Bauforschung

Entwicklung eines Prüfverfahrens zur Beurteilung des Brandverhaltens von Baustoffen

Abschlußbericht Tl. 2
Versuchsergebnisse, Vorversuche

T 2818/2

Fraunhofer IRB Verlag

Dieser Forschungsbericht wurde mit modernsten Hochleistungskopierern auf Einzelanfrage hergestellt.

Die Originalmanuskripte wurden reprotechnisch, jedoch nicht inhaltlich überarbeitet. Die Druckqualität hängt von der reprotechnischen Eignung des Originalmanuskriptes ab, das uns vom Autor bzw. von der Forschungsstelle zur Verfügung gestellt wurde.

Im Originalmanuskript enthaltene Farbvorlagen, wie z.B. Farbfotos, können nur in Grautönen wiedergegeben werden. Liegen dem Fraunhofer IRB Verlag die Originalabbildungen vor, können gegen Berechnung Farbkopien angefertigt werden. Richten Sie Ihre Anfrage bitte an die untenstehende Adresse.

1998, ISBN 3-8167-5505-4

Fraunhofer IRB Verlag
Fraunhofer-Informationszentrum Raum und Bau

Postfach 80 04 69
70504 Stuttgart

Nobelstraße 12
70569 Stuttgart

Telefon (07 11) 9 70 - 25 00
Telefax (07 11) 9 70 - 25 08

e-mail irb@irb.fhg.de

URL http://www.irb.fhg.de

Entwicklung eines Prüfverfahrens zur Beurteilung des Brandverhaltens von Baustoffen

Abschlußbericht Teil 2

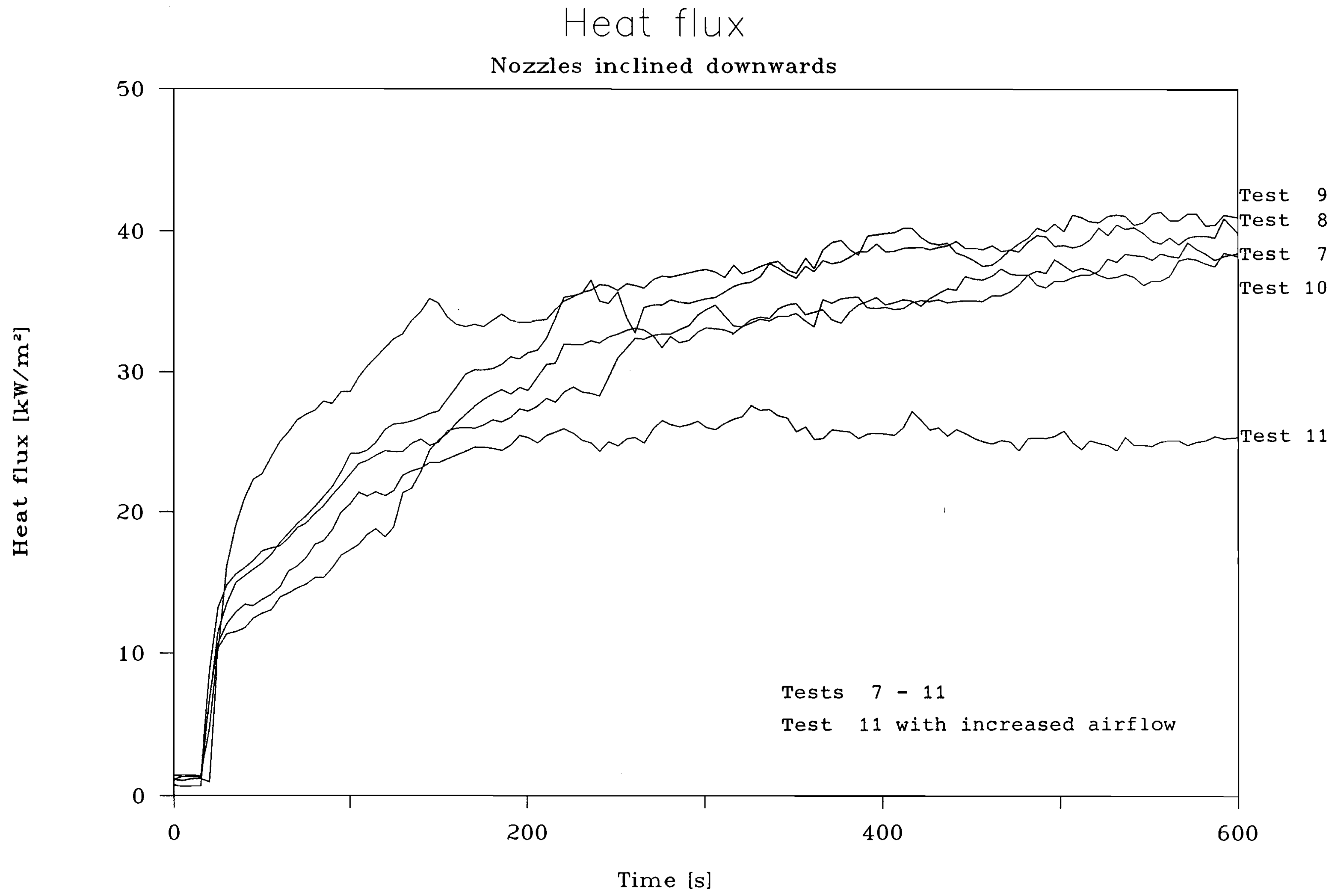
Versuchsergebnisse - Vorversuche

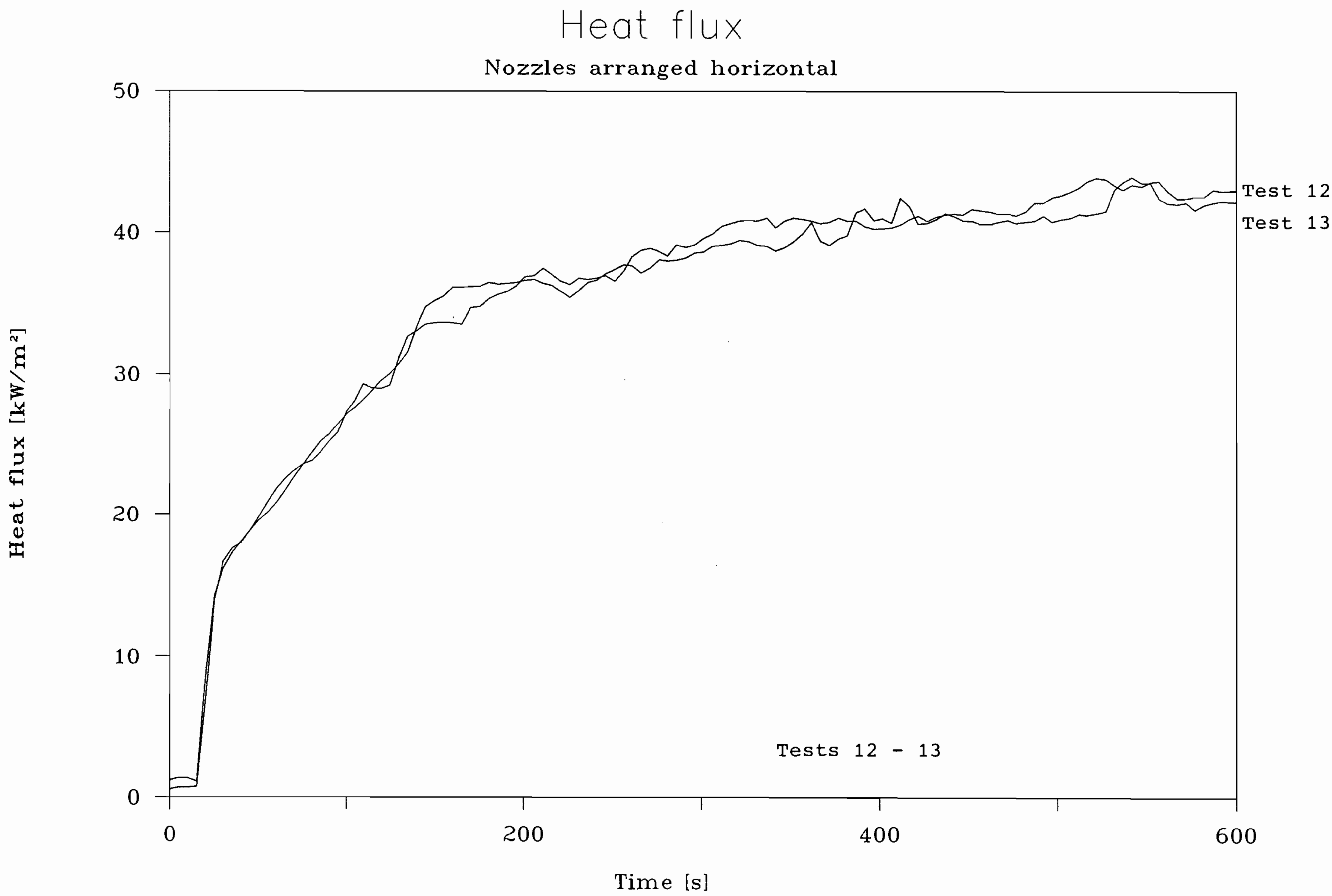
Materialprüfungsamt NRW

Dezember 1997

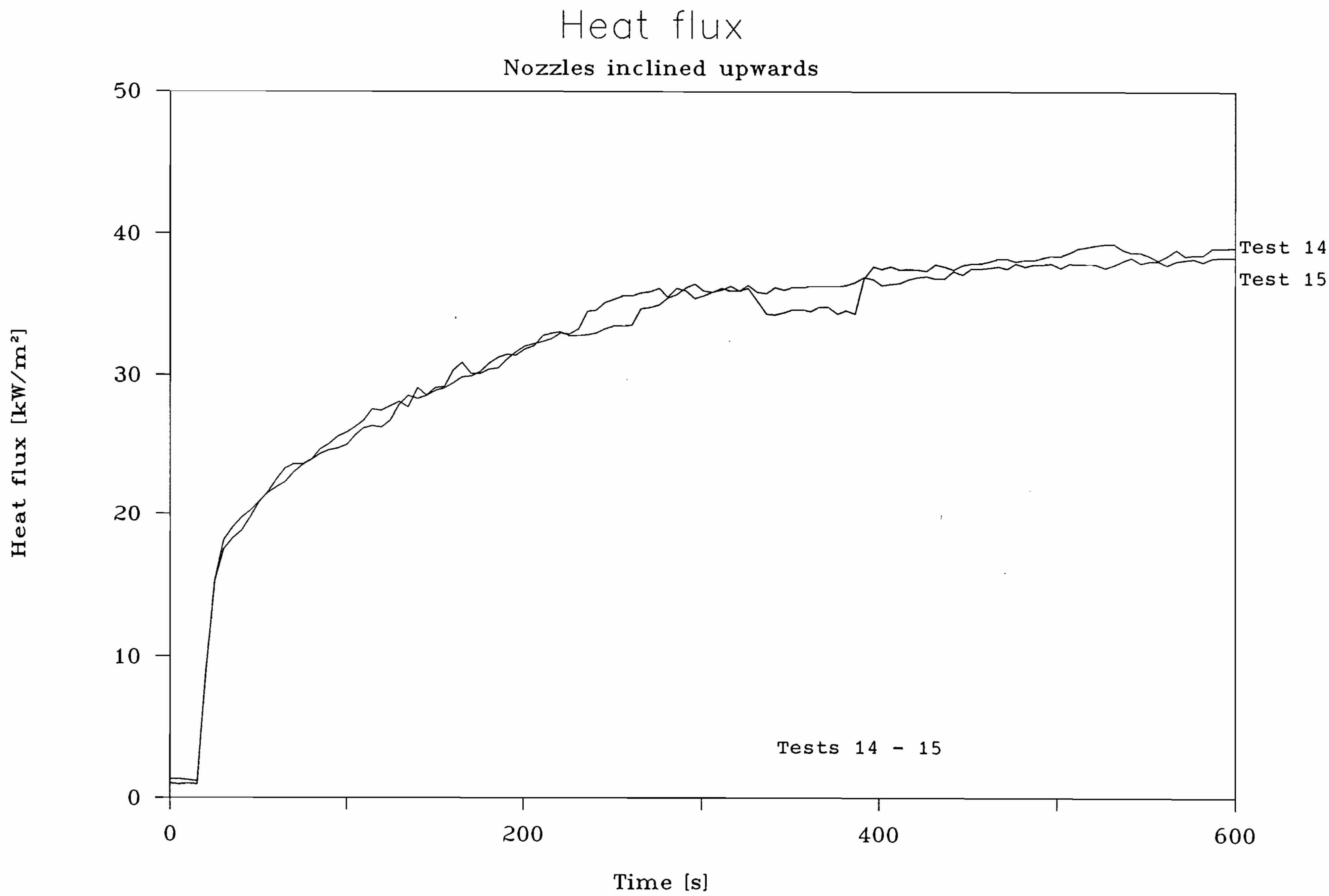
Abschnitt 1

Untersuchungen des MPA NRW über die Wärmeflußdichte bei verschiedenen Brennern


Heat flux
Nozzles inclined downwards
Heat flux [kW/m²]
50
40
30
20
10
0
200
400
600
Time [s]
Test 9
Test 8
Test 7
Test 10
Test 11
Tests 7 - 11
Test 11 with increased airflow

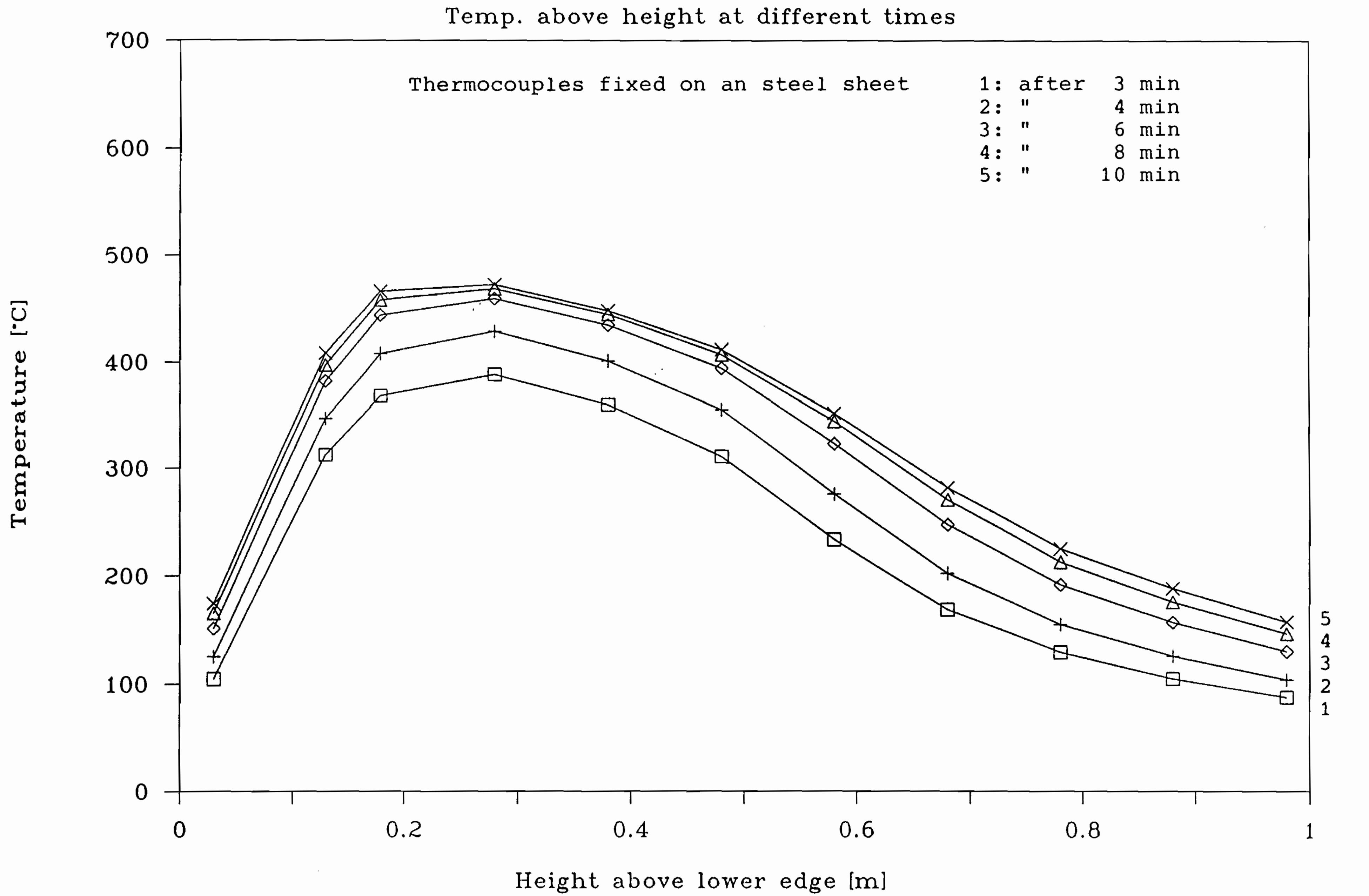


Heat flux
Nozzles arranged horizontal
Heat flux [kW/m²]
0
10
20
30
40
50
0
200
400
600
Time [s]
Test 12
Test 13
Tests 12 - 13

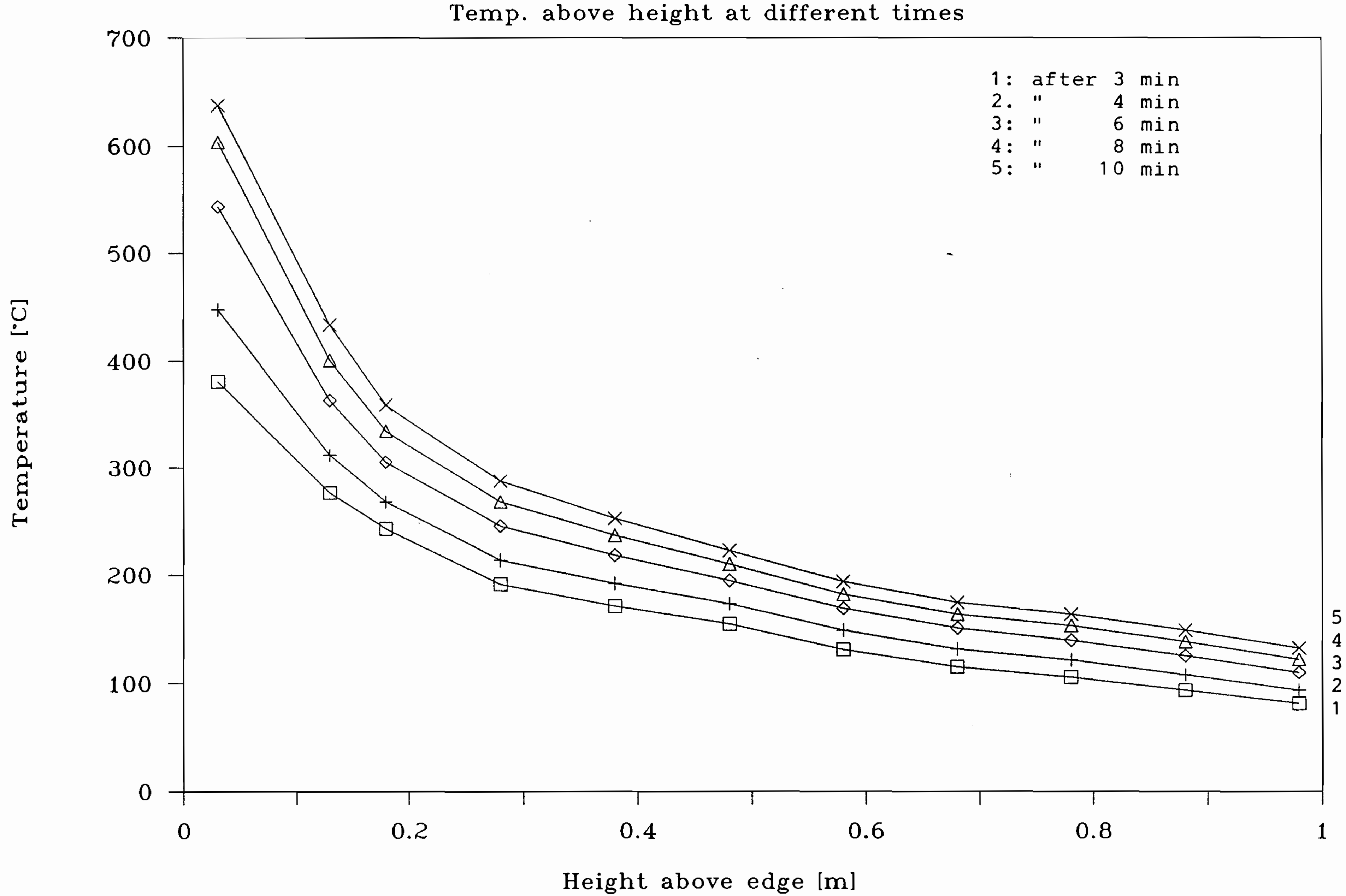


Heat flux
Nozzles inclined upwards
Heat flux [kW/m²]
50
40
30
20
10
0
200
400
600
Time [s]
Test 14
Test 15
Tests 14 - 15

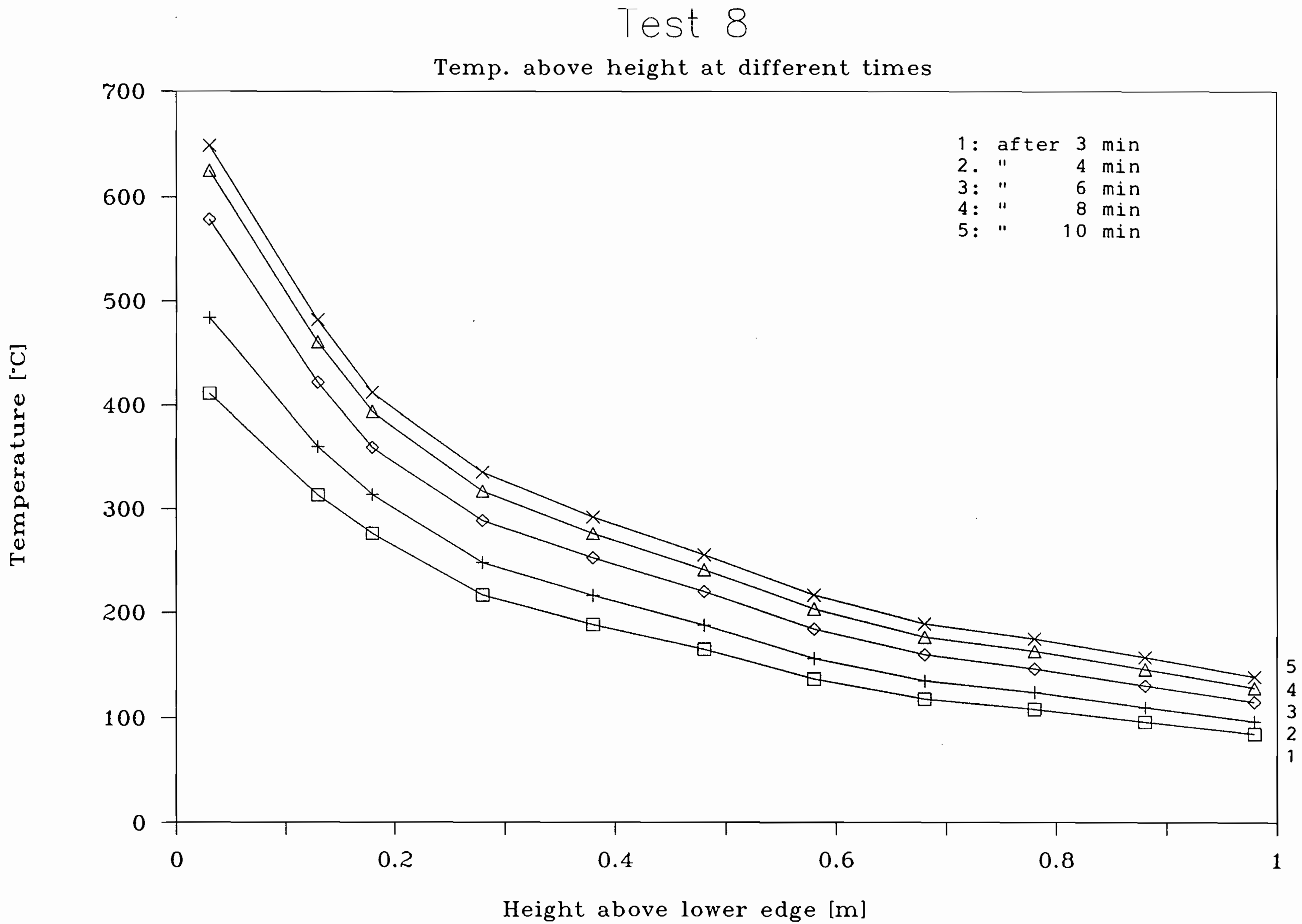
Test 6


Temp. above height at different times
Thermocouples fixed on an steel sheet
1: after 3 min
2: " 4 min
3: " 6 min
4: " 8 min
5: " 10 min
Temperature [°C]
700
600
500
400
300
200
100
0
Height above lower edge [m]
0
0.2
0.4
0.6
0.8
1
5
4
3
2
1

Test 7

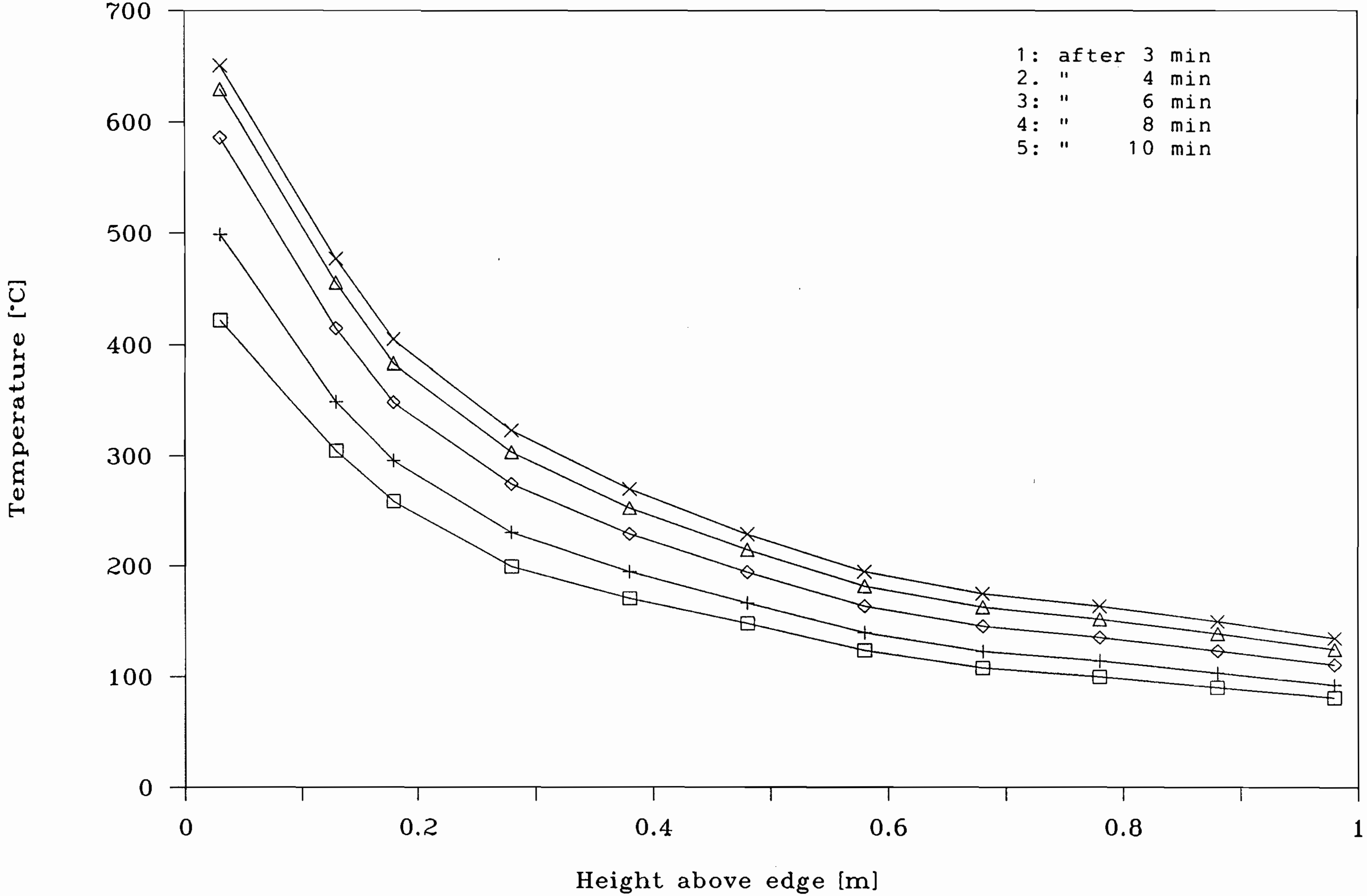


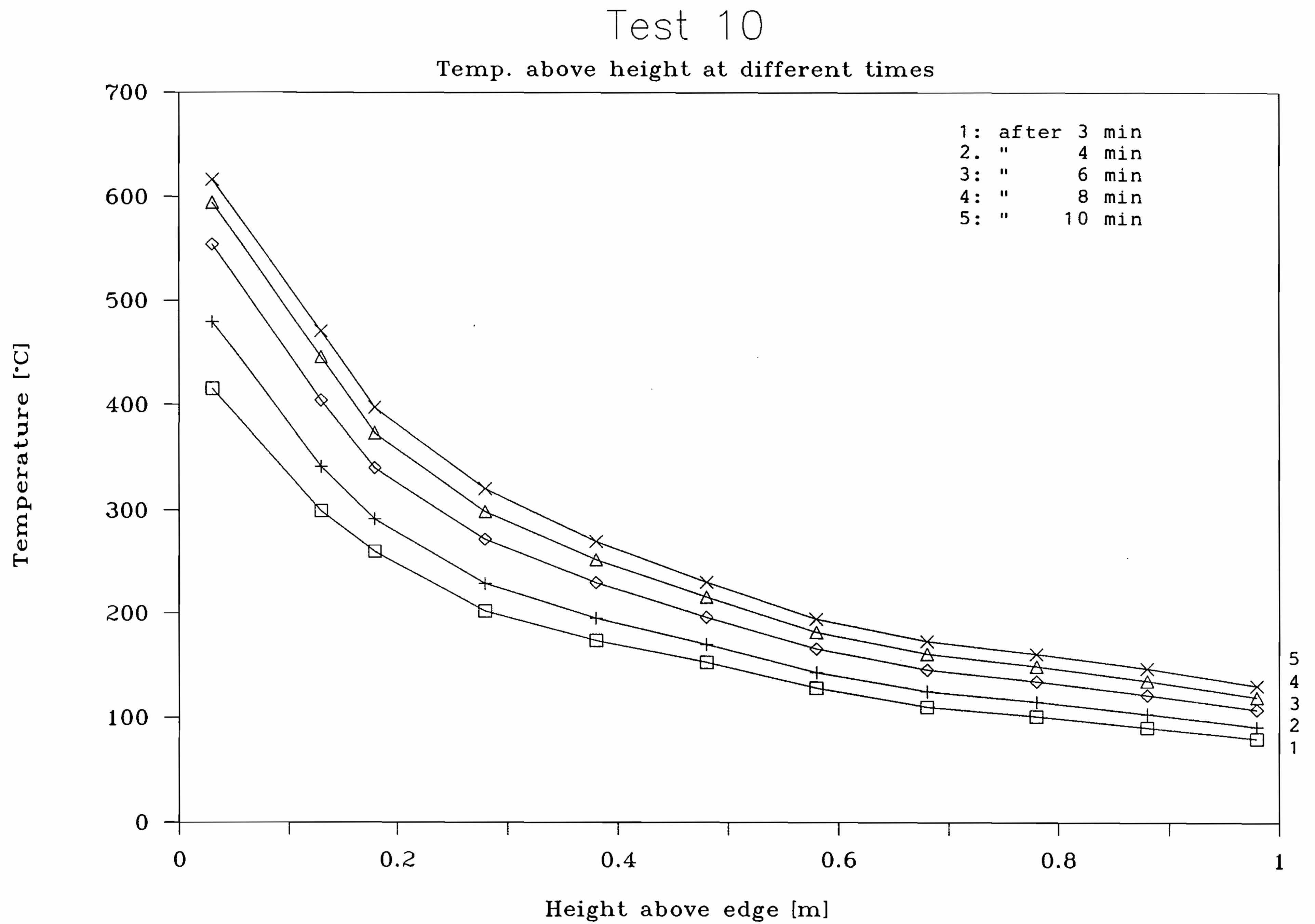
Temp. above height at different times
1: after 3 min
2. " 4 min
3: " 6 min
4: " 8 min
5: " 10 min
Temperature [°C]
Height above edge [m]
0
100
200
300
400
500
600
700
0.2
0.4
0.6
0.8
1
5
4
3
2
1


Test 8
Temp. above height at different times
1: after 3 min
2. " 4 min
3: " 6 min
4: " 8 min
5: " 10 min
Temperature [°C]
Height above lower edge [m]
0
100
200
300
400
500
600
700
0
0.2
0.4
0.6
0.8
1
5
4
3
2
1

Test 9

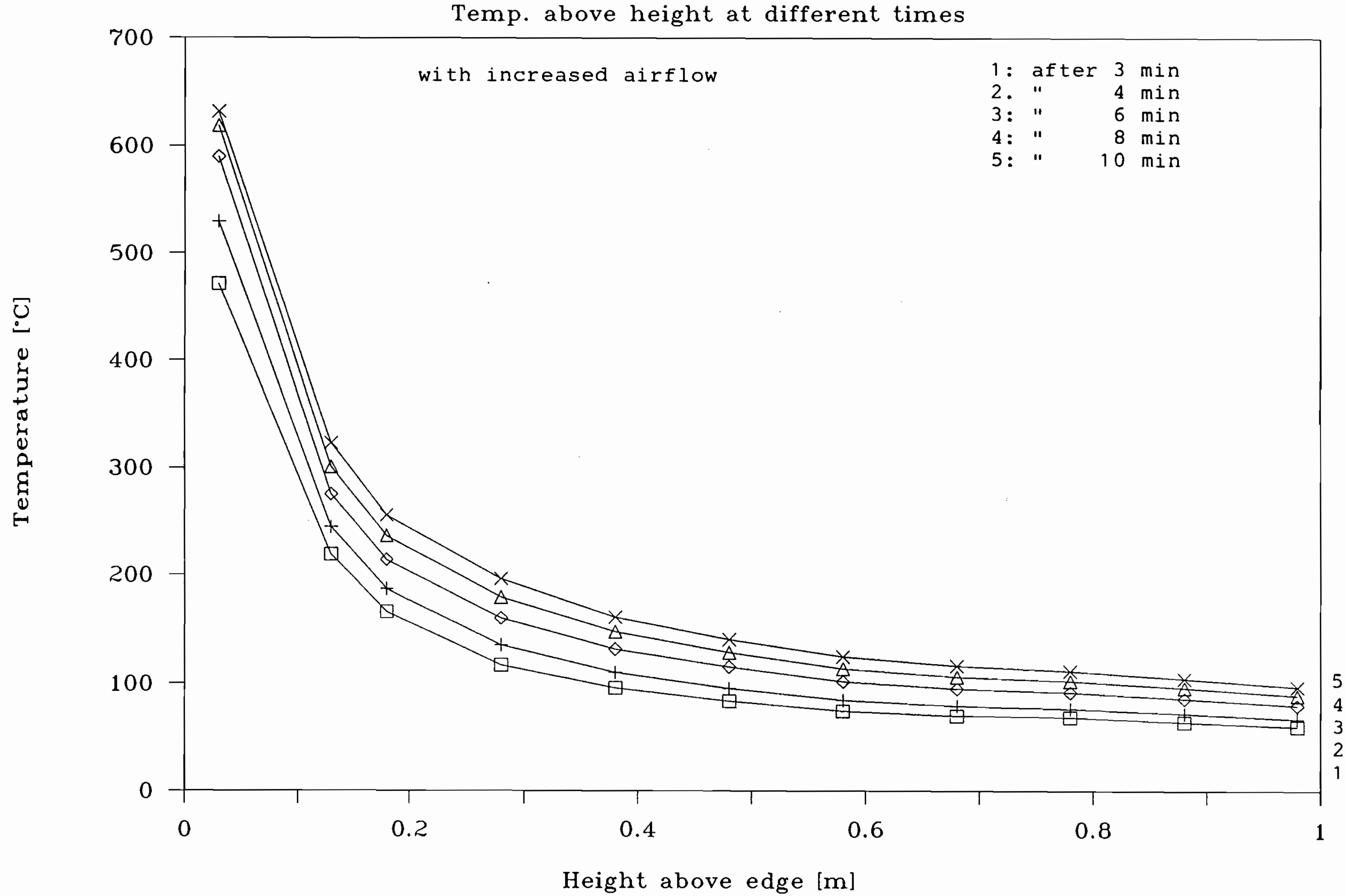
Temp. above height at different times





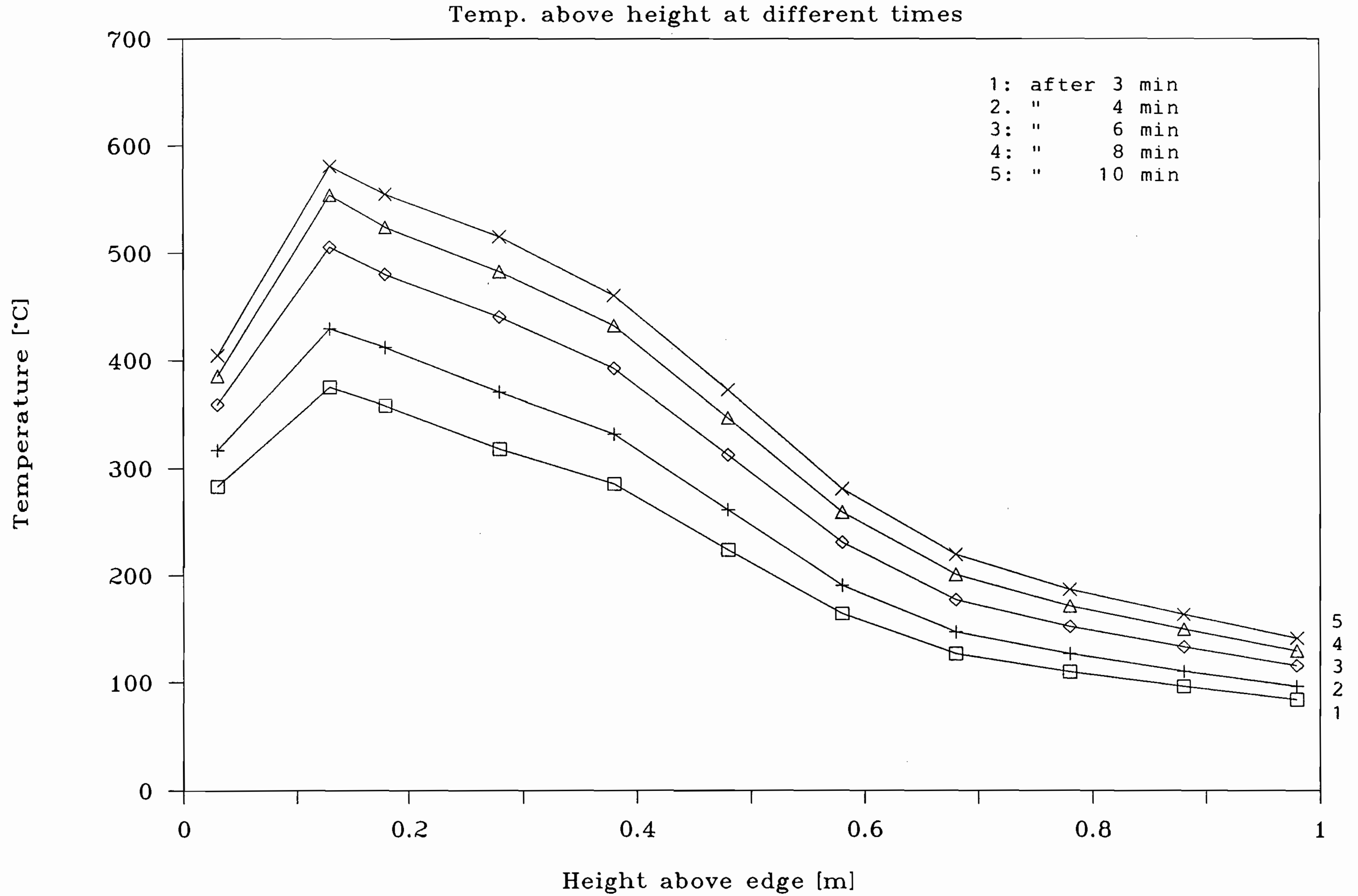
Test 10
Temp. above height at different times
1: after 3 min
2. " 4 min
3: " 6 min
4: " 8 min
5: " 10 min
Temperature [°C]
Height above edge [m]
0
100
200
300
400
500
600
700
0
0.2
0.4
0.6
0.8
1
1
2
3
4
5

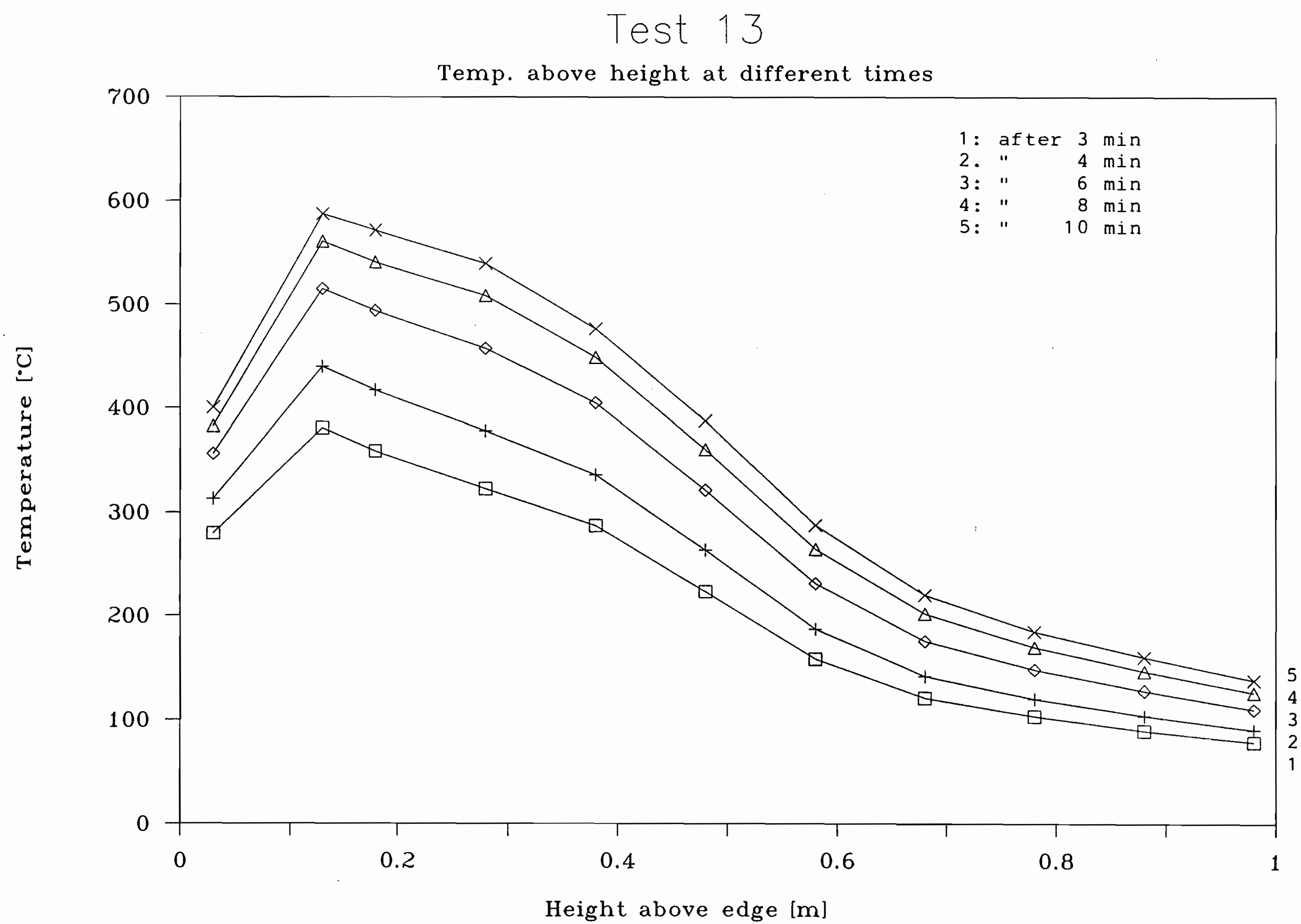
Test 11

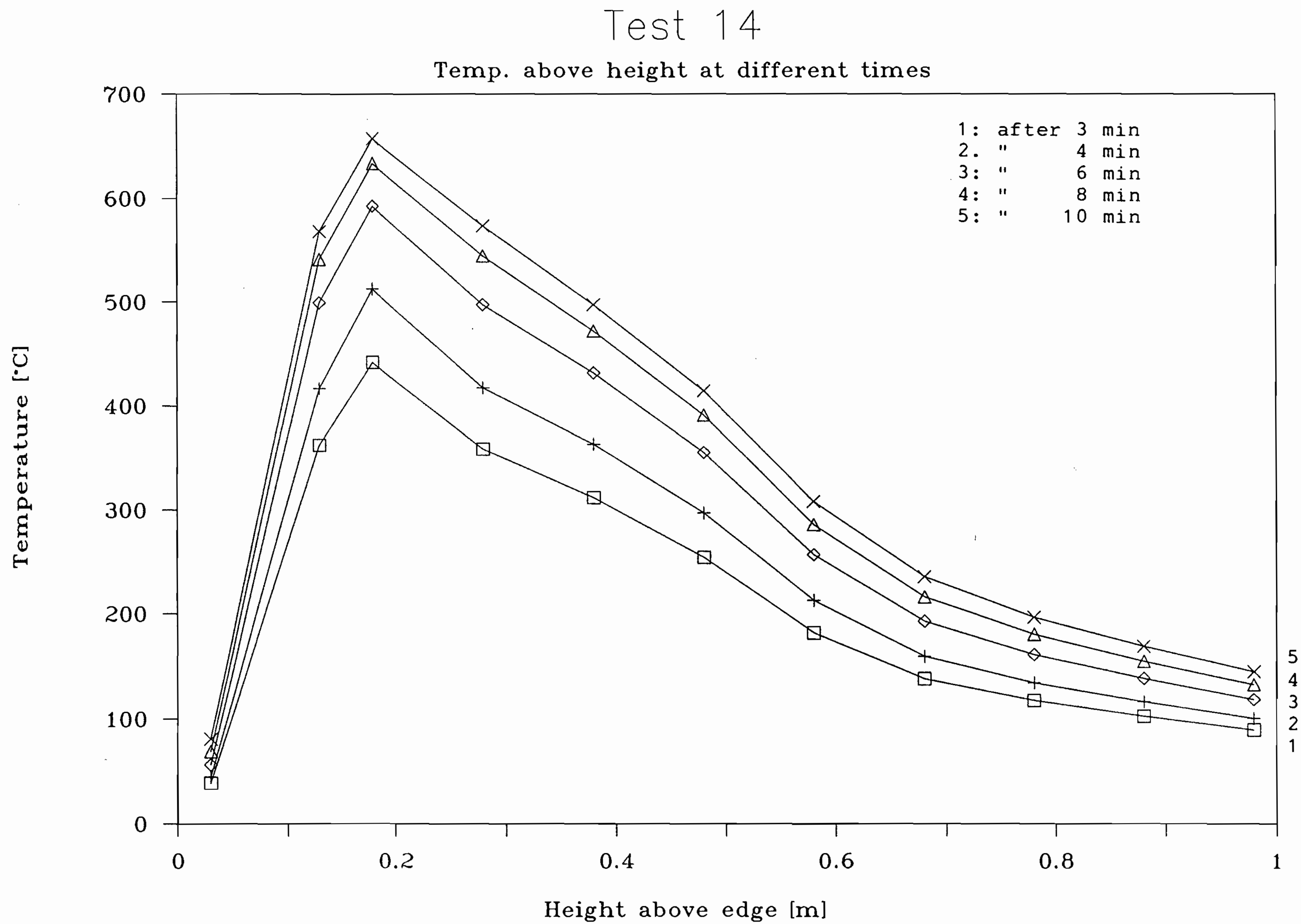


Temp. above height at different times
with increased airflow
1: after 3 min
2. " 4 min
3: " 6 min
4: " 8 min
5: " 10 min
700
600
500
400
300
200
100
0
Temperature [°C]
0
0.2
0.4
0.6
0.8
1
Height above edge [m]
5
4
3
2
1

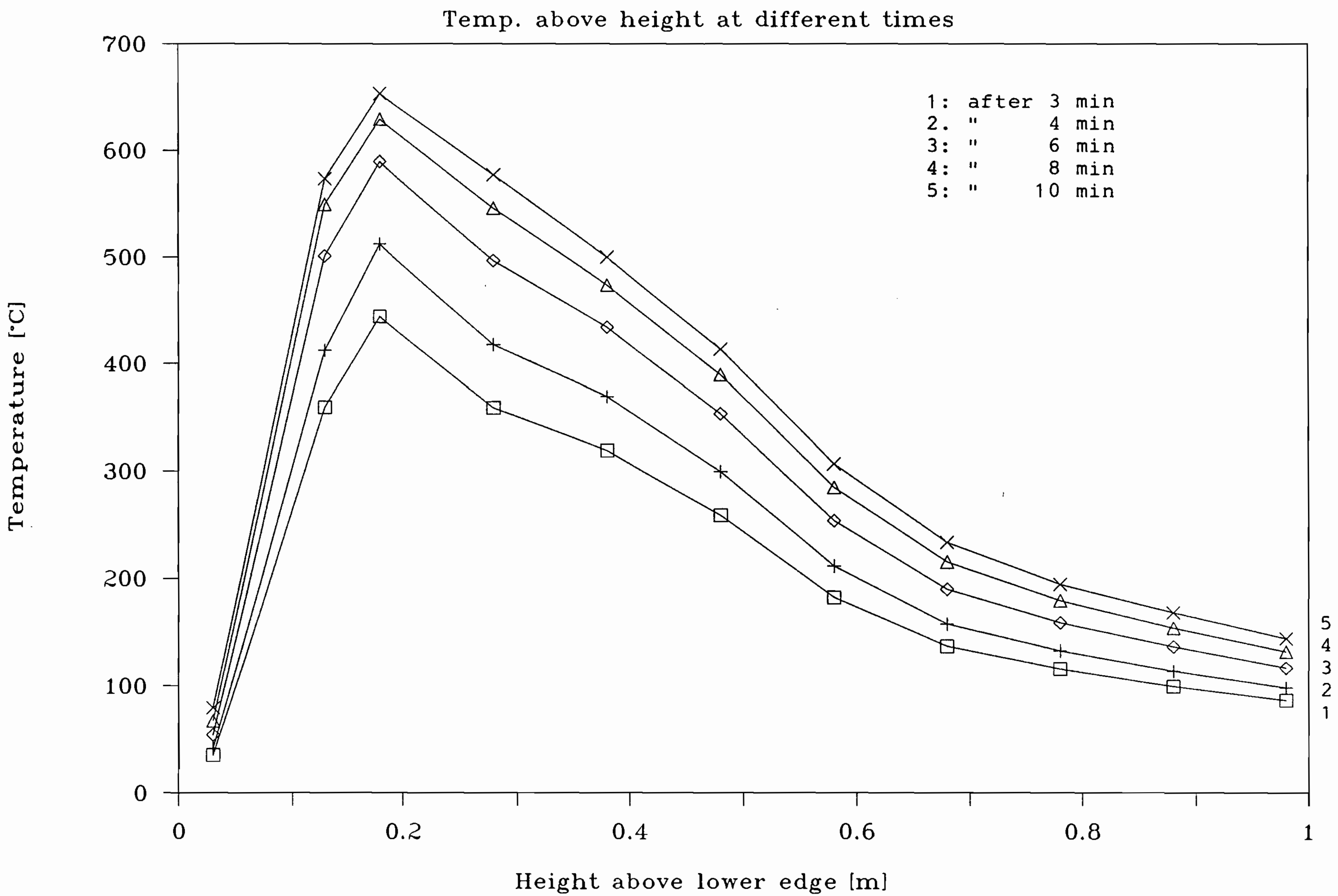
Test 12

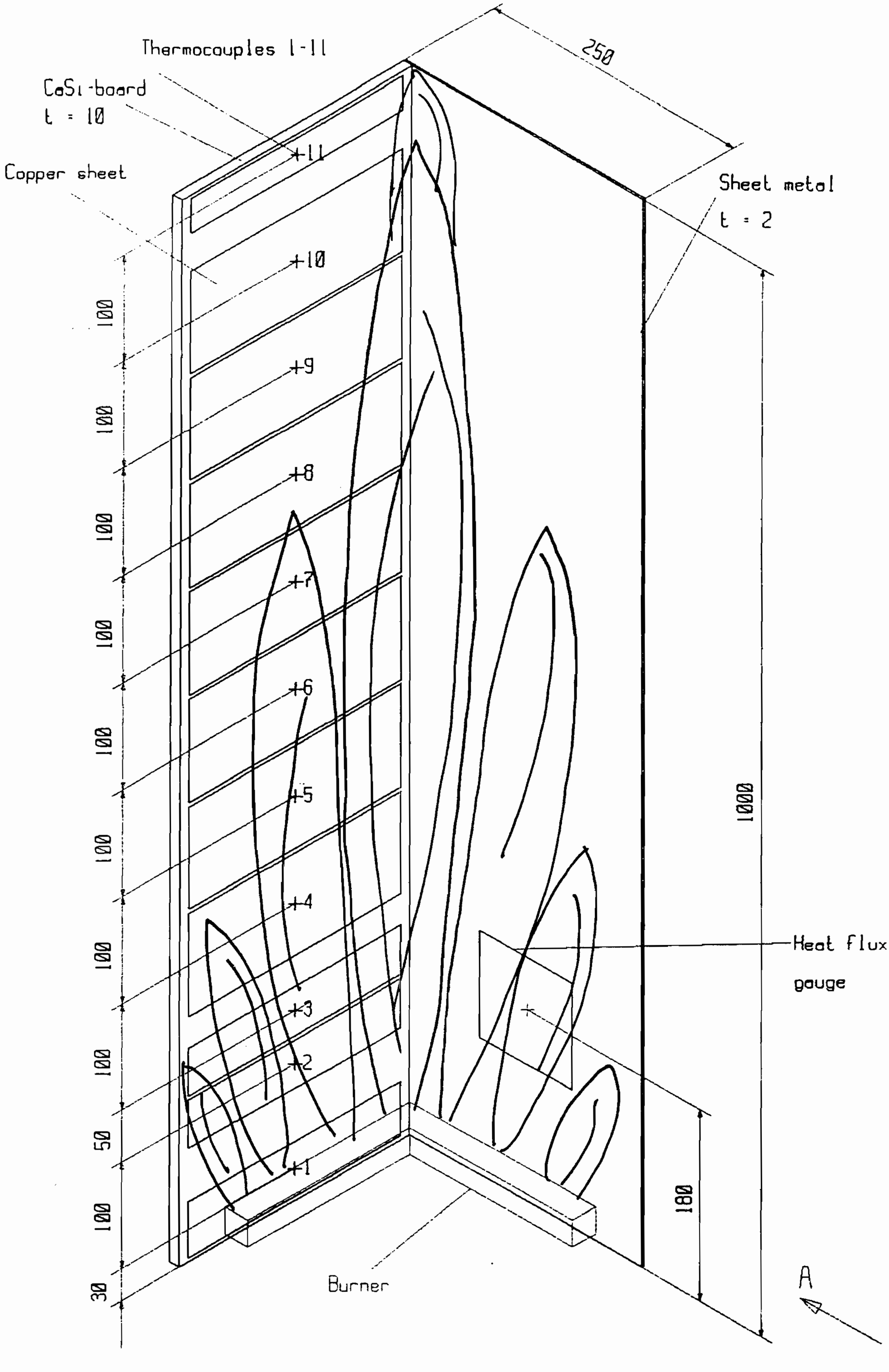

Temp. above height at different times
Temperature [°C]
700
600
500
400
300
200
100
0
1: after 3 min
2. " 4 min
3: " 6 min
4: " 8 min
5: " 10 min
5
4
3
2
1
0
0.2
0.4
0.6
0.8
1
Height above edge [m]


Test 13
Temp. above height at different times
1: after 3 min
2. " 4 min
3: " 6 min
4: " 8 min
5: " 10 min
Temperature [°C]
0
100
200
300
400
500
600
700
Height above edge [m]
0
0.2
0.4
0.6
0.8
1
5
4
3
2
1

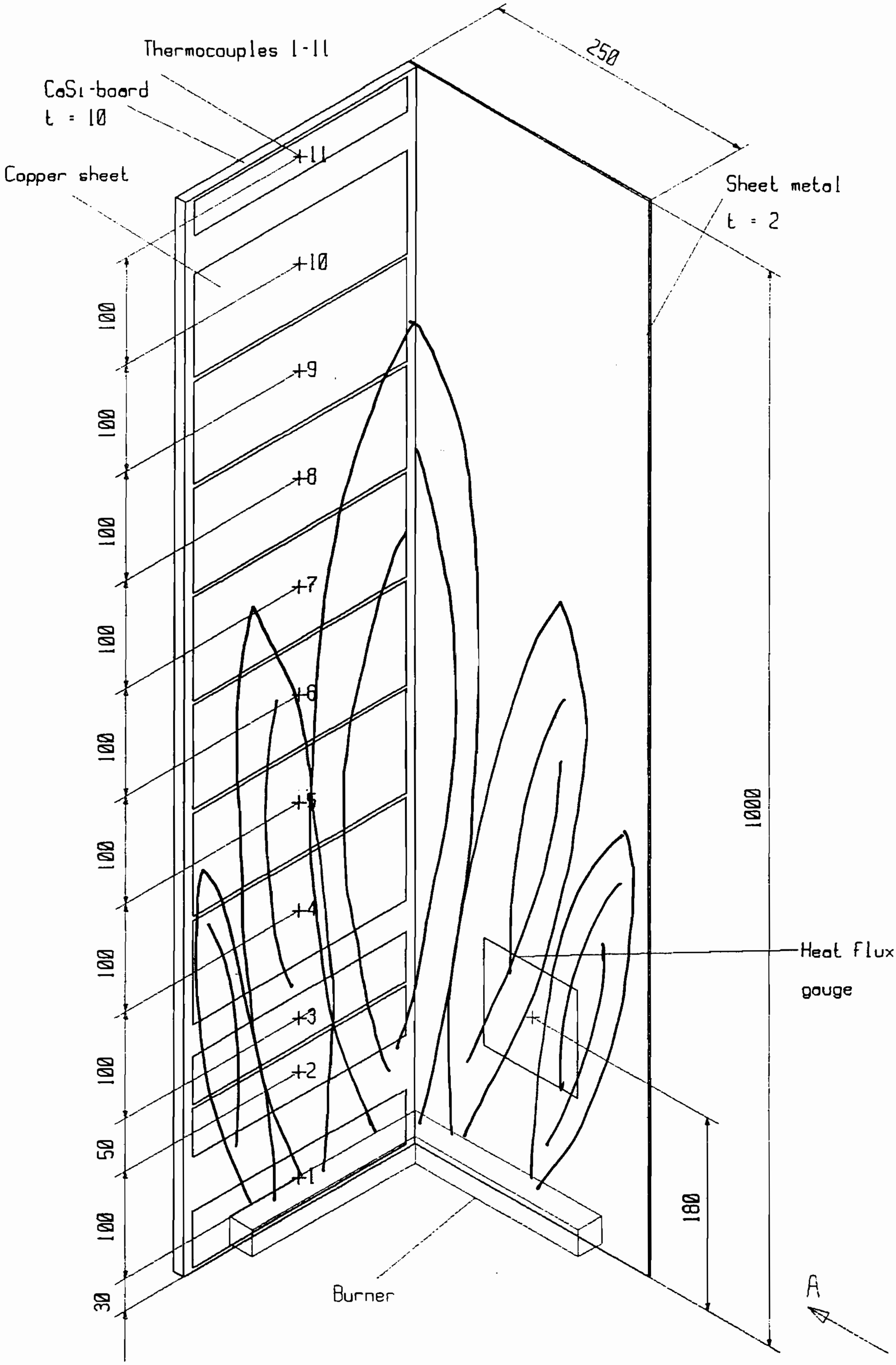

Test 14
Temp. above height at different times
1: after 3 min
2. " 4 min
3: " 6 min
4: " 8 min
5: " 10 min
Temperature [°C]
Height above edge [m]
0
100
200
300
400
500
600
700
0.2
0.4
0.6
0.8
1
5
4
3
2
1

Test 15

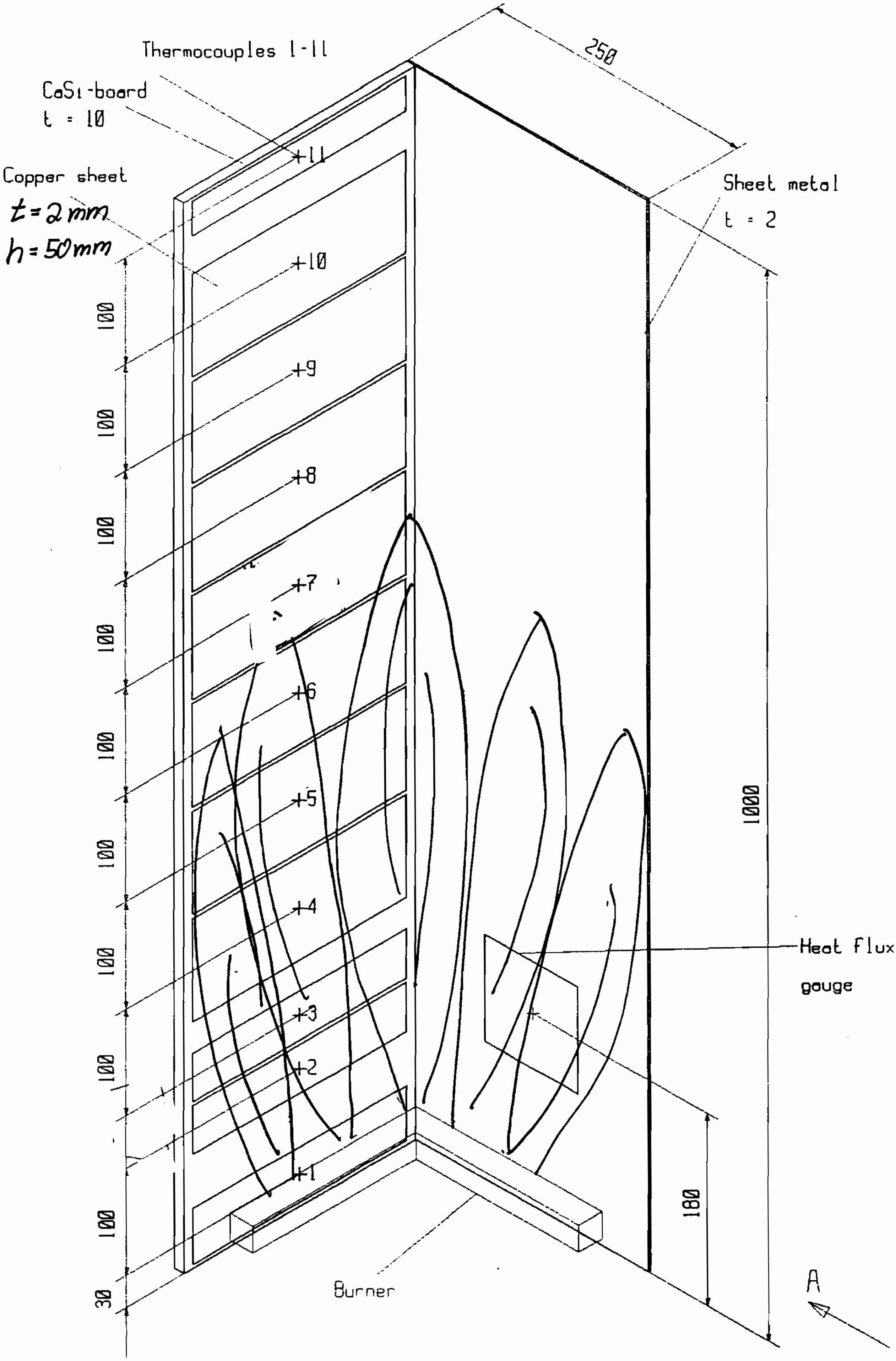

Temp. above height at different times
1: after 3 min
2. " 4 min
3: " 6 min
4: " 8 min
5: " 10 min
Temperature [°C]
0
100
200
300
400
500
600
700
Height above lower edge [m]
0
0.2
0.4
0.6
0.8
1
1
2
3
4
5



Nozzles inclined downwards



Nozzles horizontal



Nozzles inclined upwards

Abschnitt 2

Ergebnisse der Voruntersuchungen

im CSTB und MPA NRW

Development of the SBI-test

Report

Part: Results of tests at CSTB and MPA NRW

In accordance with the steering regulators group a number of tests in the SBI apparatus were done in order to investigate the influence of the variation of test parameters. In total 17 series with 155 tests were carried out. The following tables together with the legend below gives an overview of the programme.

Table 1a: Test programme carried out with sandbox burner

Series	1S	2S	3S	3S´	4S	4S´	5S	6S	7S
Burner	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND
Specimen	Ww	Ww	Wd	Wd	Ww	Wd	Ww	Ww	Dw
Ceiling	YES	NO	NO	YES	NO	NO	NO	NO	NO
3rd wall	NO	NO	NO	NO	YES	YES	YES	NO	NO
Configuration	CL	CL	CL	CL	CL	OPEN	CL	OPEN	CL
Labs	2	2	CSTB	MPA	CSTB	CSTB	MPA	CSTB	CSTB
Materials	7+7	7+5	4	4	4	4	4	4	4
Total number of tests	28	24	8	8	8	8	8	8	3

Table 1b: Test programme carried out with radiant panels

Series	1P	2P	3P	1R	2R	3R
Burner	RAD	RAD	RAD	ASTM	ASTM	ASTM
Specimen	Ww	Ww	Ww	P	Wd	P
Ceiling	YES	NO	YES	NO	NO	NO
3rd wall	NO	NO	YES	NO	NO	NO
Configuration	CL	CL	CL	CL	CL	OPEN
Labs	MPA	MPA	MPA	CSTB	CSTB	CSTB
Materials	7	2	4	7	4	4
Total number of tests	14	4	4	14	8	8

SAND: sandbox burner
RAD: SBI radiant panel
ASTM: ASTM radiant panel as used in the ROLAND project
Ww: Large wing + small wing specimen
Wd: Large Wing specimen+small wing specimen
Dw: Large wing dummy+small wing specimen
P: one plane specimen
Cl: closed configuration as in MPA and CSTB
OPEN: CSTB configuration windows removed

Material: M1: Paper-faced gypsum board
M2: FR PVC
M3: FR XPS board
M4: PUR foam panel (aluminium-faced)
M5: Varnished timber (pine)
M6: FR chipboard
M7: 3-layered FR polycarbonate panel

Materials used in the test series:
1S, 2S, 1P and 1R: M1-M7
3S, 3S´,4S, 4S´, 5S, 6S, 2P, 4P, 2R and 3R: M3-M6
7S: M3-M5
3P: M5-M6

In each test the following parameter were measured:

- Time to ignition (visual observation)
- Temperature in the exhaust duct
- Rate of heat release by oxygen depletion method
- Optical smoke density in the duct
- Vertical flame spread
- Horizontal flame spread

The performance of the materials was documented by video respectively photos. In addition to the optical documentation the following data are presented:

- Table with time to ignition for all tests
- Table with total energy released in the tests
- Table with peak values of Rate of Heat Release (RHR)
- Table with maximum temperatures in the duct
- Table with Total Smoke Production (TSP)
- Table with maximum Rate of Smoke Production (RSP)
- Table with vertical flame spread (damaged length)
- Table with horizontal flame spread (damaged width at 1m height)
- Table with horizontal flame spread (damaged width) at the top of the specimen

- Diagram Rate of Heat Release as function of time
- Diagram of released Energy as function of time
- Diagram of the temperature elevation in the duct as function of time (ΛT)
- Diagram of Rate of Smoke Production as function of time
- Diagram of Total Smoke Production as function of time
- Diagram of the ratio ΛT/RHR as function of time (only for a number of tests as example, to show to what extent these values correlate; it was not found suitable to draw this diagram for all tests as the values for lower Rate of Heat Release gives unreasonable results)

Time to ignition in sec. (visual observation)

series Nr.	test Nr.	Material Nr.						
		1 plaster-board	2 PVC	3 FR PS	4 PUR	5 varn. timber	6 FR chipb.	7 poly-carbonat
1S	1	45	46	118	26	25	?	60
	2	120	48	75	18	25	(360)	60
2S	1	-	44	95	23	30	?	-
	2	-	34	83	19	35	45	-
3´S	1	-	-	108	17	23	75	-
	2	-	-	71	30	16	80	-
5S	1	-	-	135	17	30	?	-
	2	-	-	150	17	21	(140)	-
1P	1	90	180	330	230	33	>1200	>1200
	2	80	110	203	>1200	30	>1200	75
2P	1	-	-	-	-	54	>1200	-
	2	-	-	-	-	33	>1200	-
3P	1	-	-	300	90	30	>1200	-
	2	-	-	-	-	-	-	-

TIME TO IGNITION (s) - (based on observation) -

Sets of tests		M1		M2		M3		M4		M5		M6		M7	
		e1	e2	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2
	1S	(<213)	57	25	22	60	72	18	15	28	30		(255)	38	34
	2S	60		(100)	(90)	84	85	19	15	21	20	(270)	(180)		30
	3S					55	61	22	16	21	20	(115)	(145)		
	4S					74	67	13	15	16	19	(170)	(130)		
	4S'					75	63	16	19	17	14	(190)	(200)		
	6S					85	89	31	21	19	15	(185)	(210)		
	7S					80		20		25					
$\overline{ti}$	(s)					73		18.4		20.4		186.4		34	

Total energy (at the end of test) in MJ

series Nr.	test Nr.	Material Nr.						
		1 plaster-board	2 PVC	3 FR PS	4 PUR	5 varn. timber	6 FR chipb.	7 poly-carbonat
1S	1	15	15	30	25	75	5 [1]	0
	2	0	25	60	28	58	10	20
2S	1	-	5	30	30	60	21	-
	2	-	10	35	40	50	11	-
3´S	1	-	-	40	20	20	14	-
	2	-	-	50	20	20	13	-
5S	1	-	-	35	30	45	15	-
	2	-	-	70	28	40	13	-
1P	1	0	5	50	35	90	10	0
	2	0	5	140	0	105	0	0
2P	1	-	-	-	-	90	15	-
	2	-	-	-	-	70	10	-
3P	1	-	-	40	25	80	0	-
	2	-	-	-	-	-	-	-

(1) Failure of the data acquisition programme after 5 minutes

CSTB
le futur en construction

NET HEAT RELEASE (MJ)

	M1		M2		M3		M4		M5		M6		M7	
	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2
1S	149	0.00	6.9	6.6	46.9	55.5	17.9	21.4	35.6	40.0	0.3	12.6	2.6	3.8
2S	0.00	0.06	4.5	1.2	18.5	41.4	18.4	20.3	24.6	27.0	4.3	4.6	10.2	6.6
3S					17.7	28.8	9.4	12.2	10.0	12.0	2.7	3.8		
4S					63.7	64.8	18.8	19.5	28.7	29.0	5.3	6.5		
4S'					43.5	34.3	9.7	10.0	14.5	12.6	1.4	2.6		
6S					44.7	53.2	19.2	19.4	31.3	29.4	7.7	9.8		
7S					12.6		6.4		8.9					

p = écart type

MEAN VALUES (MJ)

	M1	M2	M3	M4	M5	M6	M7
Ww	0.4 P = 0.7	4.8 P = 2.6	46.8 P = 14.8	19.4 P = 1.1	30.7 P = 4.9	6.4 P = 3.7	5.8 P = 3.4
Wd			31.1 P = 10.8	10.3 P = 1.3	12.3 P = 1.9	2.6 P = 1.0	

RHR (peak value) in kW

series Nr.	test Nr.	Material Nr.						
		1 plaster-board	2 PVC	3 FR PS	4 PUR	5 varn. timber	6 FR chipb.	7 poly-carbonat
1S	1	10	25	170	180	120	21[(1)]	0
	2	0	60	225	200	100	14	10
2S	1	-	15	205	175	100	24	-
	2	-	25	150	160	100	21	-
3´S	1	-	-	105	75	55	25	-
	2	-	-	140	80	55	20	-
5S	1	-	-	140	180	80	20	-
	2	-	-	270	150	80	16	-
1P	1	10	10	60	180	150	15	0
	2	0	10	280	0	150	0	15
2P	1	-	-	-	-	140	15	-
	2	-	-	-	-	120	15	-
3P	1	-	-	380	40	225	10	-
	2	-	-	-	-	-	-	-

[(1)] Failure of the data acquisition programme after 5 minutes

PEAK OF NET RHR (kW) - first or another peak -

	M1		M2		M3		M4		M5		M6		M7	
	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2
1S	5.70	1.5	23.0	13.8	115	130	121	184	69.9	112	3.3	15.3	16.1	14.0
2S	5.0	2.3	8.1	13.0	87.1	137	122	140	53.7	68.6	8.0	7.5	23.4	16.7
3S					63.3	88.0	41.1	31.7	21.6	19.8	5.4	6.2		
4S					166	158	114	108	63.9	68.6	8.3	8.4		
4S'					122	103	52.8	51.4	26.9	23.5	2.9	4.3		
6S					145	126	111	116	56.8	70.9	12.3	12.5		
7S					33.7		44.6		21.0					

MEAN VALUES

p = écart type

	M1	M2	M3	M4	M5	M6	M7
Ww	3.63 P = 2.04	14.5 P = 6.2	133 P = 25.0	127 P = 25.0	70.6 P = 17.9	9.5 P = 3.7	17.6 P = 4.1
Wd			94.1 P = 24.8	44.3 P = 9.9	23.0 P = 3.0	4.7 P = 1.4	

ΔT$_{max}$ in K (elevation over reading at start of test
■ with sandburner: excl. effect of burner
■ with radiand panel: excl. effect of panel)

series Nr.	test Nr.	Material Nr.						
		1 plaster-board	2 PVC	3 FR PS	4 PUR	5 varn. timber	6 FR chipb.	7 poly-carbonat
1S	1	15	25	100	110	80	10[1]	20
	2	15	20	130	110	80	17	(10)
2S	1	-	25	95	120	90	21	-
	2	-	20	130	120	105	21	-
3´S	1	-	-	60	40	30	15	-
	2	-	-	100	45	50	22	-
5S	1	-	-	100	150	75	20	-
	2	-	-	205	140	90	22	-
1P	1	0	15	20	90	130	0	10
	2	0	15	60	0	80	0	10
2P	1	-	-	-	-	100	0	-
	2	-	-	-	-	100	0	-
3P	1	-	-	250	25	210	0	-
	2	-	-	-	-	-	-	-

(1) Failure of the data acquisition programme after 5 minutes

PEAK DUCT TEMPERATURE INCREASE (K) - first or another peak -

RUG HOTTE	M1		M2		M3		M4		M5		M6		M7	
	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2
1S	28.7	27.3	32.1	29.4	116.0	105.3	75.0	99.3	69.7	98.9	30.3	32.3	29.4	31.2
	29.5	27.6	32.8	30.2	127.2	115	84.3	118.8	71.7	109.3	30.9	32.6	28.4	30.7
2S	28.8	19.0	33.7	31.3	76.4	133.2	89.4	105.3	63.7	68.7	33.2	33.8	38.9	30.0
	26.7	16.6	32.3	30.0	80.8	145.9	93.3	89.0	62.8	73.1	30.4	31.6	37.2	27.9
3S					50.8	80.1	34.0	29.6	28.7	27.3	24.2	23.6		
					54.5	83.3	35.2	29.9	27.7	28.4	21.5	21.2		
4S					174	146	79.0	81.1	62.3	61.3	28.5	28.8		
					197.6	166.8	89.9	89.5	65.9	66.0	27.9	28.3		
4S'					123	110	49.6	48.6	36.6	31.8	23.7	23.0		
					133.4	116.4	51.4	50.3	36.9	34.1	23.9	22.4		
6S					131	125	87.2	84.5	70.7	66.9	35.3	35.2		
					144.6	131.1	91.3	87.6	67.9	68.2	32.3	32.5		
7S					44.8		45.9		37.7					
					41.8		48.4		34.8					

MEAN VALUES (K)

	M1		M2		M3		M4		M5		M6		M7	
Ww	26.0	P=4.7	31.6	P=1.8	125.9	P=28.7	87.6	P=10.3	70.3	P=12.1	32.2	P=2.7	32.4	P=4.4
	25.1	P=5.8	31.3	P=1.4	138	P=34	93.0	P=10.8	73.1	P=15.0	30.8	P=1.8	31.1	P=4.3
Wd					91.0	P=32.2	40.5	P=10.2	31.1	P=4.1	23.6	P=0.5		
					96.9	P=35.1	41.7	P=10.8	31.8	P=4.5	22.3	P=1.2		

Total Smoke production TSP in m²

series Nr.	test Nr.	Material Nr.						
		1 plaster-board	2 PVC	3 FR PS	4 PUR	5 varn. timber	6 FR chipb.	7 poly-carbonat
1S	1	50	1000	550	600	450	56[1]	400
	2	50	1000	1900	900	400	410	(400)
2S	1	-	500	900	800	400	262	-
	2	-	1000	1300	800	400	338	-
3´S	1	-	-	1200	500	400	241	-
	2	-	-	1600	500	400	311	-
5S	1	-	-	1500	900	300	287	-
	2	-	-	2600	900	300	311	-
1P	1	0	600	1000	1000	300	500	0
	2	0	1000	3000	0	300	500	0
2P	1	-	-	-	-	200	0	-
	2	-	-	-	-	200	900	-
3P	1	-	-	1500	500	300	800	-
	2	-	-	-	-	-	-	-

[1] Failure of the data acquisition programme after 5 minutes

TOTAL SMOKE PRODUCTION (m^2)

	M1		M2		M3		M4		M5		M6		M7	
	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2
1S	247	217	1159	1171	1596	1674	675	754	219	209	484	482	353	324
2S	268	274	816	865	987	1521	490	505	390	292	503	529	479	353
3S					817	1113	491	456	297	298	412	464		
4S					1158	1851	593	576	328	370	523	542		
4S'					1275	1137	453	466	291	286	447	439		
6S					1343	1462	442	441	266	250	309	273		
7S					703		394		257					

MEAN VALUES (m^2)

p = écart type

	M1	M2	M3	M4	M5	M6	M7
Ww	252 P = 26	1003 P = 188	1524 P = 271	560 P = 112	291 P = 67	456 P = 104	377 P = 69
Wd			1086 P = 193	467 P = 17	293 P = 6	441 P = 22	

Rate of Smoke production RSP_{max} in m²/sec.

series Nr.	test Nr.	Material Nr.						
		1 plaster-board	2 PVC	3 FR PS	4 PUR	5 varn. timber	6 FR chipb.	7 poly-carbonat
1S	1	0	3	6	6	1	0,3[(1)]	1
	2	0	3	8	7	1	0,5	1
2S	1	-	2	6	6	0	0,3	-
	2	-	3	4	4	0,5	0,4	-
3´S	1	-	-	4	2	1	0,4	-
	2	-	-	4	2	0,5	0,4	-
5S	1	-	-	5	5	0,5	0,4	-
	2	-	-	8	5	0,5	0,4	-
1P	1	0	3	5	7,5	1	1	0
	2	0	4	9	0	1	1	0
2P	1	-	-	-	-	0,5	0	-
	2	-	-	-	-	0,5	1	-
3P	1	-	-	15	2	1	1	-
	2	-	-	-	-	-	-	-

