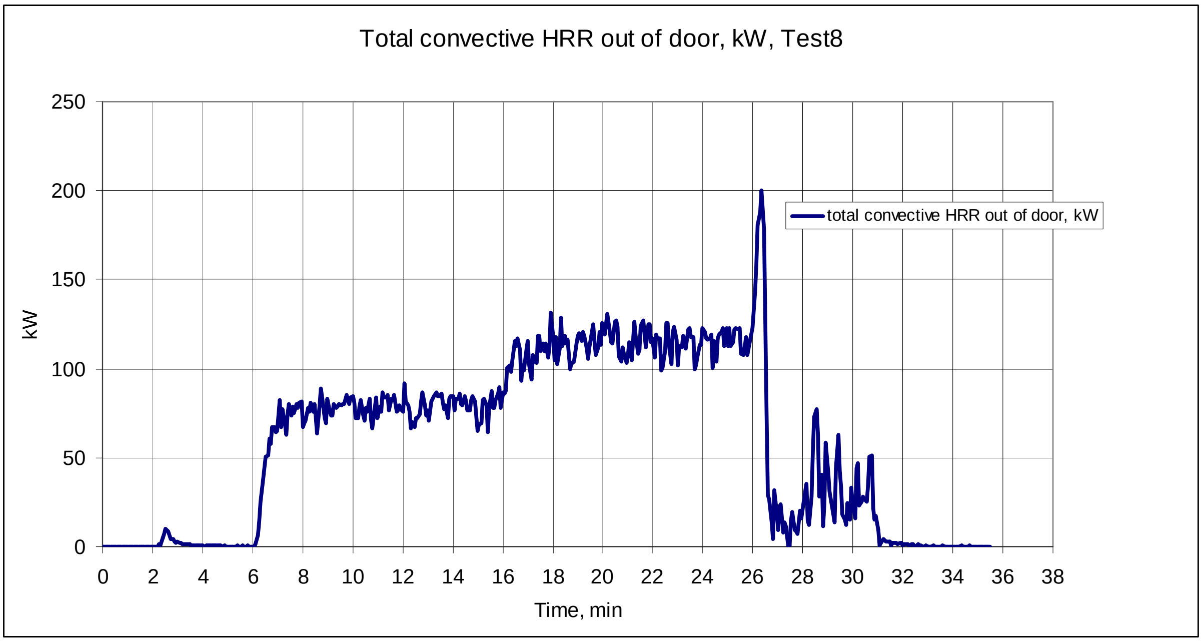

Figure 105 Total convective HRR flow out of door opening in Test 8.

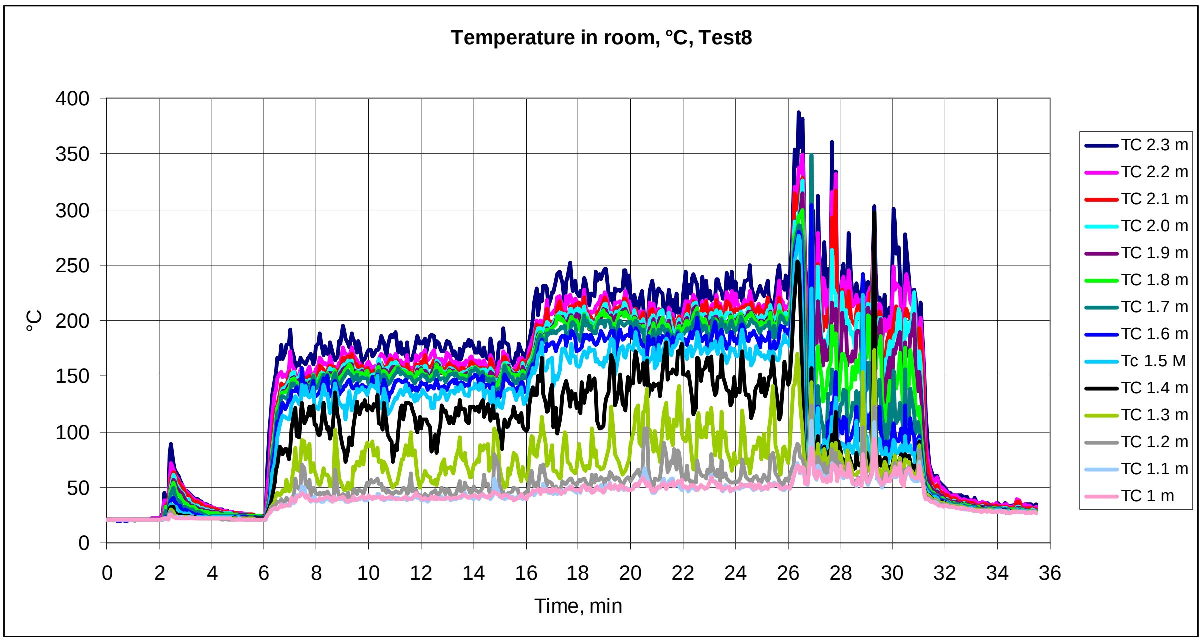

Figure 106 Temperature readings in middle of room Test 8.

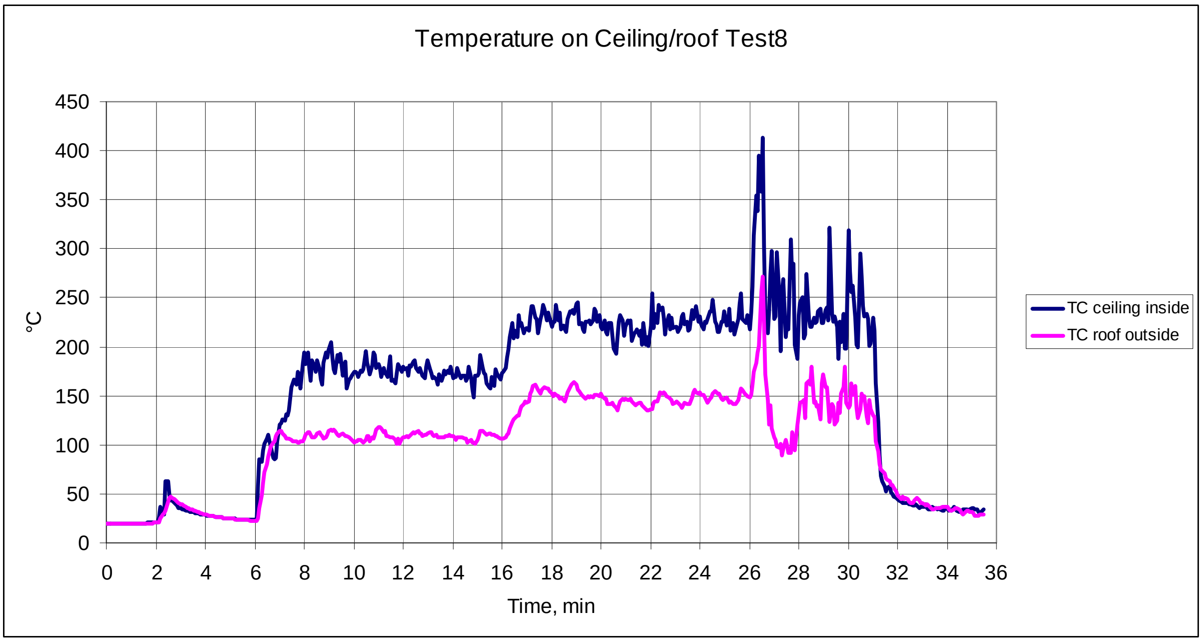

Figure 107 Temperature readings on membrane from Test 8.

