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Equivalency Sprinkler Fire Tests

Nordtest Project 1152-94

SP
Swedish National Testing and Research Institute
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Abstract

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Full scale sprinkler tests have been conducted in order to establish performance acceptance criteria for water based extinguishing systems equivalent to that referred to in SOLAS regulation II-2/12. The tests were conducted according to decisions taken at the 64th IMO Maritime Safety Committee meeting.

The fire scenarios studied include cabin fires, corridor fires and fires in public spaces on board passenger ships. The latter represents restaurants, lobbies and similar areas with "indefinitely" large floor area. A full presentation of the tests is given in the report, including temperature recordings and photographs.

Key words: Sprinklers, ships, water mist, large scale fire tests, test methods

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Summary

The International Maritime Organisation (IMO) has developed a fire test procedure [1] to meet the need for testing new types of water based fire extinguishing systems, such as water mist systems, to be used on board passenger ships. The objective of the test method is to evaluate the performance of one or more nozzles compared to the performance of traditional water sprinkler systems according to the SOLAS II-2/12 [2] requirements, using different fire scenarios.

At its 64th Maritime Safety Committee meeting, IMO decided to incorporate some changes to the test procedures [3]. The specification of the polyether mattress used in several of the fire scenarios was changed. To give guidance in establishing the performance acceptance criteria, IMO specified a reference sprinkler to be used for the necessary baseline tests.

This report describes large scale sprinkler tests performed at SP in the 12 m^2 cabin, corridor, open public space and corner public space scenarios according to the IMO fire test procedures. The aim of the tests was to establish performance acceptance criteria equivalent to the level of SOLAS II-2/12. Recommended criteria based on tests at both SP and the Technical Research Centre of Finland, VTT, are presented in a separate report [4].

The experience from the cabin tests is that the degree of direct hit of the water from the sprinkler to the burning material is of great importance for the result. When the fire is arranged in the lower bed, where the fire is shielded from direct hit, the results are highly dependent on the water application rate.

In the corridor fire scenario a problem arose associated with the plastic foam chosen as the loss tended to be very high, in some cases more than 90 %. This indicates that a performance criteria based on the amount of material lost is probably not appropriate. Based on our experience it can be concluded that the fire source in the corridor scenario with the type of plastic foam specified at MSC 64 is not ideal for evaluating the performance of "equivalent" sprinkler systems.

In the open public space scenarios it was observed that the material loss is not sensitive to variations in water discharge densities. In the corner tests damage was generally low, even at low water densities. The effect of higher water flow rate in the corner scenario was therefore not examined. On the other hand, a difference can be seen in the material loss between tests with 2,5 m and with 5 m ceiling height. In the corner scenario this difference is even greater, but also in the open space tests there is less loss at 2,5 m ceiling height. The variations in material loss can largely be attributed to the difference in operation time caused by the two ceiling heights.

1 Introduction

1.1 Background

The International Maritime Organisation (IMO) has developed a fire test procedure [1] to meet the need for testing new types of water based fire extinguishing systems, such as water mist systems, to be used on board passenger ships. The main objective of the test method is to evaluate the performance of one or more nozzles compared to the performance of traditional water sprinkler systems according to the SOLAS II-2/12 [2] requirements, using different fire scenarios.

At the 1994 Maritime Safety Committee meeting, MSC 64, IMO decided to incorporate some changes to the test procedures [3]. Firstly, the specification of the polyether mattress used in several of the fire scenarios was changed to increase the availability of suitable material. Secondly, a reference sprinkler was specified to guide fire test laboratories in establishing the performance acceptance criteria.

The sprinkler and the installation to be used for the reference fire tests is specified as an:

"ISO 6182-1 type spray pendent with:

K factor: 80 (metric), 15 mm sprinkler
Time Response Index RTI≤120 (metric)
Water density≥ 5 l/m²/min
Spacing≤ 4 m
Installation according to SOLAS II-2/12"

As the fire testing needed to establish the criteria requires a major amount of work, it was decided to split the work between SP and VTT. A detailed description of the tests is published in two separate reports, the present and one from VTT [5]. Recommended acceptance criteria based on the two test series are published in a jointly published report [4].

1.2 Reference sprinklers

An overview showed that no sprinkler has been tested in strict accordance with the ISO 6182-1 sprinkler standard [6]. However, the requirements therein consists of requirements taken from the test standards used by the organisations Underwriters Laboratories (UL), Factory Mutual (FM), Loss Prevention Council (LPC) and Verband der Schadenversicherer (VdS). Therefore, the approach taken was to use a sprinkler listed or approved by all of the above mentioned laboratories.

For almost all of the tests, SP chose the Grinnell Duraspeed model F950. This sprinkler is of the spray, pendent type, has a nominal K-factor of 80 l/min $\sqrt{\text{bar}}$ and has a solder link with a nominal operating temperature of 74 °C. The Response Time Index (RTI) was measured to be 104 $m^{1/2}s^{1/2}$ and the conductivity factor (C) 0,25 $(m/s)^{1/2}$ [7]. It was therefore considered that this sprinkler fulfils the requirements of IMO.

Two tests were performed with a GW DD SSP sprinkler. This sprinkler is also a spray, pendent sprinkler and has a nominal K-factor of 80 l/min $\sqrt{\text{bar}}$. This sprinkler is of the glass bulb type (5 mm bulb) with a nominal operating temperature of 68 °C and a Response Time Index (RTI) of approximately 110 $m^{1/2}s^{1/2}$.

The sprinkler is currently approved by FM, LPC and VdS and has previously been UL listed [8]. It was therefore also considered that this sprinkler fulfils the requirements set by IMO for a reference sprinkler. The GW sprinkler was used in all of the tests performed at VTT.

1.3 Test programme

The aim of the test programme was to perform the tests at both the minimum requirements, set by IMO and under more favourable conditions. Therefore additional tests were conducted in order to investigate the influence of higher flow rates and sprinklers with faster response characteristics. Tests were performed at a nominal pressure of 1 bar, corresponding to an average water density of 5 mm/min over an area of 16 m^2 and at a nominal pressure of up to 4 bar (10 mm/min). The latter pressure corresponds to the conditions when the first sprinkler in a system operates. The influence of the time to activation was investigated at VTT by using a sprinkler with fast response characteristics (i.e. 3 mm glass bulb). The complete test programme is listed in table 1.

Table 1 Test programme for equivalency sprinkler tests. Tests named EQ n.n were performed at SP and tests named IMnn were performed at VTT.

Scenario (according to [1])			Sprinkler					
			Grinnell F950		GW DD (5 mm)		GW DD (3 mm)	
			Desired pressure		Desired pressure		Desired pressure	
			1 bar	4 bar	1 bar	4 bar	1 bar	4 bar
Public space	Open							
	2,5 m	Below 4	EQ 1.4	EQ 1.5	IM11	IM12	IM10	-
		Between 2	-	-	IM13	IM14	-	-
		Under 1	-	-	IM15	-	-	-
	5,0 m	Below 4	EQ 1.7	-	IM04	IM05	IM06	
		Between 2	EQ 1.9	-	IM03	-	-	-
		Under 1	-	-	IM02	IM01 4)	-	-
	Corner							
	2,5 m	Normal	EQ 1.3	-	EQ 1.1	-	-	-
		Disabled	-	-	EQ 1.2, IM16	-	-	-
		Ventilation	EQ 1.8	-	-	-	-	-
	5,0 m	Normal	EQ 1.6	-	IM08	-	IM07	-
		Disabled	-	-	IM09	-	-	
		Ventilation	-	-	-	-	-	-
Cabin	Lower bunk bed		EQ 2.1 1)	EQ 2.5 2)	IM17 + IM26 3)	-	-	-
	Upper bunk bed		EQ 2.2 1)	-	IM18	-	-	-
	Arsonist		EQ 2.6 1)	-	IM19	-	IM20	-
	Disabled nozzle		-	-	IM27	-	-	-
Corridor	Between 2 nozzles		EQ 2.3 1)	EQ 2.8	IM22	-	IM21	IM23 5)
	Under 1 nozzle		EQ 2.7 1)	-	IM24	-	-	IM25 6)
	Ventilation		EQ 2.9	-	-	-	-	-

1) Actual pressure was 0,75 bar
2) Actual pressure was 2,2 bar
3) Actual pressure was 0,65 bar
4) Actual pressure was >2 bar
5) Actual pressure was 2,9 bar
6) Actual pressure was 3 bar
- No test performed

1.4 Combustible material used in the tests

1.4.1 Material specifications

At MSC 64 the properties of the combustible materials used in the tests were given new specifications [3] as follows:

- The ceiling tiles *"should not ignite when tested according to IMO Resolution A.653 (16)"* [9].
- The requirements for the wall lining material are given as: *"...the panels are to be approximately 3 mm thick. The ignition time of the panel should not be more than 35 seconds and the flame spread time at 350 mm position should not be more than 100 seconds as measured according to IMO Resolution A.653 (16)".*
- The mattress material is specified as *"...made of polyether and they shall have a density of approximately 33 kg/m^3. The cotton fabric shall not be fire retardant treated and it shall have an area weight of approximately 140 - 180 g/m^2. Typical values for the fire behaviour of the mattresses tested in the Cone Calorimeter according to ISO 5660-1 [10] are given below."*

Table 2 Typical values for the fire behaviour of the mattresses tested according to ISO 5660-1

Test results	Foam + fabric	Foam
Time to ignition [s]	5 - 15	2 - 6
1 min average HRR, q_{60} [kW/m^2]	250 ± 50	320 ± 50
3 min average HRR, q_{180} [kW/m^2]	300 ± 50	270 ± 50
Effective heat of combustion [MJ/kg]	28 ± 3	32 ± 3
Total heat release [MJ/m^2]	60 ± 12	50 ± 12

1.4.2 Results from reaction to fire tests

All combustible materials used in the tests were tested at SP. Additionally, the mattresses have also been tested at VTT.

The ceiling material used exhibited some content of combustible material, probably some binding ingredient, but did not ignite [11].

The wall lining material tests are reported in two separate reports [11, 12]. In the first tests series [11], ignition times varying from 43 to 45 seconds were achieved, and time to reach 350 mm flame spread varied from 103 to 119 seconds. Since the material was not properly conditioned in the first tests, it was too humid, it was decided to repeat the tests with conditioned samples. In the second test series [12], ignition times from 40 to 70 seconds were obtained, and time to reach 350 mm varied between 80 and 113 seconds. The results show that the material used barely fulfils the flame spread requirements, while the time to ignition is too long.

The wall lining material tested consisted of alternate layers of wood, topped with a printed plastic film. The front of the panels was decorated with longitudinal grooves. The variation in results is due to two reasons. Firstly the grooves make the material inhomogenous, which provides ignition points, and secondly the printed plastic film hides different kinds of exotic wood, having different properties.

Mattresses from two different manufacturers were first tested at SP. However, for both types the values for effective heat of combustion and total heat release were found to be too low compared to the IMO specification. It was therefore decided to repeat the tests both at SP and at VTT. The test specimens, examined at the two laboratories were taken from the same mattresses, in order to obtain as comparable results as possible. The results from the tests at SP [13] and the results from VTT [14] are summarized in tables 3 and 4 below.

The foam in mattress 1 was used by VTT to obtain the specifications set by IMO, but the values for foam and fabric were measured using a different fabric. Mattress 1 was made from standard polyether, and had according to the manufacturer's specification, a nominal density of 32,5 - 34,5 kg/m^3, and a nominal fabric area weight of 170 g/m^2. The actual sample that was tested had a density of 34,0 kg/m^3, and a fabric area weight of 202 g/m^2.

Mattress 2 was made from standard polyether, and had according to the manufacturer's specification, a nominal density of 32 - 34 kg/m^3, and a nominal fabric area weight of 140 g/m^2. The actual sample that was tested had a density of 33,8 kg/m^3, and a fabric area weight of 132 g/m^2.

Table 3 Test results for foam and fabric tested according to ISO 5660-1, with an irradiance of 35 kW/m^2

Test results	IMO requirement	Mattress 1 tested at SP	Mattress 1 tested at VTT	Mattress 2 tested at SP	Mattress 2 tested at VTT
Time to ignition [s]	5 - 15	8	8	6	7
1 min average HRR, q_{60} [kW/m^2]	250 ± 50	261	345	245	258
3 min average HRR, q_{180} [kW/m^2]	300 ± 50	238	286	253	296
Effective heat of combustion [MJ/kg]	28 ± 3	24,6	26,9	24,9	28,1
Total heat release [MJ/m^2]	60 ± 12	57,5	61,7	54,6	57,2

Table 4 Test results for foam tested according to ISO 5660-1, with an irradiance of 35 kW/m^2

Test results	IMO requirement	Mattress 1 tested at SP	Mattress 1 tested at VTT	Mattress 2 tested at SP	Mattress 2 tested at VTT
Time to ignition [s]	2 - 6	3	4	3	3
1 min average HRR, q_{60} [kW/m^2]	320 ± 50	246	252	244	245
3 min average HRR, q_{180} [kW/m^2]	270 ± 50	267	285	270	286
Effective heat of combustion [MJ/kg]	32 ± 3	26,8	28,4	27,1	29,3
Total heat release [MJ/m^2]	50 ± 12	48,3	52,4	48,8	52,5

All the values in tables 3 and 4 are averages between the results from three tests at each laboratory.

The results in table 3 show that the fabric and foam in mattress 2 have acceptable properties, though the fabric is somewhat lighter, 132 g/m^2, than the specified, "approximately 140 - 180 g/m^2". Also mattress 1 shows acceptable results though not as good as mattress 2.

The results in table 4 show that the foam of both mattress 1 and 2 have acceptable properties, with exception for the results for the 1 minute average heat release rate and the effective heat of combustion. The 1 minute average heat release rate is not a standard parameter specified in the ISO 5660-1 test method, and it can be considered the least important of the five parameters. Since it is the foam in mattress 1 that forms the basis for the IMO specification and the results using the same mattress at both VTT and SP show good agreement, the results can be considered acceptable. The values for mattress 2 are very close to those obtained for mattress 1.

Also the values for effective heat of combustion show good agreement for both foams and between laboratories. The systematic low values as compared to the requirements may be the result of originally choosing a too high base value for both the 1 minute average heat release rate and for the effective heat of combustion. The variations allowed could also be too narrow because only the reproducibility of the test method has been taken into account, not the qualitative variations between mattresses of the same type from the same manufacturer.

Based on the fact that the test properties presented in table 2 are given as typical values, and the general good agreement in the results from the two laboratories, the use of any of the two types of mattress is considered acceptable.

2 Full scale cabin and corridor sprinkler tests

2.1 Test arrangement

This test series was performed in a cabin/corridor set-up according to figure 1. The walls of the cabin were constructed from an inner and outer layer of nominally 12 mm thick non combustible wall board with a nominally 45 mm thick mineral wool liner in between. Also the walls and the ceiling of the corridor and the ceiling of the cabin were constructed from the nominally 12 mm thick non combustible wall board.

The cabin and corridor ceiling were covered with nominally 12 mm thick acoustical panels fastened to the board above.

Decorative plywood panels, nominally 3 mm thick were fastened to the walls of both the cabin and corridor.

The Pullman type bunk beds were equipped with standard, non-fire retardant polyether foam mattresses with a cotton fabric covering and a "pillow" made of 1/4 of a mattress put on top. The lower beds were made with a backrest of the same material as the bed itself. The arrangement of the bunk beds is shown in detail in figure 2, and the properties of the combustible materials are described in section 1.4. Mattresses of type 1 were used in most tests.

The bunk bed fires were ignited with a cube, 60 mm x 60 mm x 75 mm, made of pieces of insulating fibre board. The cube was soaked with 120 ml Heptane, wrapped in a polyethylene bag and placed at the head end of the bed.

The fire source in the corridor consisted of 8 pieces of 0,4 m x 0,4 m x 0,1 m standard, non fire retardant, polyether foam sections, without any fabric covering, piled on top of each other, placed in a basket and located 50 mm from one of the corridor walls. The igniter was identical with the one described above and located in the center, at the base of the pile, and on the side towards the center of the corridor.

In test EQ 2.9, when the fire was arranged in the corridor, a forced air flow was established through the corridor. The minimum air flow was 0,3 m/s, measured at the middle of the corridor 1 m from the floor, and 1 m from the ceiling. The fan used to create the flow had a diameter of 37 cm and was positioned outside the corridor opening, with its center 1,2 m above the floor. The cabin and corridor set-up is shown in figure 1.

2.2 Sprinkler system set-up

The sprinkler system pipe work was constructed using 25 mm steel pipes. The far end of the pipe work was fitted with a pressure gauge which made it possible to manually adjust the pump that was used to keep a constant water pressure throughout the tests. The pipe work was also fitted with a valve for air relief before each test.

One sprinkler was installed in the center of the cabin so that the plane of the sprinkler frame arms was directed parallel to the longer (4 m) side of the cabin. In the corridor, the plane of the sprinkler frame arms was directed parallel to the corridor walls and the sprinklers were located 4 m apart.

The water pressure was kept at a desired pressure of 0,75 bar (70 l/min per sprinkler), 1 bar (80 l/min per sprinkler), 2,25 bar (120 l/min per sprinkler) or 4 bar (160 l/min per sprinkler). All the sprinklers were installed using standard flush ceiling plates with the deflector located approximately 50 mm below the ceiling.

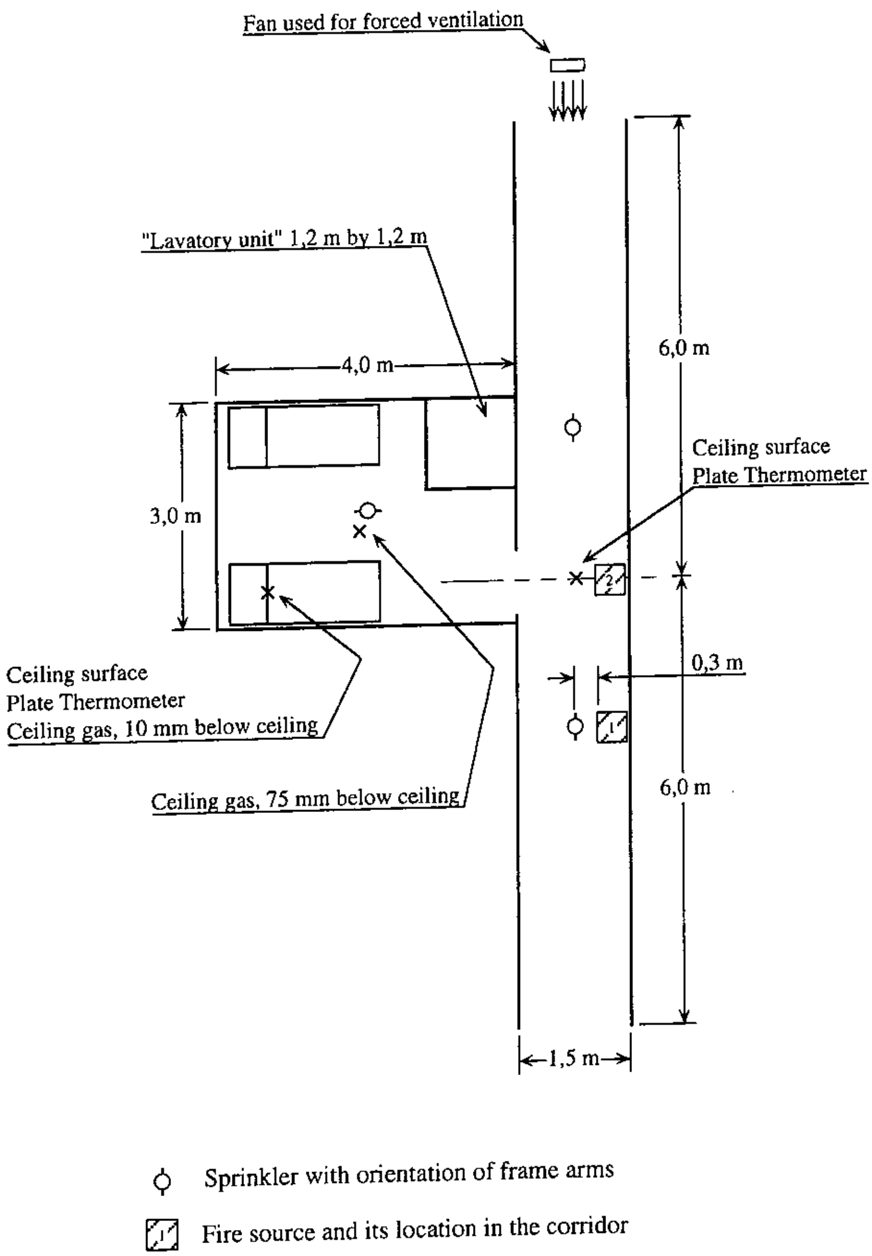


Figure 1 *Cabin/corridor layout. The positions of the sprinklers and the thermo-couples are shown. When the fire was arranged in the corridor, the fire source was located in two different positions, adjacent to one (position 1) or between two (position 2) sprinklers. In one of the tests, a forced ventilation air flow of 0,3 m/s was created with a fan directed towards one of the corridor openings. The door to the cabin was closed during the corridor tests.*

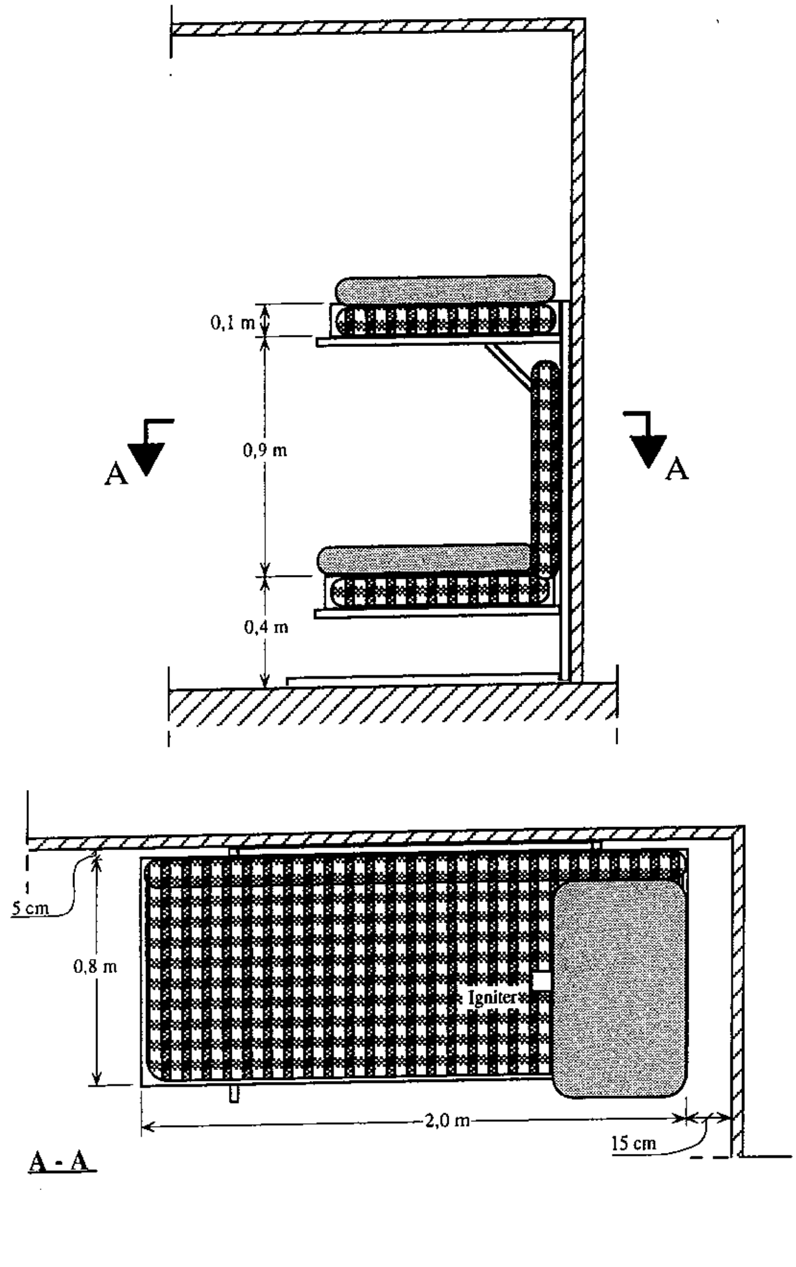


Figure 2 *A detail of the bunk bed arrangement in the cabin. The position of the igniter (same position in both lower and upper bed) is shown.*

2.3 Measurements and documentation

The tests were documented using video tape, still photographs and the recording of visual observations. During the tests, the ceiling surface and ceiling gas temperatures were measured at different positions both in the cabin and in the corridor. All the thermocouples were of type K (chromel-alumel) made from 0,5 mm wire, welded together. The ceiling surface thermocouple located directly above the fire source was installed in an acoustical ceiling tile that was changed between every test. Additionally, the ceiling surface temperature was measured using a Plate thermometer. The instrument is developed at SP [15] and consists of a 100 mm by 100 mm and 0,7 mm thin plate. A thermocouple is welded to the middle of the plate. The design of the Plate thermometer therefore primarily responds to heat flux and, to a lower degree, to convection compared to a conventional wire thermocouple. The positions and the associated channels are shown in table 5 and figure 1.