(1) Failure of the data acquisition programme after 5 minutes

PEAK OF TOTAL RSP ($m^2.s^{-1}$) - first or another peak -

	M1		M2		M3		M4		M5		M6		M7	
	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2	e1	e2
1S	0.28	0.24	3.39	2.88	2.72	3.46	3.78	4.44	0.35	0.40	0.52	0.57	0.70	0.73
2S	0.33	0.30	1.57	2.56	1.94	3.10	2.02	2.35	0.57	0.37	0.59	0.60	0.97	0.67
3S					1.54	2.12	1.06	0.84	0.28	0.27	0.47	0.63		
4S					3.79	3.74	1.92	2.14	0.43	0.48	0.63	0.62		
4S'					2.72	2.21	1.18	1.14	0.43	0.39	0.52	0.49		
6S					3.21	3.00	2.10	1.89	0.42	0.35	0.40	0.33		
7S					1.21		0.90		0.33					

MEAN VALUES ($m^2.s^{-1}$)

p = écart type

	M1	M2	M3	M4	M5	M6	M7
Ww	0.29 P = 0.04	2.60 P = 0.77	3.12 P = 0.60	2.58 P = 0.97	0.42 P = 0.07	0.53 P = 0.11	0.77 P = 0.14
Wd			2.15 P = 0.48	1.06 P = 0.15	0.34 P = 0.08	0.53 P = 0.07	

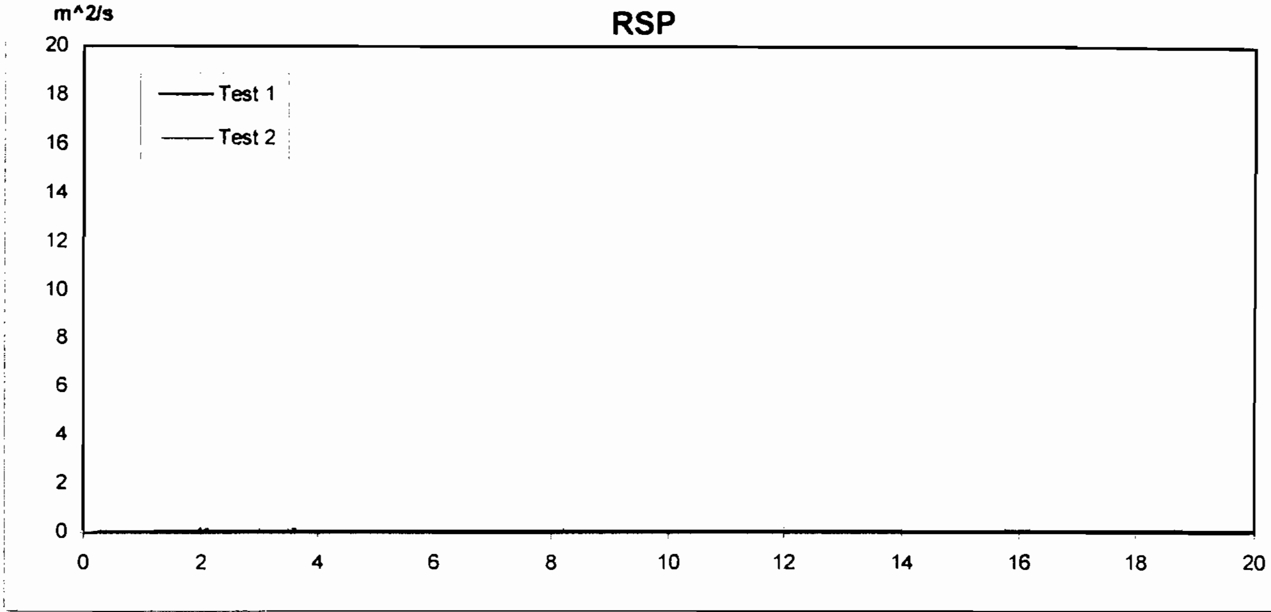
Vertical flame spread (damaged lenght) in cm

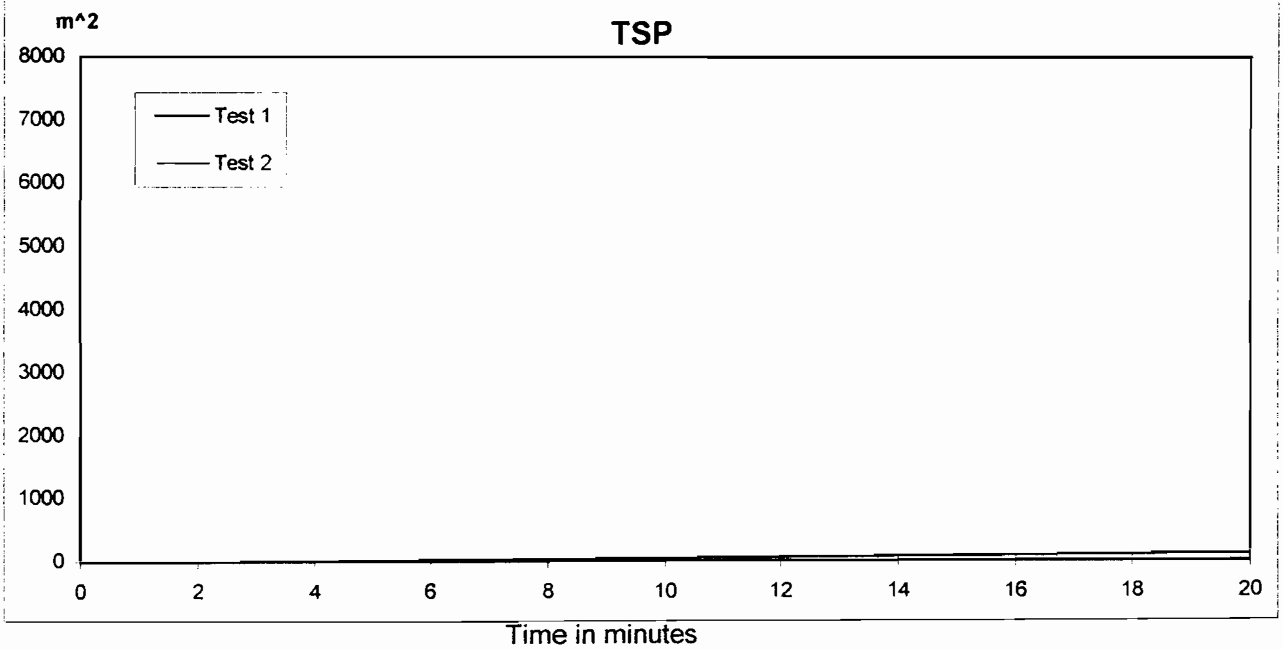
1) Tests in MPA NRW

series Nr.	test Nr.	Material Nr.						
		1 plaster-board	2 PVC	3 FR PS	4 PUR	5 varn. timber	6 FR chipb.	7 poly-carbonat
1S	1	90	100	150	150	150	130	150
	2	90	100	150	150	150	135	110
2S	1	-	100	150	150	150	145	-
	2	-	115	150	150	150	143	-
3´S	1	-	-	150	150	150	140	-
	2	-	-	150	150	150	142	-
5S	1	-	-	150	150	150	148	-
	2	-	-	150	150	150	150	-
1P	1	35	65	150	150	150	52	50
	2	33	60	150	50	150	50	55
2P	1	-	-	-	-	150	60	-
	2	-	-	-	-	150	65	-
3P	1	-	-	150	150	150	45	-
	2	-	-	-	-	-	-	-

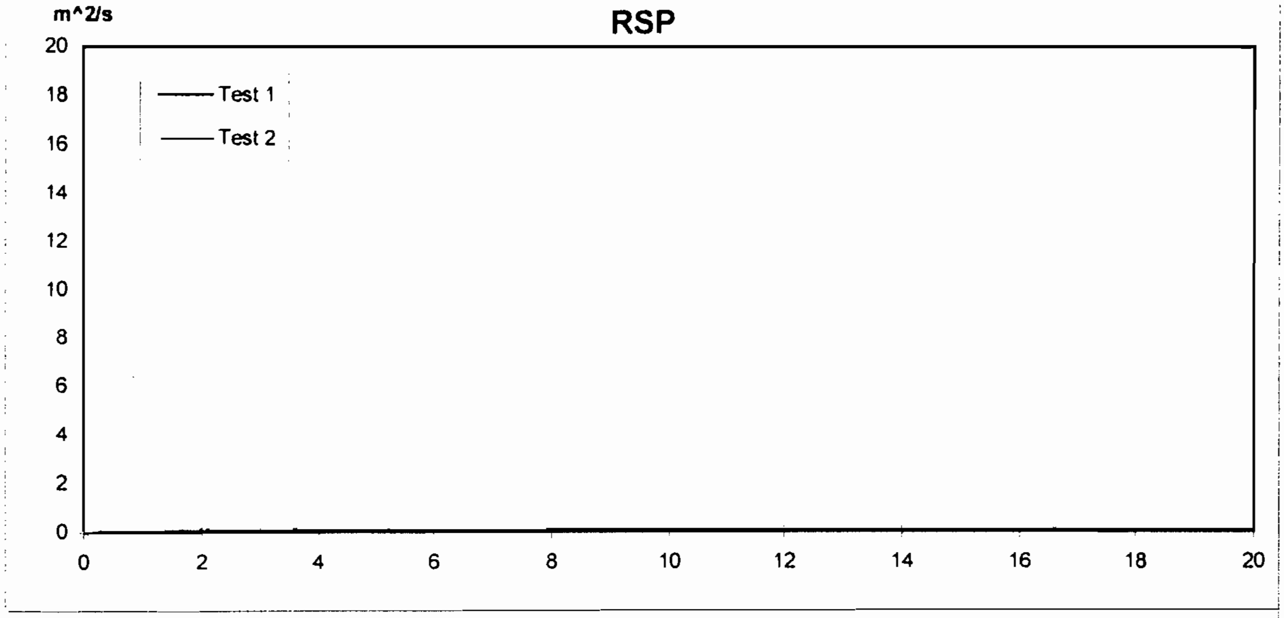
2) Tests in CSTB

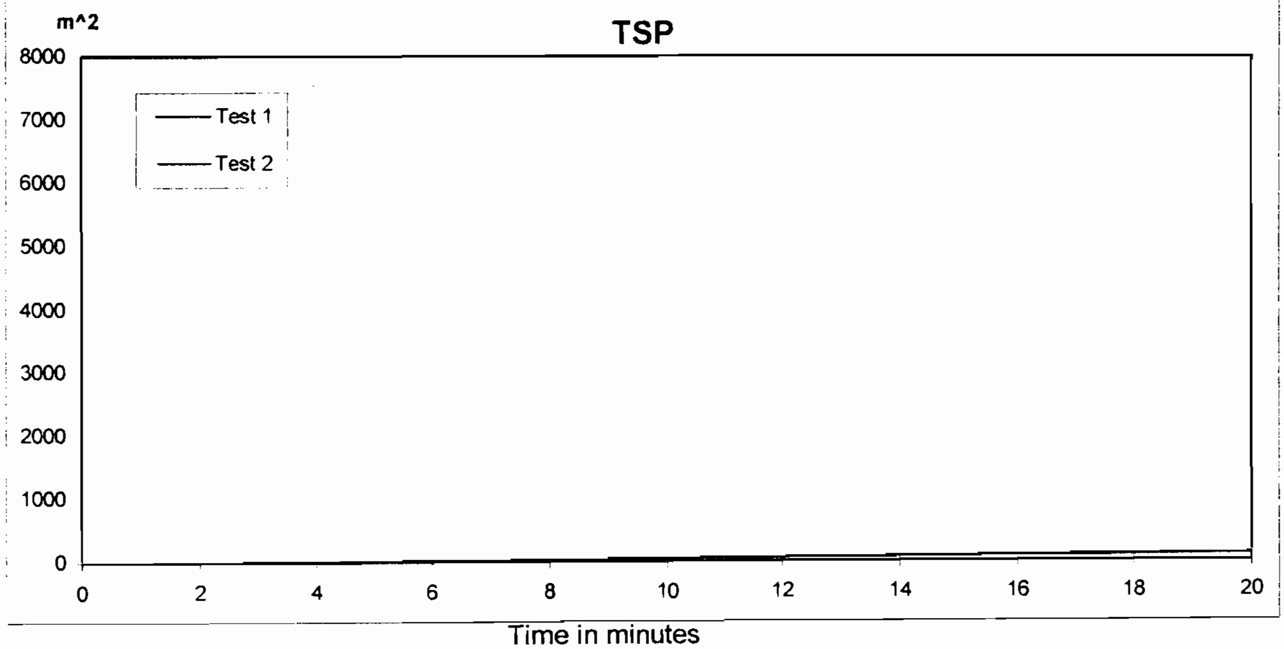
series Nr.	test Nr.	Material Nr.						
		1 plaster-board	2 PVC	3 FR PS	4 PUR	5 varn. timber	6 FR chipb.	7 poly-carbonat
1S	1	93	68	150	150	150	150	40/150
	2	91	64	150	150	150	150	40/150
2S	1	92	70	150	150	150	150	40/150
	2	98	66	150	150	150	150	40/150
3S	1	-	-	150	150	150	150	-
	2	-	-	150	150	150	130	-
4S	1	-	-	150	150	150	150	-
	2	-	-	150	150	150	150	-
4´S	1	-	-	150	150	150	120	-
	2	-	-	150	150	150	135	-
6S	1	-	-	150	150	150	150	-
	2	-	-	150	150	150	150	-
7S	1	-	-	150	150	150	150	-
	2	-	-	-	-	-	-	-
1R	1	45	51	150	0	107	65	59
	2	44	63	150	0	111	72	72
2R	1	-	-	150	0	110	67	-
	2	-	-	150	0	120	67	-
3R	1	-	-	150	0	100	58	-
	2	-	-	150	0	104	58	-