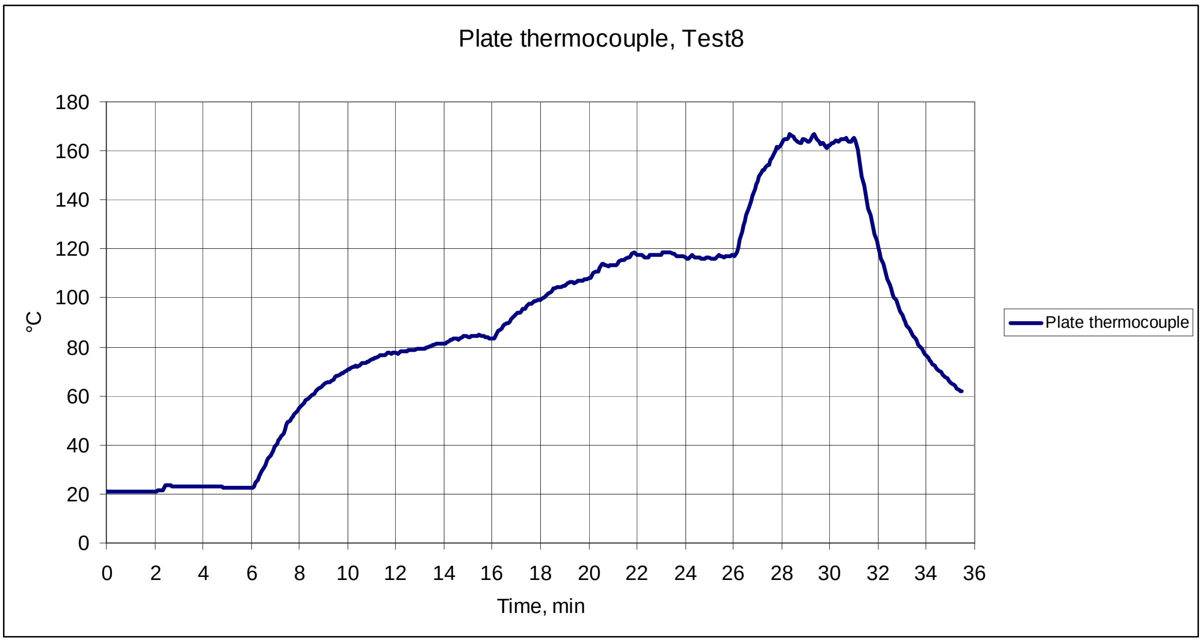

Figure 108 Plate thermocouple readings Test 8.

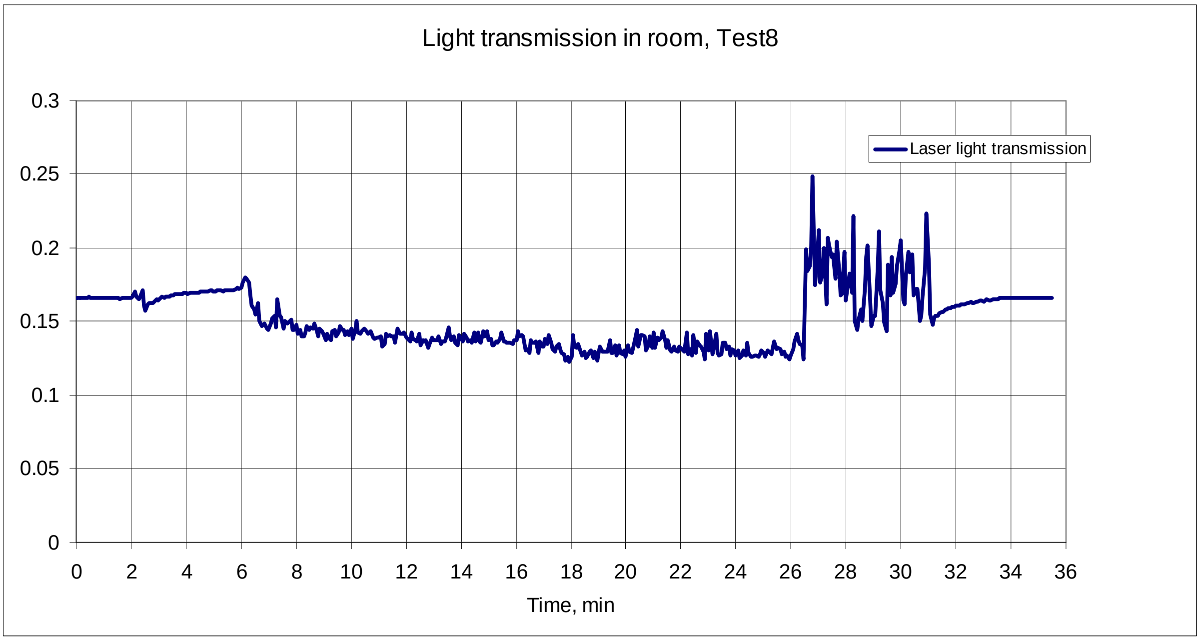

Figure 109 Laser light transmission in room Test 8.

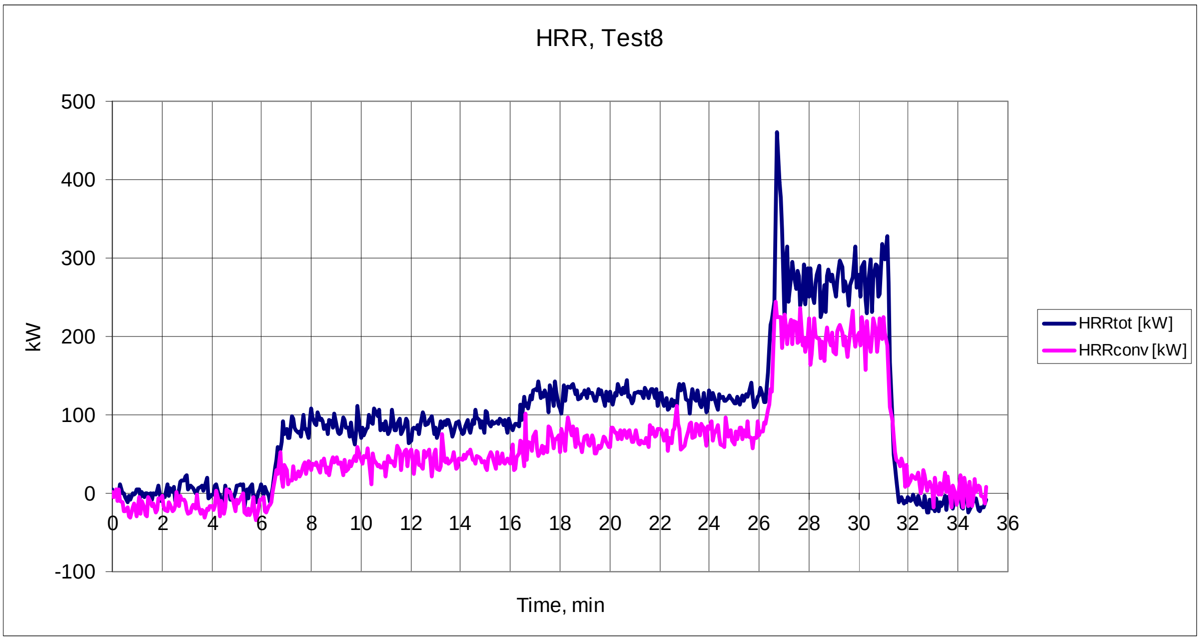

Figure 110 Total and convective Heat Release Rate in Test 8.

