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An Initial Evaluation of Different Residential Sprinklers using Heat Release Rate Measurements

SP Swedish National Testing and Research Institute
Fire Technology
SP REPORT 2000:18

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Abstract

The primary objective of this test series was to compare the initial fire development of a non-sprinklered living room fire scenario, fitted with non-combustible wall and ceiling linings, with the same room having combustible linings and being sprinkler protected.

The secondary objective was to evaluate, and to some extent quantify, the performance of three different types, commercially available, residential sprinklers. The sprinklers were of the recessed pendent, concealed and horizontal sidewall type. All sprinklers were listed by Underwriters Laboratories for use in residential occupancies per NFPA 13R and were tested at a water discharge rate that was approximately 50% higher than the minimum flow rate recommended by the manufacturer.

A corner of a room was constructed using wood studs and ceiling joists. The walls extended 2 m out from the corner and the ceiling height was 2,4 m. The absence of the other two walls allowed the smoke from the fire to be collected and the heat release rate to be measured. In addition, ceiling surface and ceiling gas temperatures were measured.

The results indicate that residential sprinklers generally will reduce the severity of the fire compared to the non-sprinklered case. However, the performance of the tested residential sprinklers was very dependent on the type of sprinkler and the way the fire was initiated.

Key words: Residential sprinklers, large-scale fire tests.

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Preface

The test programme described within this report was financed by NUTEK, the Swedish National Board for Industrial and Technical Development, under their research programme for residential sprinklers, project AIS 7.

The AIS 7 programme on residential sprinklers was started early 2000 and has got a two-year frame. There are three main objectives of the programme:

- To develop a reliable and economically feasible sprinkler protection concept for residential occupancies.
- To explain and promote the benefits of residential sprinklers for professionals as well as for the public.
- To prepare a handbook with installation requirements and guidance regarding specific building code trade-offs.

The programme is carried out by the Swedish Institute for Wood Technology Research (Trätek), the University of Lund and the Swedish National Testing and Research Institute (SP) in close corporation with the building industry, building products manufacturers, sprinkler contractors and fire protection consultants.

Sammanfattning

Sprinkler i bostäder har aktualiserats i samband med att flervåningshus med bärverk av trä blev tillåtna enligt en ny svensk byggnorm från år 1994. Målsättningen med boendesprinkler är att de i första hand skall rädda liv genom att skydda mot övertändning av lägenhetens inredning. Med sprinkler kan man acceptera vissa byggnadstekniska avsteg från byggnormens krav. Eventuellt kan lägre krav ställas på valet av inredningsmaterial vilket medger ett flexiblare materialval med mer synligt trä invändigt och på fasad.

De försök som redovisas i denna rapport finansierades av NUTEK och genomfördes inom ramen för projekt AIS 7, Boendesprinkler. Den primära målsättningen med försöken var att jämföra det initiala brandförloppet för ett rum utan sprinkler med samma rum försett med sprinkler. Skillnaden var också att rummet utan sprinkler hade ytskiktmaterial i klass I. Rummet med sprinkler hade ytskikt i klass III (trä). Försöken gav även tillfälle att jämföra tre olika typer av sprinkler som används för boendemiljöer.

Rent praktiskt genomfördes försöken så att ett hörn av ett rum byggdes. Hörnet skulle kunna vara en del av ett vardagsrum eftersom den primära brandkällan var en fåtölj. Väggar och tak bekläddes med antingen gipsskiva eller med spånskiva (sprinklerförsöken). För den rent tekniska jämförelsen användes en uppsamlingshuv med vars hjälp brandeffekten mättes. Dessutom mättes temperaturer på olika punkter vid taknivå. Branden initierades med två bomullsgarn indränkta i metanol som placerades antingen vid golvnivå, invid fåtöljens sida så att väggpanelen säkert skulle komma att involveras i branden eller på fåtöljens sittdyna.

Resultaten varierade avsevärt beroende på typ av sprinkler och var branden anlades. Trots detta bör en rimlig slutsats vara att det initiala brandförloppet i ett sprinklat bostadsrum, med ytskikt i motsvarande klass III, generellt sett är mindre intensivt än i ett osprinklat rum med ytskikt i klass I. Sprinklerna aktiveras i ett relativt tidigt skede av brandförloppet och i bästa fall dämpas branden omedelbart, i andra fall kontrolleras branden under tiden det brännbara materialet, i det här fallet i första hand fåtöljen, förbrukas.

I första hand är det skillnader i aktiveringstid mellan de tre olika sprinklerna som avspeglas i de stora skillnaderna i resultat. Bäst av sprinklerna var den nedåtriktade, infällda sprinklern, trots att den dimensionerades med det lägsta vattenflödet, 68 L/min. Denna typ av sprinkler klarade att kontrollera eller dämpa branden, oavsett var den anlades. Varken den testade väggsprinklern eller den dolda sprinklern klarade att dämpa branden när den anlades på fåtöljens sida. Resultaten indikerar att dessa sprinkler bör dimensioneras för en högre vattentäthet för att klara detta scenario. När branden initierades på fåtöljens sittdyna kunde vattnet träffa branden direkt, varför resultaten överlag blev betydligt bättre.

1 Introduction

1.1 Background

Residential sprinklers have been used since the beginning of the 1980's in the USA, but have not become very common in Sweden. There are several reasons for this, however, efforts are now undertaken to adopt and implement the residential sprinkler technology to Swedish conditions. One of the primary driving forces for using residential sprinklers is the new focus on multi-storey buildings constructed mainly from wood.

Historically, such buildings have been prohibited by the Swedish building code, unless the maximum number of floors is restricted to two. An important reason for this is several major city fires during the previous centuries. However, with the introduction of a performance based building code approach a few years ago, higher buildings are allowed if it can be shown that the level of safety for the occupants is not reduced.

Obviously, one way to improve the safety is to use sprinklers. Eventually, this would permit the use of exposed wood both for the interior as well as the exterior (facades).

1.2 Objective of the test series

The primary objective was to compare the initial fire development of a non-sprinklered living room fire scenario, fitted with non-combustible wall and ceiling linings, with the same room having combustible linings and being sprinkler protected.

The secondary objective was to evaluate, and to some extent quantify, the performance of three different types, commercially available, residential sprinklers. The sprinklers were installed in accordance with the design and installation manual of the manufacturer and were of the recessed pendent, concealed and horizontal sidewall type. Underwriters Laboratories, Inc. listed all three sprinklers for use in residential occupancies per NFPA 13R.

In order to simulate a representative and repeatable living room fire scenario a custom made upholstered chair was used as the fire source.

2 Test set-up

2.1 Test facility

A corner of a room was constructed using wood studs and ceiling joists. The walls extended 2 m out from the corner and the ceiling height was 2,4 m. The absence of the other two walls allowed the smoke from the fire to be collected and the heat release rate to be measured.

To withstand a series of consecutive fire tests with limited need for repair in between the tests, the walls and the ceiling consisted of one layer of nominally 10 mm thick plywood with an outer layer of 10 mm "Promatec" non-combustible board. Either nominally 10 mm thick particle board or nominally 13 mm thick gypsum board was used as the outer lining material. A 1200 mm by 1200 mm "Promatec" non-combustible board was placed under the upholstered chair in order to protect the concrete floor.

2.2 Instrumentation and documentation

The test facility was instrumented with thermocouples to measure ceiling gas temperatures above the fire as well as close to the installed sprinkler. All the thermocouples were of type K (chromel-alumel) made from 0,5 mm wire welded together. Ceiling surface temperatures were measured with type K thermocouples installed with the bead flush with the ceiling surface.

In addition, ceiling surface temperatures were measured with Plate Thermometers at two different positions. The Plate Thermometer is developed at SP and consists of a 100 mm by 100 mm, 0,7 mm thick plate, insulated at the backside. The design of the Plate Thermometer is such that it primarily responds to heat flux, and to a lower degree, to convection compared to a conventional wire thermocouple. The two Plate Thermometers were positioned with their centres 100 mm and 500 mm, respectively, out from the corner walls. The thermocouples were positioned adjacent to the Plate Thermometers.

Table 1 Measurement points and associated channels.

Channel	Location	Channel	Location
	100 mm from corner walls		500 mm from corner walls
Ch 21	Plate Thermometer	Ch 25	Plate Thermometer
Ch 22	Thermocouple flush with ceiling surface	Ch 26	Thermocouple flush with ceiling surface
Ch 23	Thermocouple 10 mm below ceiling	Ch 27	Thermocouple 10 mm below ceiling
Ch 24	Thermocouple 50 mm below ceiling	Ch 28	Thermocouple 50 mm below ceiling
		Ch 29	T/C close to glass bulb of sprinkler

The heat release rates of the fires were measured using the Furniture Calorimeter.