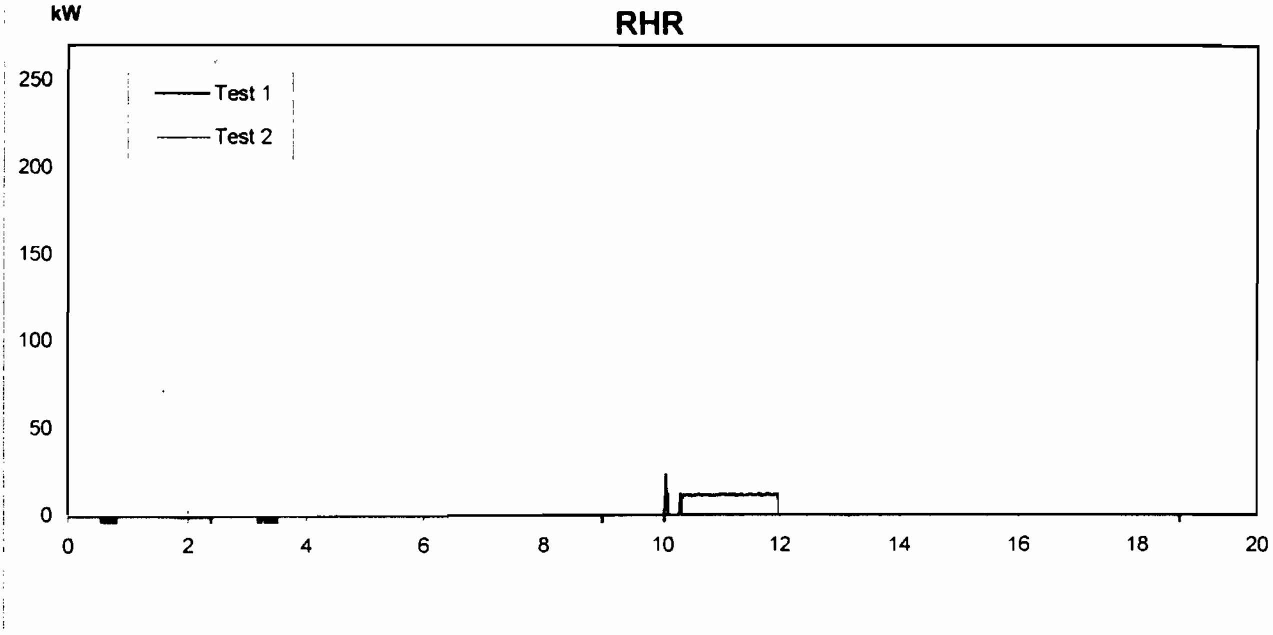


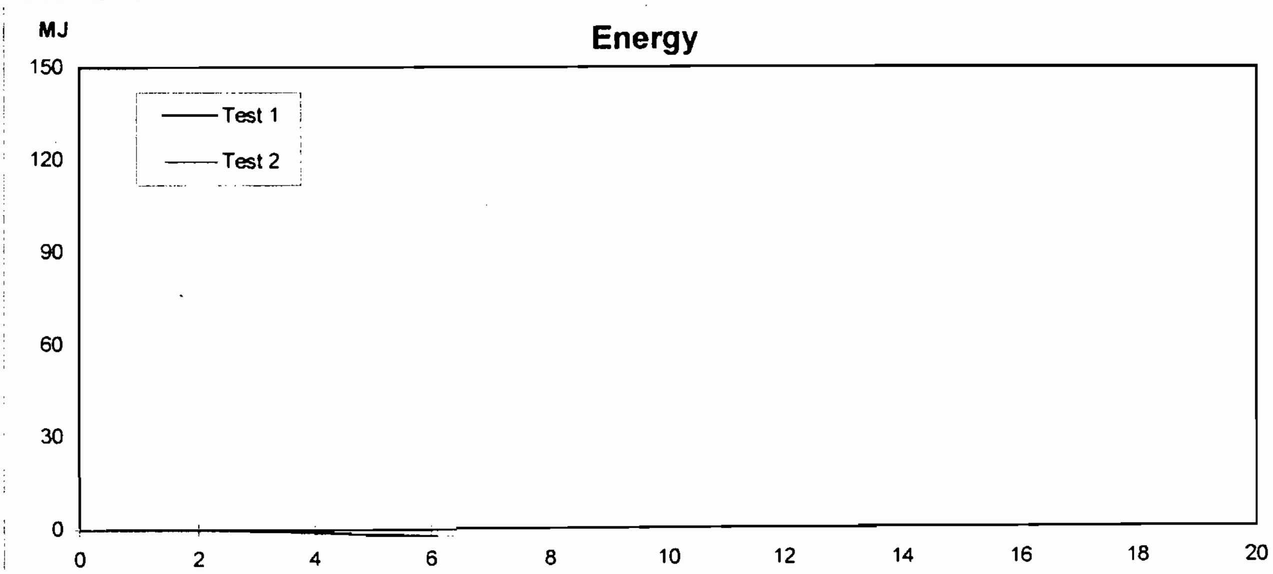
Paper faced gypsum board. Series 1S

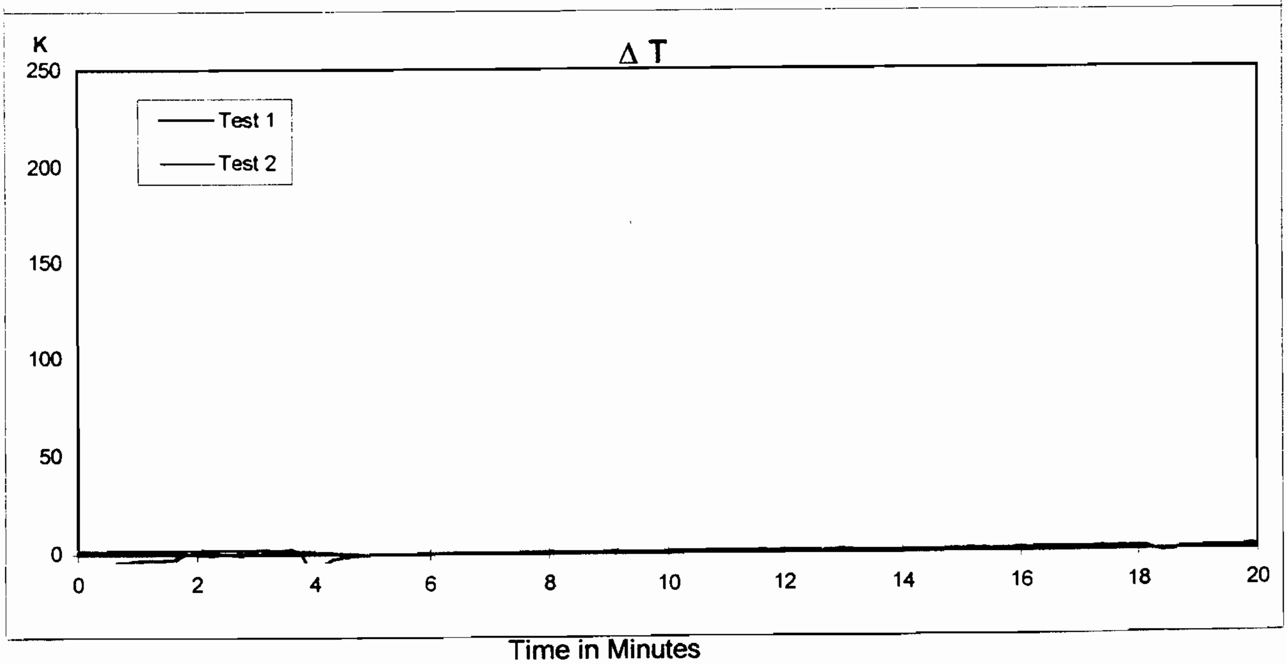




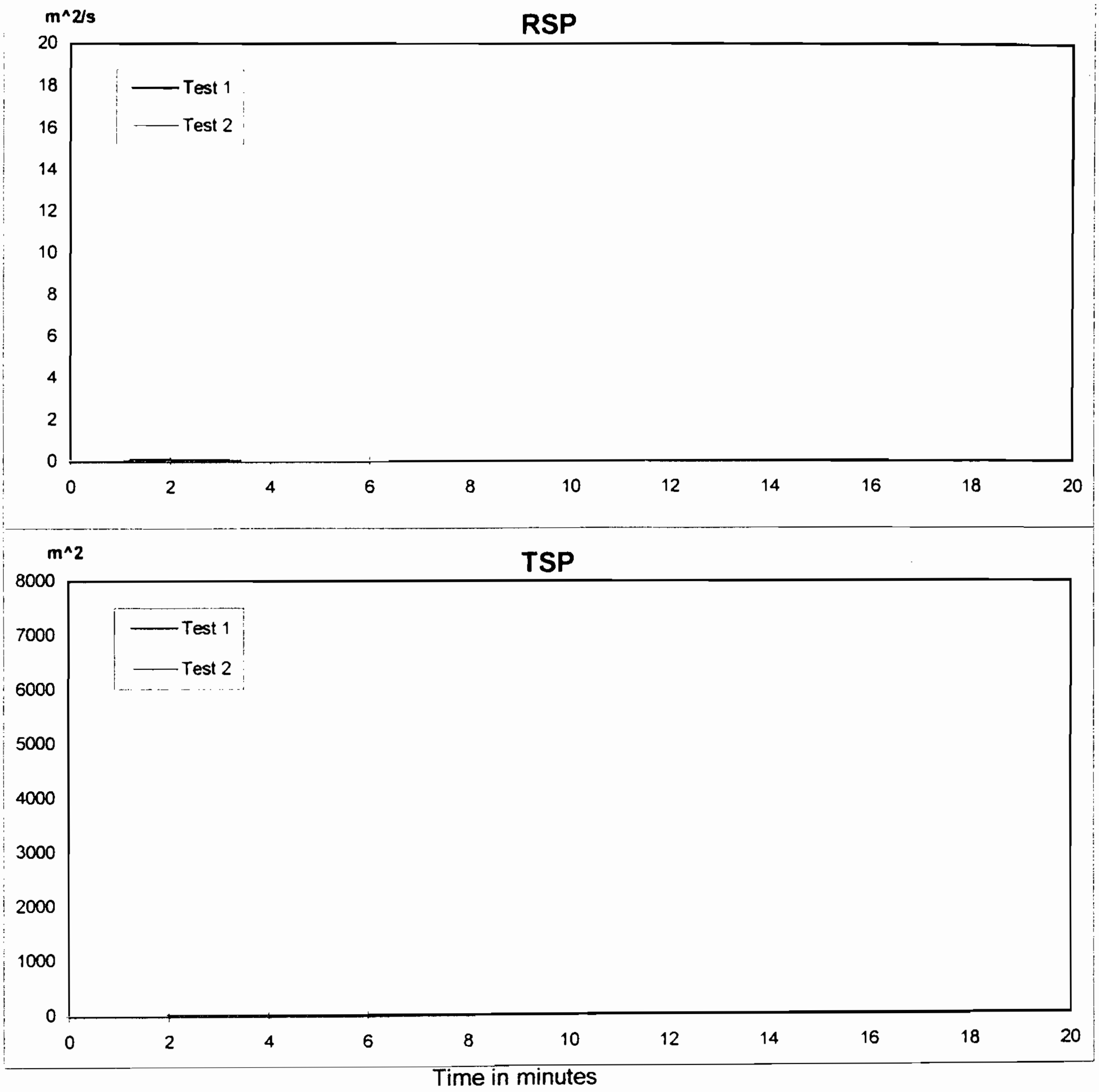
Paper faced gypsum board. Series 1S



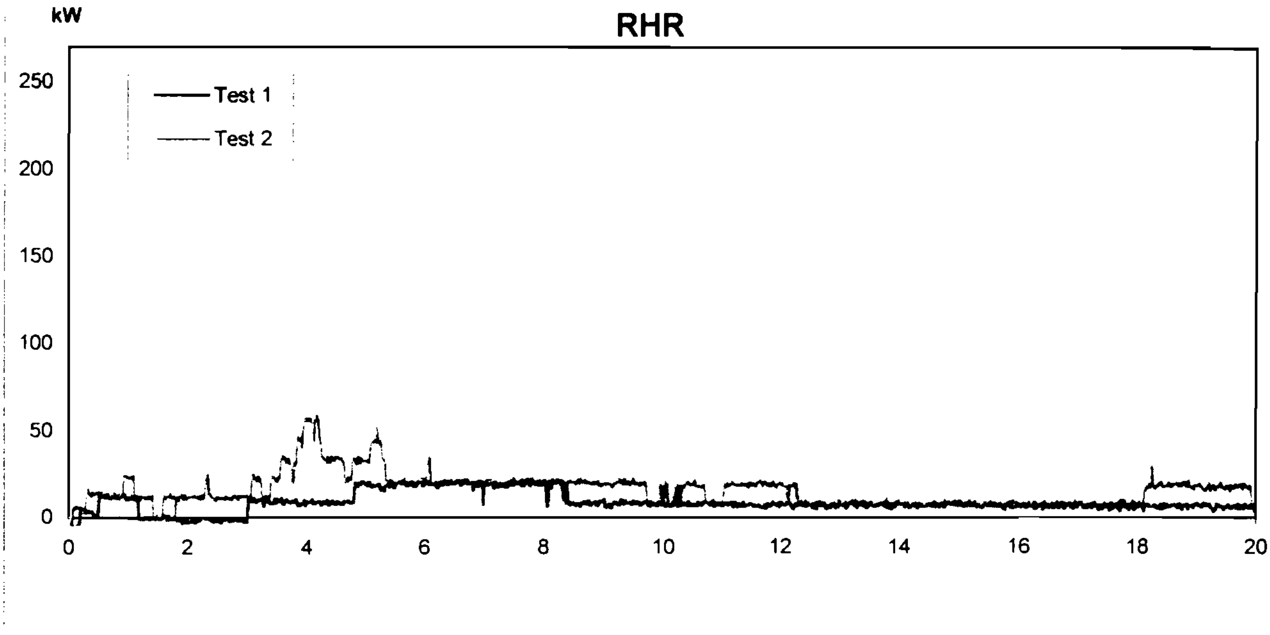


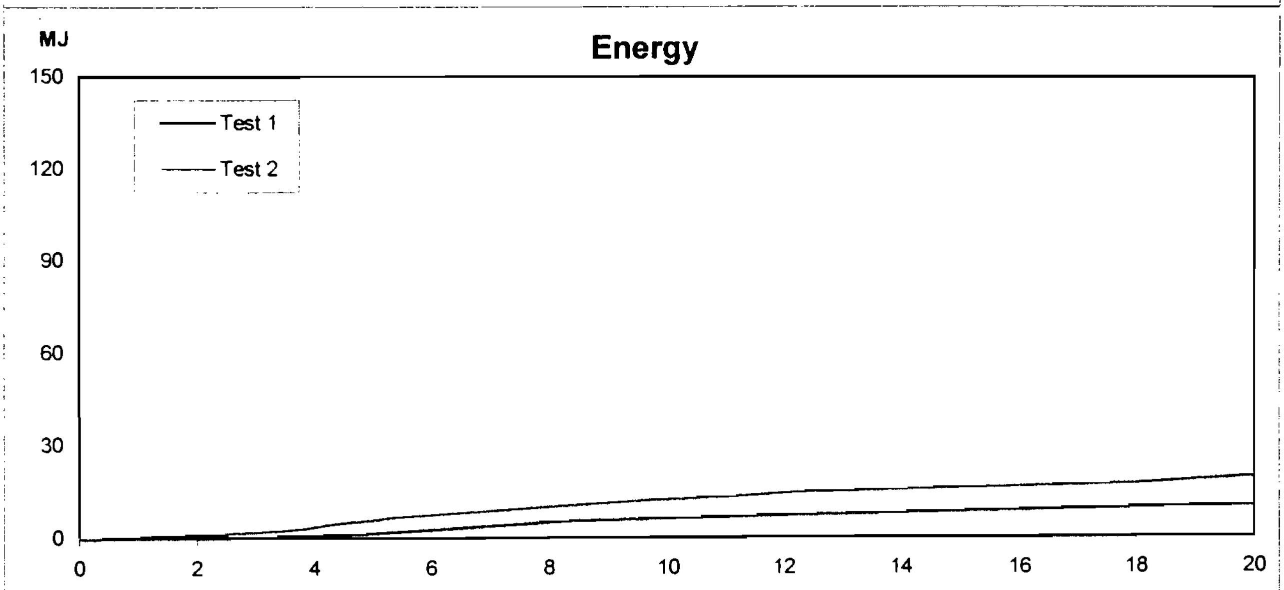


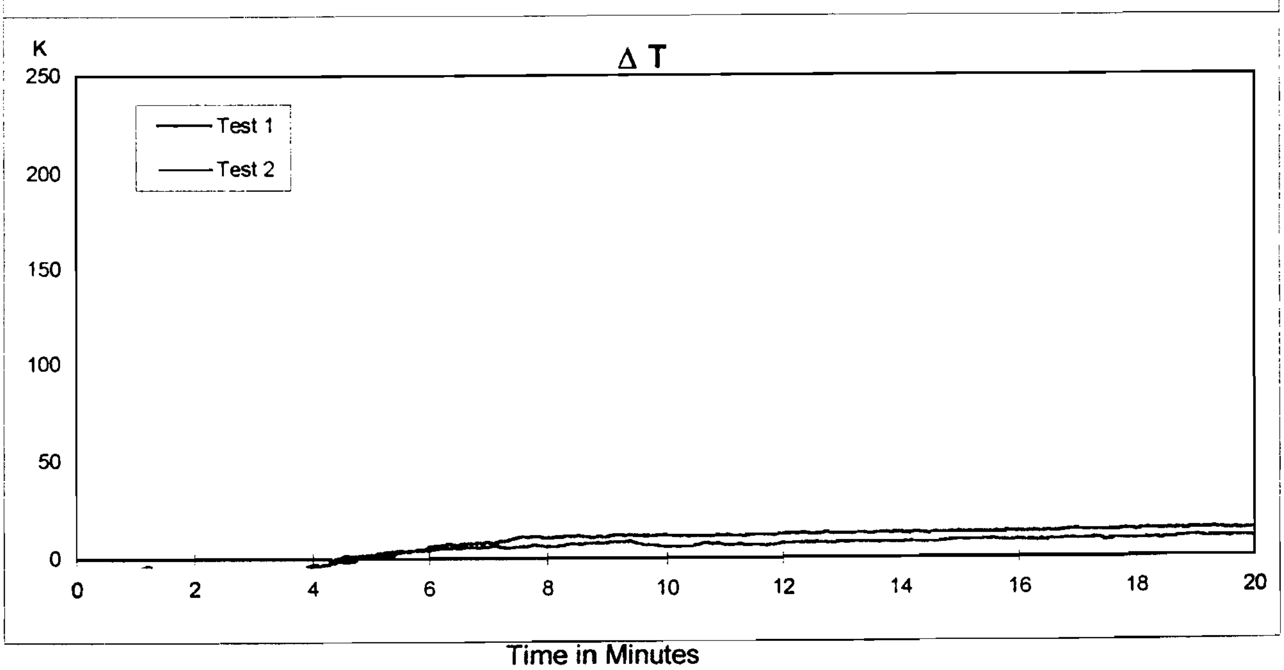
Paper faced gypsum board 1P



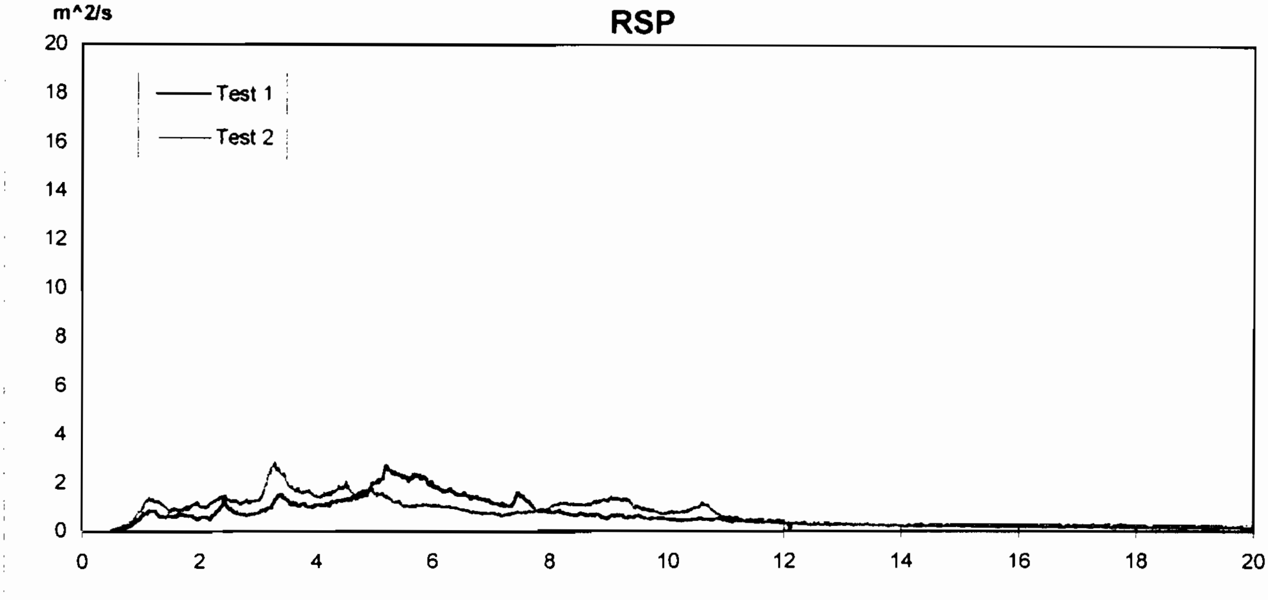
Paper faced gypsum board 1P

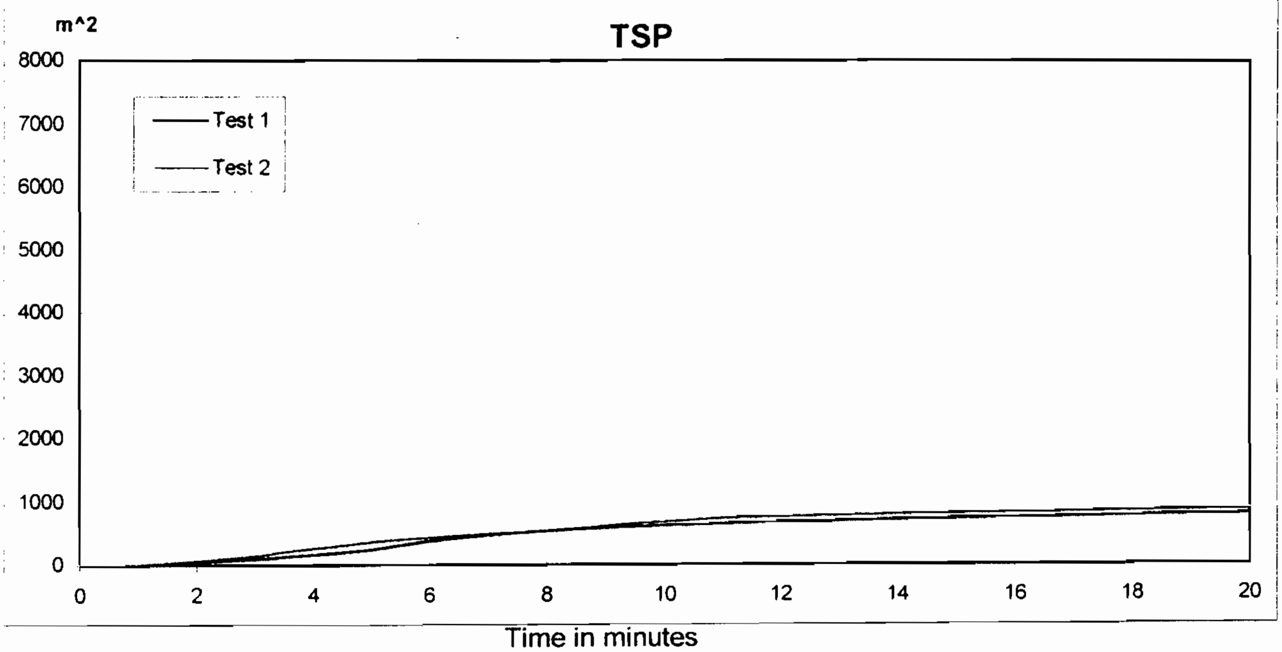




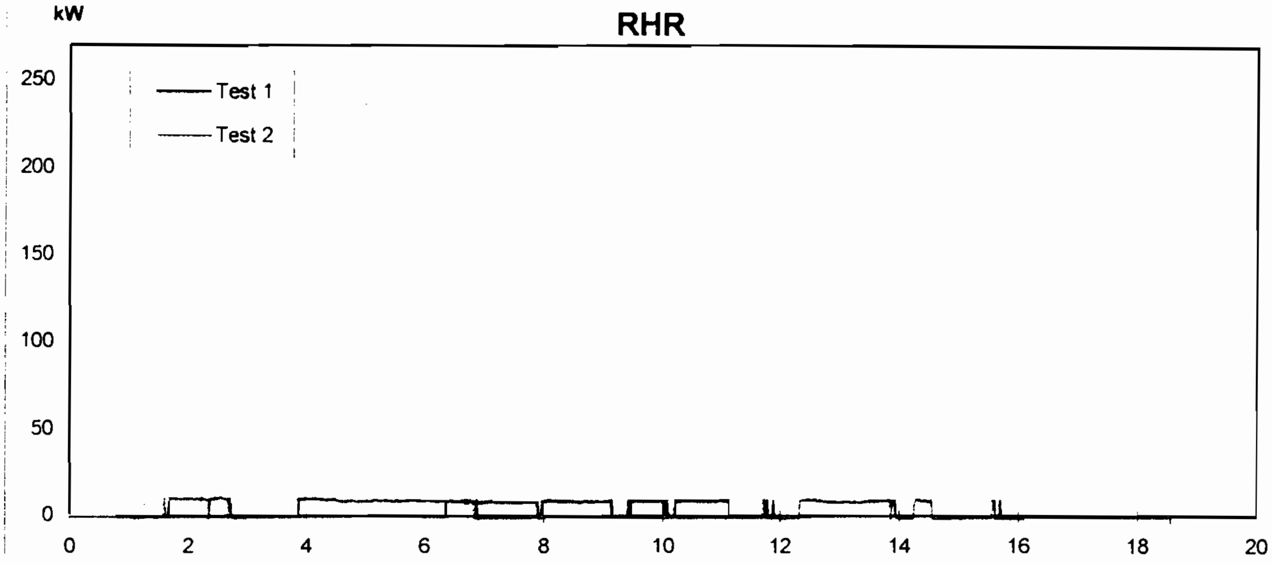


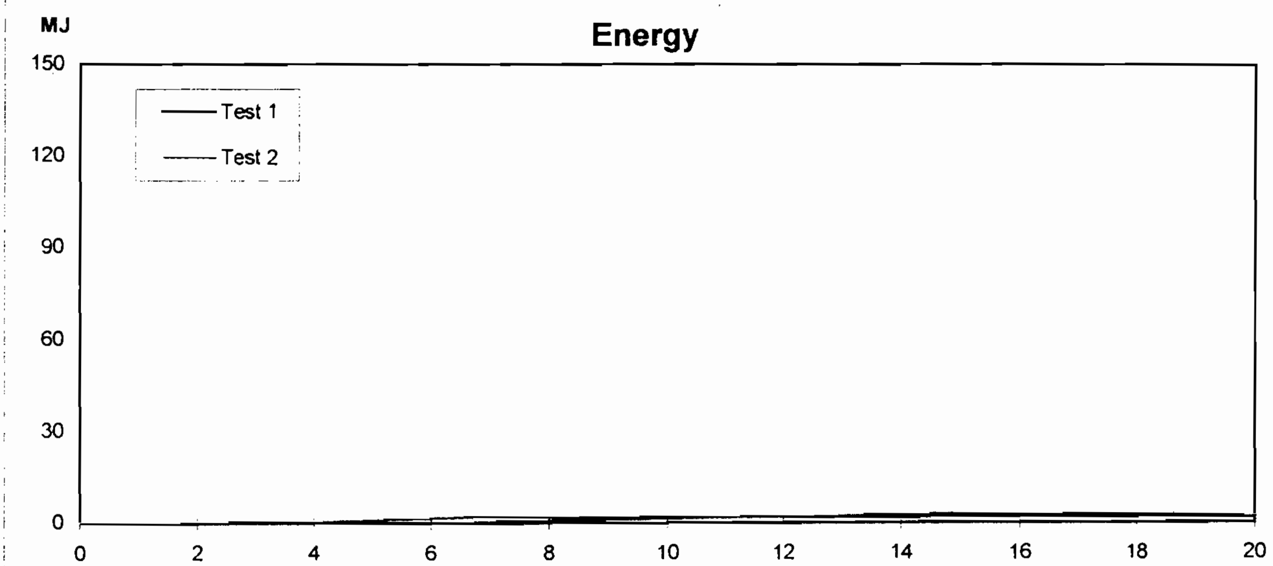
PVC. Series 1S

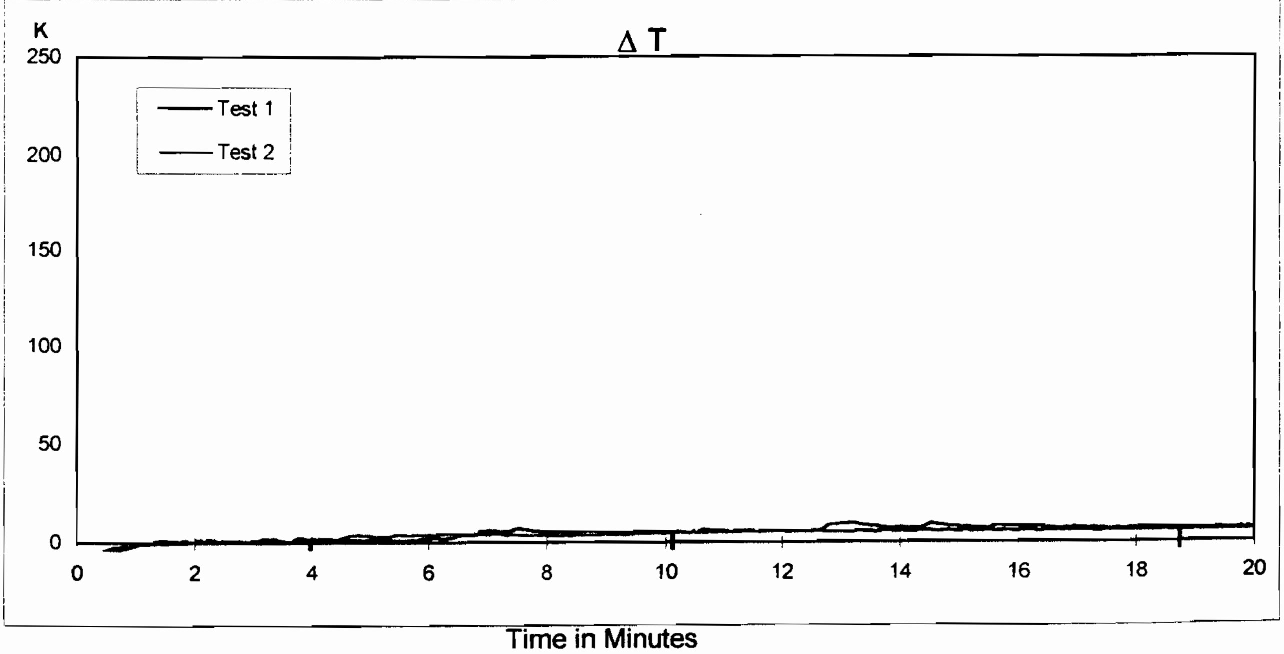




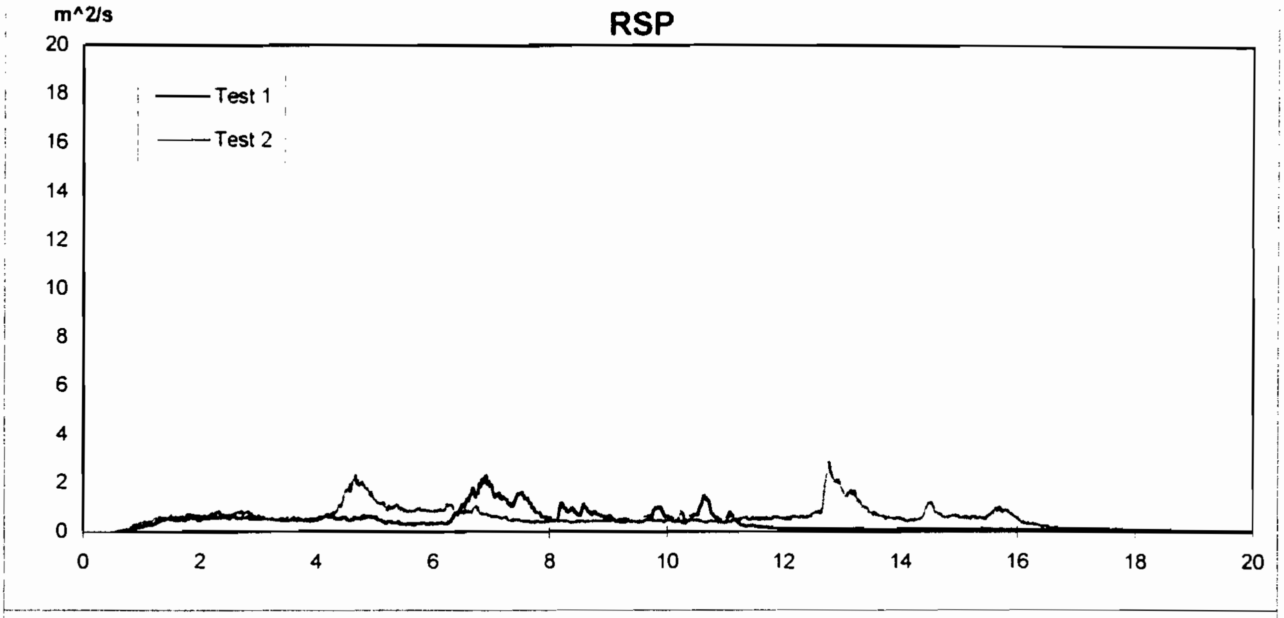
PVC. Series 1S

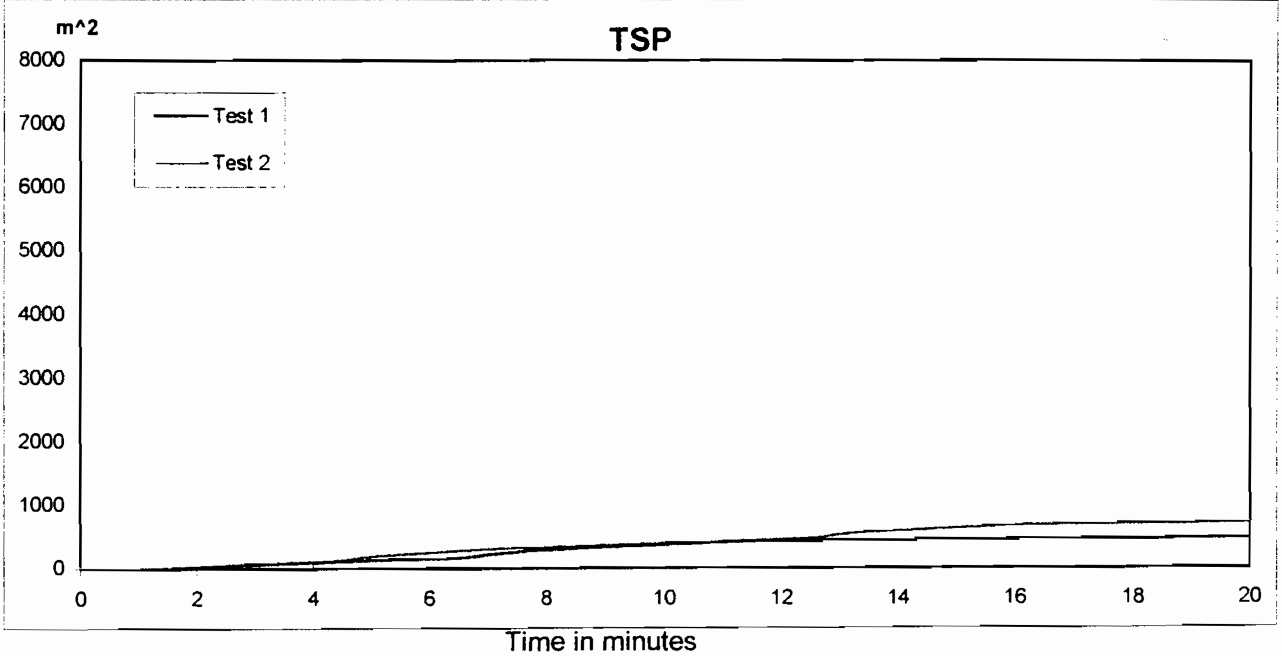




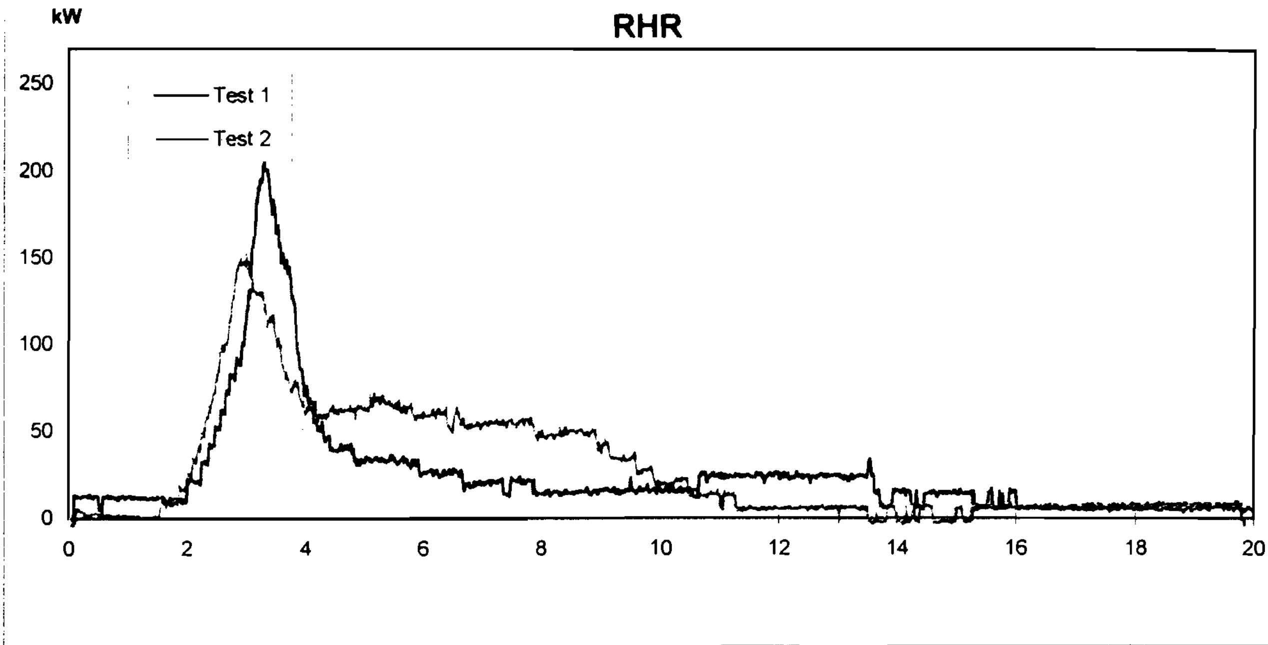


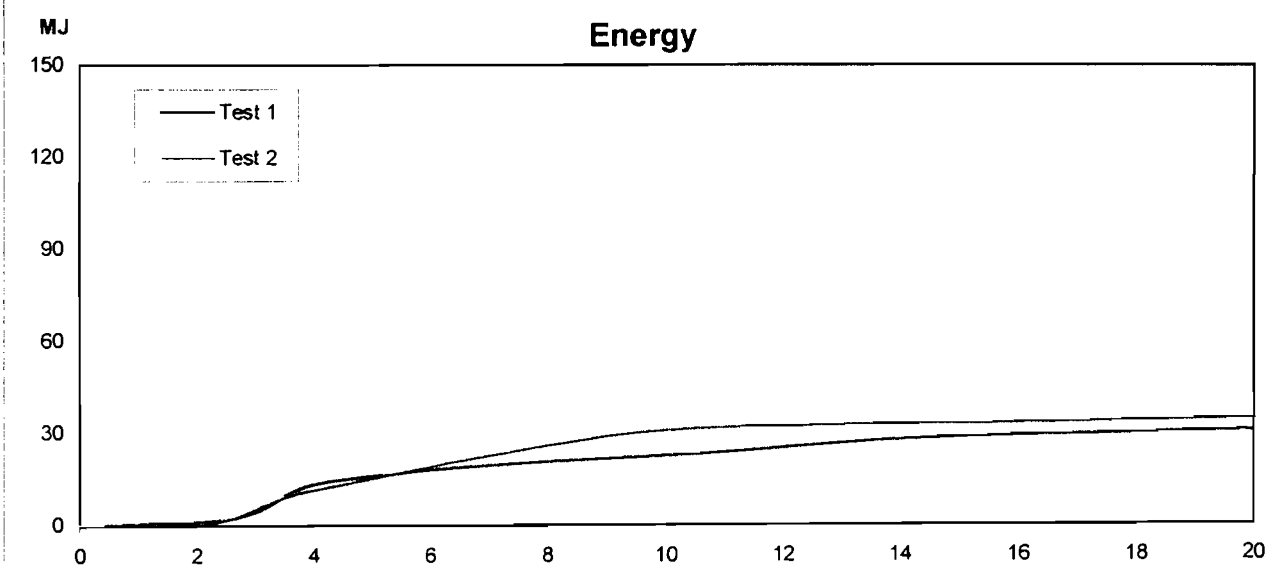
PVC. Series 1P

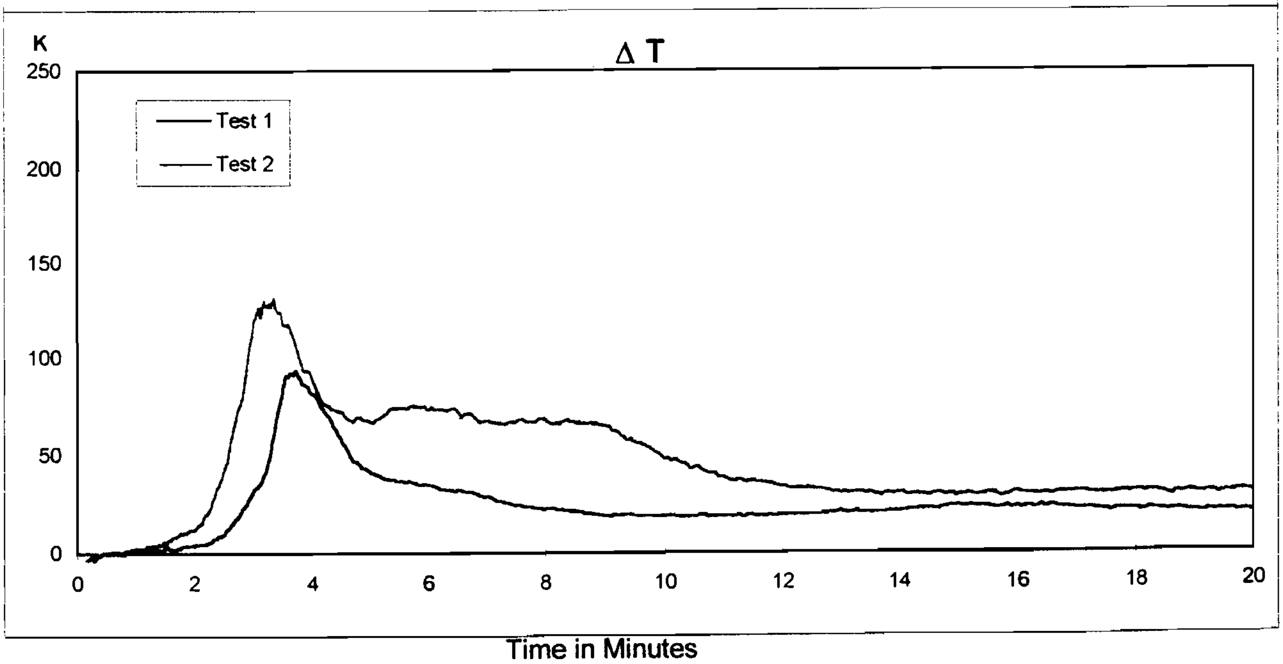




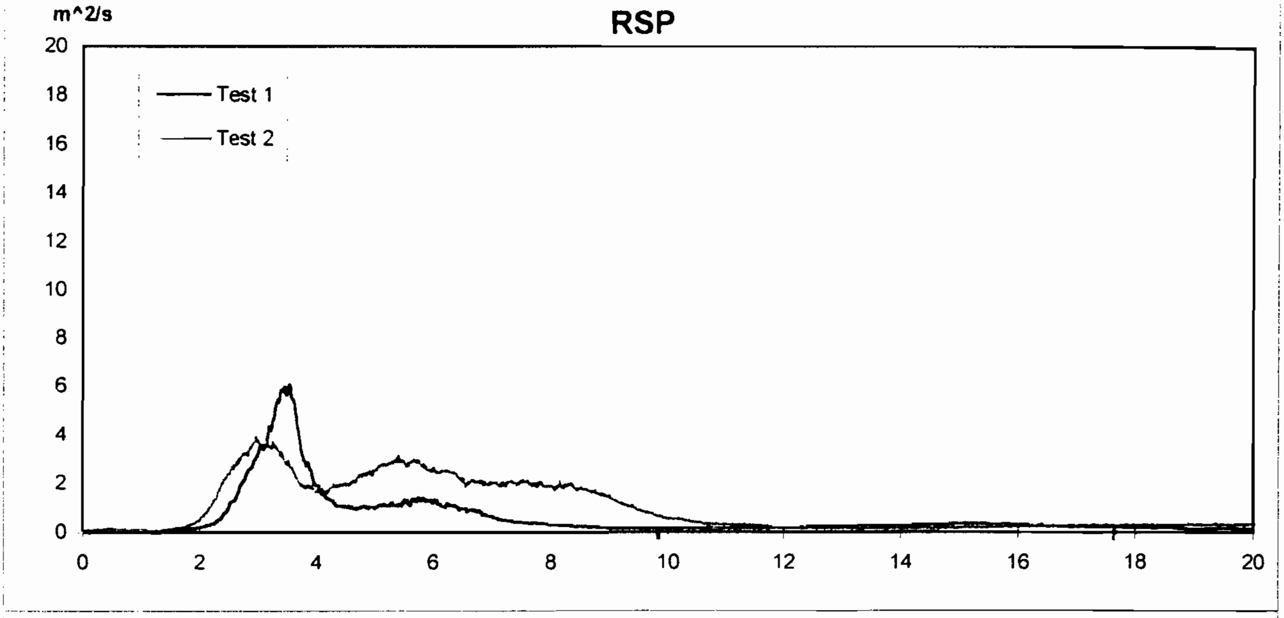
PVC. Series 1P

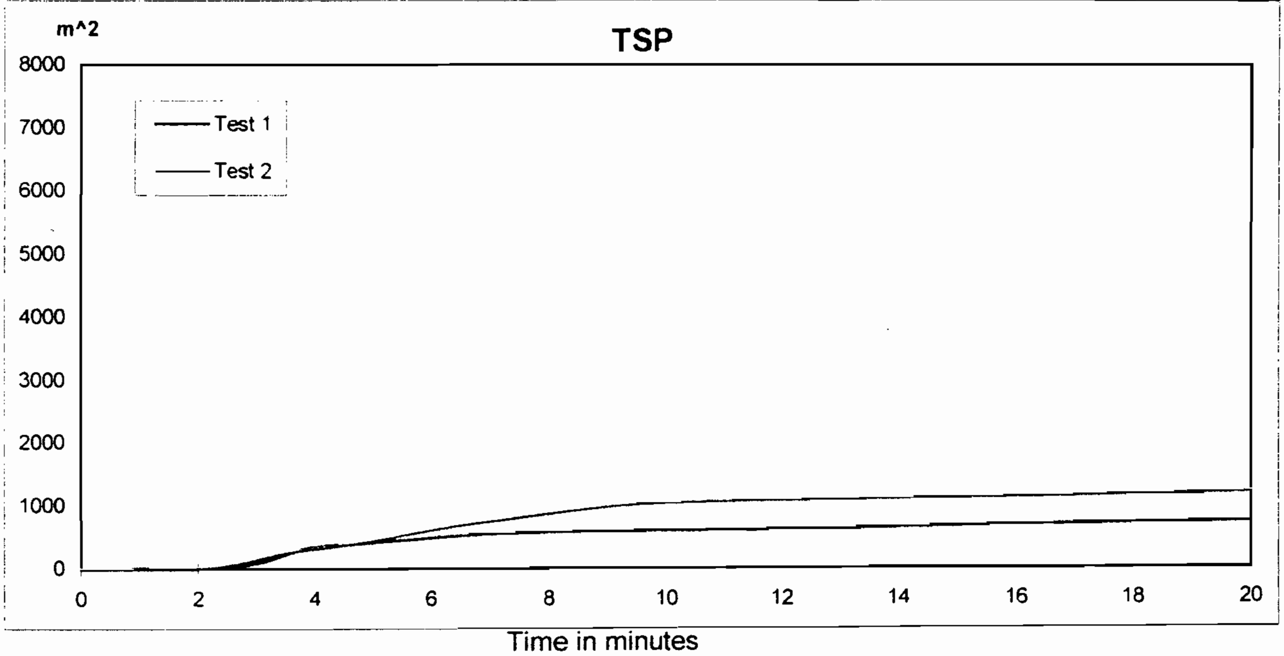




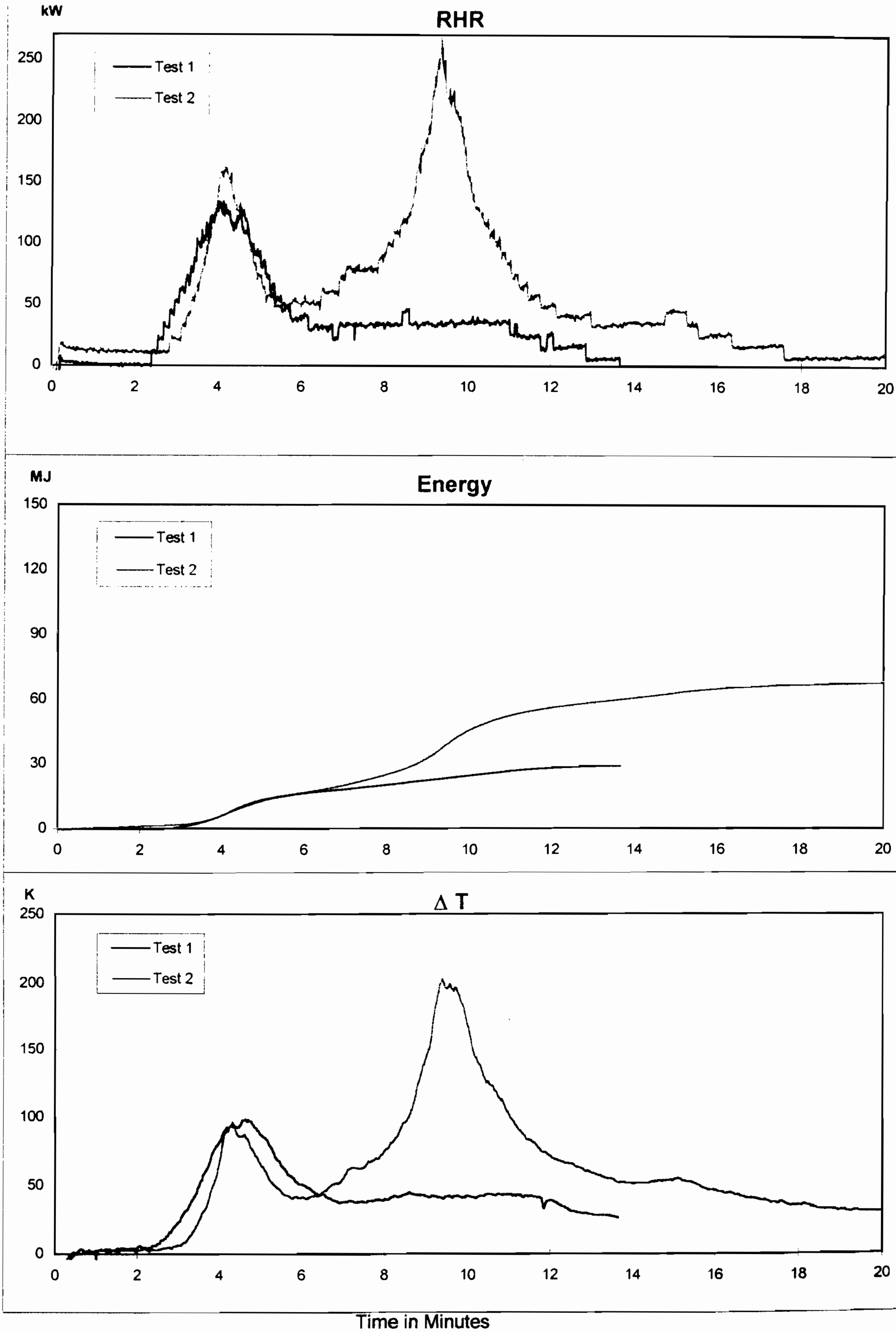


PS-foam (FR). Series 2S

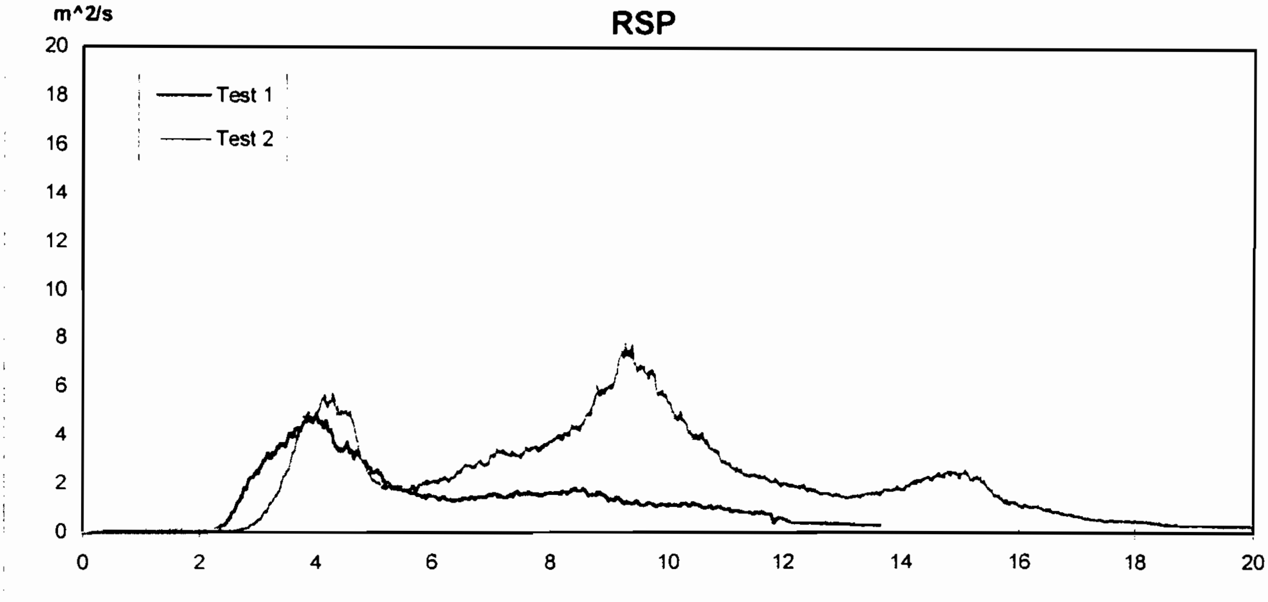


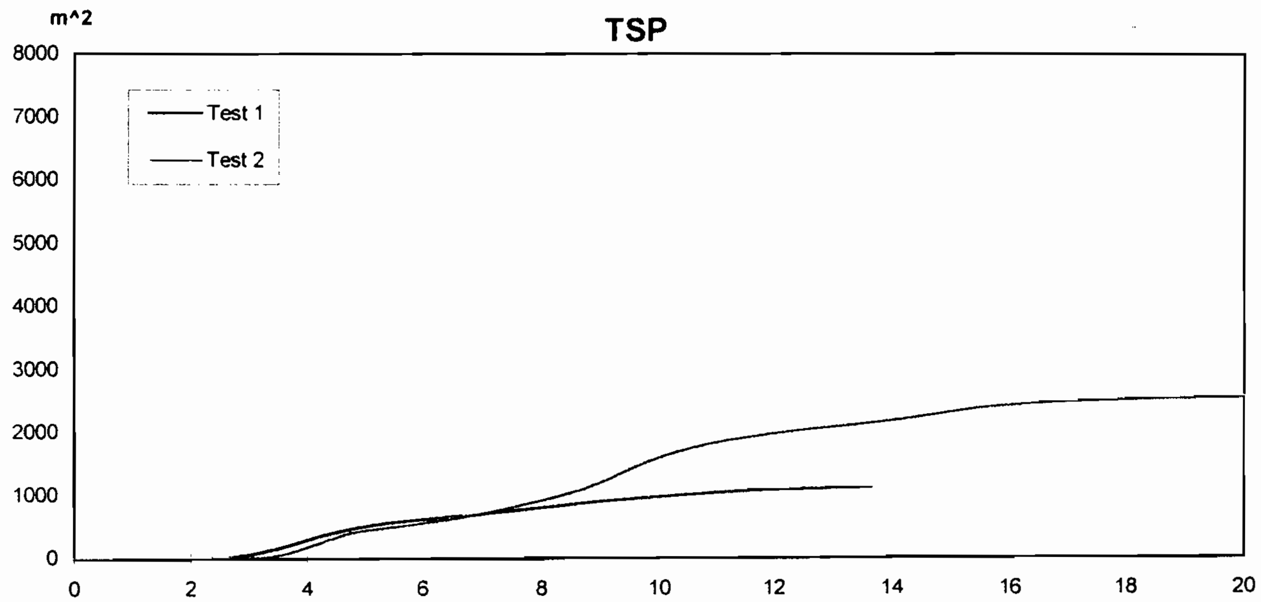


PS-foam (FR). Series 2S



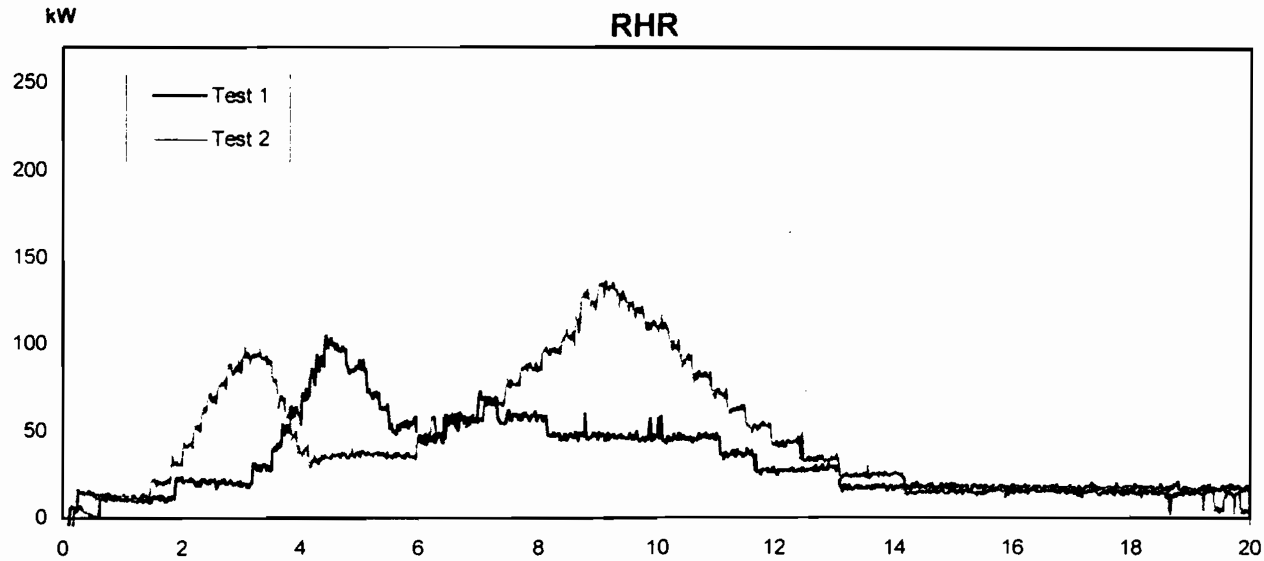
PS-foam (FR). Series 5S

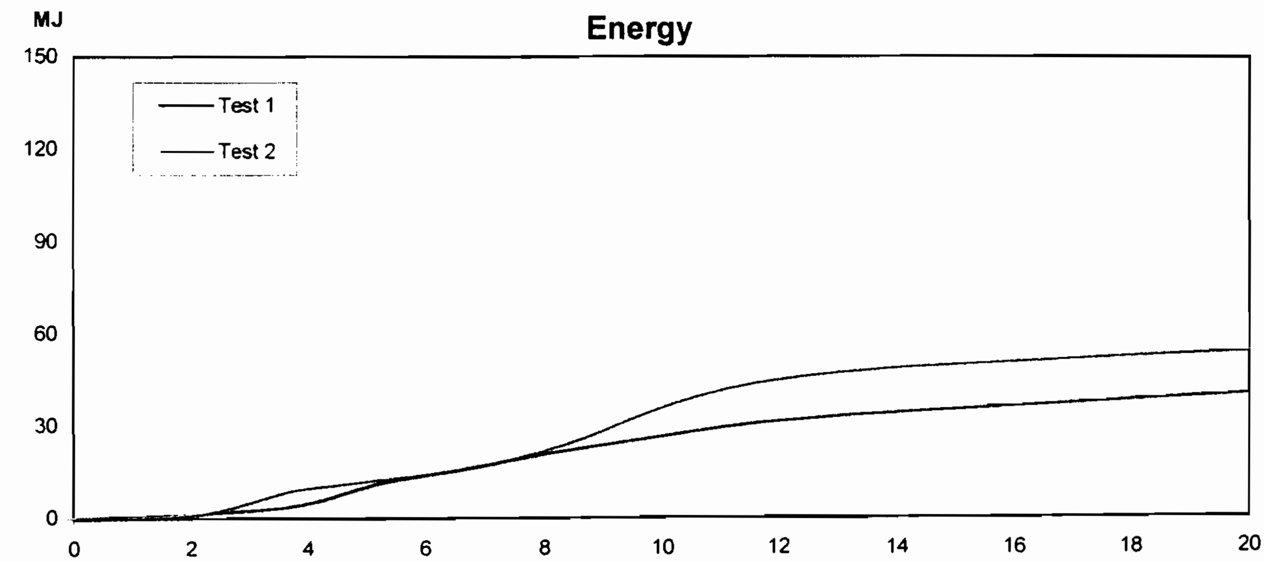


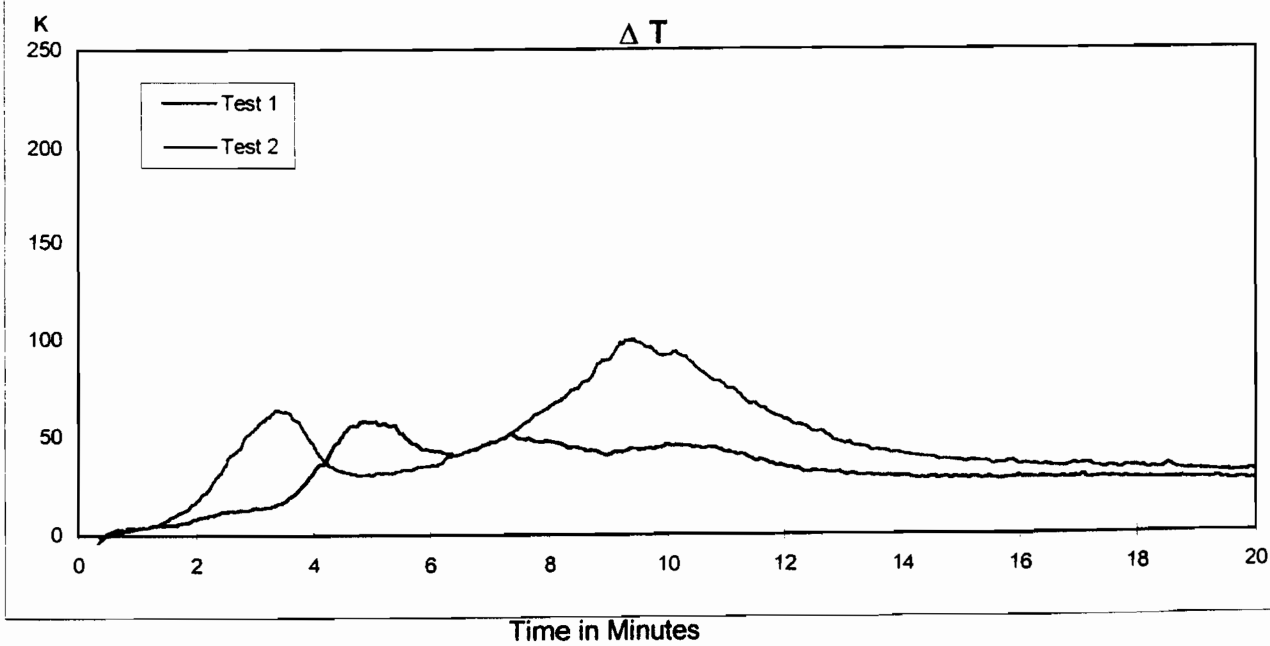


Time in minutes

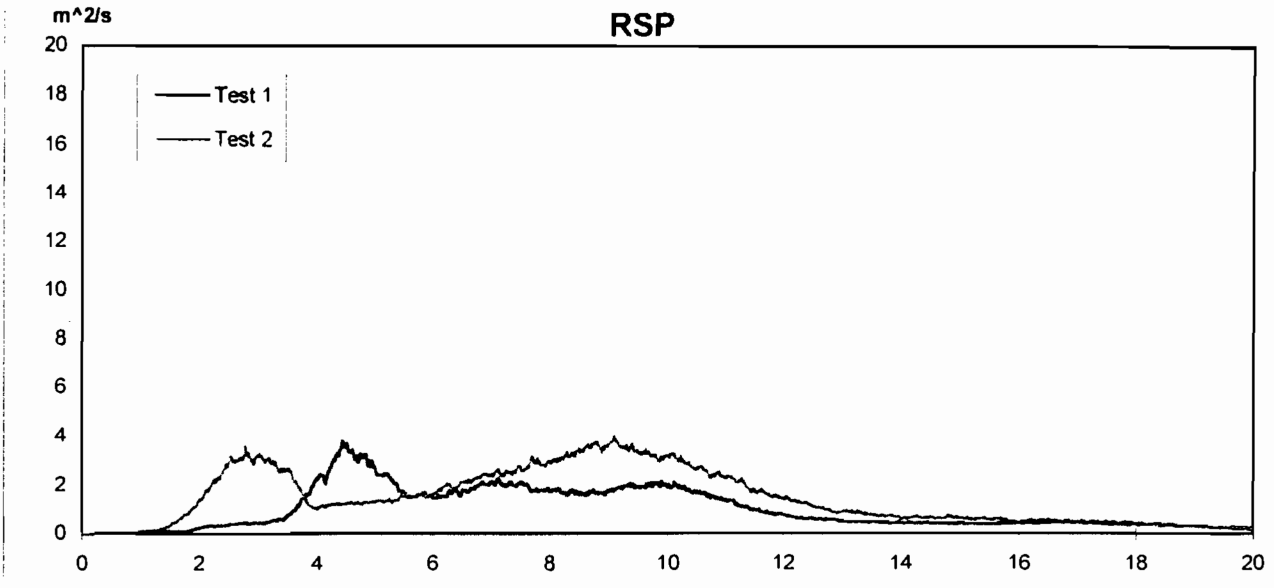
PS-foam (FR). Series 5S

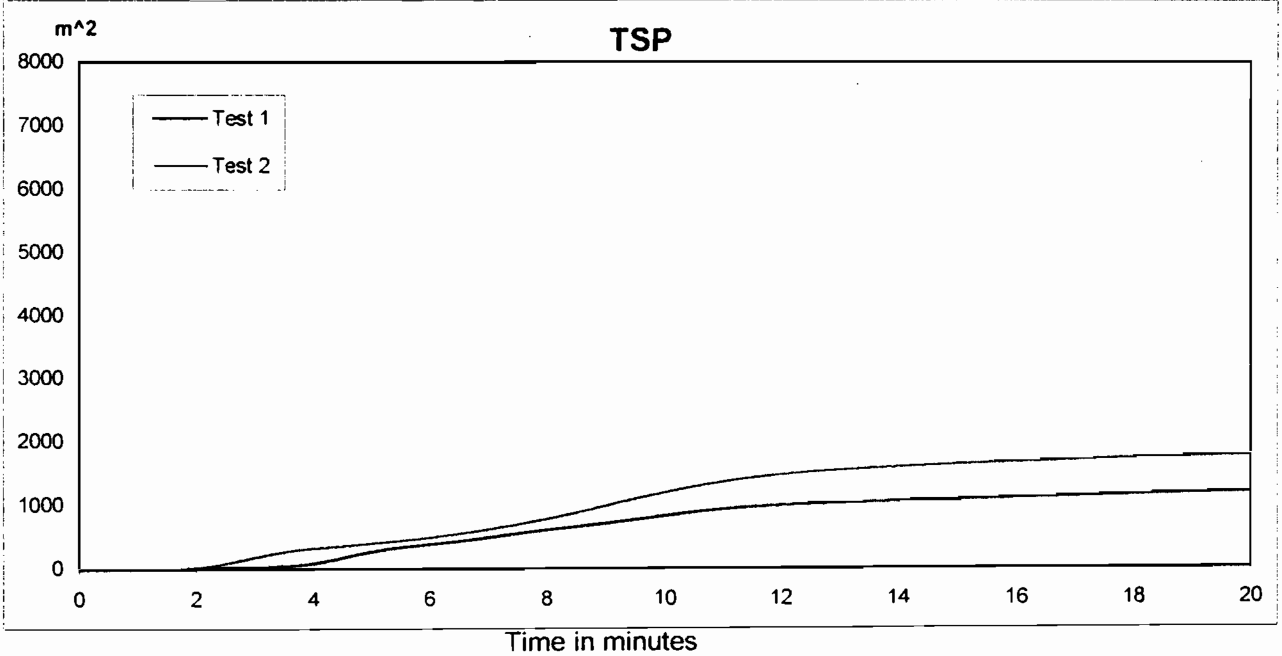




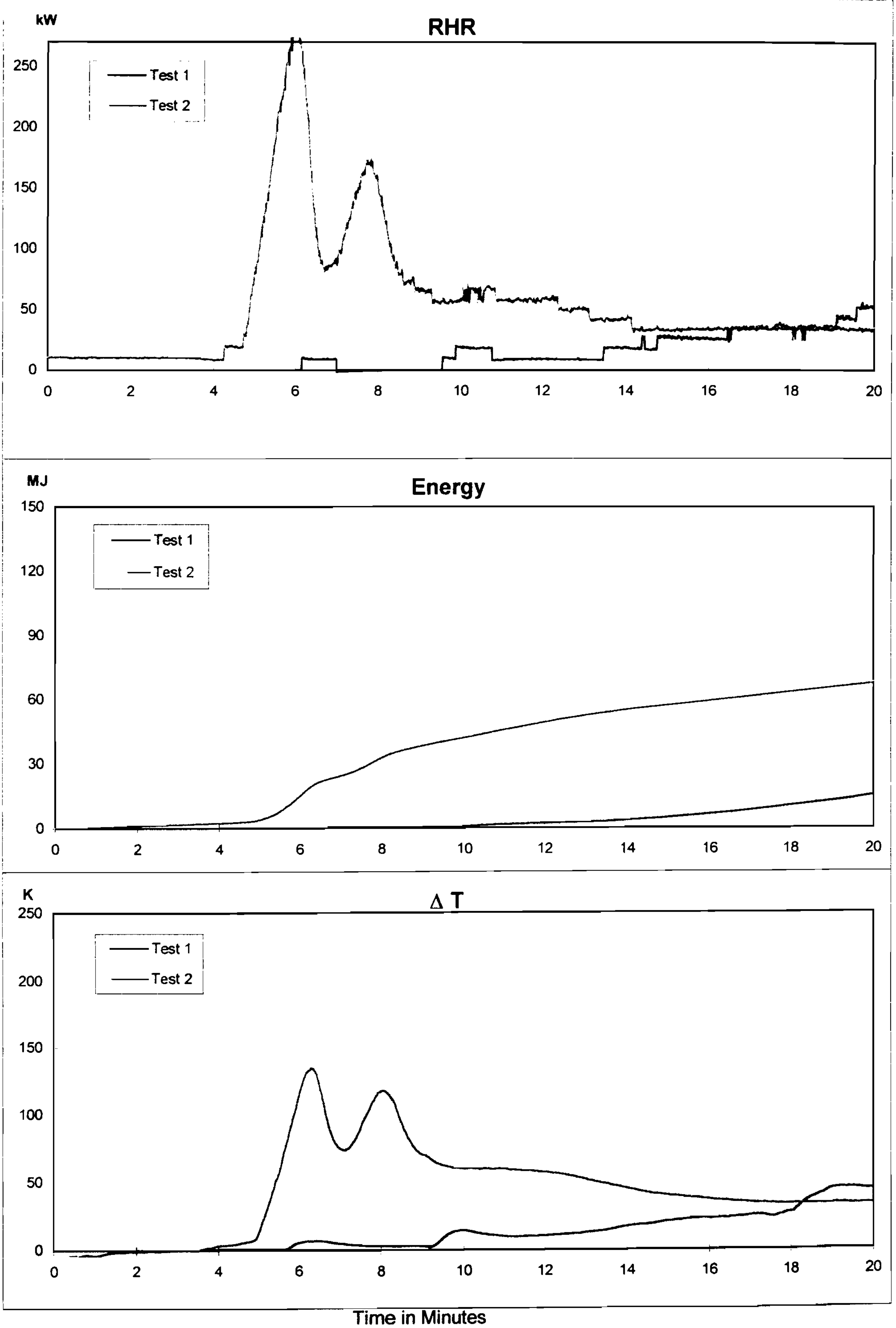


PS-Foam (FR). Series 3´S

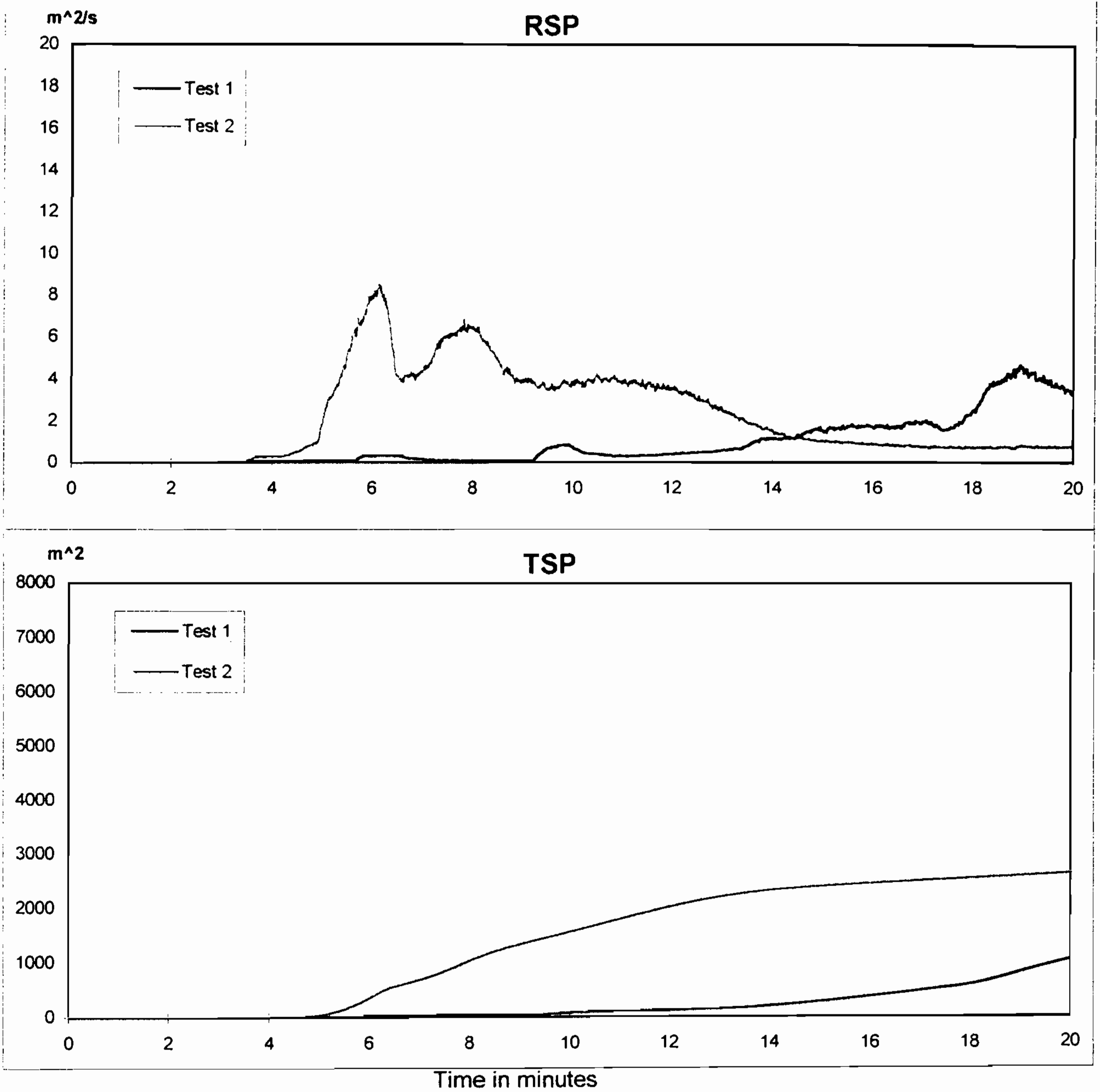




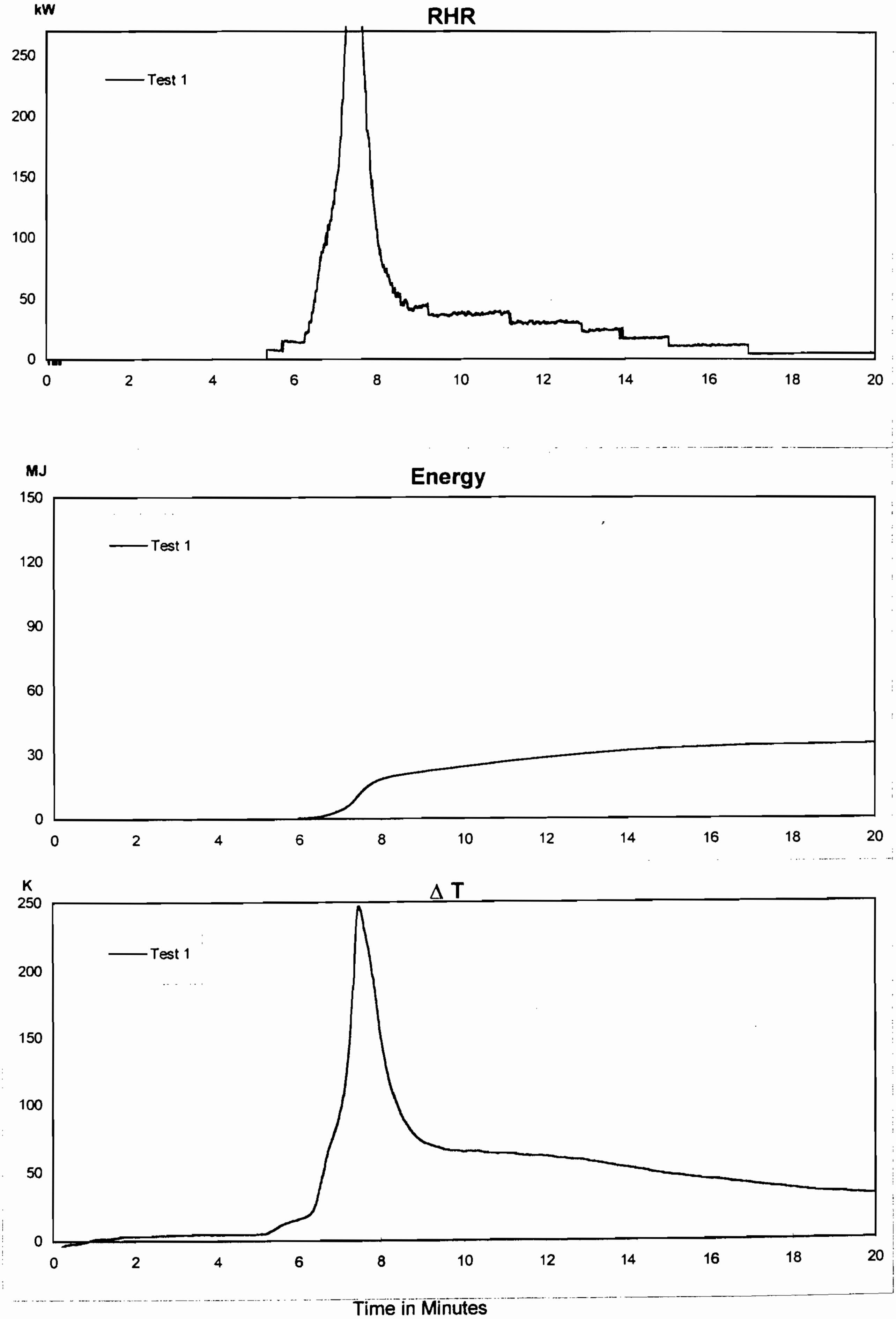
PS-Foam (FR). Series 3´S



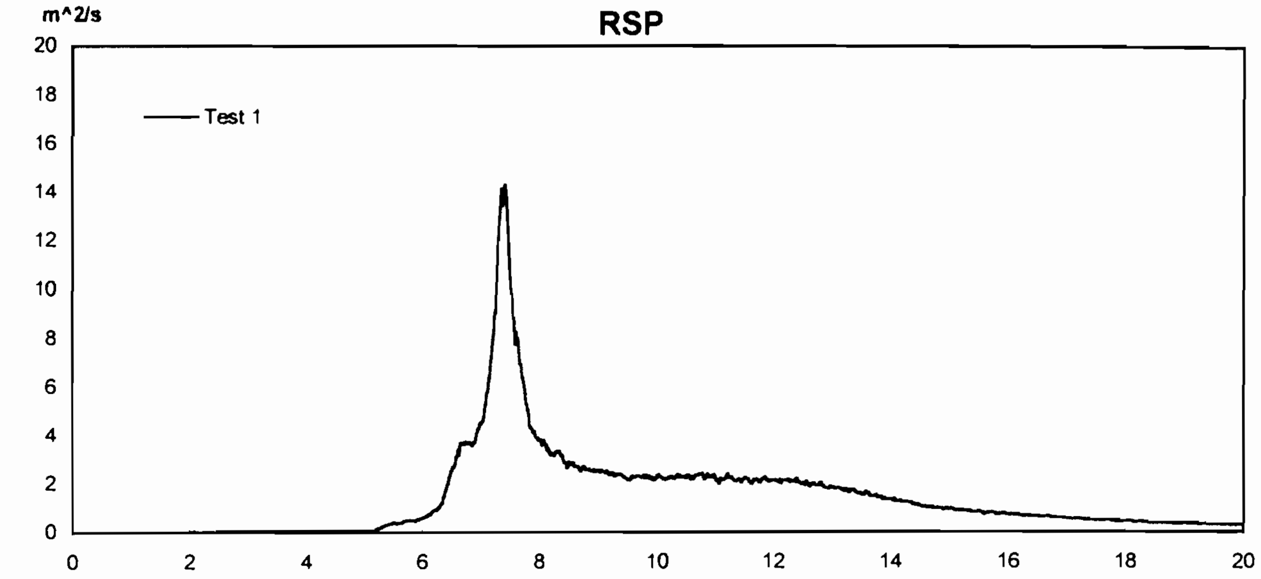
PS-Foam (FR). Series 1P

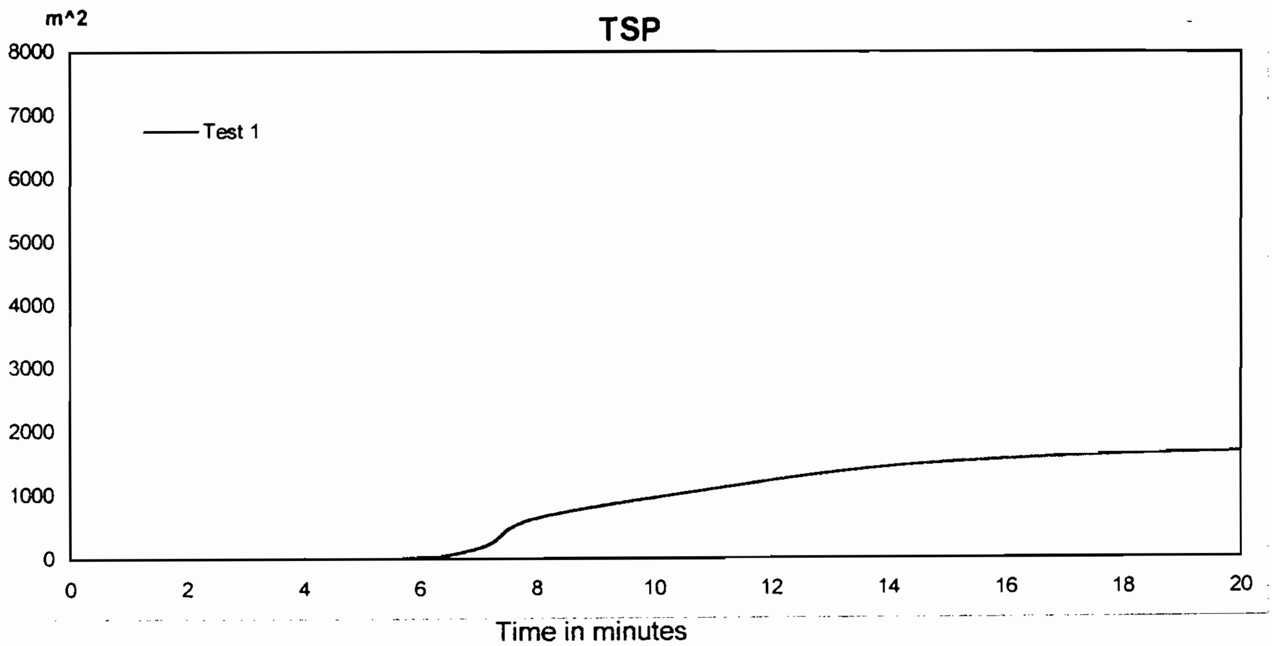


PS-Foam (FR). Series 1P

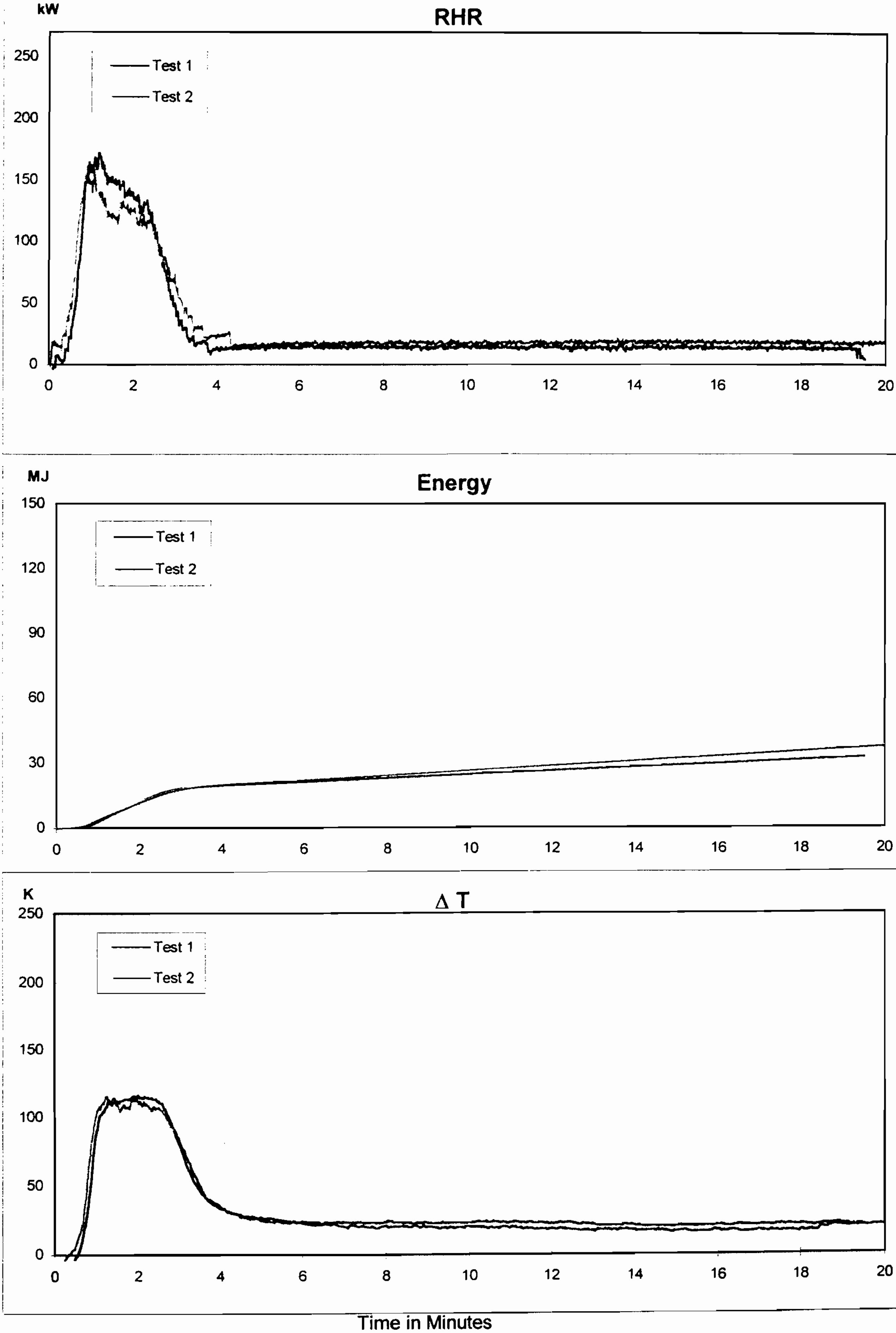


PS-Foam (FR). Series 3P

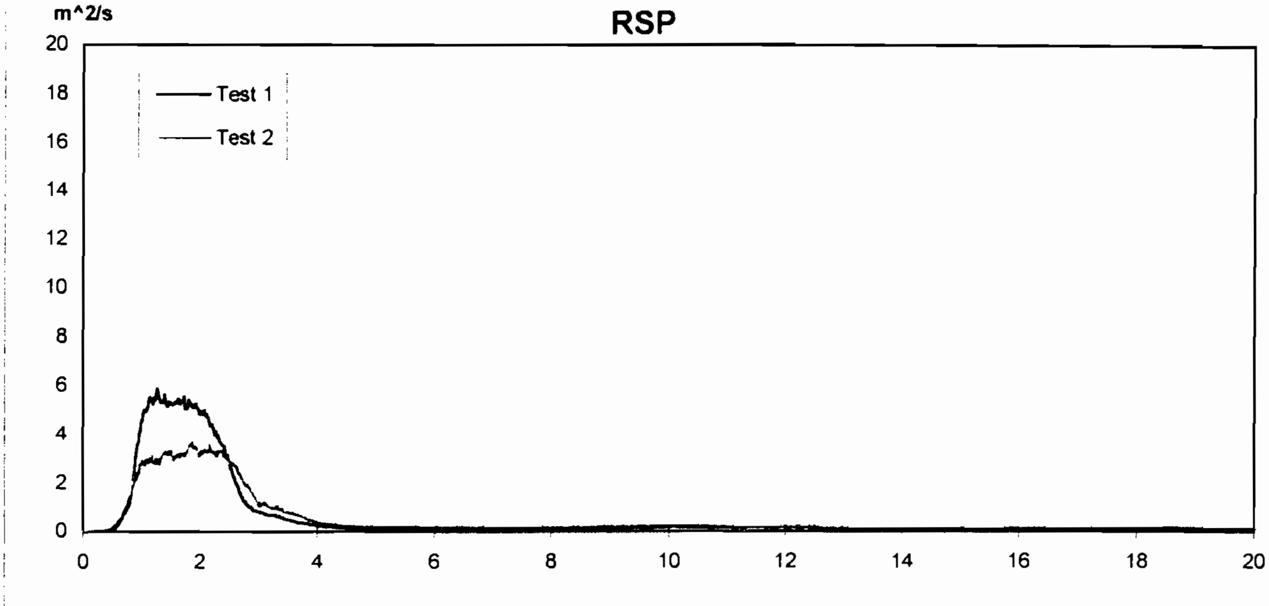


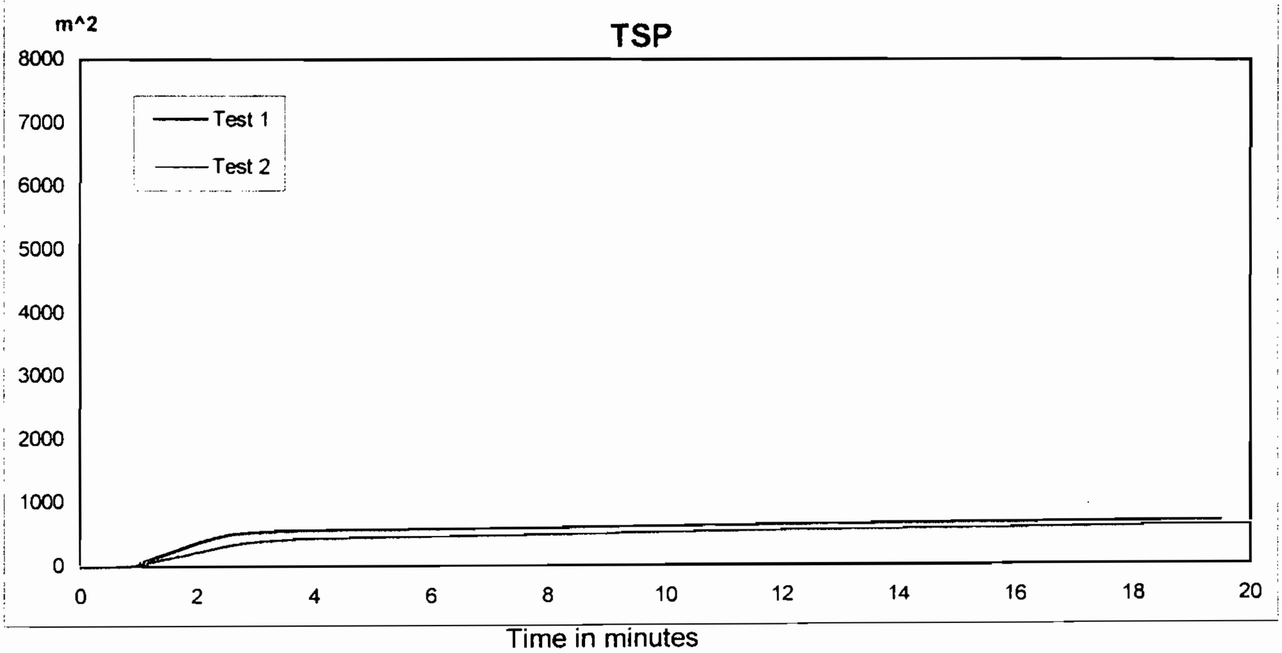


PS-Foam (FR). Series 3P

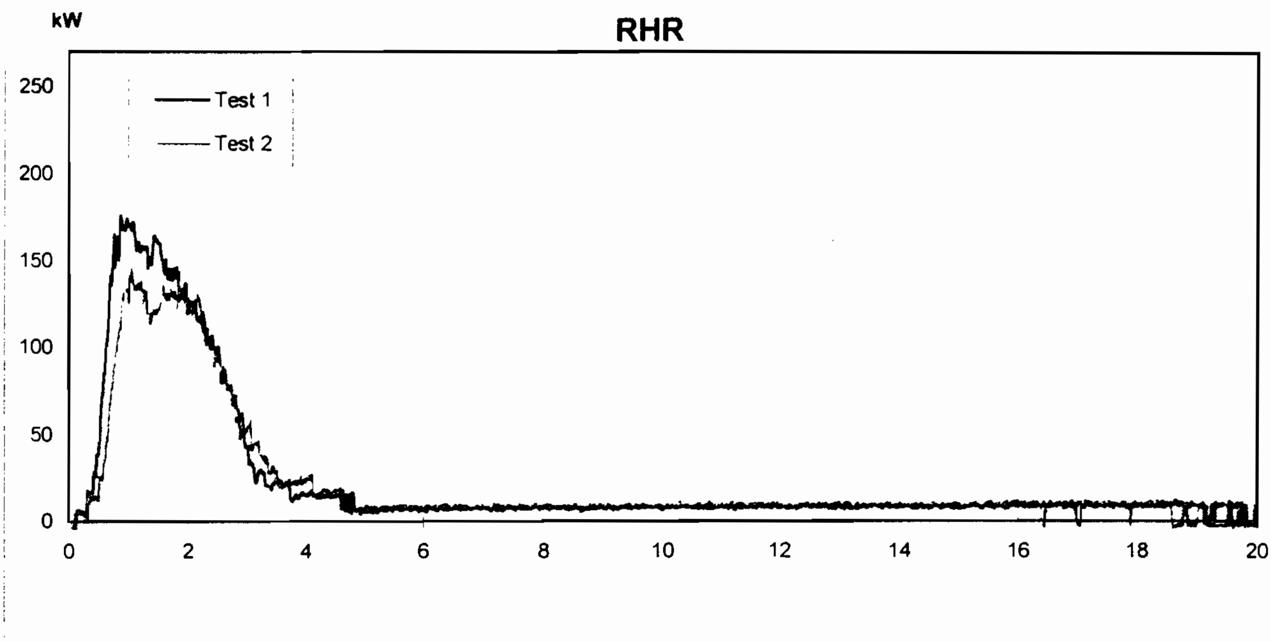


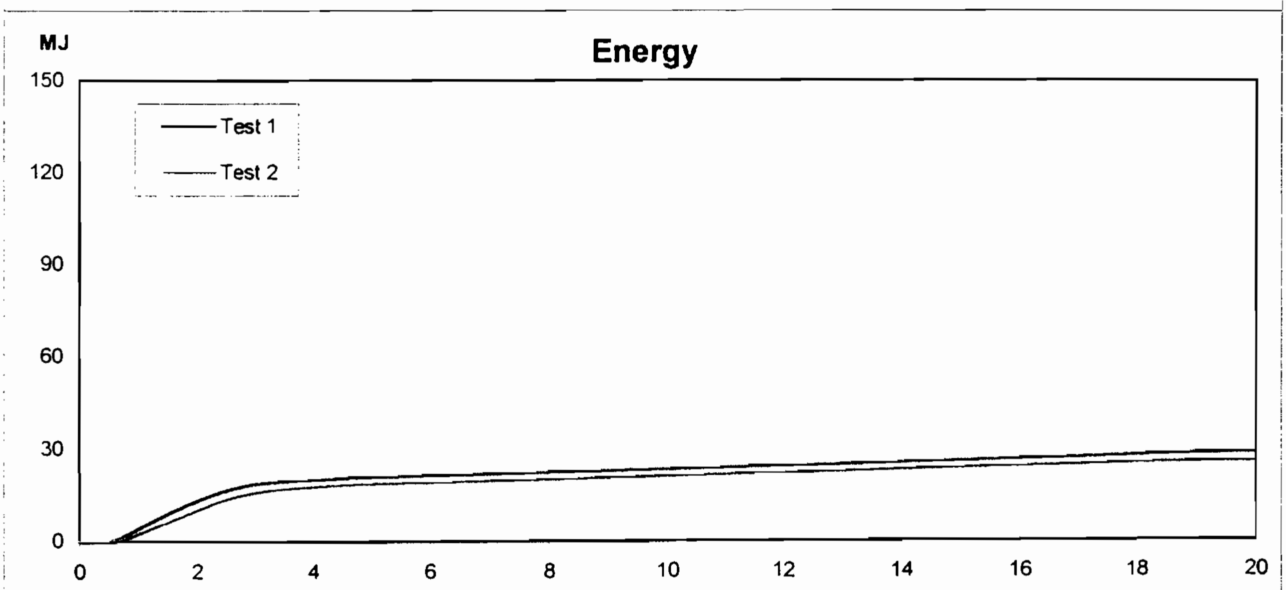
PU-foam. Series 2S

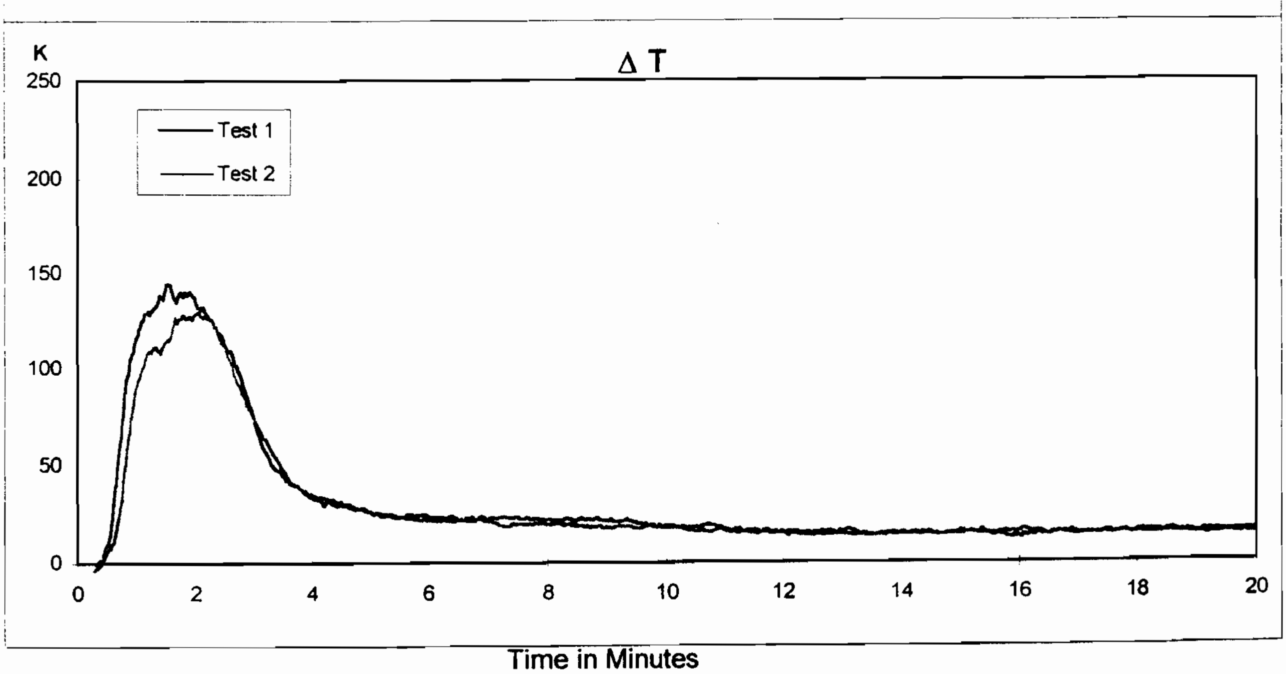




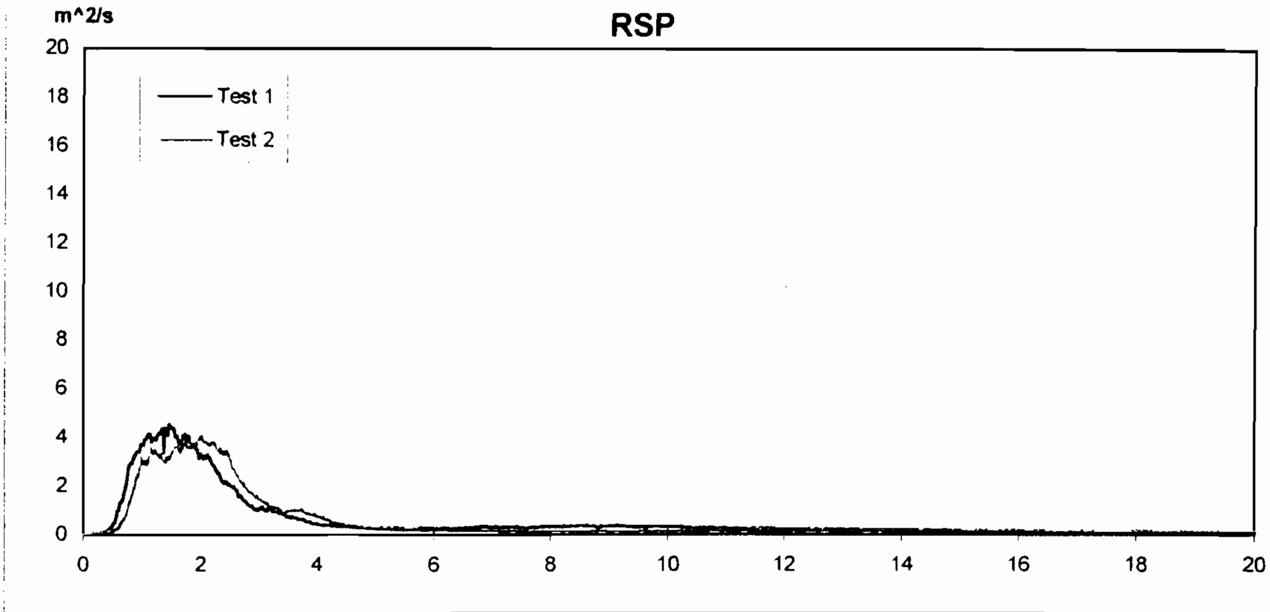
PU-foam. Series 2S

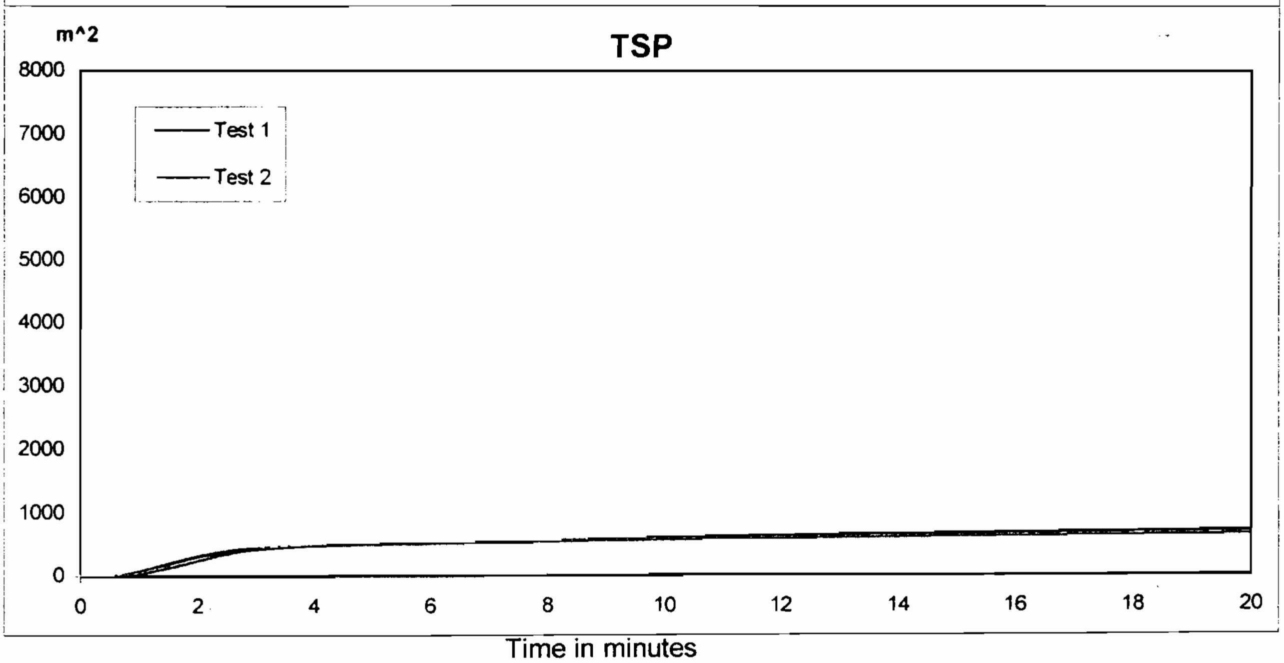




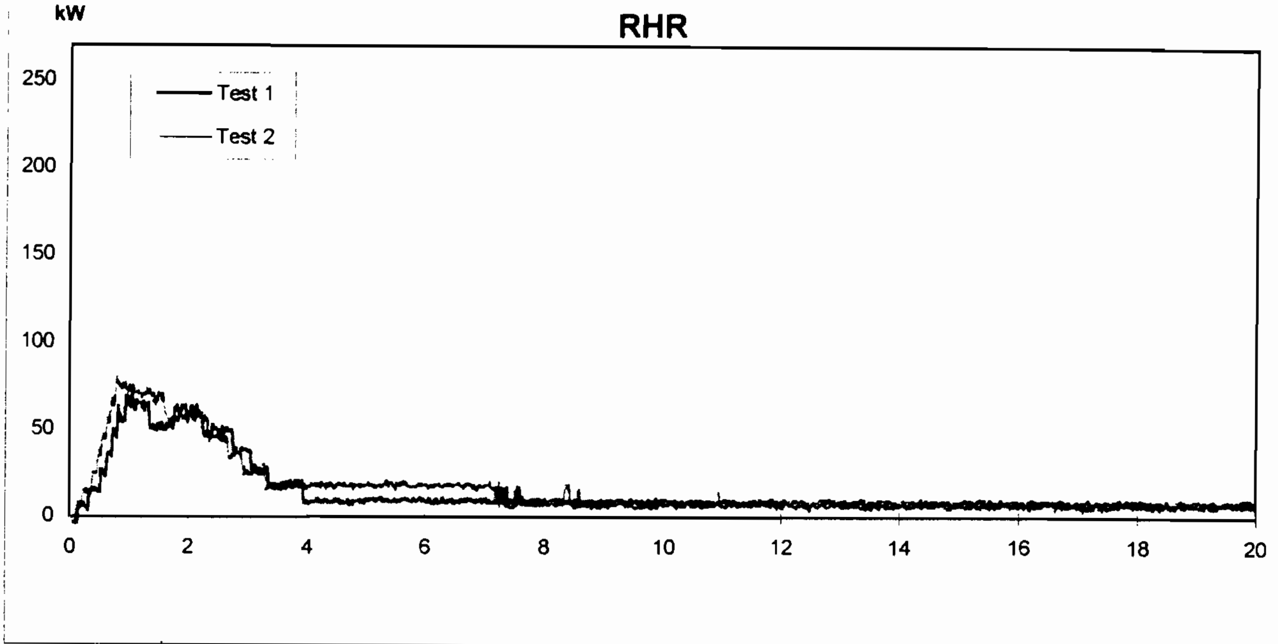


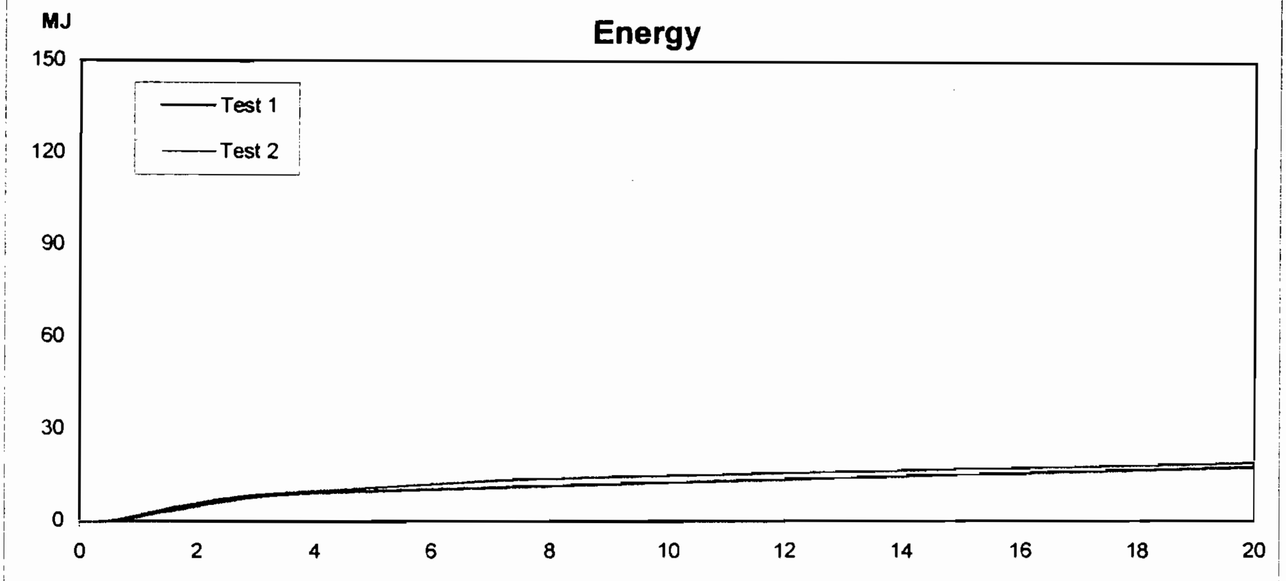
PU-foam. Series 5S

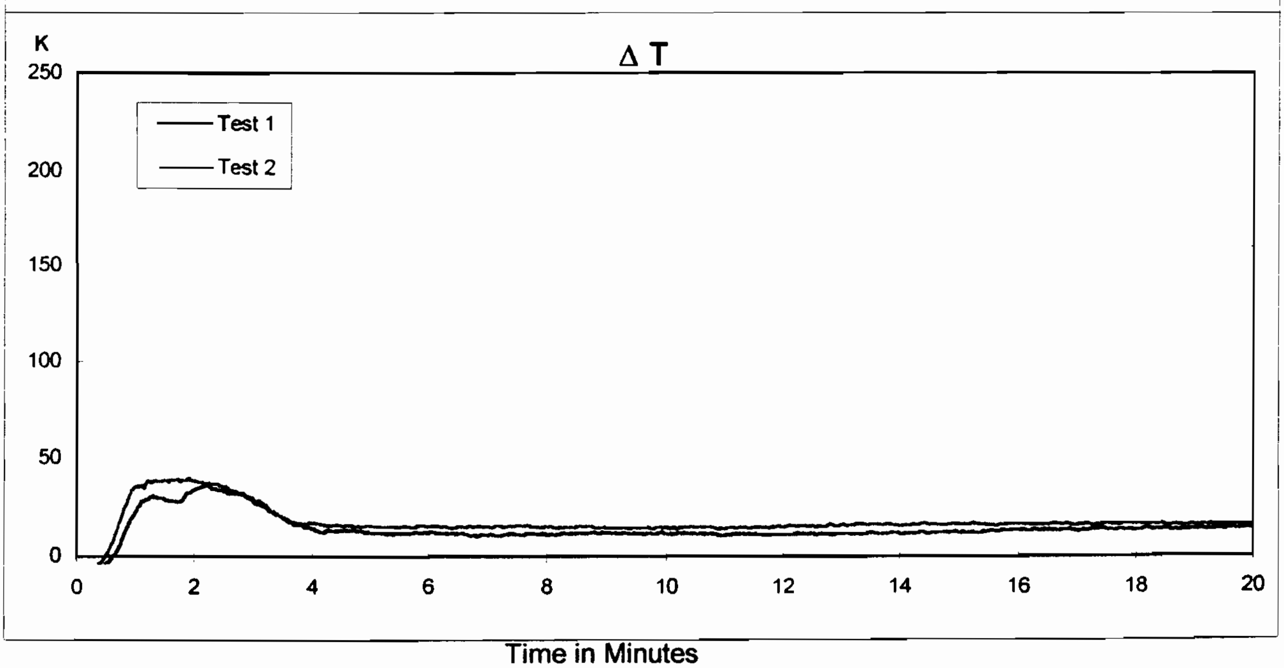




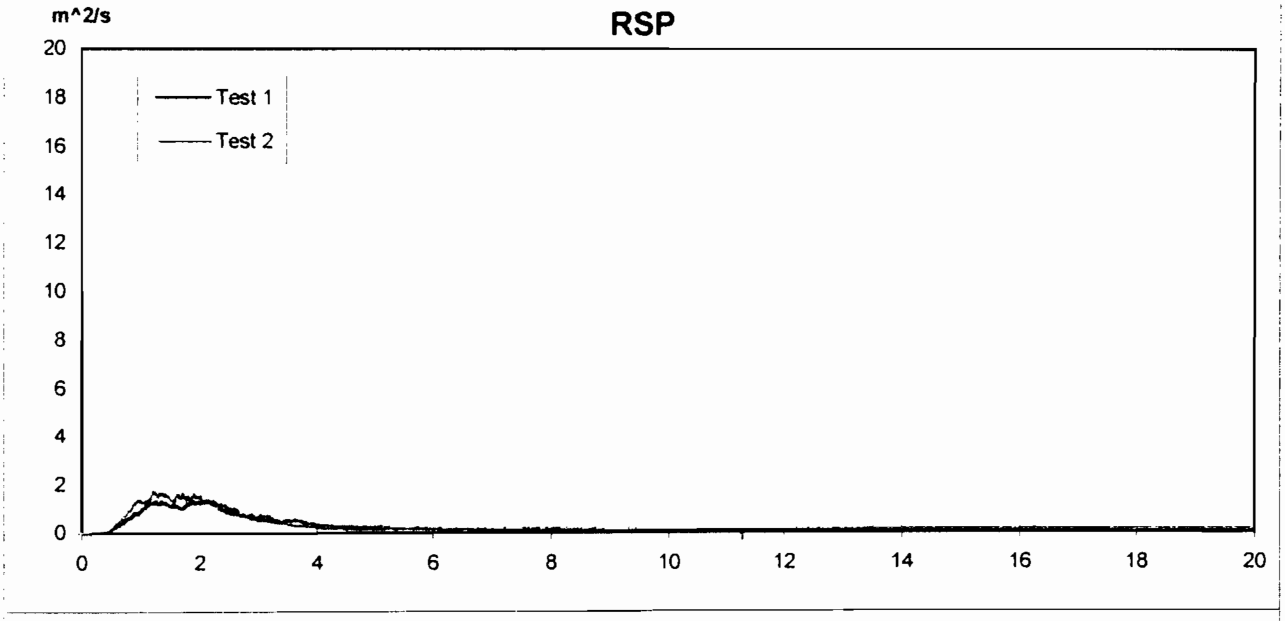
PU-foam. Series 5S

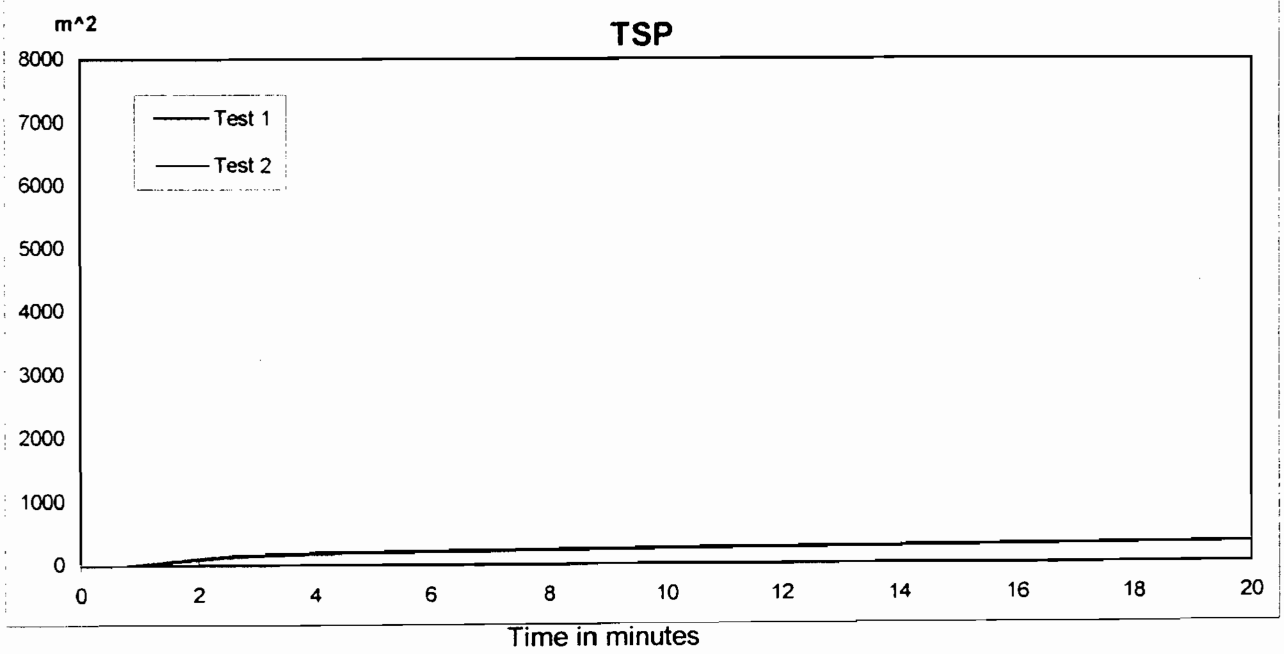




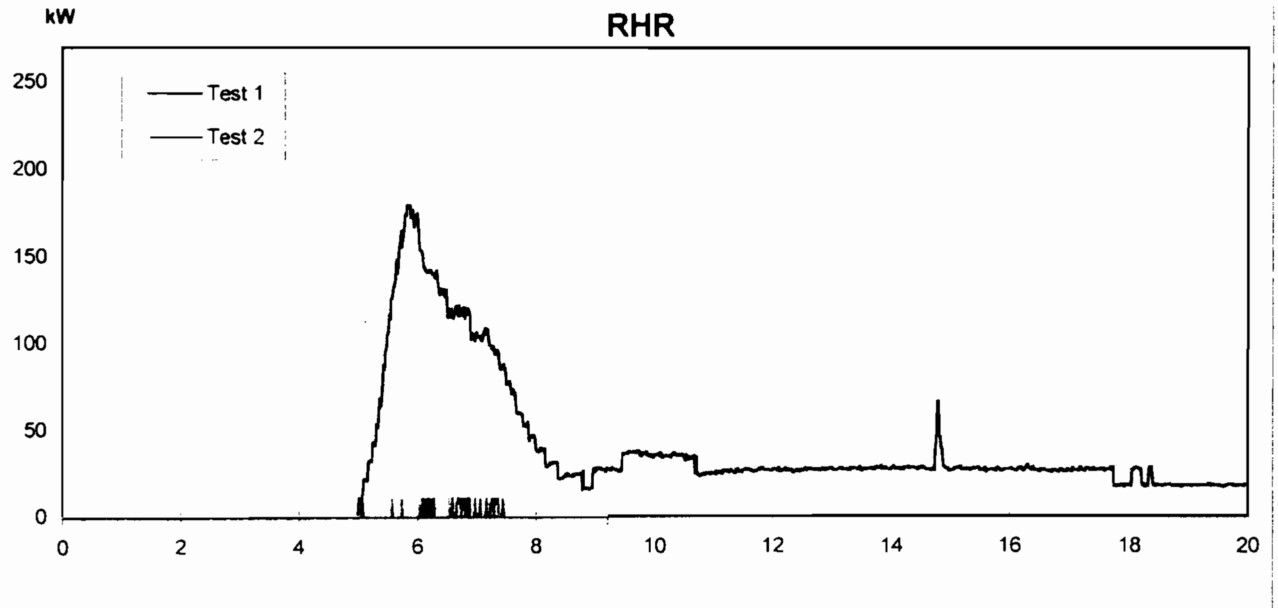


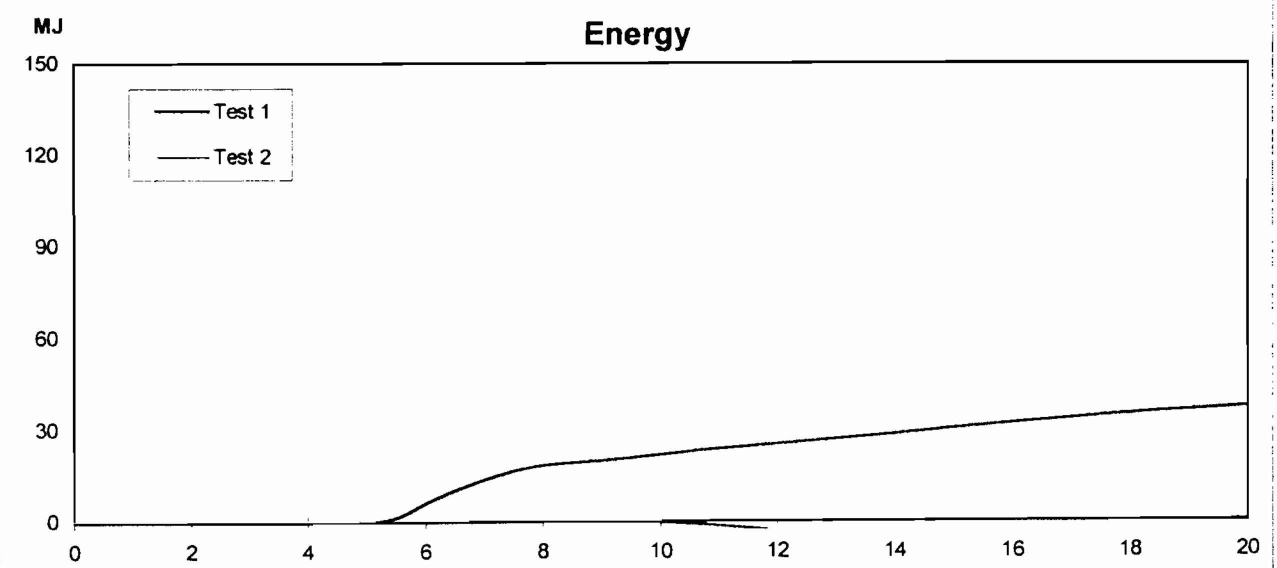