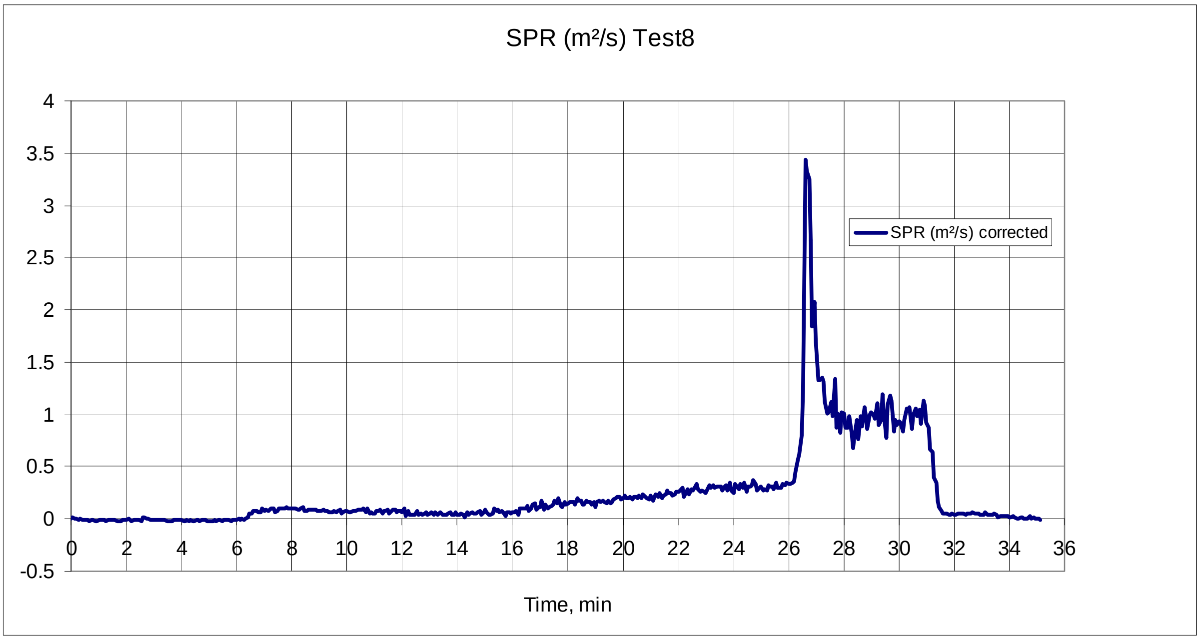

Figure 111 Smoke in duct Test 8.

3.2.4 Test 9: CFD validation test with thick PVC-PES (T3107)

The burner was placed in the middle of the room, 1 m above ground. Notes made during the test are presented in Table 11. Photos taken are presented in Figure 112 - Figure 117 and the measurement results are presented in Figure 118 - Figure 125.

Table 11 Notes made during test 9.

Time	Comment
2 minutes	Ignition of burner at 95 kW
2 minutes 6 seconds	Flames reaches ceiling
2 minutes 30 seconds	Ceiling pulsating
2 minutes 40 seconds	Smoke coming from roof
2 minutes 52 seconds	Shrinks in ceiling
3 minutes	Bubbles in ceiling
3 minutes 30 seconds	Hole about 20 cm
7 minutes	Burner increased to 140 kW
7 minutes 10 seconds	Hole starts to increase
7 minutes 30 seconds	Hole is about 0.5 x 0.5
12 minutes	Burner turned off

Comment: The hole was 63 cm × 62 cm.

Figure 112 Burner ignited (Test 9, time 2:16).

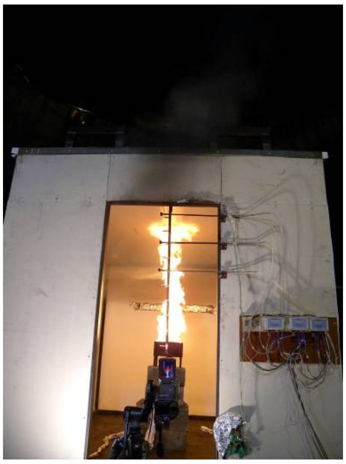

Figure 113 Just before hole opening (Test 9, time 3:22).

Figure 114 Hole is opening up (Test 9, time 3:46).

Figure 115 Burner increased to highest heat output (Test 9, time 7:22).

Figure 116 Close up of hole in ceiling (Test 9, time 7:50).

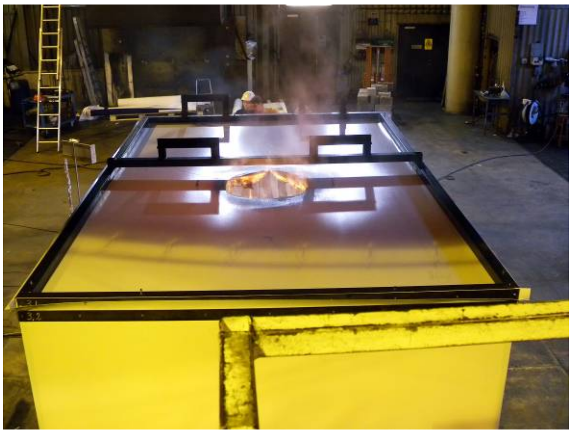

Figure 117 View of hole from above (Test 9, time 8:34).

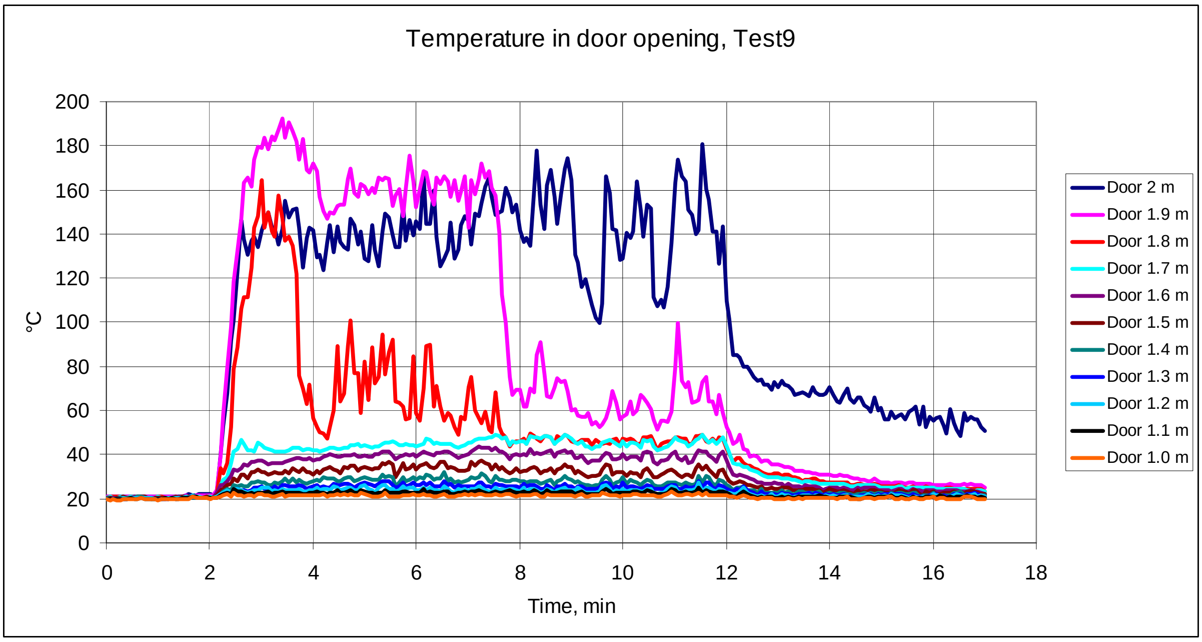

Figure 118 Temperature readings in door opening in Test 9.

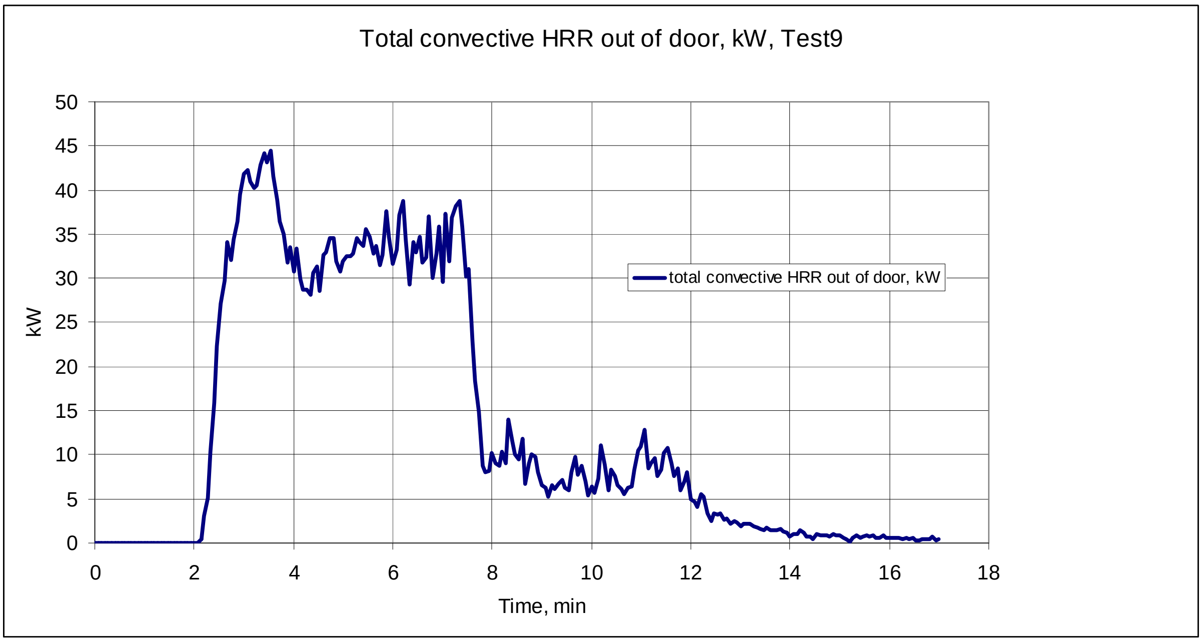

Figure 119 Total convective HRR flow out of door opening in Test 9.