Table 5 Thermocouples and their location in the cabin and corridor set-up

Channel		TC/PT	Location
EQ 2.1-2.3	EQ 2.4-2.9		
Ch21*	Ch21*	TC	Cabin, above ignition point, flush with ceiling surface
Ch24	Ch26	TC	Cabin, above ignition point, 10 mm below ceiling
Ch22*	Ch23*	TC	Cabin, centric, 75 mm below ceiling
Ch25	Ch22	PT	Cabin, above ignition point, flush with ceiling surface
Ch23*	Ch24*	TC	Corridor, centerline of corridor, outside door opening, flush with ceiling surface
-	Ch25	PT	Corridor, centerline of corridor, outside door opening, flush with ceiling surface

*) Measurement points specified in the IMO test method
TC = Thermocouple
PT = Plate thermometer

The system pressure was measured at the end of the branchline of the pipe work feeding the cabin and the flow rate was measured after the pump. This data is not presented in the report.

The damage to the fuel packages was estimated through visual observations and measurements.

2.4 Test procedure

The following scenarios were evaluated.

Fire arranged in the cabin

- Fire arranged in the lower, left side, bunk bed.
- Fire arranged in the upper, left side, bunk bed.
- Fire arranged by spreading 1 litre of white spirit evenly over the lower, left side, bed and backrest. The objective of the test is to simulate an "arsonist" fire.

Fire arranged in the corridor

- Fire arranged in pile located adjacent to (under) one sprinkler.
- Fire arranged in pile located between two sprinklers.
- Corridor ventilated with an air velocity of 0,3 m/s, fire arranged in pile located between two sprinklers.

The location of the fire source used in the corridor is shown in figure 1 and details of the pile arrangement are shown in figure 3.

The water was shut off 10 minutes after the activation of the first sprinkler, any remaining fire was extinguished manually and the damages to the combustibles were recorded.

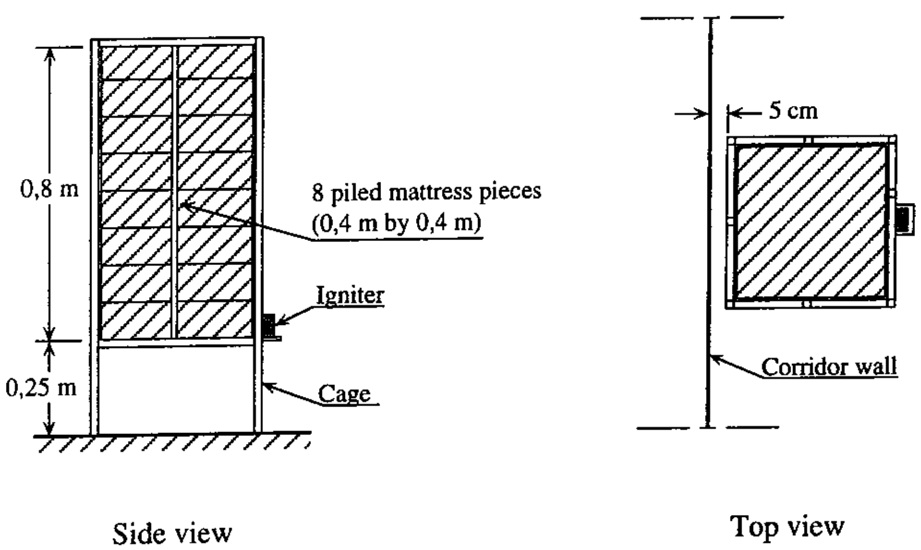


Figure 3 The fire in the corridor was arranged in 8 pieces of 0,4 m by 0,4 m foam sections that were piled on a stand. The pile was located 5 cm from one of the corridor walls and adjacent (under) one or between two sprinklers.

2.5 Summary of results

A full presentation, with all the temperature data is provided in Appendix 1 and photos are provided in Appendix 3. Times to sprinkler operation were measured from the time the fire was ignited. Mattresses of type 1 were used in all cabin and corridor tests except in test EQ 2.4.

Table 6 Cabin tests, summary of set-up and results

	Test no.	EQ 2.1	EQ 2.2	EQ 2.5	EQ 2.6
PARAMETERS	Date of test	January 3, -95	January 3, -95	January 25, -95	January 25, -95
	Number of sprinklers installed	1	1	1	1
	Sprinkler location	Centric	Centric	Centric	Centric
	K-factor [l/min bar$^{1/2}$]	80	80	80	80
	Sprinkler temperature rating [°C]	74	74	74	74
	RTI [m$^{1/2}$s$^{1/2}$]	104	104	104	104
	Sprinkler identification	Grinnell F950	Grinnell F950	Grinnell F950	Grinnell F950
	Desired water pressure [bar]	0,75	0,75	2,2	0,75
	Desired flow rate per sprinkler [l/min]	70	70	120	70
	Scenario	Lower bunk	Upper bunk	Lower bunk	Arsonist
RESULTS	Average water pressure [bar]	0,76	0,79	2,4	0,75
	Average flow rate per sprinkler [l/min]	≈ 70 *	≈ 71 *	123	69
	Average discharge density based on actual floor area (12 m^2) [mm/min]	≈ 5,8	≈ 5,8	10,2	5,8
	Average discharge density based on sprinkler coverage, 16 m^2 [mm/min]	≈ 4,4	≈ 4,4	7,7	4,3
	Sprinkler operation [min:s]	2:39	2:59	2:47	0:35
	Total loss in left side bunk bed (lower/upper) [%]	34 / 4	- / 6	7 / 0	57 / <1
	Test duration time [min:s]	10:00	10:00	10:00	10:03
	Peak 30 s average temp. above ignition flush with the ceiling	293	172	113	166
	Peak 30 s average temp. above ignition, Plate thermometer	396	220	87	258
	Peak 30 s average temp. centric in cabin 75 mm below ceiling	148	177	154	112
	Peak 30 s average temp. centric in corridor flush with the ceiling	69	35	33	89
	Peak 30 s average temp. centric in corridor, Plate thermometer	NA	NA	34	105

NA = not available
*) calculated values

Table 7 Corridor tests, summary of set-up and results

PARAMETERS	Test No.	EQ 2.3	EQ 2.7	EQ 2.8	EQ 2.9
	Date of Test	January 3, -95	January 25, -95	February 2, -95	February 2, -95
	Number of Sprinklers installed	2	2	2	2
	K-factor [l/min bar$^{1/2}$]	80	80	80	80
	Sprinkler temperature rating [°C]	74	74	74	74
	RTI [m$^{1/2}$s$^{1/2}$]	104	104	104	104
	Spacing [m]	4	4	4	4
	Sprinkler identification	Grinnell F950	Grinnell F950	Grinnell F950	Grinnell F950
	Desired water pressure [bar]	0,75	0,75	4,0	1,0
	Desired flow rate per sprinkler [l/min]	70	70	160	80
	Scenario	Between two sprinklers	Below one sprinkler	Between two sprinklers	Ventilated between two sprinklers
RESULTS	Average water pressure [bar]	0,70	0,81	4,3	1,0
	Average flow rate per sprinkler [l/min]	66	69	162	81
	Average discharge density based on actual floor area (6 m^2) [mm/min]	11	11,5	27	13,5
	Average discharge density based on sprinkler coverage, 16 m^2 [mm/min]	4,1	4,3	10,1	5,1
	1st sprinkler operation [min:s]	2:56	1:37	3:49	2:59
	2nd sprinkler operation [min:s]	3:15	-	3:54	3:03
	Total loss of foam [%]	90	8	88	93
	Test duration time [min:s]	10:04	10:00	10:00	10:00
	Peak 30 s average temp. centric in corridor flush with the ceiling	155	27	129	123
	Peak 30 s average temp. centric in corridor, Plate thermometer	NA	31	135	151

NA = not available

3 Full scale public space sprinkler tests

3.1 Test arrangement

The fire tests were conducted at SP's fire test laboratory. A schematic drawing of the 400 m^2 (6000 m^3) test hall is shown in figure 4 and 5. The facility is equipped with a ventilation system with air inlets at floor level and air exhaust near the top of the building. In all the tests the ventilation was reduced at the start of the tests to avoid unnecessary influence on sprinkler activation time and sprinkler operation sequence.

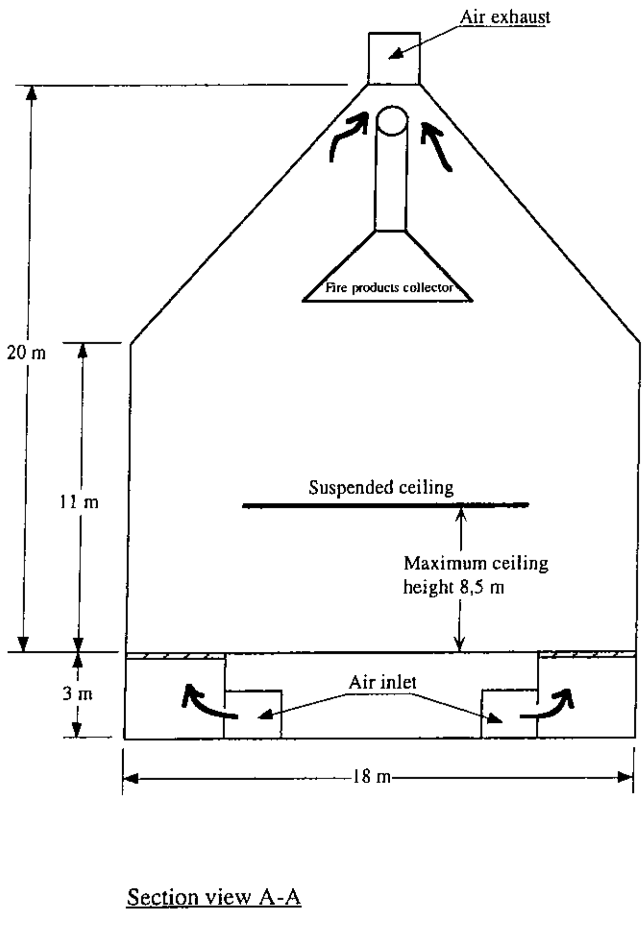


Figure 4 *Section view of the fire test hall at SP where the tests were performed. In all the tests the ventilation was kept at a minimum to avoid unnecessary influence on sprinkler activation time and sprinkler operation sequence.*

A piping arrangement consisting of a dual feed, 25 mm looped piping system was installed on top of the suspended ceiling. The looped arrangement minimizes the difference between the flow rates of operating sprinklers. Supply hoses were connected on opposite sides of the loop. A total of four sprinklers were installed spaced 4 m by 4 m, with two exceptions, see below. The pipe work was fitted with a pressure tap located near the center of the array. In test EQ 1.8 only one sprinkler connected to a single pipe was used, and in test EQ 1.9 two sprinklers were installed, connected to a single pipe, fed from its center.

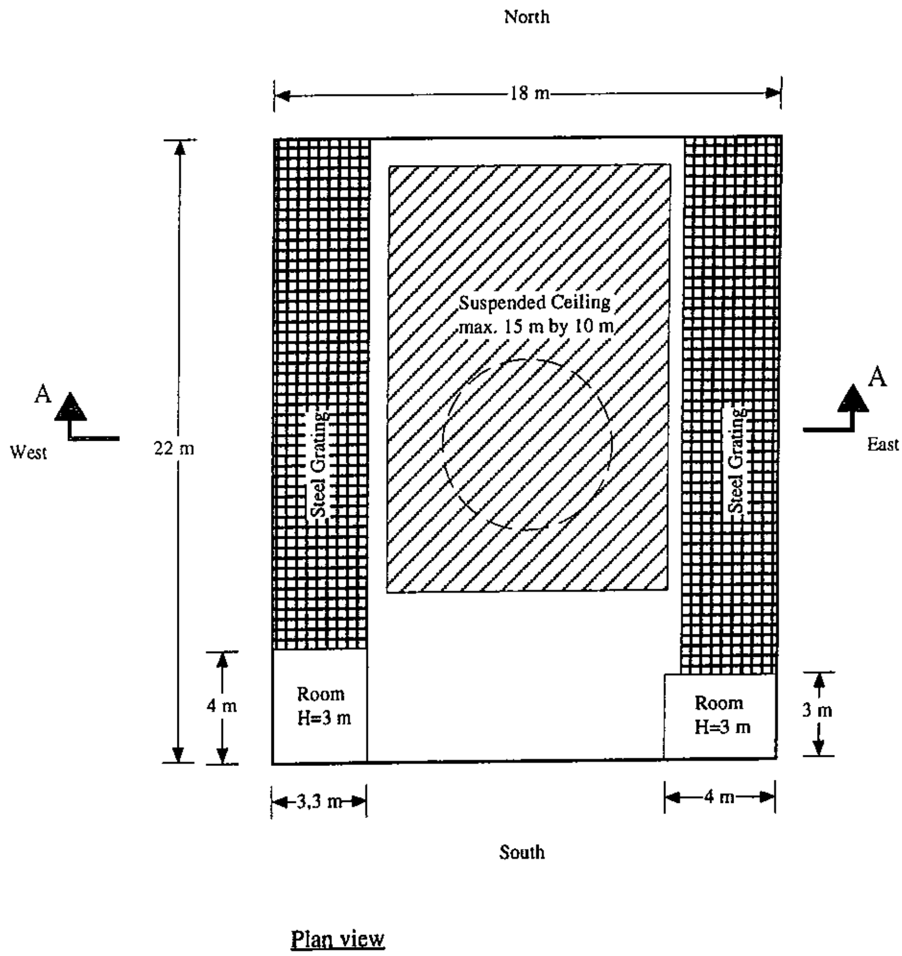


Figure 5 Plan view of the fire test hall at SP.

3.2 Test set-up

3.2.1 Open area public space

As a fire source, standard, non-fire retardant polyether foam mattresses, as described in section 1.4, were installed in "steel frame sofas". In most of the tests mattresses of type 1 were used. The steel frames are described in a Nordtest method NT Fire 032 [16], but in these tests they were slightly modified, to fit the size of the mattresses. The left and right side of the backrests were secured to the steel frame to prevent them from falling over. The arrangement is shown in figure 6.

In all tests, one of the sofas was ignited, centric, at the bottom of the backrest, with an igniter consisting of a cube, 60 mm x 60 mm x 75 mm, made of pieces of insulating fibre board, soaked with 120 ml Heptane, and wrapped in a polyethylene bag.

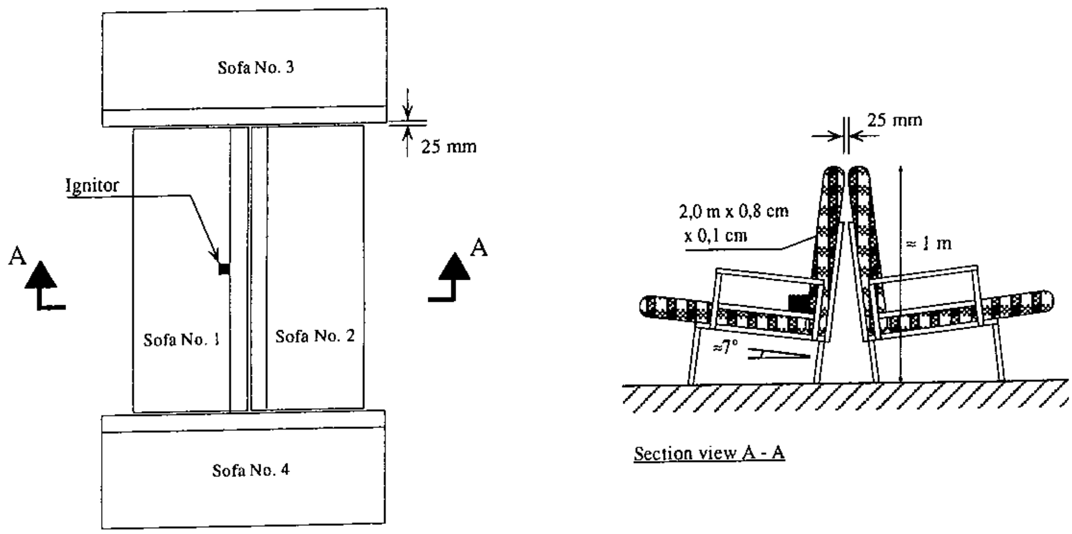


Figure 6 The fire in the Public Space was arranged in four sofas, made of mattresses that were placed in steel frames, arranged together. Sofa no. 1 was ignited, centric and at the bottom of the backrest.

3.2.2 Corner public space

Two walls made of a non combustible wall board, both 6 m long, were built so that a corner was formed. The corner walls were fitted with decorative plywood panels 3,6 m out from the corner, all the way up to the ceiling. The ceiling corner was fitted with 0,6 m by 0,6 m acoustical ceiling tiles covering an area of 3,6 m by 3,6 m.

The fire was arranged in sofa 1, placed with the backrest along and 25 mm from the right hand wall and close to the left hand wall. Sofa 2 was also placed along the right hand wall with the seat cushion 0,1 m from sofa 1. Sofa 3 was placed at a distance of 0,5 m from sofa 1 along the other wall. All the sofas were constructed as described in section 3.2.1. An igniter, as described in 3.2.1 was placed at the far left of the corner sofa, at the base of the backrest, near the left hand wall. See figures 7 and 8.

In test EQ 1.8, when the fire was arranged in the corner, a forced air flow was established towards the corner. The minimum air flow was 0,3 m/s, measured 5 m from each wall, 1 m from the floor, and 1 m from the ceiling. The fan used to create the flow had a diameter of 37 cm and was positioned under the ceiling corner opposite to the fire, with its center 1,2 m above the floor.