PU-foam. Series 3´S

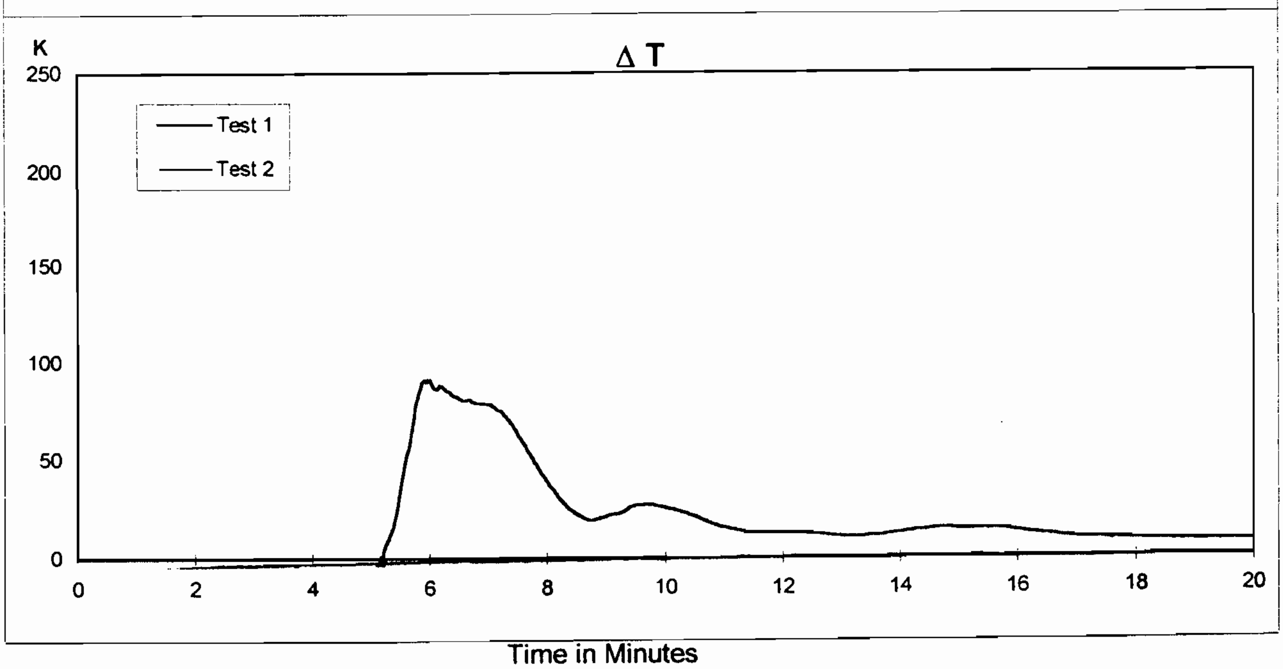




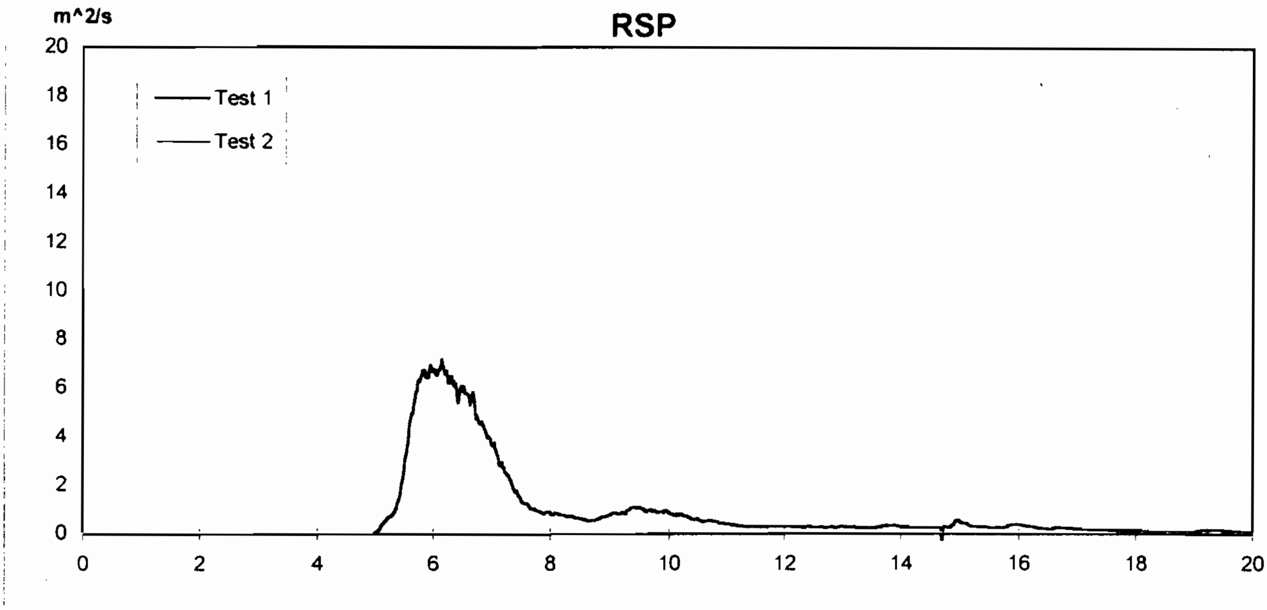
PU-foam. Series 3´S

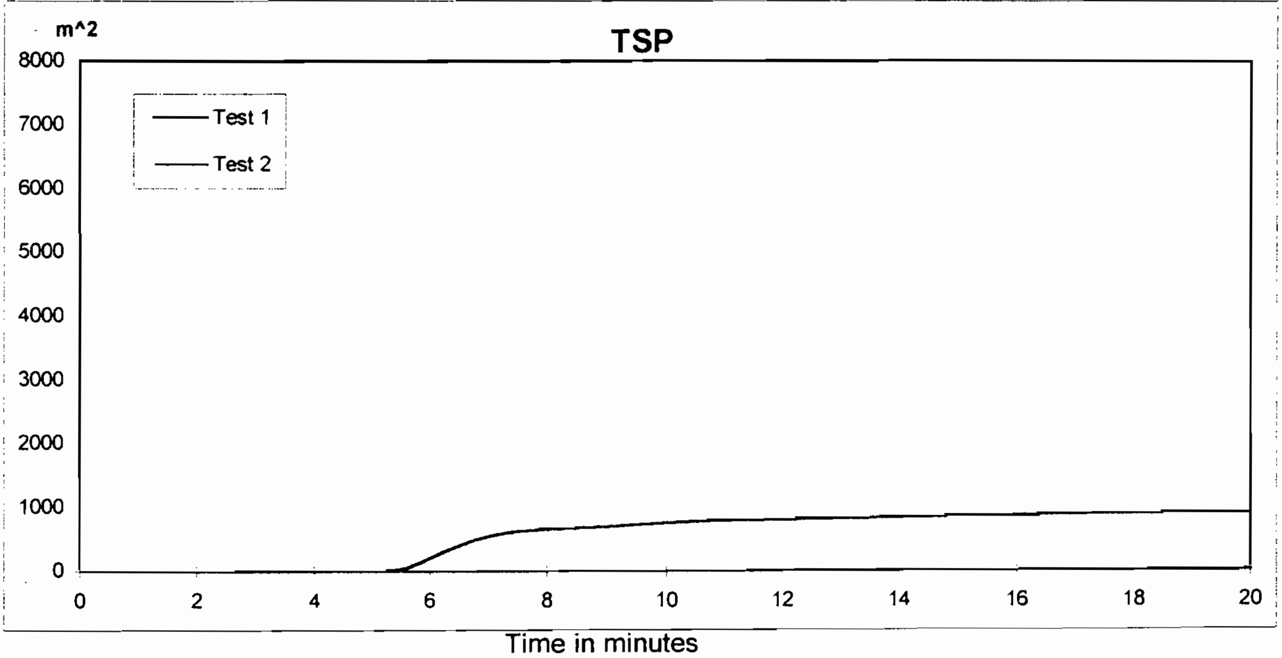




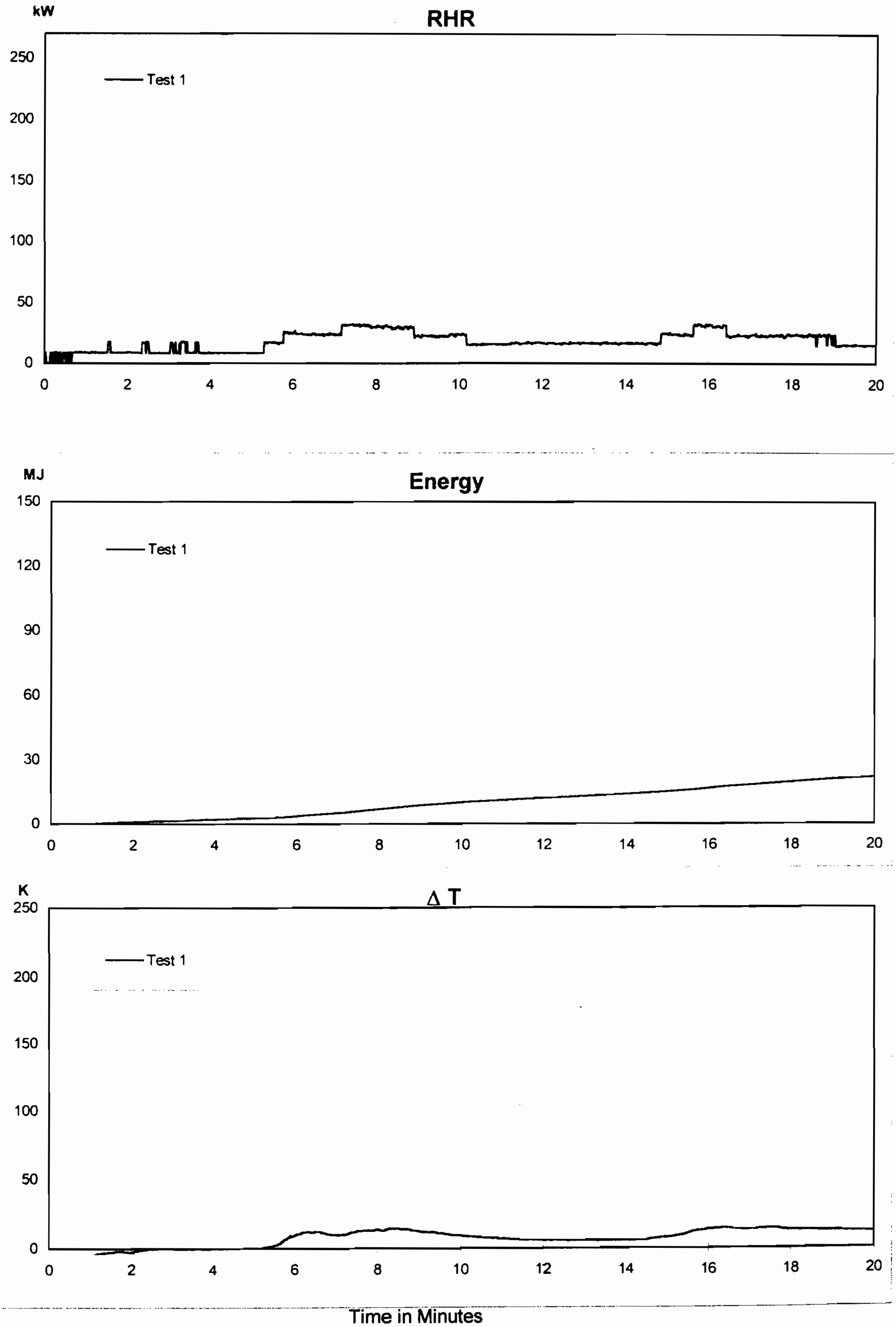


PU-Foam. Series 1P

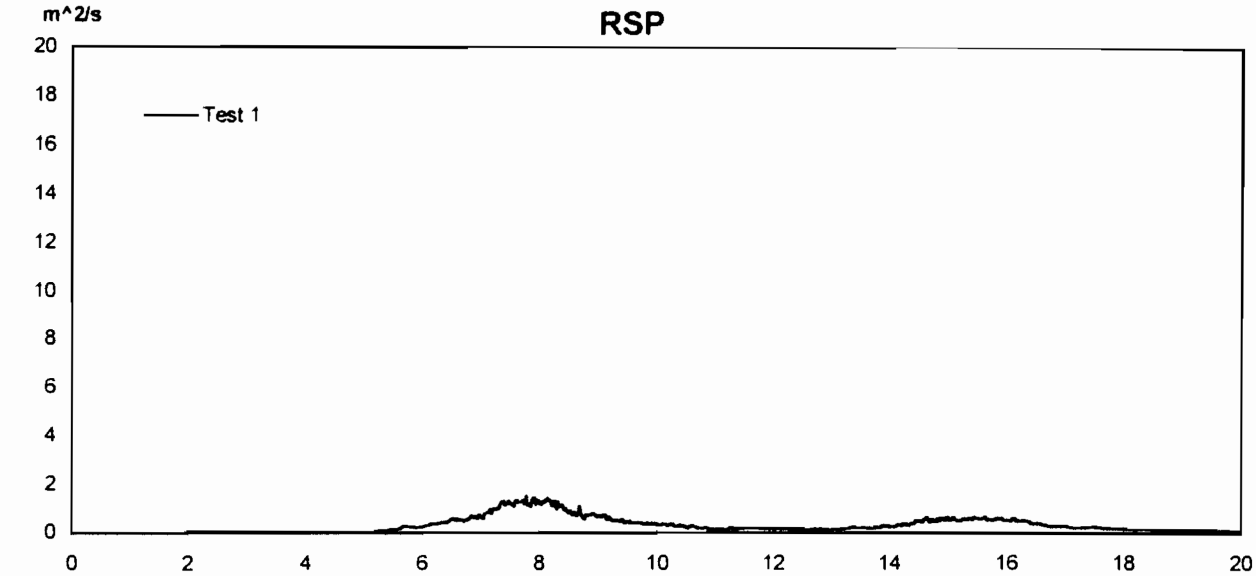


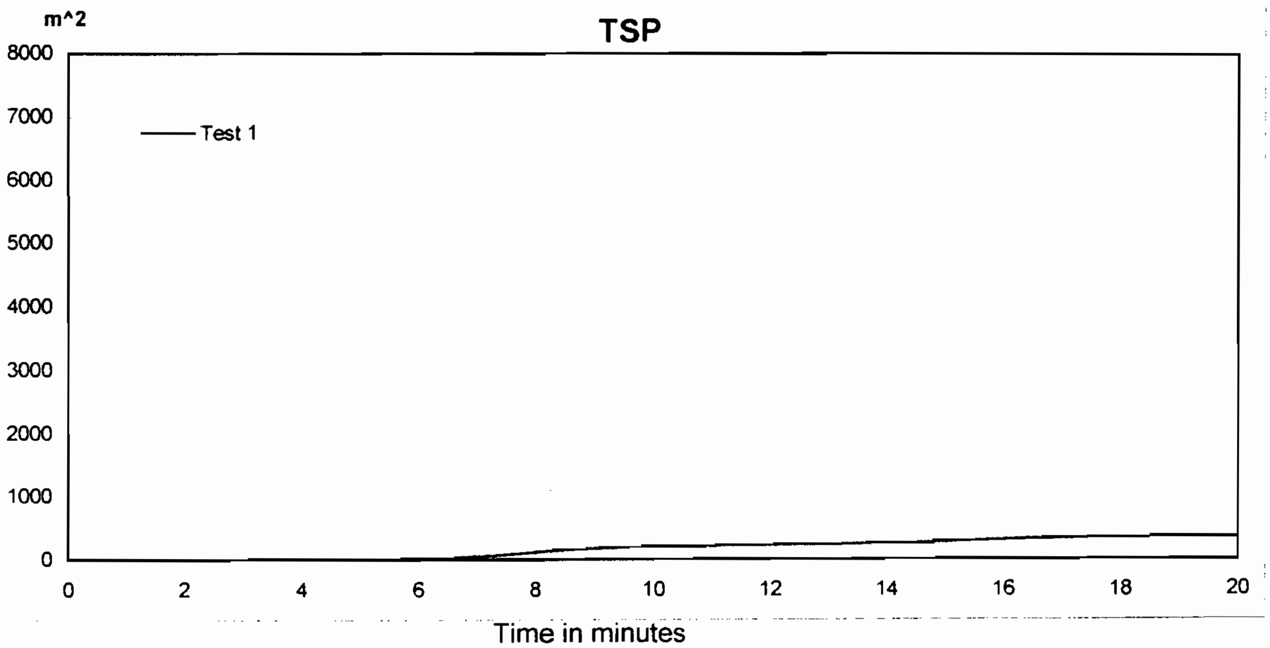


PU-Foam. Series 1P

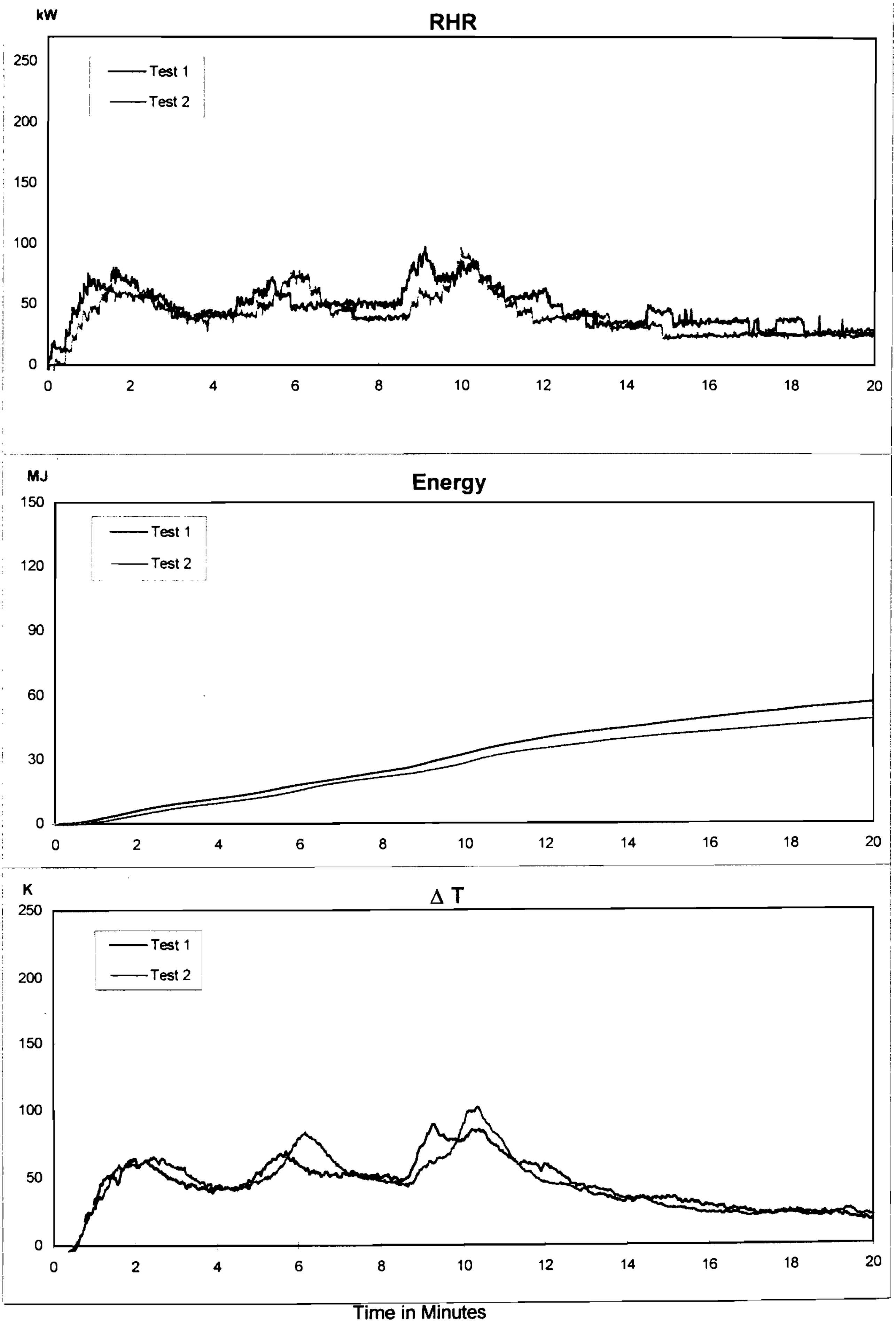


PU-foam. Series 3P





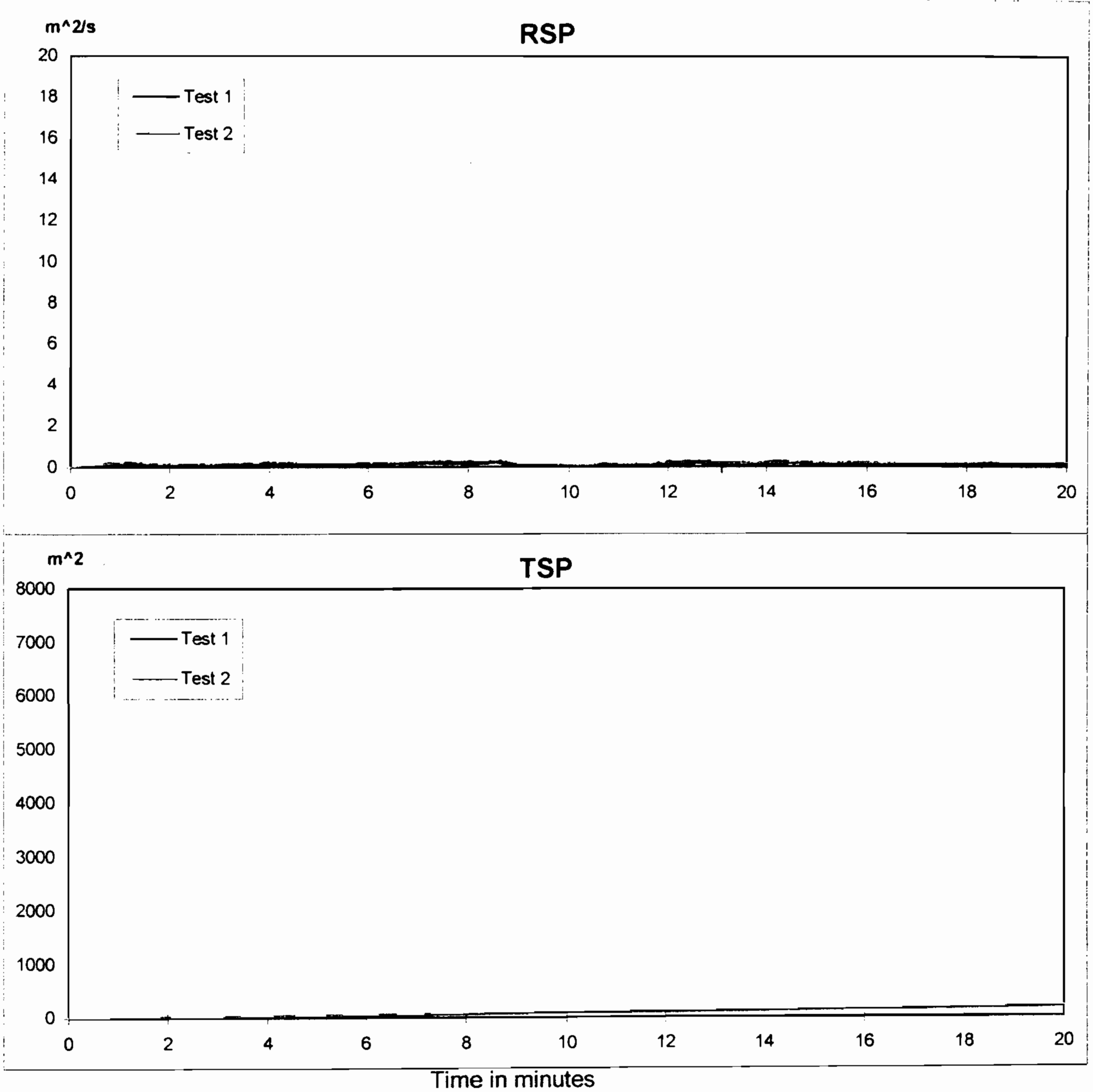
PU-foam. Series 3P



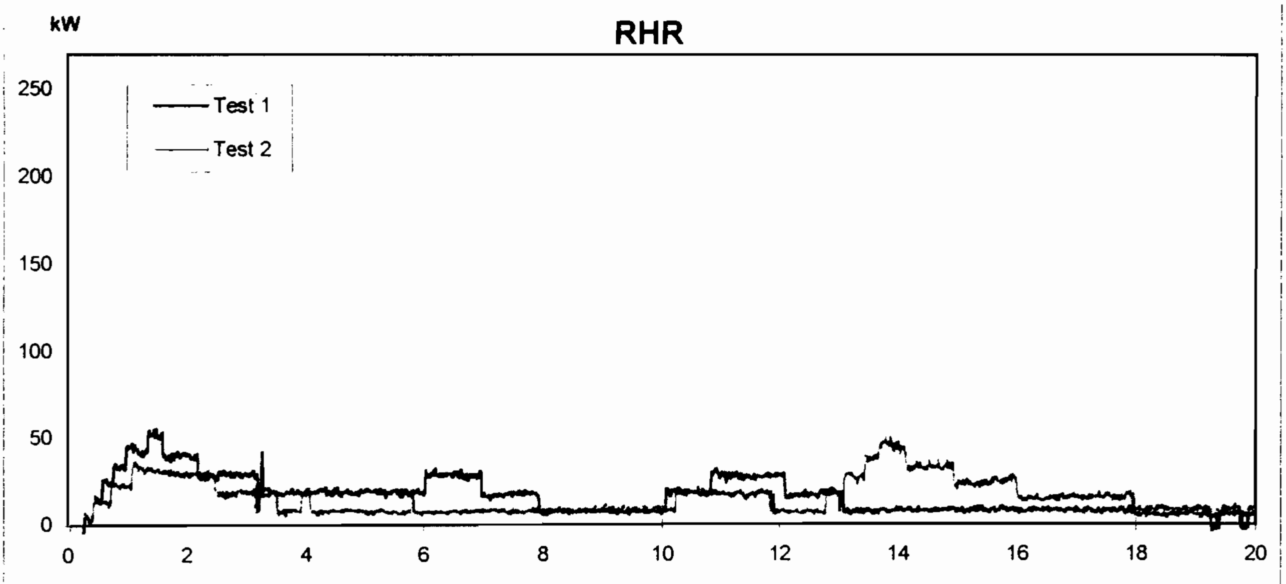
Varnished timber (Pine). Series 2S

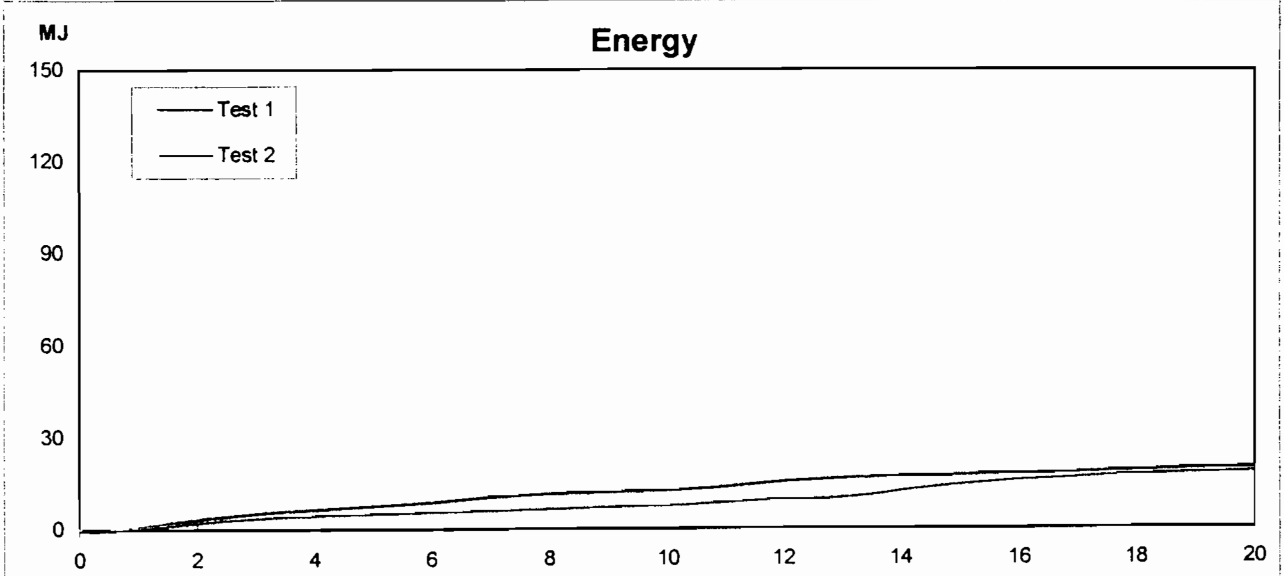
MATERIALPRÜFUNGSAMT
NORDRHEIN-WESTFALEN

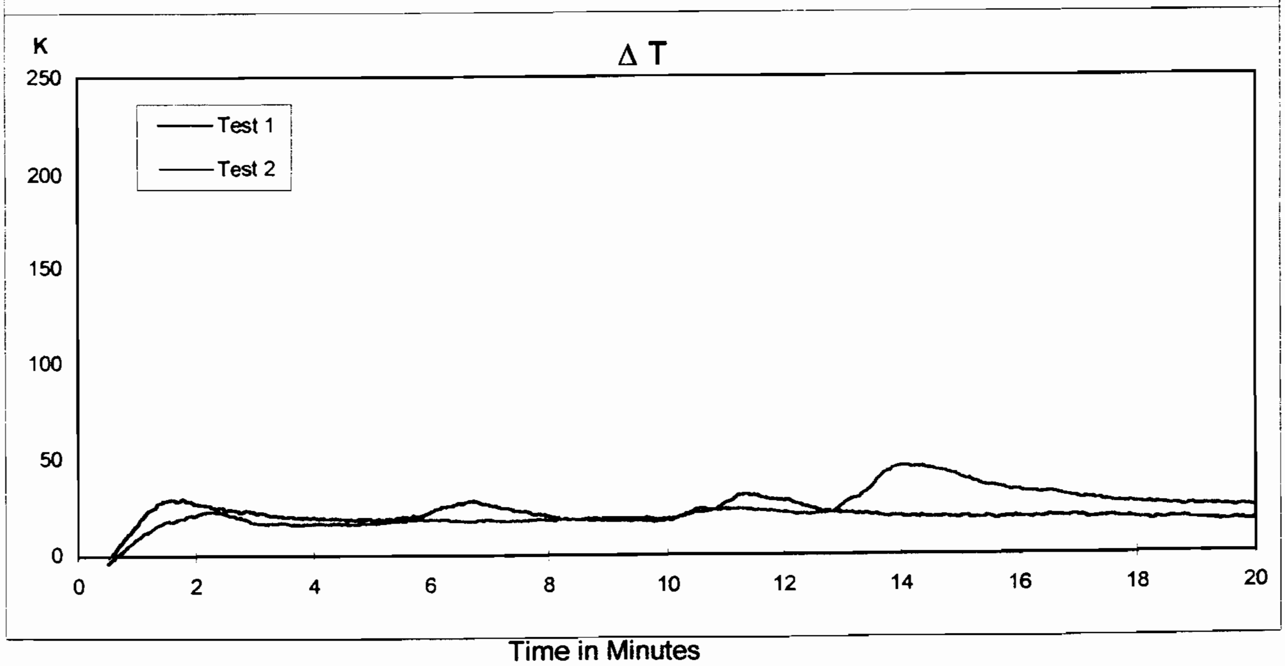
MPA NRW



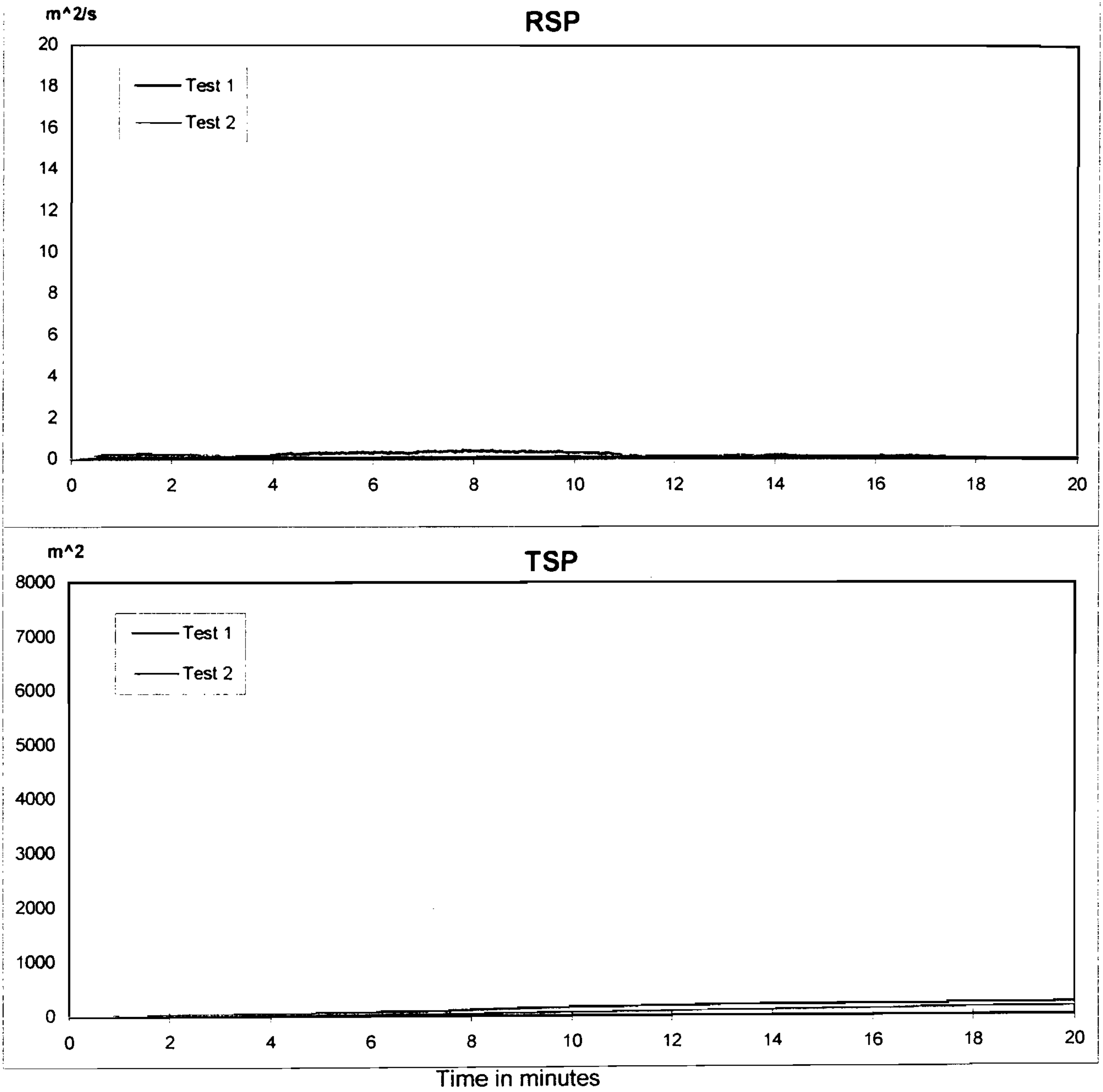
Varnished timber (Pine). Series 2S



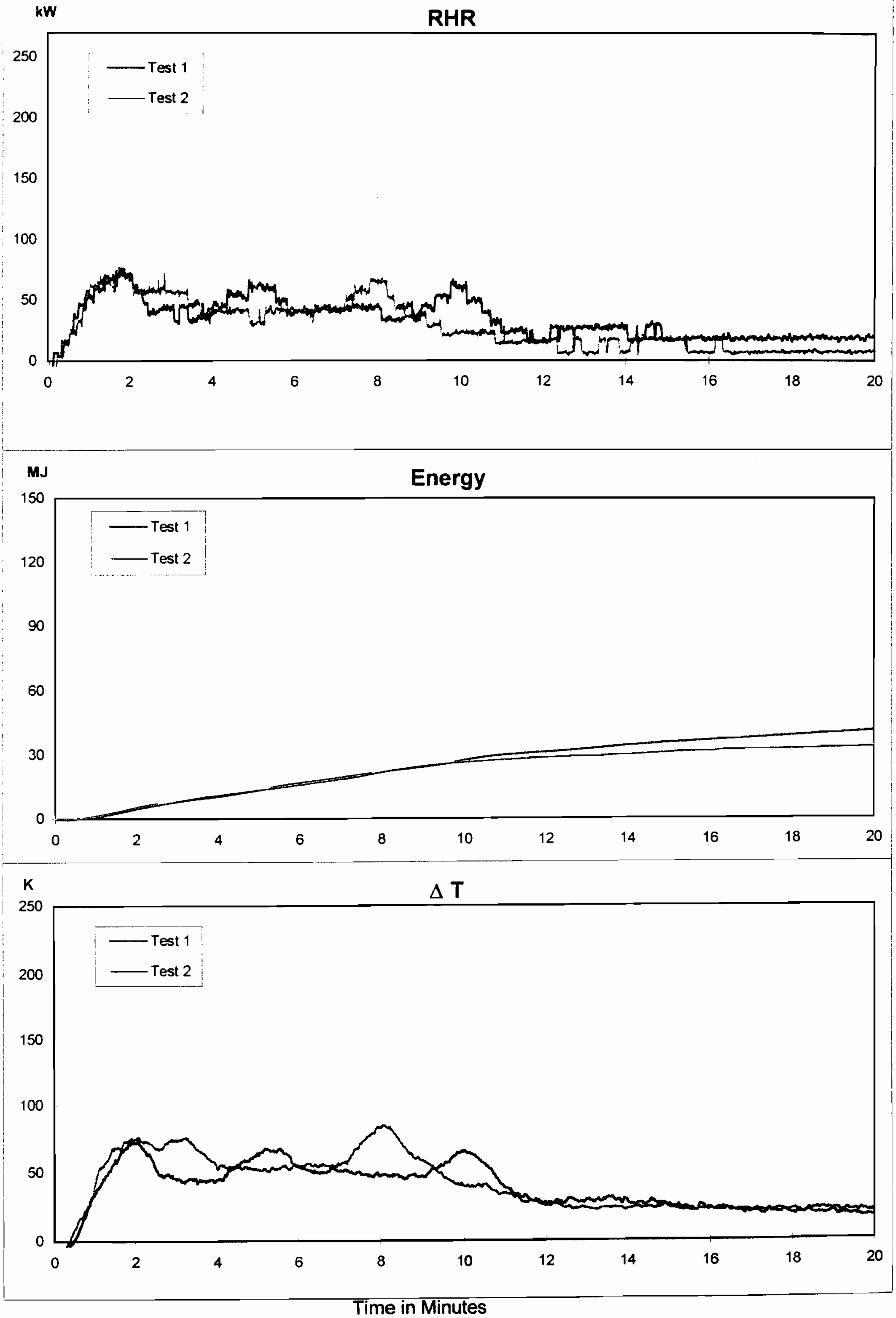




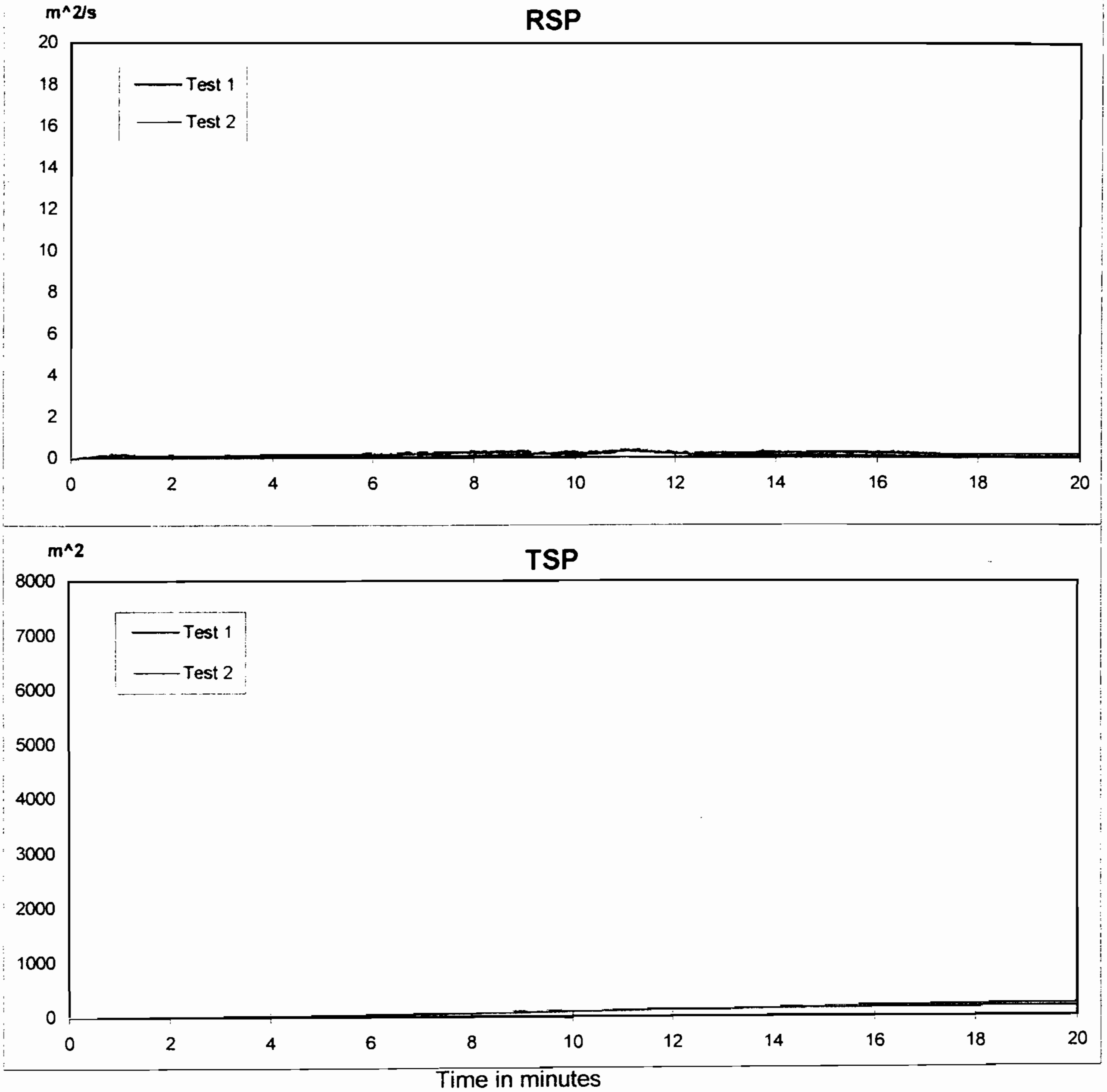
Varnished timber (Pine). Series 3´S



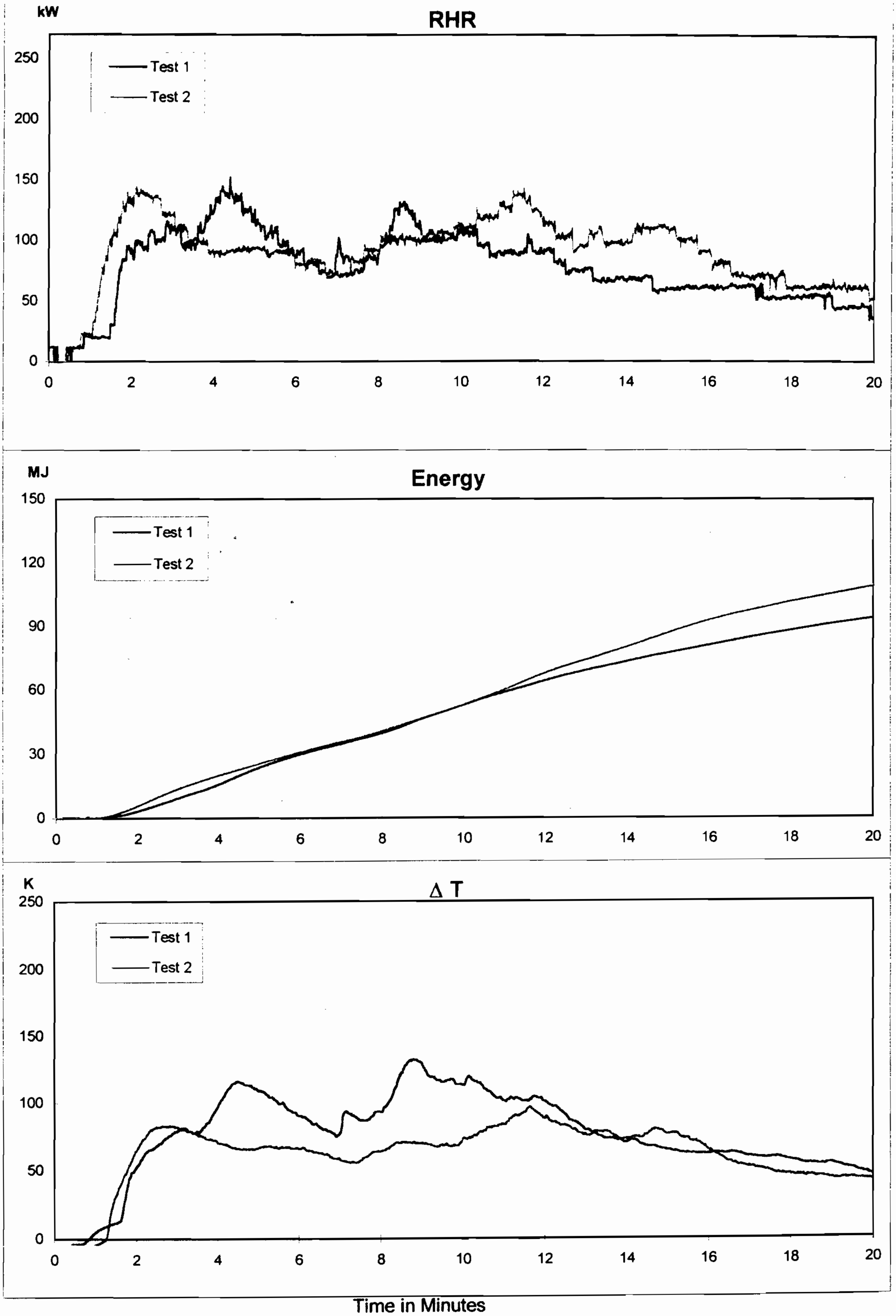
Varnished timber (Pine). Series 3´S



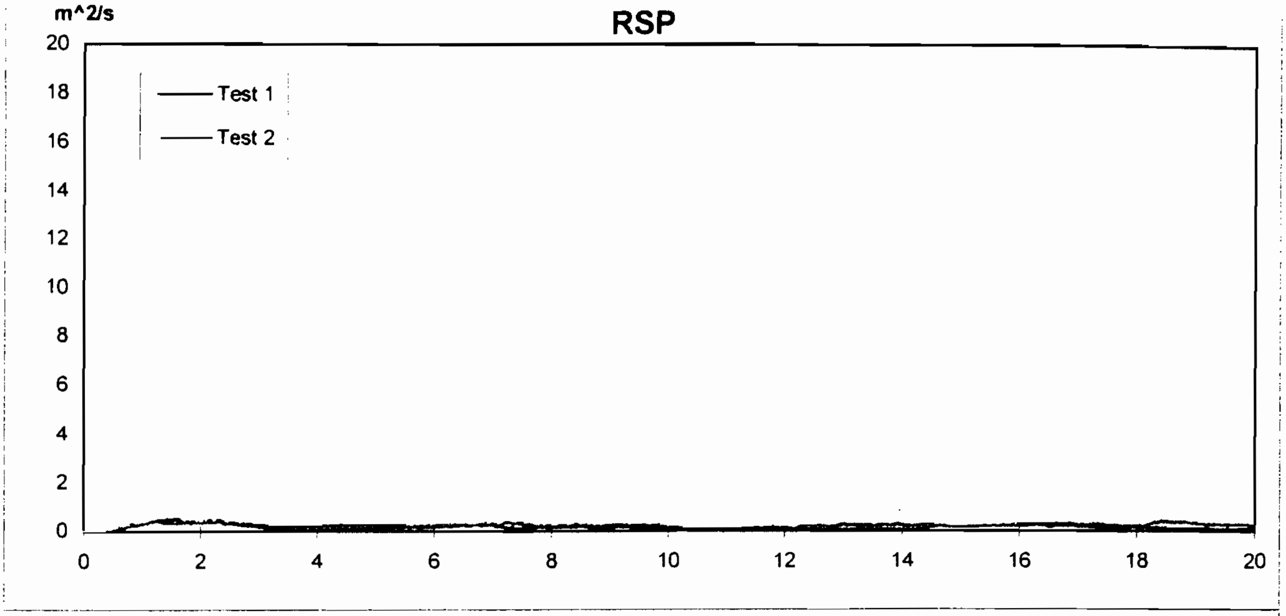
Varnished timber (Pine). Series 5S

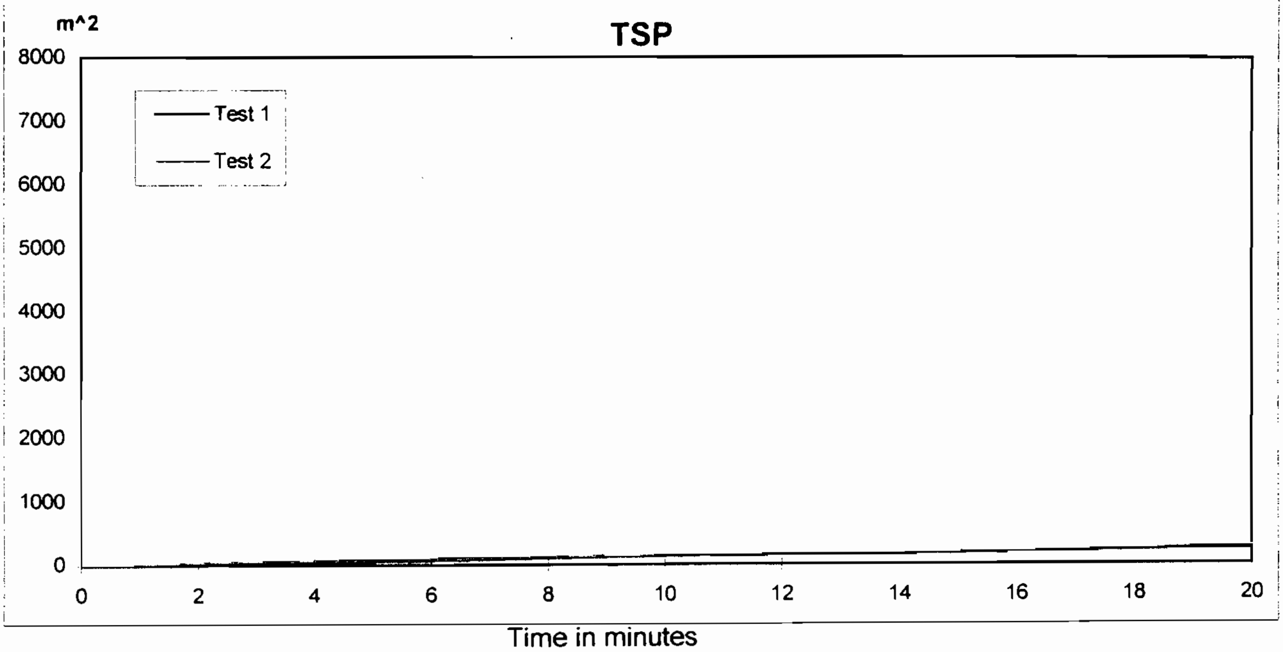


Varnished timber (Pine). Series 5S

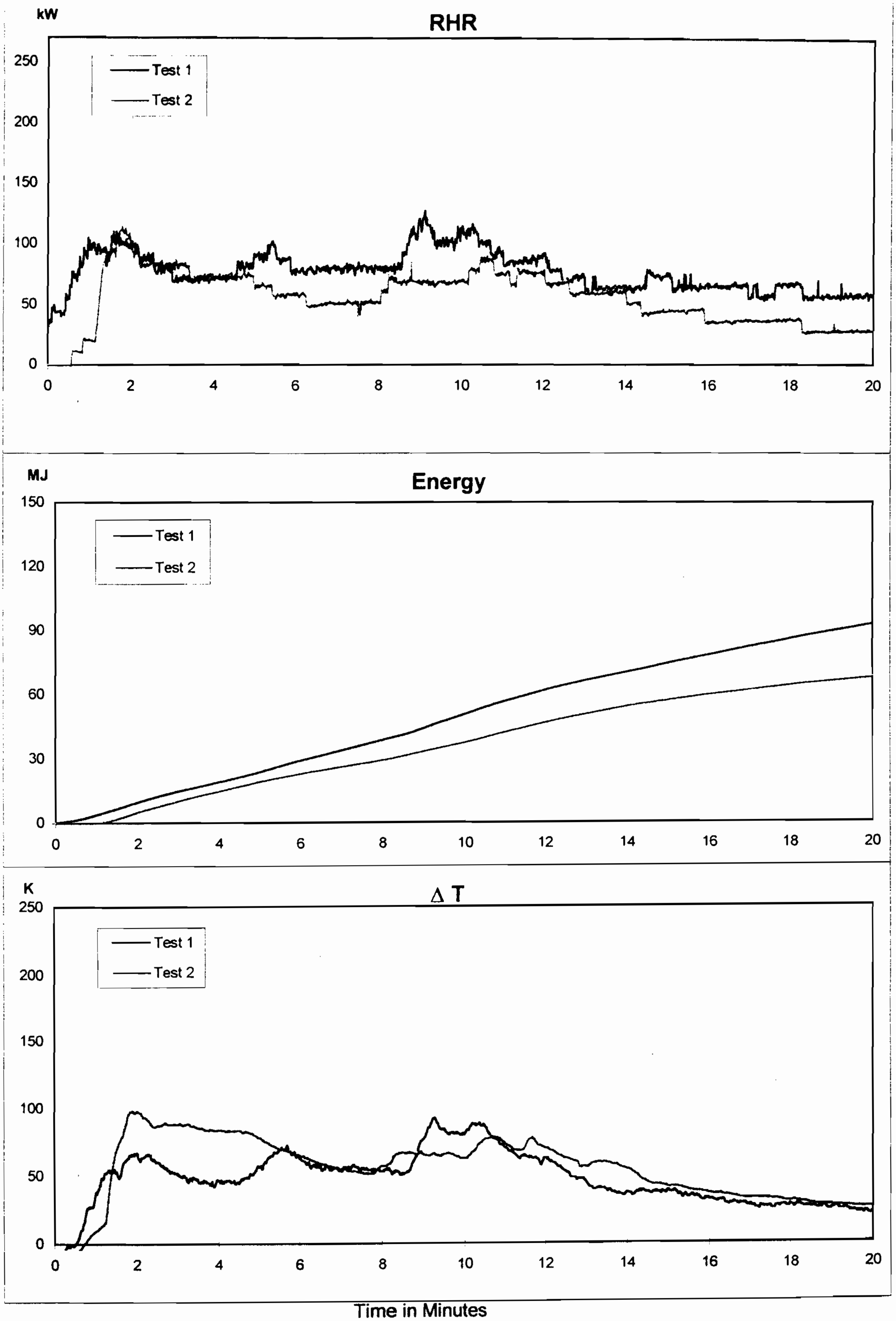


Varnished timber (Pine). Series 1P

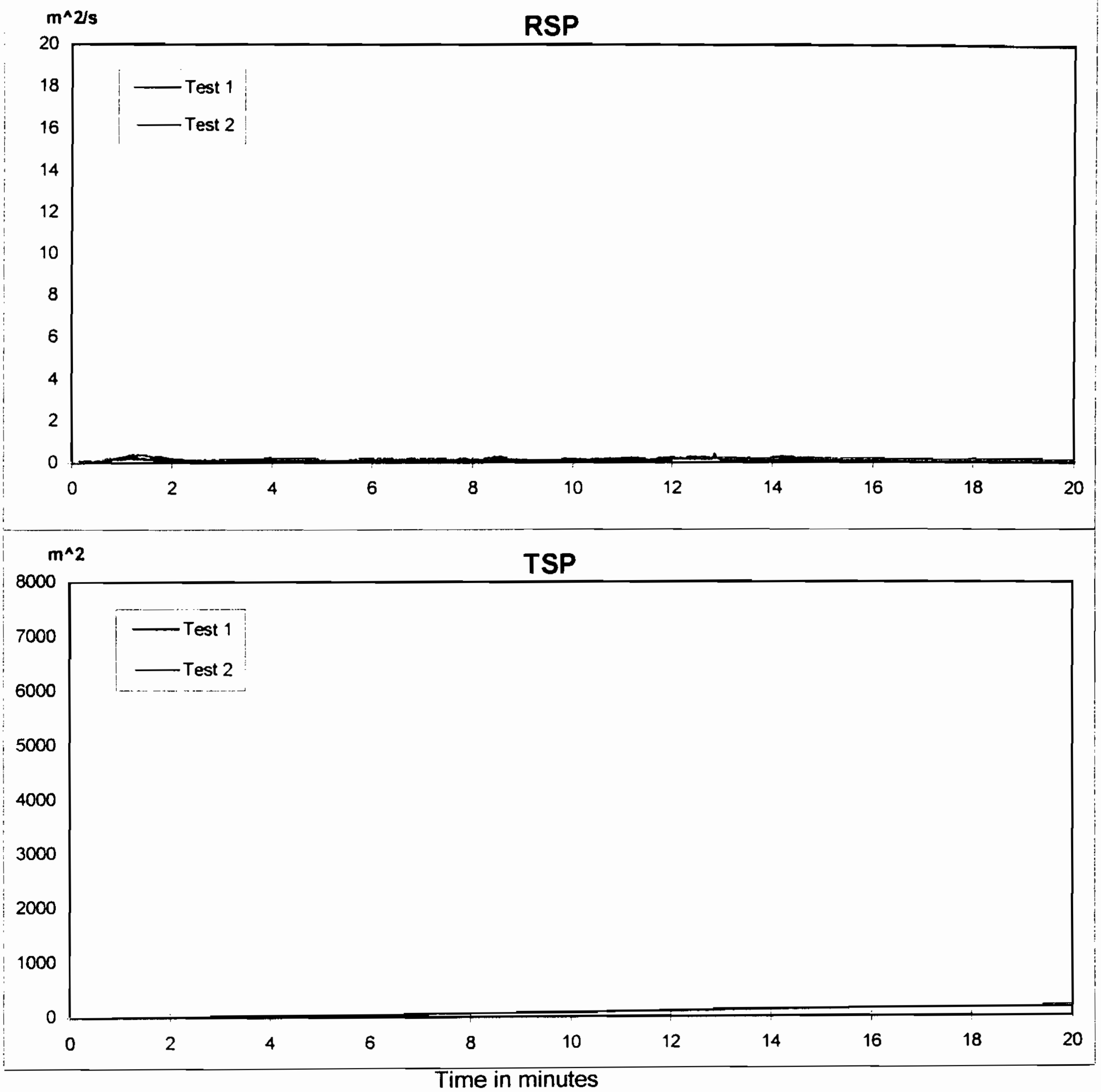




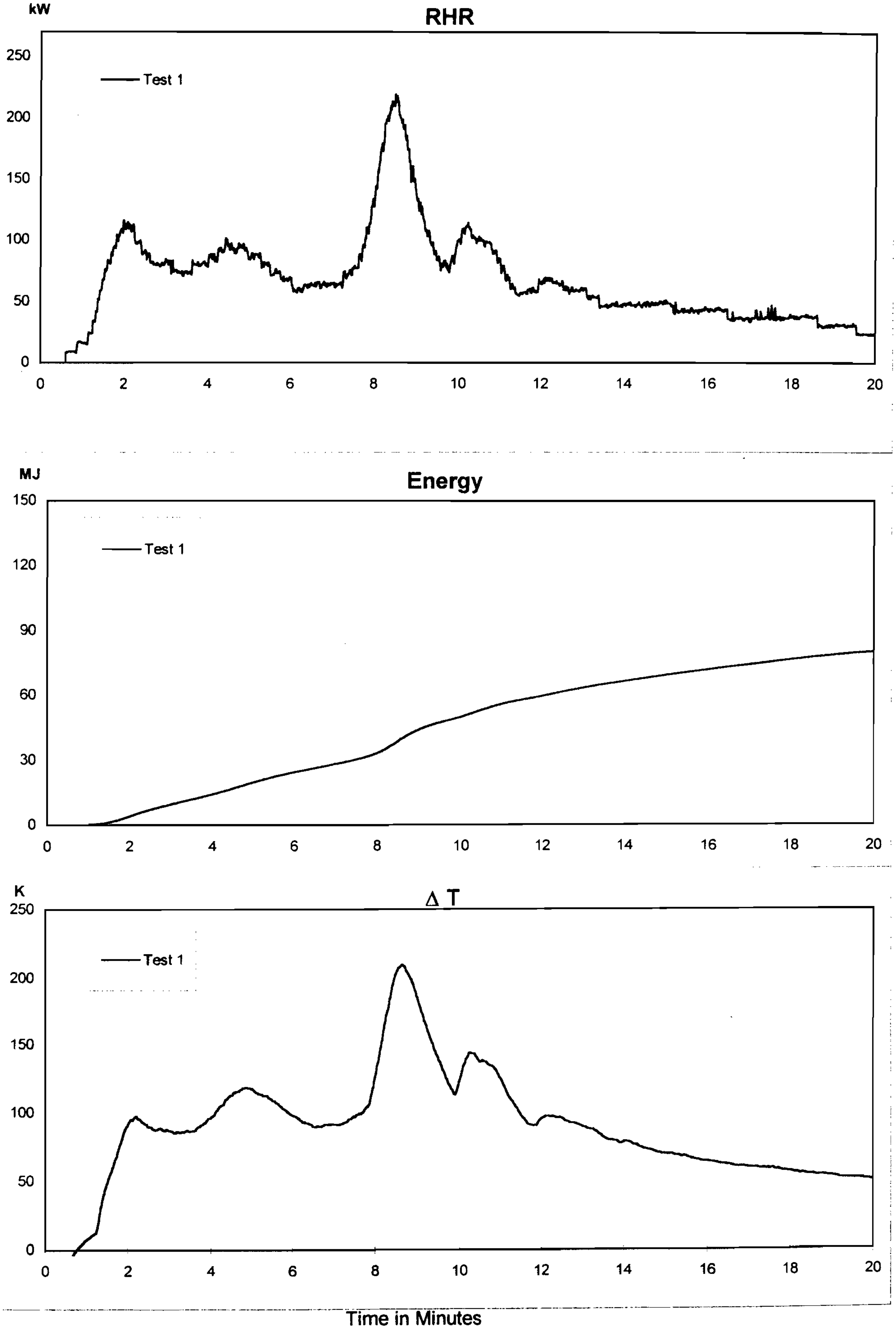
Varnished timber (Pine). Series 1P



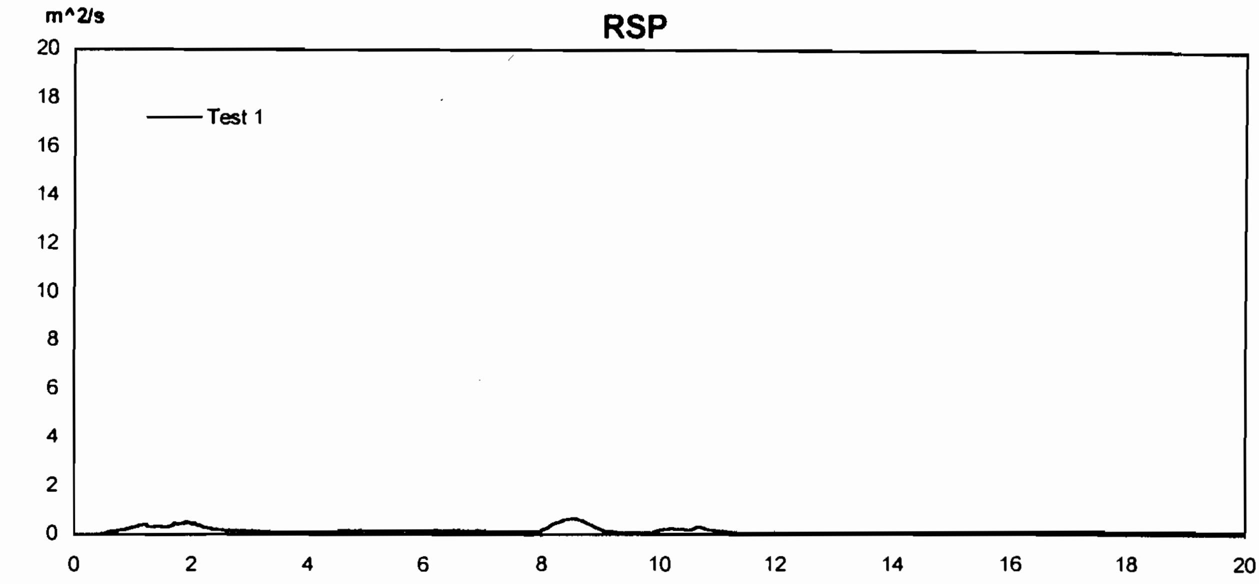
Varnished timber (Pine). Series 2P

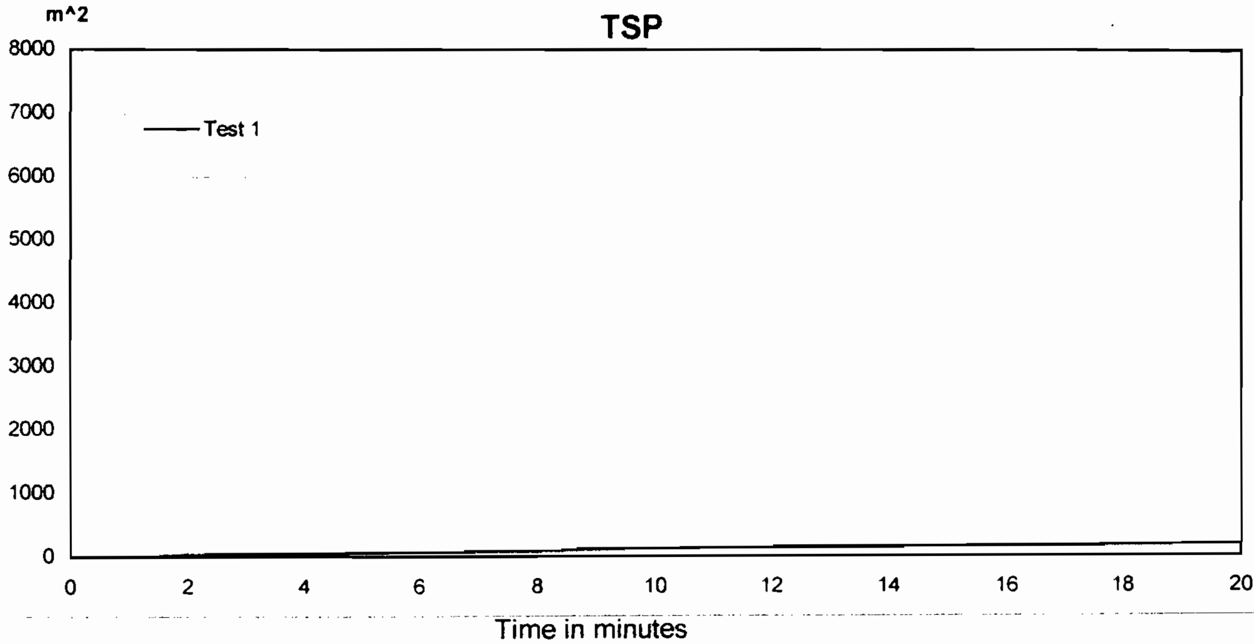


Varnished timber (Pine). Series 2P

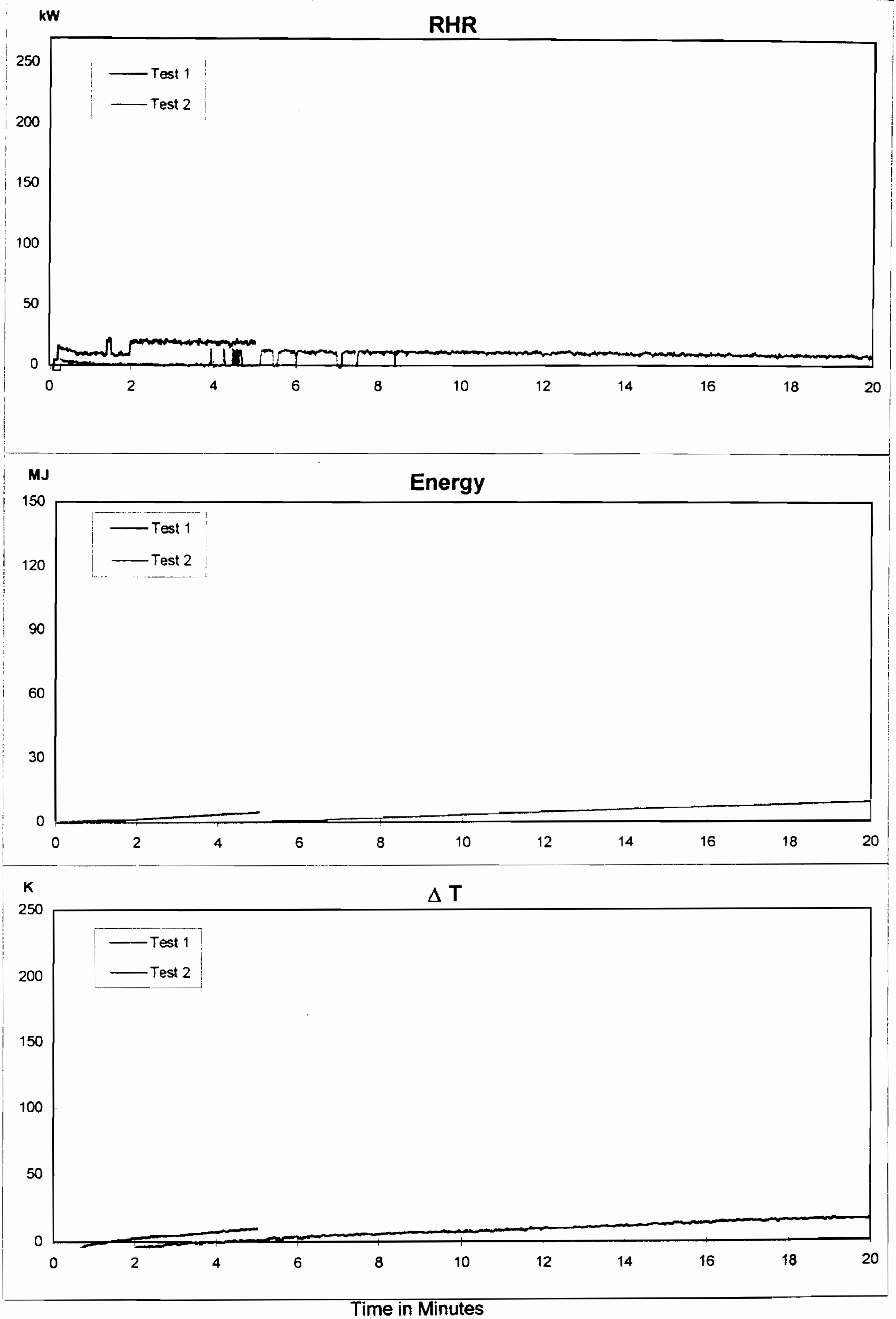


Varnished timber (Pine). Series 3P

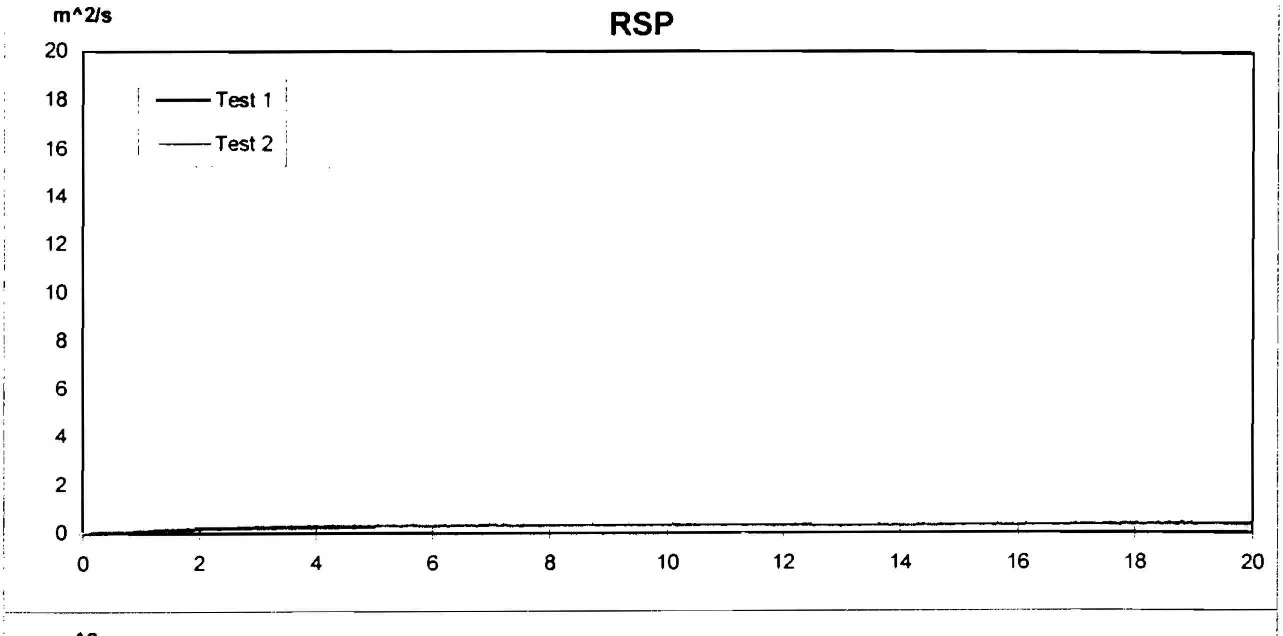


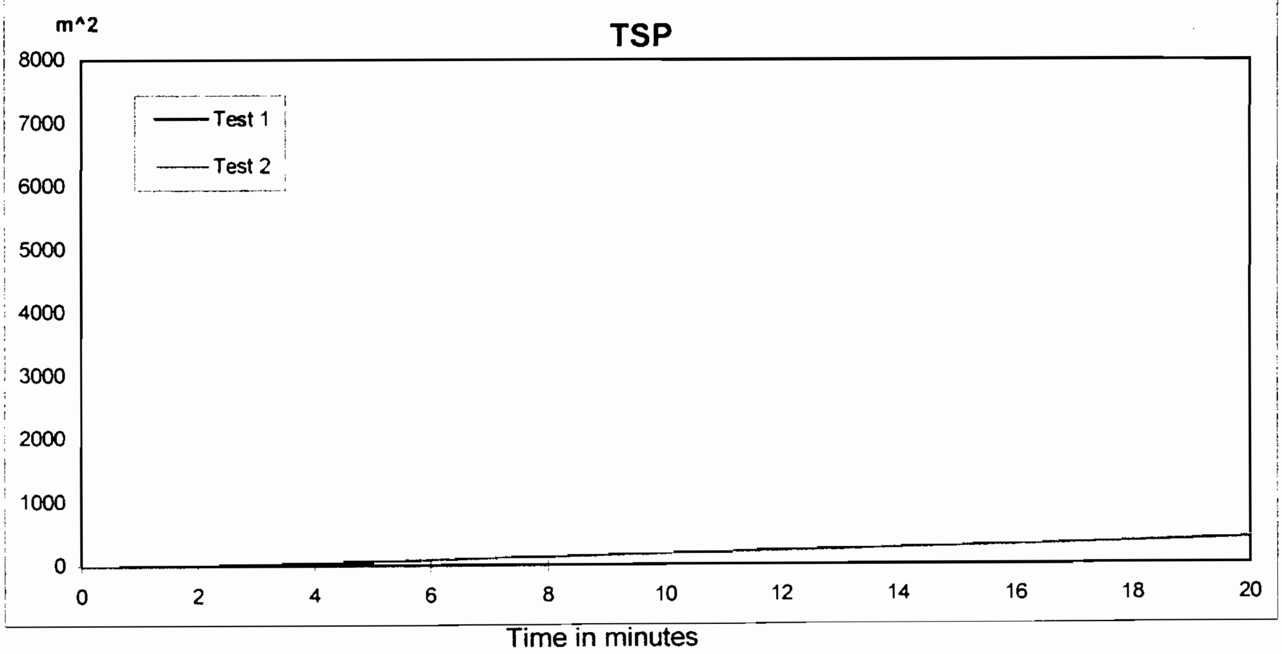


Varnished timber (Pine). Series 3P

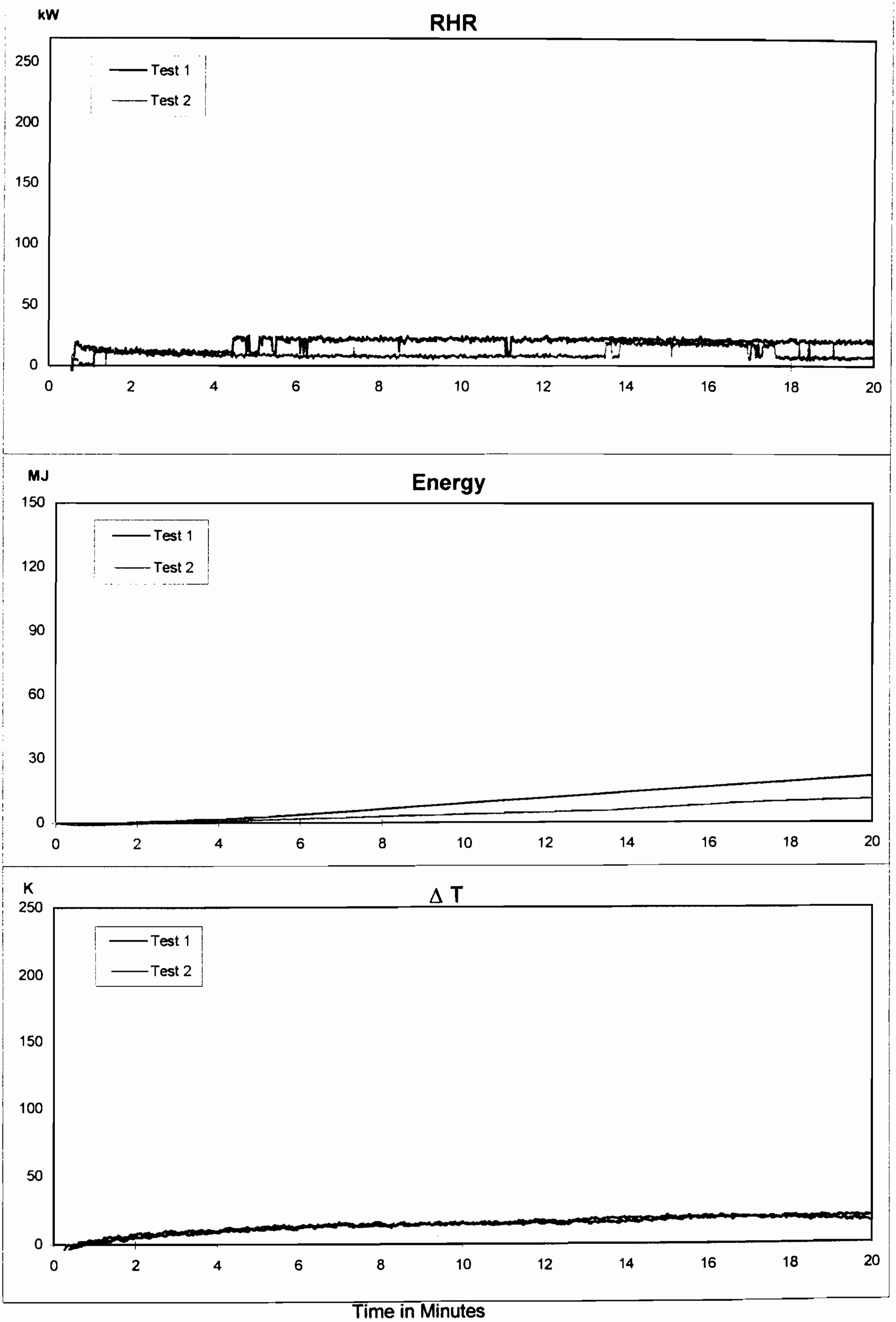


Fire retardant chipboard. Series 1S

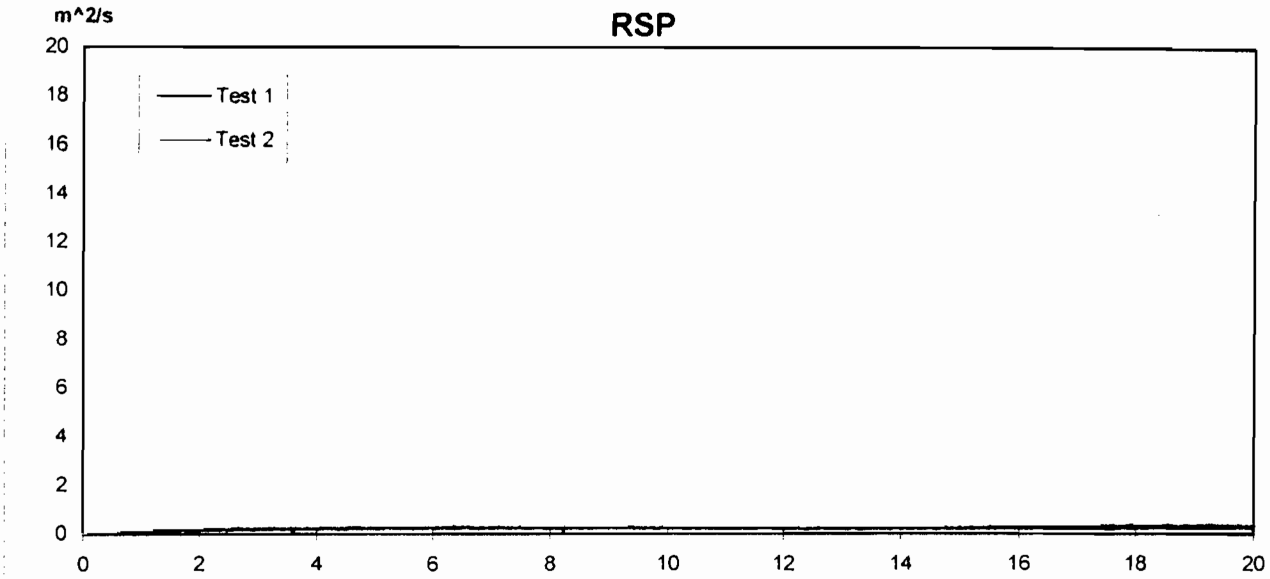


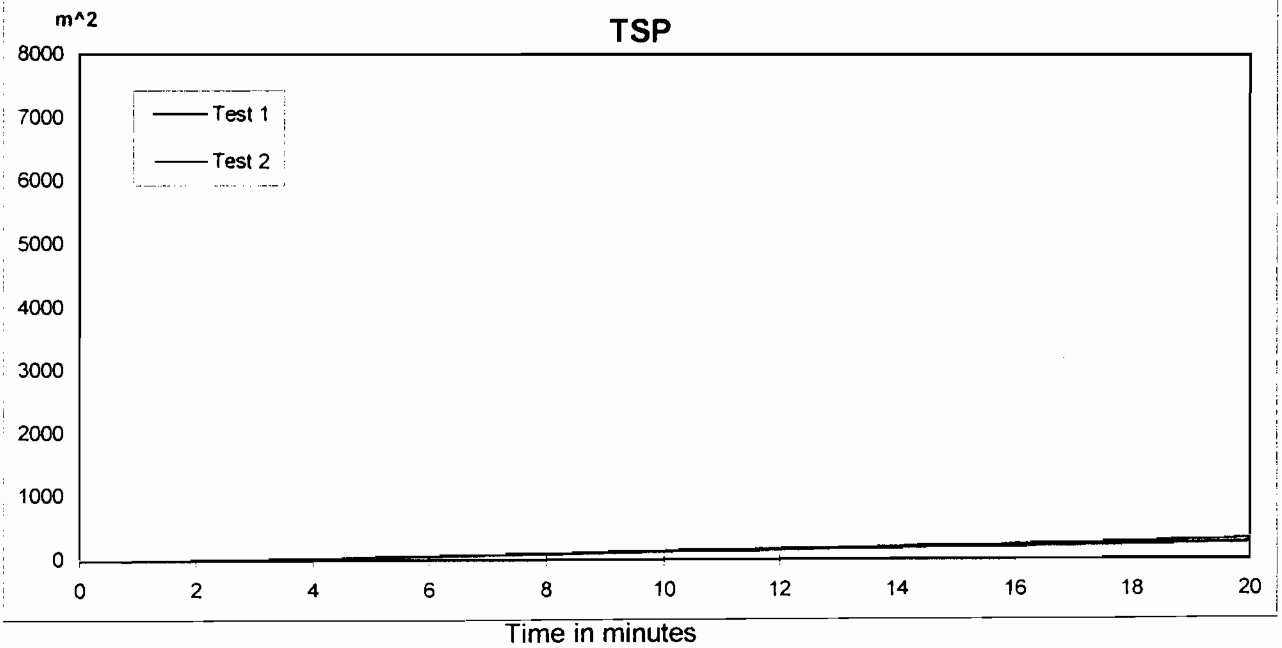


Fire retardant chipboard. Series 1S

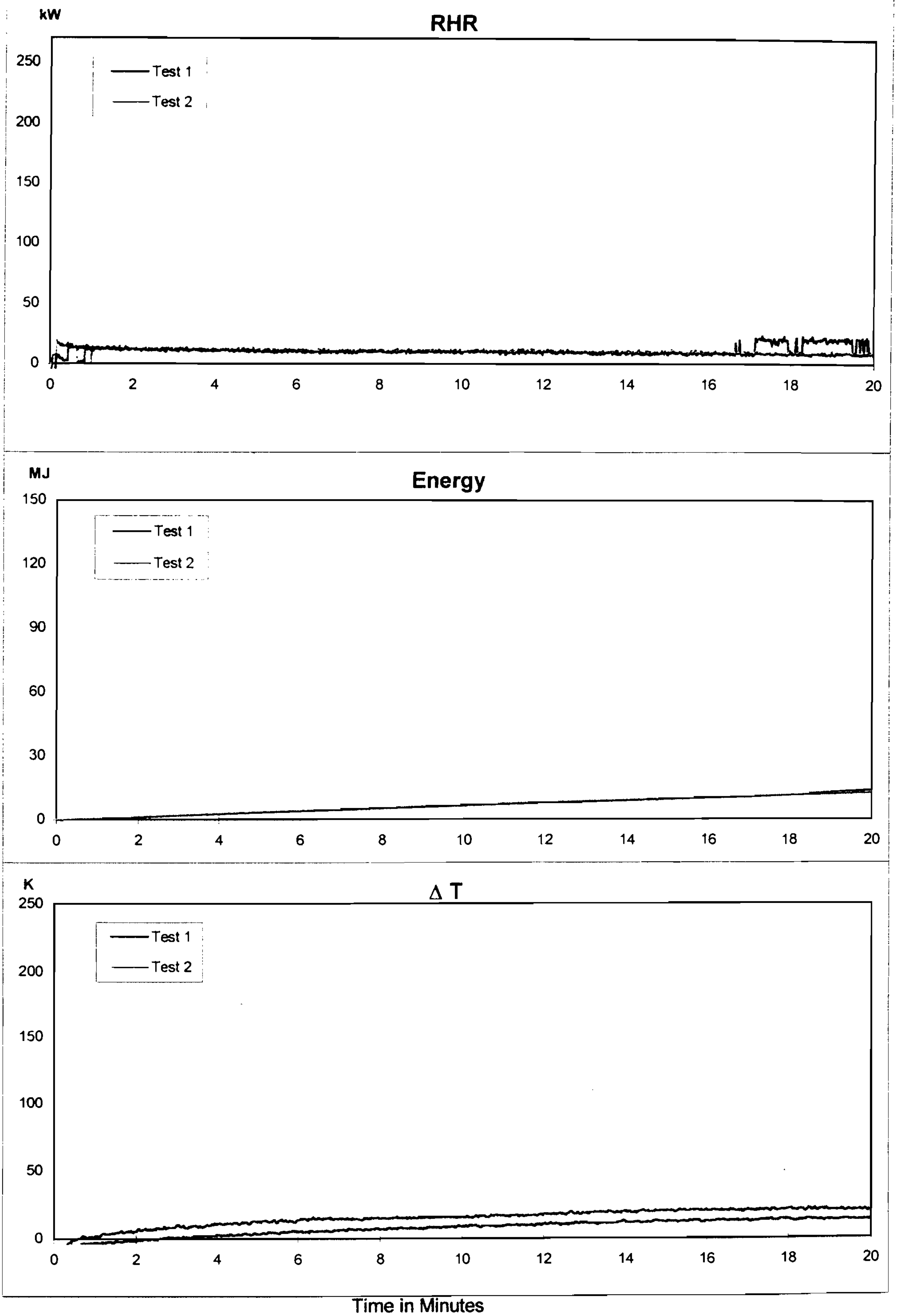


Fire retardant chipboard. Series 2S

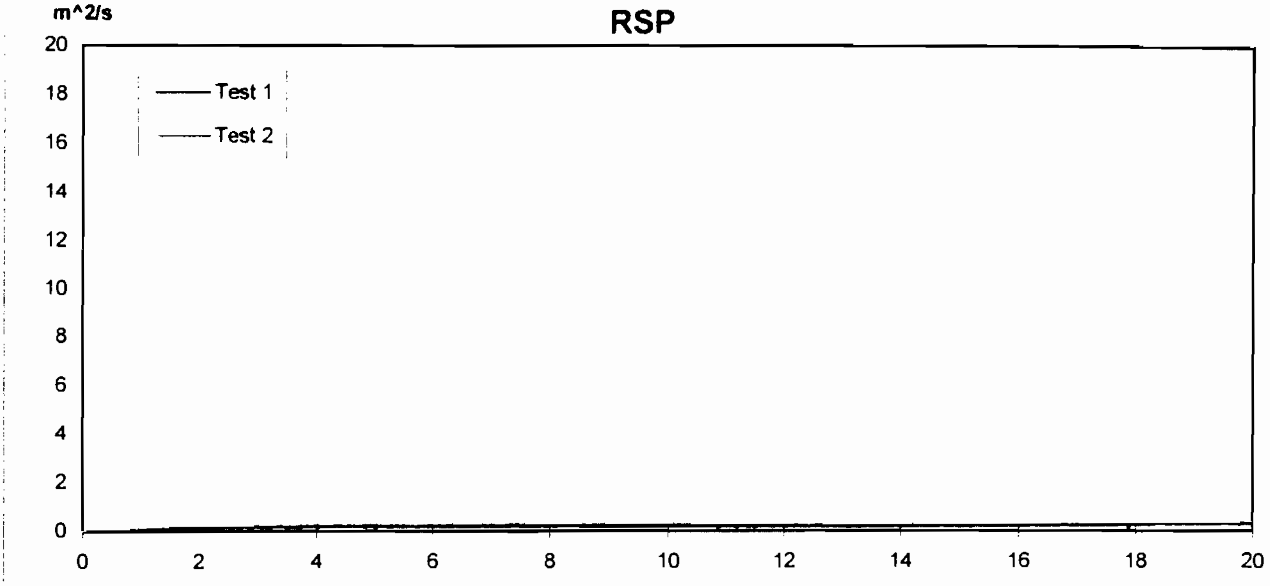


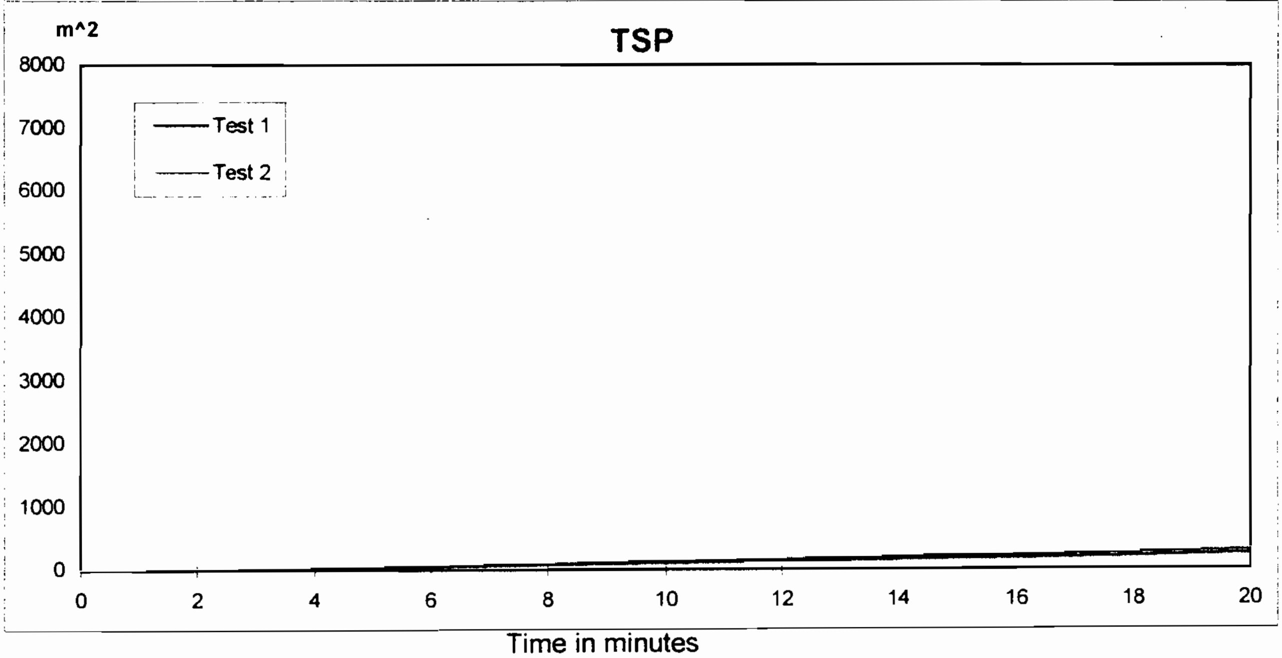


Fire retardant chipboard. Series 2S

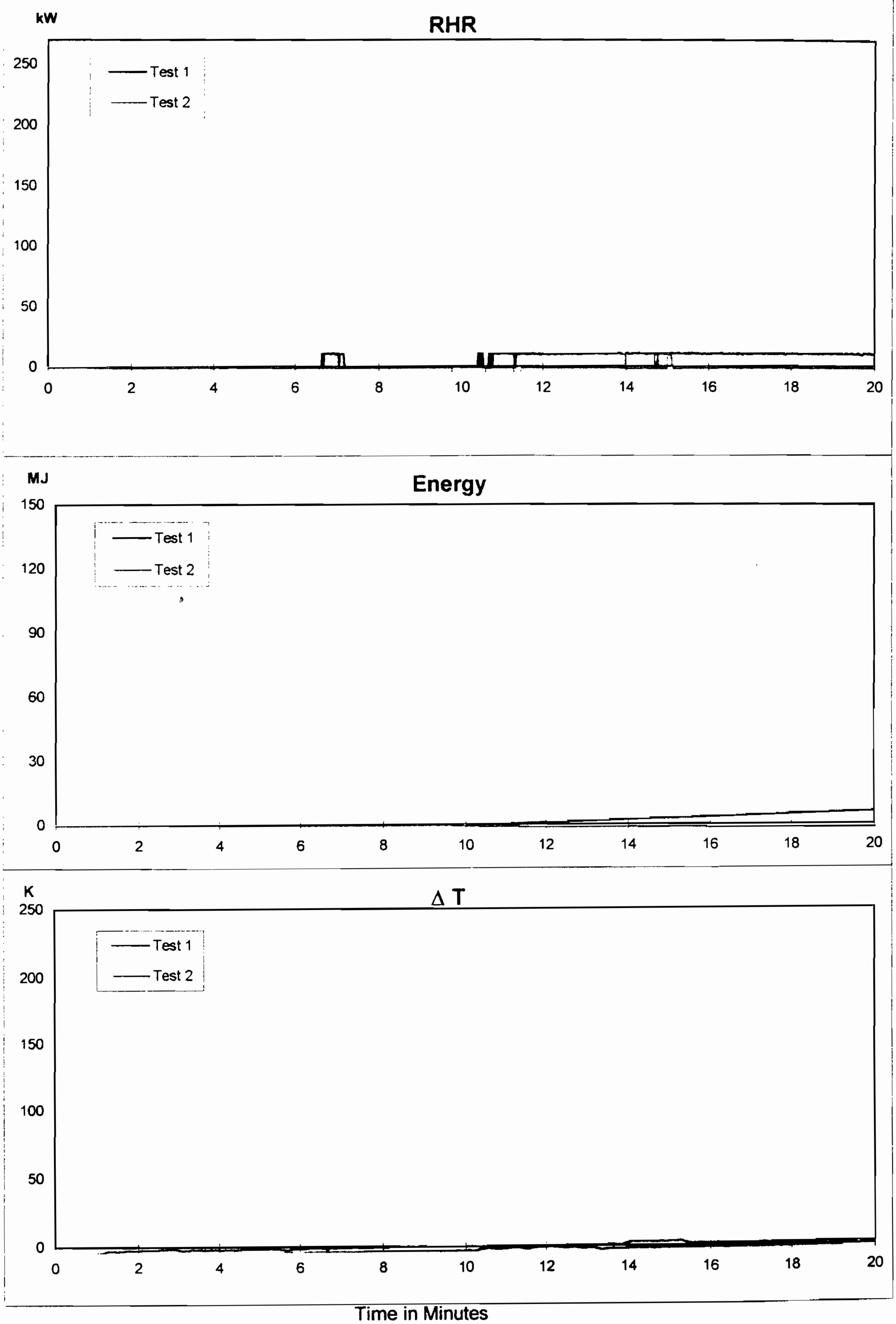


Fire retardant chipboard. Series 3´S

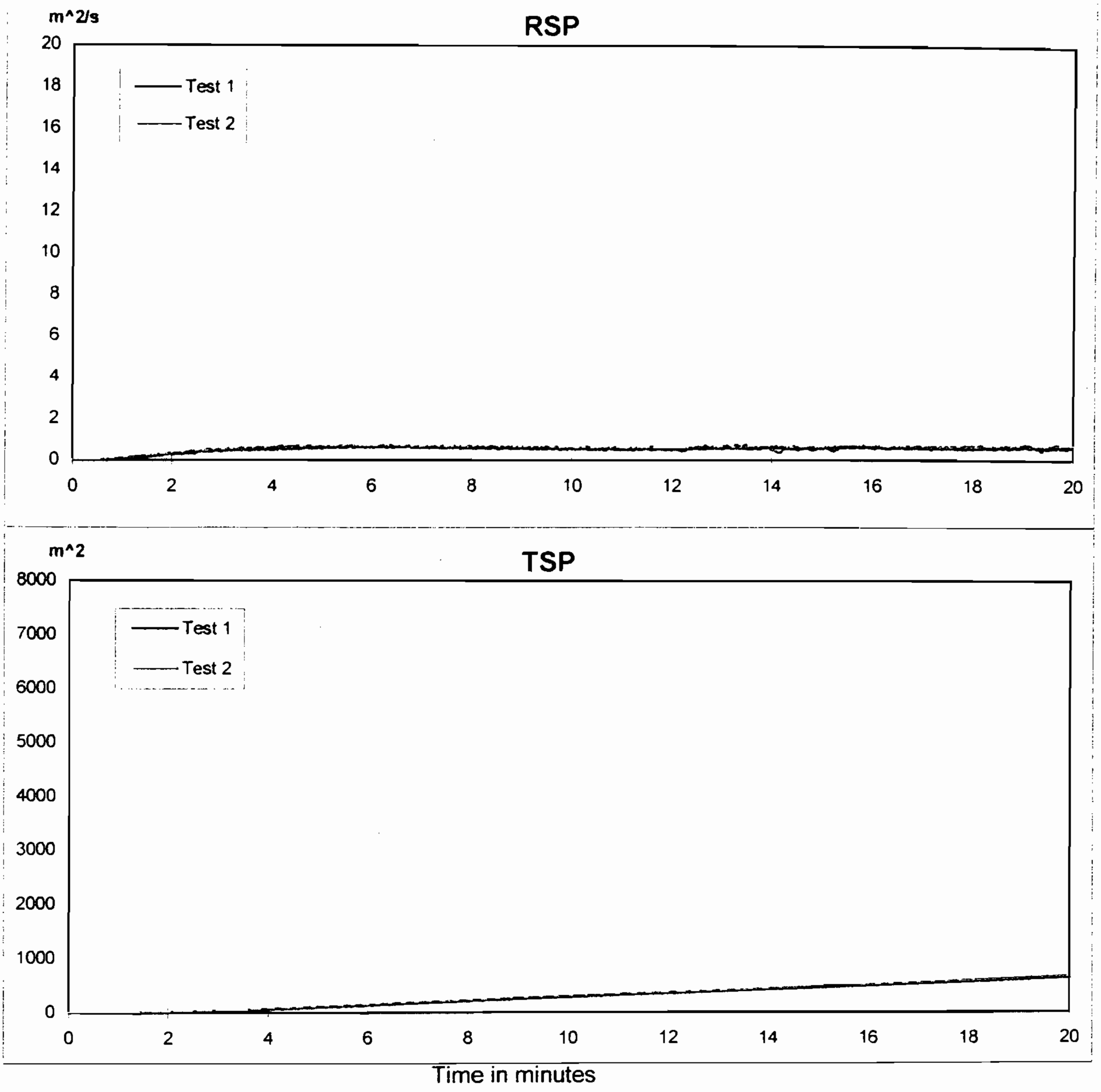




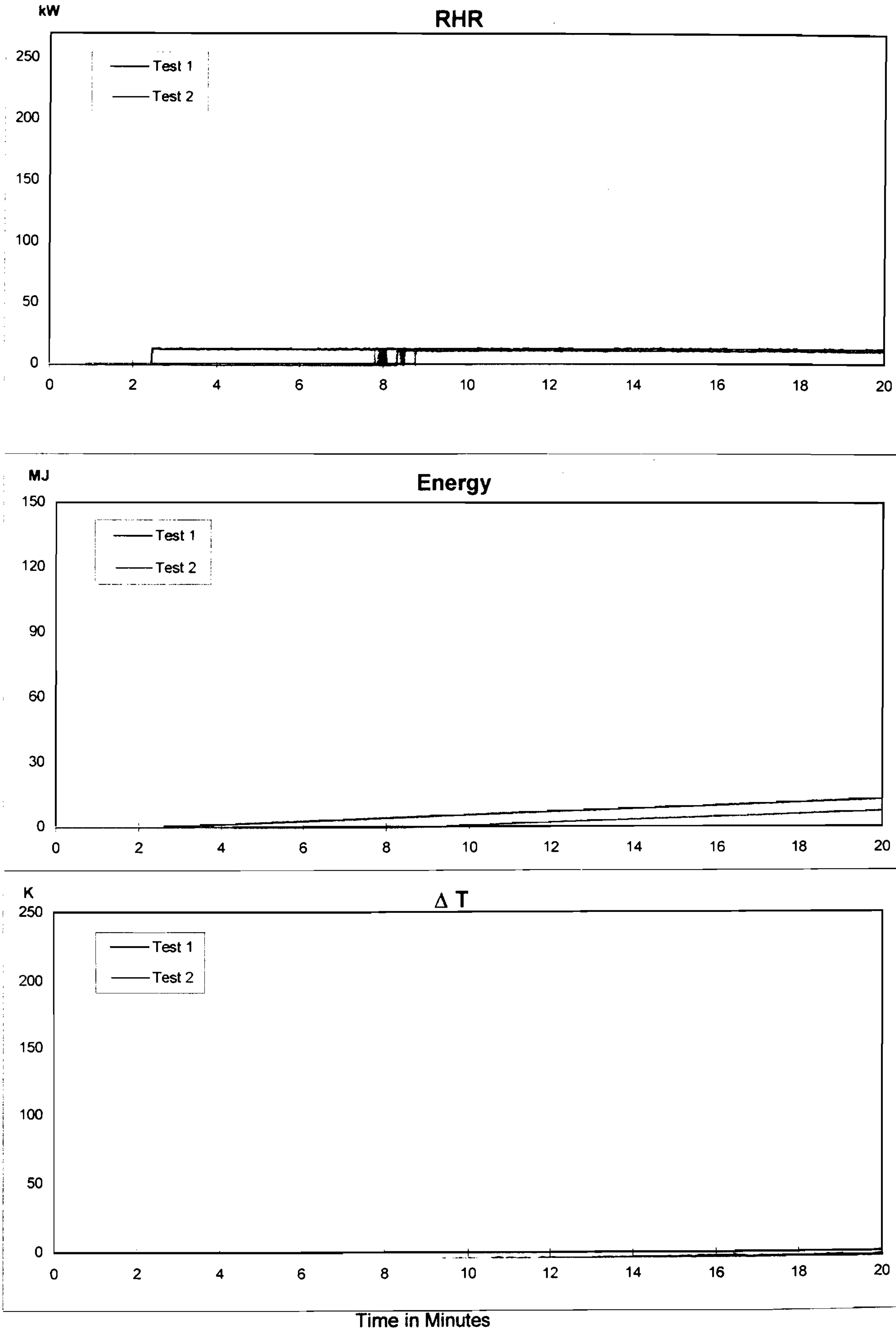
Fire retardant chipboard. Series 3´S



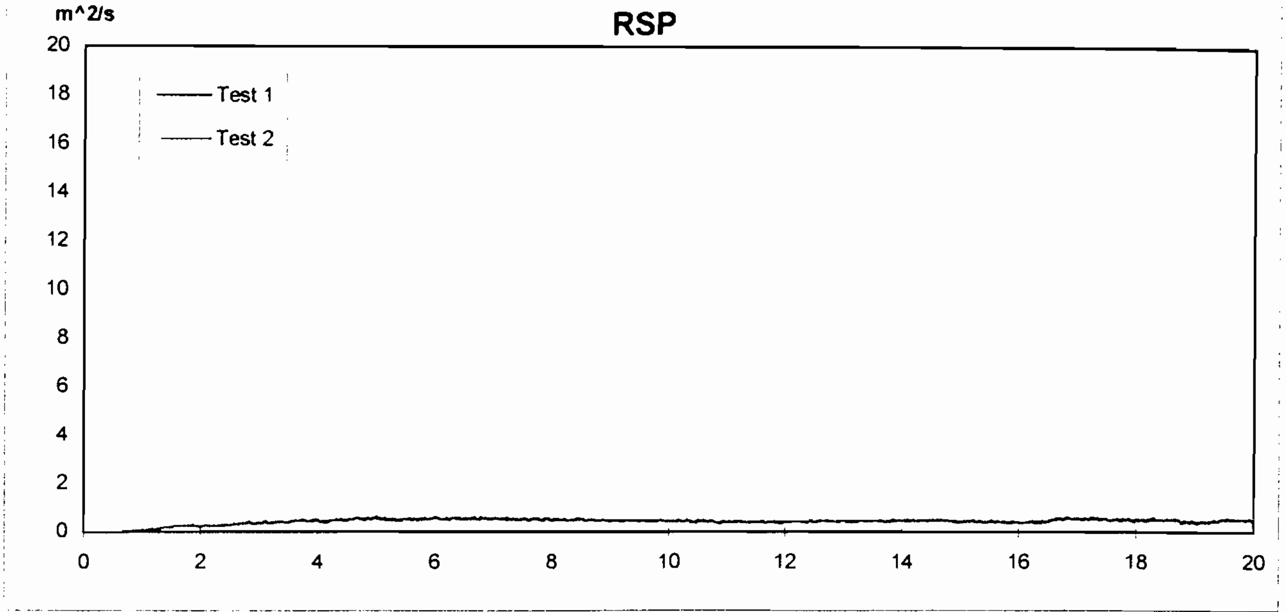
Fire retardant chipboard. Series 1P

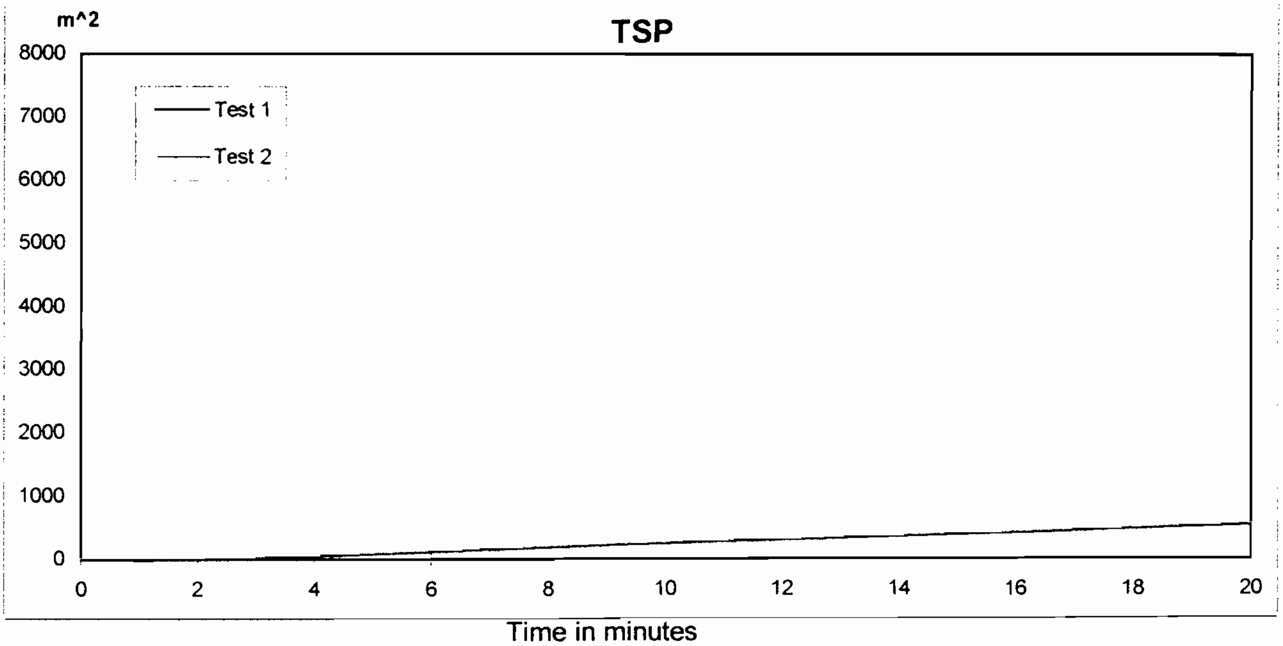


Fire retardant chipboard. Series 1P



Fire retardant chipboard. Series 2P
Test 1: No data for smoke measurement available