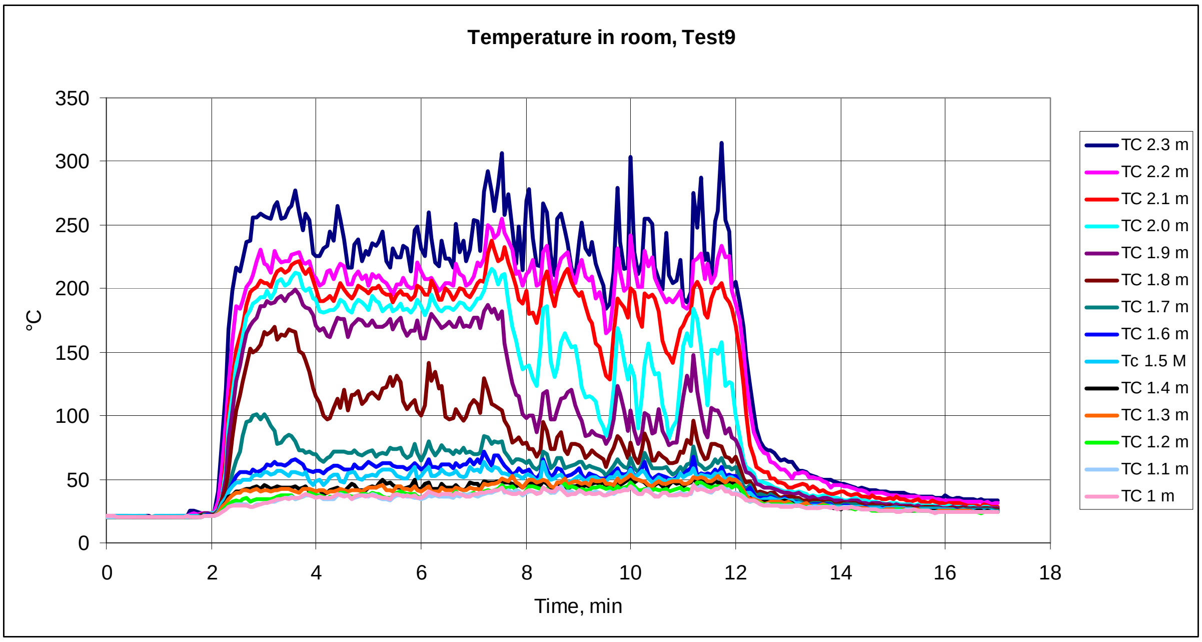

Figure 120 Temperature readings in middle of room Test 9.

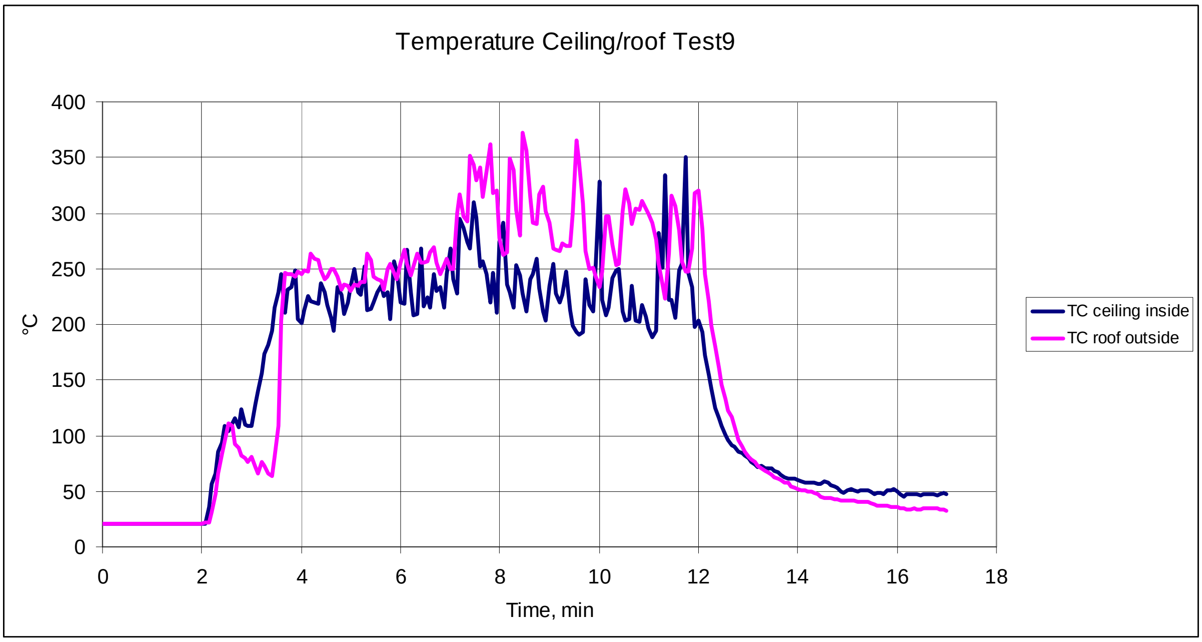

Figure 121 Temperature readings on membrane from Test 9.

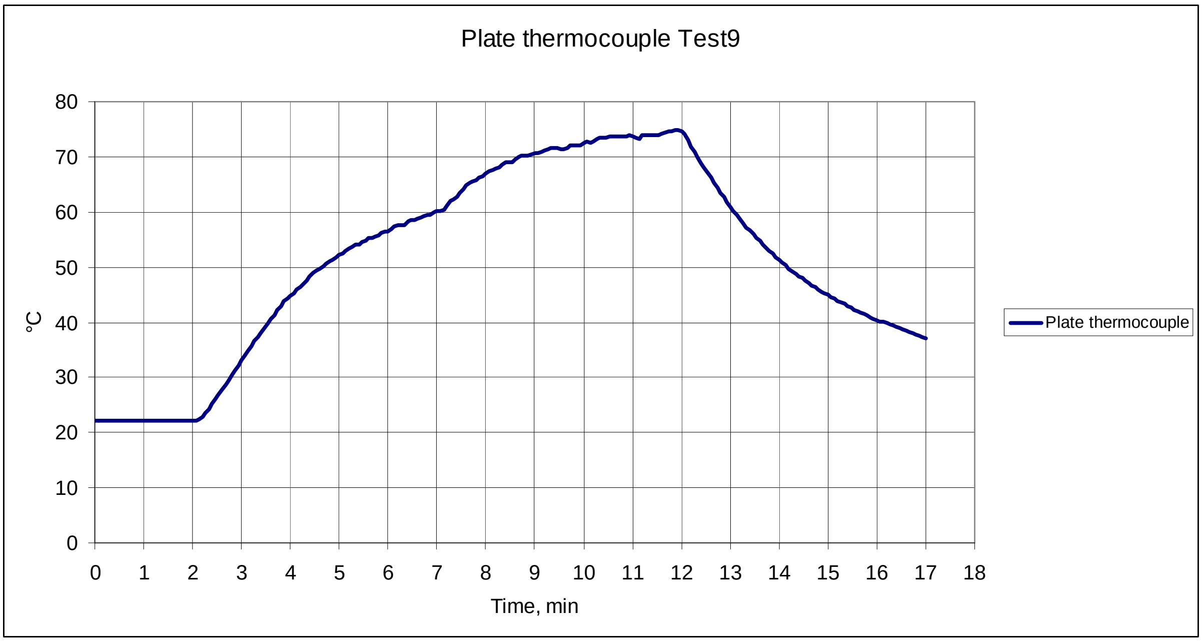

Figure 122 Plate thermocouple readings Test 9.