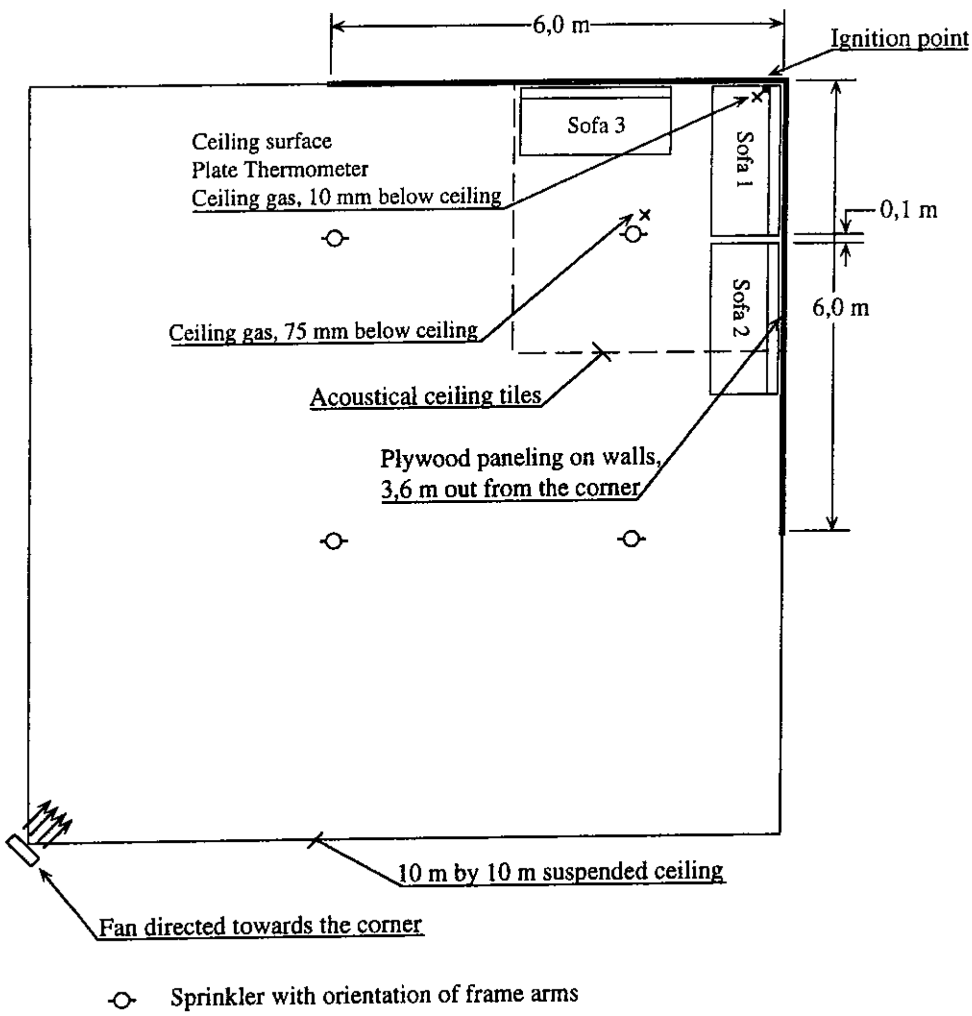


Figure 7 An overview of the corner public space arrangement.

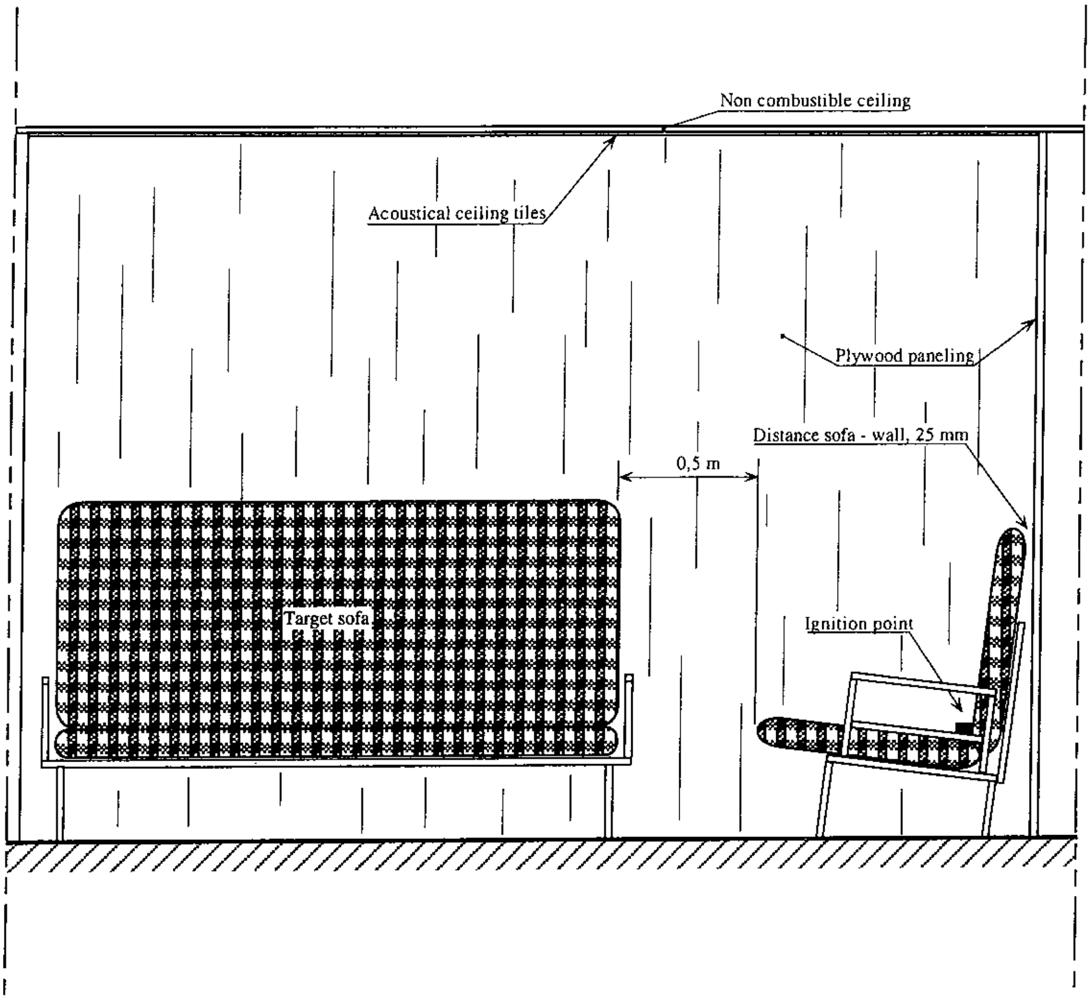


Figure 8 A detail of the sofa arrangement in the corner.

3.3 Measurements and documentation

The tests were documented using video tape, still photographs and the recording of visual observations. The temperatures were measured continuously using the following instrumentation, see table 8 and figures 6, 7 and 8.

All the thermocouples were of type K (chromel-alumel) made from 0,5 mm wire, welded together. The ceiling surface thermocouple located directly above the fire source was installed in an acoustical ceiling tile that was changed between every test. Additionally a Plate thermometer was used to measure the ceiling surface temperature above the ignition point of the fire source. A full description of the Plate thermometer is given in [15].

The system pressure was measured near the center of the array of the pipe work and the flow rate was measured after the pump. This data is not presented in the report.

The damage to the fuel packages was estimated through visual observations and measurements.

Table 8 Thermocouples and their location in the public space set-up

Channel 1.1-1.5	Channel 1.6-1.7	Channel 1.8-1.9	Open and corner Public Space TC/PT	Location
Ch 22	Ch 21	Ch 21	TC	Above ignition point, flush with ceiling surface
Ch 21	Ch 23	Ch 22	PT	Above ignition point, Plate thermometer
Ch 24		Ch 23 *	TC	1,8 m, horizontal distance, from ignition point, 75 mm below ceiling
Ch 25	Ch 24	Ch 23 **	TC	Sprinkler nearest ignition point, 75 mm below ceiling
Ch 23	Ch 22	Ch 26	TC	Above ignition point, 10 mm below surface

*) in test EQ 1.9
**) in test EQ 1.8
TC = Thermocouple
PT = Plate thermometer

3.4 Test procedure

The following scenarios were evaluated.

Open public space

The fire source was located either below four, between two or directly underneath one sprinkler. In the case when the fire source was between two sprinklers, the backrests of the middle sofas were orientated perpendicular to the line between the two sprinklers. The location of the fire source and the orientation of the frame arms of the sprinklers is shown in figure 9.

Tests were performed both at 2,5 and 5,0 m ceiling height, respectively, and at a desired pressure of 1 bar (80 l/min per sprinkler) and 4 bar (160 l/min per sprinkler).

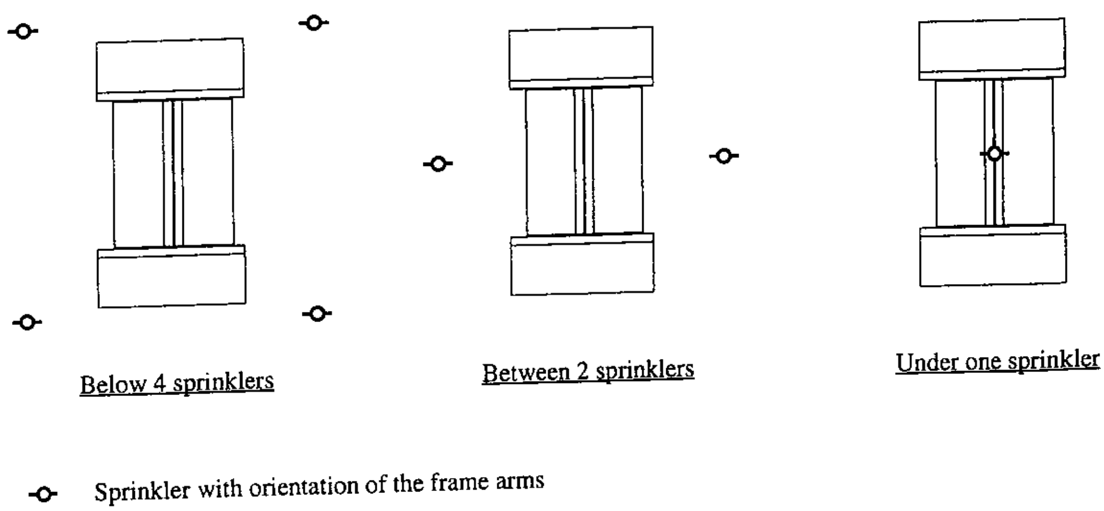


Figure 9 The location of the sofa set-up relative the sprinklers in the different tests, from left to right below 4 sprinklers, between 2 sprinklers and under 1 sprinkler.

Corner public space

In the corner public space scenario, tests were performed both with all the sprinklers in operation and, at 2,5 m ceiling height, with the sprinkler closest to the corner disabled. In addition, a test was performed using forced ventilation. The air flow was arranged with a fan directed in a 45° angle towards the corner, see figure 7.

The water was shut off 10 minutes after the activation of the first sprinkler, any remaining fire was extinguished manually and the damages to the combustibles were recorded.

3.5 Summary of results

A full presentation, with temperature data, for all the tests, is provided in Appendix 2 and photos are provided in Appendix 3. Times to sprinkler operation were measured from the time that fire was ignited. Mattresses of type 1 were used in all public space tests except tests EQ 1.6 and EQ 1.7.

Table 9 Open public space tests, summary of set-up and results

	Test no.	EQ 1.4	EQ 1.5	EQ 1.7	EQ 1.9
PARAMETERS	Date of test	Dec. 19, -94	Dec. 19, -94	Dec. 16, -94	February 7, -94
	Ceiling height [m]	2,5	2,5	5	5
	Number of sprinklers installed	4	4	4	2
	K-factor [l/min bar$^{1/2}$]	80	80	80	80
	Nozzle temperature rating [°C]	74	74	74	74
	RTI [m$^{1/2}$s$^{1/2}$]	104	104	104	104
	Spacing [m]	4 x 4	4 x 4	4 x 4	4 x 4
	Sprinkler identification	Grinnell F950	Grinnell F950	Grinnell F950	Grinnell F950
	Desired water pressure [bar]	1	4	1	1
	Desired flow rate per sprinkler [l/min]	80	160	80	80
	Scenario	Below 4 sprinklers	Below 4 sprinklers	Below 4 sprinklers	Between 2 sprinklers
RESULTS	Average water pressure [bar]	0,97	4,0	0,92	1,0
	Average flow rate per sprinkler [l/min]	80	160	107	82
	Average discharge density [mm/min]	4,9	10,0	6,7	5,1
	1st sprinkler operation [min:s]	3:34	3:18	4:57	4:24
	2nd sprinkler operation [min:s]	3:42	3:40	5:14	4:26
	3rd sprinkler operation [min:s]	3:59	-	5:16	-
	4th sprinkler operation [min:s]	4:10	-	-	-
	Losses to 1st sofa seat/backrest [%]	15 / 90	12 / 78	95 / 98	40 / 82
	Losses to 2nd sofa seat/backrest [%]	1 / 96	0 / 80	25 / 92	0 / 81
	Losses to 3rd sofa seat/backrest [%]	0 / SB	0 / SB	SB / 62	1 / 77
	Losses to 4th sofa seat/backrest [%]	0 / 24	0 / 65	0 / 90	0 / <1
	Total amount of loss [%]	28	29	58	35
	Test duration time [min:s]	10:00	10:00	10:03	10:01
	Peak 30 s average temp. above ignition flush with the ceiling	378	345	100	74
	Peak 30 s average temp. above ignition, Plate thermometer	472	475	107	88
	Peak 30 s average temp. 75 mm below ceiling 1,8 m from point of ignition	159	203	100 *	92

*) Temperature measured at sprinkler that never operated

SB Slightly burnt, indicates very small damage such as charred fabric

Table 10 Corner public space tests, summary of set-up and results

	Test no.	EQ 1.1	EQ 1.2	EQ 1.3	EQ 1.6	EQ 1.8
PARAMETERS	Date of test	Dec. 15, -94	Dec. 15, -94	Dec. 16, -94	Jan. 10, -95	Feb. 3, -95
	Ceiling height [m]	2,5	2,5	2,5	5	2,5
	Number of sprinklers installed	4	3	4	4	1
	K-factor [l/min bar$^{1/2}$]	80	80	80	80	80
	Nozzle temperature rating [°C]	68	68	74	74	74
	RTI [m$^{1/2}$s$^{1/2}$]	110	110	104	104	104
	Spacing [m]	4 x 4	4 x 4	4 x 4	4 x 4	4 x 4
	Sprinkler identification	GW DD	GW DD	Grinnell F950	Grinnell F950	Grinnell F950
	Desired water pressure [bar]	1	1	1	1	1
	Desired flow rate per sprinkler [l/min]	80	80	80	80	80
	Scenario	Corner	Corner, disabled	Corner	Corner	Corner ventilated
RESULTS	Average water pressure [bar]	0,97	1,1	0,99	NA	NA
	Average flow rate per sprinkler [l/min]	79	84	79	NA	82
	Average discharge density [mm/min]	4,9	5,2	5,0	≈ 5	5,1
	1st sprinkler operation [min:s]	2:06	3:04	2:25	2:58	2:12
	Losses to 1st sofa seat/backrest [%]	<1 / 5	100 / 100	<1 / 10	5 / 60	<1 / 2
	Losses to right hand target sofa [%]	None	90 / 90	None	None	None
	Losses to left hand target sofa [%]	None	65 / 88	None	None	None
	Total amount of loss to 1st sofa [%]	3	100	5	32	1
	Test Duration Time [min:s]	10:00	9:56	10:00	10:07	10:00
	Peak 30 s average temp. above ignition flush with the ceiling	387	667	300	86	256
	Peak 30 s average temp. above ignition, Plate thermometer	370	870	341	136	366
	Peak 30 s average temp. 75 mm below ceiling at sprinkler closest to corner	128	980	142	109	229

NA = not available

4 Discussion

These equivalency tests have been performed in order to establish performance acceptance criteria for the evaluation of "equivalent" sprinkler systems. Fire tests according to the various scenarios have previously been conducted using a different, less flammable type of mattress, and acceptance criteria were then established using sprinklers with slower response characteristics. The main difference compared to the type of mattress previously used is that the mattress specified at MSC 64 is more difficult to suppress and extinguish. The thermoplastic foam melts when heated and formations of pool fires of varying sizes were experienced in most tests. In all tests the fire is well established in the foam before the sprinkler is activated (with exception for the cabin arsonist test). The cotton cover is wetted by the sprinklers, but the water has great difficulty in affecting the further development of the fire in the foam underneath the shielding cotton cover.

The effects of the sprinkler can be divided into three categories, control, suppression and extinguishment. The following definitions of control and suppression taken from the NFPA 13 sprinkler standards [17] are used in the discussion below, and in the appendices. The definition of extinguishment is obvious.

Fire control. Limiting the size of a fire by distribution of water so as to decrease the heat release rate and pre-wet adjacent combustibles, while controlling ceiling gas temperatures to avoid structural damage.

Fire suppression. Sharply reducing the heat release rate of a fire and preventing its regrowth by means of direct and sufficient application of water through the fire plume to the burning fuel surface.

One intention with the test programme was to investigate the influence of water discharge density on the ceiling temperatures and material loss of the combustibles. As a sprinkler system in general is designed for a minimum water density and an expected maximum area of sprinkler operation, the first sprinklers that operates will deliver a substantially higher water flow than the minimum required. Tests were therefore conducted at both the minimum required design water flow rate and at higher flow rates, as typically achieved when the first sprinklers in a system is activated.

The cabin scenario asks for a variety of qualities from a sprinkler or water mist system, especially with regard to the location of the fires. When the fire was arranged in the lower bunk bed, the upper bunk bed acts like an obstruction, shielding the combustibles from direct water application. When the fire was arranged in the upper bunk bed, the fire is levelled high, only approximately 1 meter from the ceiling and close to the ceiling surface thermocouple.

These tests indicates that the results, for sprinklers of the type used, with regard to the lower bunk bed fire is strongly dependent on the flow rate. This was illustrated by two tests, test EQ 2.1, conducted at 5,8 mm/min where fire control was obtained, and the loss in the lower bunk was 34 %. In test EQ 2.5, conducted at 10 mm/min, where suppression was obvious and only 7 % was lost. For the upper bunk bed, an average discharge density of 5 mm/min is enough to provide fast extinguishment with a very limited loss of material.

In the corridor tests the difficulties to suppress or control the fire source was obvious. When the pile of foam was positioned between two sprinklers the loss was severe, regardless of the water discharge density, see tests EQ 2.3 and EQ 2.8. In principle all the foam was consumed and the amount of material left seems to depend more on whether or not, and when the pile collapses, and if material pieces fall out of the cage. When positioned adjacent to (under) one sprinkler, the time to activation is shorter and the loss less. However, these tests raise the question if the fire source is appropriate, as a material loss performance criteria close to complete loss seems unsatisfactory. It was also observed that the spread of fire to the wall lining is largely dependent on whether and how the pile collapse. It is clear though that the amount of combustible lining needed on the corridor walls can be limited to an area just behind the location of the pile.

In the public space scenarios it was observed that the material loss was not as sensitive to variations in water discharge densities. On the other hand there was a factor two difference in the material loss between the results in the open scenario tests at 2,5 m ceiling height compared to the results at 5 m. In the corner scenario the difference was even greater, but unfortunately only one test has been performed in the corner with 5 m ceiling height. The variations in material loss can depend on the differences in operation time caused the differences in ceiling heights. Once the sprinkler system is operating, the damage is to a large extent determined by the number of mattresses already ignited. The already ignited mattresses will suffer almost total damage, but fire spread to adjacent mattresses after sprinkler operation is prevented by the prewetted cotton fabric. This tendency was especially observed for horizontally orientated mattresses. Variations in peak temperatures can also be explained by the different ceiling heights.

In the open public space, the influence from higher water density seems to be low. The flow rate per sprinkler was twice as high in test EQ 1.5 compared to EQ 1.4. However in the test with the higher water density only two sprinkler operated. The results from the two tests show very similar amounts of damage.

The so called disabled nozzle test, EQ 1.2, where the sprinkler closest to the corner was plugged, resulted in almost complete loss of all combustibles. A violent flash-over was observed within 4 minutes after activation, though three sprinklers were in operation at that time. It is difficult to judge if fire spread out from the corner would have occurred, had more combustible material been available. For certain more sprinklers than the three that were installed in the test would have operated. When the flash-over occurred, flames reached 8 - 10 m out from the corner over a period of a couple of minutes.

As the fire testing needed to establish the criteria requires a major amount of work, it was decided to split the work between SP and VTT. A detailed description of the tests is published in two separate reports, the present and one from VTT [5]. Recommended acceptance criteria based on the two test series are published in a jointly published report [4].

References

[1] IMO FP39/19 ANNEX 5, *Fire Test Procedures for Equivalent Sprinkler Systems in Accommodation, Public Space and Service Areas on Passenger Ships*, International Maritime Organisation, London, England, July 21, 1994.

[2] *SOLAS, The International Convention for Safety of Life at Sea*, International Maritime Organisation, London, England, First Edition 1992.

[3] MSC 64 WP.10, FIRE PROTECTION, Fire-fighting systems, Report of the working group, Annex 2, *Proposed amendments to draft assembly resolution on revised guidelines for approval of sprinkler systems equivalent to that referred to in SOLAS regulation II-2/12 (Annex 5 to FP39/19)*, Maritime Safety Comittee - 64th session, December 7, 1994.

[4] Arvidson, Magnus, Isaksson, Sören, Tuomisaari, Maarit, *Recommended acceptance criteria for sprinkler systems equivalent to SOLAS II-2/12*, SP-REPORT 1995:19, Swedish National Testing and Research Institute, Borås, 1995.

[5] Tuomisaari, Maarit, *Acceptance criteria for fire suppression systems equivalent to SOLAS II-2/12 in accommodation and public space areas on passenger ships*, Test report R5SU00133, Technical Research Centre of Finland (VTT), Helsinki, 1995.

[6] *ISO 6182-1, Fire Protection - Automatic sprinkler systems - Part 1: Requirements and methods of test for sprinklers,* ISO, Revised February 14, 1994.

[7] *Determination of Response Time Index (RTI) and Conductivity Factor (C) for the Listed Grinnell Duraspeed Model F950 Automatic Sprinkler in the 74°C Remperature Rating*, Test Report 95NK1377, Underwriters Laboratories, Northbrook, IL, USA, January 11, 1995.

[8] Personal communication with Carsten Palle, GW Sprinkler A/S.

[9] IMO Resolution A.653 (16).

[10] ISO 5660-1, *Fire tests - Reaction to fire- Part 1: Rate of heat release from building products (Cone calorimeter method)*, ISO, June 1993.

[11] Test report 94 R21753, Swedish National Testing and Research Institute, Borås, February 6, 1995.

[12] Test report 95 R21791, Swedish National Testing and Research Institute, Borås, February 6, 1995.

[13] Test report 95 R21792A, Swedish National Testing and Research Institute, Borås, February 22, 1995.

[14] Fax from VTT dated April 28, 1995.

[15] Wickström, Ulf, *The plate thermometer - A simple instrument for reaching harmonized fire resistance tests*, SP-REPORT 1989:03, Swedish National Testing and Research Institute, Borås, 1989.

[16] Nordtest method, NT FIRE 032, *Upholstred furniture: burning behaviour - Full scale test*, edition 2, approved 1991-05.

[17] *Standard for the Installation of Sprinkler Systems,* NFPA 13, National Fire Protection Association, Batterymarch Park, Quincy, MA, USA, 1994 edition.