The water pressure was measured with a pressure gauge close to the installed sprinkler and the water flow rate was measured after the pump.

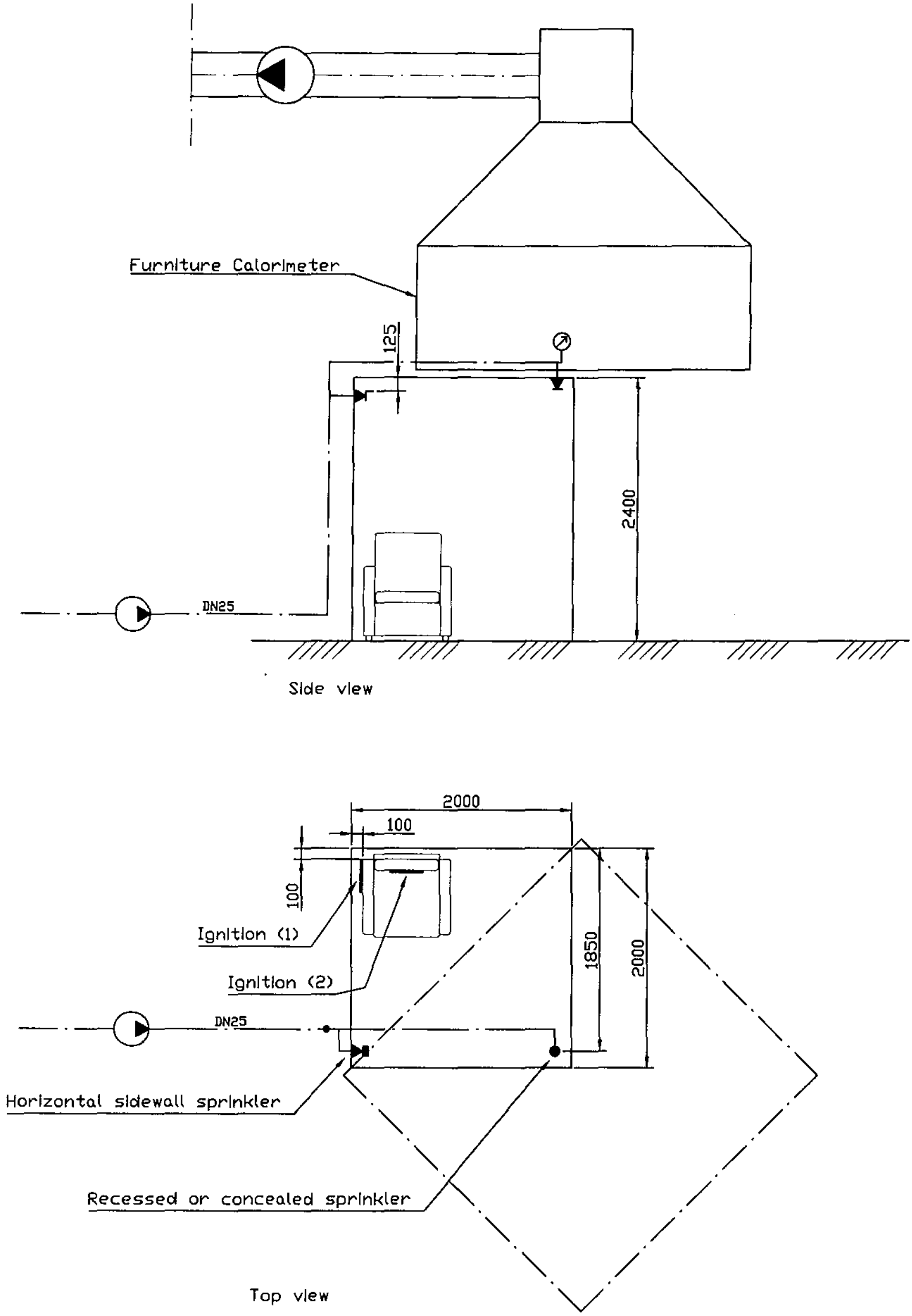


Figure 1 *The test set-up showing the Furniture Calorimeter that was used to determine the heat release rate of the fires.*

2.3 The sprinklers used for the tests

Three different type sprinklers were used for the test programme, a recessed pendent sprinkler, a concealed pendent sprinkler and a horizontal sidewall sprinkler. The sprinklers were installed in accordance with the design and installation manual from the manufacturer. Underwriters Laboratories, Inc. listed all three sprinklers for use in residential occupancies per NFPA 13R.

All sprinklers were installed at their maximum distance from the walls, 1,85 m (6 ft) that corresponds to a sprinkler coverage area of 3,7 m (12 ft) by 3,7 m (13,4 m^2).

All sprinklers were of the frangible bulb type with 3 mm glass bulbs and a nominal temperature rating of 68°C (155°F).

The recessed pendent and the horizontal sidewall sprinkler had a nominal K-factor of 63,4 L/min/bar$^{1/2}$ (K=4,4), respectively. The concealed pendent sprinkler had a nominal K-factor of 60,5 L/min/bar$^{1/2}$ (K=4,2).

The table below summarises the installation criteria of the sprinklers for use in residential occupancies at the sprinkler coverage area of 3,7 m by 3,7 m that was utilised throughout these tests.

Table 2 The installation criteria given by the manufacturer, for the sprinklers used in the tests.

Type of sprinkler	Maximum coverage area	Minimum flow, one sprinkler flowing	Minimum flow, multiple sprinklers flowing
Recessed pendent residential sprinkler	3,7 m by 3,7 m (12 ft by 12 ft)	45 L/min (12 gpm)	45 L/min (12 gpm)
Concealed pendent residential sprinkler	3,7 m by 3,7 m (12 ft by 12 ft)	61 L/min (16 gpm)	45 L/min (12 gpm)
Horizontal sidewall residential sprinkler	3,7 m by 3,7 m (12 ft by 12 ft)	49 L/min (13 gpm)	45 L/min (12 gpm)

The recessed pendent sprinkler was height adjusted to its nominal mid-height, a nominal distance of 29 mm from the escutcheon plate. Given the thickness of the plate, the distance measured from the ceiling to the bottom of the deflector was nominally 33 mm. The sprinkler was orientated such that the plane of the frame arms was parallel to the right hand side wall (the wall facing the back side of the upholstered chair).

The separable two-piece design of the cover plate and mounting cup of the concealed sprinkler provides for 12,7 mm of vertical adjustment, to reduce the accuracy to which the length of the fixed pipe drops of an actual system must be cut. For these tests, the pipe drop was prepared such that the sprinkler could be adjusted to its lowest position. From the standpoint of activation, this was probably the most advantageous adjustment. The sprinkler was orientated such that the plane of the frame arms was parallel to the right hand side wall (the wall facing the back side of the upholstered chair).

The horizontal sidewall sprinkler was installed with the top of its deflector 125 mm below the ceiling, which is mid-height of the recommended distance of 100 to 150 mm. A recessed escutcheon plate was used with the sprinkler and the sprinkler was adjusted to the nominal mid-level distance from the plate, 32 mm.

The pipe-work was made from DN 25 mm steel pipe, connected via a DN 34 mm hose to the pump. The desired water flow rate was set discharging the actual sprinkler type (with the deflector removed) before each test. As the far end of the pipe-work was fitted with a pressure gauge and the water flow rate was constantly measured, manual adjustment of the pump during the tests was possible.

2.4 The fire scenario

In order to simulate a representative living room fire scenario an upholstered chair was used as the primary fire source.

The upholstered chair was custom made specifically for the tests, with the custom made chairs used in the Combustion Behaviour of Upholstered Furniture (CBUF) research programme as the example. However, the chair for this programme was made slightly larger. The chair had a timber frame with arms, seat and back going down to the ground. The chair had polyether foam filling with a density of 25 kg/m^3 and a fabric made from polyester having a nominal area weight of 225 g/m^2. The average overall weight of one chair was 16,8 kg.

The heat release of the chair under free-burning conditions was determined using the Furniture Calorimeter. In addition, the chair was placed on a load cell to determine the weight loss during the test.

The ignition source consisted of two axially parallel and adjacent cotton wicks, each 300 mm long and nominally 8 mm thick. The wicks were soaked with 25 mL of methanol prior to ignition. Ignition took place either at the bottom, left hand side of the chair or centric at the seat, close to the bottom of the backrest.

2.5 Test programme

The test programme consisted of a total of nine tests, including the two free-burn tests of the upholstered chair. One additional free-burn test was conducted with the walls and the ceiling covered with gypsum board. This was considered an important reference test as such linings fulfils the requirements of the Swedish building code for multi-storey buildings.