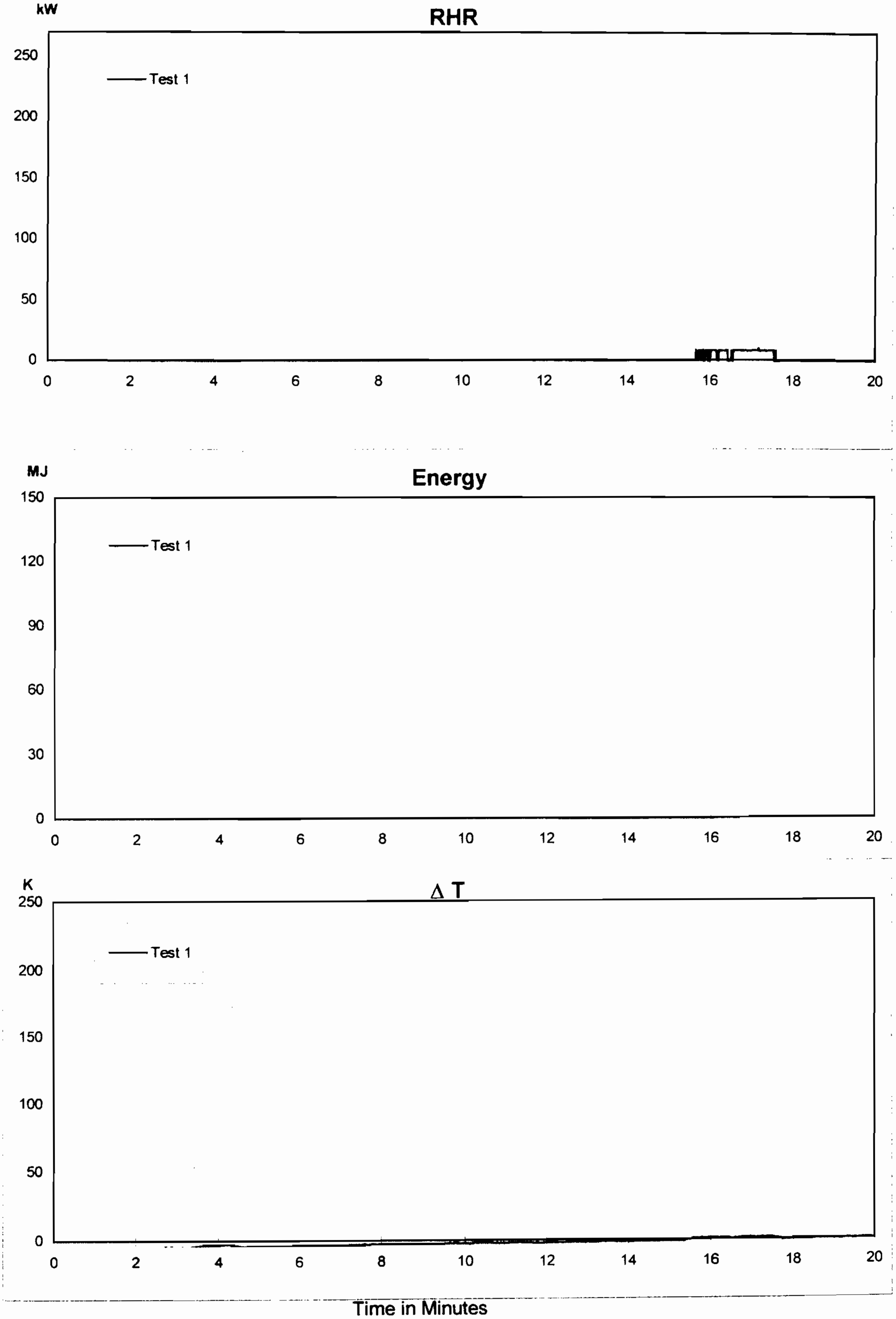




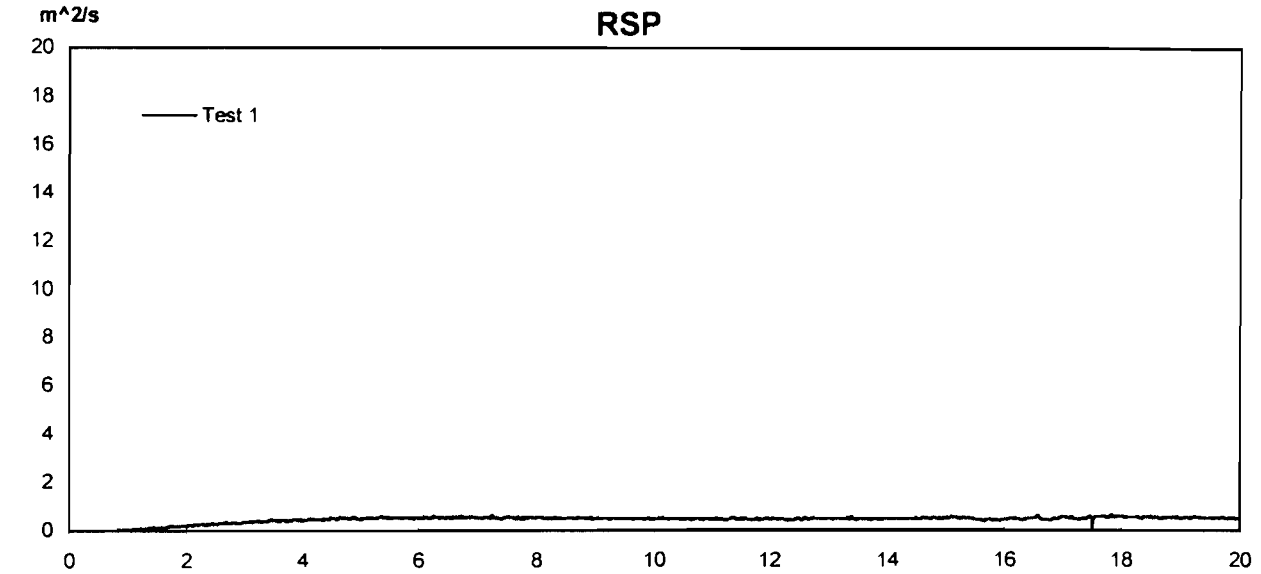
Fire retardant chipboard. Series 2P
Test 1: No data for smoke measurement available

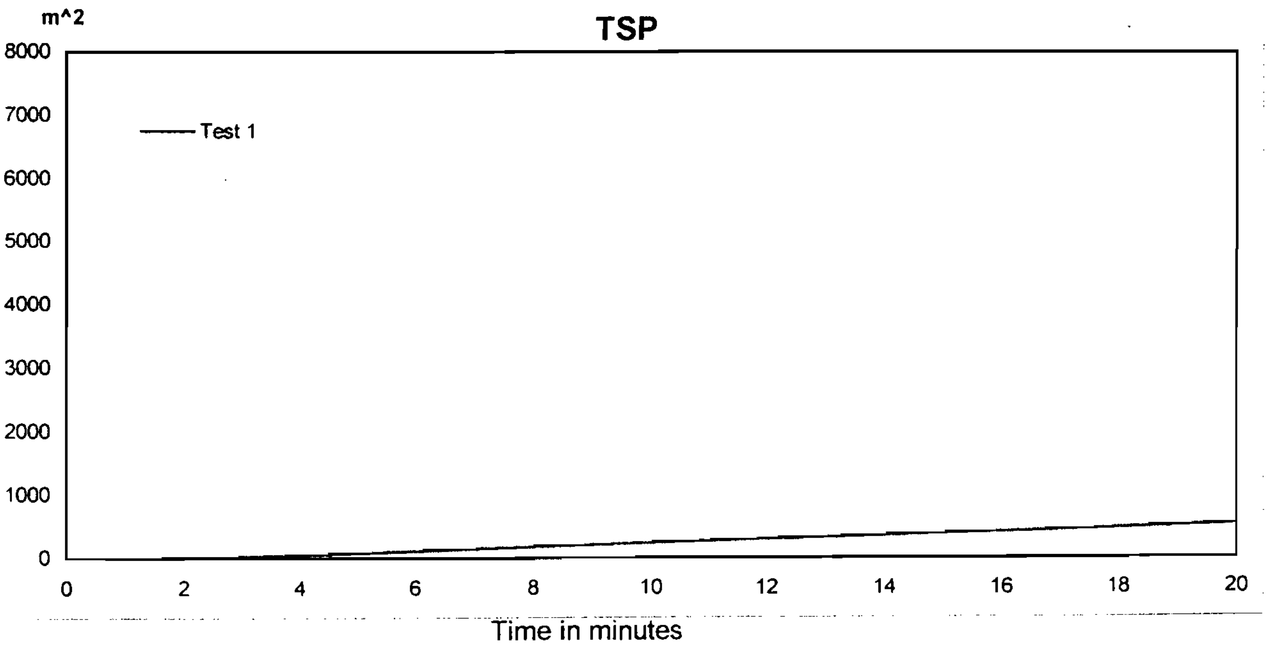
M A T E R I A L P R Ü F U N G S A M T
N O R D R H E I N - W E S T F A L E N

MPA NRW

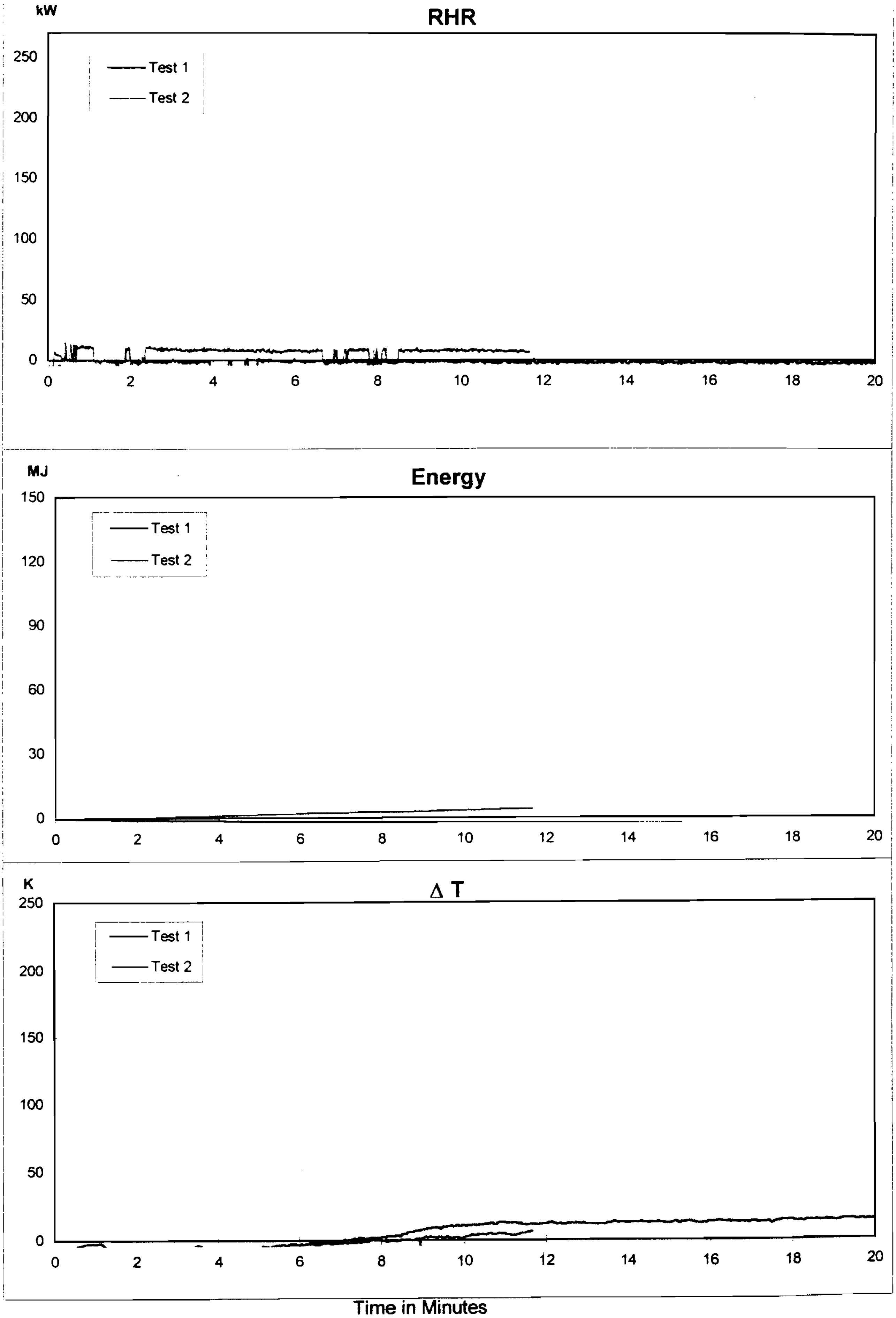


Fire retardant chipboard. Series 3P

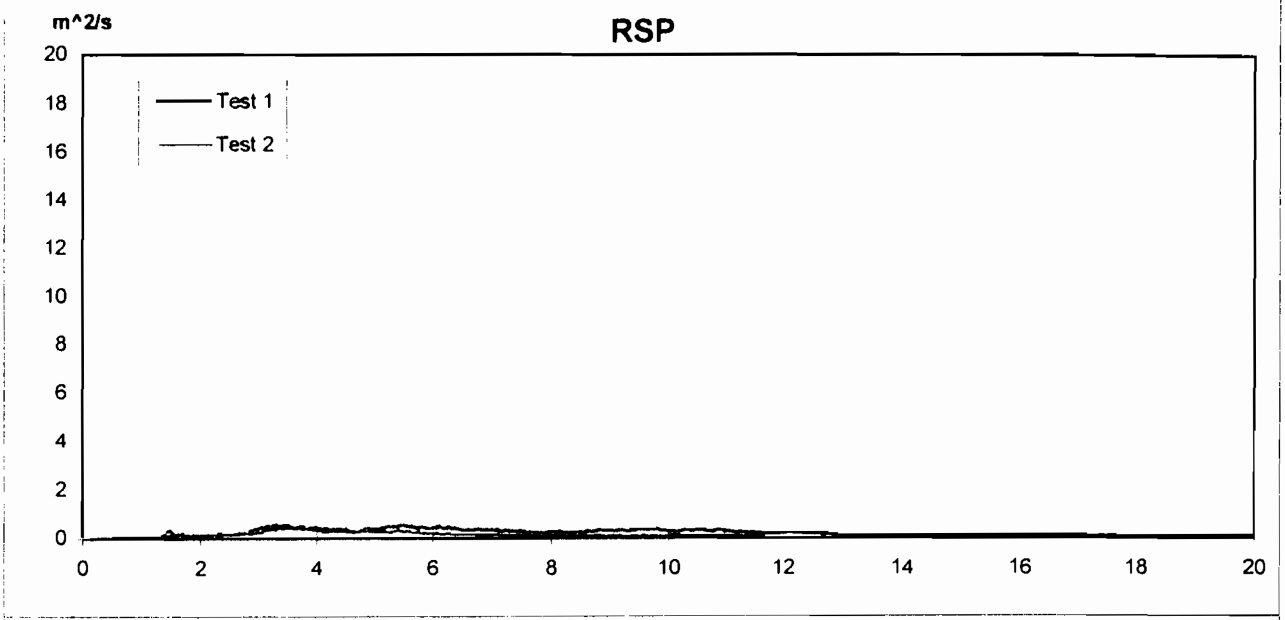


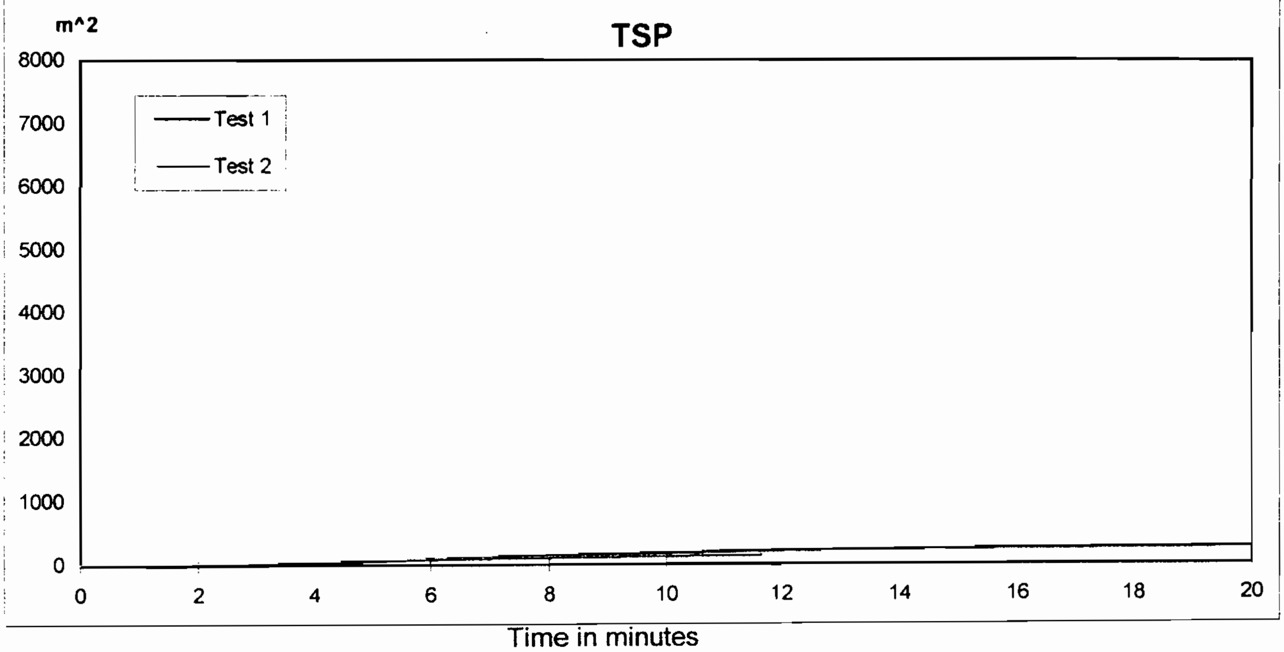


Fire retardant chipboard. Series 3P

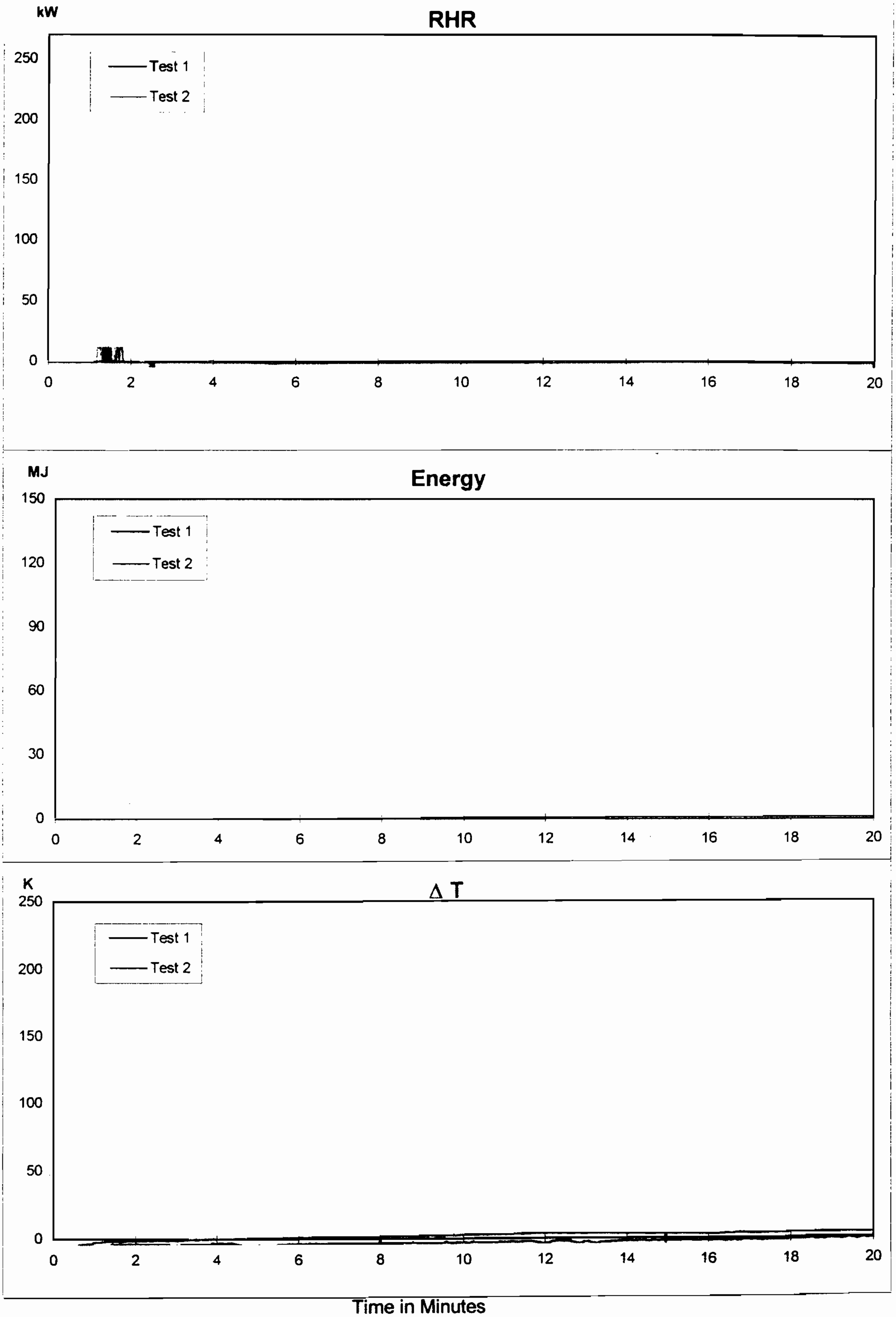


3 layered polycarbonate panel. Series 1S

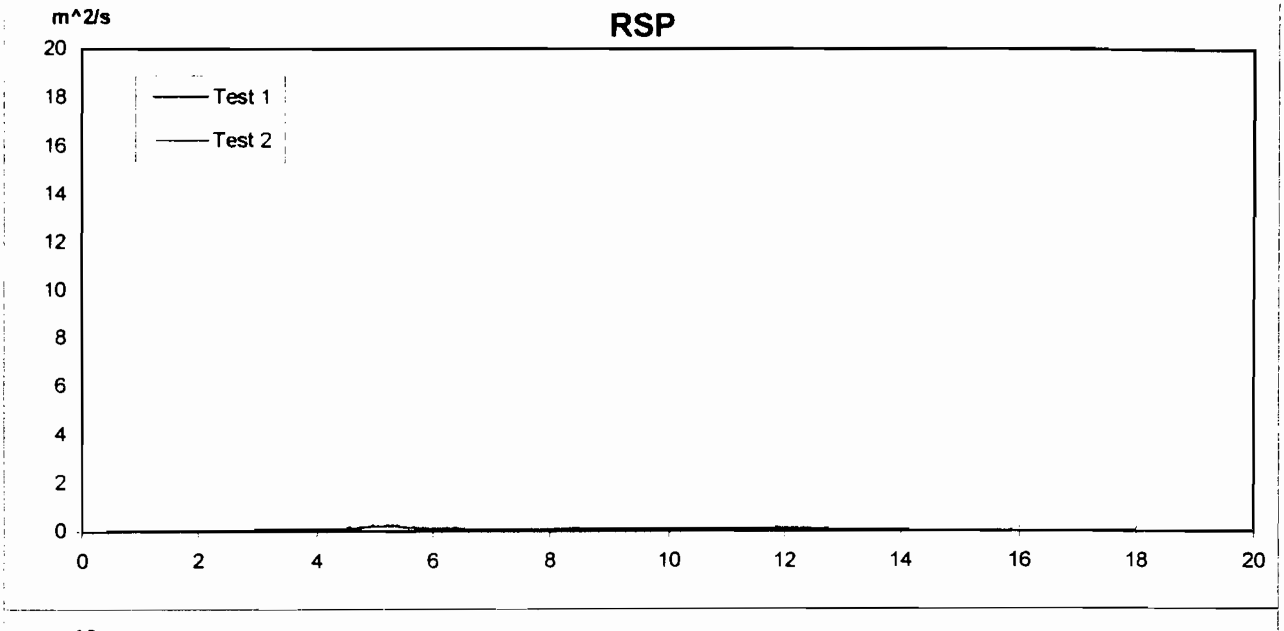


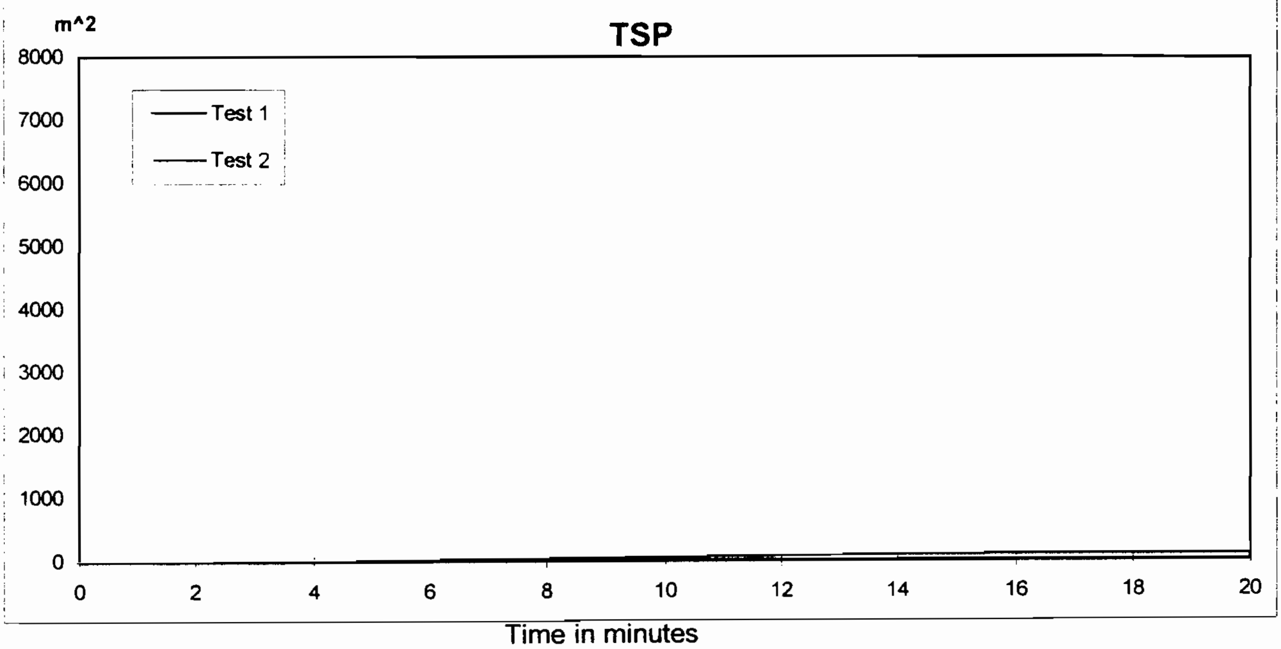


3 layered polycarbonate panel. Series 1S



3-layered polycarbonate panel. Series 1P





3-layered polycarbonate panel. Series 1P

Abschnitt 3

Versuche mit verschiedenen Brennern

(unterschiedliche Form)

SBI RR 3a

SBI-Test-Programme

Exposure conditions with burners of different sizes and shapes

Object

In order to improve the possibility of the flame spread observation in theSBI-test an attempt was made, to achieve the flux profile according to the regulators mandate by a burner with smaller flames.

Test arrangement

For this purpose 3 modified sandbox-burners were tried out maintaining the basic concept of the burner used in the first series of proving tests (hereafter named "Standard burner"):

- diffusion flame of propane, passing through a layer of gravel/sand
- simple construction
- easy to repair/clean in case of burning droplets/falling debries of the specimen

The following burners were included in this exercise:

* standard burner

* burner 2
    - same shape like the standard burner
    - size increased by factor 2 against the standard burner
    - output 30 kW (like standard burner)

* burner 3
    - triangular shape like the standard burner, length of one side doubled against the standard burner
    - size increased by a factor 2 against the standard burner
    - output 30 kW (like standard burner)

* burner 4
    - shape: corner of 2 rectangular boxes 115 mm wide
    - size: increased by factor 1,54 against the standard burner
    - output: a) 30 kW like standard burner
      b) 20 kW, 1/3 less than standard burner

The design of the burners is given in annex 1 and 2.

Measurements

For each burner a test to establish the exposure of specimen was made. The 1 m dummy specimen had 3 vertical rows of measuring points, which were situated at 4 different height levels. The 50 cm dummy specimen had 2 of these vertical rows. For each measuring point a hole was prepared to insert the heat flux meter.

The tests were started by igniting the burner and adjusting the gas supply to the given output. After about 15 minutes having reached stabilised conditions the heat flux measurements were started. For each measuring point the heat flux meter were brought in position and the readings were taken after having reached a constant value. After the completion of the measurements at each point the series was repeated two times. The results given in annex 3 - 7 show the averages of these repeated measurements.

Discussion of results

Standard burner

With the given heat output a flame height of 70 - 80 cm left only 50 % of the specimen height for observation of flame spread. In the lower part of the specimen (100 mm height - 300 mm height) the required heat flux level of 40 KW was reached - even slightly exceeded. Also at a height of 75 cm the required value of 10 KW directly in the corner was exceeded. In a distance of 200 mm from the corner this value was met. The measured values show that a sudden decrease of the heat flux to the sides at the edge of the burner as required by the regulators was established.

Burner 2

With the given heat output of 30 kW the maximum height of the flames was lower (50 cm - 70 cm) than with the standard burner. The fluctuations of the flames which create difficulties in observing exactly the flame spread, were a slightly greater than with the standard burner. The maximum heat flux values in the lower part of the specimen were significantly higher than with the standard burner. The values at the top of the specimen were lower than with the standard burner. Both observations can be explained by the larger size of the burner which resulted in a smaller gas speed so that the combustion was concentrated more in the lower part of flames. The level of heat flux which was reached in comparison with the required value would allow to reduce the total heat output, which than would lead to an even reduced flame height but also to a reduction of the flux in the upper part of the specimen.

Burner 3

This burner was chosen for two reasons. On the one hand the positive result of burner 2 was aimed. On the other hand the shape was modified in such a form, that the width of the outlet area for the gas was not increased against the standard burner. By this modification, in which the shape of the burner is adapted to the specimen arrangement. The air access to the combustion zone should be improved.

The test results show, that the combustion in the lower part of the flames was much more intensive than with the other burners. The maximum heat flux values (about 55 kW/m^2) exceeded significantly the required values. This would allow a reduction of the heat output of the burner which would lead to a smaller flame height.

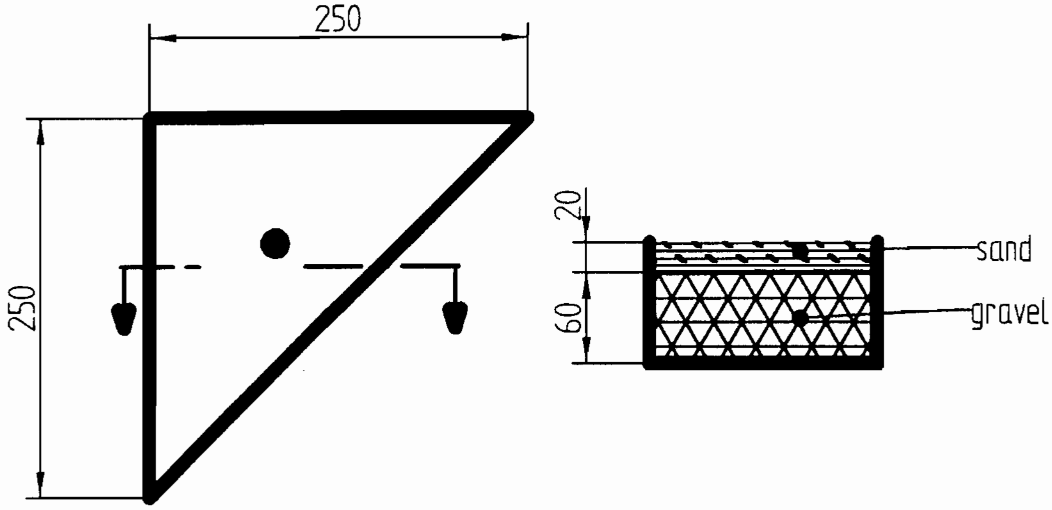
Burner 4

Using a heat output of 30 KW the flame height and the measured heat flux values were in the same order of magnitude like with the standard burner. A reduction of the heat output of the burner to 20 kW resulted in a reduction of the flame height to 50 cm, which was less fluctuating than the standard burner flames. The heat flux values in the lower part of the flames were slightly increased due to an improved air access to the flames in the lower part of the flames. The values at 70 cm height were in accordance with the values required by the regulators. The sudden decrease of heat flux to the sides also comply with the given requirements.

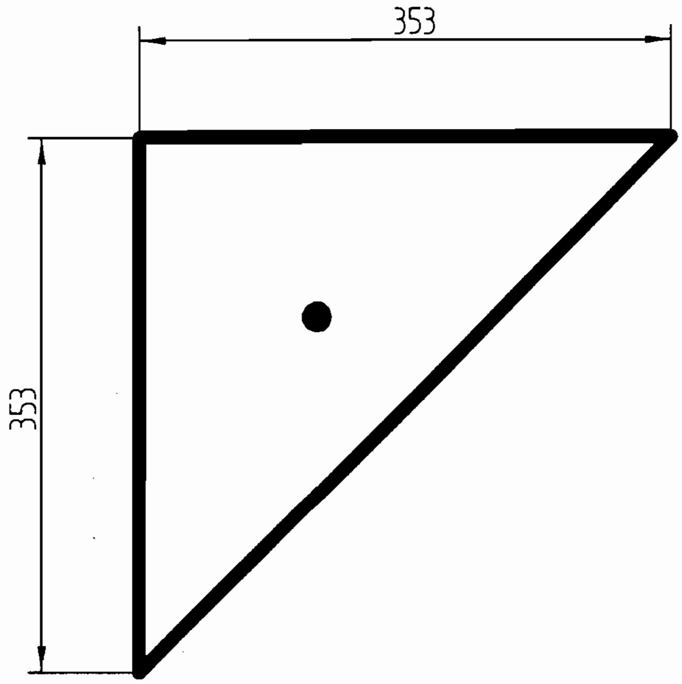
Conclusions

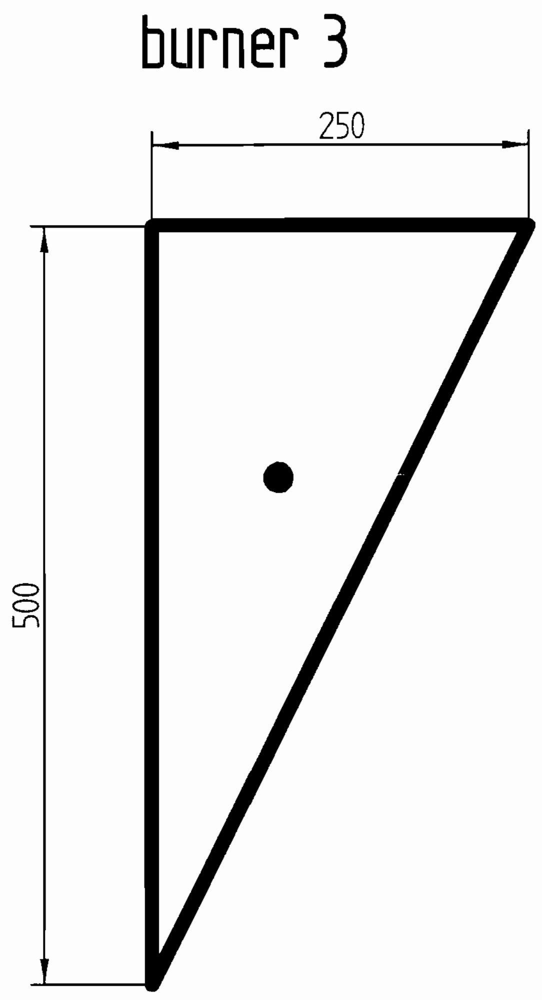
An increase of the size of the burner leads to a slower exit of the gases from the burner and to an improvement of the combustion in the lower zone of the flames. This is due to the better access of air into the flames and leads to maximum heat flux values which exceed the requirements. A reduction of the total heat output of the burners will be able to compensate for this and at the same time would lead to a lower flame height and an improved possibility of observation of flame spread. Some tests with combustible materials would show whether there is also an effect of this modification on the reaction to fire behaviour of the materials.

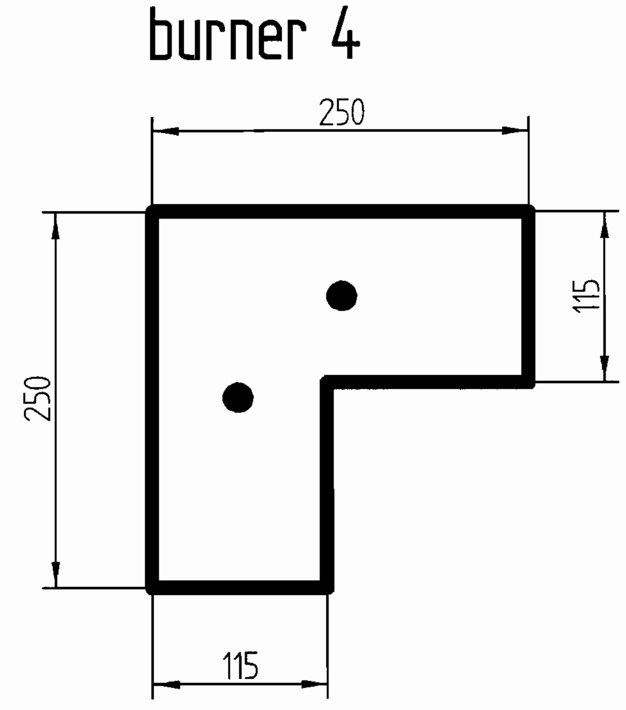
Standard burner



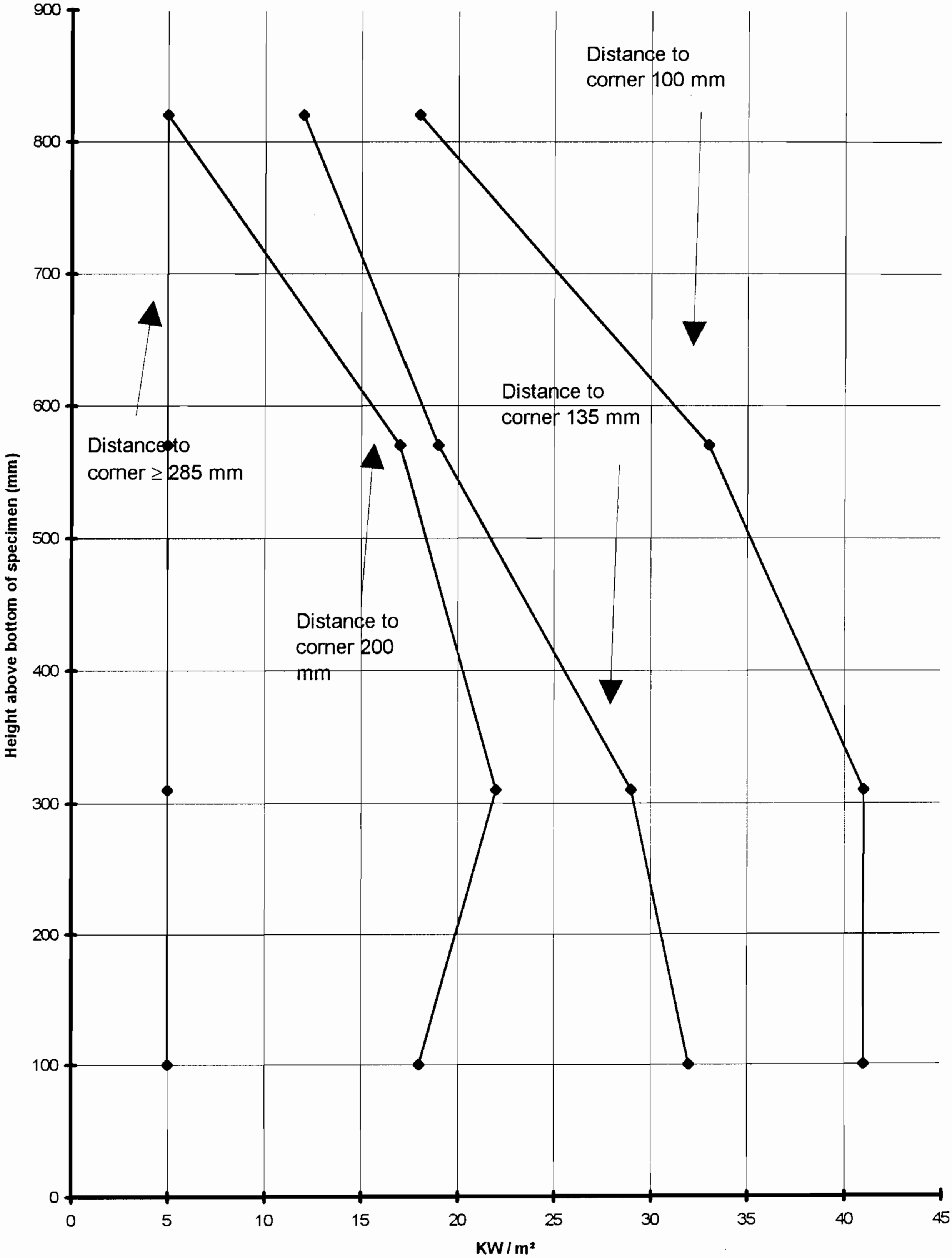
burner 2



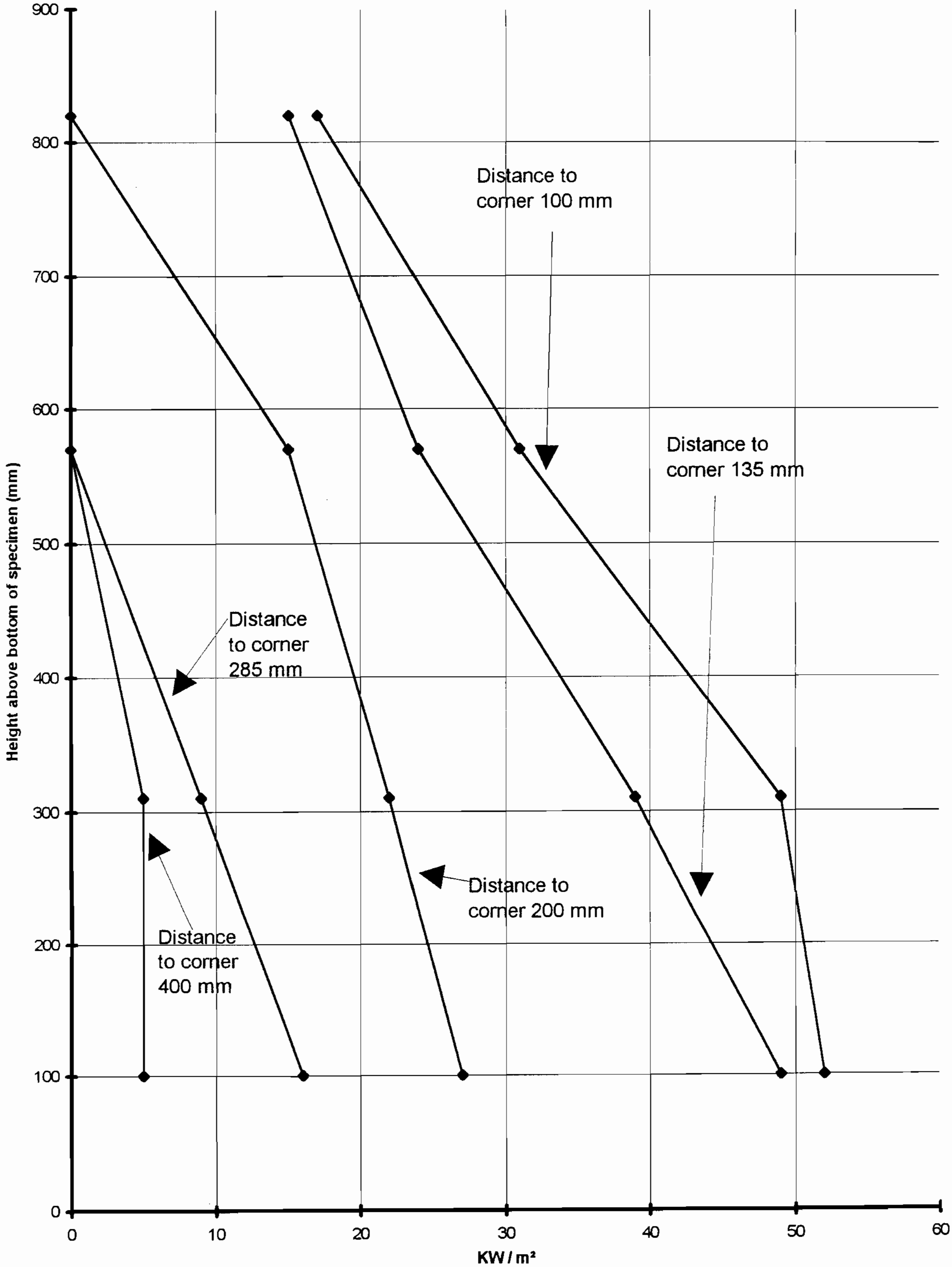

burner 3
250
500

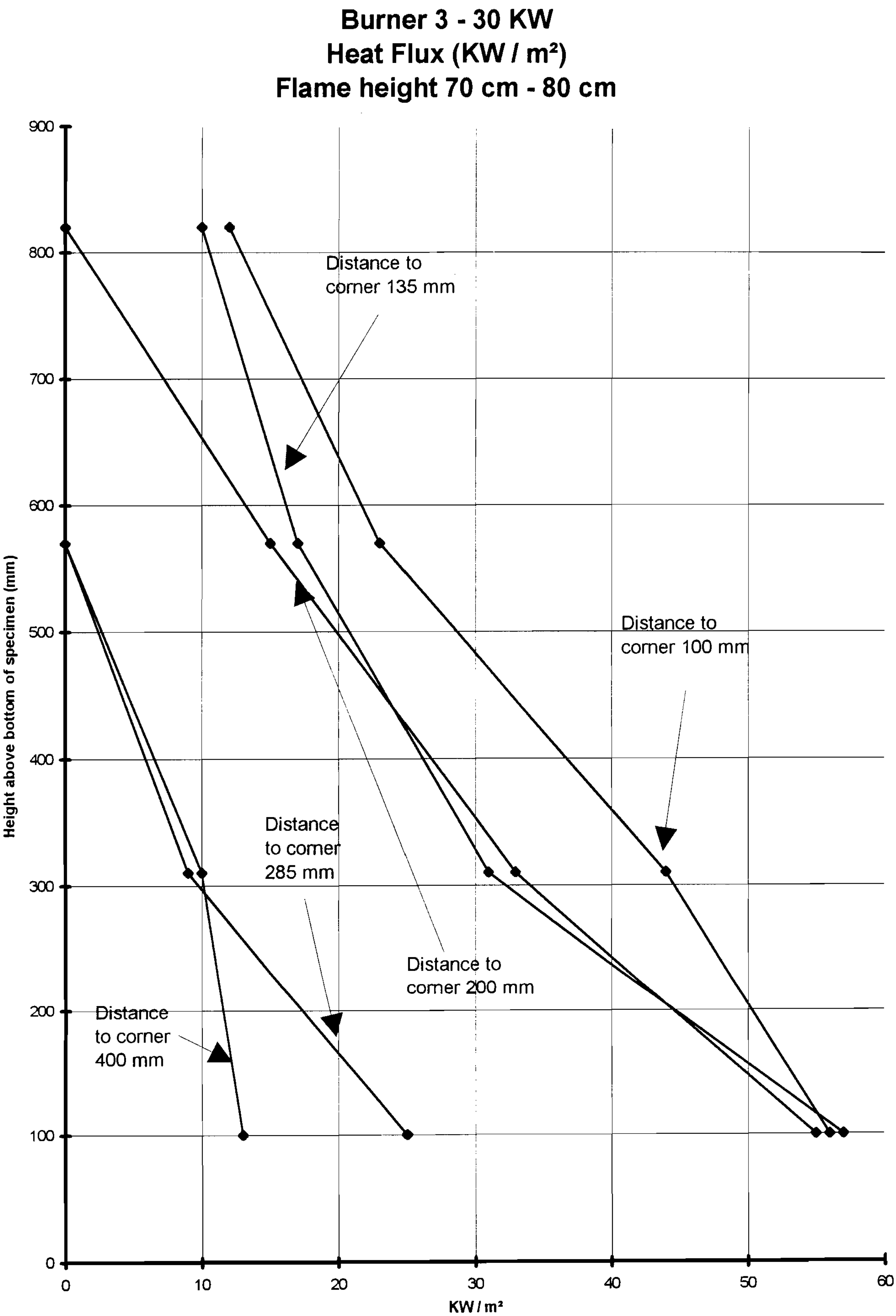

burner 4
250
250
115
115

Standard burner - 30 KW
Heat Flux (KW / m²)
Flame height 70 cm - 80 cm

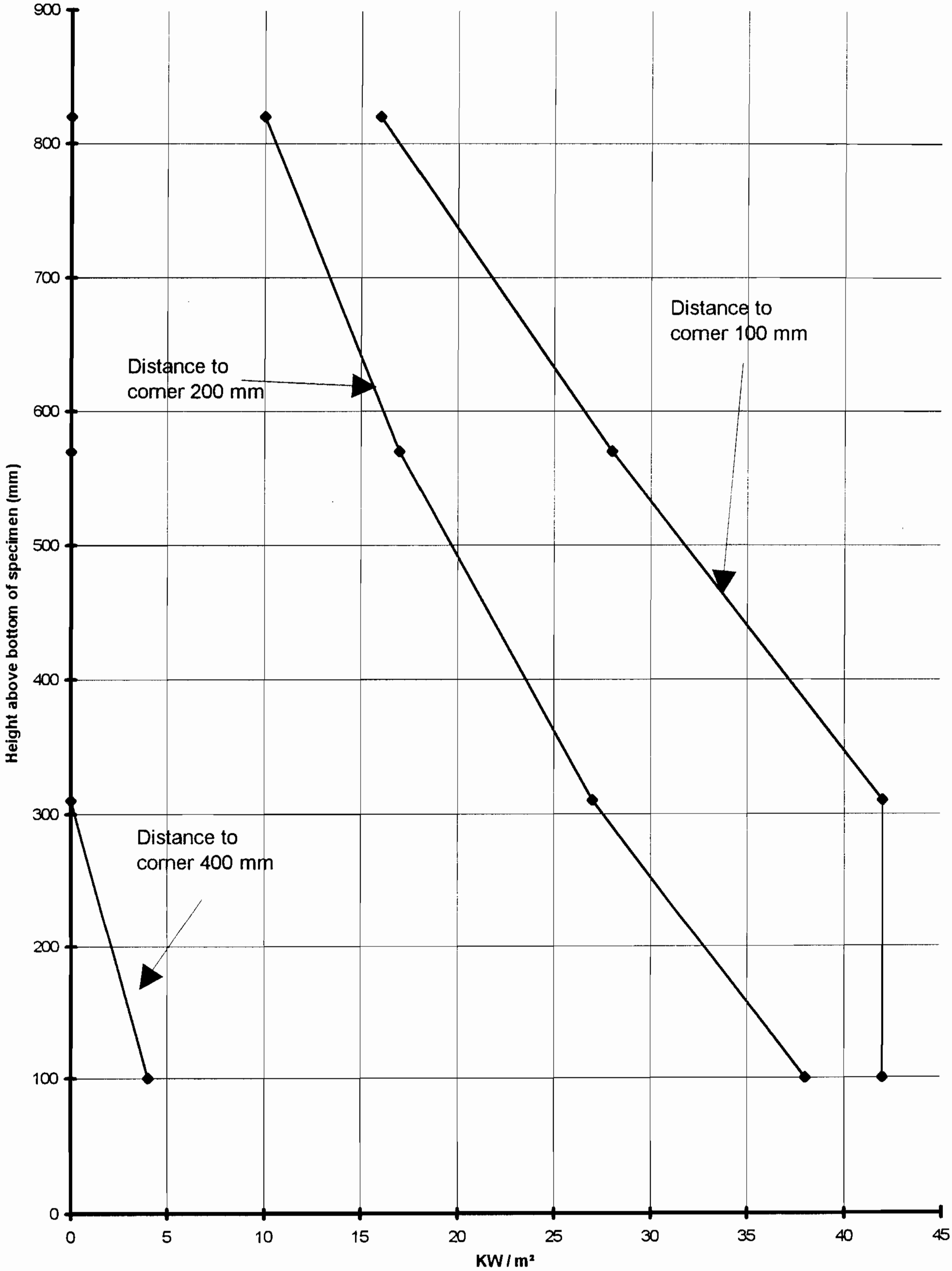


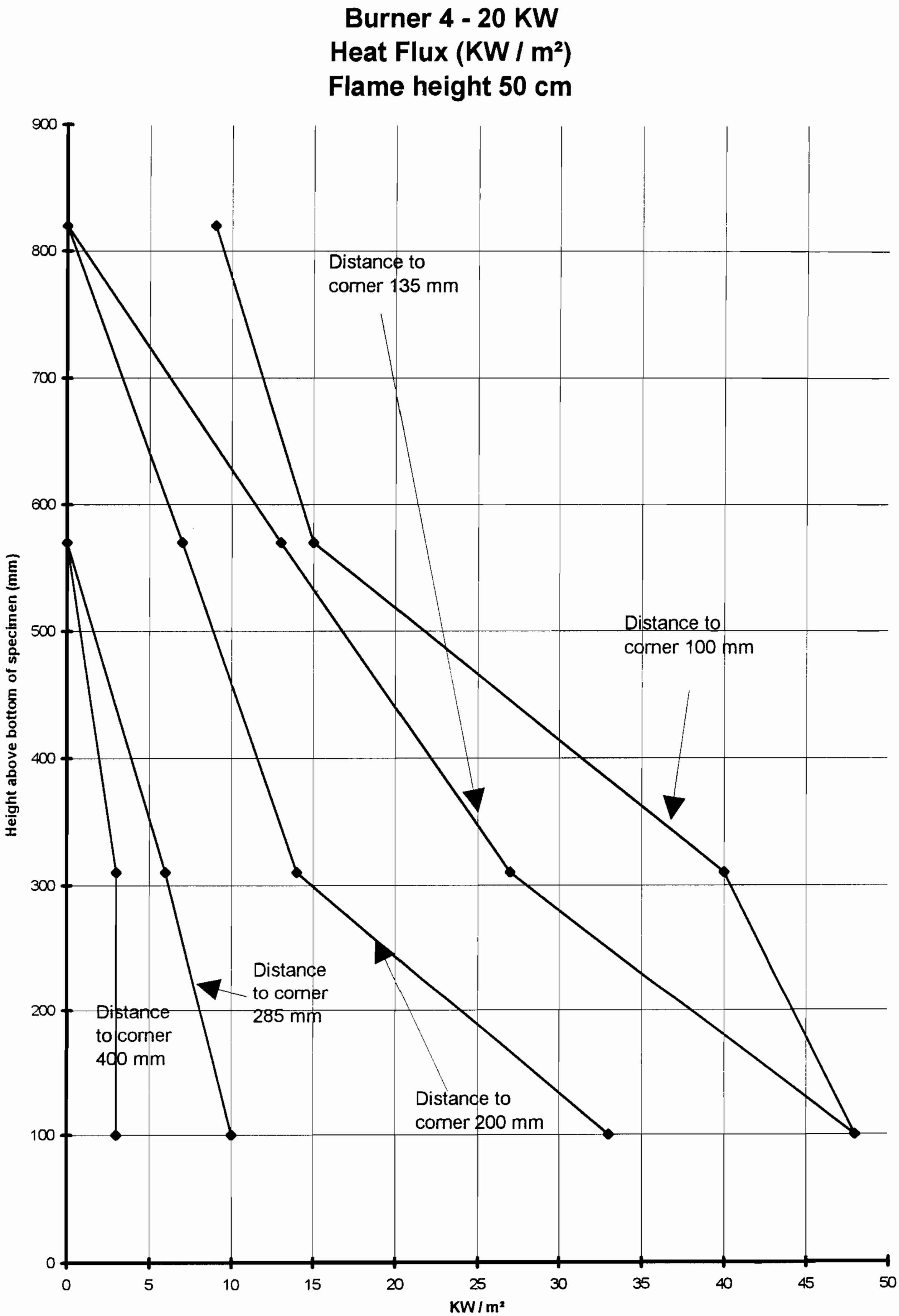
Burner 2 - 30 KW
Heat Flux (KW / m²)
Flame height 50 cm - 70 cm




Burner 3 - 30 KW
Heat Flux (KW / m²)
Flame height 70 cm - 80 cm
Height above bottom of specimen (mm)
KW / m²
Distance to corner 135 mm
Distance to corner 100 mm
Distance to corner 285 mm
Distance to corner 200 mm
Distance to corner 400 mm
900
800
700
600
500
400
300
200
100
0
10
20
30
40
50
60

Burner 4 - 30 KW
Heat Flux (KW / m²)
Flame height 70 cm - 80 cm




Burner 4 - 20 KW
Heat Flux (KW / m²)
Flame height 50 cm
Height above bottom of specimen (mm)
KW / m²
0
100
200
300
400
500
600
700
800
900
0
5
10
15
20
25
30
35
40
45
50
Distance to corner 135 mm
Distance to corner 100 mm
Distance to corner 285 mm
Distance to corner 400 mm
Distance to corner 200 mm

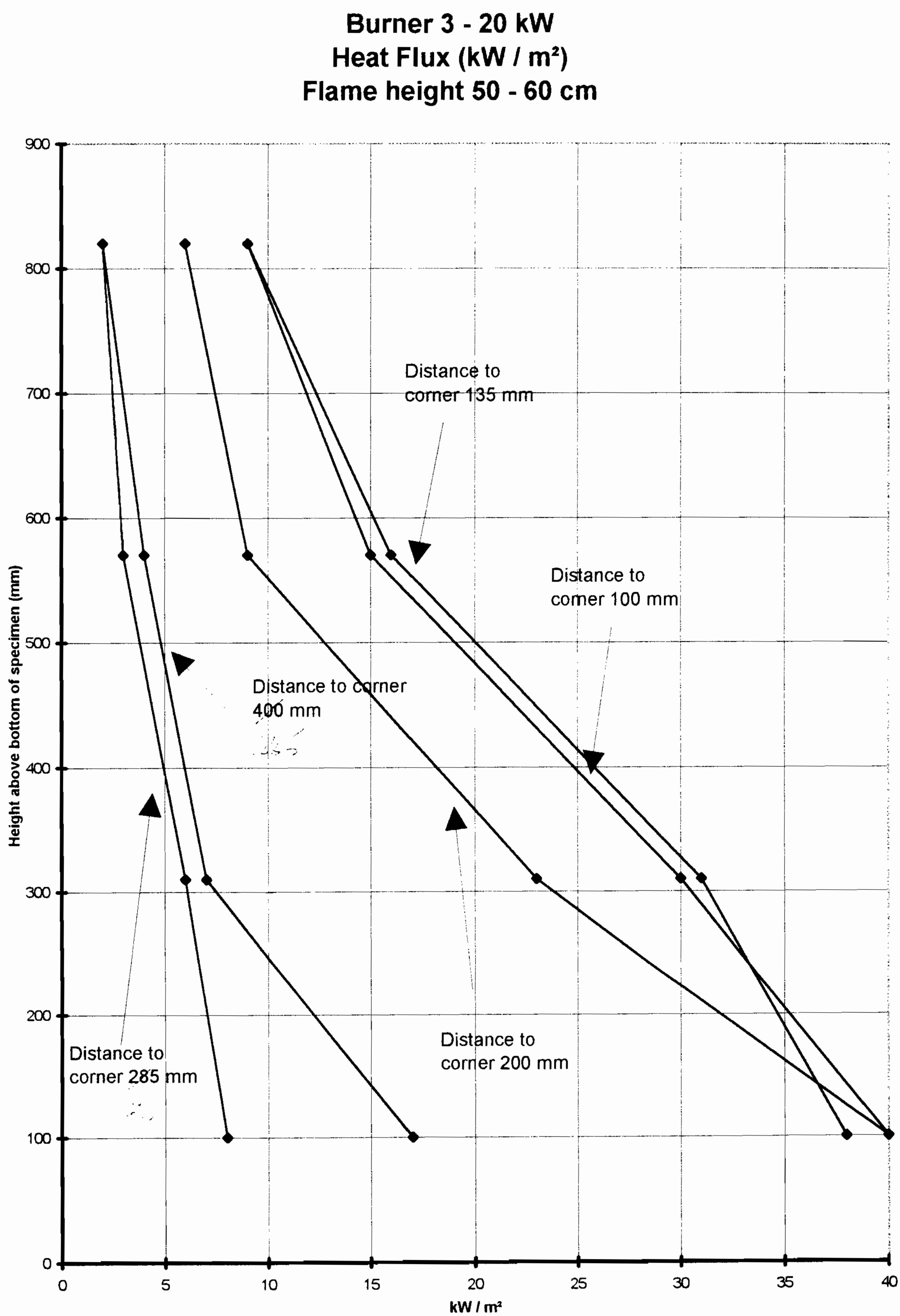
SBI-Test-Program

Exposure conditions with burners of different sizes and shapes

Part 2
Tests with a modified burner
Burner 3

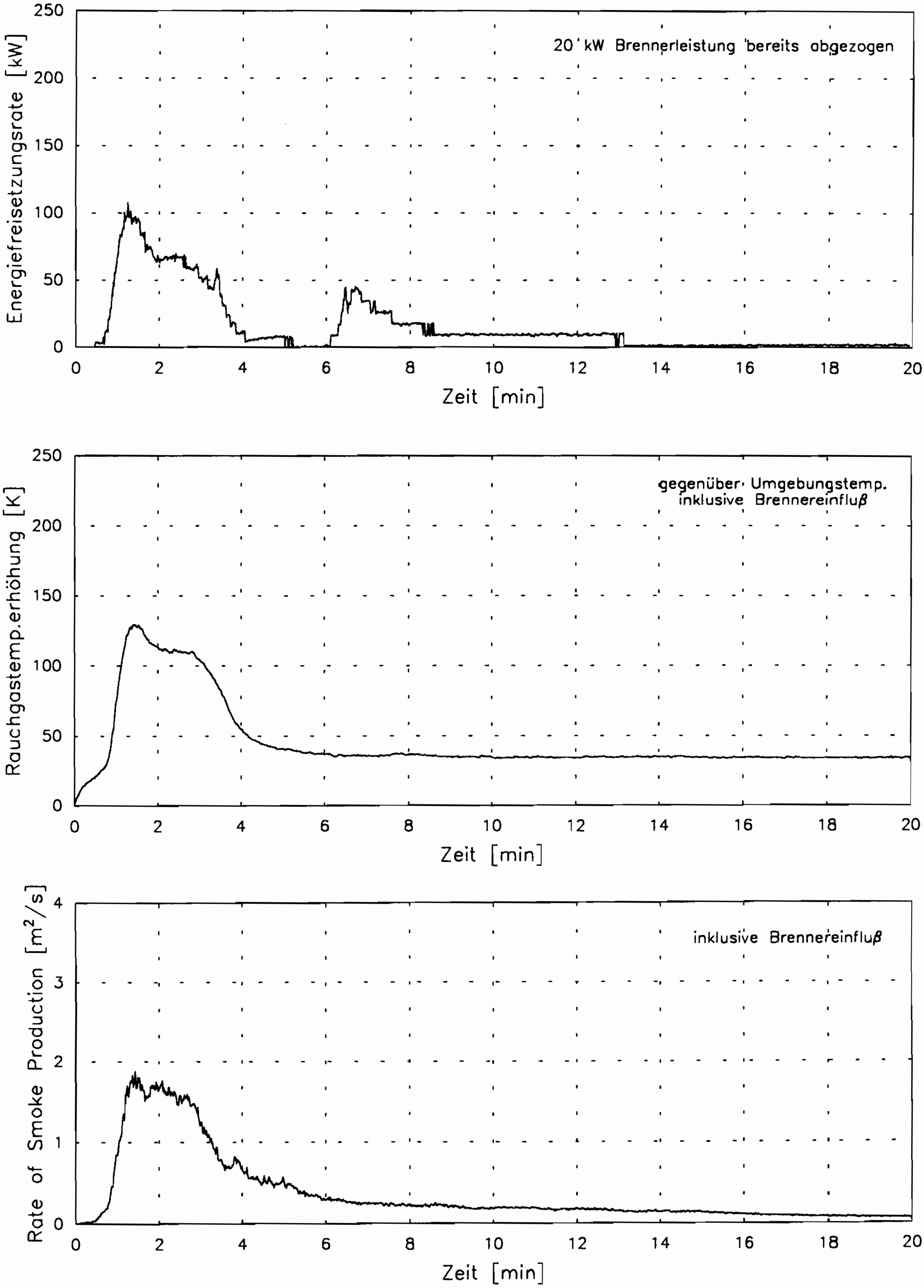
Object

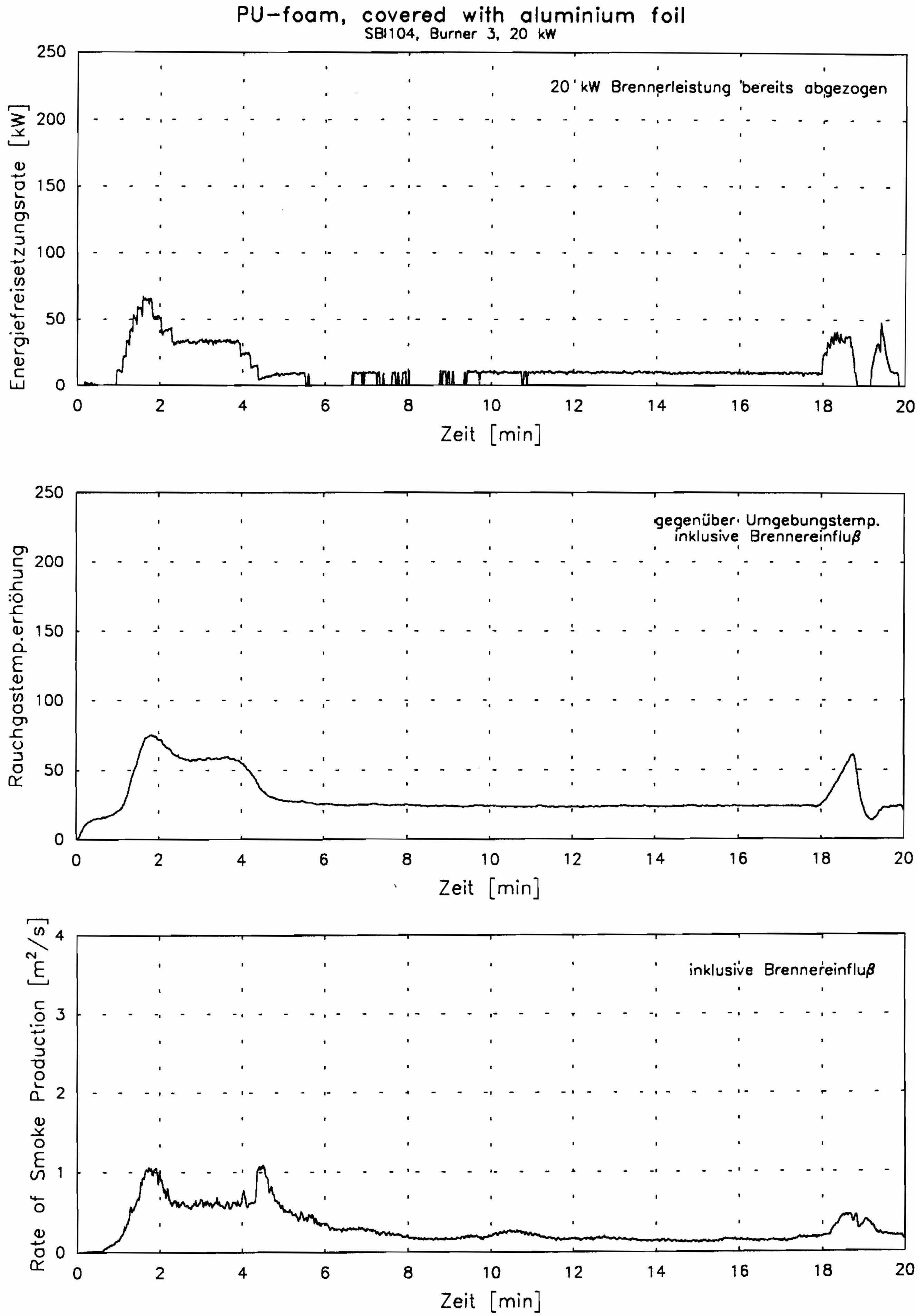
In order to improve the possibility of the flame spread observation in the SBI-test an attempt was made, to achieve the flux profile according to the regulators mandate by a modified burner with smaller flames (burner 3, 20 kW). The flux profile was measured (annex 1). Tests on 3 materials of the previous program were carried out. The results are shown together with those of the standard burner (annex 2 to 9).