Appendix A

Test protocolls and graphs from test series 2

Fire tests to establish acceptance criteria for systems equivalent to SOLAS II/2/12 in 12 m^2 cabin and corridor

Test EQ 2.1 Date: January 3, 1995

Test conditions

Fire scenario: Cabin, lower bunk

Combustibles: Mattress, pillow and backrest in lower and upper bed on the left side. 3 mm plywood lining on all cabin walls.

Sprinkler type: Grinnell F950, 74 °C solder link, K=80, RTI=104

Number of Sprinklers installed: 1

Sprinkler location: Centric

Average system pressure during test: 0,76 bar

Average flow per sprinkler: ≈ 70 l/min

Average flux density based on actual floor area (12 m^2): ≈ 5,8 mm/min

Average flux density based on sprinkler coverage (16 m^2): ≈ 4,4 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
02:38	Fire spreads to the backrest
03:30	Flames reach the ceiling
03:39	Automatic activation of the sprinkler
04:10	Fire observed in upper bed
05:30	The head end of backrest collapses
06:30	Fire intensity decreases
07:00	Only a small fire left
13:39	Water flow turned off, manual extinguishment starts
14:26	Still a small fire burning

Results

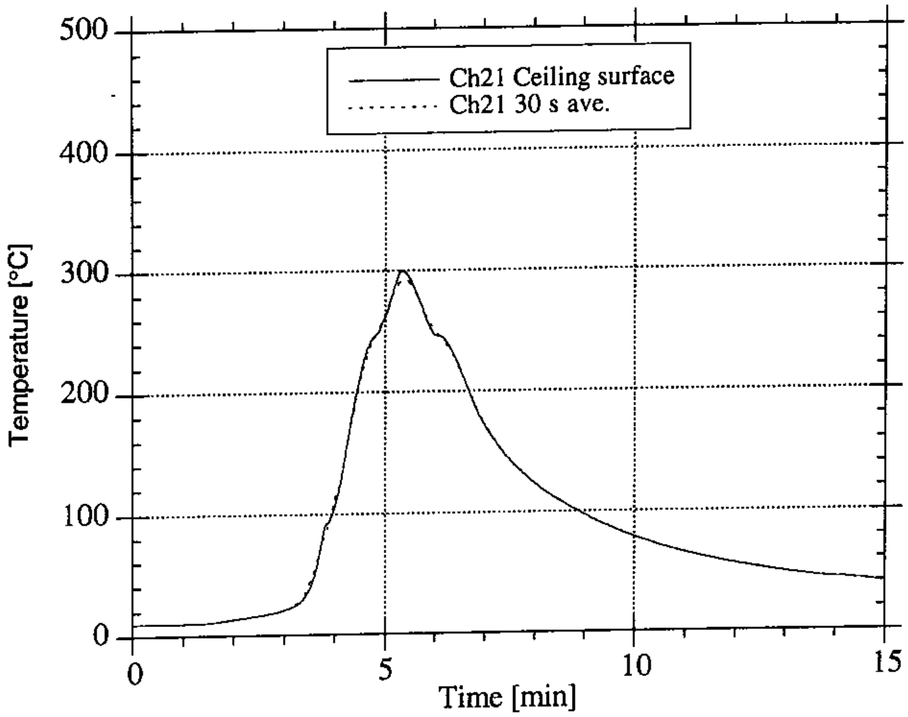
Maximum 30 second average temperatures

Ceiling surface temperature above point of ignition in cabin (channel 21)	293 °C
Gas temperature 75 mm from the ceiling in cabin center (channel 22)	148 °C
Plate thermometer above point of ignition in cabin (channel 25)	396 °C
Ceiling surface temperature centric in corridor (channel 23)	69 °C

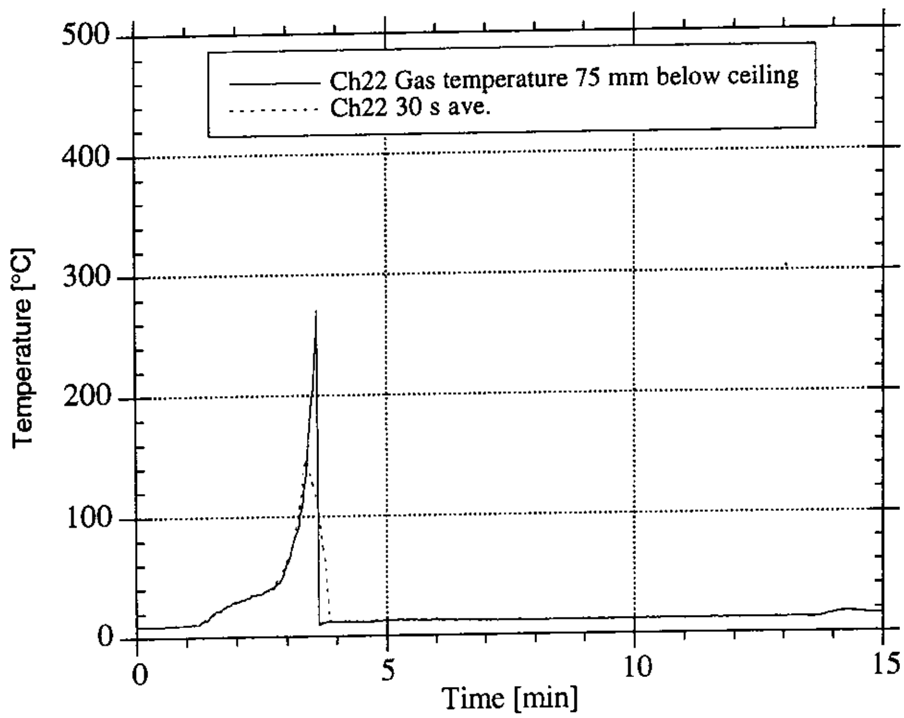
Damages to mattresses

	Mattress	Pillow	Backrest
Upper left side bed	4	5	-
Lower left side bed	22	70	37

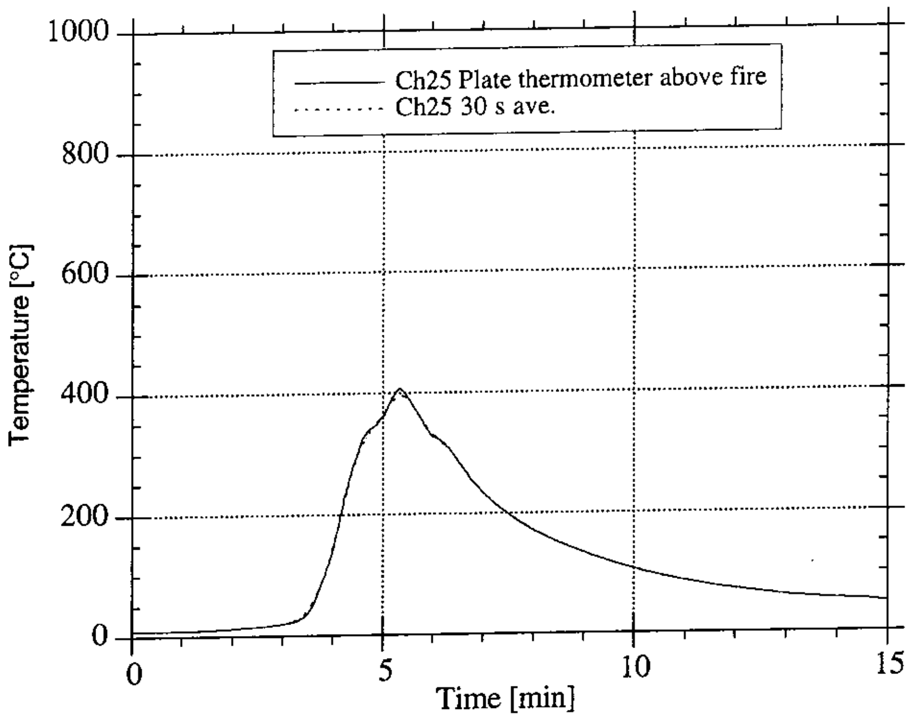
EQ 2.1


Ch21 Ceiling surface
Ch21 30 s ave.
Temperature [°C]
Time [min]
0
100
200
300
400
500
0
5
10
15

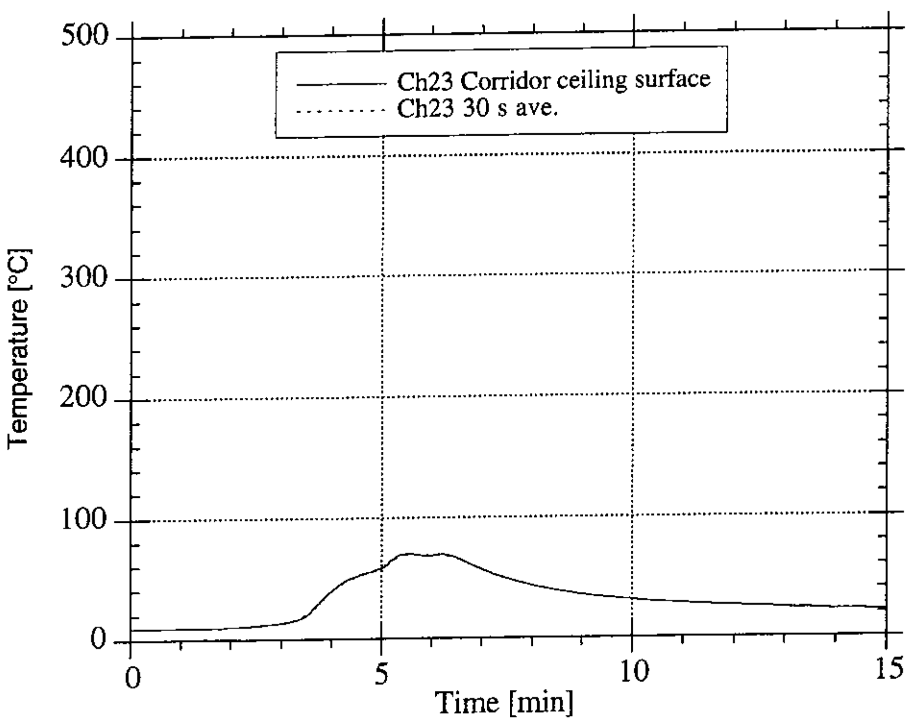
EQ 2.1


Ch22 Gas temperature 75 mm below ceiling
Ch22 30 s ave.
Temperature [°C]
Time [min]
0
100
200
300
400
500
0
5
10
15

EQ 2.1


Ch25 Plate thermometer above fire
Ch25 30 s ave.
1000
800
600
400
200
0
Temperature [°C]
0
5
10
15
Time [min]

EQ 2.1


Ch23 Corridor ceiling surface
Ch23 30 s ave.
500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]

Test EQ 2.2 Date: January 3, 1995

Test conditions

Fire scenario: Cabin, upper bunk

Combustibles: Mattress and pillow in upper bed on the left side. 3 mm plywood lining on all cabin walls.

Sprinkler type: Grinnell F950, 74 °C solder link, K=80, RTI=104

Number of Sprinklers installed: 1

Sprinkler location: Centric

Average system pressure during test: 0,79 bar

Average flow per sprinkler: ≈70 l/min

Average flux density based on actual floor area (12 m^2): ≈ 5,8 mm/min

Average flux density based on sprinkler coverage (16 m^2): ≈ 4,4 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
03:59	Automatic activation of the sprinkler
04:30	Fire suppressed, and resricted to pillow
07:43	Fire extinguished
13:39	Water flow turned off

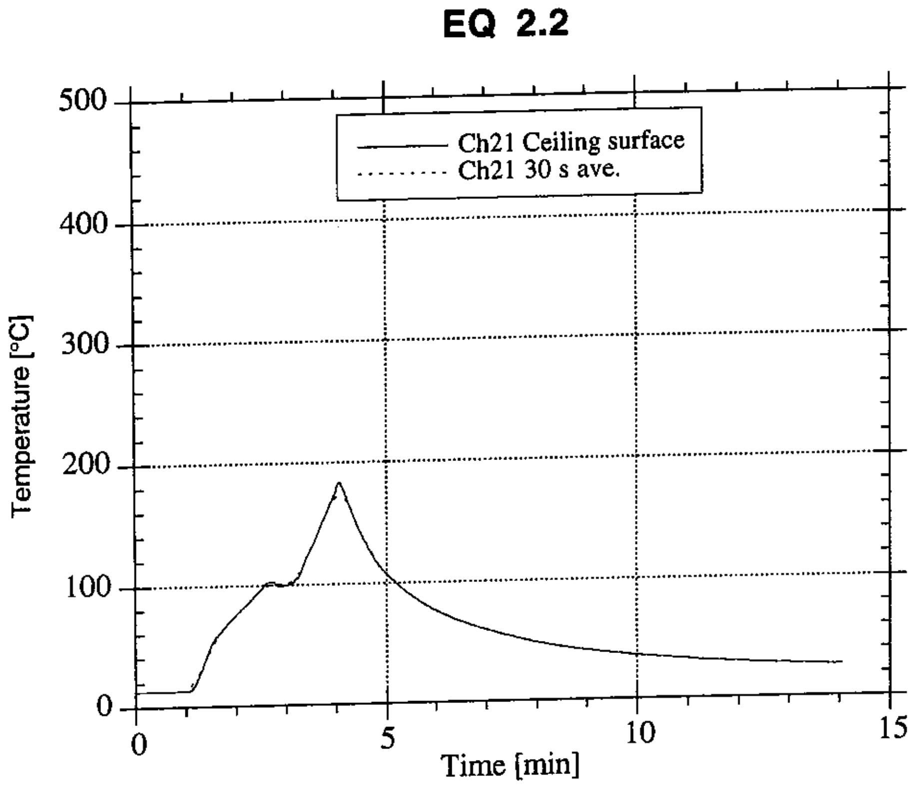
Results

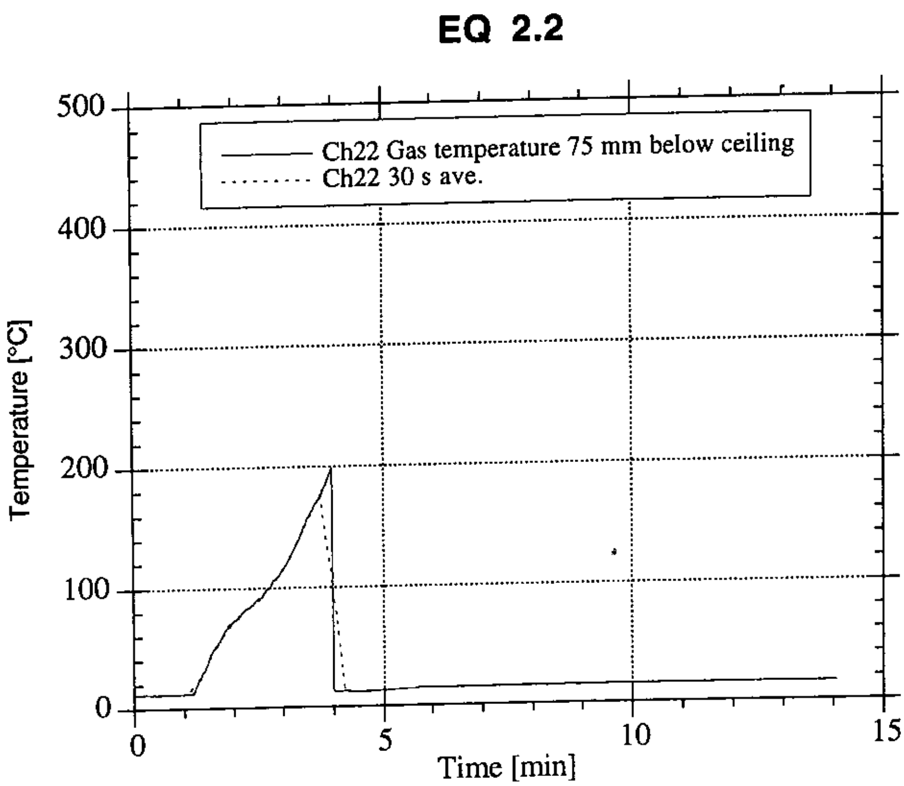
Maximum 30 second average temperatures

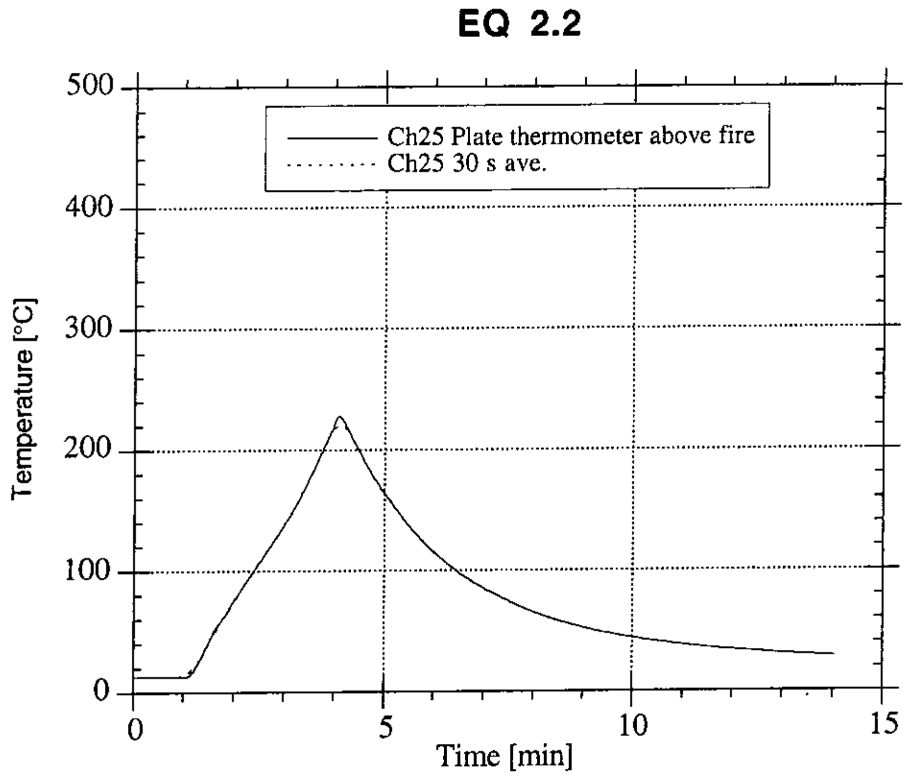
Ceiling surface temperature above point of ignition in cabin (channel 21)	172 °C
Gas temperature 75 mm from the ceiling in cabin center (channel 22)	177 °C
Plate thermometer above point of ignition in cabin (channel 25)	220 °C
Ceiling surface temperature centric in corridor (channel 23)	35 °C

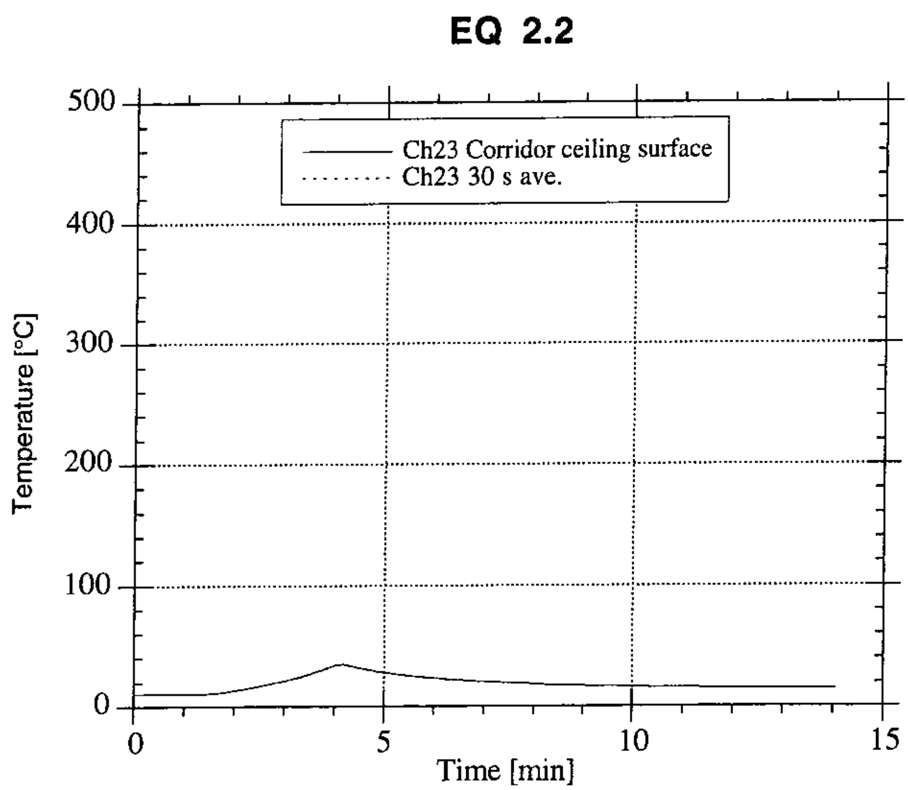
Damages to mattresses

	Mattress	Pillow	Backrest
Upper left side bed	1	28	-
Lower left side bed	-	-	-


EQ 2.2
Ch21 Ceiling surface
Ch21 30 s ave.
Temperature [°C]
Time [min]
0
100
200
300
400
500
0
5
10
15


EQ 2.2
Ch22 Gas temperature 75 mm below ceiling
Ch22 30 s ave.
Temperature [°C]
Time [min]
0
100
200
300
400
500
0
5
10
15


EQ 2.2
Ch25 Plate thermometer above fire
Ch25 30 s ave.
Temperature [°C]
Time [min]
0
100
200
300
400
500
0
5
10
15


EQ 2.2
Ch23 Corridor ceiling surface
Ch23 30 s ave.
Temperature [°C]
Time [min]
0
100
200
300
400
500
0
5
10
15

Test EQ 2.3 Date: January 3, 1995

Test conditions

Fire scenario: Corridor, between two sprinklers

Combustibles: A basket containing 8 pieces of polyether foam. 3 mm plywood lining on the corridor wall closest to the basket.