During all tests the chair was positioned with its side and its back, 100 mm from the corner walls.

It was decided to conduct the sprinkler tests at an approximately 50% higher desired water flow rate than the minimum flow rate recommended by the manufacturer of the sprinklers. The reason was to avoid being at the very limit of the capabilities of the sprinklers and to some extent represent the initial higher flow rate expected in an actual sprinkler installation. For the recessed pendent sprinkler, the desired water flow of 68 L/min equalled the minimum 18 gpm flow rate as required by the 1999 edition of

NFPA 13R, flowing one sprinkler. All the sprinkler tests were conducted with particle board at the walls and at the ceiling.

In sprinkler tests 4 through 6 the upholstered chair was ignited at the bottom, left hand side. The intention was to allow the fire to involve the combustible wall panelling prior to the activation of the sprinkler. In addition, the chair itself prevented the water spray from directly hitting the base of the fire. For tests 7 through 9, the ignition took place centric at the seat, close to the bottom of the backrest. This allowed a more direct hit of the water spray.

The two methanol soaked cotton wicks as described above were used as the ignition source.

The test programme is summarised in the table below.

Table 3 Test programme.

Test	Ignition position	Wall and ceiling lining	Type of sprinkler
1	Left hand side	None	None
2	At seat	None	None
3	Left hand side	Gypsum board	None
4	Left hand side	Particle board	Recessed pendent sprinkler
5	Left hand side	Particle board	Horizontal sidewall sprinkler
6	Left hand side	Particle board	Concealed pendent sprinkler
7	At seat	Particle board	Recessed pendent sprinkler
8	At seat	Particle board	Horizontal sidewall sprinkler
9	At seat	Particle board	Concealed pendent sprinkler

3 Test results

Test results and observations are summarised in the tables below with corresponding graphs showing the total heat release rate histories. Heat release rate histories and temperature graphs for all tests are given in Appendix A.

Table 4 Test results for the free-burn tests.

Test no.	1	2	3
Date of test	2000-03-01	2000-03-01	2000-03-06
Wall and ceiling lining	None	None	Gypsum board
Peak HRRconv [kW]	760 kW	700 kW	860 kW
Peak HRRtot [kW]	1370 kW	1160 kW	1820 kW
Total energy, 15 minutes [MJ]	187 MJ	199 MJ	238 MJ
Weight loss of chair [kg]	12,5 kg	12,8 kg	N/M
Peak temperatures [°C]			
100 mm from corner walls			
Ch 21, Plate Thermometer	-	-	783
Ch 22, flush w/ ceiling surface	-	-	854
Ch 23, 10 mm below ceiling	-	-	801
Ch 24, 50 mm below ceiling	-	-	845
500 mm from corner walls			
Ch 25, Plate Thermometer	-	-	879
Ch 26, flush w/ ceiling surface	-	-	993
Ch 27, 10 mm below ceiling	-	-	868
Ch 28, 50 mm below ceiling	-	-	1037
Note:	1)	2)	1)

1) Ignition took place at the bottom, left hand side of the upholstered chair.
2) Ignition took place centric at the seat, close to the bottom of the backrest of the upholstered chair.
N/M – Not Measured

Based on the free-burn tests it can be concluded that the initial fire development was faster for the case when ignition took place at the seat of the chair. However, the growth time from 100 kW to the maximum heat release rate was faster, 80 seconds, when ignition took place on the side of the chair. The corresponding fire growth time when ignition took place at the seat was 95 seconds.

In addition, the peak heat release rate was higher for this case when ignition took place on the side of the chair.

When the upholstered chair was burned close to the corner, with gypsum boards at the walls and ceiling, the fire growth was similar but the peak heat release rate was higher.

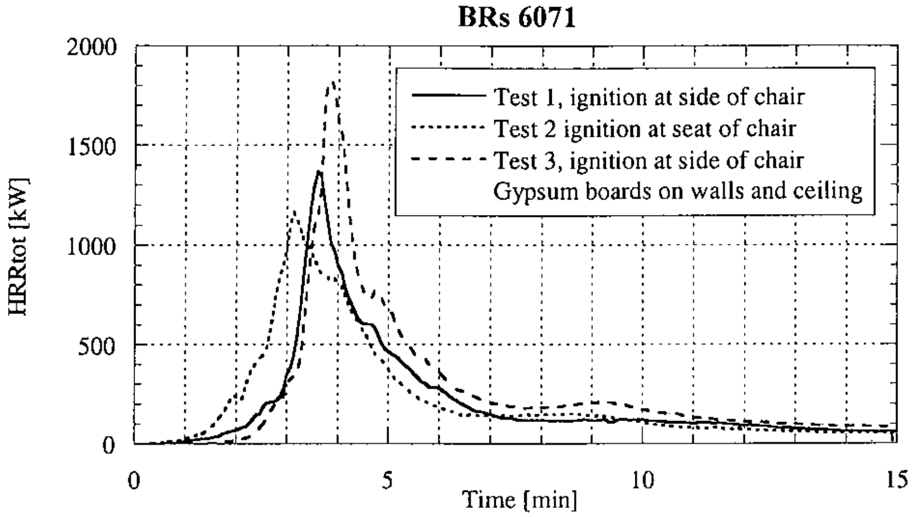


Figure 2 *Total heat release rate histories for the free-burn tests. Test 3 was conducted using gypsum boards on the walls and at ceiling.*

Table 5 *Test results for sprinkler tests. Ignition took place at the bottom, left hand side of the upholstered chair.*

Test no.	4	5	6
Date of test	2000-03-07	2000-03-07	2000-03-08
Wall and ceiling lining	Particle board	Particle board	Particle board
Type of sprinkler	Recessed pendent	Horizontal sidewall	Concealed pendent
Desired flow rate [L/min]	68 L/min (18 gpm)	75 L/min (20 gpm)	90 L/min (24 gpm)
Activation time [min:s]	02:45	02:36	02:39
HRRconv at activation [kW]	70 kW	190 kW	245 kW
HRRtot at activation [kW]	160 kW	370 kW	390 kW
Peak HRRconv [kW]	390 kW	720 kW	910 kW
Peak HRRtot [kW]	930 kW	1650 kW	1900 kW
Total energy, 15 minutes [MJ]	144 MJ	184 MJ	212 MJ
Weight loss of chair [kg]	7,1 kg	8,0 kg	7,9 kg
Peak temperatures [°C]			
100 mm from corner walls			
Ch 21, Plate Thermometer	533	647	728
Ch 22, flush w/ ceiling surface	641	844	773
Ch 23, 10 mm below ceiling	532	727	758
Ch 24, 50 mm below ceiling	623	799	818
500 mm from corner walls			
Ch 25, Plate Thermometer	574	720	900
Ch 26, flush w/ ceiling surface	570	862	887
Ch 27, 10 mm below ceiling	726	879	928
Ch 28, 50 mm below ceiling	822	945	1013
Ch 29, close to sprinkler	102	108	316
Note:	-	-	-

In sprinkler tests 4 through 6 the upholstered chair was ignited at bottom, left hand side. The intention was to allow the fire to involve the combustible wall panelling prior to the activation of the sprinkler. In addition, the chair itself prevented the water spray from directly hitting the base of the fire.

As expected the recessed pendent sprinkler activated at an earlier stage of the fire compared to the other type sprinklers. Upon activation this sprinkler was not able to suppress the fire, but the rate at which the fire develop was decreased and the fire size was controlled to below 1 MW while the upholstered chair burnt out.

The horizontal sidewall sprinkler initially suppressed the fire. However, the fire redeveloped and the fire became very intense with flames spreading across the ceiling of the test facility. The fire in the wall panelling was, however, extinguished as the upholstered chair was consumed. It is though very likely that an actual room would have been severely fire damaged if more combustibles had been present, for example if a two or a three seat sofa had been used instead of just a single upholstered chair.

The concealed type sprinkler activated at a late stage and did only marginally affect the heat release rate of the fire. Flames spread across the walls and the ceiling for a significant period of time during the test and large parts of the walls and the ceiling was severely burnt afterwards. From both a life safety and a property protection standpoint, the performance of this sprinkler can be judged inappropriate for the tested scenario.

It can be concluded that an important reason for the difference in performance is the difference in time to activation. The fire size was more than twice the size upon the activation of the concealed type sprinkler compared to the size when the recessed pendent sprinkler activated.

It should be noted that the initial fire development was slightly slower during test 4 which make a strict comparison of the activation time for this particular test uncertain.