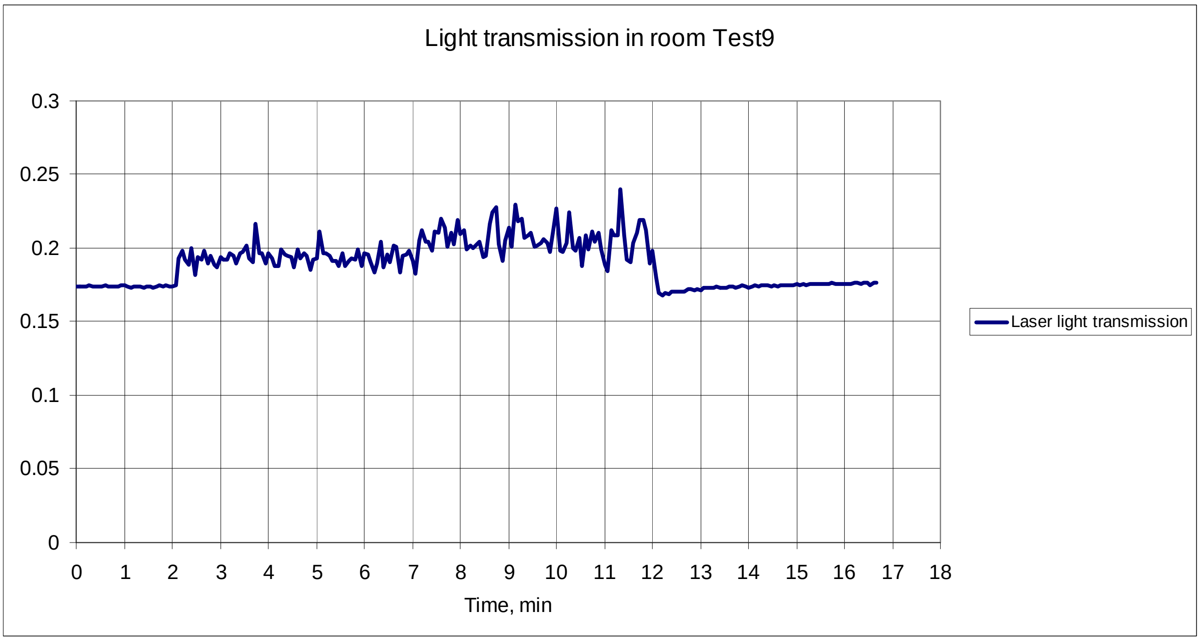

Figure 123 Laser light transmission in room Test 9 corrected for drift.

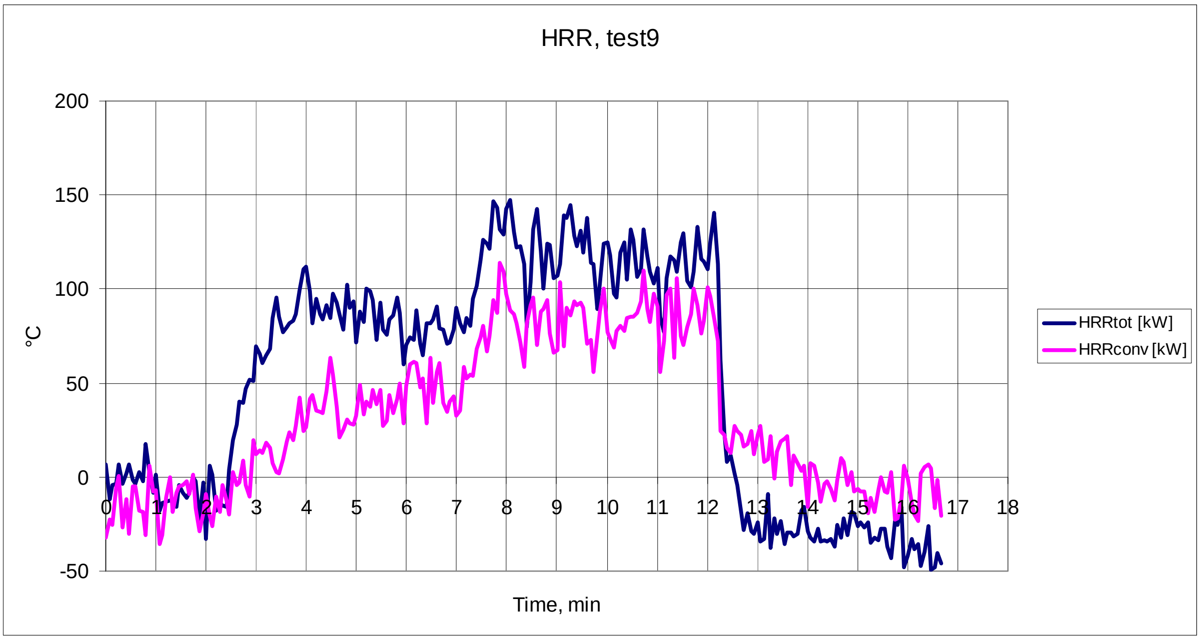

Figure 124 Total and convective Heat Release Rate in Test 9.

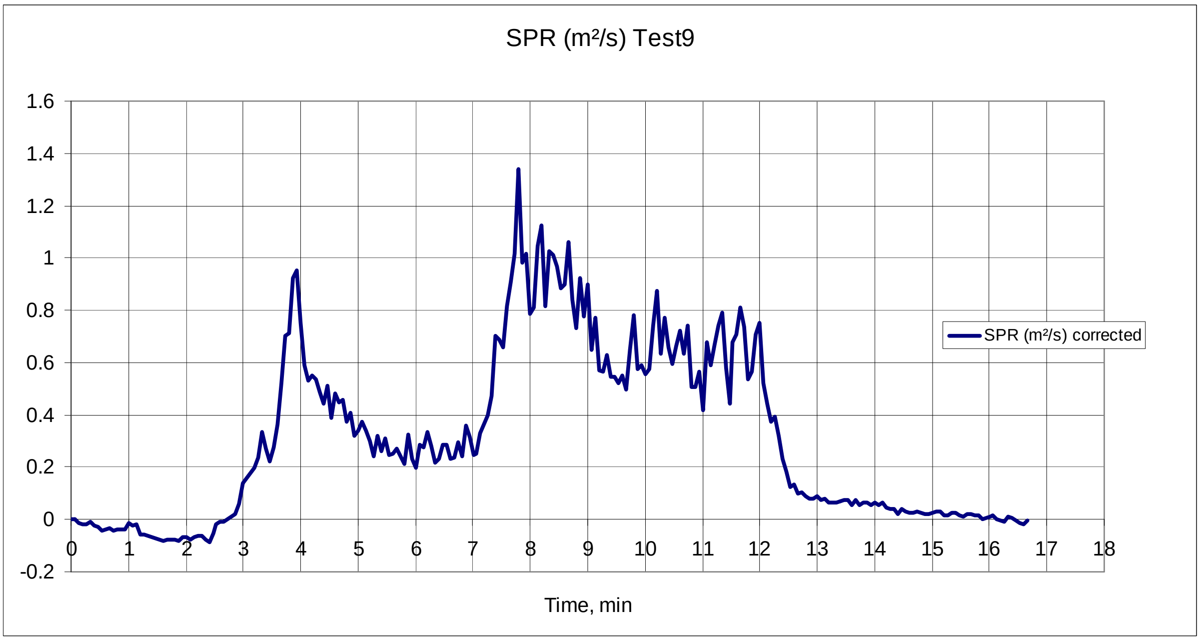

Figure 125 Smoke in duct Test 9.