Sprinkler type: Grinnell F950, 74 °C solder link, K=80, RTI=104

Number of Sprinklers installed: 2

Sprinkler spacing: 4,0 m

Average system pressure during test: 0,70 bar, for whole discharge period

Average flow per sprinkler: ≈ 66 l/min

Average flux density based on actual floor area (6 m^2): 11,0 mm/min

Average flux density based on sprinkler coverage (16 m^2): 4,1 mm/min

Test record

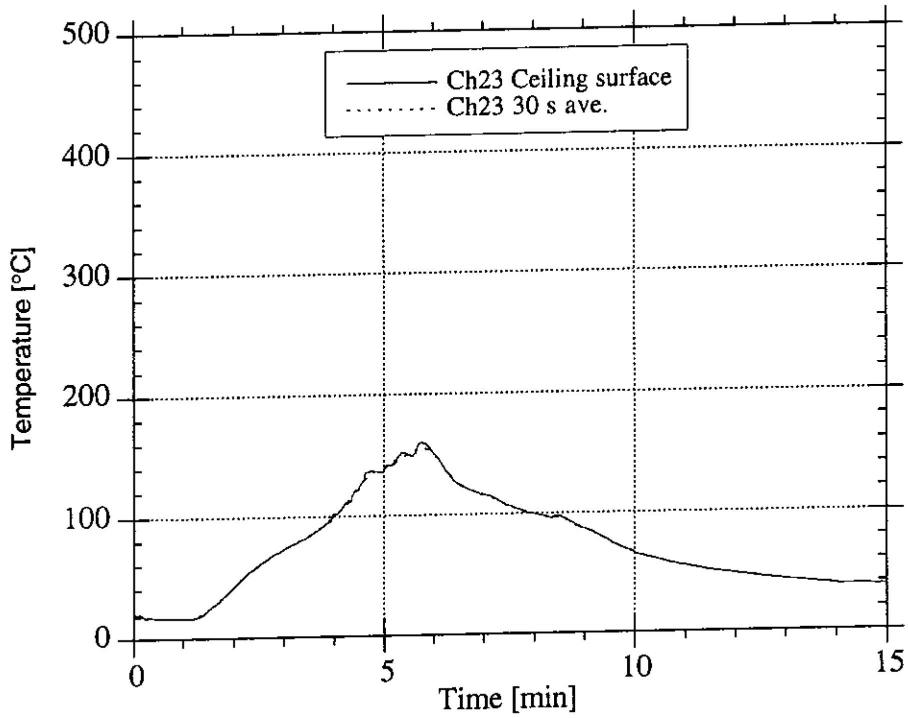
Min:s	Observation
00:00	Start of logging
01:00	Ignition
03:56	Automatic activation of first sprinkler, pressure 0,82 bar, flow 75 l/min
04:15	Automatic activation of second sprinkler, pressure decreases to 0,25 bar
04:30	Flames reach the ceiling
05:30	Fire spreads to wall lining
06:00	Pressure raised to 0,78 bar, flow 140 l/min
06:30	Fire in wall lining extinguished
09:00	Small fire, little fuel left
11:20	Fire extinguished
14:00	Water flow turned off

Results

Maximum 30 second average temperatures

Ceiling surface temperature centric in corridor (channel 23)	155 °C
Damages to pile of foam	90 %

EQ 2.3



Test EQ 2.5 Date: January 25, 1995

Test conditions

Fire scenario: Cabin, lower bunk

Combustibles: Mattress, pillow and backrest in lower and upper bed on the left side. 3 mm plywood lining on all cabin walls.

Sprinkler type: Grinnell F950, 74 °C solder link, K=80, RTI=104

Number of Sprinklers installed: 1

Sprinkler location: Centric

Average system pressure during test: 2,4 bar

Average flow per sprinkler: 123 l/min

Average flux density based on actual floor area (12 m^2): 10,2 mm/min

Average flux density based on sprinkler coverage (16 m^2): 7,7 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
02:32	The fire spreads to the backrest
03:47	Automatic activation of the sprinkler
04:50	Fire in ignition source and upper part of backrest
05:06	The visibility in the cabin reduced due to smoke and water vapour. No observations possible
07:50	Cotton cover of backrest glows, no flames
13:47	Water flow turned off

Results

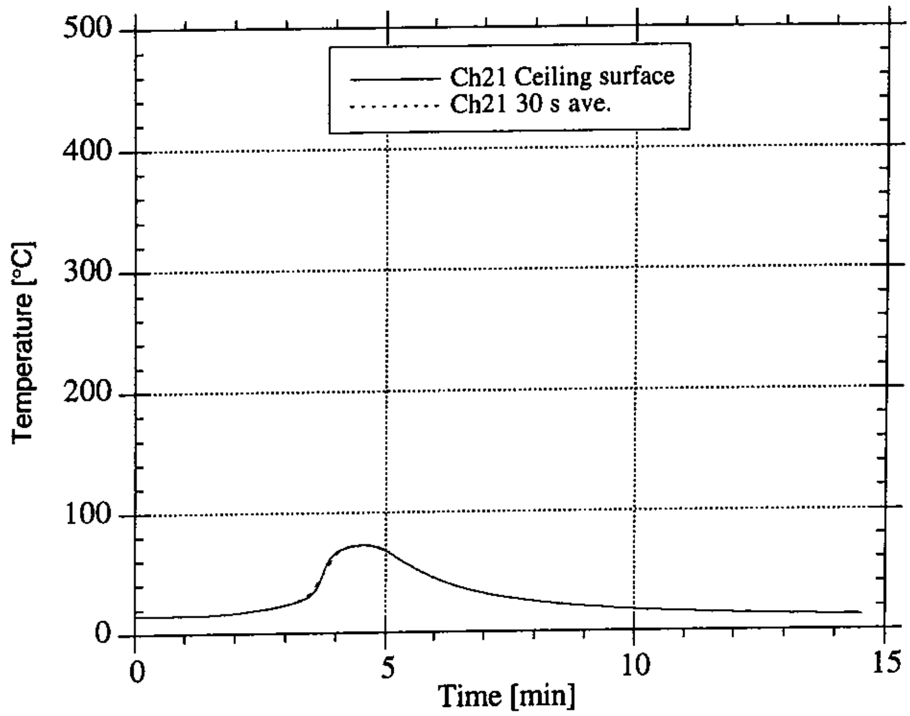
Maximum 30 second average temperatures

Ceiling surface temperature above point of ignition in cabin (channel 21)	113 °C
Gas temperature 75 mm from the ceiling in cabin center (channel 23)	154 °C
Plate thermometer above point of ignition in cabin (channel 22)	87 °C
Ceiling surface temperature centric in corridor (channel 24)	33 °C
Plate thermometer centric in corridor (channel 25)	34 °C

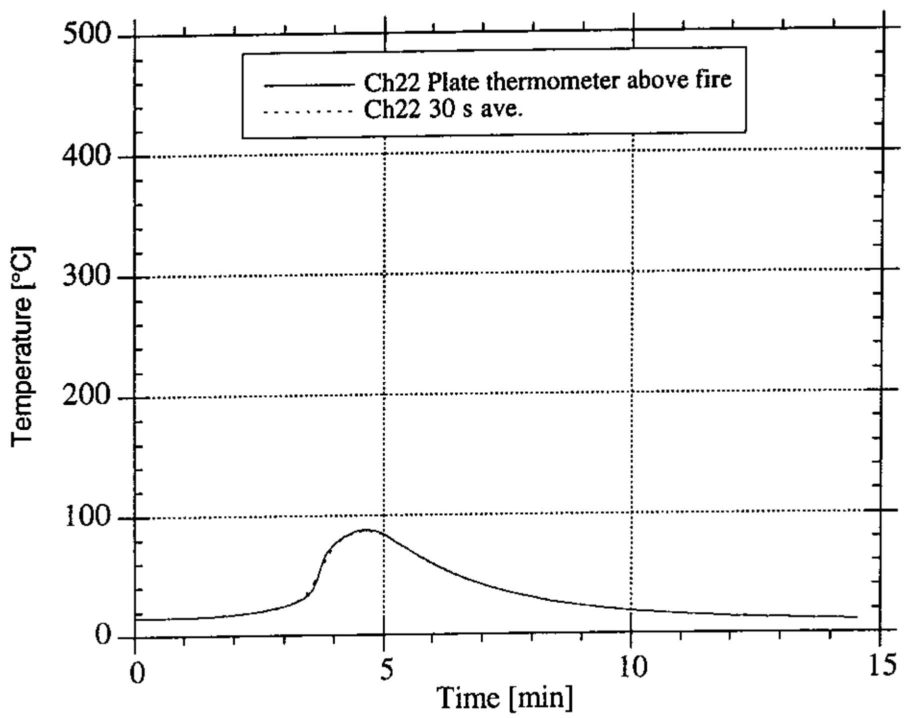
Damages to mattresses

	Mattress	Pillow	Backrest
Upper left side bed	0	0	-
Lower left side bed	3	20	8

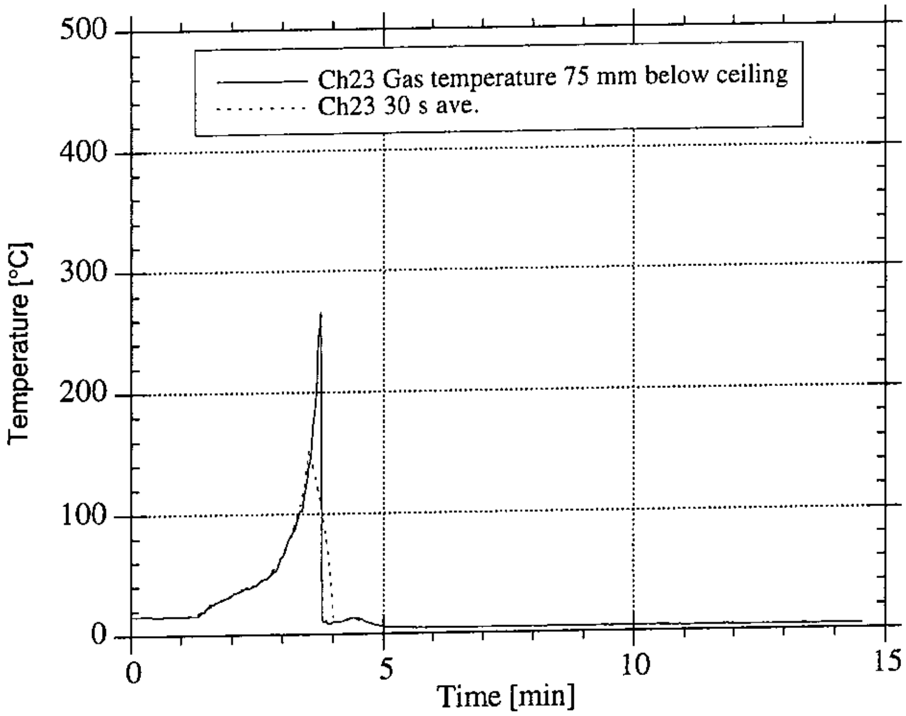
EQ 2.5


Ch21 Ceiling surface
Ch21 30 s ave.
500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]

EQ 2.5

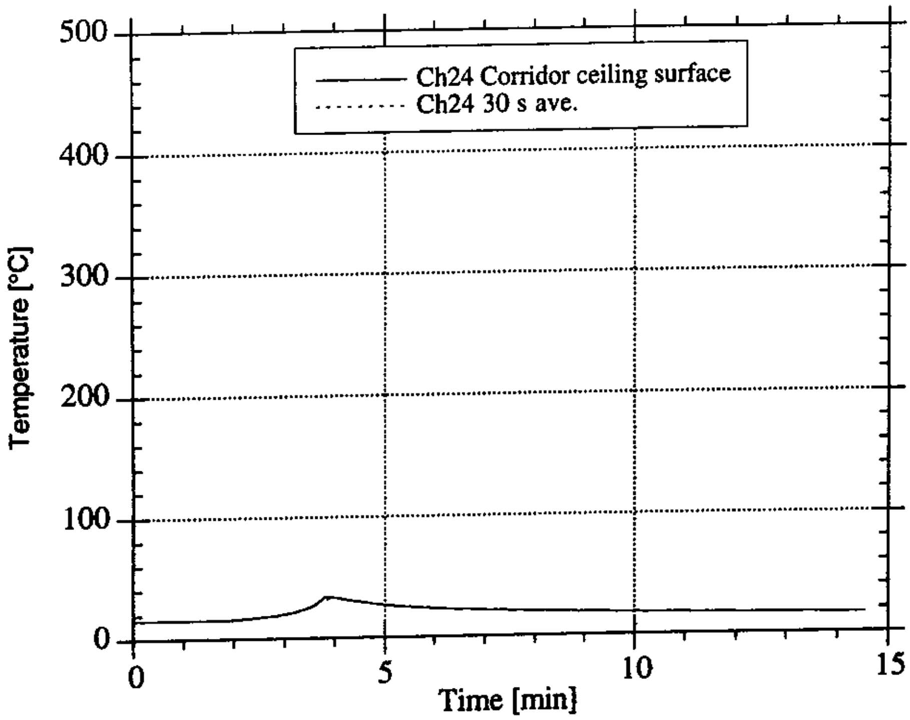

Ch22 Plate thermometer above fire
Ch22 30 s ave.
500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]

EQ 2.5

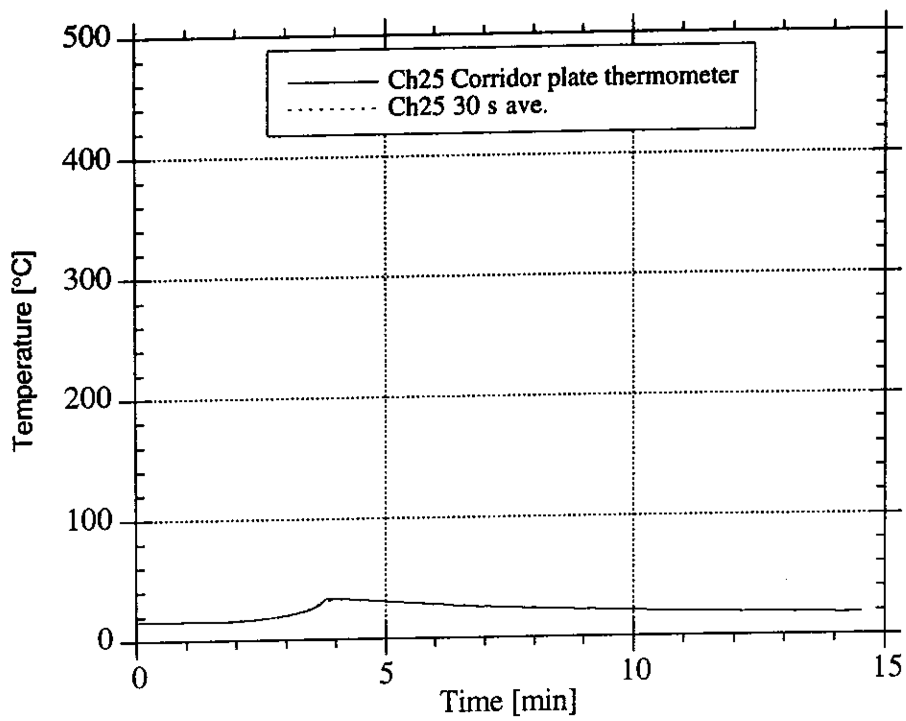


Ch23 Gas temperature 75 mm below ceiling
Ch23 30 s ave.
500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]

EQ 2.5


500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]
Ch24 Corridor ceiling surface
Ch24 30 s ave.

EQ 2.5


500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]
Ch25 Corridor plate thermometer
Ch25 30 s ave.

Test EQ 2.6 Date: January 25, 1995

Test conditions

Fire scenario: Cabin, arsonist

Combustibles: Mattress, pillow and backrest in lower and upper bed on the left side. 3 mm plywood lining on all cabin walls.

Sprinkler type: Grinnell F950, 74 °C solder link, K=80, RTI=104

Number of Sprinklers installed: 1

Sprinkler location: Centric

Average system pressure during test: 0,75 bar

Average flow per sprinkler: 69 l/min

Average flux density based on actual floor area (12 m^2): 5,7 mm/min

Average flux density based on sprinkler coverage (16 m^2): 4,3 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
01:35	Automatic activation of the sprinkler
02:00	Fire growth stops, probably due to that White Spirit is consumed
03:00	Backrest collapses over mattress and sheilds the fire except at head end where the backrest alreday is consumed
05:10	Fire observed at head end and at outer corner of foot end of lower bed
08:00	Small fires at head end, in ignition source and at outer corner of foot end of lower bed
11:40	Water flow turned off, manual extinguishment starts
12:30	Fire completely extinguished

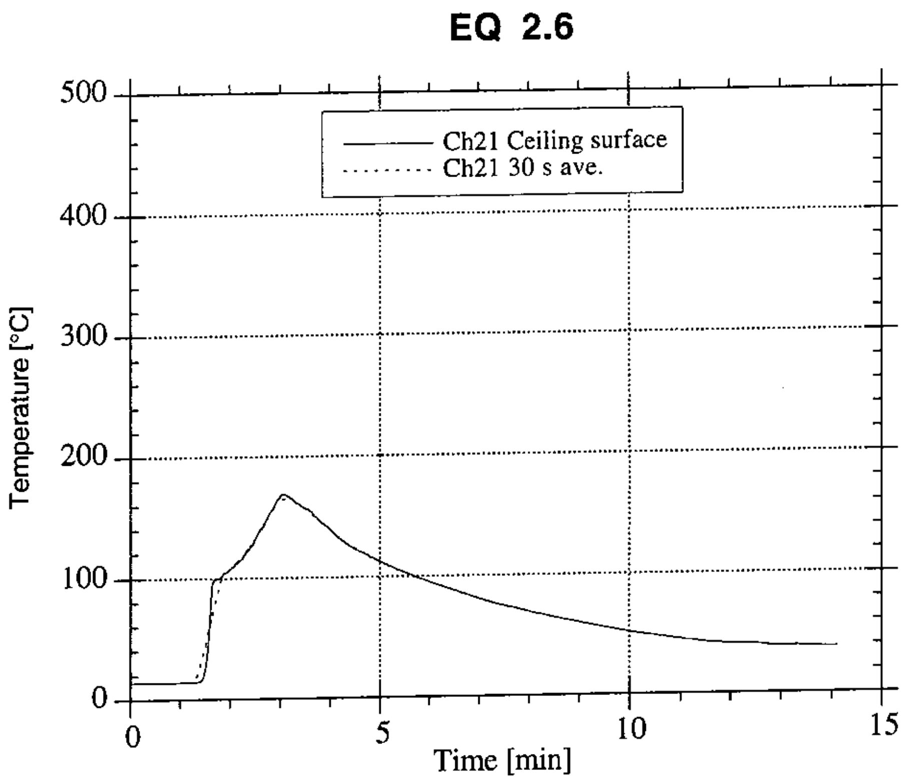
Results

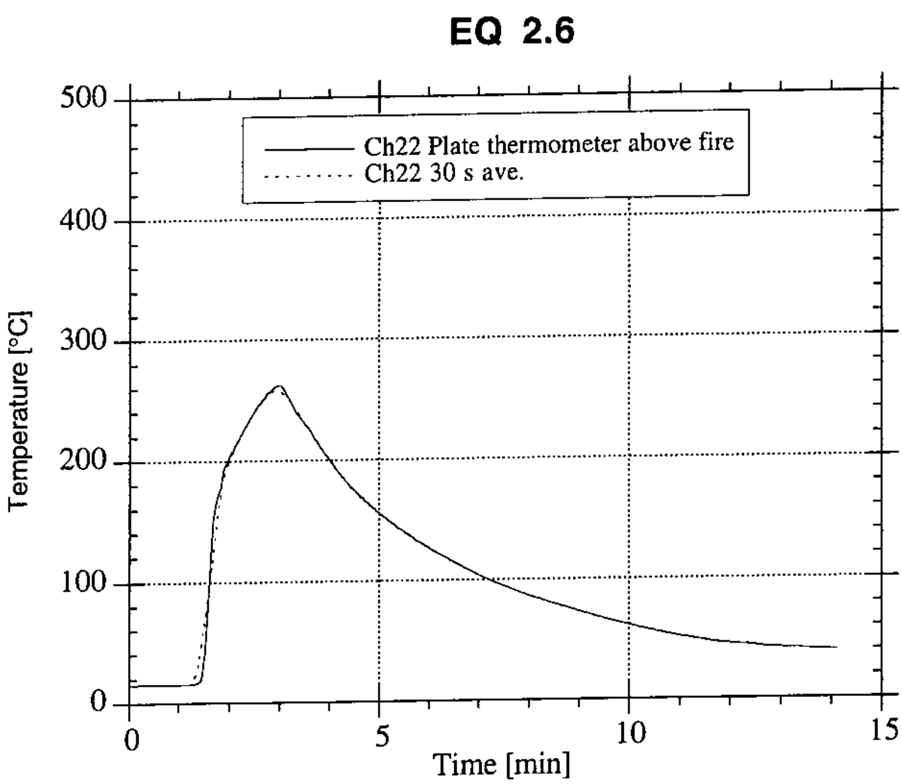
Maximum 30 second average temperatures

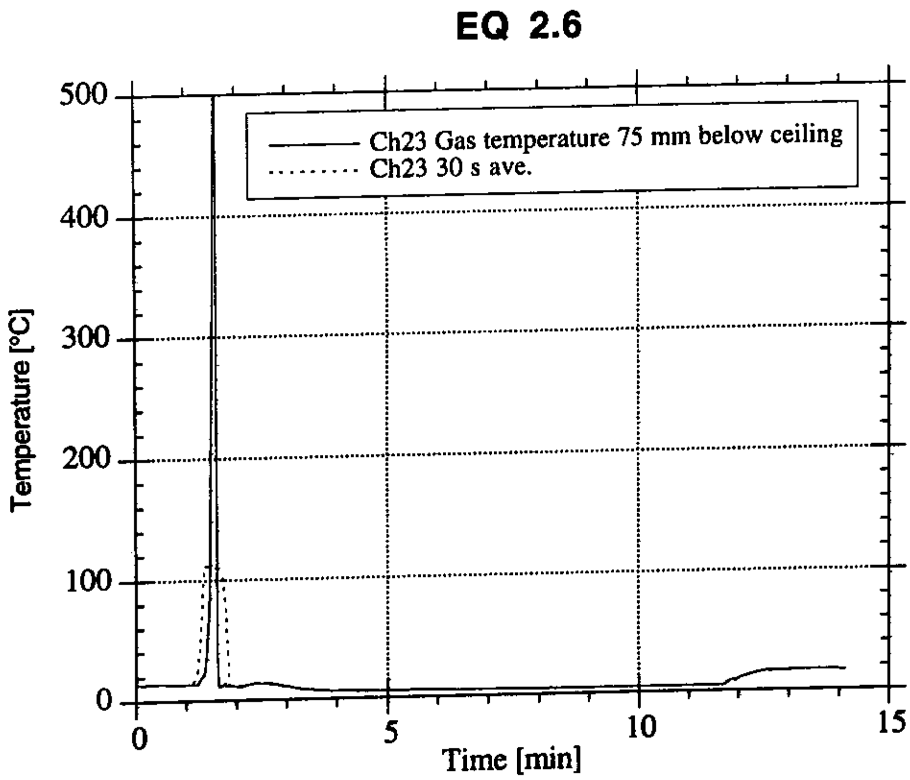
Ceiling surface temperature above point of ignition in cabin (channel 21)	166 °C
Gas temperature 75 mm from the ceiling in cabin center (channel 23)	112 °C
Plate thermometer above point of ignition in cabin (channel 22)	258 °C
Ceiling surface temperature centric in corridor (channel 24)	89 °C
Plate thermometer centric in corridor (channel 25)	105 °C