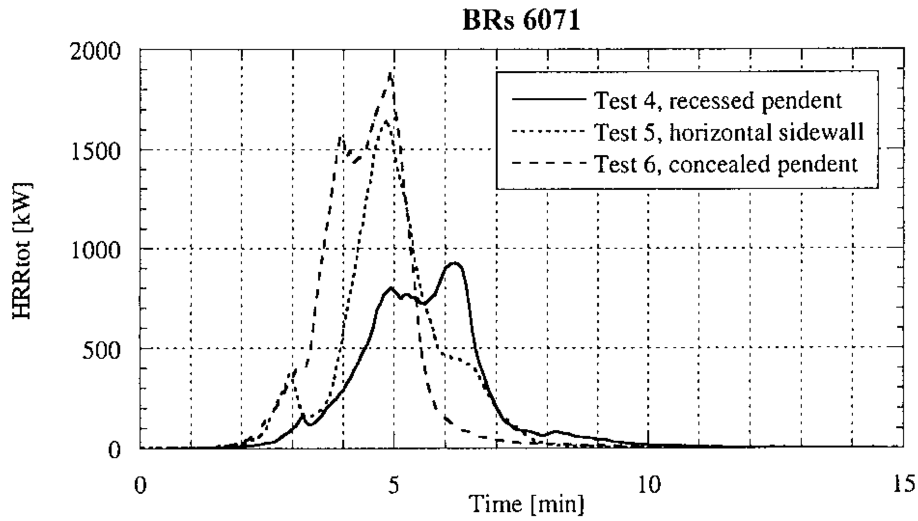


Figure 3 *Total heat release rate histories for the sprinkler tests where ignition took place at the bottom, left hand side of the upholstered chair.*

Table 6 Test results for sprinkler tests. Ignition took place centric at the seat, close to the bottom of the backrest of the upholstered chair.

Test no.	7	8	9
Date of test	2000-03-08	2000-03-09	2000-03-09
Wall and ceiling lining	Particle board	Particle board	Particle board
Type of sprinkler	Recessed pendent	Horizontal sidewall	Concealed pendent
Desired flow rate [L/min]	68 L/min (18 gpm)	75 L/min (20 gpm)	90 L/min (24 gpm)
Activation time [min:s]	01:29	01:22	01:45
HRRconv at activation [kW]	180 kW	90 kW	370 kW
HRRtot at activation [kW]	330 kW	190 kW	730 kW
Peak HRRconv [kW]	180 kW	550 kW	370 kW
Peak HRRtot [kW]	340 kW	1320 kW	810 kW
Total energy, 15 minutes [MJ]	27 MJ	138 MJ	31 MJ
Weight loss of chair [kg]	1,8 kg	7,3 kg	1,5 kg
Peak temperatures [°C]			
100 mm from corner walls			
Ch 21, Plate Thermometer	133	564	293
Ch 22, flush w/ ceiling surface	404	776	584
Ch 23, 10 mm below ceiling	302	632	554
Ch 24, 50 mm below ceiling	399	788	705
500 mm from corner walls			
Ch 25, Plate Thermometer	125	638	343
Ch 26, flush w/ ceiling surface	307	833	751
Ch 27, 10 mm below ceiling	389	828	743
Ch 28, 50 mm below ceiling	435	883	815
Ch 29, close to sprinkler	129	98	313
Note:	-	-	-

For tests 7 through 9, the ignition took place centric at the seat, close to the bottom of the backrest. This allowed a more direct hit of the water spray, which was reflected by generally better test results as compared to tests 4 through 6.

All three type sprinklers were able to initially suppress the fire. However, during the test with the horizontal sidewall sprinkler the fire spread under the seat of the chair, where water could not reach. Gradually the fire redeveloped, spread up the corner walls and did not decline until the chair was more or less consumed.

Also for this scenario the fire size was approximately twice the size upon activation of the concealed type sprinkler as compared to the size when the recessed pendent sprinkler activated. However, for this case the wall panelling was never as involved in the fire and the fire in the chair was not as shielded which explains why the water flow rate was appropriate to suppress the fire.

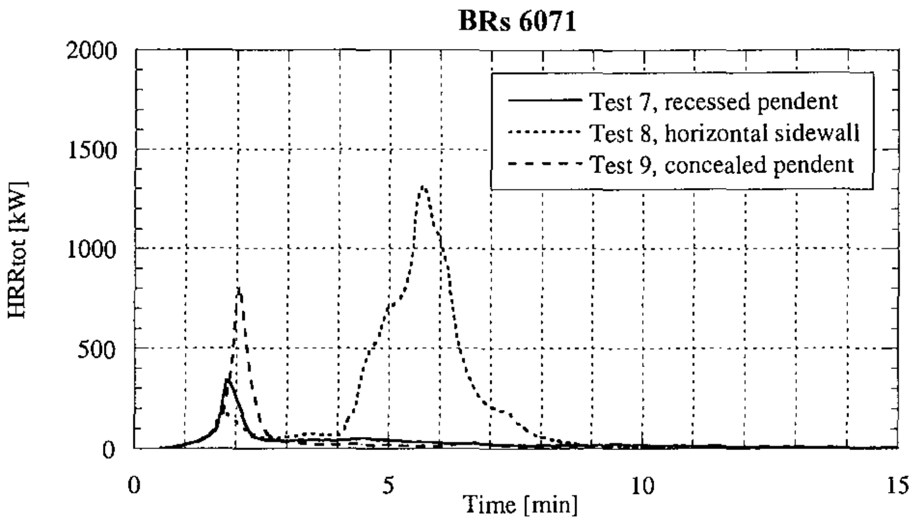


Figure 4 *Total heat release rate histories for the sprinkler tests where ignition took place at the seat, close to the bottom of the backrest of the chair.*

4 Discussion and conclusions

The primary objective was to compare the initial fire development of a non-sprinklered living room fire scenario, fitted with non-combustible wall and ceiling linings, with the same room having combustible linings and being protected residential sprinklers.

Under the premises given above and based on these tests, it can be concluded that residential sprinklers will reduce the severity of the fire compared to the non-sprinklered case. However, the test results are a reminder that every fire scenario cannot be expected to be controlled, nor suppressed and indicate that the performance is very dependent on the type of sprinkler and the way a fire starts.

During the first three sprinkler tests the fire was allowed to involve the combustible wall panelling prior to the activation of the sprinkler. In addition, the upholstered chair itself prevented the water spray from directly hitting the base of the fire, which makes the scenario very challenging, although not unique in a real case situation. It may be the case that the use of the Furniture Calorimeter to some extent influences the outcome of the tests, as it generates a draft of fresh air to the fire. This potential influence was never investigated, however, no particular wind velocity was observed near or around the fire.

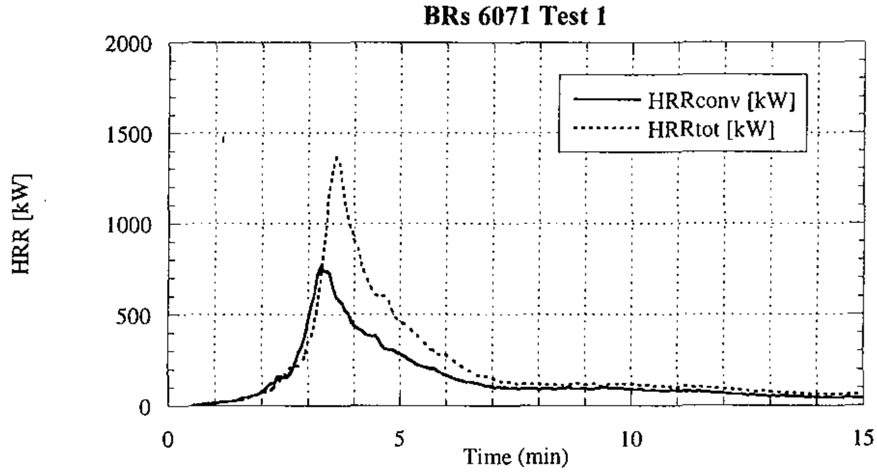
The results shows that the recessed pendent sprinkler activated at an earlier stage of the fire compared to the other two type sprinklers and managed to reasonably well reduce the fire development as well as the ceiling temperatures. The horizontal sidewall sprinkler activated at a later stage, and was able to initially suppress the fire. However, the fire redeveloped, spread up the corner walls and burned very intensely.

The concealed type sprinkler activated at a very late stage, with limited effect on the fire and with severe fire damage to the wall and ceiling lining. The results indicate that these sprinklers require to be designed for a higher initial discharge density than used in these tests to be able to handle the tested scenario.