3.2.5 Test 10: CFD validation test with thick PVC (T3107)

The burner was placed in the middle of the room, 45cm above ground. Notes made during the test are presented in Table 12. Photos are presented in Figure 126 - Figure 131 and the measurement results in Figure 132 - Figure 139.

Table 12 Notes made during test 10.

Time	Comment
2 minutes	Ignition of burner at 95 kW
12 minutes	Burner increased to 140 kW
22 minutes	Burner increased to 300 kW
22 minutes 35 seconds	Hole towards the right hand side, flames from ceiling visible
22 minutes 55 seconds	Falling pieces
24 minutes 40 seconds	Another hole more to the middle opens
25 minute 50 seconds	The two holes becomes one bigger hole
27 minutes	Burned turned off

Comment: The hole was 110 cm × 90 cm after the test.

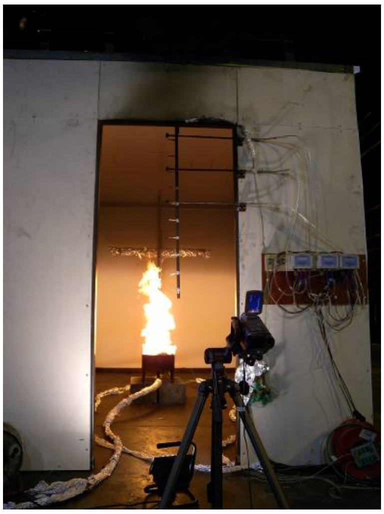

Figure 126 Burner at 140 kW heat output (Test 10, time 13:54).

Figure 127 Burner at 300 kW. Flame leaning to the right and a small hole has opened in the ceiling (Test 10, time 22:32).

Figure 128 Larger hole is opening up in ceiling (Test 10, time 22:50).

Figure 129 Pieces of melted membrane is falling from the ceiling (Test 10, time 23:02).

Figure 130 The maximum size of the hole in the end of the test (Test 10, time 26:06).

Figure 131 Close up on the hole in the ceiling (Test 10, time 26:16).

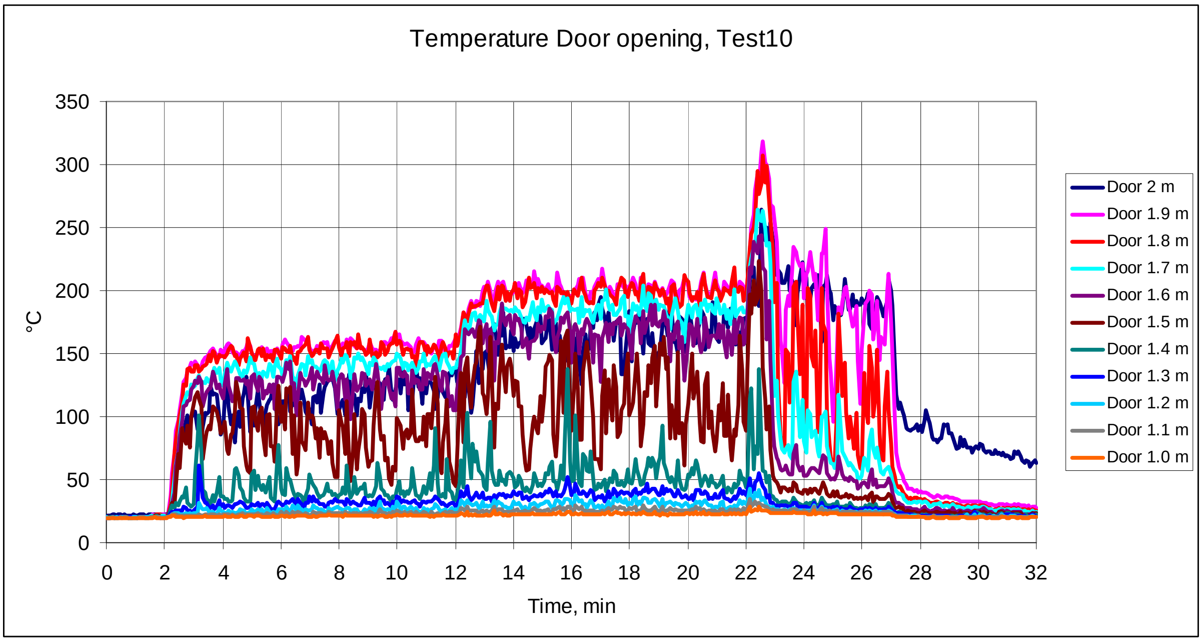

Figure 132 Temperature readings in door opening in Test 10.

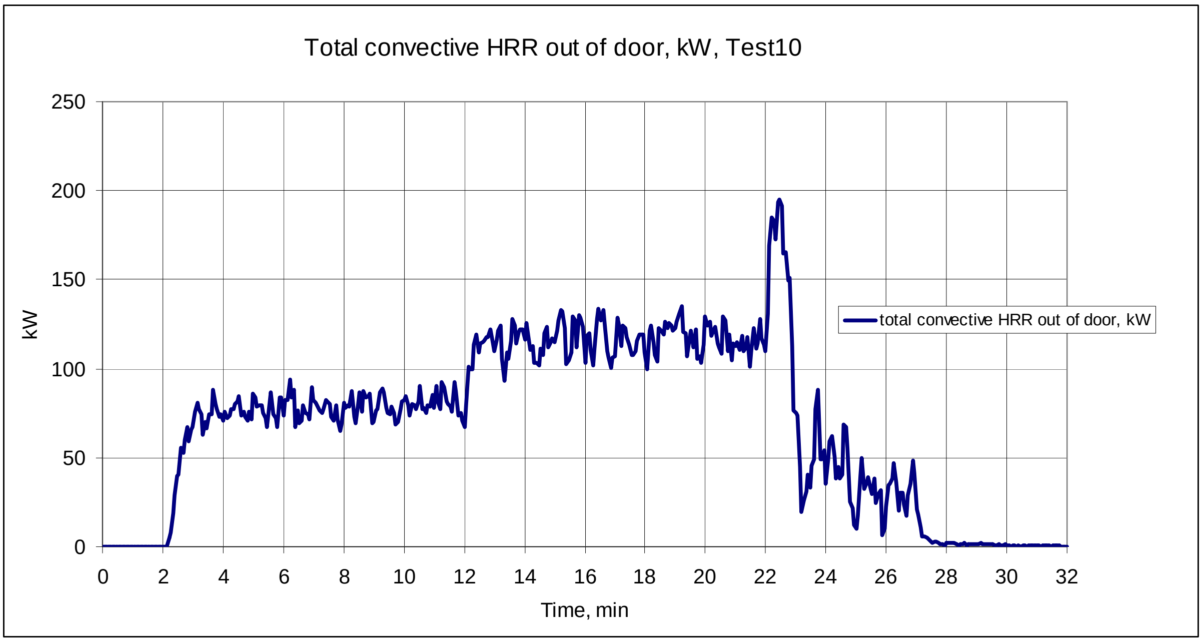

Figure 133 Total convective HRR flow out of door opening in Test 10.