Damages to mattresses

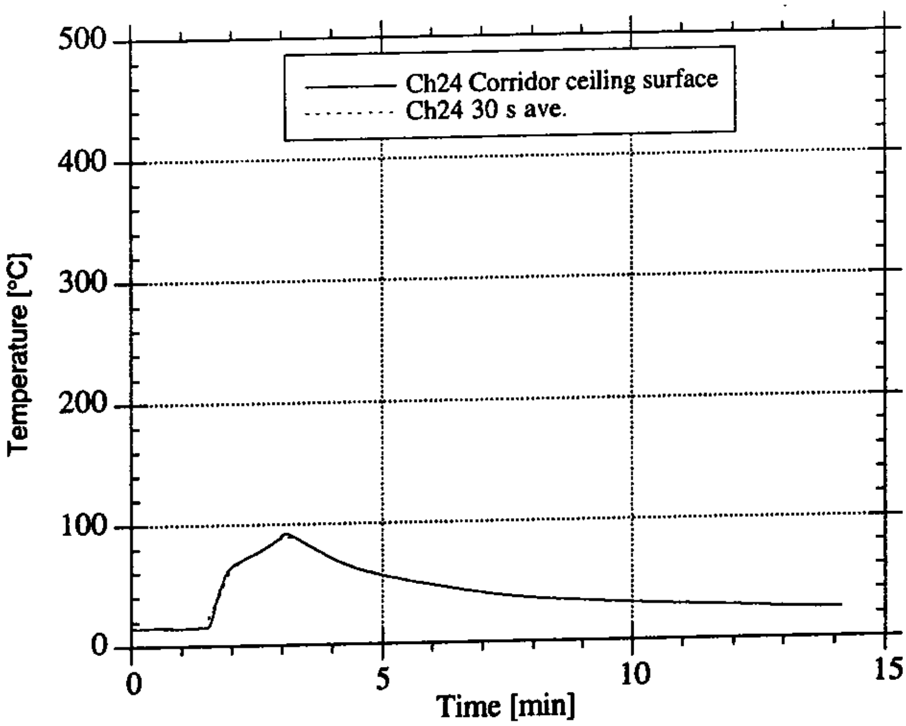
	Mattress	Pillow	Backrest
Upper left side bed	2 %	3 %	-
Lower left side bed	30 %	47 %	86 %


EQ 2.6
Ch21 Ceiling surface
Ch21 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]

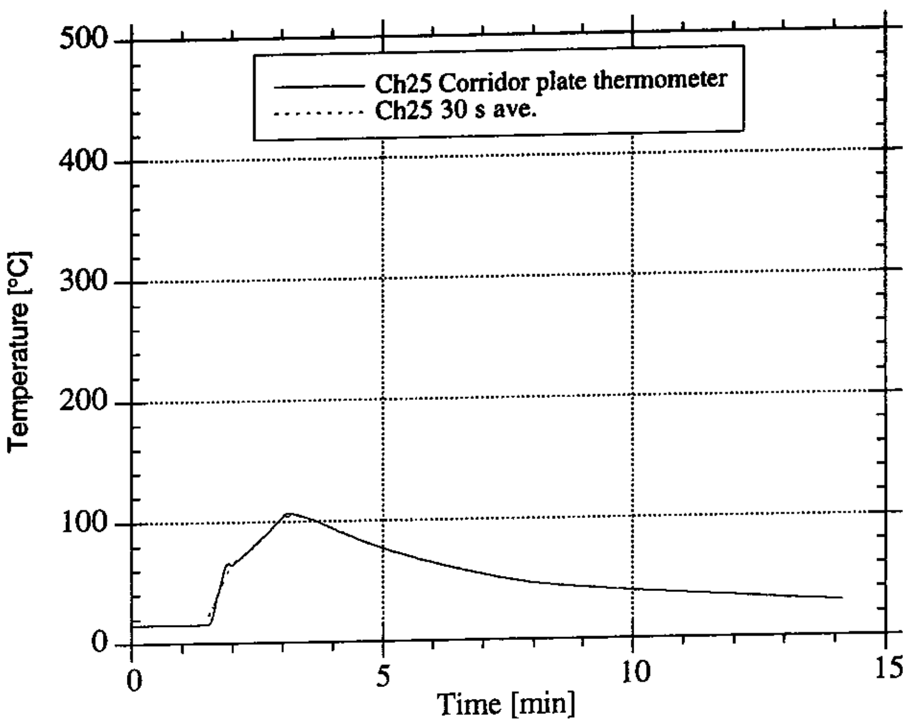

EQ 2.6
Ch22 Plate thermometer above fire
Ch22 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]


EQ 2.6
Ch23 Gas temperature 75 mm below ceiling
Ch23 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]

EQ 2.6


500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]
Ch24 Corridor ceiling surface
Ch24 30 s ave.

EQ 2.6


500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]
Ch25 Corridor plate thermometer
Ch25 30 s ave.

Test EQ 2.7 Date: January 25, 1995

Test conditions

Fire scenario: Corridor, below one sprinkler

Combustibles: A basket containing 8 pieces of polyether foam. 3 mm plywood lining on the corridor wall closest to the basket.

Sprinkler type: Grinnell F950, 74 °C solder link, K=80, RTI=104

Number of Sprinklers installed: 2

Sprinkler spacing: 4,0 m

Average system pressure during test: 0,81 bar

Average flow per sprinkler: 69 l/min

Average flux density based on actual floor area (6 m^2): 11,5 mm/min

Average flux density based on sprinkler coverage (16 m^2): 4,3 mm/min

Test record

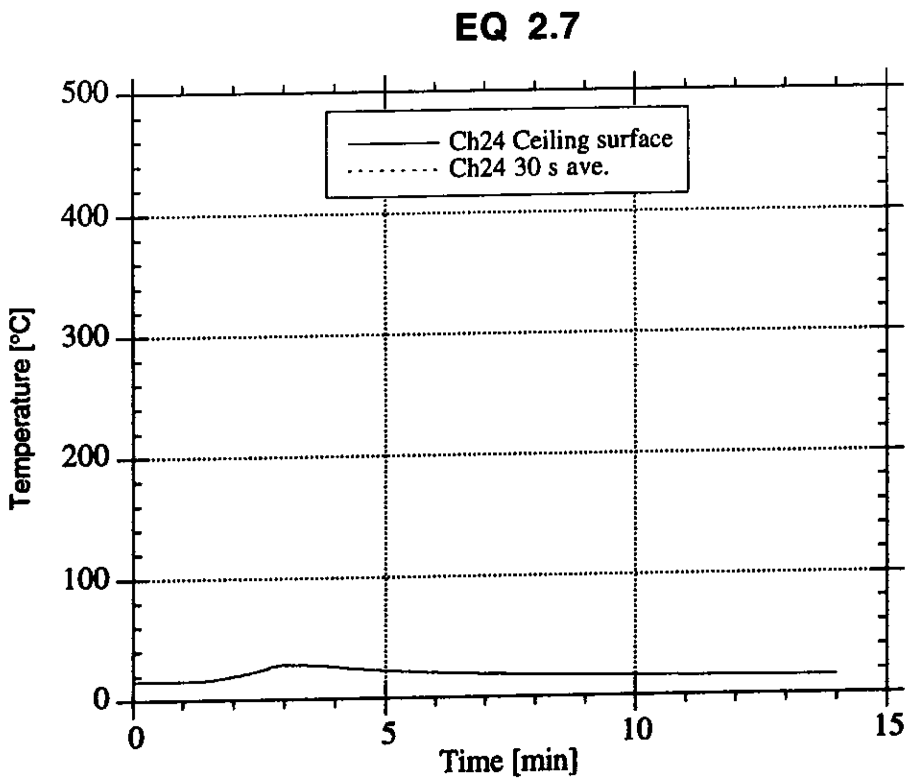
Min:s	Observation
00:00	Start of logging
01:00	Ignition
02:37	Automatic activation of first sprinkler
03:00	Flames reach 0,4 - 0,5 m over top of basket
04:05	Flames reach just above the top of pile
09:40	Fire is extinguished
12:37	Water flow turned off

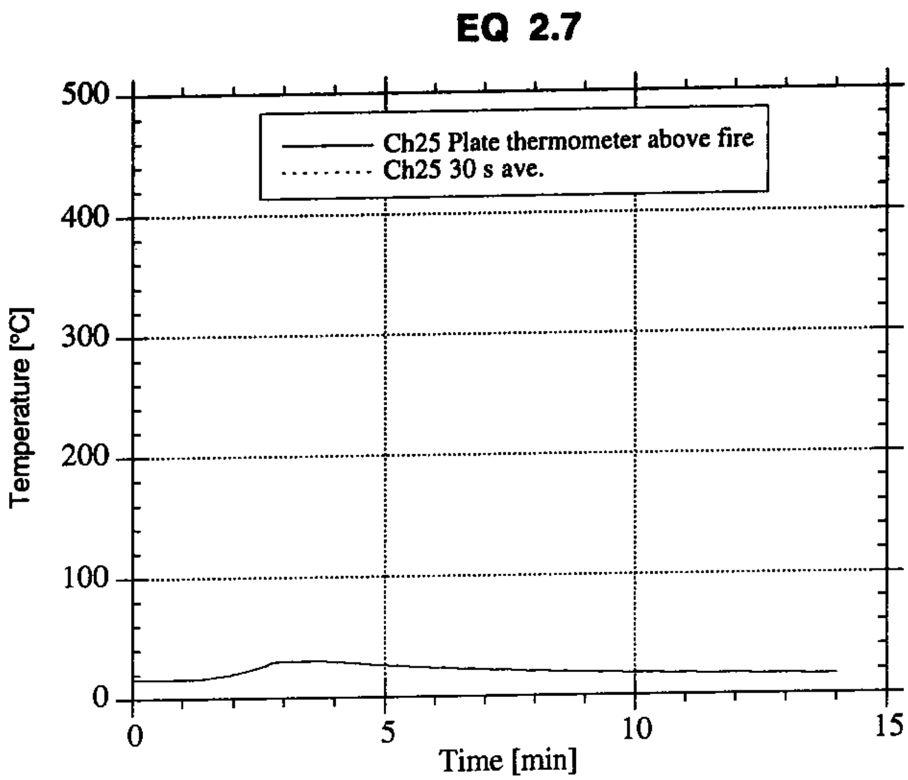
Results

Maximum 30 second average temperatures

Ceiling surface temperature centric in corridor (channel 24)	29 °C
Plate thermometer centric in corridor (channel 25)	31 °C

Damages to pile of foam	8 %


EQ 2.7
Ch24 Ceiling surface
Ch24 30 s ave.
Temperature [°C]
0
100
200
300
400
500
0
5
10
15
Time [min]


EQ 2.7
Ch25 Plate thermometer above fire
Ch25 30 s ave.
Temperature [°C]
0
100
200
300
400
500
0
5
10
15
Time [min]

Test EQ 2.8 Date: February 2, 1995

Test conditions

Fire scenario: Corridor, between two sprinklers

Combustibles: A basket containing 8 pieces of polyether foam. 3 mm plywood lining on the corridor wall closest to the basket.

Sprinkler type: Grinnell F950, 74 °C solder link, K=80, RTI=104

Number of Sprinklers installed: 2

Sprinkler spacing: 4,0 m

Average system pressure during test: 4,3 bar

Average flow per sprinkler: 162 l/min

Average flux density based on actual floor area (6 m^2): 27 mm/min

Average flux density based on sprinkler coverage (16 m^2): 10,1 mm/min

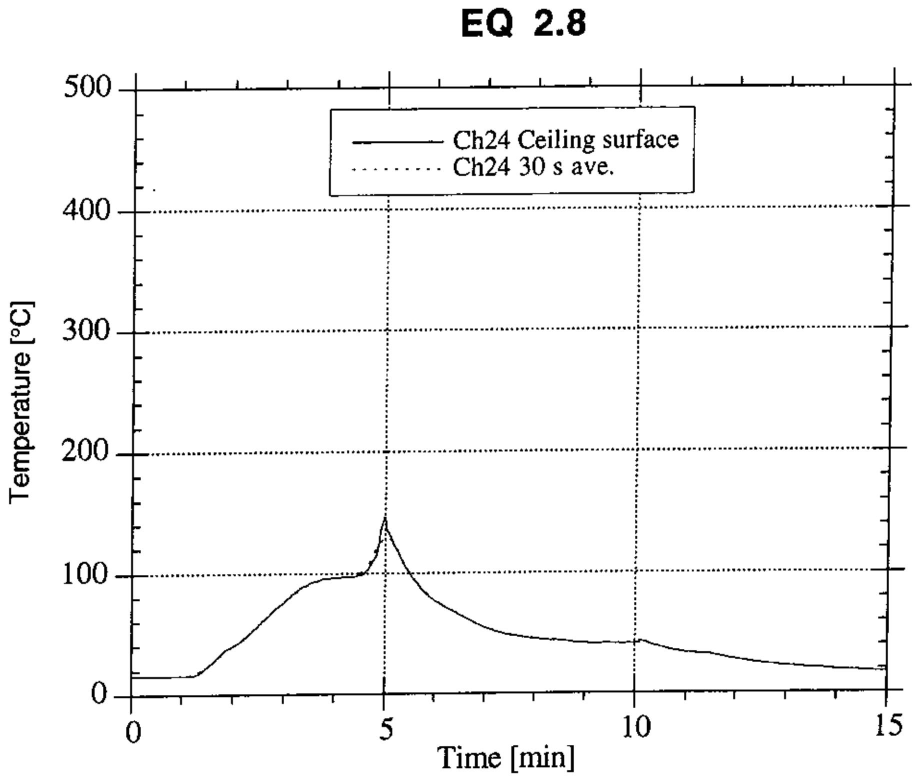
Test record

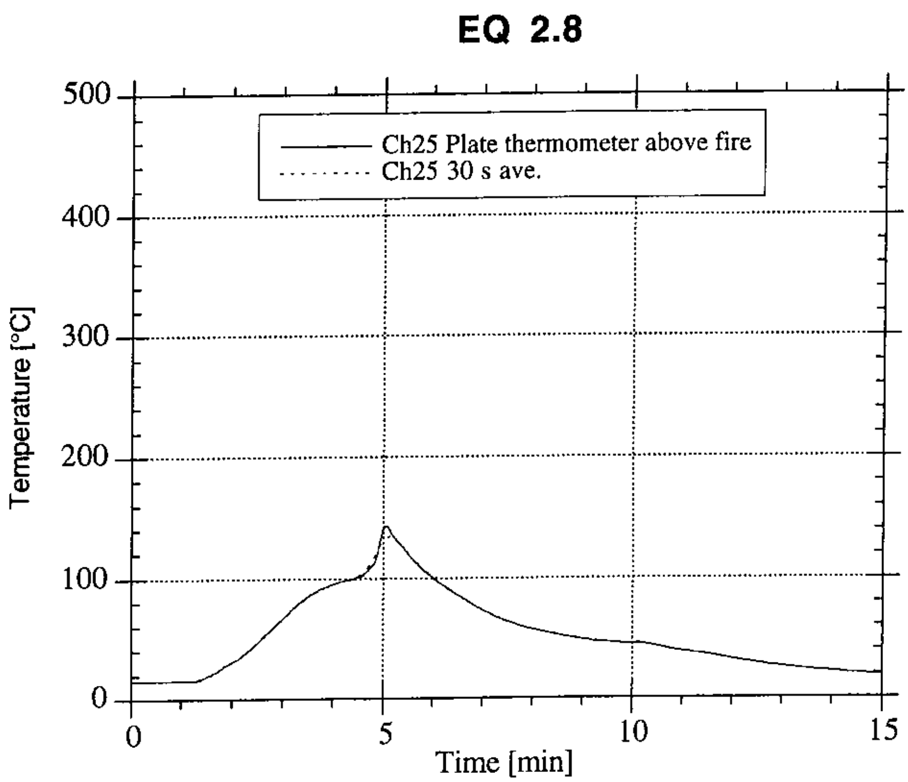
Min:s	Observation
00:00	Start of logging
01:00	Ignition
03:15	The whole top of the pile burns, poolfire underneath
04:30	Poolfire ignites pile from below
04:49	Automatic activation of first sprinkler
04:54	Automatic activation of second sprinkler
05:15	Flames reach almost to the top of the basket
06:00	Pile of foam tilts outwards
10:00	Pile of foam collapses partly
10:27	Pile of foam collapses again, the fire intensity decreases
11:00	Fire intensity increases, the flames measure approximately 0,3 m in height
14:49	Water flow turned off, fire extinguished manually

Results

Maximum 30 second average temperatures

Ceiling surface temperature centric in corridor (channel 24)	129 °C
Plate thermometer centric in corridor (channel 25)	135 °C
Damages to pile of foam	88 %


EQ 2.8
Ch24 Ceiling surface
Ch24 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]


EQ 2.8
Ch25 Plate thermometer above fire
Ch25 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]

Test EQ 2.9 Date: February 2, 1995

Test conditions

Fire scenario: Ventilated in corridor, between two sprinklers

Combustibles: A basket containing 8 pieces of polyether foam. 3 mm plywood lining on the corridor wall closest to the basket.

Sprinkler type: Grinnell F950, 74 °C solder link, K=80, RTI=104

Number of Sprinklers installed: 2

Sprinkler spacing: 4,0 m

Average system pressure during test: 1,0 bar

Average flow per sprinkler: 81 l/min

Average flux density based on actual floor area (6 m^2): 13,5 mm/min

Average flux density based on sprinkler coverage (16 m^2): 5,1 mm/min

Test record

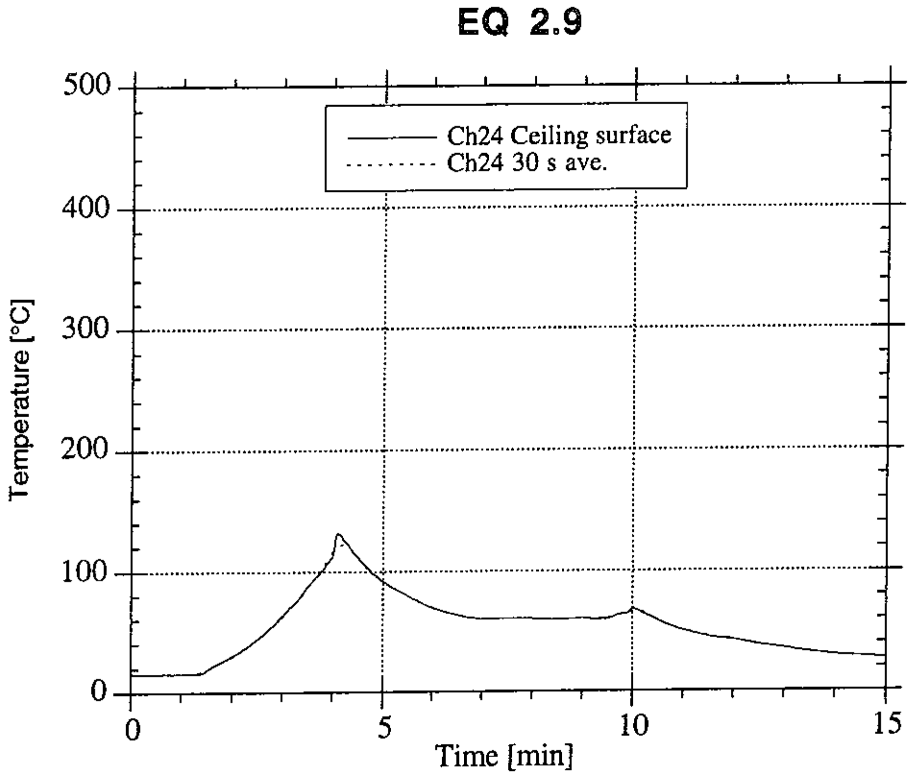
Min:s	Observation
00:00	Start of logging
01:00	Ignition
03:20	Poolfire ignites pile from below
03:59	Automatic activation of first sprinkler
04:03	Automatic activation of second sprinkler
04:25	The flames reach to the top of the basket
05:30	Pile of foam tilts outwards
08:56	Pile of foam collapses partly
09:58	Pile of foam collapses again, pieces of foam fall to the floor
11:50	More foam pieces fall to the floor
14:00	Water flow turned off, fire extinguished manually

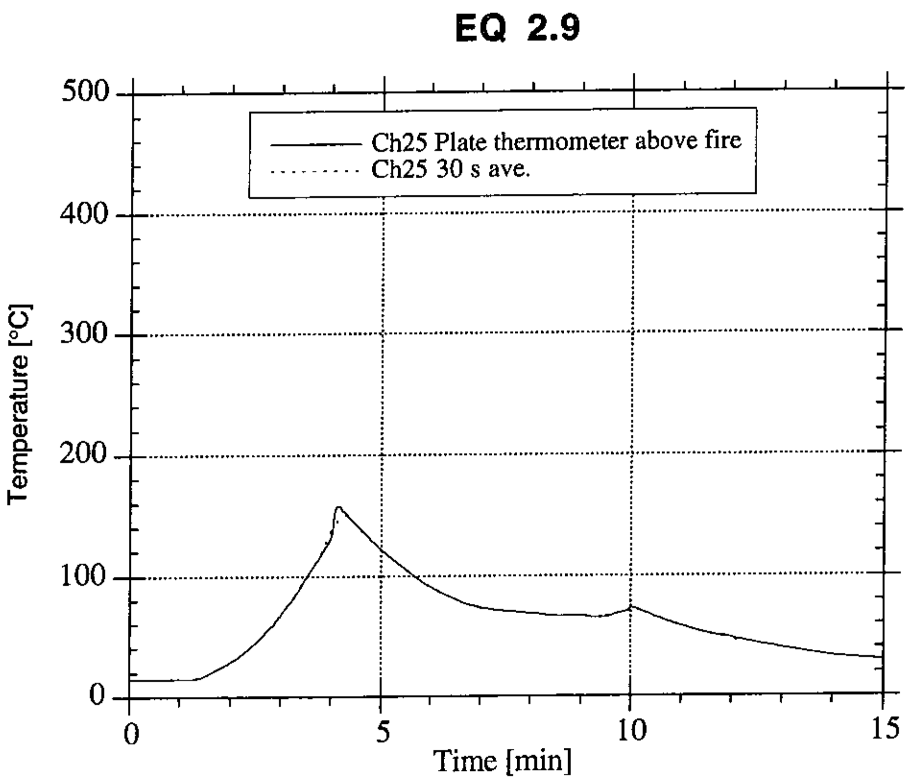
Results

Maximum 30 second average temperatures

Ceiling surface temperature centric in corridor (channel 24)	123 °C
Plate thermometer centric in corridor (channel 25)	151 °C

Damages to pile of foam	93 %


EQ 2.9
Ch24 Ceiling surface
Ch24 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]


EQ 2.9
Ch25 Plate thermometer above fire
Ch25 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]

Appendix B

Test protocolls and graphs from test series 1

Fire tests to establish acceptance criteria for systems equivalent to SOLAS II/2/12 in public spaces with 2,5 and 5 m ceiling height

Test EQ 1.1 Date: December 15, 1994

Test conditions

Fire scenario: Corner public space, 2,5 m ceiling height.