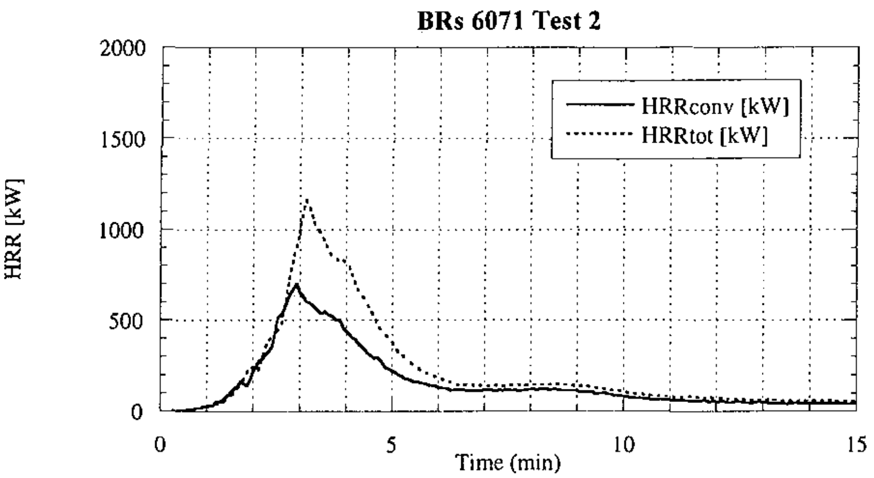
For the three tests where the water spray directly could reach the seat of the fire, the fire was immediately suppressed. However, for one of these tests, the test with the horizontal sidewall sprinkler the fire spread under the seat of the chair, where water could not reach. Gradually the fire redeveloped, spread up the corner walls and did not decline until the chair was more or less consumed. The fact that this occurred with the horizontal sidewall sprinkler was probably only a coincidence and cannot be related to this specific type sprinkler.

The outcome of the work presented within this report, along with expected future work, will serve as a baseline for the development of a recommendation regarding the installation and design of residential sprinklers for Swedish conditions.

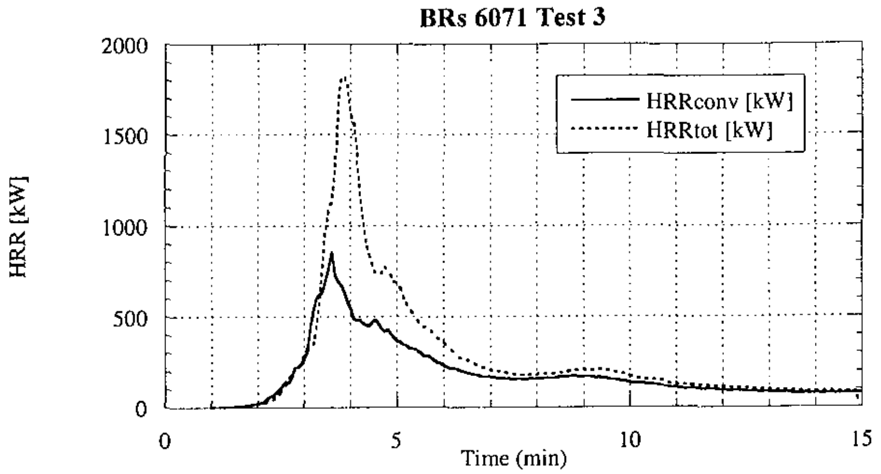
Appendix A

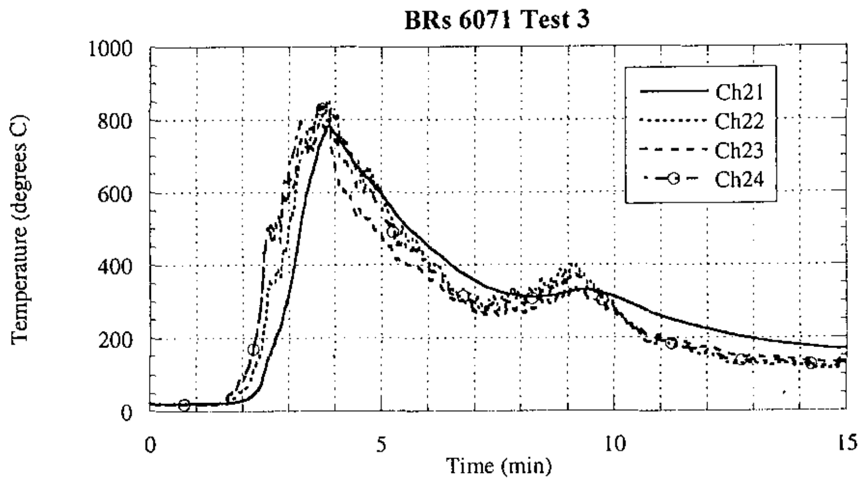


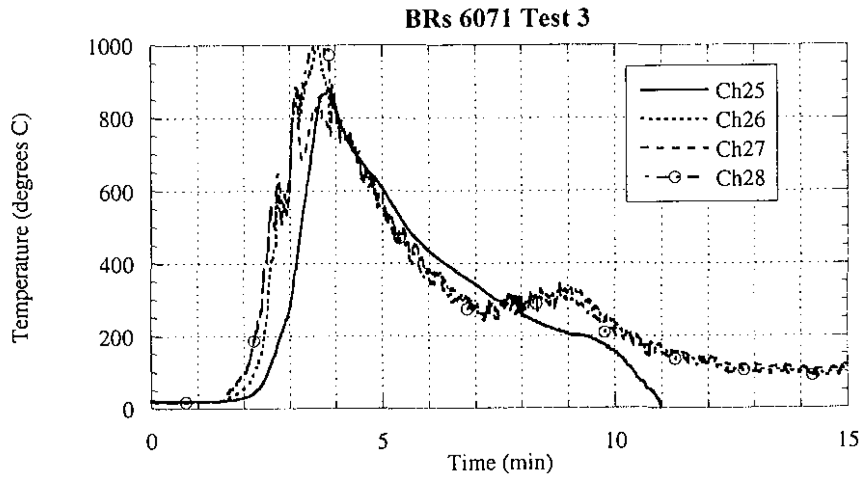
No temperature measurements were conducted during test 1 as the chair was positioned directly under the calorimeter.

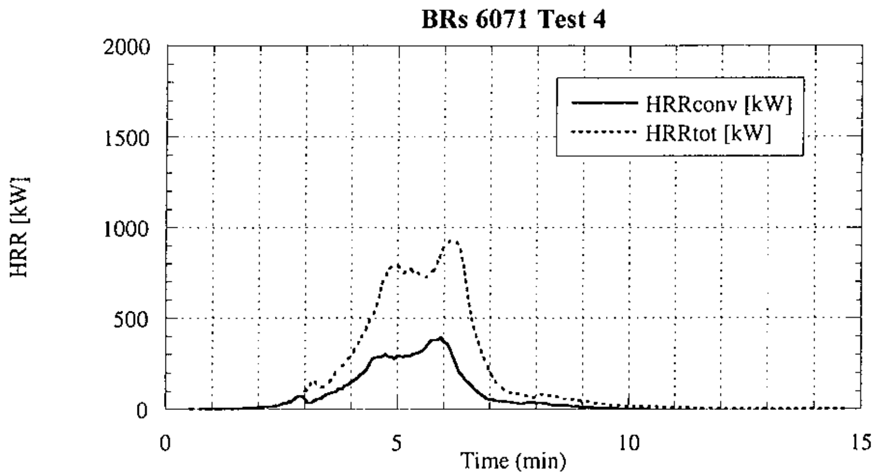


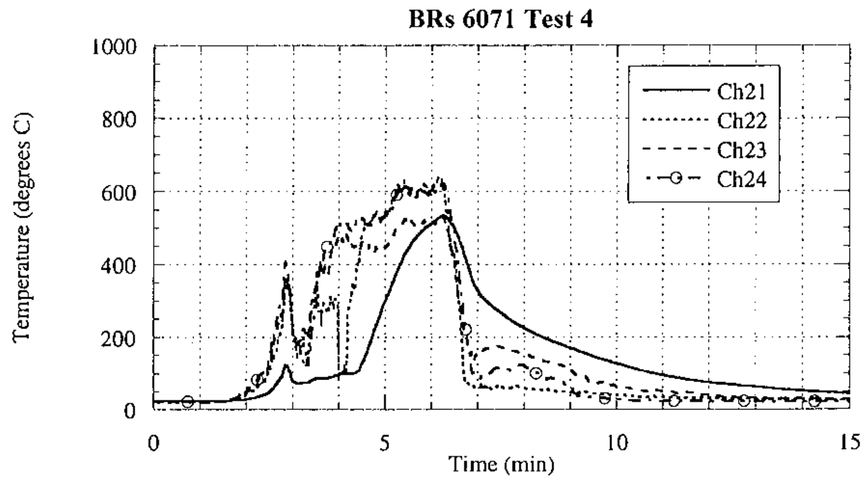
No temperature measurements were conducted during test 2 as the chair was positioned directly under the calorimeter.