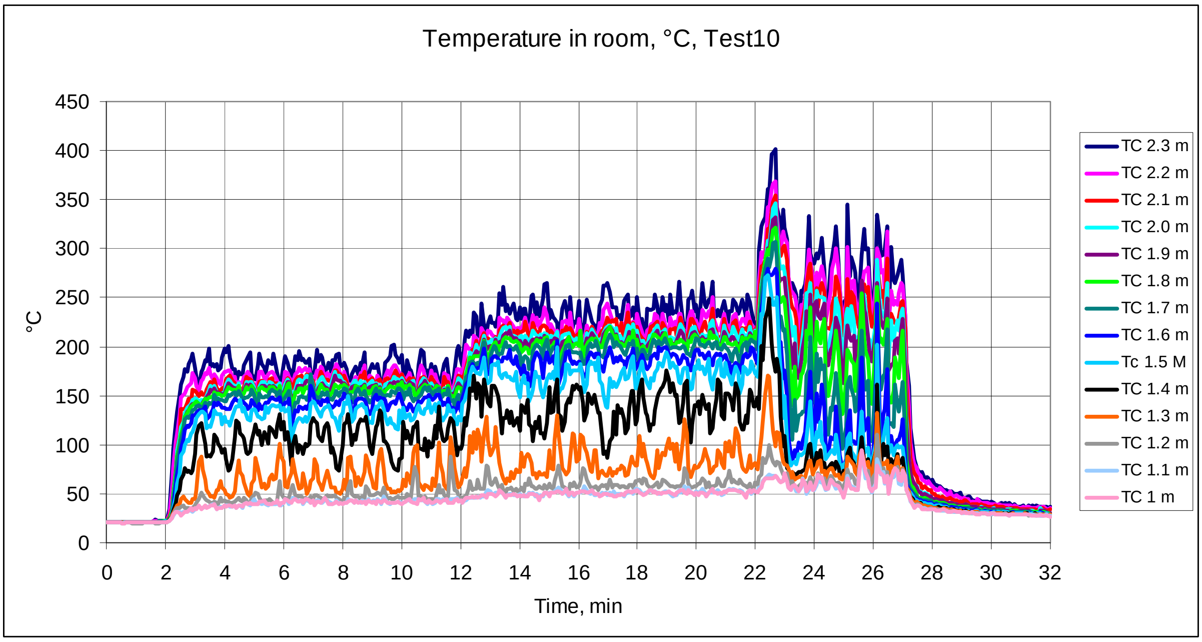

Figure 134 Temperature readings in middle of room Test 10.

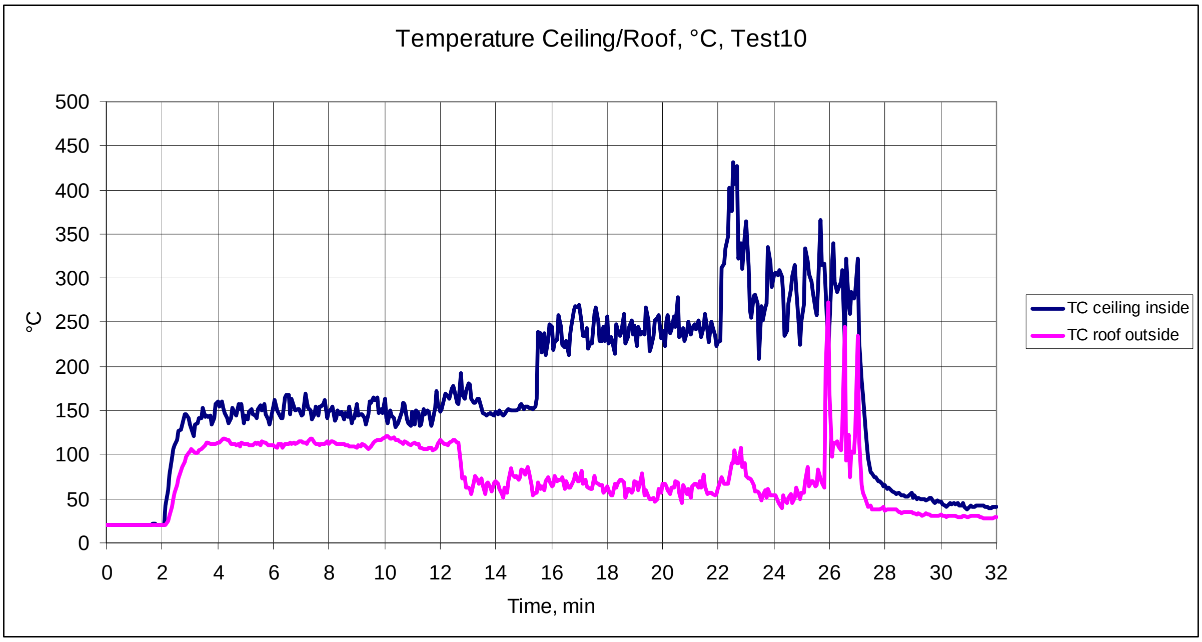

Figure 135 Temperature readings on membrane from Test 10.

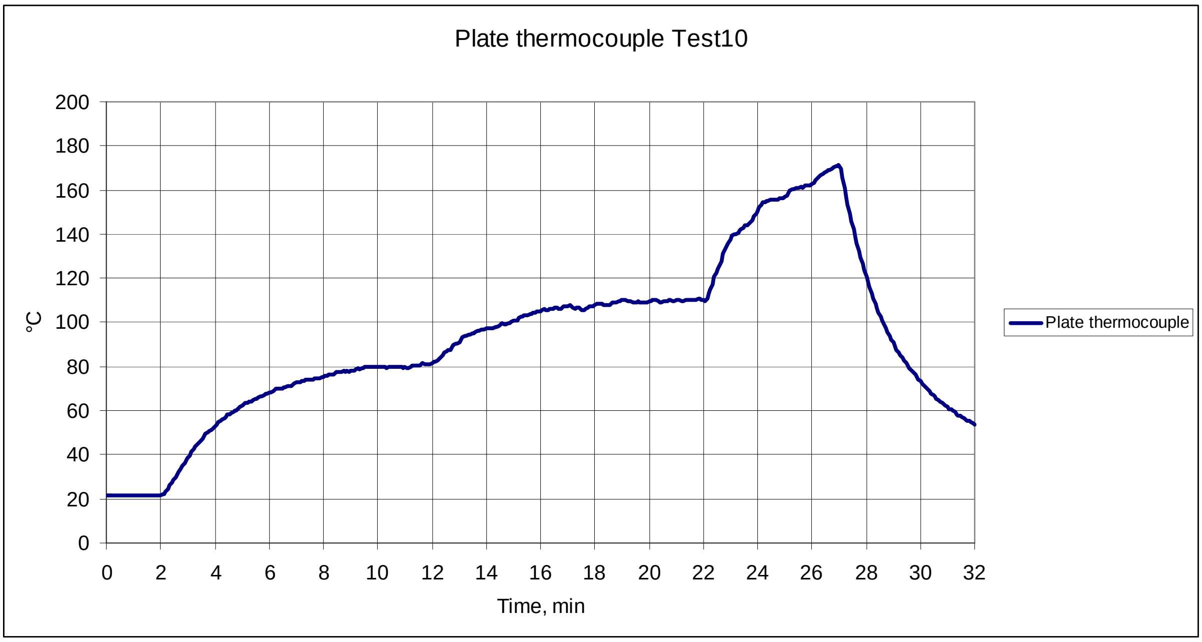

Figure 136 Plate thermocouple readings Test 10.

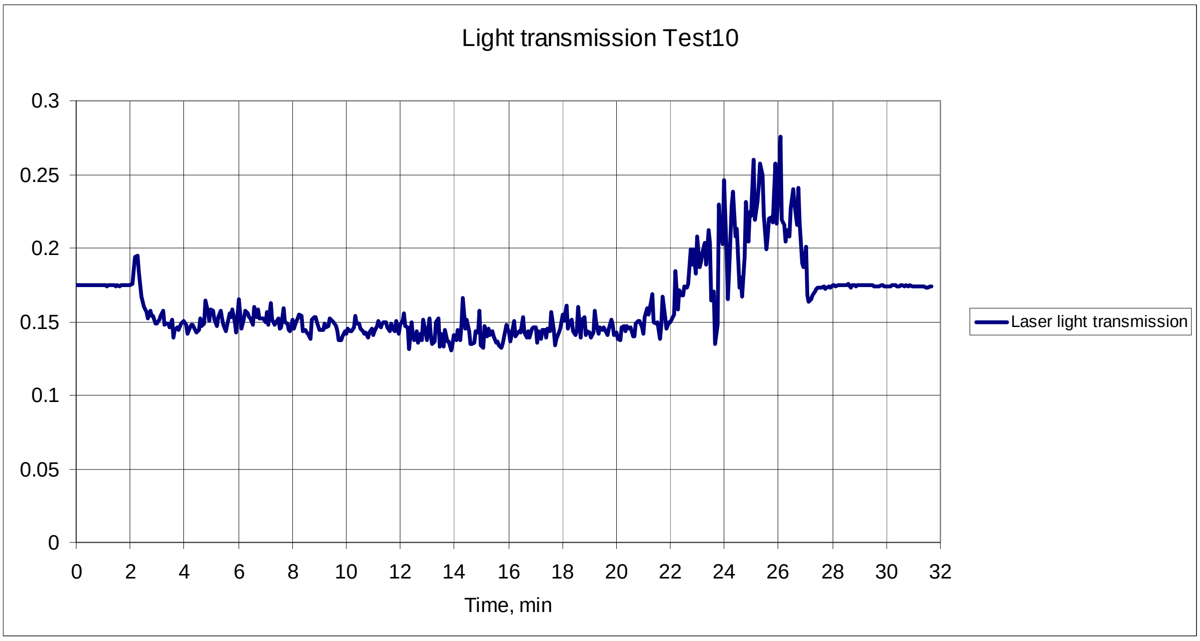

Figure 137 Laser light transmission in room Test 10.