Burner 3 - 20 kW
Heat Flux (kW / m²)
Flame height 50 - 60 cm
Height above bottom of specimen (mm)
kW / m²
0
100
200
300
400
500
600
700
800
900
0
5
10
15
20
25
30
35
40
Distance to corner 135 mm
Distance to corner 100 mm
Distance to corner 400 mm
Distance to corner 285 mm
Distance to corner 200 mm

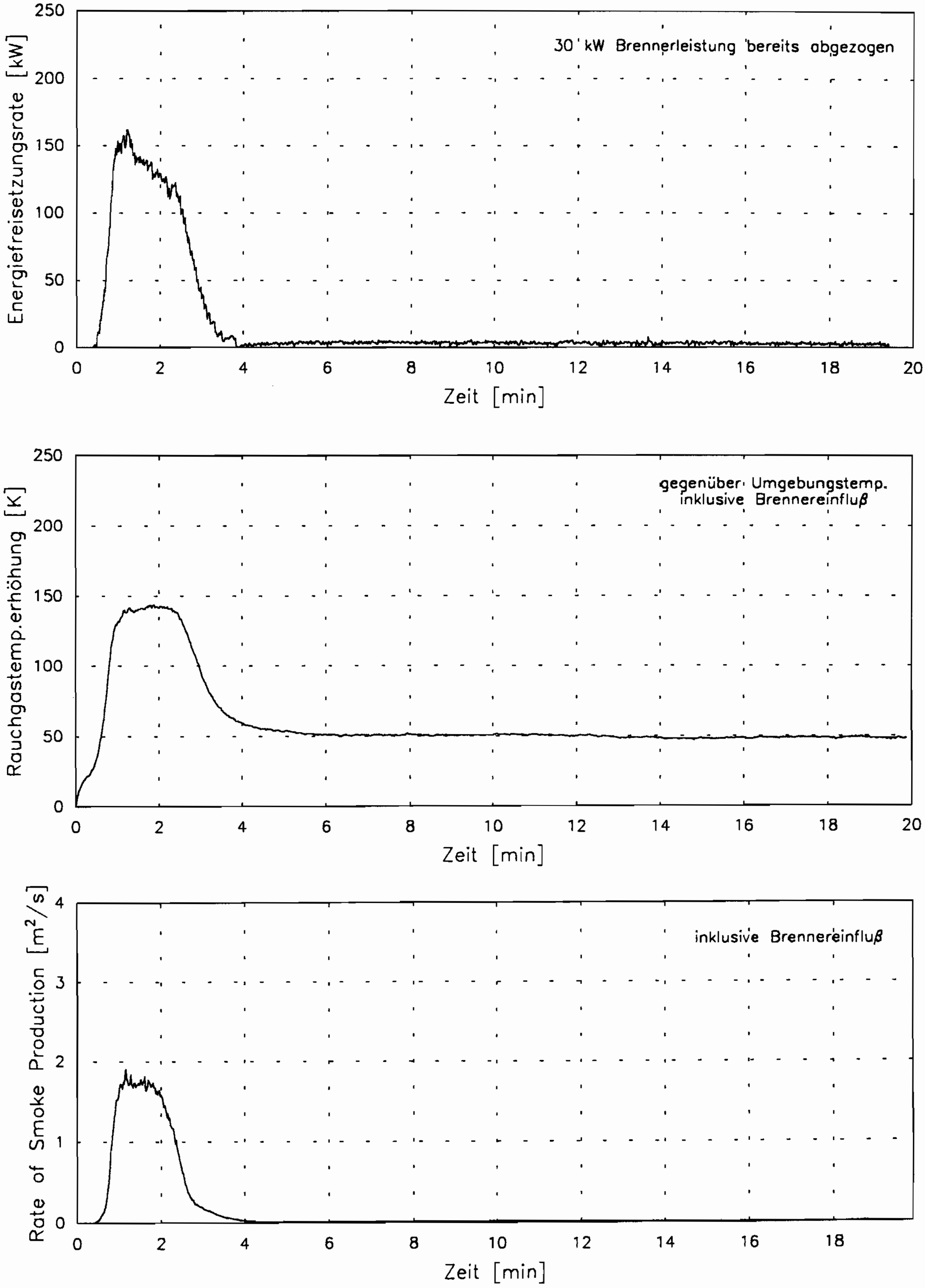
PU–foam, covered with aluminium–foil
SBI103, Burner 3, 20 kW




PU-foam, covered with aluminium foil
SBI104, Burner 3, 20 kW
Energiefreisetzungsrate [kW]
20 kW Brennerleistung bereits abgezogen
Zeit [min]
Rauchgastemp.erhöhung
gegenüber Umgebungstemp.
inklusive Brennereinfluß
Zeit [min]
Rate of Smoke Production [m²/s]
inklusive Brennereinfluß
Zeit [min]

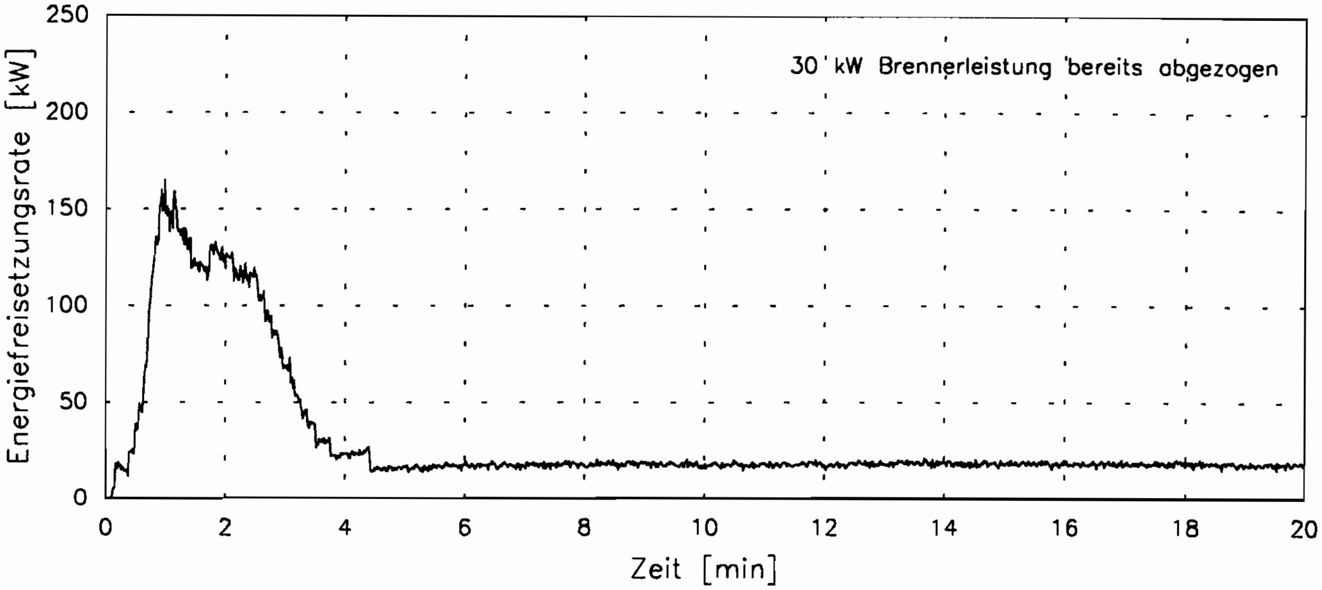
PU–Foam, covered with aluminium–foil

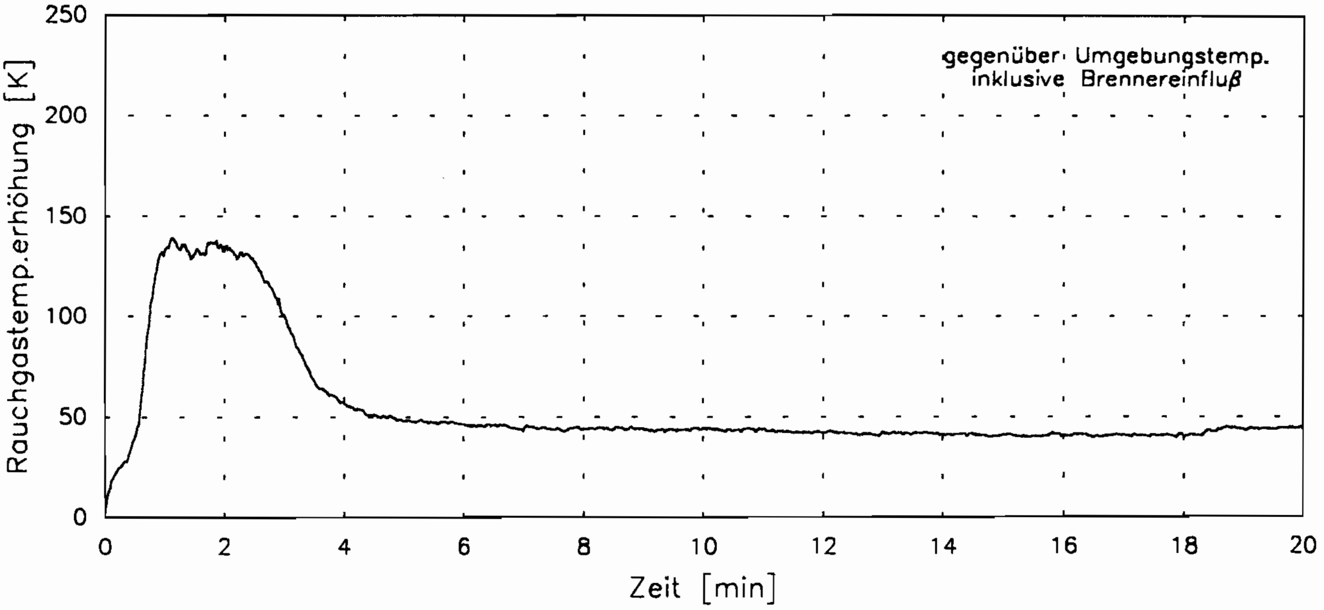
SBIPU1. Standard burner, 30 kW

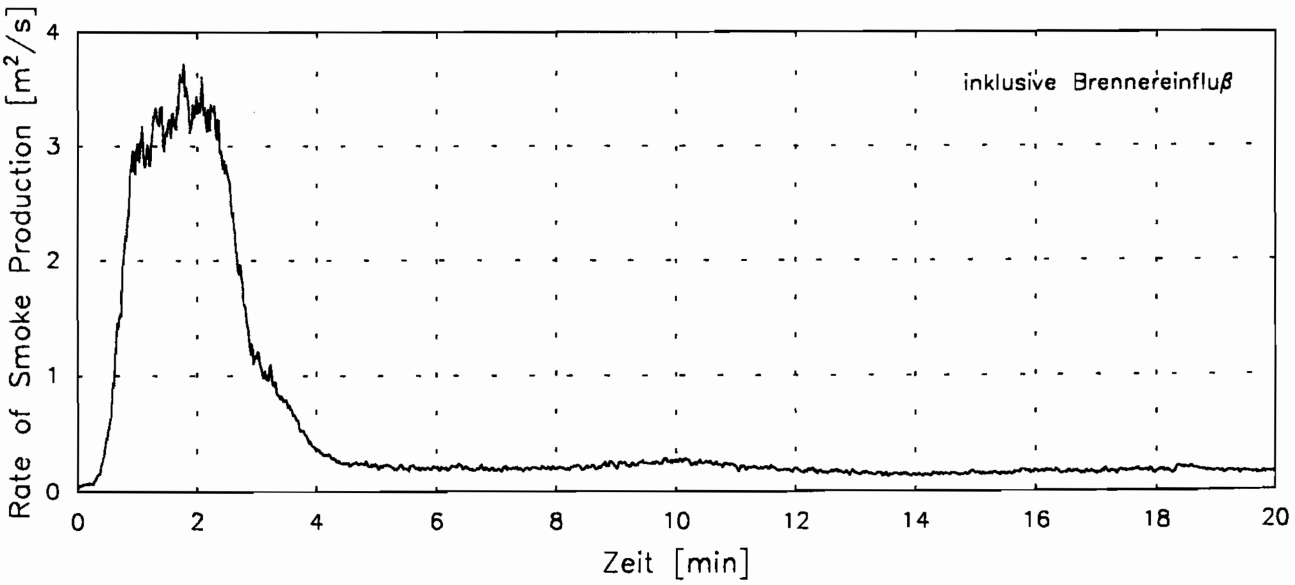


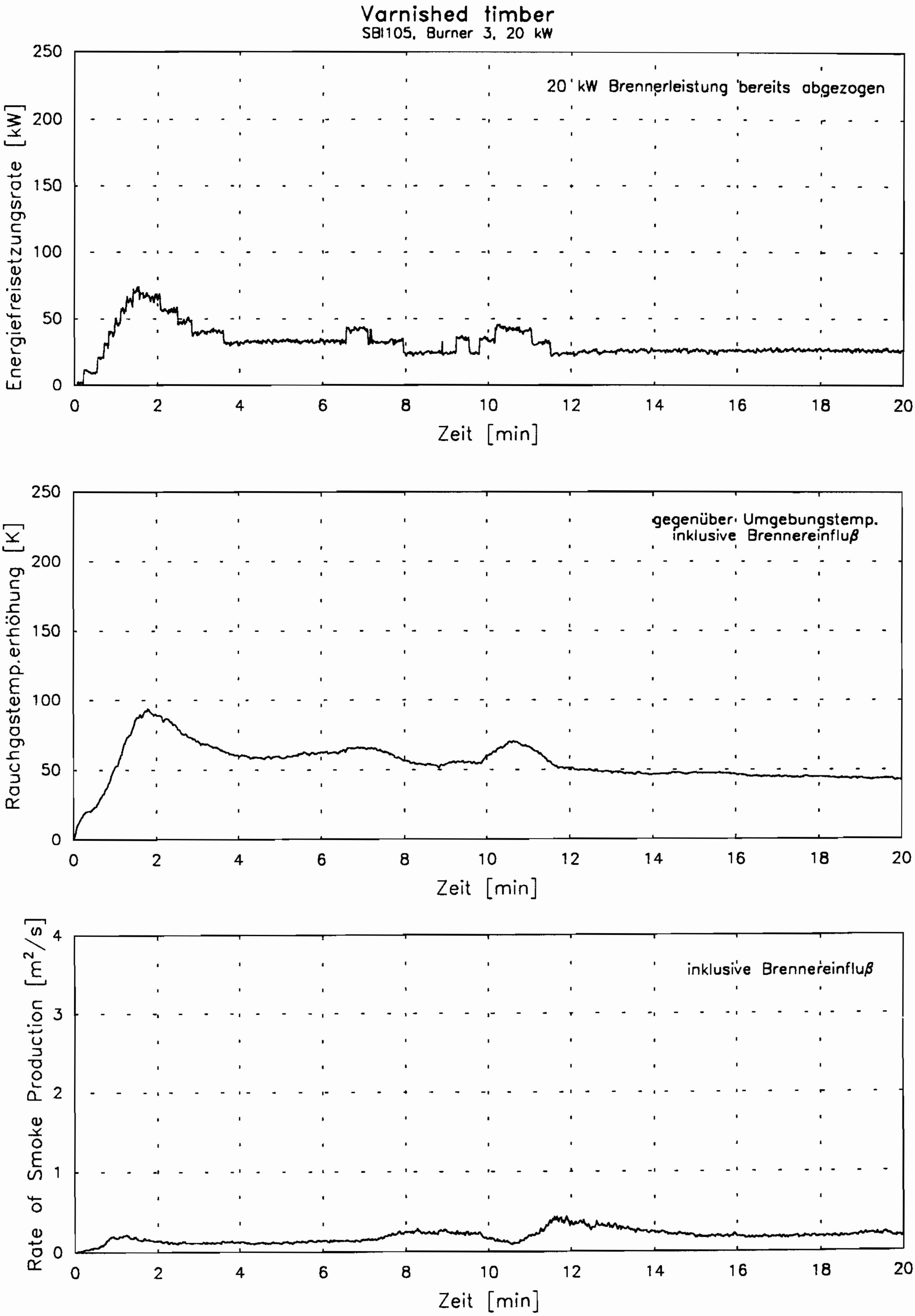
PU-foam, covered with aluminium foil

SBIPU2, Standard burner, 30 kW



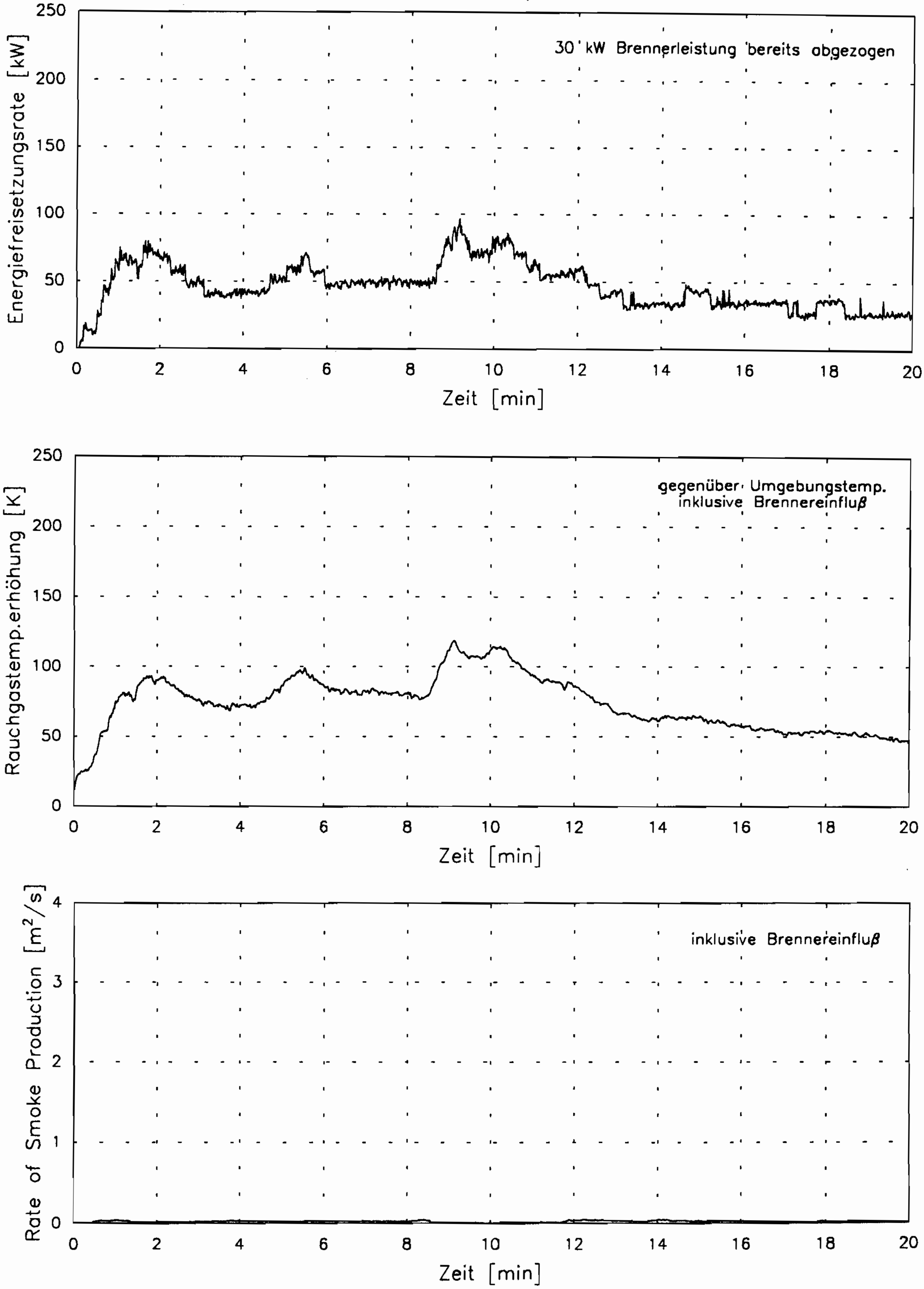





Varnished timber
SBI105, Burner 3, 20 kW
20 kW Brennerleistung bereits abgezogen
Energiefreisetzungsrate [kW]
250
200
150
100
50
0
0 2 4 6 8 10 12 14 16 18 20
Zeit [min]
gegenüber Umgebungstemp.
inklusive Brennereinfluß
Rauchgastemp.erhöhung [K]
250
200
150
100
50
0
0 2 4 6 8 10 12 14 16 18 20
Zeit [min]
inklusive Brennereinfluß
Rate of Smoke Production [m²/s]
4
3
2
1
0
0 2 4 6 8 10 12 14 16 18 20
Zeit [min]

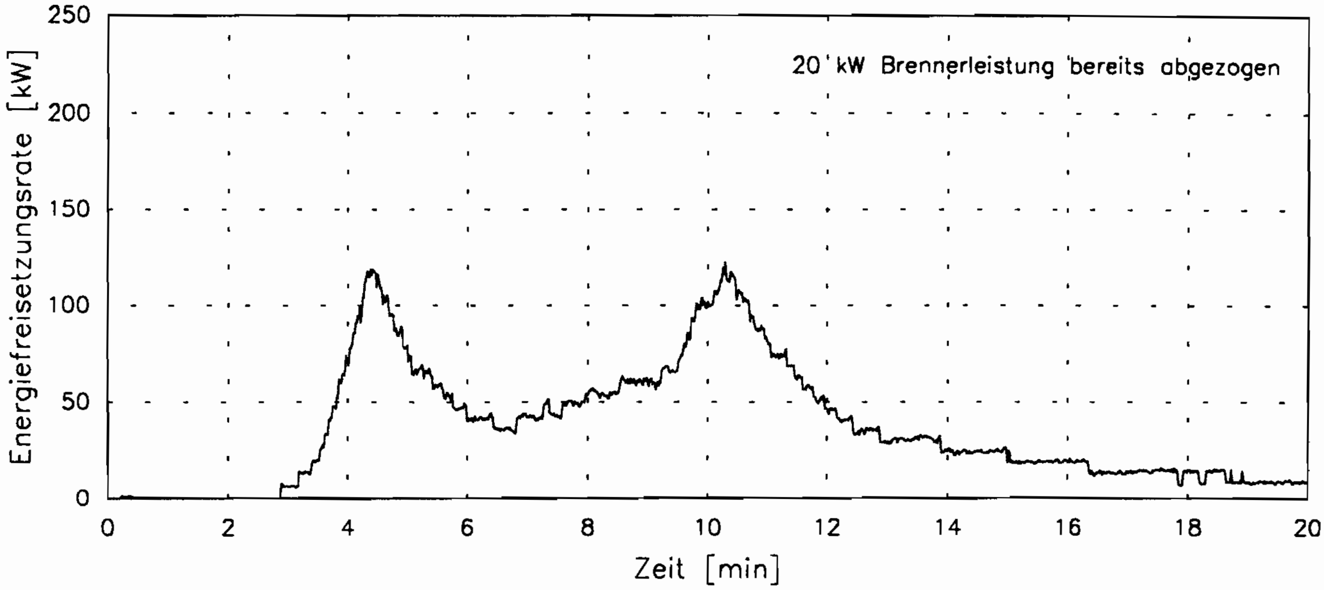
Varnished timber

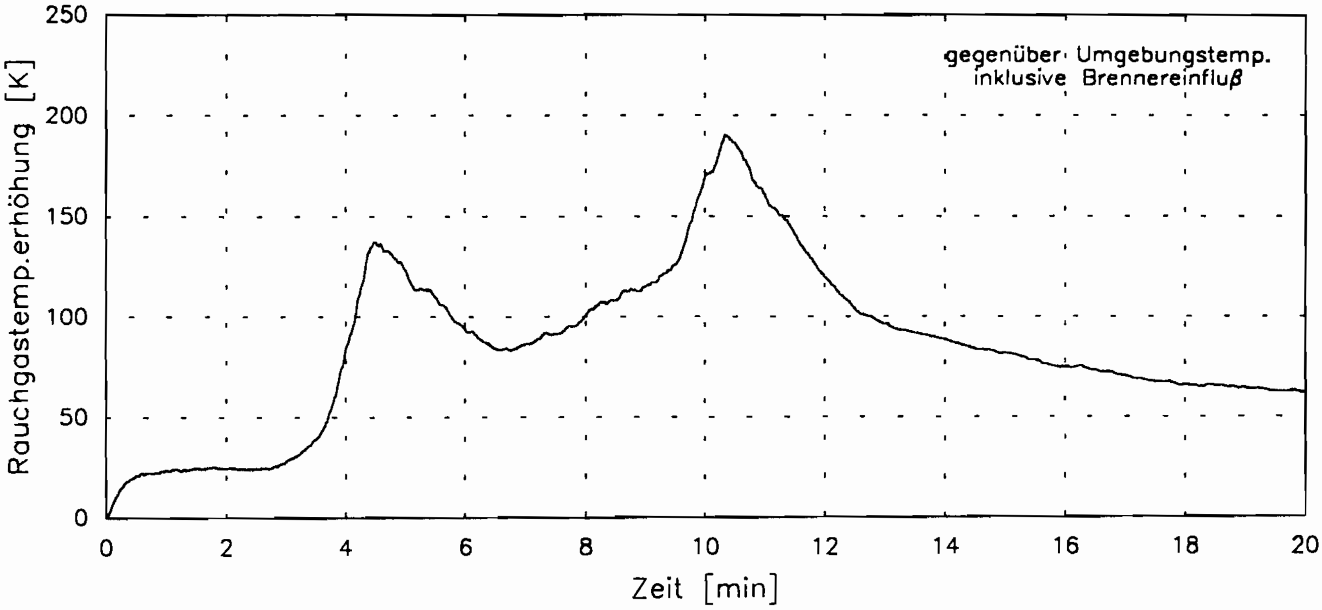
SBITIM1 Standard burner, 30 kW

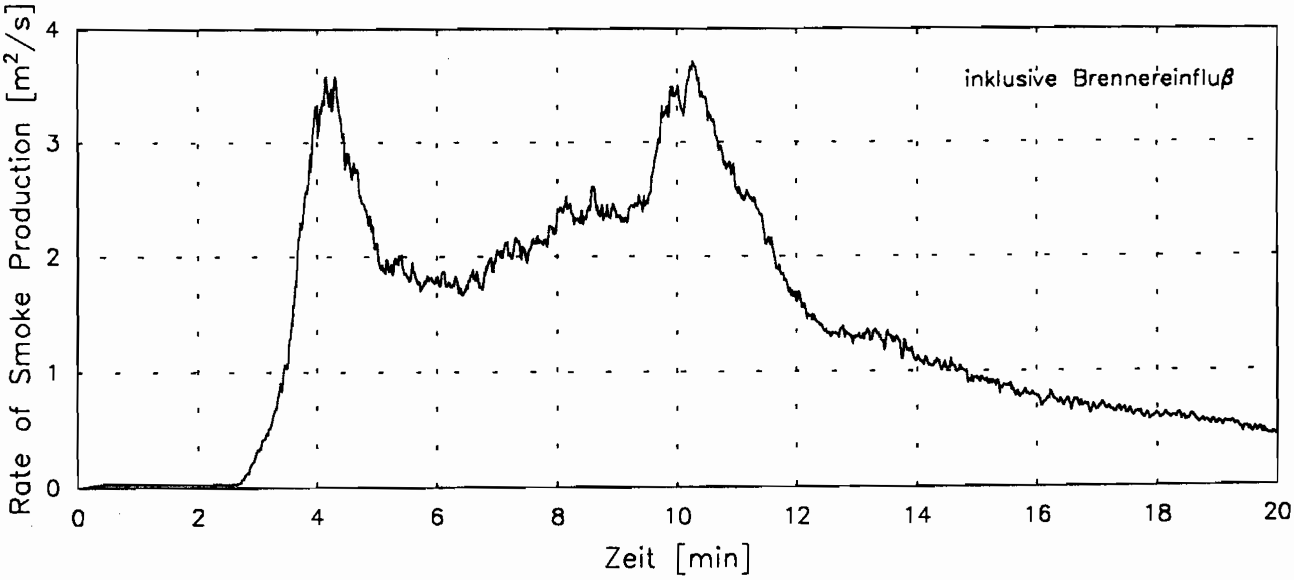


PS-foam

SBI107, Burner 3, 20 kW

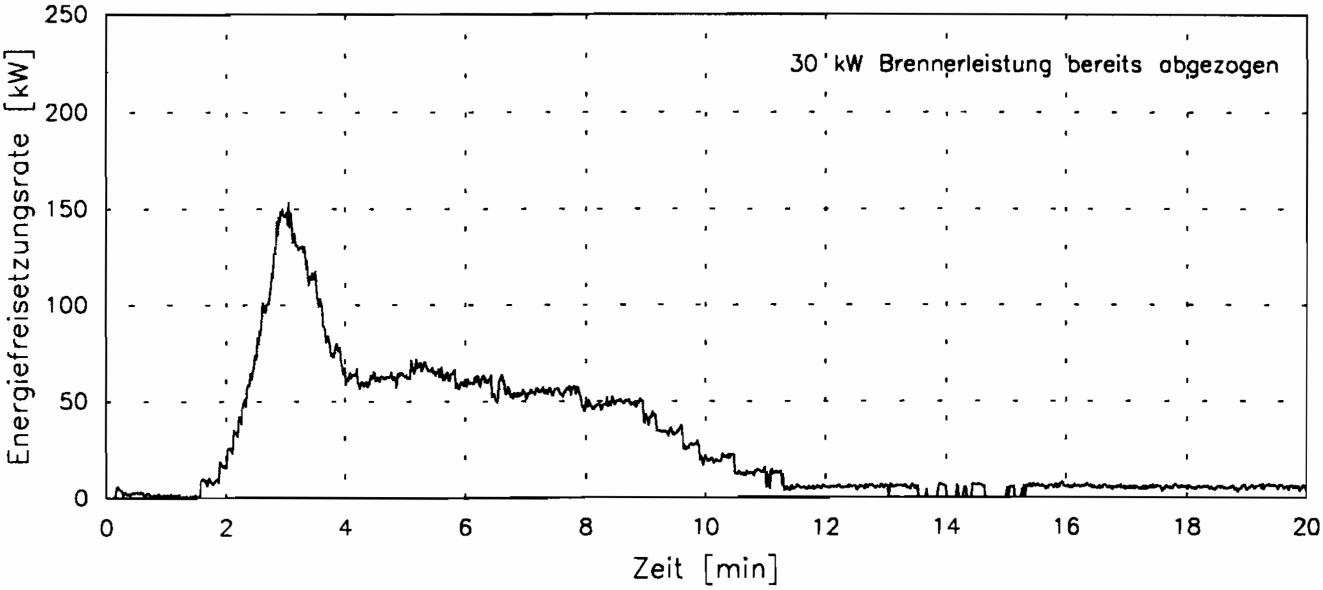


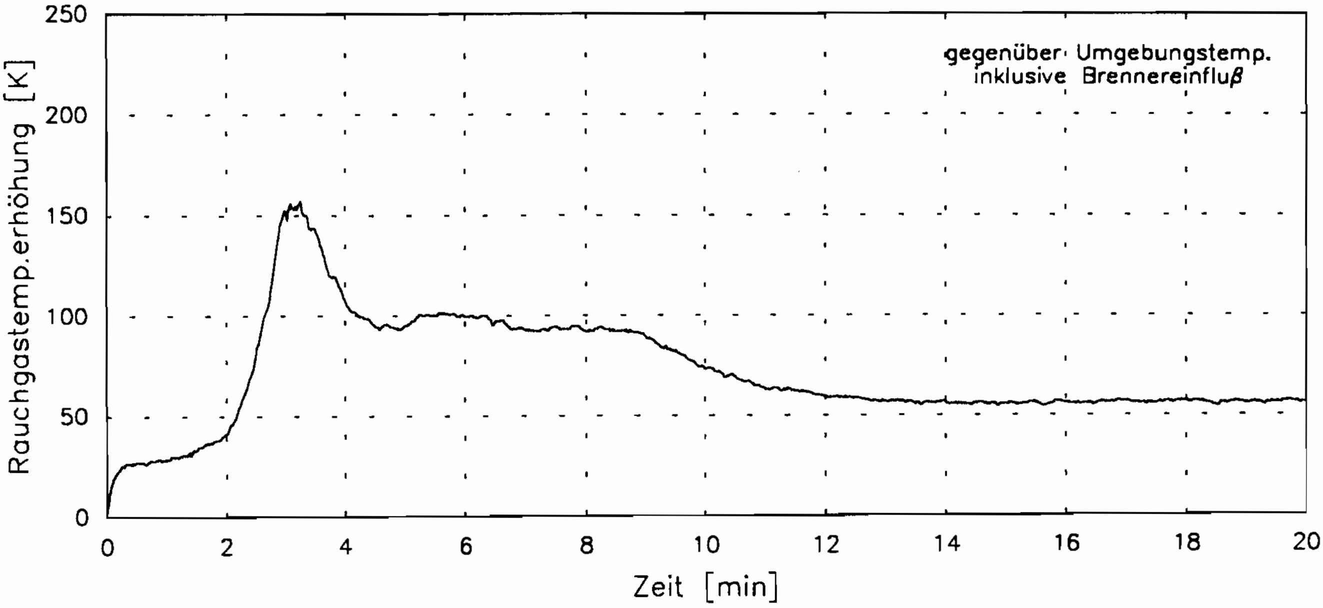


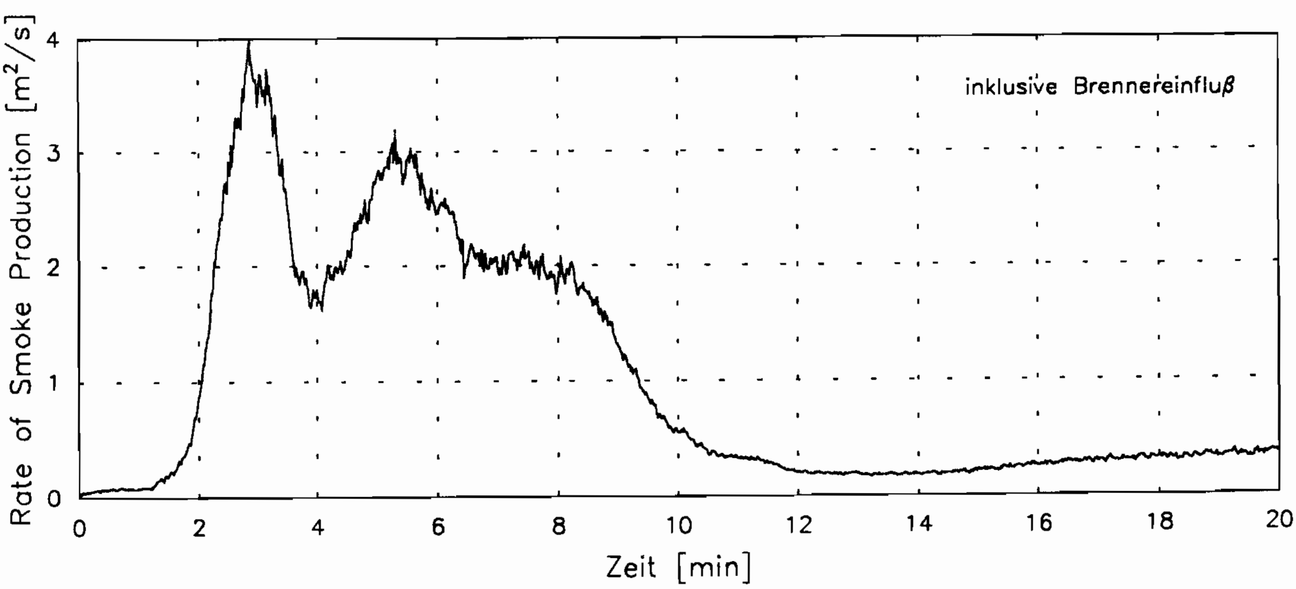


PS-foam

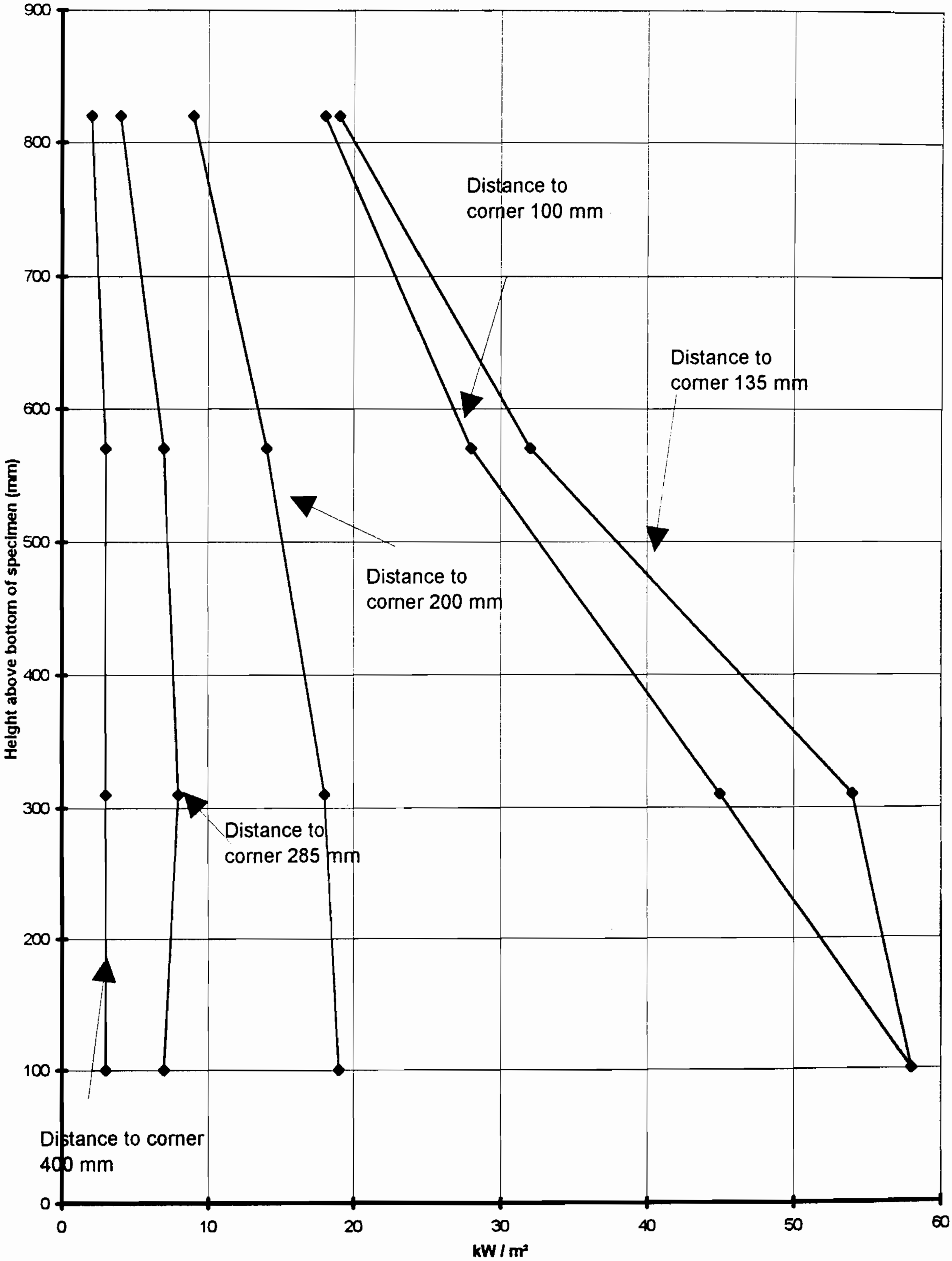
SBIPS2, Standard burner, 30 kW



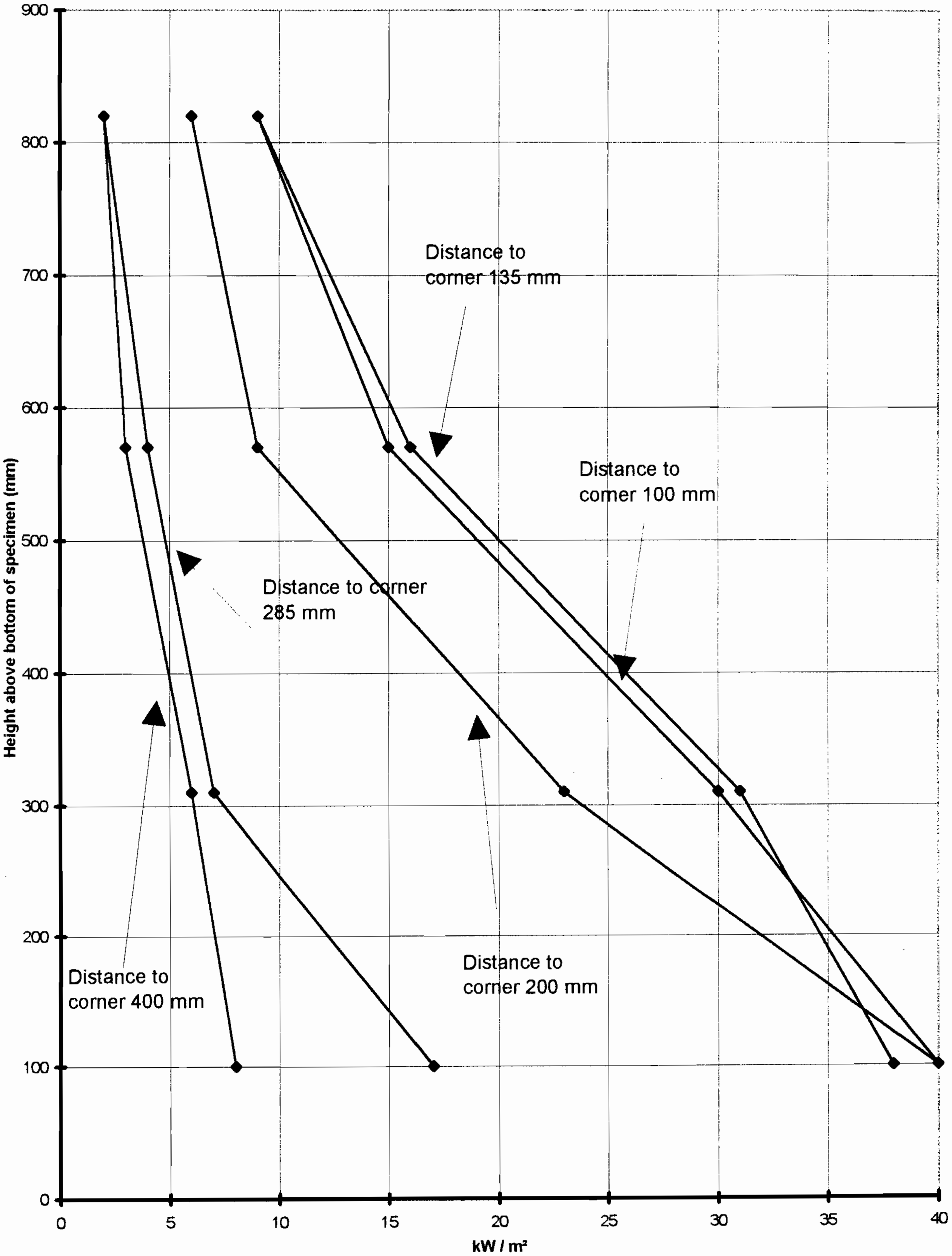


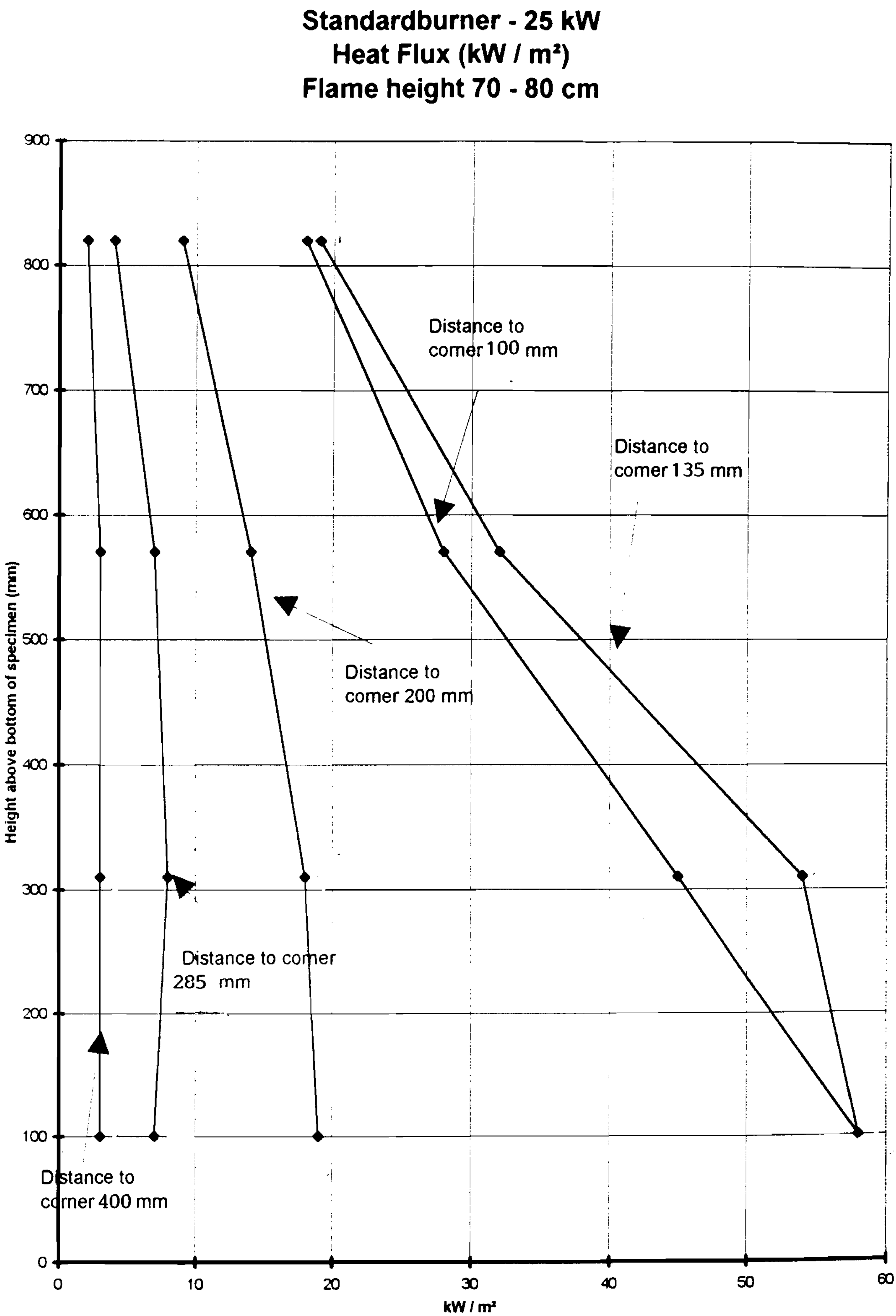


Standardburner - 25 kW
Heat Flux (kW / m²)
Flame height 70 - 80 cm



Burner 3 - 20 kW
Heat Flux (kW / m²)
Flame height 50 - 60 cm

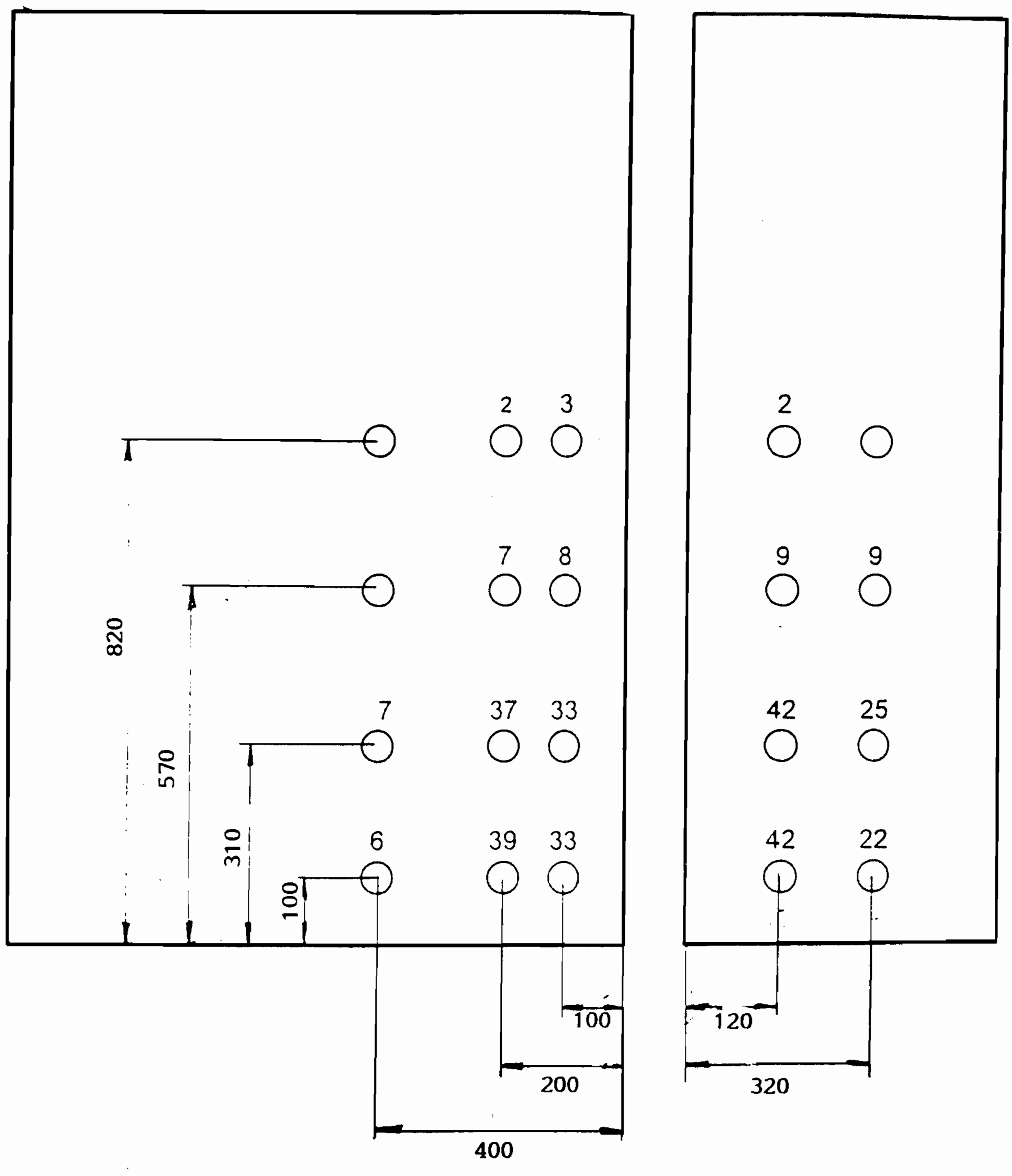




Standardburner - 25 kW
Heat Flux (kW / m²)
Flame height 70 - 80 cm
Height above bottom of specimen (mm)
kW / m²
Distance to corner 100 mm
Distance to corner 135 mm
Distance to corner 200 mm
Distance to corner 285 mm
Distance to corner 400 mm
0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60

Heat flux measurement using Radiant Panel at MPA

Heat flux in kW/m²



Wärmestromdichte

Brenner 3

Brennerleistung: 20 kW

Flammenhöhe: ca. 50 - 60 cm

Meßstelle	Mittelwert in kW/m^2	Maximum in kW/m^2	Minimum in kW/m^2	Standardabweichung in kW/m^2
1	40	62	28	6.0
2	40	61	27	5.3
3	17	28	10	3.4
4	30	44	21	3.5
5	23	35	15	3.3
6	7	12	5	1.2
7	15	21	10	2.3
8	9	13	6	1.3
9	4	5	2	0.6
10	9	11	6	1.1
11	6	9	4	1.1
12	2	4	1	0.4
13	38	57	23	5.0
14	8	10	7	0.3
15	31	42	23	3.0
16	6	7	5	0.2
17	16	22	11	2.0
18	3	5	3	0.3
19	9	12	6	1.2
20	2	4	1	0.4
21	2	2	2	0.1
22	2	2	1	0.1

Wärmestromdichte

Brenner: Brenner E (Dreieck, 270 x 270 mm)

Brennerleistung: 25 kW

Flammenhöhe: ca. 60 - 70 cm

Meßstelle	Mittelwert in kW/m²	Maximum in kW/m²	Minimum in kW/m²	Standardabweichung in kW/m²
1	56	68	45	5.0
2	27	44	17	5.0
3	3	3	3	0.1
4	53	63	38	5.3
5	18	32	13	3.5
6	3	3	3	0.1
7	31	43	23	4.3
8	-	-	-	-
9	-	-	-	-
10	-	-	-	-
11	-	-	-	-
12	-	-	-	-
13	57	70	42	6.9
14	-	-	-	-
15	-	-	-	-
16	-	-	-	-
17	-	-	-	-
18	-	-	-	-
19	-	-	-	-
20	-	-	-	-
21	-	-	-	-
22	-	-	-	-

Wärmestromdichte

Brenner: Brenner E (Dreieck, 270 x 270 mm)

Brennerleistung: 20 kW

Flammenhöhe:

Meßstelle	Mittelwert in kW/m^2	Maximum in kW/m^2	Minimum in kW/m^2	Standardabweichung in kW/m^2
1	52	65	40	5.9
2	24	39	16	4.2
3	3	3	3	0.1
4	45	56	34	5.4
5	-	-	-	-
6	-	-	-	-
7	-	-	-	-
8	-	-	-	-
9	-	-	-	-
10	-	-	-	-
11	-	-	-	-
12	-	-	-	-
13	48	60	33	6.2
14	-	-	-	-
15	-	-	-	-
16	-	-	-	-
17	-	-	-	-
18	-	-	-	-
19	-	-	-	-
20	-	-	-	-
21	-	-	-	-
22	-	-	-	-

Wärmestromdichte

Brenner: Standardbrenner

Brennerleistung: 20 kW

Flammenhöhe: 60-70 cm

Meßstelle	Mittelwert in kW/m^2	Maximum in kW/m^2	Minimum in kW/m^2	Standardabweichung in kW/m^2
1	49	67	34	6.2
2	18	28	13	3.8
3	2	2	2	0.1
4	45	53	34	4.2
5	13	19	10	2.1
6	2	3	2	0.1
7	20	26	14	3.0
8	9	16	6	1.7
9	2	3	1	0.2
10	10	16	6	2.0
11	6	9	3	1.2
12	2	3	1	0.4
13	55	68	43	5.9
14	5	6	5	0.2
15	45	57	33	5.3
16	5	8	4	0.5
17	21	30	15	2.9
18	4	7	3	0.8
19	11	16	7	1.8
20	3	7	2	0.7
21	-	-	-	-
22	-	-	-	-

Wärmestromdichte

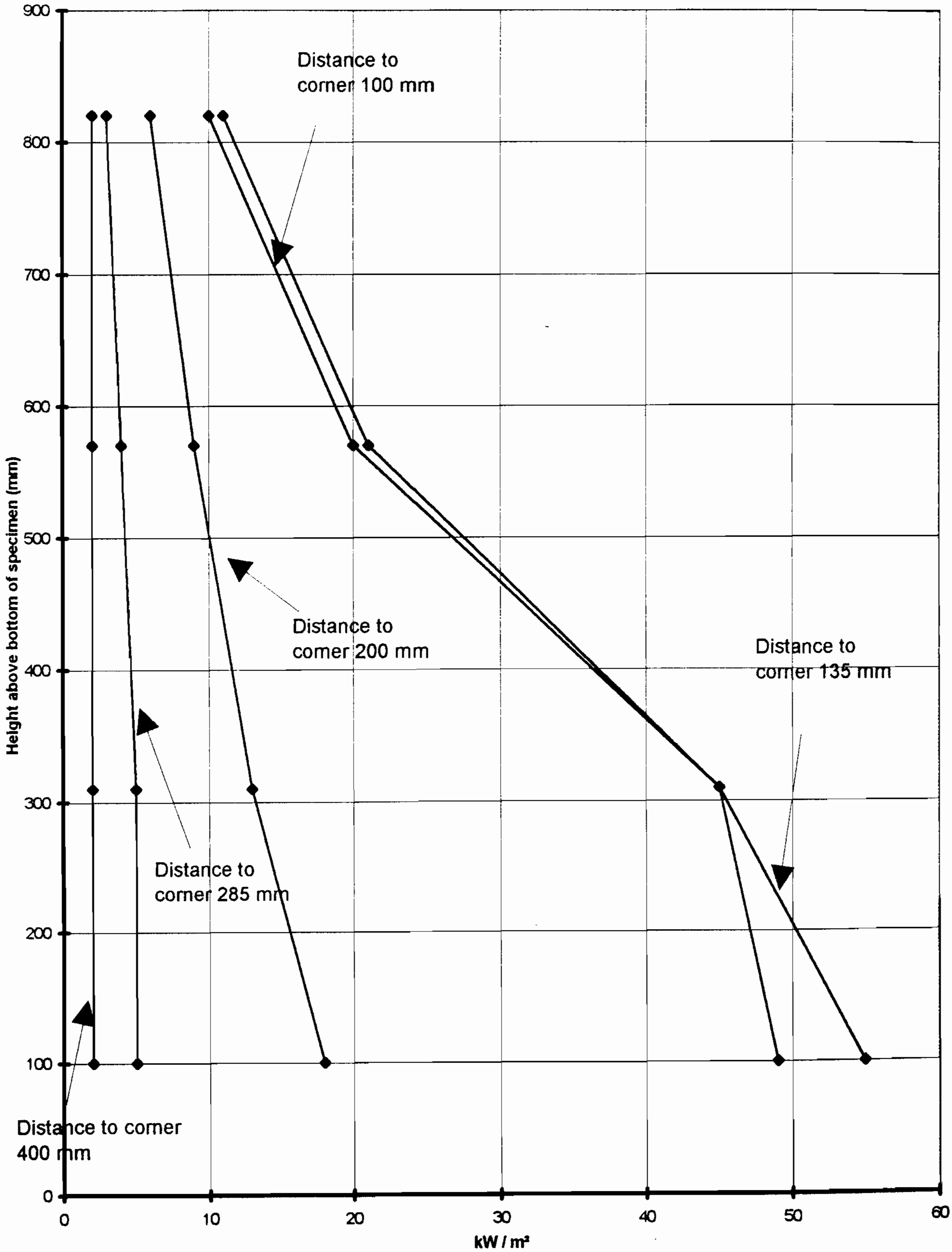
Brenner: Standardbrenner

Brennerleistung: 30 kW

Flammenhöhe: 70-80 cm

Meßstelle	Mittelwert in kW/m^2	Maximum in kW/m^2	Minimum in kW/m^2	Standardabweichung in kW/m^2
1	60	70	49	4.6
2	26	41	17	5.2
3	-	-	-	-
4	57	68	48	4.7
5	-	-	-	-
6	-	-	-	-
7	37	45	28	4.0
8	-	-	-	-
9	-	-	-	-
10	25	32	14	3.6
11	-	-	-	-
12	-	-	-	-
13	67	75	51	4.9
14	-	-	-	-
15	61	68	48	4.4
16	-	-	-	-
17	36	44	29	3.2
18	-	-	-	-
19	23	31	16	3.0
20	-	-	-	-
21	-	-	-	-
22	-	-	-	-

Standardburner - 20 kW
Heat Flux (kW / m²)
Flame height 60 - 70 cm



Wärmestromdichte

Brenner: Brenner 5 (Dreieck, 270 x 270 mm)

Brennerleistung: 20 kW

Flammenhöhe: 60 – 70

Meßstelle	Mittelwert in kW/m²	Maximum in kW/m²	Minimum in kW/m²	Standardabweichung in kW/m²
1	52	65	40	5.9
2	24	39	16	4.2
3	3	3	3	0.1
4	45	56	34	5.4
5	-	-	-	-
6	-	-	-	-
7	-	-	-	-
8	-	-	-	-
9	-	-	-	-
10	-	-	-	-
11	-	-	-	-
12	-	-	-	-
13	48	60	33	6.2
14	-	-	-	-
15	-	-	-	-
16	-	-	-	-
17	-	-	-	-
18	-	-	-	-
19	-	-	-	-
20	-	-	-	-
21	-	-	-	-
22	-	-	-	-

Abschnitt 4

Versuche der TU München zur Erprobung eines Verfahrens zur Messung der Flammenhöhe

FB-000/1-7/96

INSTITUT FÜR HOLZFORSCHUNG
UNIVERSITÄT MÜNCHEN

80797 München, Winzererstr. 45
Institutsleiter: Prof. Dr. Dr. habil. G. Wegener

Abschlußbericht Nr. 964 205

zum Auftrag 8041(81260 75/94-3) MPA NRW

"Entwicklung einer Meßvorrichtung zur Bestimmung der Flammenhöhe"

im Rahmen des DIBt Forschungsvorhabens "Kalorimetrisches Prüfverfahren für Bauprodukte"

1. Einleitung

Im Rahmen der Messungen mit dem neu entwickelten SBI-Gerät soll während des Brandversuchs die Brandausbreitung an Hand des zeitlichen Verlaufs der Flammenhöhe bestimmt werden. Bisher geschieht dies üblicherweise bei Abbrandversuchen an Baustoffen ausschließlich durch in regelmäßigen Abständen vorgenommene, visuelle Beobachtungen.

Mit dem vorliegenden Projekt sollte eine Vorrichtung entwickelt werden, mit der die Flammenhöhe in Höhenschritten von 5 bis 10 cm fortlaufend über der Zeit gemessen werden kann. Für die Weiterverarbeitung und Registrierung der Signale war dann vorgesehen, sie über die Meßdatenerfassungsanlage vorzunehmen, um so die Messung der Flammenausbreitung beim SBI-Gerät zu objektivieren und automatisieren.

Absprachegemäß sollte das Flammenhöhenmeßgerät aus einer Reihen von 20 Meßzellen mit elektrischen Einzelausgängen bestehen. Dabei war zunächst vorgesehen, daß die spektrale Empfindlichkeits-Kurve in Übereinstimmung mit dem bisherigen, visuellen Verfahren der Augenempfindlichkeit entspricht. Später wurde entschieden, auch Sensoren anderer spektraler Empfindlichkeit zu erproben.

Es war vereinbart, zunächst eine entsprechende Vorrichtung zu entwerfen, einen verkleinerten Prototypen zu bauen, und diesen dann an einer provisorischen Abbrand-Versuchsanordnung im Brandschacht zu erproben. Bei Bewährung dieses Prototyps sollte dann eine anschlußfertige Meßeinrichtung mit 20 Lichtaufnehmern gebaut werden.

2. Durchgeführte Arbeiten

2.1 Grundkonstruktion

Die Meßvorrichtung zur Bestimmung der Flammenhöhe ("Meßharfe") besteht aus aus mehreren gleich aufgebauten Lichtaufnehmern, die in 5 oder 10 cm Abstand übereinander angeordnet sind. Die Achsen der Meßelemente sind horizontal und parallel zur Oberfläche einer (der beiden) Proben ausgerichtet. Der Abstand der Meßstrahlachse zur Oberfläche beträgt 1,5 cm.

2.2 Konstruktion der Lichtaufnehmer

Um einen ausreichend engen Meßwinkel und damit auf eine Meßentfernung von 50 bis 100 cm ein eindeutiges Signal zu erzielen sowie zur Erhöhung der Empfindlichkeit, wurden die Lichtaufnehmer mit einer (einfachen) Optik ausgerüstet. In einem orientierenden Vorversuch ergab eine solche Anordnung eine gute Richtwirkung und klare Signale sowohl bei Kerzen- wie auch Bunsenbrenner-Flammen. Am inneren Ende des 200 mm langen Leitrohrs wurde deshalb eine Plankonvex-Linse mit 76 mm Brennweite angeordnet. Der Meßstrahl-Durchmesser betrug ca. 20 mm. Als Meßzellen wurden zunächst Silizium-Photodioden (BPW 21) mit eingebautem Farbkorrekturfilter zur Anpassung an die Augen-Empfindlichkeit (460-560-750 nm) und einer lichtempfindlichen Fläche von 4 mm x 4 mm verwendet. Einen Querschnitt durch den Lichtaufnehmer zeigt Abbildung 1.

2.3 Versuchsaufbau für die Messung mit einem Prototypen

Es wurden 3 Lichtaufnehmer gebaut (Abbildung 2) und in einer Haltevorrichtung für 5 Meßpositionen eingesetzt (Abbildung 3). An die Stelle der normalen Tür eines Brandschachts wurde eine Klappe aus einer 19 mm Thermax-Platte mit einer ca. 50 cm x 100 cm großem hitzebeständigen Verglasung eingebaut (Abbildung 4 und 5). Damit sollten parallel zu den Flammenhöhen-Messungen Video-Aufzeichnungen ermöglicht werden. Wie in Abbildung 6 dargestellt, wurde der Brandschacht-Probenhalter entfernt und dafür zwei winkelförmig angeordnete Proben von je 50 cm Breite und 100 cm Höhe in 25 mm Abstand zum Brenner auf den Siebboden gestellt.

2.4 Versuchsergebnisse mit dem Prototypen

2.4.1 Erste Versuchsreihe im Institut für Holzforschung

Es wurden mehrere Versuche mit dieser Meßanordnung im umgebauten Brandschacht durchgeführt. Dabei zeigte sich, daß die Richtwirkung der Lichtempfänger gut und die Meßfeldgröße für den Meßzweck richtig gewählt war.

Leuchtende Flammen, wie die von ungeschützten Spanplatten oder PVC, führten zu einem ausreichenden, wenn auch, bedingt durch schnelle zeitlich Änderung der Flammenhöhe (Flammenspitzen), stark schwankenden Signal. Es erwies sich jedoch als unmöglich, die Flammenhöhe von nur schwach leuchtenden Flammen, die charakteristisch z.B. für flammgeschütze Werkstoffe wie B1-Holzspanplatten oder dergleichen sind, mit ausreichender Sicherheit zu bestimmen. Das schwache, durch schnelle Änderungen der Flammenhöhe stark schwankende Signal der Flammen überlagerte sich mit dem Grundrauschen des Signals derart, daß trotz zusätzlichem Einsatz einer spezielle Verstärkerschaltung keine ausreichende Differenzierung zu erreichen war.

Um die Sichtbarkeit der Flammengrenze zu verbessern, wurde weiterhin versucht, dem Brennergas aus einer durchströmten Lösung geringe Mengen Natrium-Ionen in Form von Kochsalz beizumischen. Die dabei vom Brennergas aufgenommene Menge war jedoch zu klein, um den gewünschten Effekt zu erzeugen. Bei einer größeren Menge, z.B. Kochsalz in Pulverform, wären Reaktionen mit den zu prüfenden Materialien nicht mehr auszuschließen, so daß auch dieser Ansatz wieder fallen gelassen wurde. Insgesamt führten die Versuche zu keinem befriedigenden Ergebnis.

2.4.2 Messungen im Materialprüfungsamt NRW in Erwitte

Da die Anzeige- und Rausch-Empfindlichkeit auch von dem angeschlossenen Meßgerät abhängt, wurden eine 5fach-Meßharfe mit 3 Lichtempfängern dem Materialprüfungsamt NRW übergeben, wo auch die Software für die Meßdaten-Erfassung und Auswertung entwickelt werden sollte. In der Außenstelle Erwitte wurden zwischen März und Juni 1994 hiermit weitere Versuche im Brandschacht an B1- und B2-Spanplatten sowie an PVC-Platten durchgeführt. Die Versuchsergebnisse des Instituts für Holzforschung wurden dabei bestätigt. (Vergleiche hierzu den Bericht: "Interim Test Report on Flame Height Measurement" MPA NRW vom Juni 1995.)

2.4.3 Weitere Versuche mit Zellen anderer Empfindlichkeitsmaxima

Nach einer Beratung dieser Resultate im begleitenden Ausschuß im Dezember 1994 wurde beschlossen, in einer weiteren Versuchsreihe auch Sensoren zu erproben, deren Kennlinie nicht der Augenempfindlichkeit entsprechen (Sitzung des begleitenden Ausschusses vom 2.12.94). Daraufhin wurden 1 weitere Fotodiode mit einer zum Infraroten verschobenen Empfindlichkeit (350-900-1150nm) und 4 CdS-Fotowiderstände mit einer mehr zum blauen Teil des Spektrums verschobenen Empfindlichkeitsmaximum von 530 nm in Kombination mit 3 verschiedenen Verstärkern eingesetzt.

Wie sich bei Versuchen im Brandschacht an B1-Spanplatte zeigte, ergeben beide Ansätze keine besseren Resultate. Insbesondere sind bei den CdS-Fotowiderständen, trotz der sehr hoher Empfindlichkeit, die damit gemessenen Flammenhöhen mit -15 bis -30 cm wesentlich niedriger als die visuell festgestellten Werte. Gleichzeitig ist die Anzeigeträgheit so groß, daß keine befriedigende Flammenhöhen-Verfolgung mehr zu erzielen war, wie sie bei visueller Beobachtung möglich ist.

Als Ergebnis der Versuche mußte somit festgestellt werden, daß das Ziel, die Flammenhöhe mit optischen Methoden zu bestimmen, mit dem vorgesehenen Ansatz nicht zu erreichen ist.

3. Diskussion der mit der Flammenhöhenmessung verbundenen Probleme

3.1 Grundsätzliche Erfahrungen aus den Versuchen

Wenn die Höhe sehr schwach leuchtender, stark schwankender Flammen durch den visuellen Eindruck der Flammengrenze definiert sein soll, ergeben sich kaum lösbare Probleme durch das Rauschens des Sensors. Eine Dämpfung des Signals nivelliert auch das Signal für die natürliche Fluktuation der Flammenhöhe, so daß kurz andauernde Flammenspitzen nicht mehr angezeigt werden und das Ergebnis nicht mit der bei visuellen Beobachtung festgestellten maximale Flammenhöhe übereinstimmt.

Da die Flammen-Farbe und -Intensität je nach untersuchtem Baustoff und verwendetem Flammschutzmittel sehr unterschiedlich ist, ist es nur schwer möglich, eine sinnvolle, einheitliche Helligkeitsschwelle anzugeben, wenn die maximale Empfindlichkeit des Lichtempfängers außerhalb des sichtbaren Bereichs liegt.

Das Hauptproblem liegt darin, daß es für die Flammenspitze kein physikalisch definiertes Ende gibt und somit der Randbereich keine klaren Grenzen aufweist. Aus diesem Grund arbeiten Flammendetektoren nicht mit der Flammengrenz-Struktur sondern mit dem Wellenlängen- und Zeit-Verhalten einer größeren (Flammen-)Fläche. Derartige pyroelektrischen Sensoren für Flammendetektoren entsprechender Fachfirmen arbeiten im Infrarot-Bereich mit Wellenlängen von 2 bis 100 μm und sind sehr träge. Sie sind deshalb auch nicht zur Messung der Flammenhöhe geeignet. Bei IR-Sensoren wären zusätzliche Schwierigkeiten durch IR-Strahlung erhitzter Oberflächen zu erwarten.

3.2 Beobachtungen am SBI-Gerät

Wie sich bei ersten Brandversuchen mit dem Prototypen des SBI zeigte, sind die Flammen hierbei teilweise anders strukturiert, als es den Erfahrungen mit dem Brandschacht entspricht, Eine automatische Erfassung der Flammenhöhe wird somit beim SBI-Test zusätzlich kompliziert oder unmöglich gemacht.

Trotz stabiler Primärflamme ist die Flamme auf der Probenoberfläche extrem unruhig und fluktuiert stark. Um zu eindeutigen Ergebnissen zu kommen, wäre es also notwendig, in die Meßkette ein Dämpfungsglied einzubauen. Dies würde bedeuten, daß die Messungen an unterschiedlichen Prüfstellen nur schwer objektivierbar bzw. reproduzierbar wären.

Die Flammen lösen sich bei Beanspruchung der Probe durch den Kiesbett-Brenner als kompakte Flammenkissen wolkenförmig von der Probe und steigen davor auf, so daß nicht mehr von einer Flammenhöhe auf der Probe gesprochen werden und sie bei der vorgesehenen Anordnung vom Meßstrahl nicht mehr korrekt erfaßt werden kann.

Die Flammenfront ist sehr uneinheitlich und weist oft mehre Spitzen auf. Die Flammen zogen sich nicht immer in die Ecke zwischen den beiden Proben zusammen, sondern spalteten sich teilweise nach außen auf. Somit ist es bei der vorliegenden Übereck-Anordnung der Proben im SBI-Gerätes u.U. nicht möglich die maximale Flammenhöhe mit einer festehenden Meßvorrichtung zu erfassen, da die Meßstrahlen nur eine der beiden Probenoberflächen erfassen. Teilweise bildeten sich auch auf der Probenrückseite Flammen, die ebenfalls mit einer vor den Proben angeordneten Meßeinrichtung nicht festzustellen sind.

4. Zusammenfassung der Ergebnisse

Das vorgesehene Verfahren der automatischen Bestimmung der Flammenhöhe bei Brandversuchen durch optische Erfassung mittels einer Reihe von Lichtaufnehmer mit unterschiedlicher spektraler Empfindlichkeit hat sich, hauptsächlich wegen der unterschiedlichen Intensität und Färbung der material-spezifischen Flammen unterschiedlicher Baustoffe, bei den Erprobungsversuchen als nicht praktikabel herausgestellt.

5. Ausblick

Derzeit erscheint auch kein anderer Weg zur Lösung der aufgetretenen Probleme gangbar, wenn man an der bisher üblichen Definition der Brandausbreitung als der maximalen Flammenausbreitung festhalten will. Zu einem späteren Zeitpunkt kann eventuell hierfür ein Bildverarbeitungsverfahren eingesetzt werden. Z.Zt. läßt sich dies jedoch in dem vorgesehenen Rahmen wegen des hohen Rechenaufwands nicht realisieren.

München, den 13.09.96

i.A.