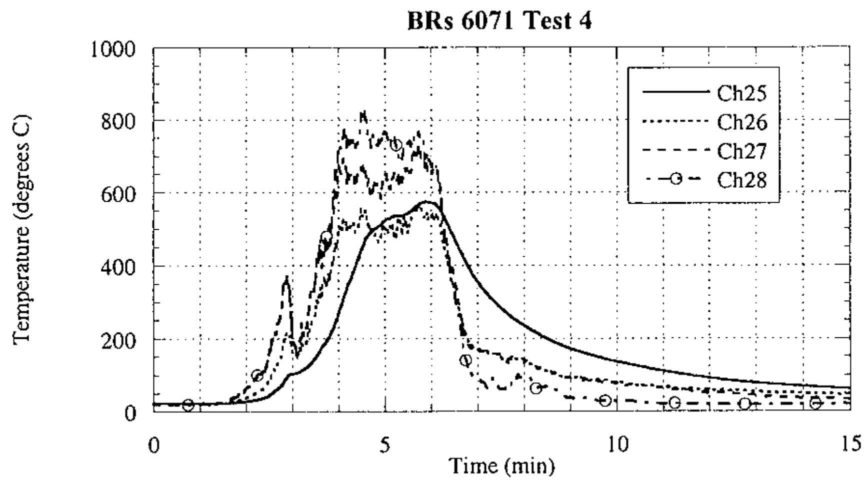

BRs 6071 Test 3
HRR [kW]
2000
1500
1000
500
0
0
5
10
15
Time (min)
HRRconv [kW]
HRRtot [kW]

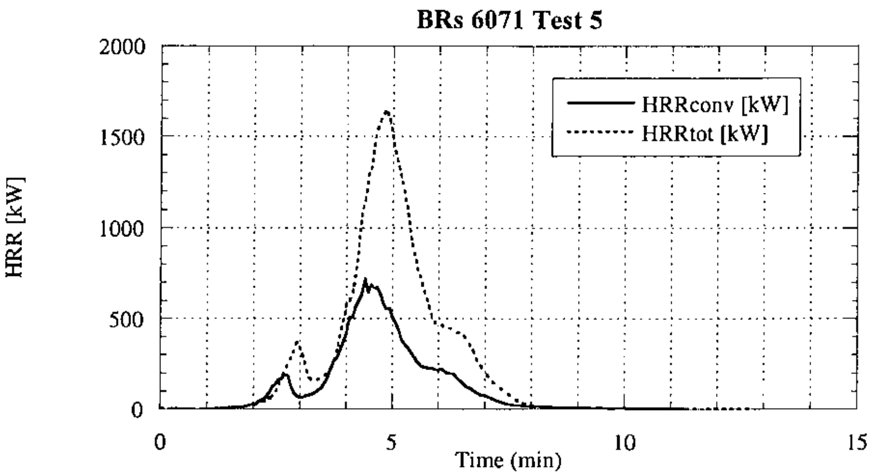

BRs 6071 Test 3
Temperature (degrees C)
1000
800
600
400
200
0
0
5
10
15
Time (min)
Ch21
Ch22
Ch23
Ch24

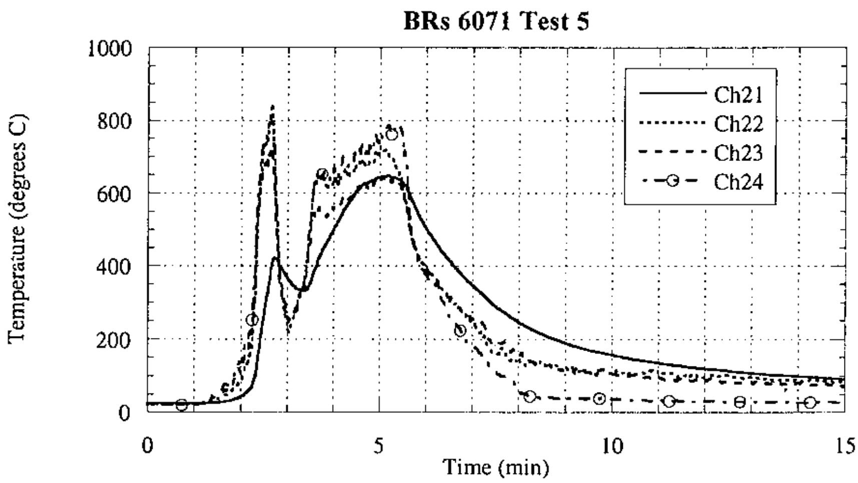

BRs 6071 Test 3
Temperature (degrees C)
1000
800
600
400
200
0
0
5
10
15
Time (min)
Ch25
Ch26
Ch27
Ch28

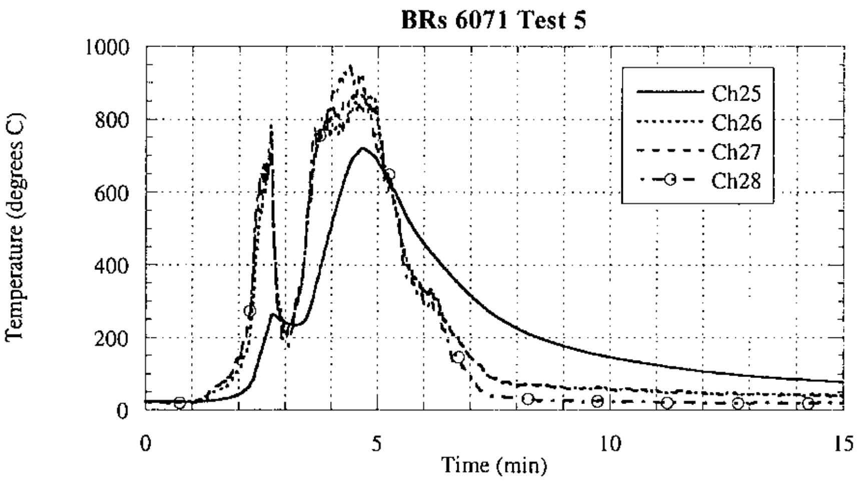

BRs 6071 Test 4
2000
1500
1000
500
0
HRR [kW]
HRRconv [kW]
HRRtot [kW]
0
5
10
15
Time (min)

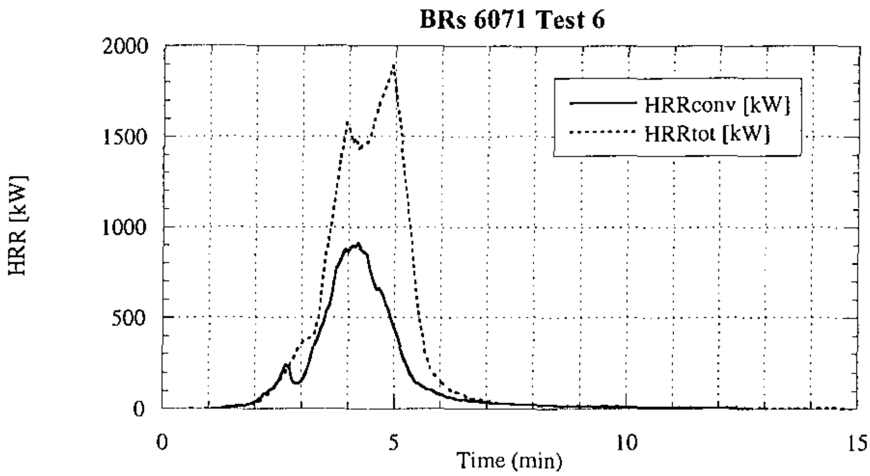

BRs 6071 Test 4
1000
800
600
400
200
0
Temperature (degrees C)
Ch21
Ch22
Ch23
Ch24
0
5
10
15
Time (min)