Combustibles: 3 sofas and plywood lining 3,6 m out from the corner

Sprinkler type: GW DD SSP F2, K 80, 5 mm 68 °C glass bulb, RTI value 110

Spacing: 4 m (half distance, 2 m to corner walls)

Pressure preset to 1 bar with one sprinkler open.

Average system pressure during test: 0,97 bar

Water flow per nozzle: 79 l/min

Average flux density: 4,9 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
02:15	Fire spreads to wall lining
02:30	Steady flames to the ceiling
03:06	Sprinkler closest to the corner activates, fire extinguished except for the ignition source
13:06	Sprinkler turned off, the fire is extinguished

Results

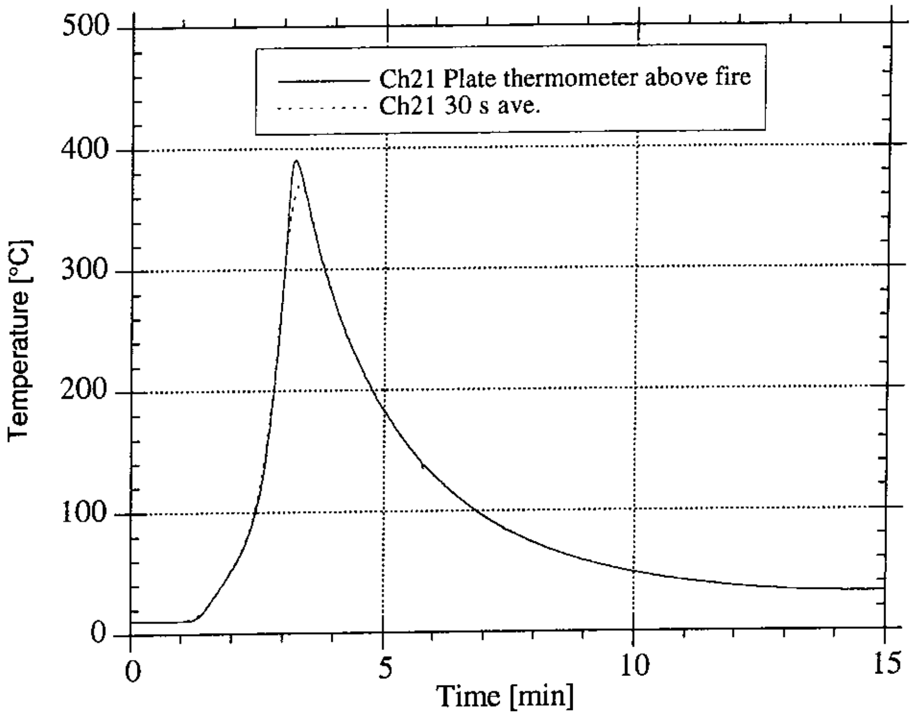
Maximum 30 second average temperatures

Ceiling surface above point of ignition (channel 22)	387 °C
Gas temperature at nozzle closest to point of ignition (channel 25)	128 °C
Plate thermometer above point of ignition (channel 21)	370 °C

Damages to mattresses

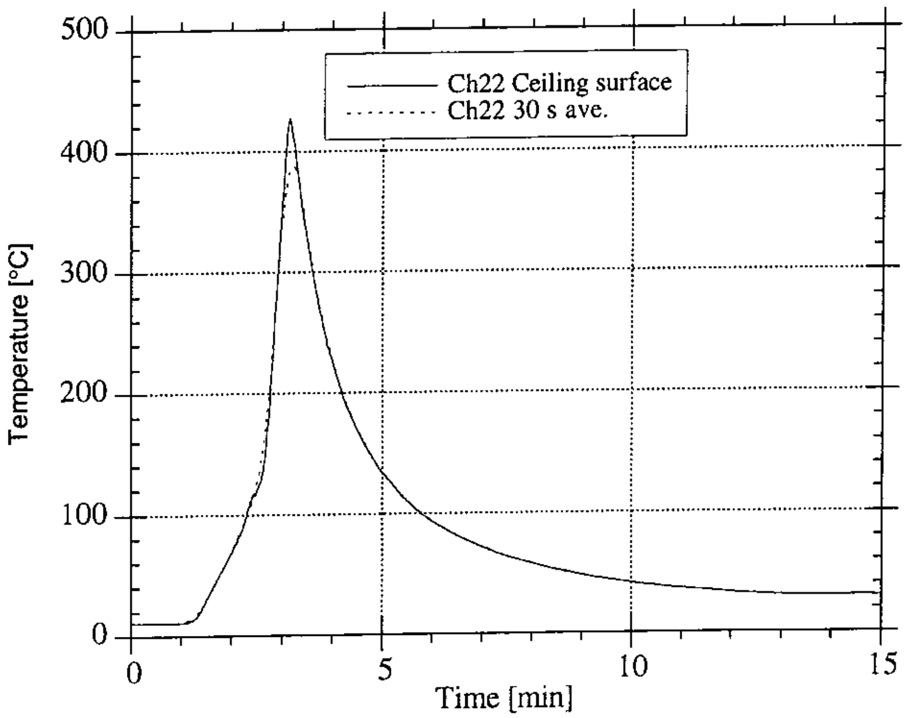
	Seat	Backrest
Sofa 1	< 1 %	5 %
Sofa 2	0 %	0 %
Sofa 3	0 %	0 %

EQ 1.1



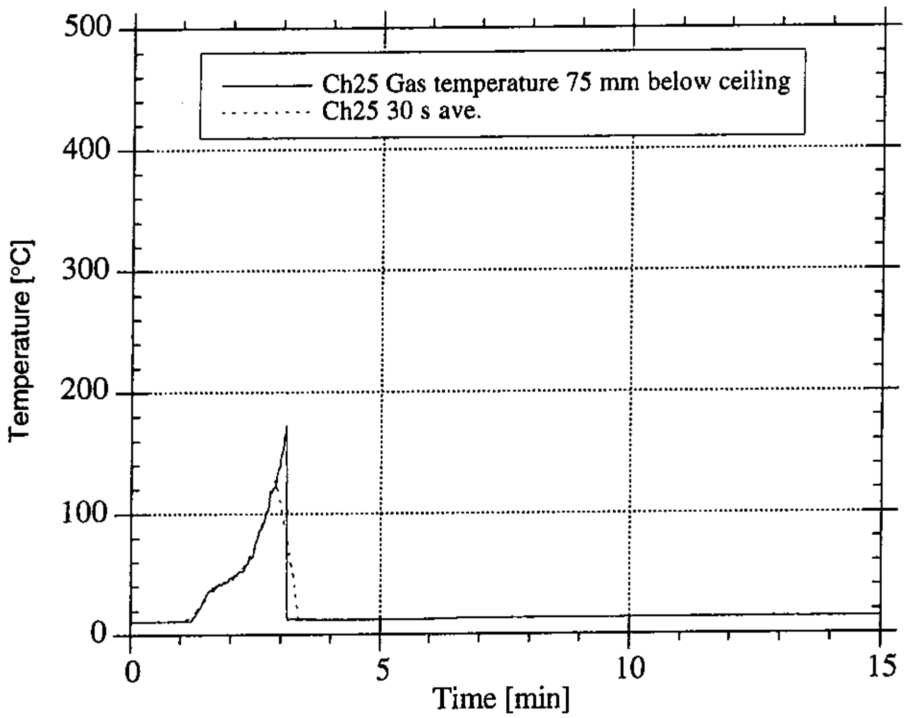
Ch21 Plate thermometer above fire
Ch21 30 s ave.
500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]

EQ 1.1



Ch22 Ceiling surface
Ch22 30 s ave.
500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]

EQ 1.1



Ch25 Gas temperature 75 mm below ceiling
Ch25 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]

Test EQ 1.2 Date: December 15, 1994

Test conditions

Fire scenario: Corner public space corner sprinkler disabled, 2,5 m ceiling height.

Combustibles: 3 sofas and plywood lining 3,6 m out from the corner

Sprinkler type: GW DD SSP F2, K 80, 5 mm 68 °C glass bulb, RTI value 110

Spacing: 4 m (half distance, 2 m to corner walls)

Water flow preset to 160 l/min with two sprinkler open.

Average system pressure during test: 1,1 bar

Water flow per nozzle: 84 l/min

Average flux density: 5,2 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
02:20	Fire spreads to wall lining
02:55	Steady flames to the ceiling
04:04	Sprinkler closest to sofa 3 activates
04:11	Sprinkler closest to sofa 2 activates
04:30	Sprinkler furthest from the corner activates, flashover soon afterwards
09:00	Sofa 1 burnt out
14:00	Sprinkler turned off
14:15	Fire extinguished manually

Results

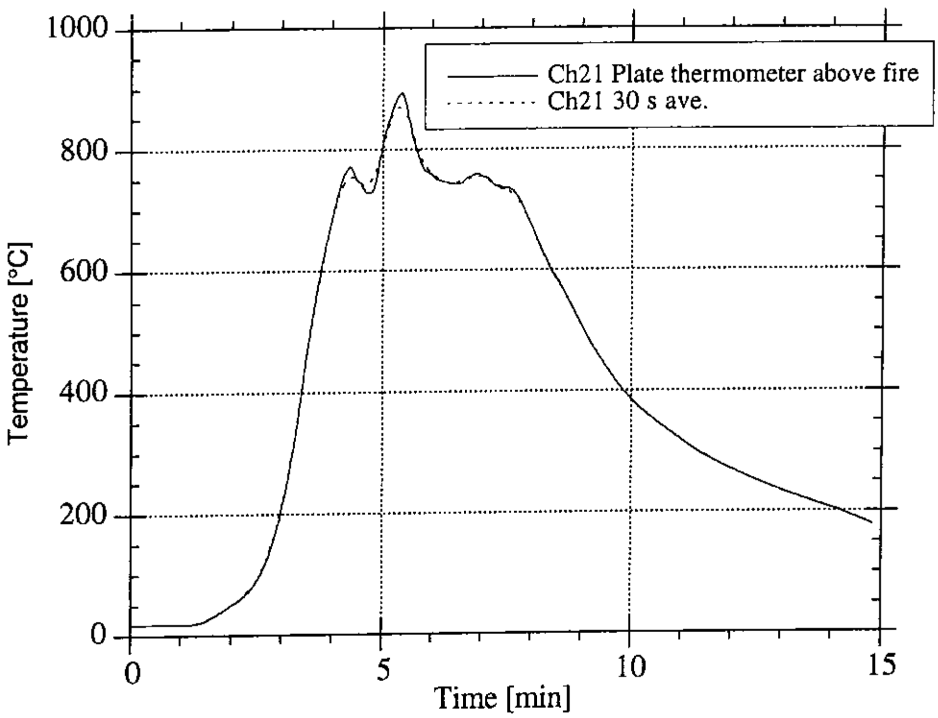
Maximum 30 second average temperatures

Ceiling surface above point of ignition (channel 22)	667 °C
Gas temperature at nozzle closest to point of ignition (channel 25)	980 °C
Plate thermometer above point of ignition (channel 21)	870 °C

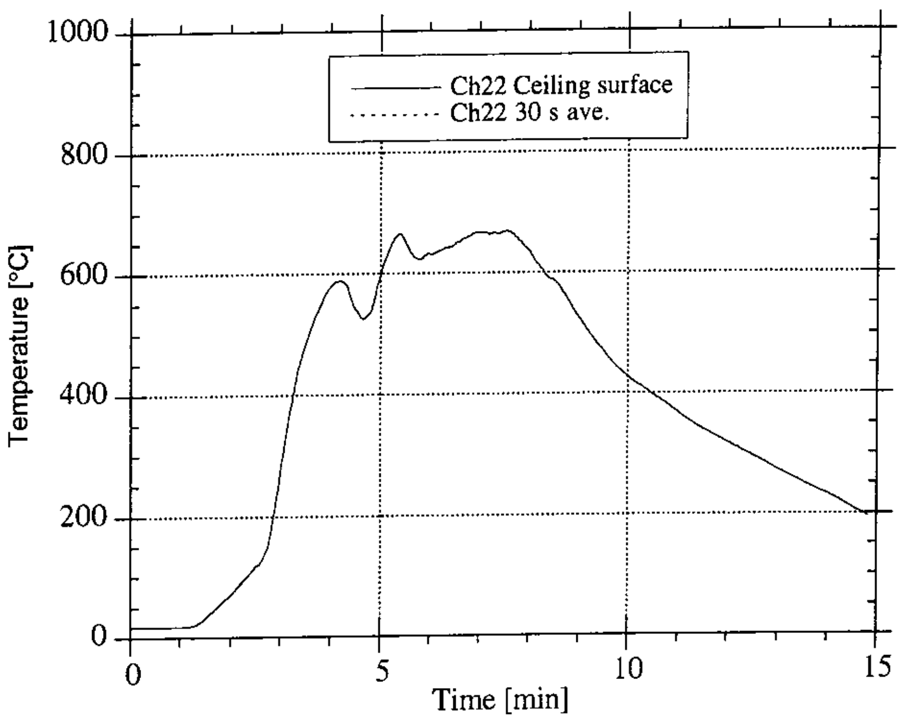
Damages to mattresses

	Seat	Backrest
Sofa 1	100 %	100 %
Sofa 2	90 %	90 %
Sofa 3	65 %	88 %

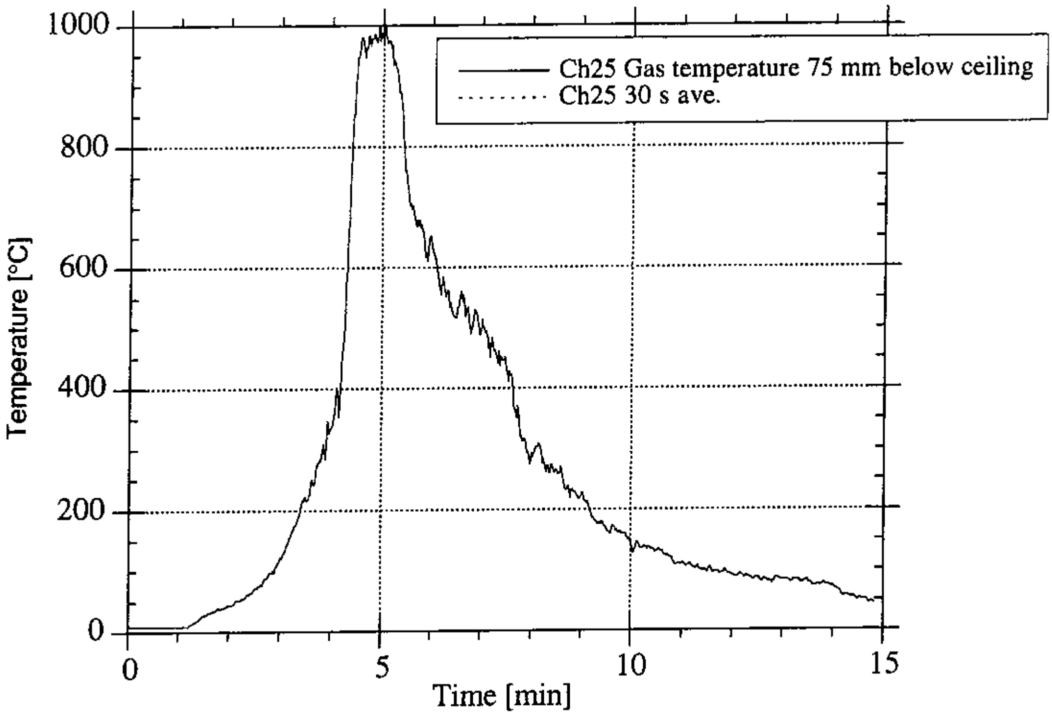
EQ 1.2


Ch21 Plate thermometer above fire
Ch21 30 s ave.
Temperature [°C]
Time [min]
0
200
400
600
800
1000
0
5
10
15

EQ 1.2


Ch22 Ceiling surface
Ch22 30 s ave.
Temperature [°C]
Time [min]
0
200
400
600
800
1000
0
5
10
15

EQ 1.2



Ch25 Gas temperature 75 mm below ceiling
Ch25 30 s ave.
Temperature [°C]
1000
800
600
400
200
0
0
5
10
15
Time [min]

Test EQ 1.3 Date: December 16 1994

Test conditions

Fire scenario:	Corner public space, 2,5 m ceiling height.
Combustibles:	3 sofas and plywood lining 3,6 m out from the corner
Sprinkler type:	Grinnell F950, 74 °C solder link, K=80, RTI=104
Spacing:	4 m (half distance, 2 m to corner walls)

Water flow preset to 1 bar and 80 l/min with 1 sprinkler open.