(AK.Dir Dr. P. Topf)

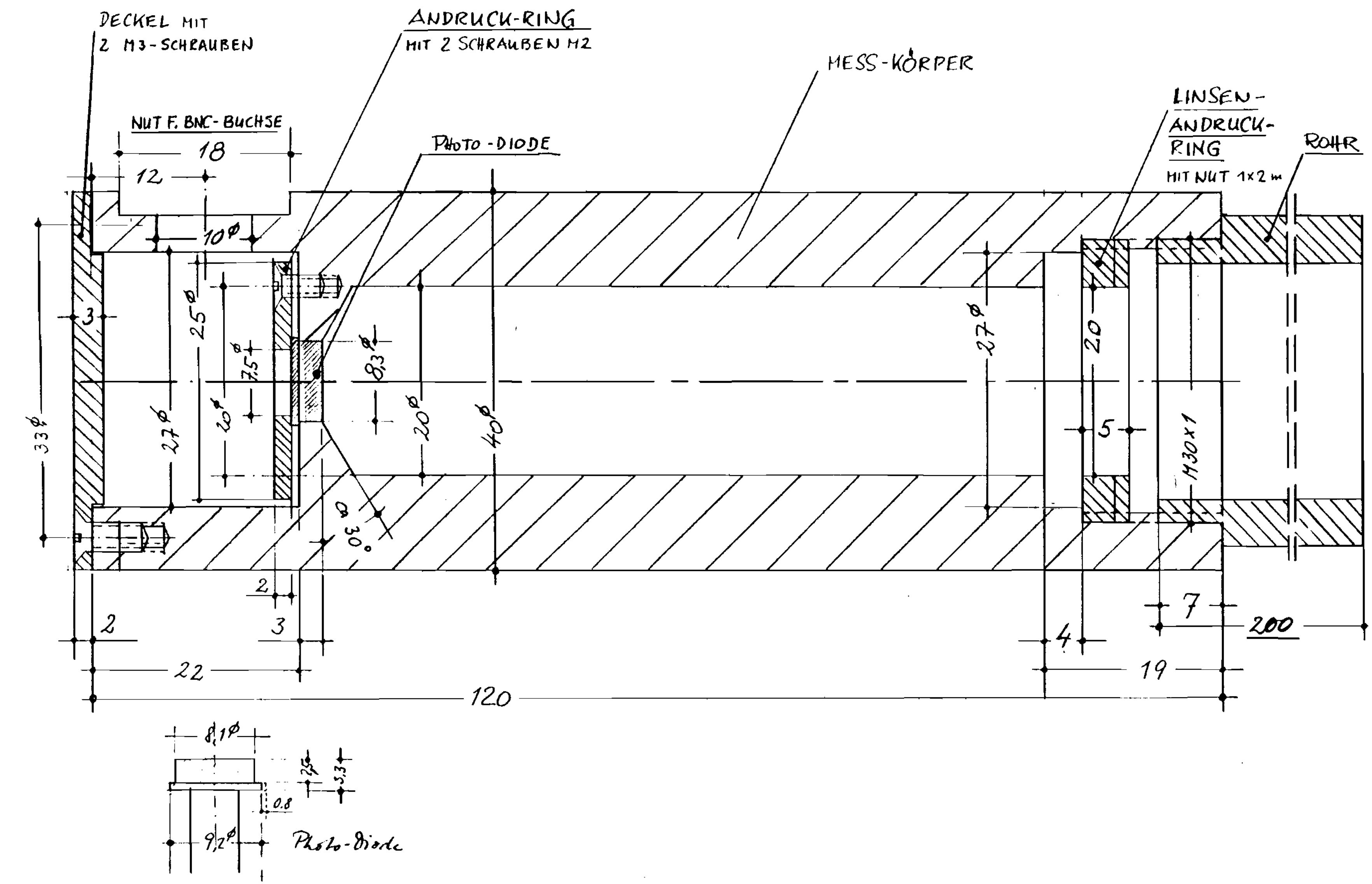


Abbildung 1 Lichtaufnehmer, Querschnitt

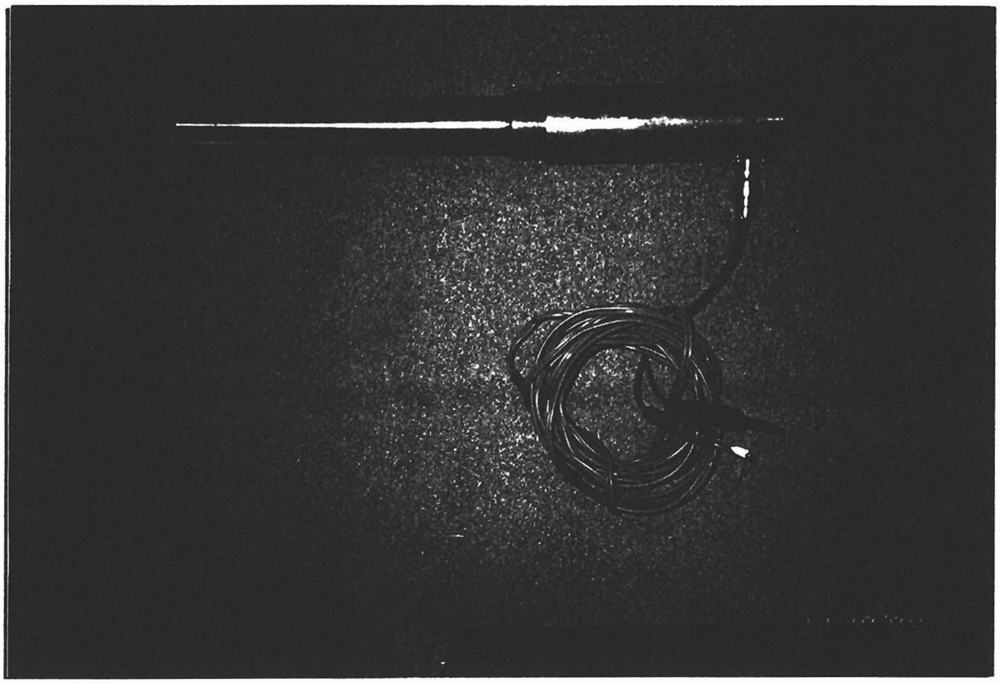


Abbildung 2 Lichtaufnehmer, Ansicht

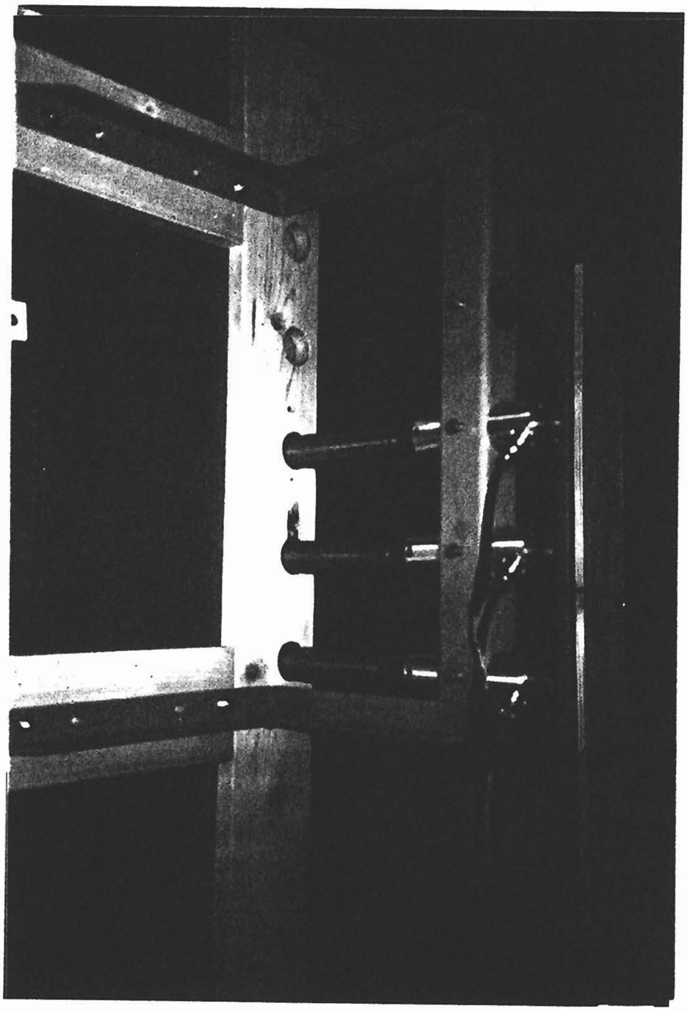


Abbildung 3 Haltevorrichtung mit 3 Lichtaufnehmern

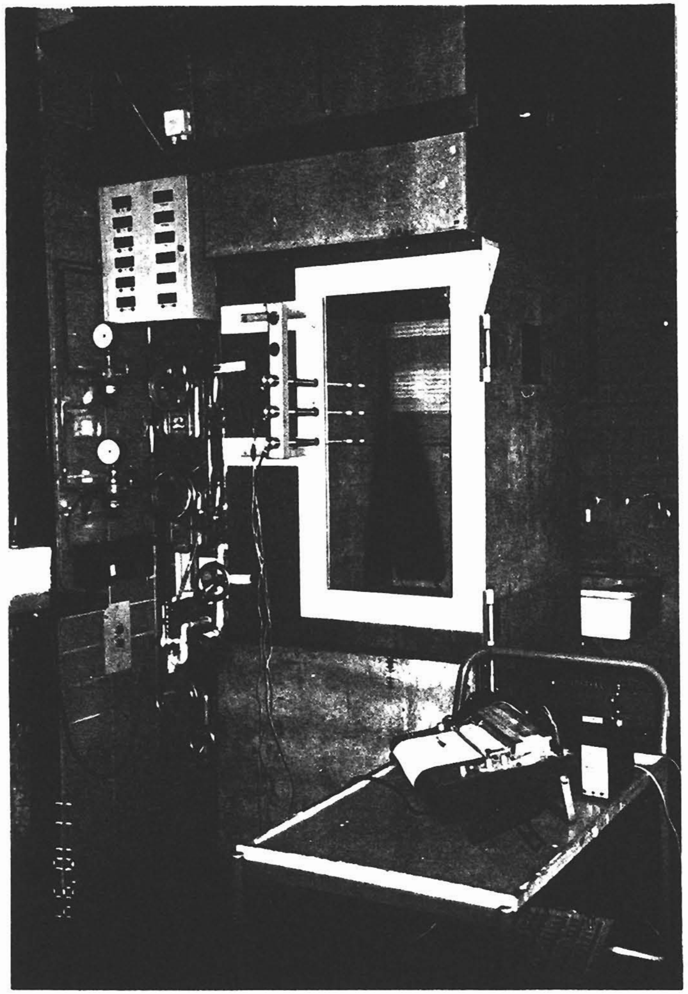


Abbildung 4 Brandschacht mit Prototypen

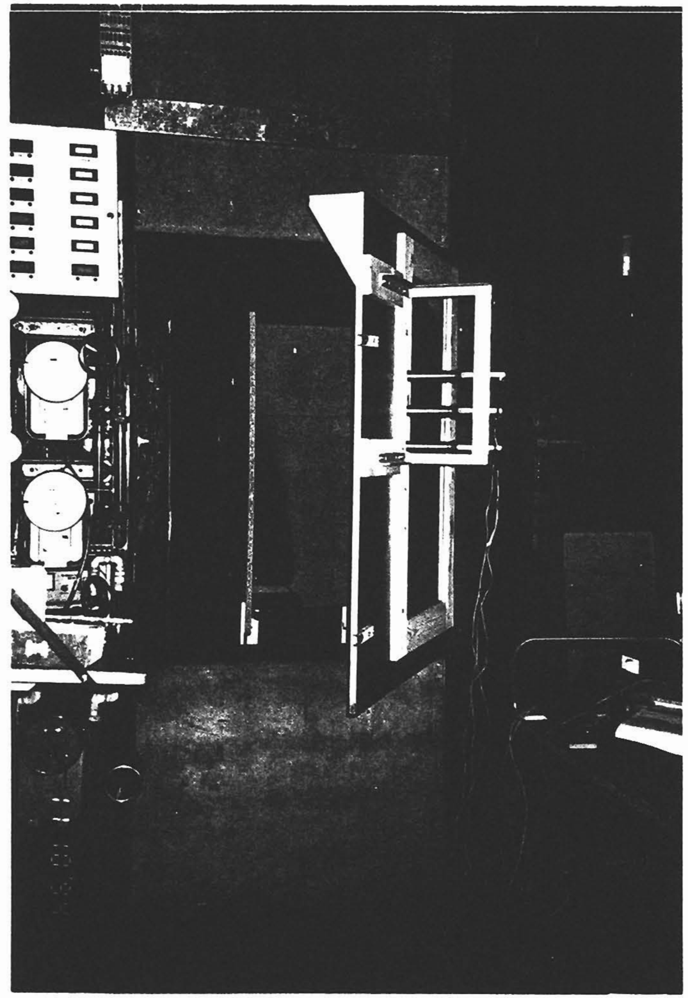


Abbildung 5 Brandschacht mit Prototypen

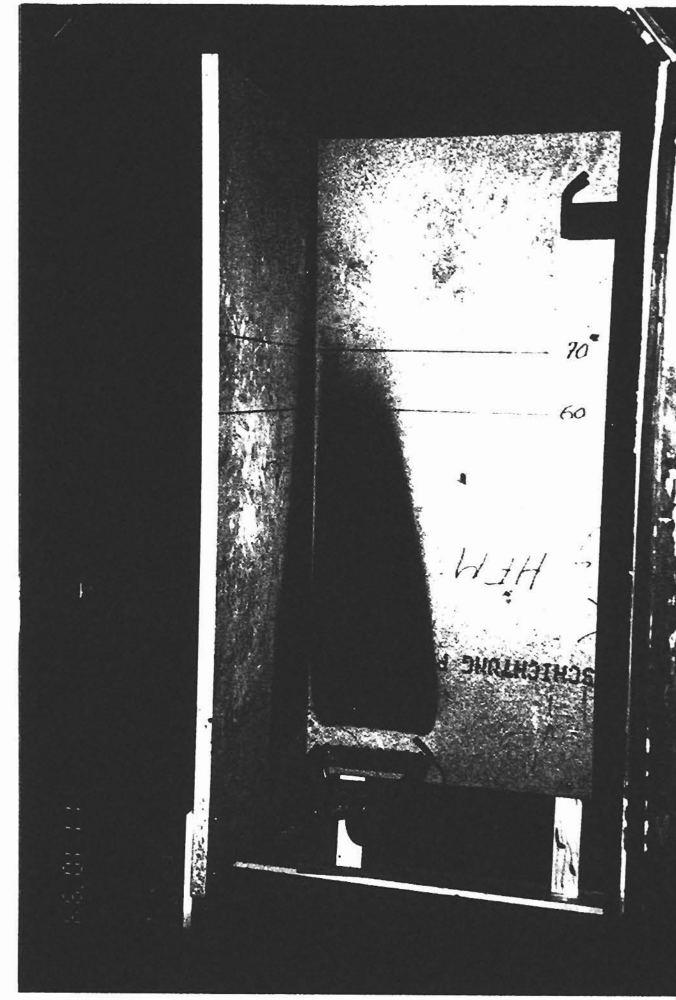


Abbildung 6 Spanplattenproben im Brandschacht

Abschnitt 5

Bericht über die Auswertung der Vorversuche an die Gruppe der Regulators

GROUP OF REGULATORS ON FIRE SAFETY		
RG	N. 88	[redacted]

Status Report of Development of Single Burning Item Test

May 6, 1996

CONTENTS

SUMMARY

In this preliminary phase, two pre-prototypes of SBI apparatus were built in order to examine different configurations of the test arrangement and deliver information to RG in support of decisions to be taken. The configuration variations examined were: presence of ceiling, presence of third wall, specimen size, specimen configuration shape, closed or open configuration, and type of ignition source.

The configuration variations were compared in terms of their potential influence on the measurability of parameters, repeatability, reproducibility and discrimination capability. The parameters examined were time to ignition, damaged length, flame/fire spread rate, smoke production, and heat production determined by ΔT measurement and oxygen depletion calorimetry.

For the reasons of simplicity, it is recommended not to include a ceiling in the specimen configuration as it does not have a significant effect on the discrimination capability of the test, the measurability of parameters, or the repeatability and reproducibility of the results.

It is recommended not to include a third wall in the test configuration, since no systematic nor significant effect of the third wall on the test results was observed. Discrimination capability, measurability of parameters, repeatability and reproducibility were similar both with and without the third wall. The deletion of the third wall improves the possibility to make visual observations on the burning specimen and simplifies the test configuration.

The use of a corner specimen arrangement with specimen material for both wings is recommended. This provides a significant improvement to the discrimination capability of the test. Taking into account the requirement of testing the products in end-use conditions and the advantage of similarity with the Room/Corner reference scenario, it is recommended to select the method of fixing the specimen in the corner as used at MPA.

It is recommended to choose the sandbox burner as ignition source rather than the SBI radiant panel or ASTM radiant panel. The reasons for this recommendation are the poor repeatability of SBI radiant panel tests, the insufficient discrimination capability of the ASTM and (in some cases) SBI radiant panels, and several practical aspects related to the use of radiant sources, as well as the ease of calibration procedures when using the sandbox burner.

The decision whether to use a closed or open configuration of the test apparatus has a significant, though not necessarily systematic, influence on the test results. Thus, for the reasons of reproducibility and operator protection the closed configuration is recommended.

The tests carried out so far suggest sufficient repeatability but also indicate the need for the exact similarity of the test apparati. Consequently, it is strongly advised that a single design with all identical details of the apparatus will be used in all laboratories in order to guarantee the reproducibility of the test results.

The visual observation of the ignition of the product tested is possible but may be difficult in some cases (e.g. fire retarded materials). It is hence advised to determine the ignition time on

the basis of a certain increase in RHR or ΔT signal which also defines the time when the material tested actually starts to contribute to the fire development.

The lateral flame spread on the front surface of the specimen can be observed visually. The visual observation of vertical flame spread during the test is more difficult, like in all reaction to fire tests. Consequently, a combination of damaged area measurement and RHR curve slope determination (related to the rate of flame spread) is recommended to be examined for the evaluation of fire spread.

The measurement of smoke production by light obscuration in the exhaust duct proved to be straightforward.

The results of ΔT measurements in the exhaust duct were not directly proportional to RHR values measured by oxygen depletion calorimetry. The heat production peaks are under-estimated in ΔT measurements, and ΔT/RHR is dependent on material burning as well as the time history of heat production. In addition, reproducibility problems are expected if the apparati of different laboratories are not identical. Consequently, it is recommended that both ΔT and RHR measurements will be continued throughout the Round Robin and the final decision of the heat release measurement method will be made later.

1. INTRODUCTION

The Proposal for the Development of a Single Burning Item Test, agreed in revised form by the Regulators Group in April 1995, sets out a work programme arranged in nine steps. The objectives of Step 2 of the programme are as follows:

" - *Evaluation of heat sources in existing Nordtest apparatus (sandbox, line burner, gas radiant panel and electric radiant panel),*
- *construction of two examples of the preliminary test apparatus according to Resolution No8 taken by the Regulators Group in April 1995,*
- *commissioning of apparatus and calibration tests to determine optimum operating conditions,*
- *tests on the 8 materials identified in RG Resolution No7, using one flaming heat source and one radiant panel, with assessment of 'small room' enclosure (MPA to make airflow and ventilation rate measurements) and of the presence or not of a 'third wall' at 1.0m distance from the sample,*
- *initial assessment of how best to measure required characteristics (eg ΔT or O_2 for rate of heat release, visual observation or RHR signal for time to ignition, visual or measured assessment of flame spread)."*

The outcome of Step 2 is expected to provide the following:

" - *Decision on the retention of one flaming heat source and one radiant panel,*
- *two examples of the preliminary test apparatus in operation,*
- *first experience with handling the test apparatus,*
- *initial decisions on optimum operating conditions,*
- *test data showing the influence of variations of the heat source and 'small room' enclosure,*
- *initial indications of the measurability of the desired characteristics, together with initial indications of their repeatability and reproducibility and of the need or not for the third wall,*
- *basis for the design of the prototype apparatus."*

The first part of the objectives, the evaluation of four heat sources, has been completed and reported to the Regulators Group. This report describes the results of work undertaken in support of the remaining objectives. The construction of two prototypes and a programme of experimental work using these have been carried out by CSTB (France) and MPA (Germany). Additional analysis of the combined results was undertaken by VTT (Finland) in conjunction with RUG (Belgium).

The full results of the CSTB and MPA studies are included as an annex, forming Part 2 of the Report. Part 1 briefly describes apparatus and the experimental arrangements, and sets out an analysis of the results aimed at elucidating the effect of various aspects of the design of the prototype, as required under Step 2, and to providing initial indications of repeatability and reproducibility. The lessons learned from the practical use of the prototypes is reviewed as a guide to preparing operational protocols for the test method.

2. PROTOTYPES

2.1 Prototype apparatus

2.1.1 General

Two sets of apparatus were constructed, one at MPA and one at CSTB. Although notionally identical, local requirements resulted in a number of differences. Each set of apparatus is described briefly below.

Each apparatus had in common a moveable sample holder, consisting of a carriage upon which the specimen, consisting of two sheets of material mounted vertically and abutting at 90° could be mounted. Each of the sheets was 1.5 m high but differed in width - one being 1.0 m wide, and the other, 0.5 m wide. The carriage was equipped with a removable 'third wall', opposite the longer side of the specimen, and a removable triangular 'ceiling'.

The carriage could be introduced into a fixed housing within which the ignition source was mounted. A four-sided, pyramidal hood situated above the housing was connected in each case to a duct, containing a section for measurement instrumentation, through which air and combustion products could be extracted. The measuring section in each case was identical, although its position relative to the main part of the apparatus was different.

2.1.2 CSTB prototype

In order to conform with the requirements of the experimental hall within which the CSTB apparatus was built, it was necessary to mount the central components on a mezzanine floor. In order and to avoid unwanted air flows, resulting from the use a large openable door to the experimental hall, a partially glazed, ventilated enclosure was built around the apparatus. The windows of this enclosure could, however, be removed in order to achieve an 'open' arrangement. Fig. 1 shows a schematic diagram of the apparatus.

The air extracted from the hood was first taken vertically through a 1.2 m high square duct of internal dimensions 0.4 m x 0.4 m and containing 0.4 m high stainless steel guide vanes The duct was then transformed via a connecting piece to a circular duct of internal diameter 0.335 m. The circular duct for 13 m, via several bends to the measuring section. Beyond the measuring section, the duct was connected to a variable speed extract fan and thence, via a 13 m high chimney, to atmosphere. In addition to the instrumentation in the measuring section, five thermocouples were placed above the guide vanes at the exit of the hood.

2.1.3 MPA prototype

The MPA prototype was of simpler construction. Apart from the arrangement for mounting the specimen, the carriage, its housing and the hood were similar to the CSTB prototype. The exit to the hood, however, consisted of a square section right angle bend, fitted with guide vanes. This was then connected, via a transformation piece to the measuring section which started at 1.05 m from the vertical centreline of the hood.

The apparatus was contained within an enclosed room, 3.0 m x 2.85 m in plan and 3.1 m high. Provision was made for the entry of combustion air and for glazed panels to allow the observation of tests. Fig. 2 shows a schematic diagram of the apparatus.

2.1.4 Differences between prototypes

Although every effort was made to ensure similarity between the two prototypes, local requirements resulted in some differences which need to be taken into account in comparing results. These are summarised below:

(i) Specimen arrangement

The specimen holder in the CSTB apparatus was arranged so that each sheet of the specimen abutted an incombustible corner piece. In the MPA apparatus, however, the sheets overlapped at the corner. These arrangements are shown in Fig. 3.

(ii) Location of measuring section

Whereas in the CSTB apparatus the main measuring section is some 13 m downstream of the hood, in the MPA apparatus, the distance is only of the order of 1.0 m. This means that a direct comparison between the prototypes of the absolute values of ΔT is not possible, although there is no limitation on the ability to compare within each apparatus the validity of ΔT measurements for measuring heat release rate.

The gases in the duct at the measuring section in the MPA apparatus are likely to be less well-mixed than those at the same point in the CSTB apparatus, although this is to certain extent catered for by the initial calibration.

(iii) Air entry to the room enclosure

The arrangements for the entry of air into the room enclosure surrounding the apparatus differed, as indicated by comparing Figs. 1 and 2.

2.2 Ignition sources

2.2.1 General

Following the preliminary studies by RUG and FRS, two sources were selected by the Regulators Group:

(a) A sandbox burner with a propane diffusion flame, and
(b) a dihedral gas-fired radiant panel.

In addition, at the request of the Regulators Group a limited number of tests were undertaken with a plane radiant panel. The ignition sources are described briefly below.

2.2.2 Sandbox burner

The sandbox, made of welded mild steel, is a right isosceles triangle in plan with the equal sides of length 25 cm. It is 10 cm deep and open at the top. The first 6.5 cm are filled with gravel and the remaining 3.5 cm with sand. Propane is introduced at the base of the gravel layer. The flow rate of propane was adjusted to give the required heat output.

2.2.3 Gas-fired radiant panel

The gas-fired radiant panel was similar to that used for the earlier burner comparisons. It consisted of a single right-angled ceramic radiant panel forming two adjacent walls of a chamber within which a controlled natural gas/air mixture was burned. The products of combustion were ducted out of the chamber, away from the SBI test specimen, A small gas-fired pilot burner was placed at the base of the radiant panels. Once the panel temperature had reached equilibrium it was placed with the radiant surfaces at a distance of 100 mm from each of the faces of the specimen.

2.2.4 ASTM radiant panel

Referred to in this report as the ASTM panel, this is based upon the gas-fired radiant heat source used in ASTM E648 and closely resembles that used in a number of other test methods.

2.3 Instrumentation and measurements

2.3.1 Instrumentation

The main measuring system was common to both prototypes. This was provided with measuring points for the following quantities:

(i) Gas concentration (principally oxygen, but also for CO and CO_2)
(ii) Gas temperature (at four measuring locations)
(iii) Gas velocity (calibrated against volume flow rate)
(iv) Smoke opacity

The output from the instrumentation associated with these measuring points was recorded on a datalogger at 1 second intervals at MPA and at 3 second intervals at CSTB during the test.

As noted earlier, in addition to the temperatures measured at the main measuring section, the CSTB apparatus also included five temperature measuring points just upstream of the hood.

In addition to the measurements noted above, both sets of apparatus were fitted with windows to allow observations to be made, where possible, of the time at which the specimen ignited and of the spread of flame.

2.3.2 Calibration

Each prototype was subject to initial calibration to enable the flow rate of gases to be determined from the velocity at a fixed point in the measuring section. All measuring instruments were calibrated at appropriate intervals.

An overall check of rate of heat release measurements using the oxygen depletion system was made by comparison at regular intervals with a propane burner having a directly measured fuel supply rate.

Due to the extensive preliminary work on ignition sources, reported previously, it was not necessary to carry out a detailed programme of calibration for the burners. Nevertheless, measurements were made to ensure that the heat flux at the surface of the specimens would conform to the requirements set out in RG Resolution No1.

3. PROGRAMME OF MEASUREMENTS

3.1 Materials

A set of seven common materials, distributed by DIFT, were used by both MPA and CSTB. These, together with their designation code (M-), were as follows:

- M1 Paper-faced gypsum board
- M2 Fire retardant-treated PVC
- M3 Fire retardant-treated extruded polystyrene
- M4 PUR foam panel, faced with aluminium foil
- M5 Varnished timber (pine)
- M6 Fire retardant-treated chipboard
- M7 Fire retardant-treated three-layer polycarbonate panel

An eighth material, acrylic glazing, was initially included but, following preliminary tests, was rejected due to the possible danger to the apparatus resulting from the very rapid rate of burning and high heat release rate.

3.2 Test arrangements

Taking into account the variations in test arrangement set out in Step 2 of the SBI programme, together with further requirements proposed by the Regulators Group, the test programme included the following variables:

(i)	Burner type	(3 conditions)
(ii)	Material	(7 conditions)
(iii)	Third wall	(2 conditions)
(iv)	Ceiling	(2 conditions)
(v)	Open/closed configuration	(2 conditions)
(vi)	Specimen arrangement	(3 conditions)
(vii)	Repeatability	(2 conditions, minimum)

If all of the above combinations had been tested in each laboratory, a minimum of over 2000 experiments would have been required. This would have been prohibitive in terms of both time and cost and a more limited programme was designed. The combinations used are summarised in Tables 1a and 1b, resulting in 93 sets of measurements by CSTB and 62 sets of measurements by MPA.

Table 1a. Test programme carried out with sandbox burner.

Series	1S	2S	3S	3S'	4S	4S'	5S	6S	7S
Burner	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND	SAND
Specimen	Ww	Ww	Wd	Wd	Ww	Wd	Ww	Ww	Dw
Ceiling	YES	NO	NO	YES	NO	NO	NO	NO	NO
3rd wall	NO	NO	NO	NO	YES	YES	YES	NO	NO
Configuration	CL	CL	CL	CL	OPEN	OPEN	CL	OPEN	CL
Labs	2	2	CSTB	MPA	CSTB	CSTB	MPA	CSTB	CSTB
Materials	7 + 7	7 + 5	4	4	4	4	4	4	3
Total number of tests	28	24	8	8	8	8	8	8	3

Table 1b. Test programme carried out with radiant panels.

Series	1P	2P	3P	1R	2R	3R
Burner	RAD	RAD	RAD	ROL	ROL	ROL
Specimen	Ww	Ww	Ww	P	Wd	P
Ceiling	YES	NO	YES	NO	NO	NO
3rd wall	NO	NO	YES	NO	NO	NO
Configuration	CL	CL	CL	CL	CL	OPEN
Labs	MPA	MPA	MPA	CSTB	CSTB	CSTB
Materials	7	2	4	7	4	4
Total number of tests	14	4	4	14	8	8

SAND : sandbox burner
RAD : SBI radiant panel
ROL : ASTM radiant panel (included for comparison with ROLAND type of panel)
Ww : Large Wing + small wing specimen
Wd : Large Wing specimen + small wing dummy
Dw : Large Wing dummy + small wing specimen
P : one plane specimen
CL : closed configuration as in MPA and CSTB
OPEN : CSTB configuration windows removed

Materials used in the test series:

1S, 2S, 1P and 1R	: M1 - M7
3S, 3S', 4S, 4S', 5S, 6S, 3P, 2R and 3R	: M3 - M6
7S	: M3 - M5
2P	: M5 - M6

3.3 Parameters measured or calculated

Abbreviations used in this report for the measured or calculated parameters are as follows:

ΔT	: duct temperature increase (K)
ΔT_{max}	: maximum value of duct temperature increase, first peak (K)
RHR	: rate of heat release (kW)
RHR_{max}	: maximum value of rate of heat release, first peak (kW)
THR	: total heat release, time integral of RHR (MJ)
SPR	: smoke production rate (m^2/s)
SPR_{max}	: maximum value of smoke production rate, first peak (m^2/s)
TSP	: total smoke production, time integral of SPR (m^2)

The results of the series are summarised in Tables A1 - A9 of Appendix A. The average values of ΔT_{max}, RHR_{max}, THR, SPR_{max}, TSP, damaged length of the specimen in vertical and lateral directions, and visually observed ignition times are presented for the duplicate tests of each test series.

The results in Tables A1 - A5 are based on the analysis made by VTT and may slightly differ from those presented by CSTB and MPA, due to minor differences of base line determination procedures etc. The effect of the ignition source is subtracted from RHR and ΔT curves (unless otherwise stated). For the calculation of the integral values, error peaks of RHR and SPR are removed and negative values are replaced by zero.

In some tests of M3 and M5, more than one peak were observed in ΔT, RHR and SPR curves. To improve the comparability, the maximum value of the first peak is used in Tables A1, A2 and A4 for all tests, even though higher peaks were measured later in some cases.

The reason for the two peaks of M3 was the aluminium foil used at the bottom of the specimen platform to keep the molten material in place. Some tests, however, were carried out without the aluminium foil. Consequently, the integral values (THR and TSP) of the repeat tests of series 2S and 3S at CSTB and 1S, 2S, 3S' and 5S at MPA are not comparable since two peaks were observed in one test but not in another. This is indicated by brackets in Tables A3 and A5.

4. EFFECTS OF CONFIGURATION VARIATIONS ON TEST RESULTS

In this chapter, the comparisons of the various test series are mainly based on the test results of materials M3, M4 and M5 exhibiting considerable reactions to fire.

For products with relatively low heat release (M1, M2, M6 and M7), significant effects of the configuration variations studied cannot be demonstrated. At these values, the variation of maximum values originates to great extent from the deviation caused by the measurement equipment.

All these comparison measurements were carried out at 0.7 m^3/s exhaust flow rate level in both laboratories.

4.1 Influence of ceiling

The influence of the ceiling was estimated comparing the results of the test series 1S (with the ceiling) and 2S (without the ceiling). The percentual differences in average values of RHR_{max}, ΔT_{max} and SPR_{max} for materials M3, M4 and M5 are presented in Tables 2a, 2b and 2c, respectively. In addition, material M2 with considerable smoke production is included in Table 2c.

Table 2a. Change in RHR_{max} due to ceiling.

Change in RHR_{max}	1S and 2S, CSTB	1S and 2S, MPA
M3	+ 19 %	+ 9 %
M4	+ 26 %	+ 11 %
M5	+ 9 %	+ 45 %

Table 2b. Change in ΔT_{max} due to ceiling.

Ignition source included.

Change in ΔT_{max}	1S and 2S, CSTB	1S and 2S, MPA
M3	- 10 %	+ 1 %
M4	+ 1 %	- 6 %
M5	- 13 %	+ 1 %

Ignition source subtracted.

Change in ΔT_{max}	1S and 2S, CSTB	1S and 2S, MPA
M3	- 13 %	+ 2 %
M4	+ 1 %	- 7 %
M5	- 19 %	+ 2 %

Table 2c. Change in SPR_{max} due to ceiling.

Change in SPR_{max}	1S and 2S, CSTB	1S and 2S, MPA
M2	+ 52 %	+ 38 %
M3	+ 41 %	+ 30 %
M4	+ 88 %	+ 31 %
M5	(- 21 %) [1)]	(+ 80 %) [1)]

[1)] Small numbers compared.

Change in Parameter = 100 % * (Test $result_{1S}$ - Test $result_{2S}$) / Test $result_{2S}$

The shapes of the curves were similar in both test series. The tests with ceiling were more severe causing somewhat higher rate of heat release. At MPA, the RHR_{max} values were about 10 % higher (except 45 % for material M5) for the tests with the ceiling. At CSTB, the increase caused by the ceiling was 9 - 26 %.

The difference between the ΔT_{max} results with and without ceiling is relatively small and unsystematic, which may be caused by the response mechanism of this parameter.

Considerable increase of SPR_{max} due to the ceiling (30 - 88 %) was observed for most materials. The increase of smoke production is mainly due to the increase of heat release. A local reduction of oxygen concentration in the specimen corner caused by the ceiling may result in an additional increase of smoke production. Large deviations observed for M5 are due to the low smoke production of the material.

Locally on the upper edge of the specimen, there was an effect on lateral flame spread (see Table A8 in Appendix A) which is caused by the flames bending under the ceiling.

The presence or absence of the ceiling has a systematic influence on RHR_{max} and SPR_{max} but it does not change the ranking order of the materials. The increase of the parameters due to the ceiling, however, does not have a significant influence on the discrimination capability of the test (see Chapter 7.4 and Figs. 13 - 17). Thus, the ceiling can be deleted from the test configuration in order to simplify the apparatus.

4.2 Influence of third wall

The effect of the third wall was studied in series 5S (with third wall) and 2S (without third wall) in closed configuration at MPA, and in series 4S (with third wall) and 6S (without third wall) in open configuration at CSTB. The percentual differences in average values of RHR_{max}, ΔT_{max} and SPR_{max} for materials M3, M4 and M5 are presented in Tables 3a, 3b and 3c, respectively.

Table 3a. Change in RHR_{max} due to third wall.

Change in RHR_{max}	5S and 2S, MPA	4S and 6S, CSTB
M3	- 17 %	- 2 %
M4	- 4 %	- 2 %
M5	+ 3 %	+ 4 %

Table 3b. Change in ΔT_{max} due to third wall.

Ignition source included.

Change in ΔT_{max}	5S and 2S, MPA	4S and 6S, CSTB
M3	- 10 %	- 4 %
M4	+ 14 %	- 7 %
M5	+ 9 %	- 3 %

Ignition source subtracted.

Change in ΔT_{max}	5S and 2S, MPA	4S and 6S, CSTB
M3	- 12 %	- 5 %
M4	+ 17 %	- 9 %
M5	+ 12 %	- 4 %

Table 3c. Change in SPR_{max} due to third wall.

Change in SPR_{max}	5S and 2S, MPA	4S and 6S, CSTB
M3	+ 6 %	- 6 %
M4	- 10 %	+ 2 %
M5	(+ 27 %) [1)]	(+ 18 %) [1)]

[1)] Small numbers compared.

Change in Parameter = 100 % * (Test $result_{5S}$ - Test $result_{2S}$) / Test $result_{2S}$ or
Change in Parameter = 100 % * (Test $result_{4S}$ - Test $result_{6S}$) / Test $result_{6S}$

No systematic nor significant effect of the third wall was observed for either RHR_{max}, ΔT_{max} or SPR_{max}. The variation of the parameters may be dependent on material properties, or just the deviation of the results.

As a consequence, it is proposed to delete the third wall of the apparatus. This improves the possibility to make visual observations on the burning specimen and simplifies the construction of the apparatus.

4.3 Influence of using non-combustible board as small / large wing

The influence of the sample size was studied comparing the following test series:

- 3S' and 1S: Wd / Ww, with ceiling, closed configuration
- 3S and 2S: Wd / Ww, without ceiling, closed configuration
- 4S' and 4S: Wd / Ww, without ceiling, open configuration
- 7S and 2S: Dw / Ww, without ceiling, closed configuration

Ww = large wing and small wing specimen (specimen area of 2.25 m^2)
Wd = large wing specimen and small wing dummy (specimen area of 1.5 m^2)
Dw = large wing dummy and small wing specimen (specimen area of 0.75 m^2)

The percentual differences in average values of RHR_{max}, ΔT_{max} and SPR_{max} for materials M3, M4 and M5 are presented in Tables 4a, 4b and 4c, respectively. It must be noted, however, that the total specimen area does not necessarily contribute to production of heat and smoke and therefore the values of 1/3 and 2/3 do not directly compare to the percentual changes reported in the Tables 4a, 4b and 4c.

Table 4a. Change in RHR_{max} due to sample size.

Change in RHR_{max}	Specimen area reduction of 1/3			Specimen area reduction of 2/3
	3S' and 1S, MPA	3S and 2S, CSTB	4S' and 4S, CSTB	7S and 2S, CSTB
M3	- 48 %	- 45 %	- 38 %	- 65 %
M4	- 60 %	- 70 %	- 53 %	- 66 %
M5	- 57 %	- 66 %	- 62 %	- 66 %

Table 4b. Change in ΔT_{max} due to sample size.
Ignition source included.

Change in ΔT_{max}	Specimen area reduction of 1/3			Specimen area reduction of 2/3
	3S' and 1S, MPA	3S and 2S, CSTB	4S' and 4S, CSTB	7S and 2S, CSTB
M3	- 41 %	- 44 %	- 31 %	- 45 %
M4	- 52 %	- 63 %	- 39 %	- 47 %
M5	- 45 %	- 54 %	- 46 %	- 43 %

Ignition source subtracted.

Change in ΔT_{max}	Specimen area reduction of 1/3			Specimen area reduction of 2/3
	3S' and 1S, MPA	3S and 2S, CSTB	4S' and 4S, CSTB	7S and 2S, CSTB
M3	- 49 %	- 59 %	- 39 %	- 59 %
M4	- 64 %	- 82 %	- 52 %	- 61 %
M5	- 61 %	- 77 %	- 68 %	- 62 %

Table 4c. Change in SPR_{max} due to sample size.

Change in SPR_{max}	Specimen area reduction of 1/3			Specimen area reduction of 2/3
	3S' and 1S, MPA	3S and 2S, CSTB	4S' and 4S, CSTB	7S and 2S, CSTB
M3	- 43 %	- 31 %	- 12 %	- 42 %
M4	- 75 %	- 57 %	- 43 %	- 59 %
M5	(- 39 %) [1]	(- 26 %) [1]	(- 10 %) [1]	(- 29 %) [1]

[1] Small numbers compared.

Change in Parameter = 100 % * (Test $result_{3S'}$ - Test $result_{1S}$) / Test $result_{1S}$ or
Change in Parameter = 100 % * (Test $result_{3S}$ - Test $result_{2S}$) / Test $result_{2S}$ or
Change in Parameter = 100 % * (Test $result_{4S'}$ - Test $result_{4S}$) / Test $result_{4S}$ or
Change in Parameter = 100 % * (Test $result_{7S}$ - Test $result_{2S}$) / Test $result_{2S}$

The smaller specimen size reduced the RHR_{max} values by 38 - 70 %, ΔT_{max} values by 39 - 82 % (ignition source subtracted); and SPR_{max} values by 12 - 75 %. The decrease of heat and smoke production is due to the smaller amount of burning material and the lack of thermal feedback of the second specimen wing. This substantial reduction of heat and smoke release clearly lowers the discrimination capability of the test because a much smaller fraction of the available measurement scale is in use. The relative deviation of the results increase with decreasing absolute values (see Chapters 6.1 and 7.4).

Using non-combustible board as a substitute of one of the specimen wings decreases substantially the discrimination capability of the test method. Thus, it is proposed to use specimens to constitute both wings of the corner configuration.

4.4 Influence of using plane or L-shaped specimen

In the tests with ASTM radiant panel, either L-shaped or plane specimens were used. The width of the plane specimen was equal to the width of the large wing of the L-shaped specimen. The small wing of the L-shaped specimen was made of non-combustible board, resulting in the same area of combustible material in both cases. The effect of the specimen shape was examined by comparing series 1R (with plane specimen) and 2R (with L-shaped specimen). The results are summarised in Table 5.

Table 5. Changes in RHR_{max}, ΔT_{max} and SPR_{max} due to using plane specimen.

Change in RHR_{max}	1R and 2R, CSTB
M3	- 31 %
M4	(- 47 %) [1]
M5	- 4 %

Change in ΔT_{max}	1R and 2R, CSTB
M3	- 30 %
M4	(- 32 %) [1]
M5	+ 5 %

Change in SPR_{max}	1R and 2R, CSTB
M3	- 5 %
M4	(- 10 %) [1]
M5	(+ 15 %) [2]

[1] Material M4 was not ignited in tests of series 1R and 2R.
[2] Small numbers compared.

Change in Parameter = 100 % * (Test $result_{1R}$ - Test $result_{2R}$) / Test $result_{2R}$

The effect of using plane specimen, i.e. the removal of the small wing, was to reduce the production of heat and smoke for material M3. RHR_{max} and ΔT_{max} of M3 were decreased by

30 %. In case of SPR_{max}, the reduction was small. For material M5, no significant difference between these specimen configurations was observed. Material M4 did not ignite in these configurations.

Note: the magnitude of the absolute values of ΔT_{max}, RHR_{max} and SPR_{max} is considerably smaller in R series than in S series with both wings made of specimen material, leading to reduced discrimination capability. For smaller absolute values the deviation of results is relatively larger.

In conclusion, the corner arrangement is preferred to the plane specimen configuration because of the discrimination capability (see Chapter 7.4 and Figs. 13, 14 and 16).

4.5 Influence of using closed or open configuration

The difference between open and closed configuration was examined comparing the results of series 6S and 2S with sandbox burner and series 3R and 1R with ASTM radiant panel. To obtain the open configuration, windows were removed from the closed configuration at CSTB. The comparisons of RHR_{max}, ΔT_{max} and SPR_{max} are presented in Tables 6a, 6b and 6c, respectively.

Table 6a. Change in RHR_{max} due to using open configuration.

Change in RHR_{max}	6S and 2S, CSTB	3R and 1R, CSTB
M3	+ 33 %	- 30 %
M4	- 7 %	(+ 13 %) [1]
M5	+ 4 %	- 16 %

Table 6b. Change in ΔT_{max} due to using open configuration.

Ignition source included.

Change in ΔT_{max}	6S and 2S, CSTB	3R and 1R, CSTB
M3	+ 22 %	- 40 %
M4	- 1 %	(- 36 %) [1]
M5	- 4 %	- 31 %

Ignition source subtracted.

Change in ΔT_{max}	6S and 2S, CSTB	3R and 1R, CSTB
M3	+ 30 %	- 40 %
M4	- 1 %	(- 36 %) [1]
M5	- 6%	- 31 %

Table 6c. Change in SPR_{max} due to using open configuration.

Change in SPR_{max}	6S and 2S, CSTB	3R and 1R, CSTB
M3	+ 16 %	- 42 %
M4	- 8 %	(+ 39 %) [1]
M5	(- 18 %) [2]	(- 18 %) [2]

[1] Material M4 was not ignited in tests of series 1R and 3R.
[2] Small numbers compared.

Change in Parameter = 100 % * (Test $result_{6S}$ - Test $result_{2S}$) / Test $result_{2S}$ or
Change in Parameter = 100 % * (Test $result_{3R}$ - Test $result_{1R}$) / Test $result_{1R}$

In case of S series (sandbox burner), no systematic effect of removing the windows was observed in any of these parameters. The peak values of open configuration tests appear to be randomly higher, lower or equal to those of closed configuration tests.

The comparison of the results of material M4 in R series is irrelevant because the material did not ignite. Based on the results of M3 and M5 only, removing of the windows systematically decreases the parameter values by 16 - 42 %.

There is a substantial but not necessarily systematic influence of the presence of the windows. For that reason, a decision has to be taken on whether an open or closed configuration will be used. For reasons of reproducibility and operator protection, the closed configuration is recommended. Furthermore, it is advised that identical test apparati are built in all laboratories.

4.6 Comparison of ignition sources

The comparison of ignition sources was based on the series 1P (with SBI radiant panel) and 1S (with sandbox burner), 2P (with SBI radiant panel) and 2S (with sandbox burner), and 2R (with ASTM radiant panel) and 3S (with sandbox burner). The percentual differences in average values of RHR_{max}, ΔT_{max} and SPR_{max} for materials M3, M4 and M5 are presented in Tables 7a, 7b and 7c, respectively.

Table 7a. Change in RHR_{max} due to using radiant panel.

Change in RHR_{max}	1P and 1S, MPA	2P and 2S, MPA	2R and 3S, CSTB
M3	- 71 % / + 46 % [1]	--- [3]	+ 11 %
M4	- 4 % [2]	--- [3]	(- 93 %) [4]
M5	+ 39 %	+ 53 %	+ 33 %

Table 7b. Change in ΔT_{max} due to using radiant panel (ignition source subtracted).

Change in ΔT_{max}	1P and 1S, MPA	2P and 2S, MPA	2R and 3S, CSTB
M3	- 61 % / + 17 % [1]	--- [3]	+ 46 %
M4	- 17 % [2]	--- [3]	(- 78 %) [4]
M5	+ 44 %	+ 24 %	+ 72 %

Table 7c. Change in SPR_{max} due to using radiant panel.

Change in SPR_{max}	1P and 1S, MPA	2P and 2S, MPA	2R and 3S, CSTB
M3	- 28 % / + 31 % [1]	--- [3]	+ 3 %
M4	+ 14 % [2]	--- [3]	(- 99 %) [4]
M5	(- 9 %) [5]	(+ 11 %) [5]	(- 37 %) [5]

[1] Duplicate tests of 1P are compared separately to the average of duplicate tests of 1S.
[2] Test 1 of 1P is compared to the average of duplicate tests of 1S (no ignition in test 2 of 1P).
[3] Materials M3 and M4 were not tested in series 2P.
[4] Material M4 was not ignited in tests of series 2R.
[5] Small numbers compared.

Change in Parameter = 100 % * (Test result$_{1P}$ - Test result$_{1S}$) / Test result$_{1S}$ or
Change in Parameter = 100 % * (Test result$_{2P}$ - Test result$_{2S}$) / Test result$_{2S}$ or
Change in Parameter = 100 % * (Test result$_{2R}$ - Test result$_{3S}$) / Test result$_{3S}$

The comparison of the test results of series 1P and 1S is somewhat complicated due to the poor repeatability of tests with SBI radiant panel. In series 1P, material M3 burned weakly in one test but severely in another. Thus, the test results are compared separately to the average values of M3 tests in series 1S. For all parameters, the results of series 1S were between the duplicate test results of series 1P.

Material M4 was ignited in one test of series 1P but not in another. The comparison to series 1S is based on the test with ignition. In this case, RHR_{max} was approximately the same for both ignition sources. A decrease of 17 % was observed in ΔT_{max} values due to the radiant panel, whereas SPR_{max} was 14 % higher in the SBI radiant panel test than in sandbox burner tests.

In case of material M5, the use of SBI radiant panel instead of sandbox burner increased RHR_{max} and ΔT_{max} values by 39 and 44 %, respectively.

Materials M3 and M4 were not tested in series 2P. Consequently, the comparison to series 2S cannot be done with these materials. For material M5, all parameters were higher for SBI radiant panel tests than for sandbox burner tests. Especially the increase of RHR_{max} was considerable (+ 53 %).

In series 2R, material M4 was not ignited in either of the duplicate tests. Thus, RHR_{max}, ΔT_{max} and SPR_{max} were practically equal to zero resulting in large differences from the values of series 3S. For materials M3 and M5, RHR_{max} and ΔT_{max} were 11 - 72 % higher in ASTM radiant panel tests than in sandbox burner tests. No effect on SPR_{max} was observed for material M3. It must be noted, however, that the absolute values of the parameters in both of these two test series were considerably smaller than those measured in sandbox burner test series with both wings made of specimen material.

In conclusion, substantial but non-systematic differences between the test results of sandbox burner and SBI radiant panel were observed, partly due to the poor repeatability of SBI radiant panel tests. When the test results of sandbox burner and ASTM radiant panel were compared, higher RHR_{max} and ΔT_{max} values were measured for the latter. In this comparison, however, a specimen configuration with only one wing made of the specimen material was used, leading to insufficient discrimination capability in both test series. Consequently, the selection of the ignition source have to be made on the basis of practical aspects (see Chapter 5), repeatability (see Chapter 6.1) and discrimination capability (see Chapter 7.4). As a result, it is recommended to use sandbox burner as an ignition source.

5. PRACTICAL ASPECTS OF USE OF IGNITION SOURCES

Besides the influence on the test results, the practical advantages and disadvantages of both the sandbox burner and the radiant panel should be kept in mind in the decision on the ignition source for the SBI-test.

5.1 Sandbox burner

The sandbox burner produces a diffusion flame, which fits well to the prescriptions made in respect to the ignition source (max. 40 kW/m^2 decreasing to 10 kW/m^2 at the height of 75 cm). The flames simulate rather well the heat exposure by a single burning item (e.g. a burning waste basket or a burning chair etc.).

The simple design of the burner which is very insensitive against spoiling and which can easily be repaired in case of damage or major spoiling is a big advantage.

After the fire test and closing the gas supply, the specimen is freely accessible for extinguishing activities. The smoke produced by this procedure is extracted by the hood of the test arrangement. After moving the specimen holder car out, the test arrangement is freely accessible for the removal of burned parts of the specimen and cleaning of the apparatus.

A problem is created by the flames of the sandbox burner, which are fluctuating significantly in height, so that a precise evaluation of the flame spread on the specimen is difficult. Due to the height of the burner flames (ca. 80 cm) the length available for the observation of the vertical flame spread is rather short. However, the damaged height of the specimen in the vertical direction can be used as a measure of the vertical flame spread.

The area with the maximum heat input to the specimen, i.e. the area where the first ignition occurs, is located behind the flames of the burner. A visual determination of the time of the first ignition is obstructed by the burner flames. Nevertheless, the determination of time to ignition was possible in most cases.

An incomplete mixing of gas and air by the diffusion prevents complete combustion in the flame zone. This can very slightly influence the RHR measurement in the calibration of the test apparatus and in the tests. The formation of soot due to incomplete combustion has a small effect on the measurement of smoke density but no practical influence on the test results.

One of the advantages of the sandbox burner is the possibility to use it also for the calibration of the test arrangement. Without additional effort, this equipment allows to check the correct settings of all the measuring equipment in each test by comparing the results with the theoretical energy release provided by the pre-set gas/airflow.

5.2 SBI radiant panel

The radiant panel used in MPA represents a significantly optimised version of the first prototype. Its original size (710 mm Height x 750 mm Length x 345 mm Width) was reduced to a measure which is much easier to handle than the first version. Nevertheless, a remaining weight of ca. 220 kg requires a corresponding supporting construction.

During the first heating-up procedure which, according to the prescriptions of the panel manufacturer, was carried out very slowly, the corner-shaped radiant panel made of silicon carbide cracked in such a way that it could not be used any more. Fortunately, a spare panel had been delivered together with the apparatus by the manufacturer. After its installation the heating-up procedure was repeated but cracking occurred again. However, these cracks remained internal, and the operation could be continued. The apparatus remained operable for the whole test series of 22 tests carried out with this arrangement . During the test series, the radiant panel worked without any disturbance.

Despite a temperature of 1300°C within the furnace of the radiant panel, the required heat flux of 40 kW/m^2 at a dummy specimen located at the intended distance of 150 mm from the radiant panel was not achieved. To achieve this heat flux level it was necessary to reduce the distance of the radiant panel to the specimen to 100 mm. With this distance the heat flux profile corresponded nearly to the requirements settled for the tests.

A disadvantage of this radiant panel is its high cost (8500 ECU). In addition, the replacement of the corner-shaped panels is also expensive. Reliable information on the life time of this corner-shaped radiant panel is not yet available. In respect to the costs, also the high energy consumption has to be mentioned. The amount of gas needed to heat up the apparatus to the required temperature and to maintain this temperature is higher than the energy consumption of the sandbox burner.

For the practical handling of the test arrangement with the radiant panel, it is important that the specimen holder car is brought in place precisely and quickly in order to avoid uncontrolled conditions at the start of the tests. Special arrangements for that should be provided. Otherwise protection screens which are removed after the specimen is in place are needed.

In relation to the operator protection an additional problem has to be mentioned which occurs with the dismounting of the specimen after test. In normal routine testing in order to allow the next test to be done it is necessary to extinguish the specimen after the test. This is not possible with the specimen in front of the radiant panel. Therefore the specimen holder car has to be withdrawn from the apparatus. For operator protection reasons a second hood outside the enclosure is necessary in order to remove the smoke during this extinguishing period. This and additional operator protection measures will require additional costs.

The furnace for the radiant panel which is still rather massive creates an obstacle for the observation of the specimen which are located behind the apparatus. Due to the small distance of 100 mm between the furnace and the specimen, a restriction of the airflow to this area and an influence on the combustion of the specimen are also expected.

Special attention has to be paid to the size, form and application of a pilot flame which has a significant influence on the test results for a number of materials. An arbitrary definition of the pilot flame can lead to inverse ranking of materials (in respect to all measured parameters). This questions the worth of all test results. The application of the pilot flame by hand as done in MPA requires operator protection measures like masks or one-way suits. An automatic application of the pilot flame is linked with the risk that the most unfavourable location of its application is not met.

Using this radiant panel for the test, additional tests for the calibration of the test arrangements will be necessary. The advantage of the sandbox burner providing a quick check of the measuring equipment settings at the start of each test is not available with the SBI radiant panel.

5.3 ASTM radiant panel

The ASTM radiant panel (which also is used in the ROLAND programme) represents a durable and well-known ignition source. The advantage of this panel is given by its modest size which provides a good visibility to the specimen and does not create a significant obstacle for air access to the specimen.

The costs for the supply of the panel are reasonable. In this respect, however, the gas consumption for the 20 minute preheating and cooling phases and the related time loss have to be mentioned.

Concerning the handling of the specimens, their introduction into the test arrangement, their removal, and the cleaning of the apparatus, similar problems exist as with the corner-shaped panel.

In relation to the application of a pilot flame, the statements given for the corner-shaped panel apply to the ASTM radiant panel as well.

The advantage of the sandbox burner to provide a check of the settings of the measurement equipment is also given by the ASTM radiant panel.

6. REPEATABILITY AND REPRODUCIBILITY

The number of repeat tests and participating laboratories is too small for a proper analysis according to ISO 5725 standard to be carried out. However, the first indication of repeatability and reproducibility can be obtained from these data by simply comparing the results of duplicate tests and different laboratories.

6.1 Repeatability

The repeatability of the duplicate tests was estimated by calculating the average variation of the test results (ΔT_{max}, RHR_{max}, THR, SPR_{max}, TSP and damaged length) for each material over all S series. Both absolute and percentual values of the variation were determined. The calculation procedure was as follows:

1. **a test result** was obtained as an average of the results of the duplicate tests,
2. **an absolute variation** was calculated as a difference between the test result (item 1) and the results of the duplicate tests,
3. **a percentual variation** is the absolute variation (item 2) divided by the test result (item 1),
4. **an average of absolute / percentual variation for material Mn** (n = 1, 2, ... , 7) was calculated by averaging the absolute / percentual variations (item 2 / item 3) for material Mn over all possible S series (1S by CSTB, 1S by MPA, 2S by CSTB, 2S by MPA, 3S by CSTB, ... , 7S by CSTB).

The average and absolute variations obtained are presented in Tables 8a and 8b, respectively.

Table 8a. Average percentual variations for different materials, S series.

	ΔT_{max} (%)	RHR_{max} (%)	THR (%)	SPR_{max} (%)	TSP (%)	Vertical damaged length (%)	Lateral damaged length at 1.0 m (%)	Lateral damaged length at 1.5 m (%)
M1	30	33	68	4	5	1	0	0
M2	11	34	40	15	10	3	17	0
M3	9	11	7	8	4	0	9	6
M4	6	7	5	9	3	0	4	1
M5	6	8	6	10	7	0	7	8
M6	8	14	21	7	5	2	2	17
M7	28	32	18	8	10	5	7	33

Table 8b. Average absolute variations for different materials, S series.

	ΔT_{max} (K)	RHR_{max} (kW)	THR (MJ)	SPR_{max} (m^2/s)	TSP (m^2)	Vertical damaged length (cm)	Lateral damaged length at 1.0 m (cm)	Lateral damaged length at 1.5 m (cm)
M1	2	1	2.4	0.01	10	1	0	0
M2	2	8	2.3	0.34	70	3	2	0
M3	7	14	3.4	0.35	50	0	6	4
M4	3	8	1.0	0.28	20	0	1	0
M5	2	5	2.3	0.04	20	0	3	4
M6	1	2	1.7	0.03	20	2	1	1
M7	4	4	1.2	0.06	40	7	1	4

For materials M3, M4 and M5, the percentual variations of the parameters are at most 10 % (with a single exception of RHR_{max} of M3 which is 11 %). According to ISO 5660 standard, a variation of 10 % of heat release test results is considered acceptable.

In case of materials M1, M2, M6 and M7 larger percentual variations are detected for some parameters. The production of heat and smoke of these materials was small, leading to an increased significance of the deviation caused by the measurement equipment. The absolute variations of the parameters, however, are usually much smaller than those of materials M3, M4 and M5.

In conclusion, the repeatability of SBI tests in S series appears to be sufficiently good.

A large number of tests was planned to be carried out using radiant panels (P and R series). In case of R series, all planned tests were not carried out due to the poor discrimination capability. The P series were not completed because of the experienced lack of repeatability. In series 1P, for example, the behaviour of materials M3 and M4 varied significantly from one test to another.

6.2 Reproducibility

To examine the reproducibility of the test method, the tests of series 1S and 2S were carried out both at CSTB and MPA.

The shapes of the curves measured at different laboratories correlate well in all test series. However, there is some variation in ΔT_{max}, RHR_{max}, THR, SPR_{max} and TSP values (presented in Tables A1 - A5 of Appendix A). RHR_{max} values measured at CSTB are systematically about 60 - 80 % of those observed at MPA. The same trend is observed for ΔT_{max} data. The SPR_{max} values measured at MPA also tend to be higher than those reported by CSTB, though there are some exceptions to this rule.

The damaged length of the specimen measured at MPA may be slightly larger than that observed at CSTB in some cases (see Tables A6 - A8 of Appendix A). The limited number of visually observed ignition time data (shown in Table A9 of Appendix A) does not show any considerable differences between the laboratories.

The reason for the difference between the results of the two laboratories may probably be the details of the corner configuration of the specimen, shown in Fig. 3. The difference in the volume of combustible material in the corner may effectively cause a difference of 5 - 10 % in heat release at maximum if all the material is burned. However, the higher heat release means more radiation and thus an additional increase in heat release, the magnitude of which is difficult to estimate.

The influence of the choice of the specimen configuration is substantial. Taking into account the requirement of testing the products in end-use conditions and the advantage of similarity with the Room/Corner reference scenario, it is recommended to select the method of fixing the specimen in the corner as used at MPA.

7. MEASURABILITY OF PARAMETERS

7.1 Determination of ignition time

The most obvious way to determine the ignition time of the specimen is visual observation. For some materials which are not ignited easily (e.g. flame retarded materials), the visual observation of ignition is difficult. Another way worth considering is the determination of ignition time based on the RHR or ΔT curve. In this case, the ignition is considered to be occurred when a certain increase to the base line of the signal is reached.

Some ignition times based on various ignition criteria are reported and compared to visual observations in Tables A10 and A11 of Appendix A. The criteria used in this preliminary study are the increase in RHR of 5 or 10 kW, and the increase in ΔT of 3 or 5 K. The increases of the signals are measured from base lines determined individually for each test based on the data points before ignition (see Fig. 4). Thus, the base line of RHR signal is not necessarily equal to the zero level of the curve. In the ΔT base line determination, the effect of the burner is taken into account but not subtracted from the curves of Figs. 4 - 6.

Based on the CSTB test results, the criteria of the RHR increase of 5 kW and the ΔT increase of 3 K give a relatively good correlation to visual observations for materials M3, M4 and M5. In most tests, the ignition times obtained using these criteria are within 10 seconds from those observed visually. It must be noted, however, that the definition of base line for materials M4 and M5 with relatively short ignition times is difficult as Fig. 5 illustrates.

The results for the criteria of 10 kW and 5 K increase tend to differ slightly more from the visual observations. For materials M1 and M6, the correlation is worse due to very low RHR and ΔT values.

MPA test results do not allow the determination of ignition time based on RHR increase of 5 kW since the curves have a step-like shape with steps of about 10 kW at low RHR values (see Fig. 6). The ignition time results based on RHR increase of 10 kW and ΔT increase of 3 K correlate reasonably well with visual observations, roughly within 15 seconds.

In general, the determination of ignition time based on RHR or ΔT curves is straightforward when the ignition time of the material is long enough to allow the base line to stabilise before the ignition. The situation is more difficult with shorter ignition times. In this case, however, RHR data measured before the beginning of the test might be helpful, provided that the heat output of the ignition source is accurately known (as it should be). For ΔT, the influence of the ignition source must be determined in advance. The base line problem can be solved by slightly modifying the test procedure.

Due to different measurement instrumentation used by various laboratories, the level of increase in RHR or ΔT at which the specimen is regarded as ignited must be considered carefully. The resolution of the system and the deviation of values around the base line must be taken into account. This is not very critical for products with moderate or high heat release since the signal level usually rises rather steeply after the ignition. In the case of low heat release, however, the defined increase levels (e.g. 5 or 10 kW in RHR) are crucial.

An example of the experimental determination of RHR base line variation is shown in Fig. 7 and Table 9. The analysis of RHR measurements resulted in standard and maximum deviations of 1.6 kW and ± 4.4 kW from the mean, in average. Consequently, an increase of 5 kW in RHR signal is a reasonable value to be used in the determination of ignition.

In addition to the base line determination, a special attention must be paid to the delay time of the oxygen analyser in order to avoid the time shift between RHR data and other measurement results.

To conclude, in addition to visual observation it is possible to determine the ignition time from RHR (or ΔT) curves. The latter procedure also defines the time when the material tested actually starts to contribute to the fire development.

Table 9. **Experimental determination of RHR base line variation: statistics of RHR measurements at volume flow of 1.0 m^3/s.**

Burner off: Mean RHR (kW)	Standard deviation (kW)	Minimum RHR (kW)	Maximum RHR (kW)	$\Delta = RHR_{max} - RHR_{min}$ (kW)
-0.8	1.6	-4.6	6.5	11.1
-0.1	1.2	-3.7	3.3	7.0
1.0	1.5	-5.6	5.4	11.0
-0.3	1.6	-3.8	2.9	6.7
0.6	1.3	-5.3	4.4	9.6
0.3	1.8	-4.2	5.1	9.3
0.3	1.3	-5.4	3.0	8.3

Burner on: Mean RHR (kW)	Standard deviation (kW)	Minimum RHR (kW)	Maximum RHR (kW)	$\Delta = RHR_{max} - RHR_{min}$ (kW)
34.2	1.8	29.8	38.1	8.3
34.4	1.4	29.9	37.6	7.7
42.5	1.9	37.7	47.0	9.3
42.0	2.1	36.2	47.8	11.6
43.8	1.4	39.9	46.6	6.7
41.4	2.1	36.1	45.7	9.6
49.6	1.5	44.9	52.8	7.8

Average value of standard deviations: 1.6 kW
Average value of deviations Δ: 8.8 kW

7.2 Determination of damaged area and fire growth rate

Lateral flame spread observation for those products for which it is relevant, is possible. The vertical flame spread rate on the front surface of the specimen has proven to be difficult to observe visually in SBI tests. Therefore, an alternative means of evaluation has to be used. A combination of total damaged area and fire growth measurement from the slope of RHR curve is suggested as a measure for fire growth giving similar information as flame spread.

7.2.1 Damaged area

The vertical and lateral damaged lengths of the specimen surfaces in all test series are presented in Tables A6 - A8 of Appendix A. Fig. 8 shows the average values for each material over S series.

In vertical direction, the specimens of materials M3, M4 and M5 were damaged to the upper edge (150 cm). For materials M6 and M7, the damaged length extended very near to the upper edge. In case of materials M1 and M2, however, the vertical damaged lengths were less than 100 cm in average.

Based on the results in lateral direction at the height of 1.5 m, two groups of material can be seen: one with damaged lengths near to zero (M1, M2, M6 and M7), and another with extensive damages (M3, M4 and M5). The lateral damaged lengths at the height of 1.0 m are more evenly distributed.

7.2.2 Measure for fire growth

The first study of the estimation of flame spread rate based on the slope of the RHR curve has been carried out. The slope of the RHR curve is assumed to be related to the increase of the surface area of the specimen burning, RHR_{max} corresponding to the maximum area of burning surface. The lateral flame spread in the tests is slow compared to the vertical flame spread, resulting in a nearly constant width of the burning area. Consequently, the increase rate of the RHR curve is expected to be proportional to the height of the burning surface area and thus to the flame spread rate in vertical direction.

Two examples of the determination of the RHR curve slopes are presented in Figs. 9a and 9b. The measured RHR values were divided by RHR_{max} to eliminate the effect of the differences in burning specimen area between the tests. The slope of the curve was defined as a straight line between RHR/RHR_{max} values of 0.1 and 0.9 (corresponding to 10 and 90 % of RHR_{max}, respectively). The results calculated until now are presented in Table 10.

Table 10. RHR curve slopes (1/s) for flame spread rate estimation.

	M3 Average ± Variation	M4 Average ± Variation	M5 Average ± Variation
1S, CSTB	0.012 ± 0.001	0.038 ± 0.000	0.012 ± 0.002
1S, MPA	0.015 ± 0.003	0.031 ± 0.004	0.013 ± 0.002
2S, CSTB	0.010 ± 0.001	0.061 ± 0.028	0.019 ± 0.003
2S, MPA	0.013 ± 0.001	0.028 ± 0.001	0.015 ± 0.001
3S', MPA	0.010 ± 0.000	0.022 ± 0.002	0.015 ± 0.001
5S, MPA	0.011 ± 0.001	0.037 ± 0.003	0.014 ± 0.001

According to these results, the flame spread rate is largest (i.e. the slope is steepest) for material M4. The flame spread rates of materials M3 and M5 are predicted to be similar. However, further examination is needed when test results on a higher number of different materials become available, and then also the time for RHR_{max} may be included in the analysis.

7.3 Comparison of ΔT and RHR results

The possibility of using ΔT measurement in the determination of heat release instead of the RHR measurement by oxygen depletion calorimetry can be estimated by comparing ΔT and RHR curves and calculating the ΔT/RHR ratio.

Two examples of RHR, ΔT and ΔT/RHR curves are shown in Figs. 10 and 11. The effect of the ignition source is included in both RHR and ΔT since the ratio of the signals is very sensitive to all deviations, e.g. the base line variation. The shapes of the ΔT and RHR curves are qualitatively the same, though the RHR peaks are sharper. The thermal inertia of the exhaust duct makes the features of the ΔT curve to be smoother than those of the RHR curve. In the beginning of the test presented in Fig. 10, ΔT/RHR varied considerably. A constant value of the ratio of the signals was reached in about 6 minutes when the heat release peak was already passed. In general, a typical trend of the ΔT/RHR curves is to increase in the beginning and then stabilise towards the end of the test. Fig. 11, however, illustrates a slightly different $\Delta T/RHR$ variation in which the ratio of the signals tends to vary throughout the test.

In conclusion, neither constant nor linear dependence between ΔT and RHR was observed in either laboratory. $\Delta T/RHR$ is dependent on material and time (history of heat exposure) as well as on the thermal inertia of the exhaust hood and the duct system.

The variation of the ratio of the time integrals of ΔT and RHR, i.e. $\int \Delta T \, dt / \int RHR \, dt$, was also examined. This ratio is not constant, although in general, it approaches an asymptote. Figs. 12a, 12b and 12c show examples of $\int \Delta T \, dt / \int RHR \, dt$ curve shapes. For materials M1, M4 and M6, which burn during one single period or do not ignite, the ratio increases constantly as soon as the burner reaches its nominal output. The thermoplastic materials M2 and M7 show a minimum before tending towards the asymptotic behaviour. For materials M3 and M5, burning with several peaks in the RHR curve, the evaluation of $\int \Delta T \, dt / \int RHR \, dt$ shows inflections corresponding to those peaks. The curve shape of material M3 is also dependent on the test configuration.

To summarise, the ratio of the integrated curves depends on time, material type and test configuration. So there is no simple relationship between $\int \Delta T \, dt$ and the heat released. ΔT measured in the duct does not strictly represent RHR determined by oxygen consumption calorimetry, as the simple comparison between the ΔT and RHR curves also suggests.

The use of ΔT results in the determination of heat release cannot be recommended. In case the classification of the materials will nevertheless be based on ΔT measurements, a special attention must be paid to the exact similarity of the configurations used in various laboratories. Otherwise, the test results and classification of products cannot be expected to be reproducible. In addition, an extensive calibration procedure using different sizes and types of heat sources would need to be developed.

7.4 Discrimination capability

7.4.1 SBI test series

The spread of the ΔT_{max}, RHR_{max}, THR, SPR_{max} and TSP results of all test series are presented in Figs. 13 - 17 (for damaged length, see Fig. 8).

The configuration variations studied in S series (with sandbox burner), excluding the reduction of the sample size, seem to have only minor effects on the discrimination capability of SBI test. The spread of the results is somewhat increased by the ceiling, but for ΔT_{max} and RHR_{max} the difference is relatively small. However, when one of the specimen wings is replaced by non-combustible board (series 3S, 3S', 4S and 7S), the discrimination capability is clearly lowered due to the decrease of the magnitude of the parameter values.

The discrimination capability of P series (with SBI radiant panel) is partly comparable to that of S series. In some cases, however, the discrimination capability is reduced due to the poor repeatability of P series.

In R series (with ASTM radiant panel), the heat and smoke production results of all materials were low compared to the results of S series with both wings made of specimen material. Thus, the discrimination capability of R series is not acceptable.

7.4.2 Comparison of ISO 9705 and SBI

ISO 9705 Room/Corner test is used as a reference scenario for SBI. In ISO 9705 tests, the specimen material is exposed to heat produced by a sandbox burner. The net heat output of the burner is 100 kW during the first 10 minutes of the test and is then increased to 300 kW for a further 10 minutes.

The materials tested in Room/Corner divided into three groups based on the RHR results. Paper-faced gypsum board, fire retardant-treated PVC and fire retardant-treated 3-layer polycarbonate panel (M1, M2 and M7) exhibited very low reaction to fire throughout the test (RHR_{max} < 150 kW). The reaction to fire of fire retardant-treated chipboard (M6) was low for the first 10 minutes of the test, but during the higher heat exposure it reacted moderately ($RHR_{max} \approx$ 400 kW). Fire retardant-treated extruded polystyrene, PUR foam panel and varnished timber (M3, M4 and M5) went to flashover (RHR > 1 MW) quite easily, in less than 2 minutes. The actual ranking order of materials based on the ISO 9705 tests, however, can change depending on how RHR, smoke and time dependence are weighed.

Taking into consideration that the effects of the higher heat exposure of ISO 9705 (from 10 to 20 minutes) cannot be simulated with 40 kW/m^2 in SBI, these results are consistent with the RHR results of the SBI tests. However, it is technically possible to increase the heat flux also in SBI by increasing the heat output and burner area in the case of sandbox. Practically the upper limit is about 60 - 70 kW/m^2.

Similarly to RHR, a division of materials into three groups on the basis of the smoke production rate (SPR) results of the ISO 9705 tests was observed as well. In this case, however, the behaviour of fire retardant-treated PVC (M2) and varnished timber (M5) was different in the ISO 9705 and SBI tests. The smoke production of varnished timber was rather low whereas fire retardant-treated PVC produced a considerable amount of smoke in SBI tests. In the ISO 9705 tests, the relative behaviour of these two materials was opposite. It should be noted that in the ISO 9705 tests high smoke production values are linked with the occurrence of flashover. The other five materials, however, showed similar SPR behaviour in both the SBI and ISO 9705 tests.

Future comparisons of test results including time dependence effects will provide more information when more products have been tested.

Appendix A:

Tables of test results

Table A1a. ΔT_{max} results (first peaks, ignition source included).

ΔT_{max} (K)

	M1	M2	M3	M4	M5	M6	M7
1S (CSTB)	28 ± 1	31 ± 1	73 ± 5	87 ± 12	57 ± 4	31 ± 1	30 ± 1
1S (MPA)	39 ± 0	40 ± 0	140 ± 15	134 ± 0	94 ± 2	39 ± 4	37 ± 5
2S (CSTB)	24 ± 5	33 ± 1	81 ± 5	86 ± 3	66 ± 3	33 ± 0	34 ± 4
2S (MPA)	-	42 ± 3	138 ± 19	143 ± 2	93 ± 0	46 ± 0	-
3S (CSTB)	-	-	45 ± 6	32 ± 2	30 ± 0	24 ± 0	-
3S' (MPA)	-	-	83 ± 3	64 ± 1	52 ± 4	44 ± 4	-
4S (CSTB)	-	-	96 ± 8	80 ± 1	62 ± 0	29 ± 0	-
4S' (CSTB)	-	-	66 ± 1	49 ± 0	33 ± 2	23 ± 0	-
5S (MPA)	-	-	125 ± 0	163 ± 7	102 ± 0	46 ± 1	-
6S (CSTB)	-	-	99 ± 5	86 ± 1	63 ± 3	35 ± 0	-
7S (CSTB)	-	-	45**	46**	38**	-	-
1P (MPA)	24 ± 1	31 ± 1	112 ± 45	68 ± 45	122 ± 16	24 ± 2	24 ± 2
2P (MPA)	-	-	-	-	107 ± 13	20 ± 1	-
3P (MPA)	-	-	269**	37**	119**	23**	-
1R (CSTB)	2 ± 0	4 ± 0	26 ± 5	2 ± 1	19 ± 0	1 ± 0	3 ± 0
2R (CSTB)	-	-	37 ± 3	3 ± 0	18 ± 3	4 ± 2	-
3R (CSTB)	-	-	15 ± 1	1 ± 0	13 ± 2	4 ± 2	-

** only one test / material

Table A1b. ΔT_{max} results (first peaks, ignition source subtracted).

ΔT_{max} (K)

	M1	M2	M3	M4	M5	M6	M7
1S (CSTB)	8 ± 1	11 ± 1	53 ± 5	67 ± 12	37 ± 4	11 ± 1	10 ± 1
1S (MPA)	14 ± 0	15 ± 0	115 ± 15	109 ± 0	69 ± 2	14 ± 4	12 ± 5
2S (CSTB)	4 ± 4	13 ± 1	61 ± 5	66 ± 3	46 ± 3	13 ± 0	14 ± 4
2S (MPA)	-	17 ± 3	113 ± 19	118 ± 2	68 ± 0	21 ± 0	-
3S (CSTB)	-	-	25 ± 6	12 ± 2	10 ± 0	4 ± 0	-
3S' (MPA)	-	-	58 ± 3	39 ± 1	27 ± 4	19 ± 4	-
4S (CSTB)	-	-	76 ± 8	60 ± 1	42 ± 0	9 ± 0	-
4S' (CSTB)	-	-	46 ± 1	29 ± 0	13 ± 2	3 ± 0	-
5S (MPA)	-	-	100 ± 0	138 ± 7	77 ± 0	21 ± 1	-
6S (CSTB)	-	-	79 ± 5	66 ± 1	43 ± 3	15 ± 0	-
7S (CSTB)	-	-	25**	26**	18**	-	-
1P (MPA)	2 ± 1	9 ± 1	90 ± 45	46 ± 45	100 ± 16	2 ± 2	2 ± 2
2P (MPA)	-	-	-	-	85 ± 13	0 ± 0	-
3P (MPA)	-	-	247**	15**	97**	1**	-
1R (CSTB)	2 ± 0	4 ± 0	26 ± 5	2 ± 1	19 ± 0	1 ± 0	3 ± 0
2R (CSTB)	-	-	37 ± 3	3 ± 0	18 ± 3	4 ± 2	-
3R (CSTB)	-	-	15 ± 1	1 ± 0	13 ± 2	4 ± 2	-

** only one test / material

Table A3. THR results (ignition source subtracted).

THR (MJ)

	M1	M2	M3	M4	M5	M6	M7
1S (CSTB)	1.1 ± 1.0	7.4 ± 0.2	(51.5 ± 4.3)	20.0 ± 1.7	38.1 ± 2.3	6.8 ± 6.0	3.6 ± 0.5
1S (MPA)	6.9 ± 6.3	15.1 ± 4.7	(38.4 ± 15.6)	25.8*	63.5 ± 8.8	10.0*	4.8*
2S (CSTB)	0.2 ± 0.0	3.5 ± 1.6	(30.4 ± 11.4)	18.6*	26.1 ± 1.1	4.8 ± 0.0	8.7 ± 1.9
2S (MPA)	-	3.7 ± 3.0	(33.0 ± 2.1)	35.0 ± 2.6	53.0 ± 3.7	16.0 ± 5.0	-
3S (CSTB)	-	-	(23.5 ± 5.6)	11.0 ± 1.4	11.3 ± 1.0	3.6 ± 0.5	-
3S' (MPA)	-	-	(47.4 ± 7.0)	18.6 ± 0.9	19.4 ± 0.6	13.5 ± 0.5	-
4S (CSTB)	-	-	64.5 ± 0.5	19.4 ± 0.3	29.1 ± 0.1	6.2 ± 0.6	-
4S' (CSTB)	-	-	39.1 ± 4.6	10.1 ± 0.1	13.8 ± 1.0	2.3 ± 0.6	-
5S (MPA)	-	-	68.1*	27.4 ± 1.3	37.6 ± 3.6	14.0 ± 1.0	-
6S (CSTB)	-	-	49.2 ± 4.3	19.5 ± 0.1	30.6 ± 1.0	9.0 ± 1.1	-
7S (CSTB)	-	-	13.1**	6.7**	9.2**	-	-
1P (MPA)	1.2*	2.8 ± 0.6	41.6 ± 26.2	19.0 ± 18.5	102 ± 8	3.1 ± 3.0	0.1 ± 0.1
2P (MPA)	-	-	-	-	80.3 ± 12.5	10.3 ± 2.5	-
3P (MPA)	-	-	35.0**	21.7**	80.2**	0.8**	-
1R (CSTB)	2.0 ± 0.4	0.9 ± 0.0	7.7 ± 2.5	0.2 ± 0.1	11.9 ± 0.6	2.9 ± 0.5	1.5 ± 0.7
2R (CSTB)	-	-	12.2 ± 0.2	1.1 ± 0.1	13.3 ± 1.2	0.8 ± 0.3	-
3R (CSTB)	-	-	7.2 ± 0.6	0.1 ± 0.0	12.8 ± 1.1	0.7 ± 0.0	-

* complete data for one test only
** only one test / material
( ) = repeat tests not comparable

Table A4. SPR_{max} results (first peaks).

SPR_{max} (m^2/s)

	M1	M2	M3	M4	M5	M6	M7
1S (CSTB)	0.26 ± 0.02	3.14 ± 0.25	2.96 ± 0.51	4.11 ± 0.33	0.37 ± 0.03	0.54 ± 0.03	0.72 ± 0.02
1S (MPA)	0.13 ± 0.00	2.82 ± 0.08	6.54 ± 1.12	6.29 ± 0.42	0.57 ± 0.04	0.40 ± 0.10	0.57 ± 0.02
2S (CSTB)	0.31 ± 0.01	2.06 ± 0.50	2.10 ± 0.16	2.18 ± 0.16	0.47 ± 0.10	0.60 ± 0.01	0.82 ± 0.15
2S (MPA)	-	2.04 ± 0.51	5.04 ± 1.05	4.81 ± 1.07	0.32 ± 0.04	0.35 ± 0.10	-
3S (CSTB)	-	-	1.46 ± 0.08	0.95 ± 0.11	0.35 ± 0.01	0.55 ± 0.08	-
3S' (MPA)	-	-	3.72 ± 0.09	1.56 ± 0.20	0.35 ± 0.10	0.40 ± 0.00	-
4S (CSTB)	-	-	2.30 ± 0.01	2.03 ± 0.11	0.46 ± 0.03	0.62 ± 0.01	-
4S' (CSTB)	-	-	2.02 ± 0.01	1.16 ± 0.02	0.41 ± 0.02	0.51 ± 0.01	-
5S (MPA)	-	-	5.34 ± 0.41	4.32 ± 0.25	0.40 ± 0.01	0.40 ± 0.00	-
6S (CSTB)	-	-	2.44 ± 0.03	2.00 ± 0.11	0.39 ± 0.03	0.37 ± 0.03	-
7S (CSTB)	-	-	1.21**	0.90**	0.33**	-	-
1P (MPA)	0.09 ± 0.03	2.60 ± 0.29	6.63 ± 1.92	3.61 ± 3.59	0.52 ± 0.01	0.76 ± 0.00	0.17 ± 0.13
2P (MPA)	-	-	-	-	0.35 ± 0.11	0.66*	-
3P (MPA)	-	-	14.3**	1.52**	0.68**	0.64**	-
1R (CSTB)	0.01 ± 0.00	0.53 ± 0.23	1.42 ± 0.20	0.01 ± 0.00	0.25 ± 0.02	0.08 ± 0.01	0.09 ± 0.03
2R (CSTB)	-	-	1.50 ± 0.09	0.01 ± 0.00	0.22 ± 0.03	0.11 ± 0.00	-
3R (CSTB)	-	-	0.83 ± 0.01	0.01 ± 0.00	0.21 ± 0.00	0.12 ± 0.00	-

* complete data for one test only
** only one test / material

Table A5. TSP results.

TSP (m^2)

	M1	M2	M3	M4	M5	M6	M7
1S (CSTB)	230 ± 20	1170 ± 10	(1640 ± 40)	710 ± 40	210 ± 0	480 ± 0	340 ± 10
1S (MPA)	120 ± 10	840 ± 40	(1220 ± 550)	750*	350 ± 40	410*	270*
2S (CSTB)	270 ± 0	840 ± 20	(1250 ± 270)	500 ± 10	340 ± 50	520 ± 10	420 ± 60
2S (MPA)	-	720 ± 210	(970 ± 240)	670 ± 30	190 ± 10	300 ± 40	-
3S (CSTB)	-	-	(960 ± 150)	470 ± 20	300 ± 0	440 ± 30	-
3S' (MPA)	-	-	(1490 ± 300)	330 ± 10	200 ± 30	280 ± 40	-
4S (CSTB)	-	-	1800 ± 50	580 ± 10	350 ± 20	530 ± 10	-
4S' (CSTB)	-	-	1210 ± 70	460 ± 10	290 ± 0	440 ± 0	-
5S (MPA)	-	-	2560*	690 ± 20	200 ± 20	300 ± 10	-
6S (CSTB)	-	-	1400 ± 60	440 ± 0	260 ± 10	290 ± 20	-
7S (CSTB)	-	-	700**	390**	260**	-	-
1P (MPA)	10*	600 ± 130	1850 ± 800	460 ± 440	260 ± 20	650 ± 0	60 ± 50
2P (MPA)	-	-	-	-	180 ± 0	550*	-
3P (MPA)	-	-	1660**	360**	180**	530**	-
1R (CSTB)	0 ± 0	80 ± 10	210 ± 60	10 ± 0	70 ± 10	50 ± 0	20 ± 0
2R (CSTB)	-	-	250 ± 10	0 ± 0	80 ± 0	80 ± 0	-
3R (CSTB)	-	-	170 ± 10	10 ± 0	90 ± 0	70 ± 0	-

* complete data for one test only
** only one test / material
( ) = repeat tests not comparable

Table A6. Vertical flame spread: damaged length of specimen.