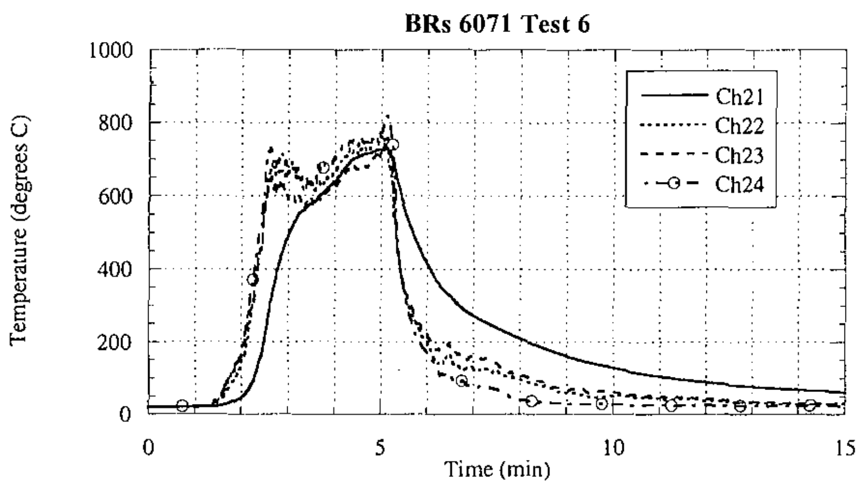

BRs 6071 Test 4
1000
800
600
400
200
0
Temperature (degrees C)
Ch25
Ch26
Ch27
Ch28
0
5
10
15
Time (min)

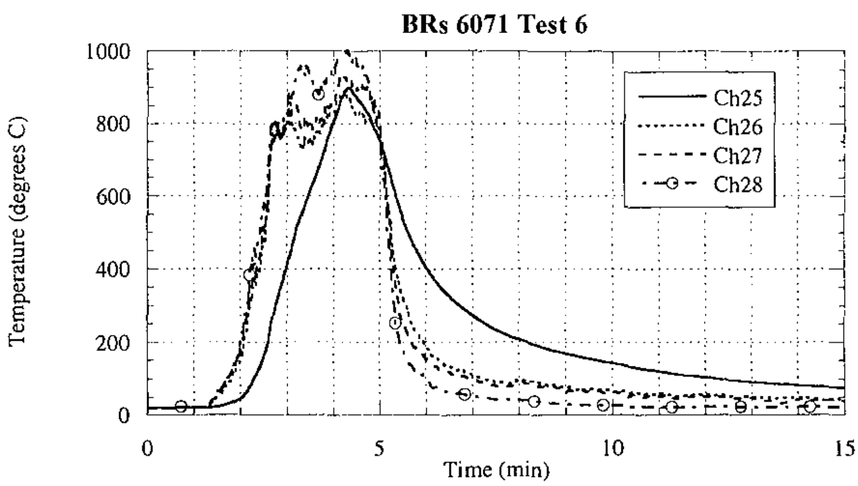

BRs 6071 Test 5
HRR [kW]
HRRconv [kW]
HRRtot [kW]
2000
1500
1000
500
0
0
5
10
15
Time (min)

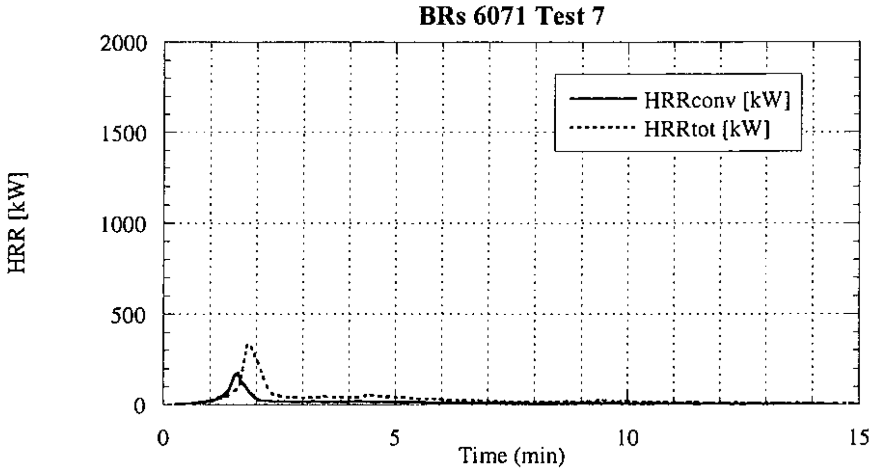

BRs 6071 Test 5
Temperature (degrees C)
Ch21
Ch22
Ch23
Ch24
1000
800
600
400
200
0
0
5
10
15
Time (min)


BRs 6071 Test 5
Temperature (degrees C)
Ch25
Ch26
Ch27
Ch28
1000
800
600
400
200
0
0
5
10
15
Time (min)

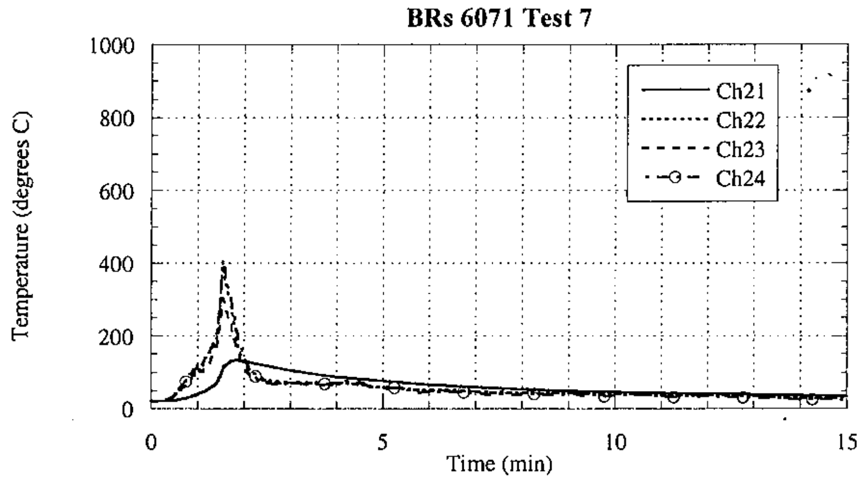

BRs 6071 Test 6
HRR [kW]
HRRconv [kW]
HRRtot [kW]
2000
1500
1000
500
0
0
5
10
15
Time (min)


BRs 6071 Test 6
Temperature (degrees C)
Ch21
Ch22
Ch23
Ch24
1000
800
600
400
200
0
0
5
10
15
Time (min)

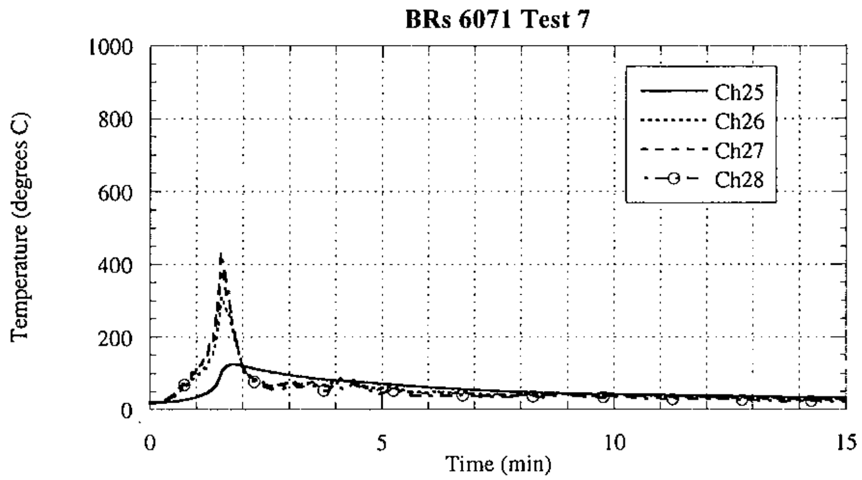

BRs 6071 Test 6
Temperature (degrees C)
Ch25
Ch26
Ch27
Ch28
1000
800
600
400
200
0
0
5
10
15
Time (min)



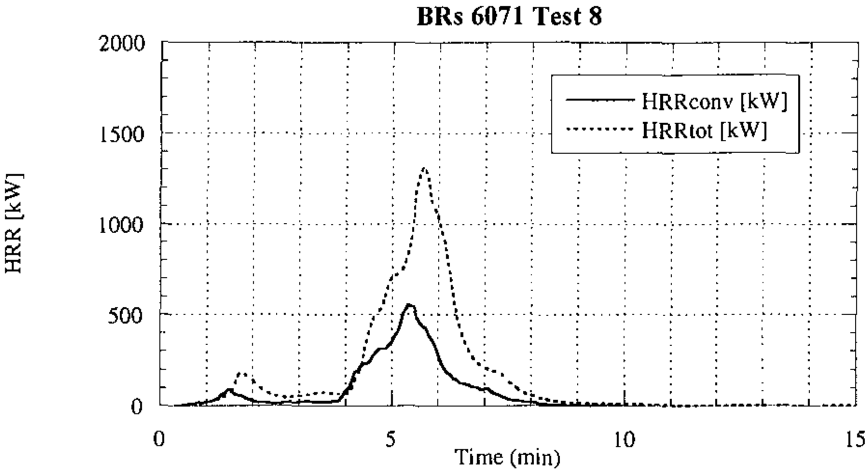
BRs 6071 Test 7
HRR [kW]
2000
1500
1000
500
0
HRRconv [kW]
HRRtot [kW]
0
5
10
15
Time (min)