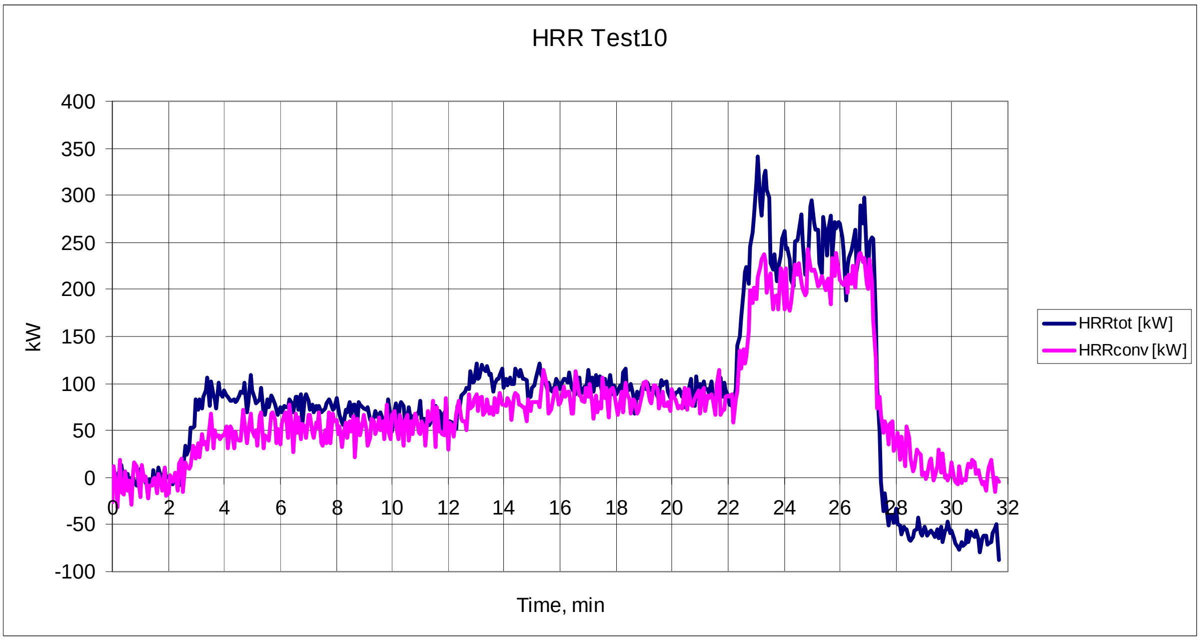

Figure 138 Total and convective Heat Release Rate in Test 10.

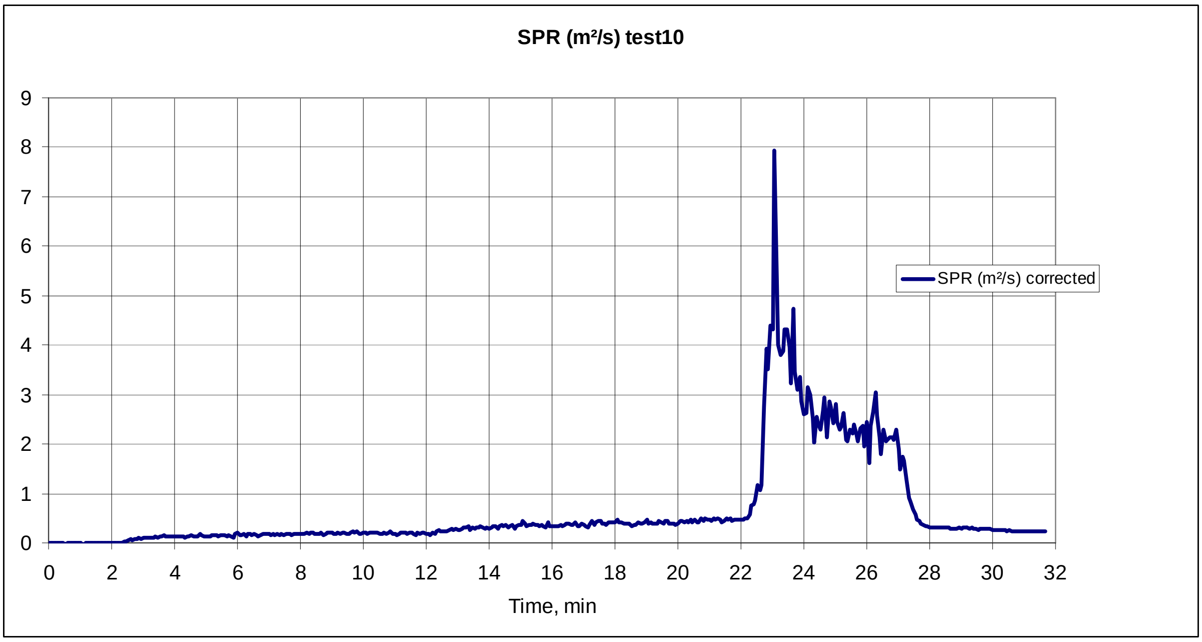

Figure 139 Smoke in duct Test 10.

4 References

[1] ISO 13784-1:2002, Reaction-to-fire tests for sandwich panel building systems -- Part 1: Test method for small rooms.

[2] ISO 9705:1993, Fire tests -- Full-scale room test for surface products.

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

[4] EN 13823:2002, Reaction to fire tests for building products – Building products excluding floorings exposed to the thermal attack of a single burning item.

[5] Contex-T WP 1.7 report, “Fire tests with textile membranes on the market – results and method development of cone calorimeter and SBI test methods”.

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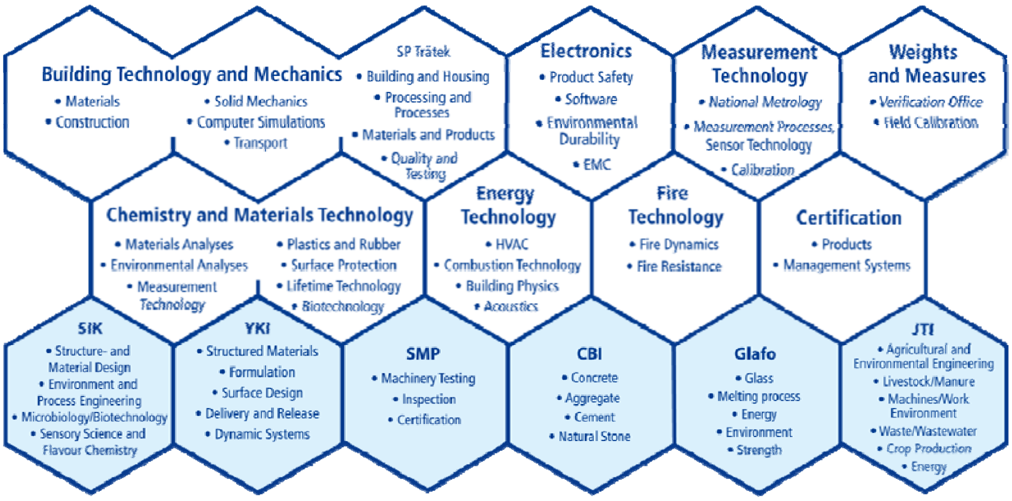

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