Vertical damaged length (cm)

	M1	M2	M3	M4	M5	M6	M7
1S (CSTB)	92 ± 1	66 ± 2	150 ± 0	150 ± 0	150 ± 0	150 ± 0	40 ± 0 or 150 ± 0
1S (MPA)	90 ± 0	100 ± 0	150 ± 0	150 ± 0	150 ± 0	133 ± 3	130 ± 20
2S (CSTB)	95 ± 3	68 ± 2	150 ± 0	150 ± 0	150 ± 0	150 ± 0	40 ± 0 or 150 ± 0
2S (MPA)	-	108 ± 8	150 ± 0	150 ± 0	150 ± 0	144 ± 1	-
3S (CSTB)	-	-	150 ± 0	150 ± 0	150 ± 0	140 ± 10	-
3S' (MPA)	-	-	150 ± 0	150 ± 0	150 ± 0	141 ± 1	-
4S (CSTB)	-	-	150 ± 0	150 ± 0	150 ± 0	150 ± 0	-
4S' (CSTB)	-	-	150 ± 0	150 ± 0	150 ± 0	128 ± 8	-
5S (MPA)	-	-	150 ± 0	150 ± 0	150 ± 0	149 ± 1	-
6S (CSTB)	-	-	150 ± 0	150 ± 0	150 ± 0	150 ± 0	-
7S (CSTB)	-	-	150**	150**	150**	-	-
1P (MPA)	34 ± 1	63 ± 3	150 ± 0	100 ± 50	150 ± 0	51 ± 1	53 ± 3
2P (MPA)	-	-	-	-	150 ± 0	63 ± 3	-
3P (MPA)	-	-	150**	150**	150**	45**	-
1R (CSTB)	45 ± 1	57 ± 6	150 ± 0	0 ± 0	109 ± 2	69 ± 4	66 ± 7
2R (CSTB)	-	-	150 ± 0	0 ± 0	115 ± 5	67 ± 0	-
3R (CSTB)	-	-	150 ± 0	0 ± 0	102 ± 2	58 ± 0	-

** only one test / material

Table A7. Lateral flame spread: damaged length of specimen at height of 1.0 m.

Lateral damaged length at 1.0 m (cm)

	M1	M2	M3	M4	M5	M6	M7
1S (CSTB)	0 ± 0	0 ± 0	100 ± 0	29 ± 1	43 ± 1	22*	20 ± 0
1S (MPA)	0 ± 0	8 ± 3	78 ± 18	30 ± 0	43 ± 3	30 ± 0	15 ± 2
2S (CSTB)	0 ± 0	0 ± 0	49 ± 8	29 ± 2	38 ± 9	?	14 ± 1
2S (MPA)	-	15 ± 5	63 ± 3	30 ± 0	45 ± 5	26 ± 1	-
3S (CSTB)	-	-	49 ± 8	27 ± 0	27 ± 0	19*	-
3S' (MPA)	-	-	70 ± 3	28 ± 3	31 ± 5	25 ± 0	-
4S (CSTB)	-	-	100 ± 0	31 ± 1	43 ± 3	18	-
4S' (CSTB)	-	-	100*	30 ± 1	36 ± 1	?	-
5S (MPA)	-	-	60 ± 10	33 ± 3	37 ± 2	32 ± 2	-
6S (CSTB)	-	-	64 ± 1	29 ± 2	37 ± 1	20*	-
7S (CSTB)	-	-	50**	31**	33**	-	-
1P (MPA)	0 ± 0	0 ± 0	64 ± 11	15 ± 15	50 ± 0	0 ± 0	0 ± 0
2P (MPA)	-	-	-	-	48 ± 3	0 ± 0	-
3P (MPA)	-	-	100**	30**	75**	0**	-
1R (CSTB)	0 ± 0	0 ± 0	45 ± 4	0 ± 0	25 ± 5	0 ± 0	0 ± 0
2R (CSTB)	-	-	52 ± 1	0 ± 0	41 ± 1	0 ± 0	-
3R (CSTB)	-	-	44 ± 4	0 ± 0	41 ± 1	0 ± 0	-

* data for one test only
** only one test / material

Table A8: Lateral flame spread: damaged length of specimen at height of 1.5 m.

Lateral damaged length at 1.5 m (cm)

	M1	M2	M3	M4	M5	M6	M7
1S (CSTB)	0 ± 0	0 ± 0	100 ± 0	100 ± 0	100 ± 0	20*	30 ± 0
1S (MPA)	0 ± 0	0 ± 0	100 ± 0	100 ± 0	100 ± 0	0 ± 0	13 ± 13
2S (CSTB)	0 ± 0	0 ± 0	56 ± 15	33 ± 1	38 ± 11	?	0 ± 0 or 8 ± 0
2S (MPA)	-	0 ± 0	73 ± 3	50 ± 0	42 ± 2	0 ± 0	-
3S (CSTB)	-	-	57 ± 1	28 ± 1	16 ± 0	0*	-
3S' (MPA)	-	-	100 ± 0	100 ± 0	80 ± 20	0 ± 0	-
4S (CSTB)	-	-	100 ± 0	34 ± 2	32 ± 1	0 ± 0	-
4S' (CSTB)	-	-	100*	32 ± 1	32 ± 2	0 ± 0	-
5S (MPA)	-	-	68 ± 13	40 ± 0	39 ± 2	8 ± 8	-
6S (CSTB)	-	-	79 ± 1	32 ± 1	28 ± 3	?	-
7S (CSTB)	-	-	50**	30**	28**	-	-
1P (MPA)	0 ± 0	0 ± 0	94 ± 7	50 ± 50	100 ± 0	0 ± 0	0 ± 0
2P (MPA)	-	-	-	-	25 ± 10	0 ± 0	-
3P (MPA)	-	-	100**	51**	100**	0**	-
1R (CSTB)	0 ± 0	0 ± 0	57 ± 7	0 ± 0	13 ± 2	0 ± 0	0 ± 0
2R (CSTB)	-	-	62 ± 2	0 ± 0	12*	0 ± 0	-
3R (CSTB)	-	-	37 ± 1	0 ± 0	0 ± 0	0 ± 0	-

* data for one test only
** only one test / material

Table A9. Visually observed ignition times.

Ignition time (s)

	M1	M2	M3	M4	M5	M6	M7
1S (CSTB)	57*	24 ± 2	66 ± 6	17 ± 2	29 ± 1	255*	36 ± 2
1S (MPA)	83 ± 38	?	?	?	25 ± 0	203 ± 158	60 ± 0
2S (CSTB)	60*	?	85 ± 1	17 ± 2	21 ± 1	225 ± 45	30*
2S (MPA)	-	?	?	?	33 ± 3	?	-
3S (CSTB)	-	-	58 ± 3	19 ± 3	21 ± 1	130 ± 15	-
3S' (MPA)	-	-	90 ± 19	24 ± 7	20 ± 4	78 ± 3	-
4S (CSTB)	-	-	71 ± 4	14 ± 1	18 ± 2	150 ± 20	-
4S' (CSTB)	-	-	69 ± 6	18 ± 2	16 ± 2	195 ± 5	-
5S (MPA)	-	-	143 ± 8	17 ± 0	26 ± 5	140*	-
6S (CSTB)	-	-	87 ± 2	26 ± 5	17 ± 2	198 ± 13	-
7S (CSTB)	-	-	80**	20**	25**	-	-
1P (MPA)	85 ± 5	145 ± 35	267 ± 64	230 / n.i.	32 ± 2	n.i.	n.i. / 75
2P (MPA)	-	-	-	-	44 ± 11	n.i.	-
3P (MPA)	-	-	300**	90**	30**	n.i.**	-
1R (CSTB)	89 ± 8	204 ± 9	366 ± 41	n.i.	34 ± 2	n.i.	378 ± 18
2R (CSTB)	-	-	376 ± 21	n.i.	89 ± 11	n.i.	-
3R (CSTB)	-	-	267 ± 31	n.i.	26 ± 2	n.i.	-

* data for one test only
** only one test / material
n.i. = no ignition

Table A10. Tests at CSTB: ignition times based on various criteria (in seconds).

Test code	Visual observation	Increase of 5 kW in RHR	Increase of 10 kW in RHR	Increase of 3 K in ΔT	Increase of 5 K in ΔT
M11S1	(< 213)	54	n.i.	57	117
M11S2	57	n.i.	n.i.	57	129
M31S1	60	72	81	78	87
M31S2	72	87	93	84	93
M32S1	84	87	93	90	93
M32S2	85	78	87	81	87
M33S1	55	72	81	72	81
M33S2	61	81	93	75	87
M34S1	74	78	84	81	87
M34S2	67	72	78	75	81
M34S'1	75	69	78	69	78
M34S'2	63	69	78	66	75
M36S1	85	102	108	99	108
M36S2	89	90	96	87	96
M41S1	18	30	33	27	30
M41S2	15	21	24	24	30
M42S1	19	24	27	27	30
M42S2	15	---	---	21	24
M43S1	22	27	30	27	33
M43S2	16	21	24	24	27
M51S1	28	39	45	42	48
M51S2	30	33	39	36	39
M52S1	21	24	30	30	36
M52S2	20	18	21	24	27
M53S1	21	24	33	27	33
M53S2	20	27	36	30	39
M61S1		n.i.	n.i.	96	153
M61S2	(255)	111	225	75	114
M62S1	(270)	738	n.i.	54	87
M62S2	(180)	693	n.i.	54	93
M63S1	(115)	963	n.i.	129	234
M63S2	(145)	762	n.i.	156	258
M31R1	406	450	468	450	459
M31R2	325	369	423	360	396
M51R1	36	63	69	60	66
M51R2	32	57	66	54	63

n.i. = no ignition
( ) = difficult to observe visually
--- = no RHR data

Table A11. Tests at MPA, ignition times based on various criteria (in seconds).

Test code	Visual observation	Increase of 10 kW in RHR	Increase of 3 K in ΔT	Increase of 5 K in ΔT
M11S1	45	47	56	64
M11S2	(120)	65	128	240
M33S'1	108	114	115	128
M33S'2	71	87	81	89
M35S1	135	145	145	154
M35S2	150	170	164	184
M43S'1	17	20	---	---
M43S'2	30	12	---	---
M45S1	17	19	---	---
M45S2	17	20	---	---
M51S1	25	15	---	---
M51S2	25	22	---	---
M52S1	30	26	---	---
M52S2	35	25	---	---
M53S'1	23	21	---	---
M53S'2	16	23	---	---
M55S1	30	17	---	---
M55S2	21	15	---	---

( ) = difficult to observe visually
--- = difficult to determine the base level of ΔT

Appendix B:

Figures

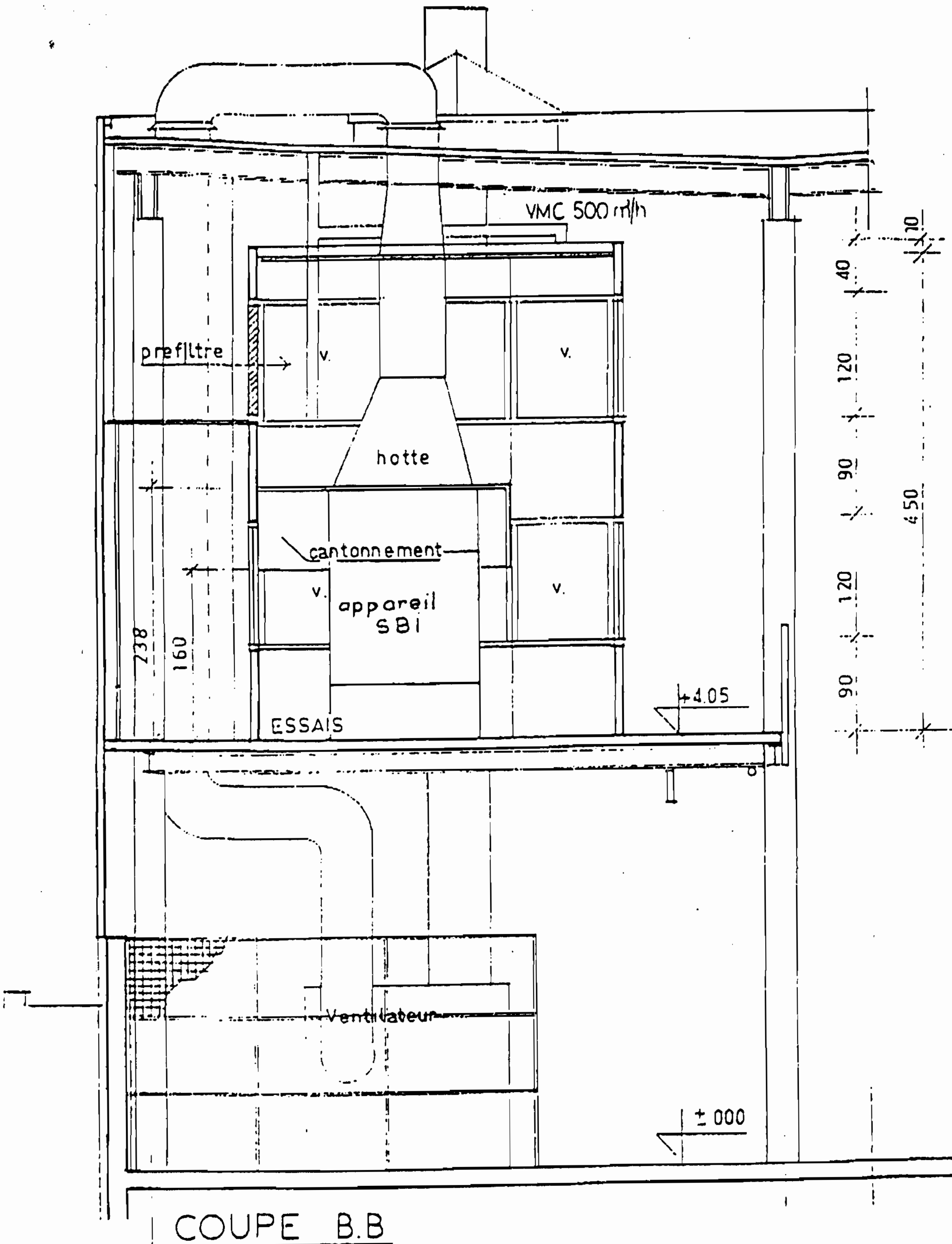


Figure 1. General view of CSTB prototype.

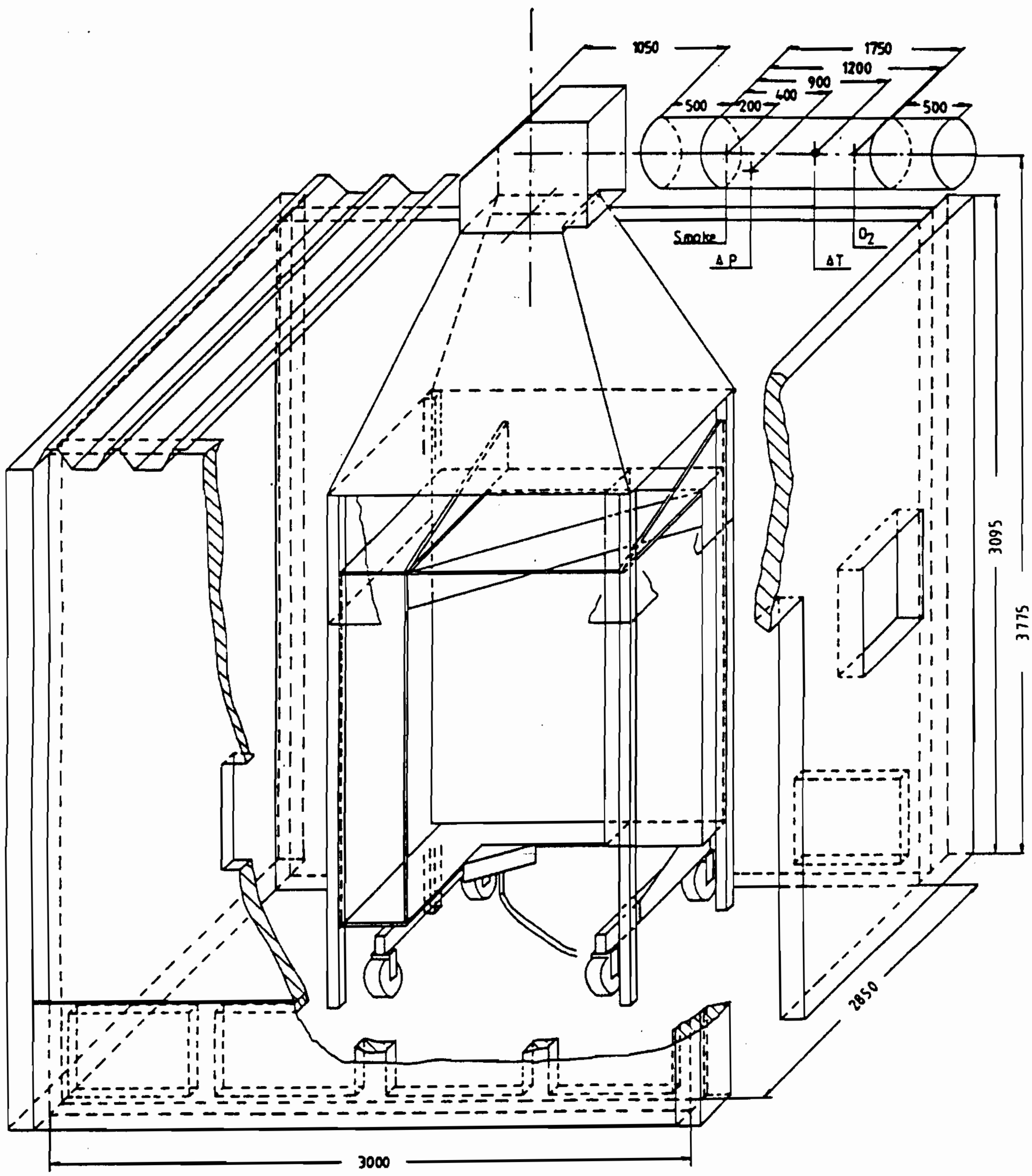


Figure 2. General view of MPA prototype.

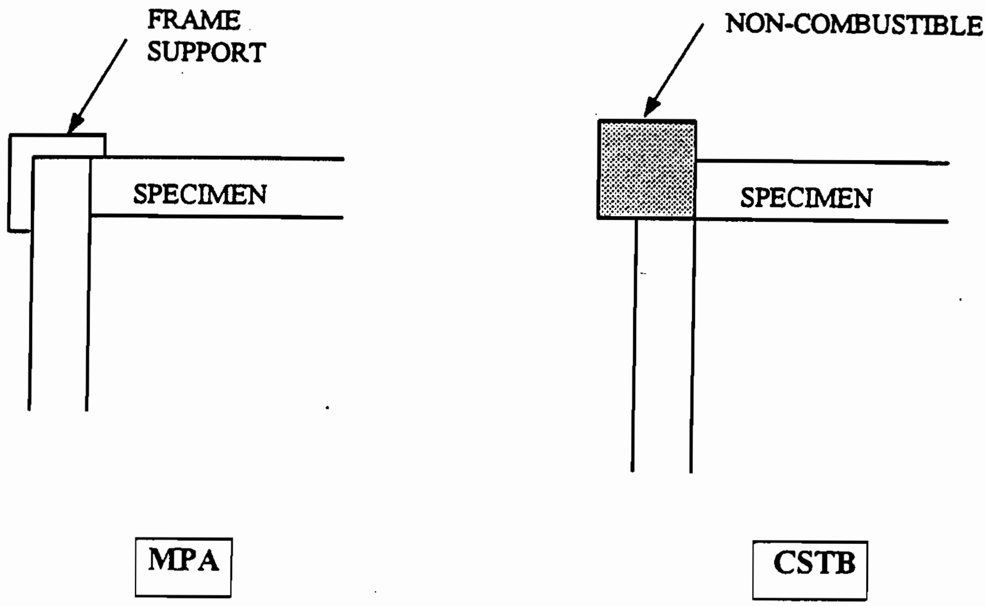
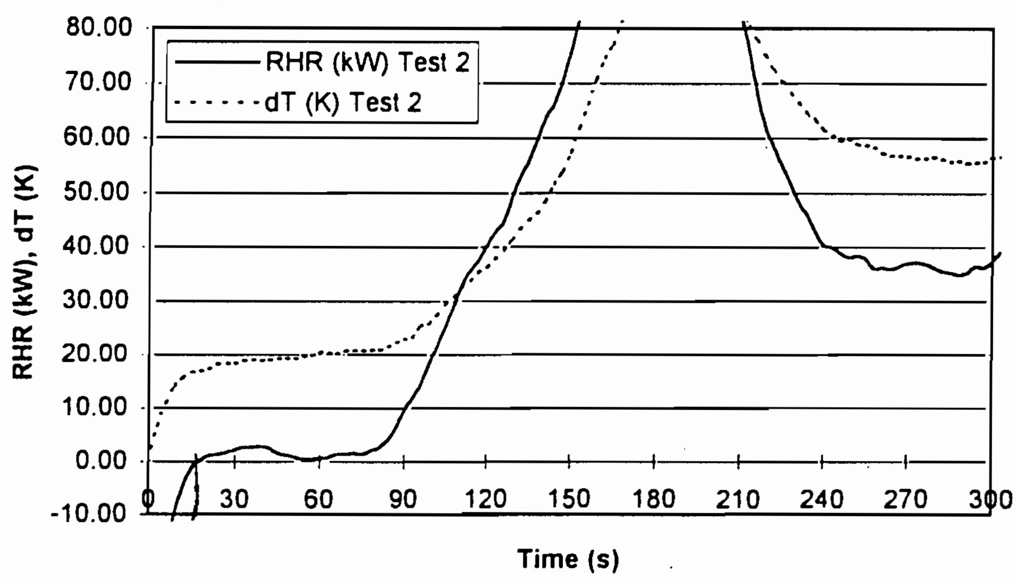
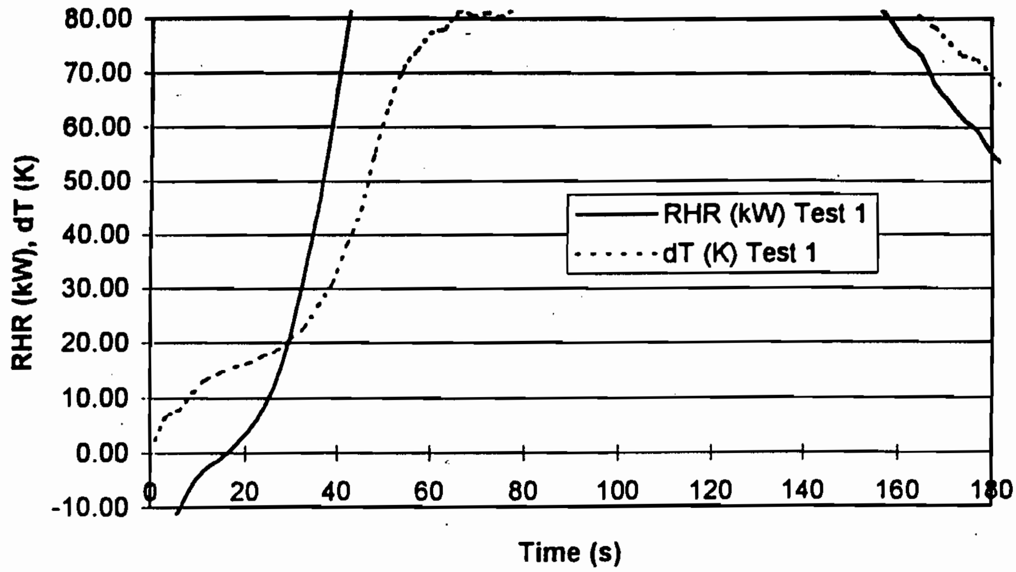


Figure 3. Comparison of specimen mounting arrangements.



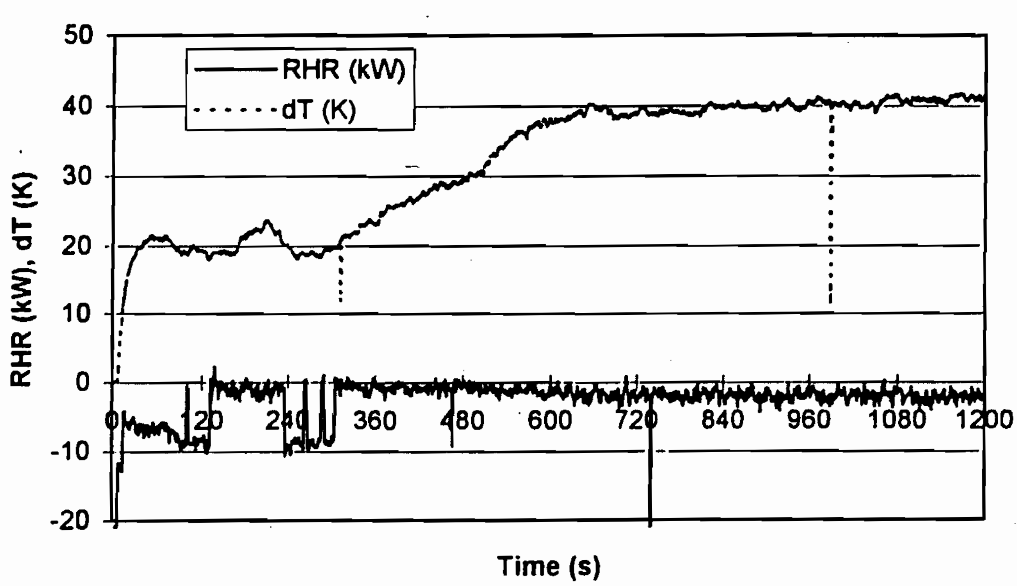
Ignition times:
Visual observation: 89 s
RHR + 5 kW: 90 s (base level 2 kW)
dT + 3 K: 87 s (base level 19 K)

Figure 4. RHR and ΔT curves of fire retardant-treated extruded polystyrene in test series 6S to determine ignition time. The effect of the burner is included in ΔT curve.



Ignition times:
Visual observation: 19 s
RHR + 5 kW: 24 s (base level 0 kW)
dT + 3 K: 27 s (base level 15 K)

Figure 5. RHR and ΔT curves of PUR foam panel in test series 2S to determine ignition time. The effect of the burner is included in ΔT curve.



Ignition time:
Visual observation: 60 s

Figure 6. RHR and ΔT curves of fire retardant-treated 3-layer polycarbonate panel in test series 1S to determine ignition time. The effect of the burner is included in ΔT curve.

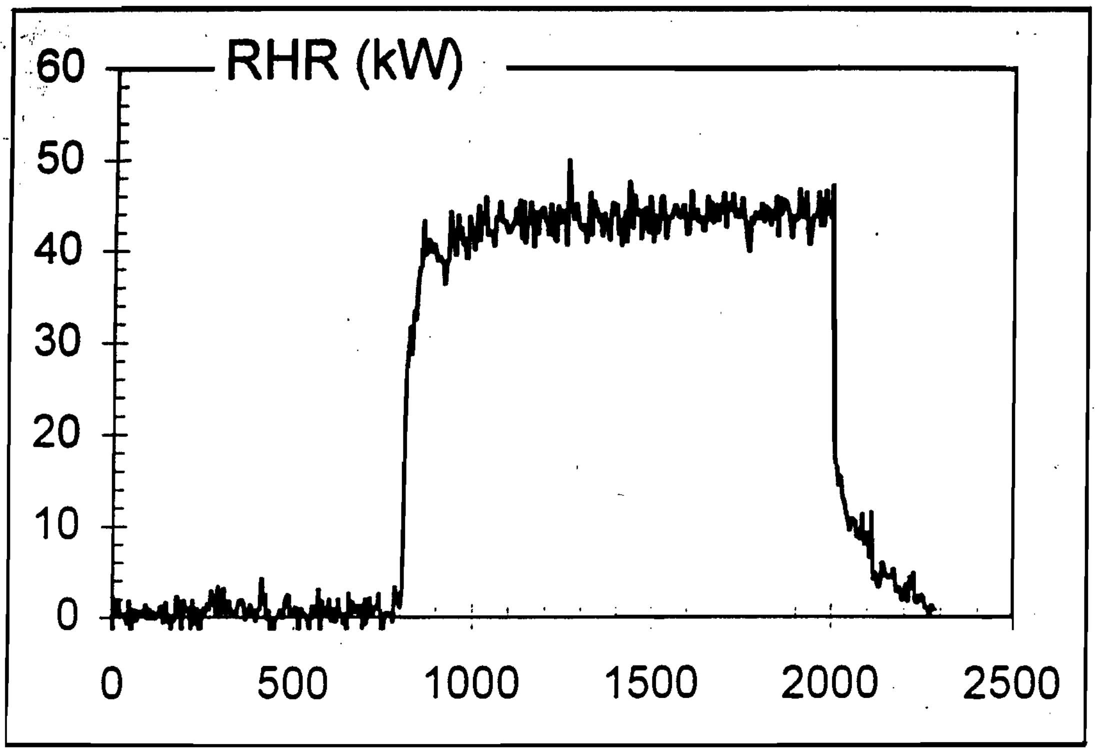


Figure 7. RHR measurement to determine base line variation.

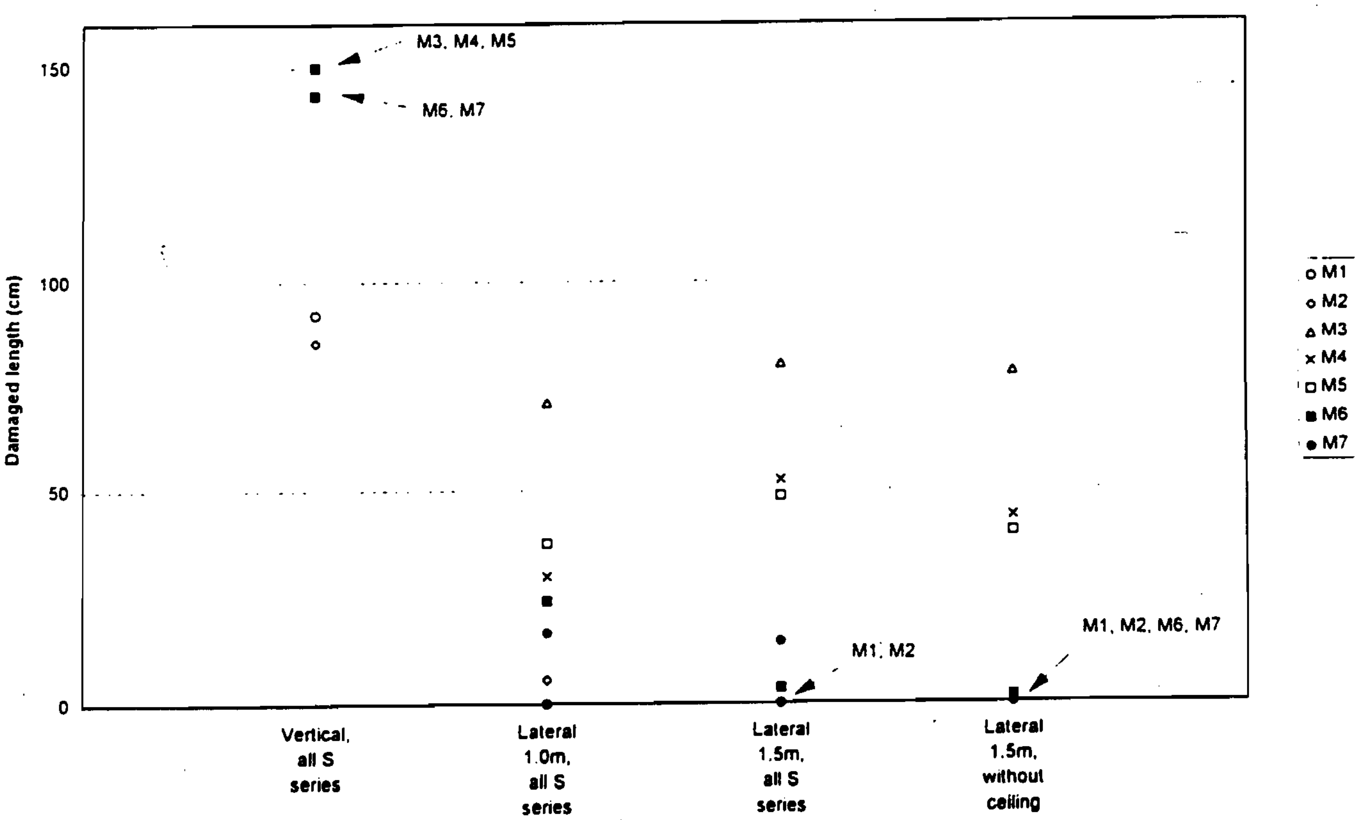


Figure 8. Average damaged lengths of materials in vertical and lateral directions (S series).

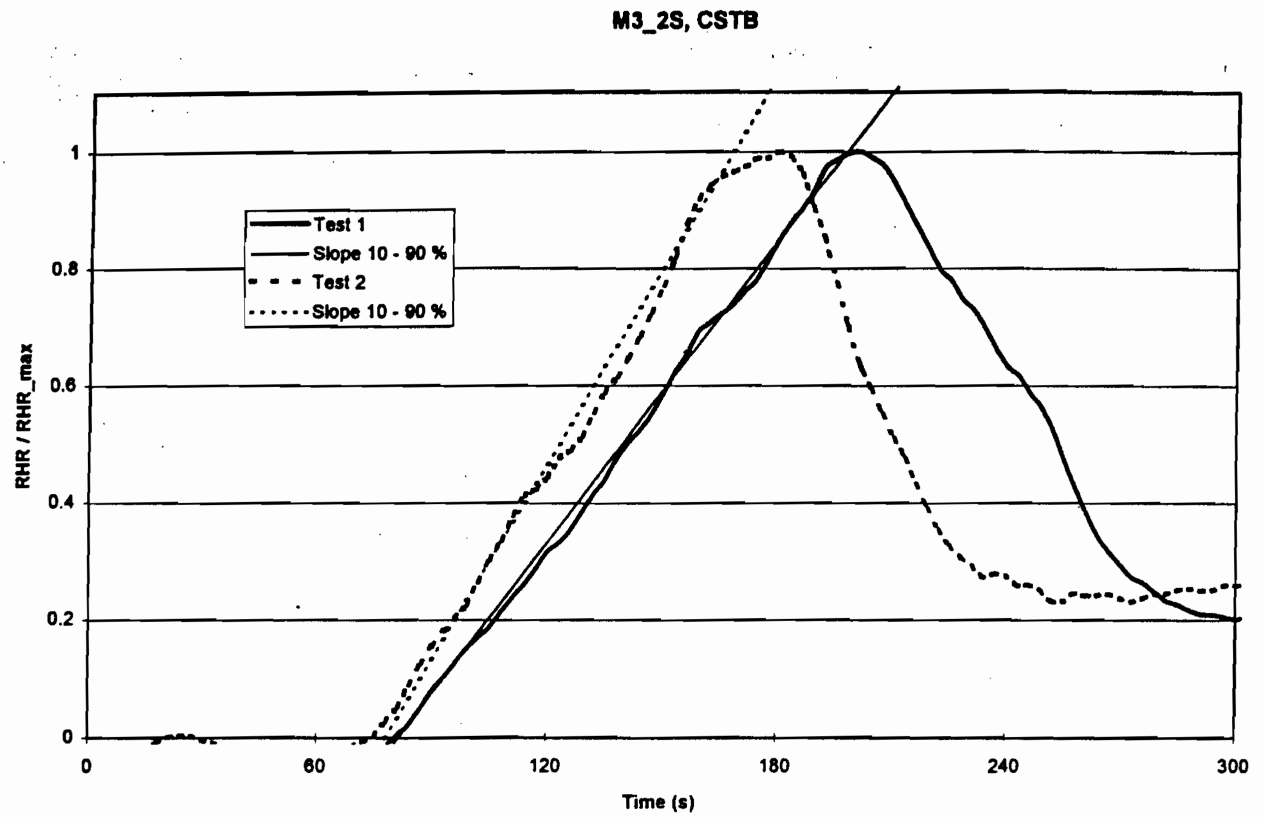


Figure 9a. Determination of RHR curve slope of fire retardant-treated extruded polystyrene in test series 2S.

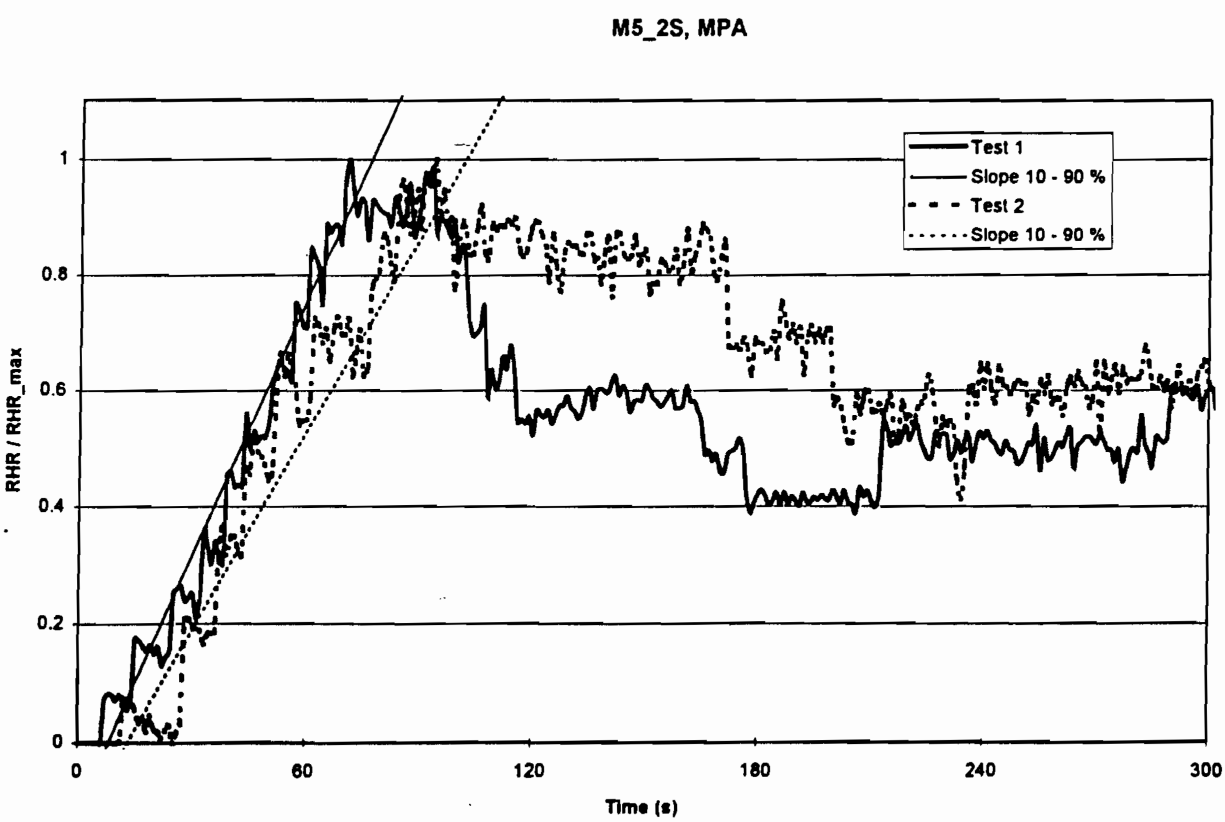


Figure 9b. Determination of RHR curve slope of varnished timber in test series 2S.

PUR foam panel (M4), series 1S

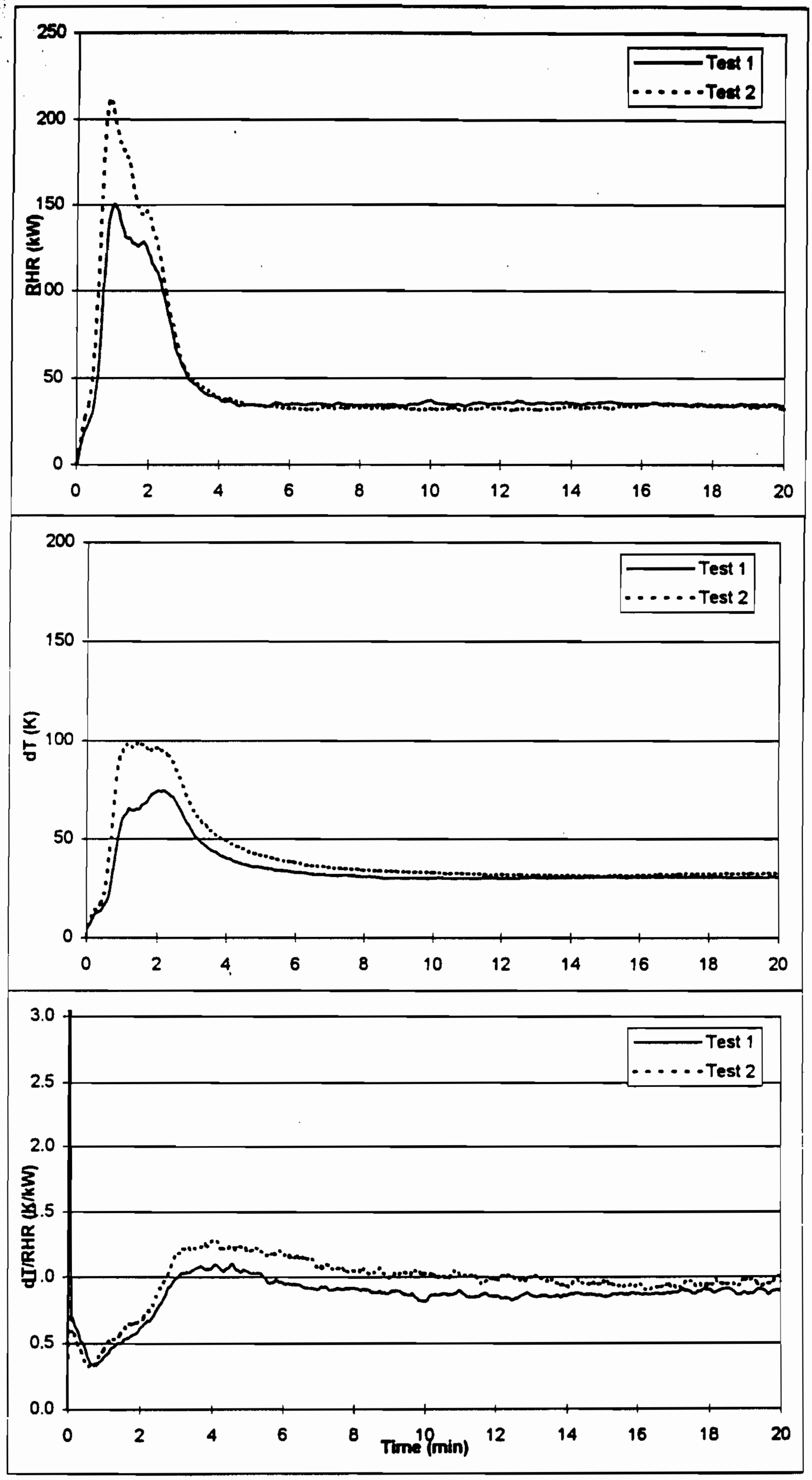


Figure 10. RHR, ΔT and ΔT/RHR curves of PUR foam panel in test series 1S. The effect of the ignition source is included in all curves.

FR XPS board (M3), series 1S

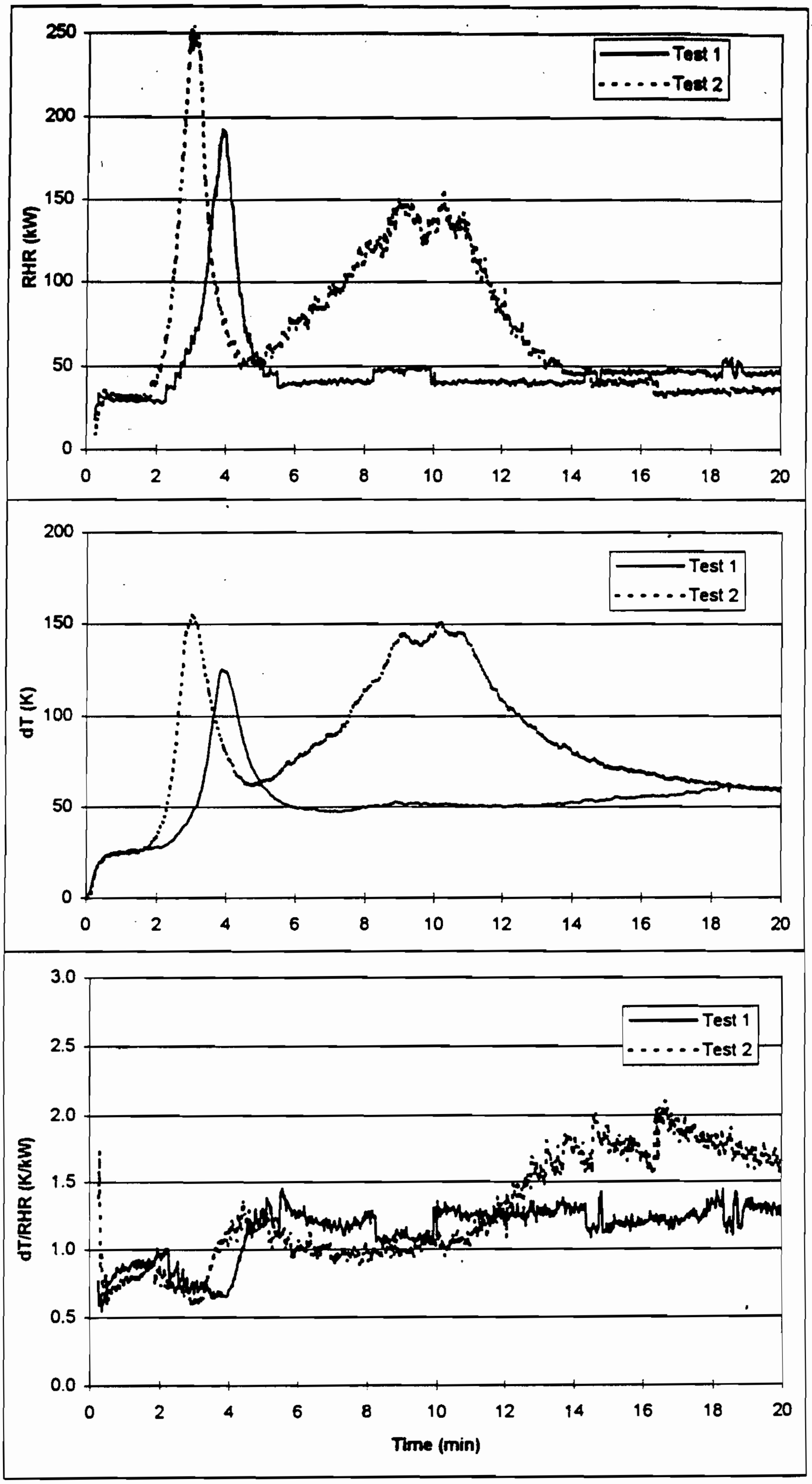


Figure 11. RHR, ΔT and ΔT/RHR curves of fire retardant-treated extruded polystyrene in test series 1S. The effect of the ignition source is included in all curves.

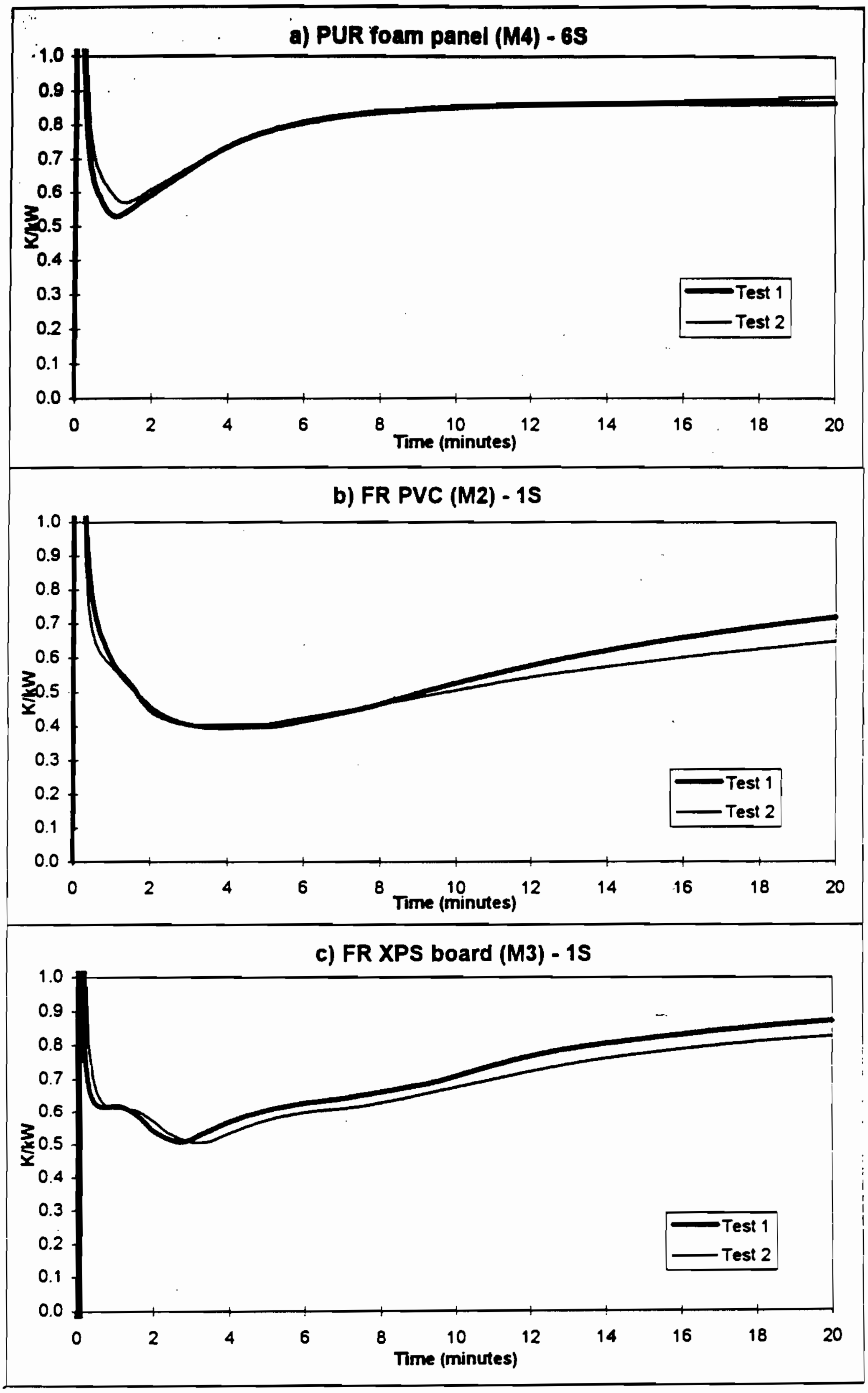


Figure 12. $\int \Delta T\, dt / \int RHR\, dt$ curves of a) PUR foam panel in test series 6S, b) fire retardant-treated PVC in test series 1S, and c) fire retardant-treated extruded polystyrene in test series 1S.

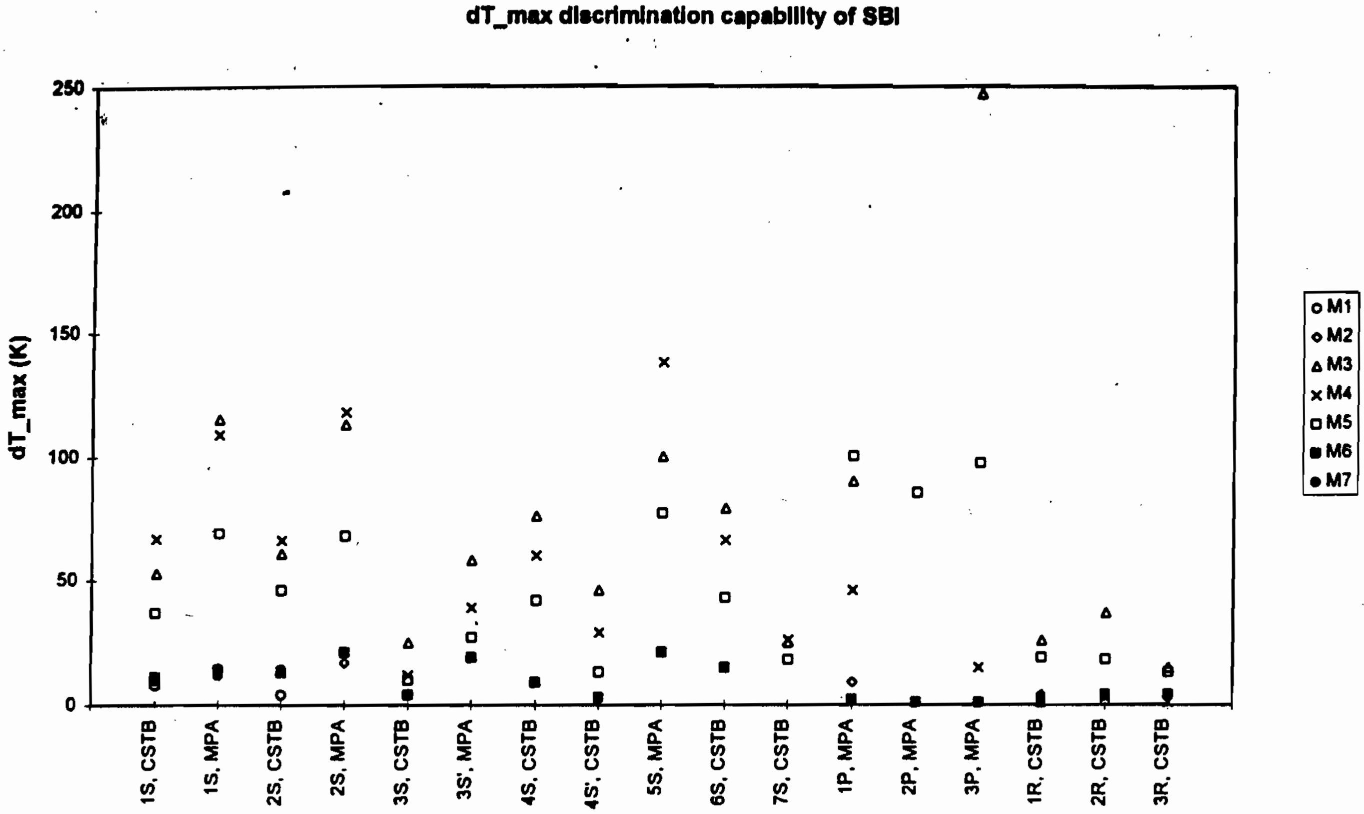


Figure 13. ΔT_{max} discrimination capability of SBI.

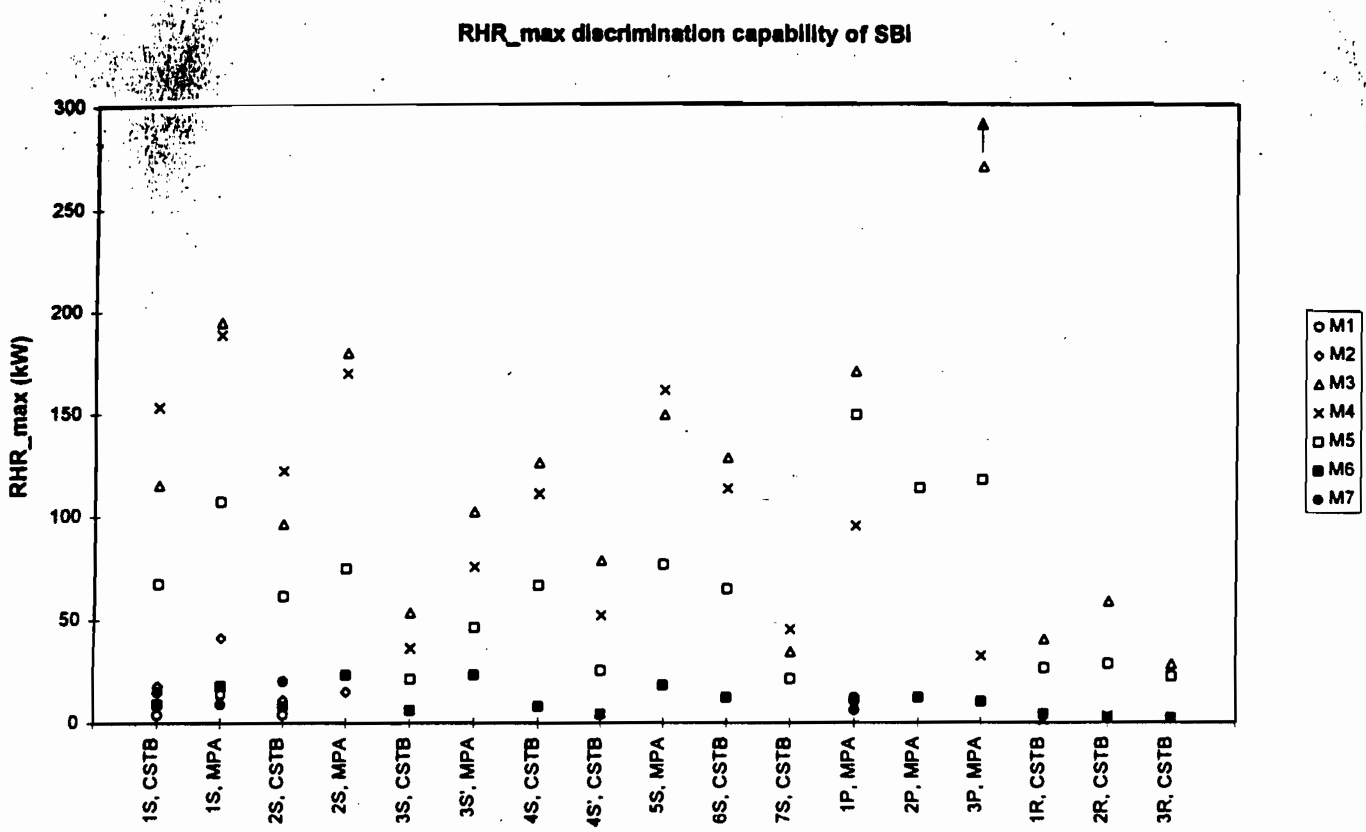


Figure 14. RHR_{max} discrimination capability of SBI.

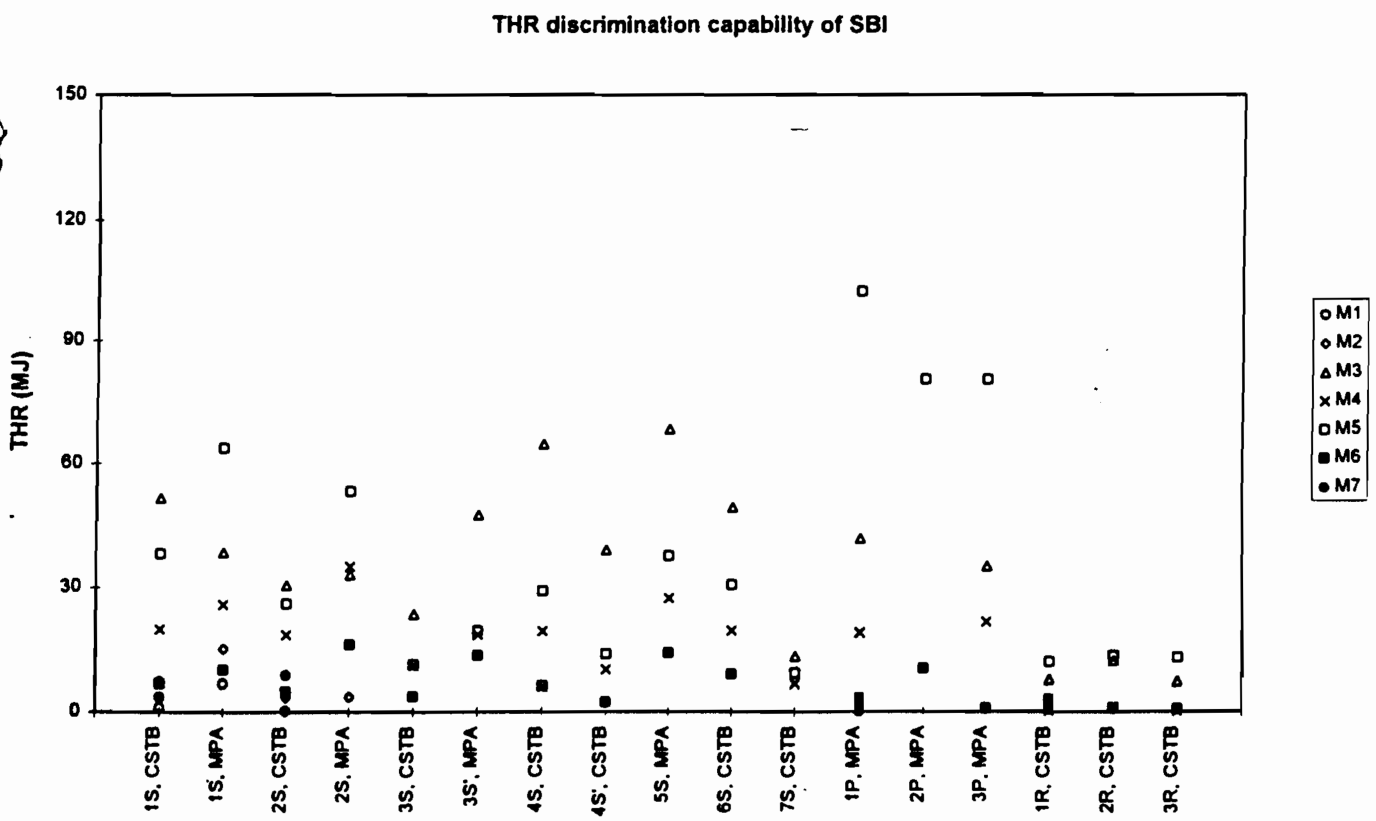


Figure 15. THR discrimination capability of SBI.

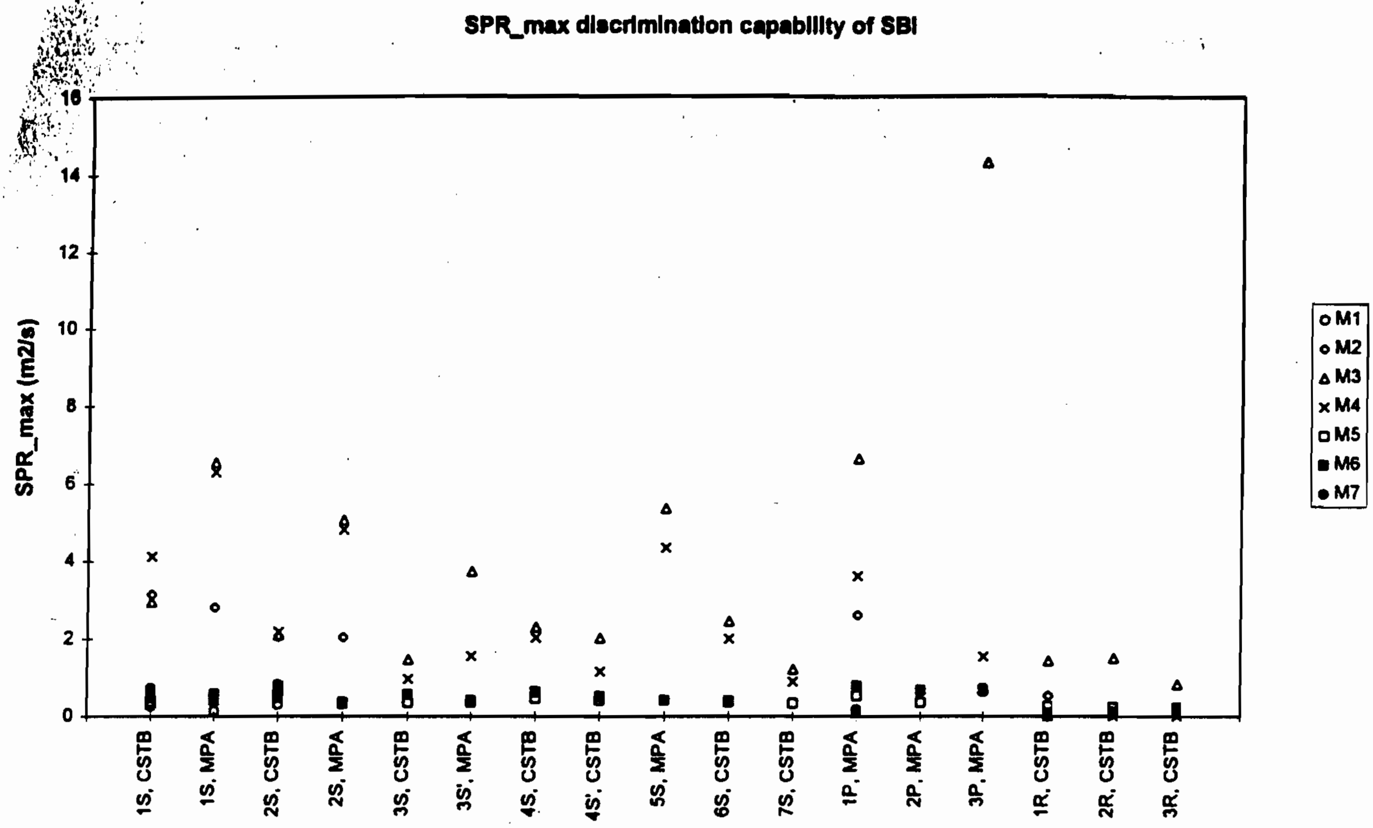


Figure 16. SPR_{max} discrimination capability of SBI.

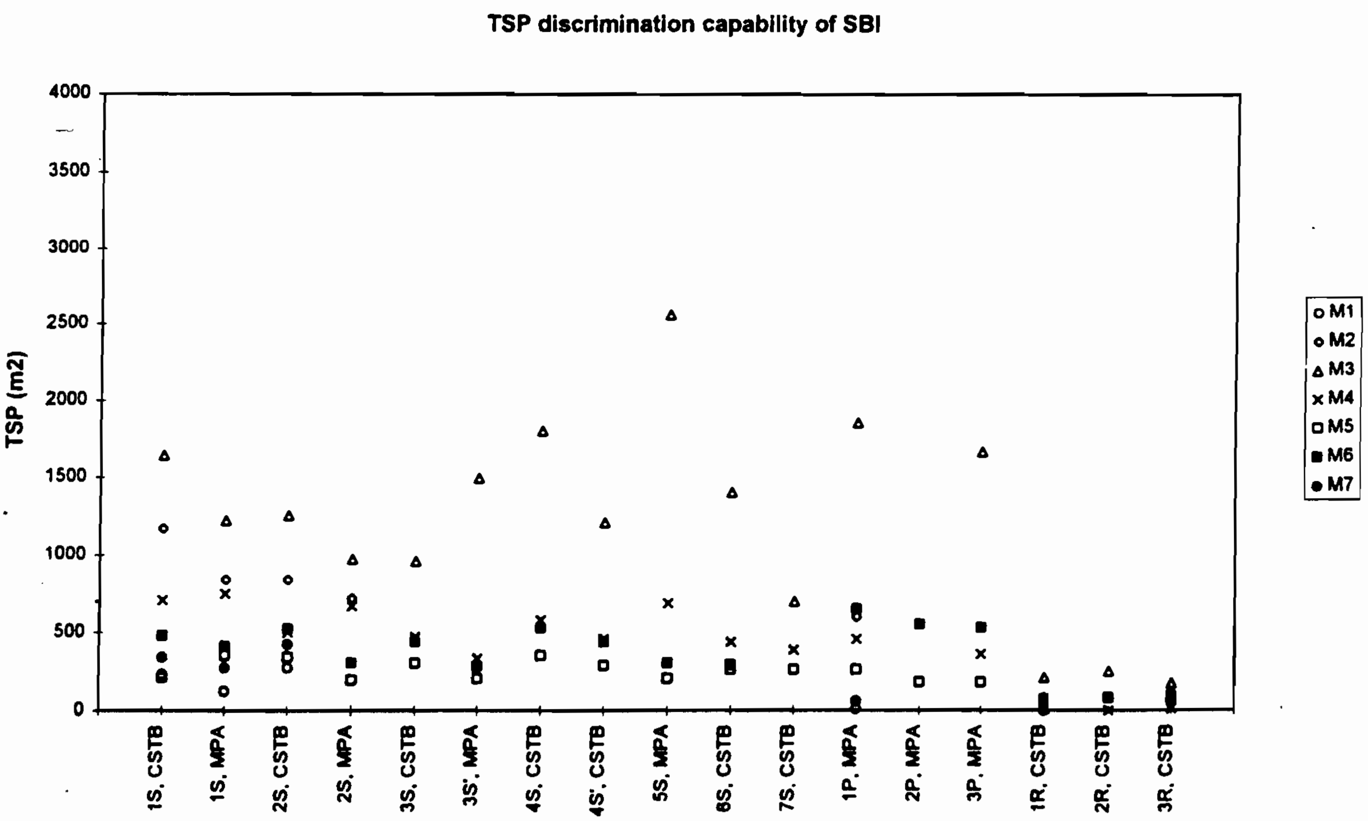
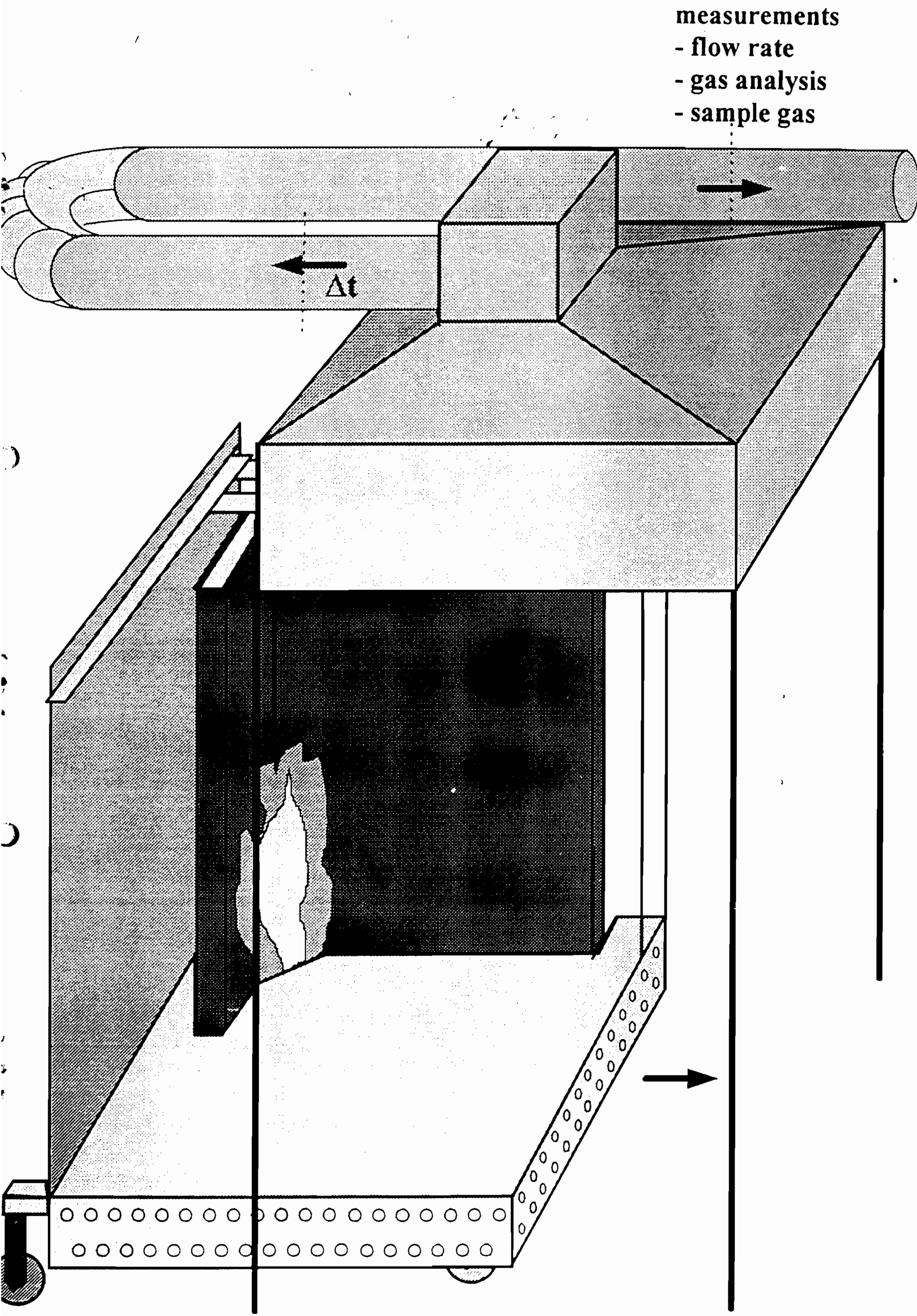
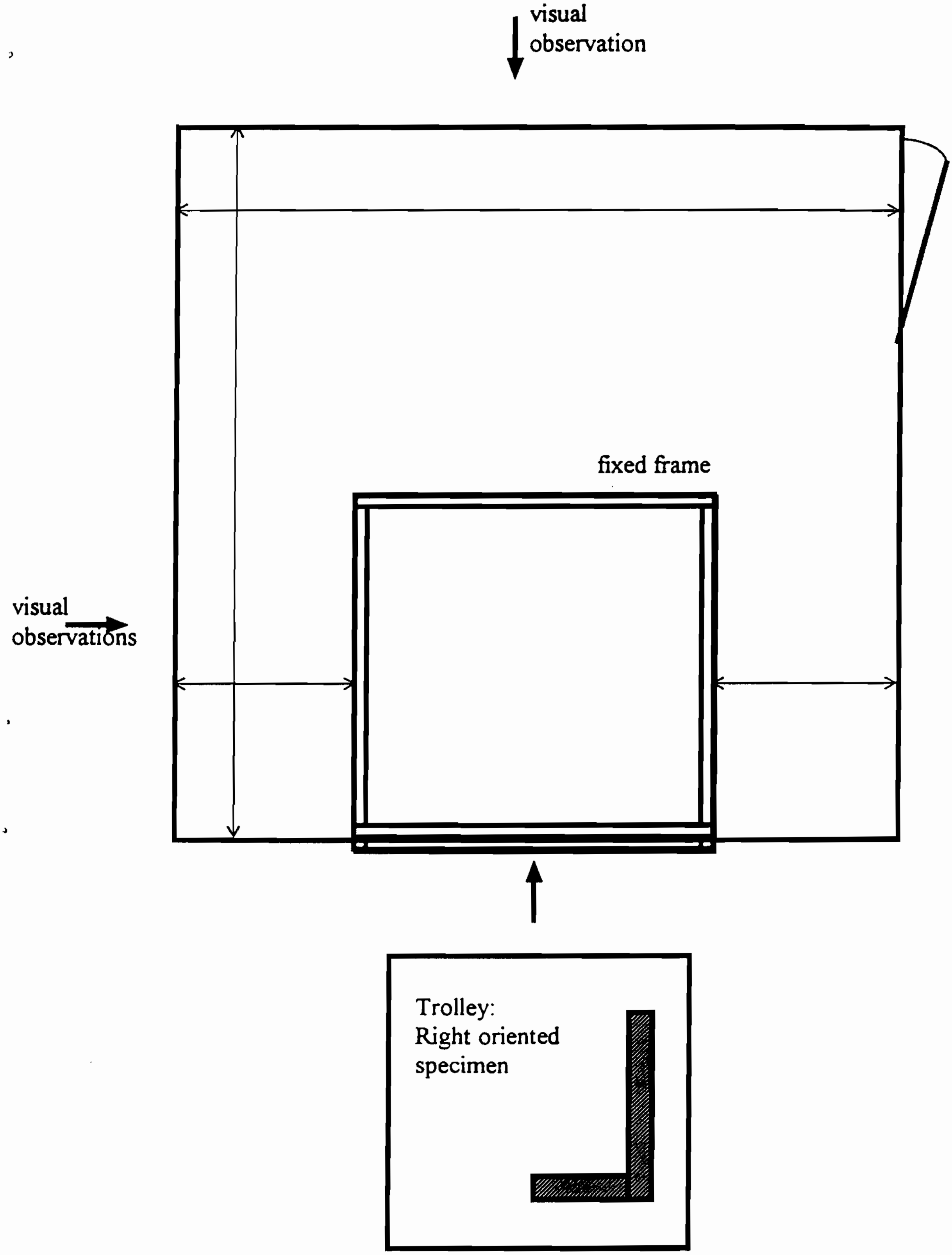


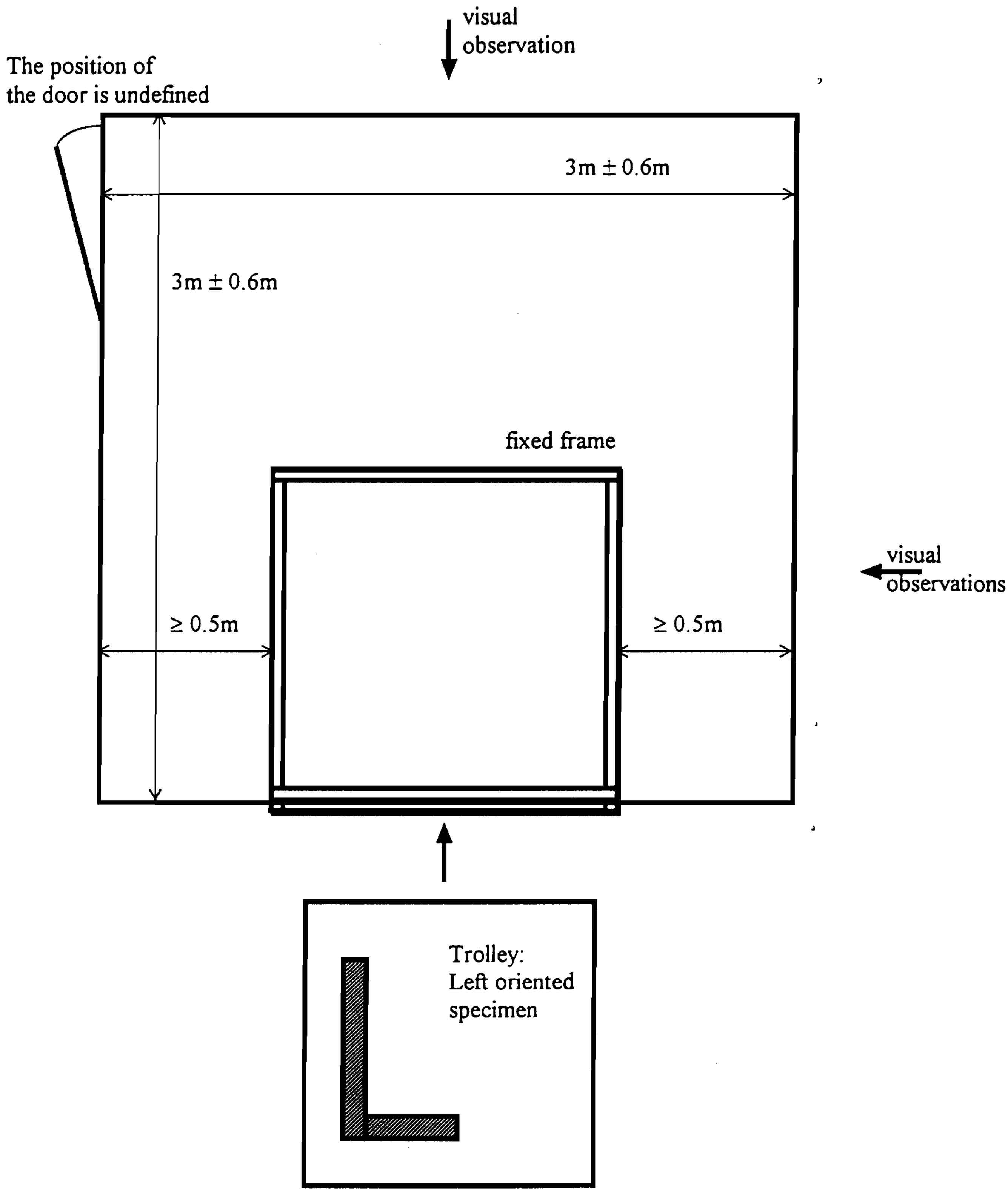
Figure 17. TSP discrimination capability of SBI.


measurements
- flow rate
- gas analysis
- sample gas
Δt

TOP VIEW (Right Oriented Specimen)



TOP VIEW (Left Oriented Specimen)



Please specify whether you want a left or right oriented specimen.