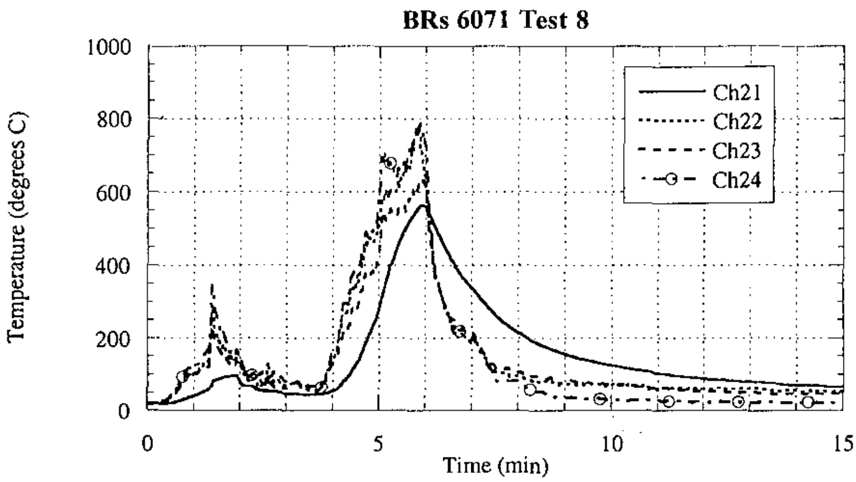


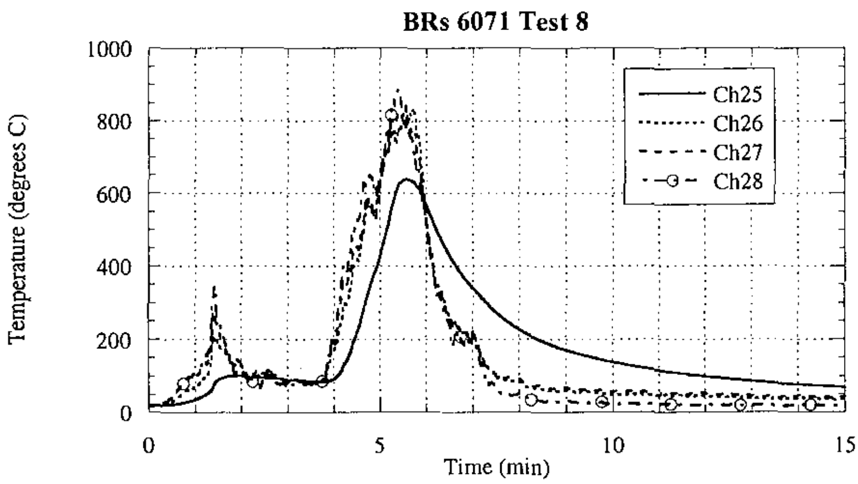
BRs 6071 Test 7
Temperature (degrees C)
1000
800
600
400
200
0
Ch21
Ch22
Ch23
Ch24
0
5
10
15
Time (min)

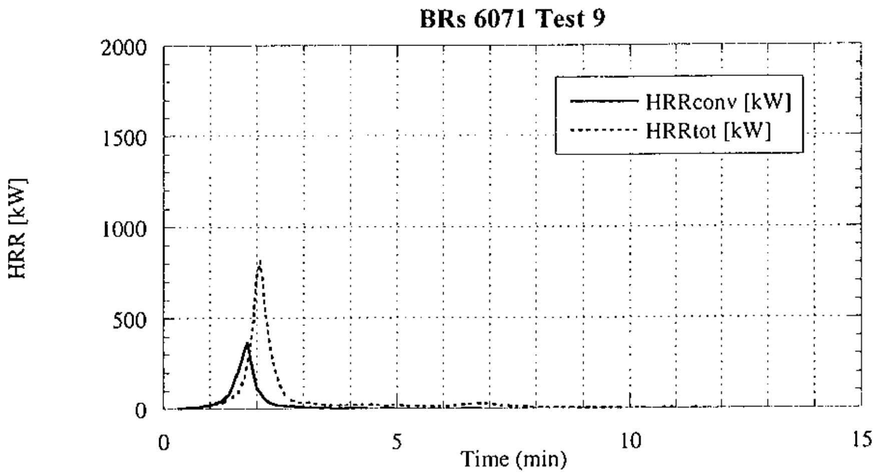


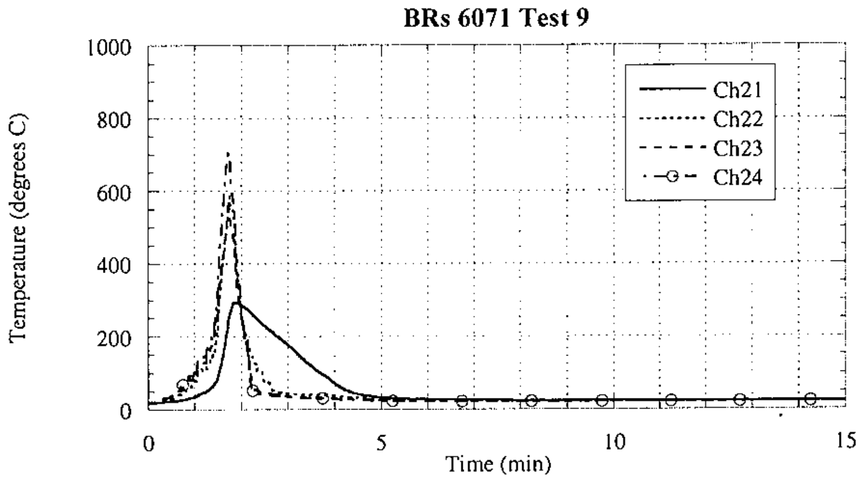
BRs 6071 Test 7
Temperature (degrees C)
1000
800
600
400
200
0
Ch25
Ch26
Ch27
Ch28
0
5
10
15
Time (min)

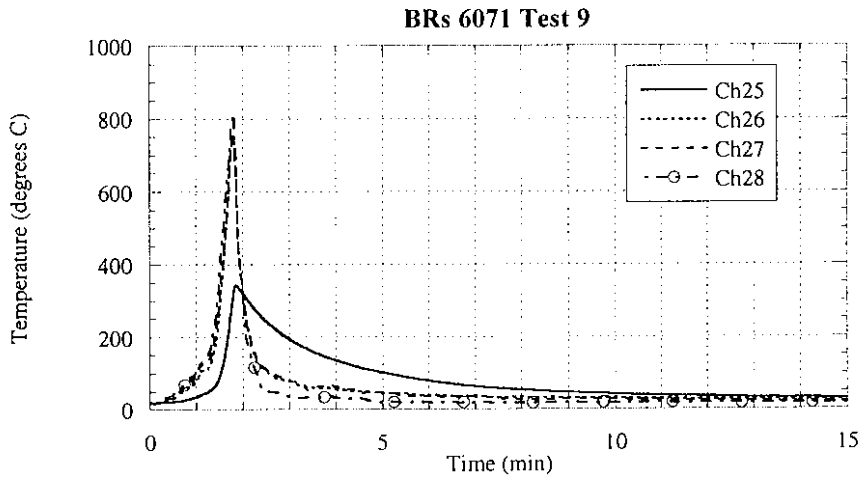

BRs 6071 Test 8
HRR [kW]
2000
1500
1000
500
0
HRRconv [kW]
HRRtot [kW]
0
5
10
15
Time (min)


BRs 6071 Test 8
Temperature (degrees C)
1000
800
600
400
200
0
Ch21
Ch22
Ch23
Ch24
0
5
10
15
Time (min)


BRs 6071 Test 8
Temperature (degrees C)
1000
800
600
400
200
0
Ch25
Ch26
Ch27
Ch28
0
5
10
15
Time (min)


BRs 6071 Test 9
HRRconv [kW]
HRRtot [kW]
HRR [kW]
Time (min)
2000
1500
1000
500
0
0
5
10
15


BRs 6071 Test 9
Ch21
Ch22
Ch23
Ch24
Temperature (degrees C)
Time (min)
1000
800
600
400
200
0
0
5
10
15


BRs 6071 Test 9
Ch25
Ch26
Ch27
Ch28
Temperature (degrees C)
Time (min)
1000
800
600
400
200
0
0
5
10
15

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