Average system pressure during test: 0,99 bar

Water flow per nozzle: 79 l/min

Average flux density: 5,0 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
02:48	Steady flames to the ceiling
03:25	Sprinkler closest to the corner activates
04:40	Flames approximately 0,1 m high
10:00	Fire only glowing
13:00	Small fire behind cotton fabric
13:25	Sprinkler turned off, a small fire is extinguished manually

Results

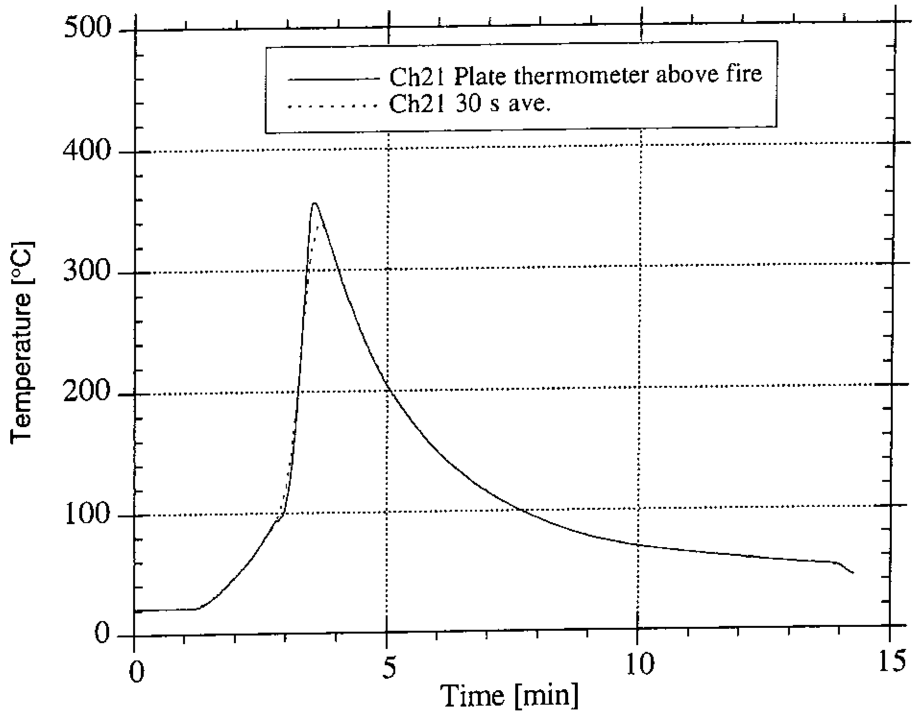
Maximum 30 second average temperatures

Ceiling surface above point of ignition (channel 22)	300 °C
Gas temperature at nozzle closest to point of ignition (channel 25)	142 °C
Plate thermometer above point of ignition (channel 21)	341 °C

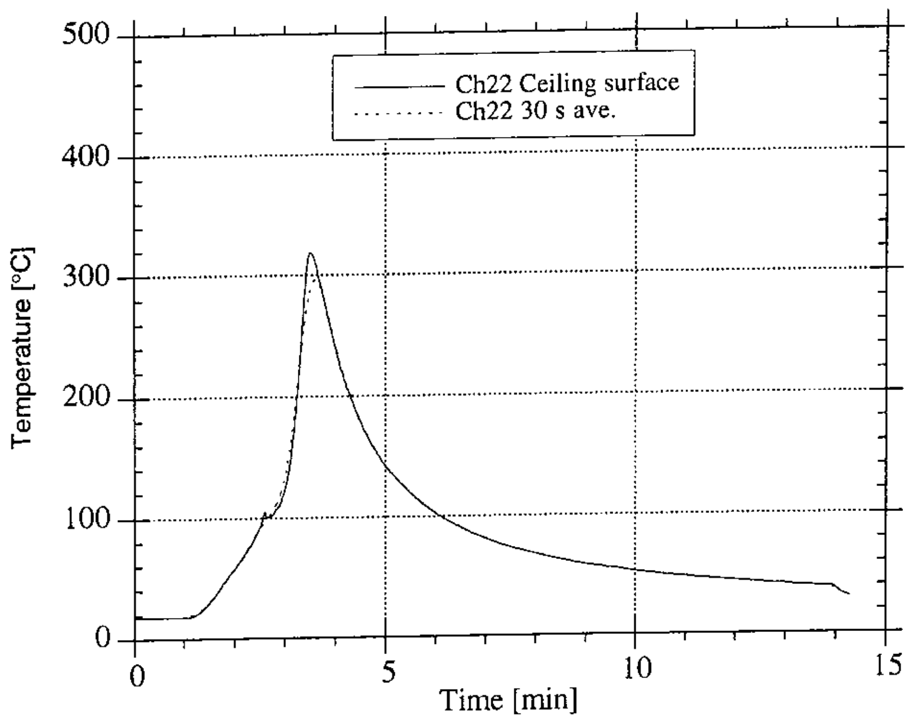
Damages to mattresses

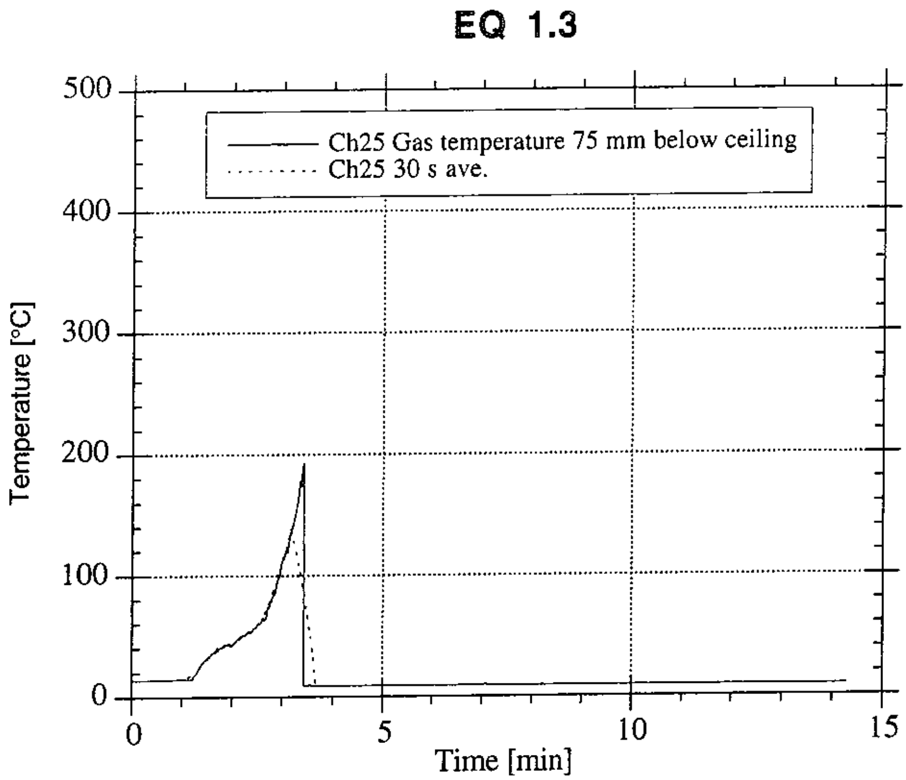
	Seat	Backrest
Sofa 1	< 1 %	10 %
Sofa 2	0 %	0 %
Sofa 3	0 %	0 %

EQ 1.3


Ch21 Plate thermometer above fire
Ch21 30 s ave.
500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]

EQ 1.3


Ch22 Ceiling surface
Ch22 30 s ave.
500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]


EQ 1.3
Ch25 Gas temperature 75 mm below ceiling
Ch25 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]

Test EQ 1.4 Date: December 19, 1994

Test conditions

Fire scenario:	Open public space, 2,5 m ceiling height, Ignition between 4 sprinklers
Combustibles:	4 sofas
Sprinkler type:	Grinnell F950, 74 °C solder link, K=80, RTI=104
Spacing:	4 m

Water flow preset to 1 bar and 160 l/min with 2 sprinkler open.

Average system pressure during test: 0,97 bar

Water flow per nozzle: 79 l/min

Average flux density: 4,9 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
03:32	Flames reach the ceiling
03:40	Fire spreads to sofa 2
04:34	First sprinkler activates
04:42	Second sprinkler activates
04:59	Third sprinkler activates
05:10	Fourth sprinkler activates, fire suppressed except between backrests
07:00	Fire intensified between sofas 1 and 2 towards sofa 4
09:00	Fire spreads to sofa 4
14:00	Fire only in backrest of sofa 4
14:35	Sprinkler turned off
15:00	Fire extinguished manually

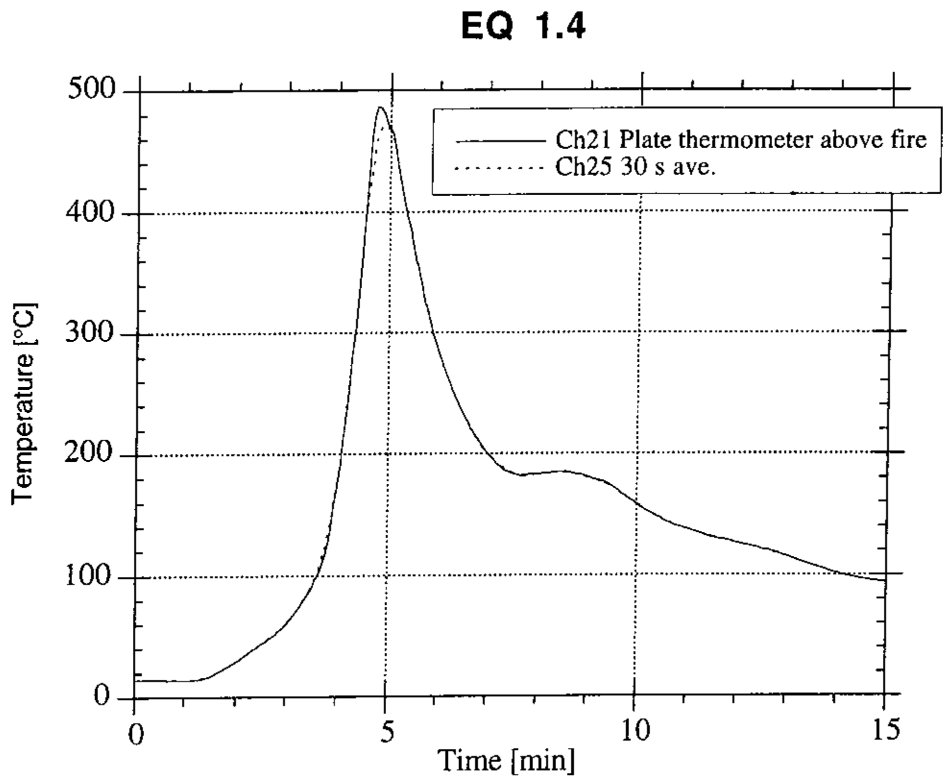
Results

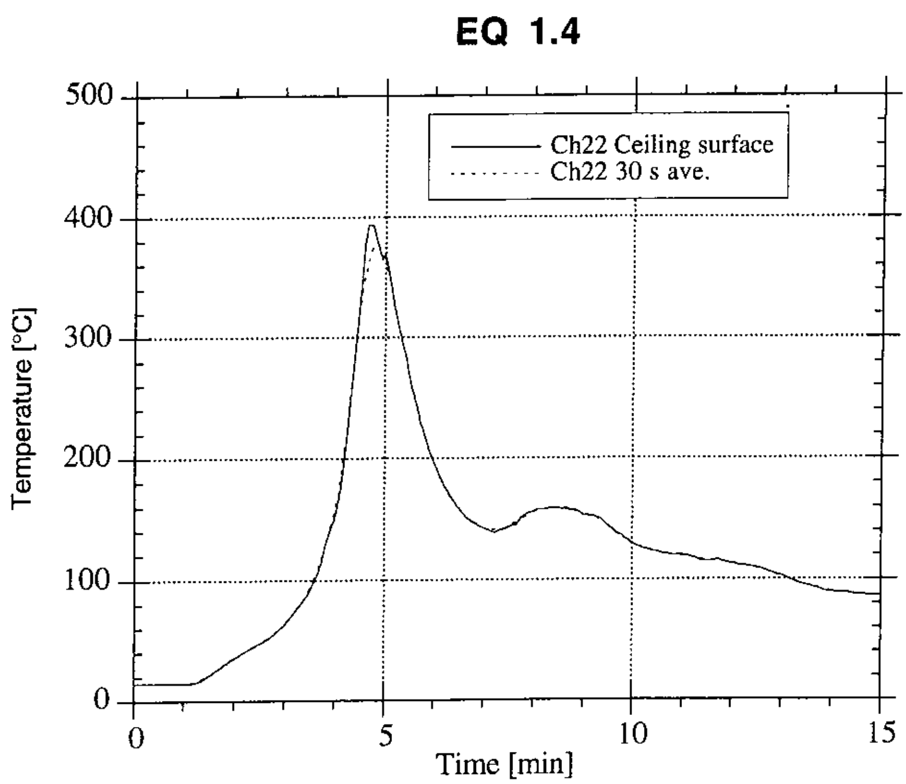
Maximum 30 second average temperatures

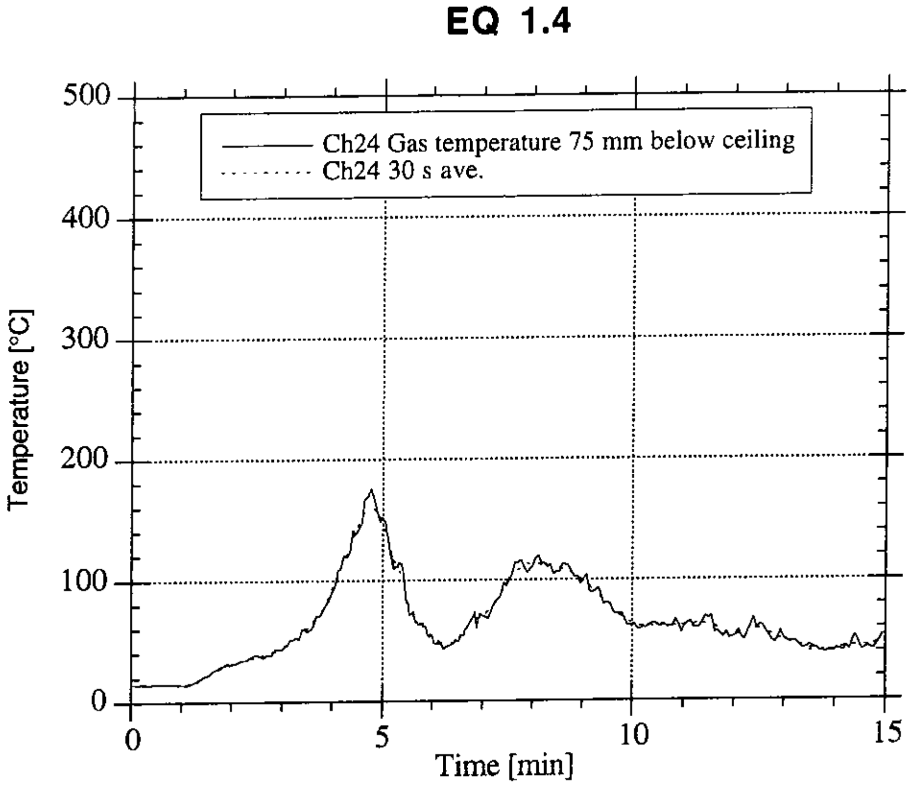
Ceiling surface above point of ignition (channel 22)	378 °C
Gas temperature 1,8 m from the point of ignition (channel 24)	159 °C
Plate thermometer above point of ignition (channel 21)	472 °C

Damages to mattresses

	Seat	Backrest
Sofa 1	15 %	90 %
Sofa 2	1 %	96 %
Sofa 3	0 %	Slightly burnt
Sofa 4	0 %	24 %


EQ 1.4
Ch21 Plate thermometer above fire
Ch25 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]


EQ 1.4
Ch22 Ceiling surface
Ch22 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]


EQ 1.4
Ch24 Gas temperature 75 mm below ceiling
Ch24 30 s ave.
Temperature [°C]
Time [min]
0
100
200
300
400
500
0
5
10
15

Test EQ 1.5 Date: December 19, 1994

Test conditions

Fire scenario: Open public space, 2,5 m ceiling height, Ignition between 4 sprinklers

Combustibles: 4 sofas

Sprinkler type: Grinnell F950, 74 °C solder link, K=80, RTI=104

Spacing: 4 m

Water flow preset to 4 bar and 320 l/min with 2 sprinkler open.

Average system pressure during test: 4,0 bar

Water flow per nozzle: 160 l/min

Average flux density: 10,0 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
03:10	Fire spreads to sofa 2
03:30	Flames reach the ceiling
04:18	First sprinkler activates
04:30	Fire spreads to sofa 4
04:40	Second sprinkler activates
07:00	Fire along the entire length of the backrest of sofa 4
07:40	Fire intensity starts decreasing because of lack of combustibles
14:00	Fire only in backrest of sofa 4
14:18	Sprinkler turned off, fire in two places
15:03	Fire extinguished manually

Results

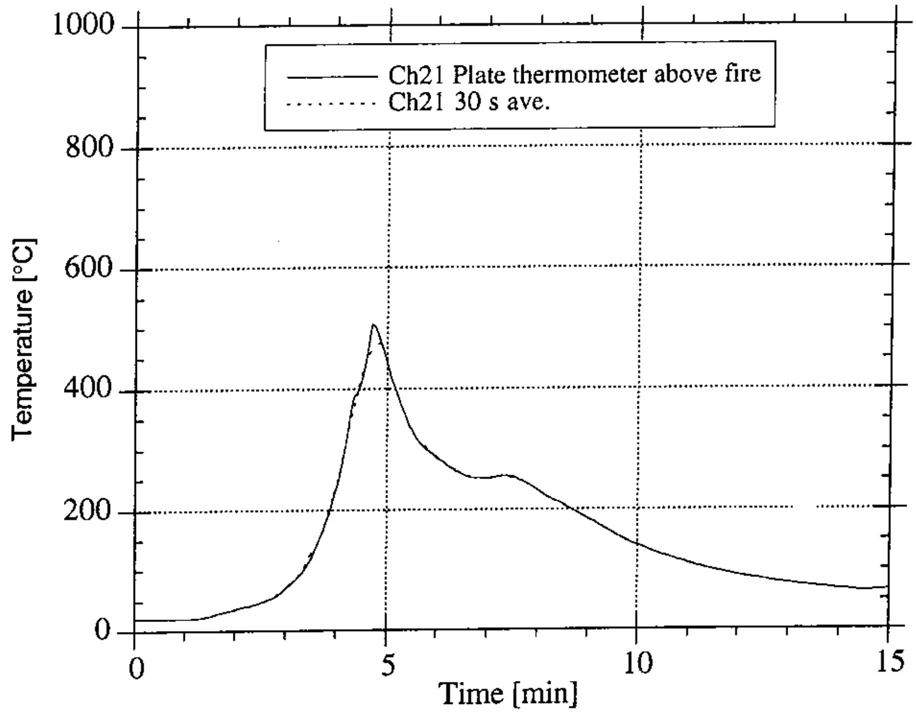
Maximum 30 second average temperatures

Ceiling surface above point of ignition (channel 22)	345 °C
Gas temperature 1,8 m from the point of ignition (channel 24)	203 °C
Plate thermometer above point of ignition (channel 21)	475 °C

Damages to mattresses

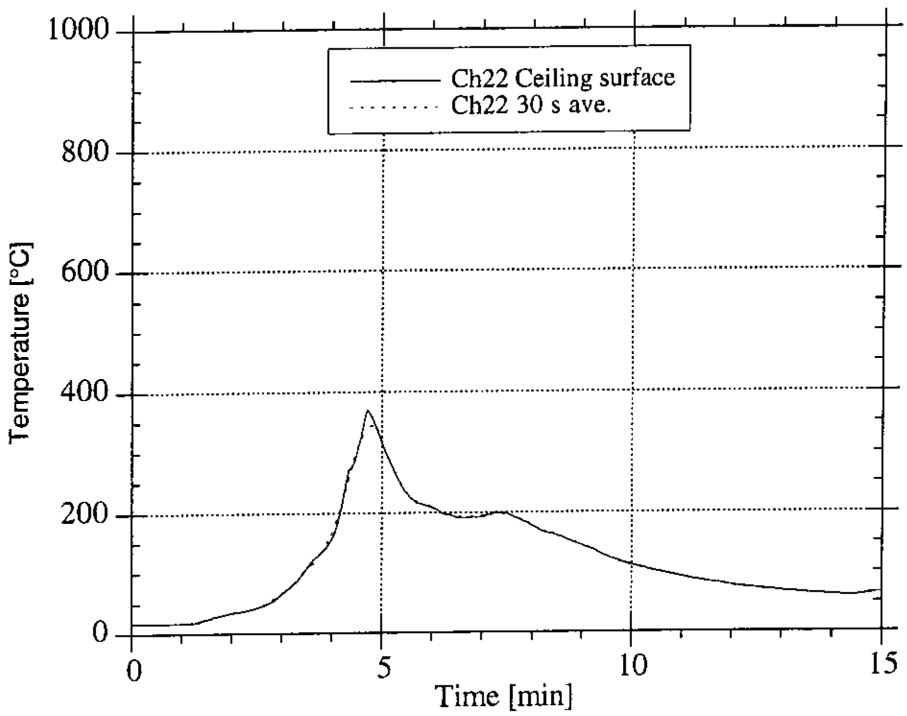
	Seat	Backrest
Sofa 1	12 %	78 %
Sofa 2	0 %	80 %
Sofa 3	0 %	Slightly burnt
Sofa 4	0 %	65 %

EQ 1.5

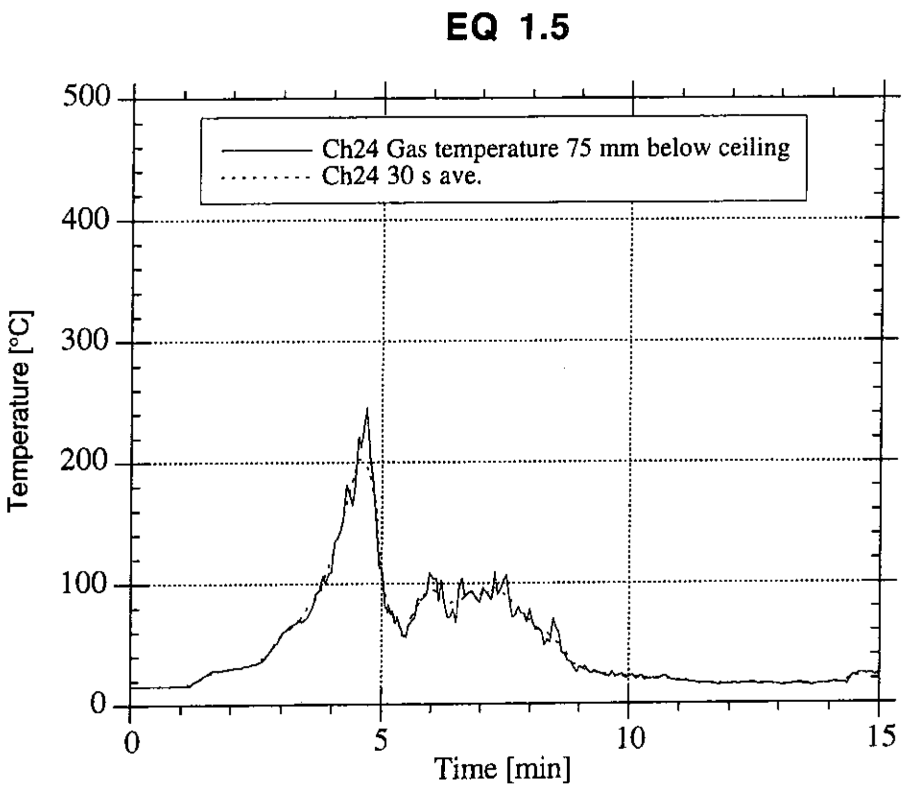


Ch21 Plate thermometer above fire
Ch21 30 s ave.
Temperature [°C]
1000
800
600
400
200
0
0
5
10
15
Time [min]

EQ 1.5



Ch22 Ceiling surface
Ch22 30 s ave.
Temperature [°C]
1000
800
600
400
200
0
0
5
10
15
Time [min]



EQ 1.5
Ch24 Gas temperature 75 mm below ceiling
Ch24 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]

Test EQ 1.6 Date: January 10, 1995

Test conditions

Fire scenario: Corner public space, 5 m ceiling height.

Combustibles: 3 sofas and plywood lining 3,6 m out from the corner

Sprinkler type: Grinnell F950, 74 °C solder link, K=80, RTI=104

Spacing: 4 m (half distance, 2 m to corner walls)

Water flow preset to 1 bar and 80 l/min with 1 sprinkler open.

Average system pressure during test not known due to measurment failure

Water flow per nozzle: ≈ 80 l/min

Average flux density: ≈ 5 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
02:30	Fire spreads to wall lining
03:35	Intermittent flames to the ceiling
03:58	Sprinkler closest to the corner activates
05:00	Flames approximately to backrest height, seat extinguished
08:00	Fire intensity increases behind backrest
14:05	Sprinkler turned off
14:15	Fire extinguished manually

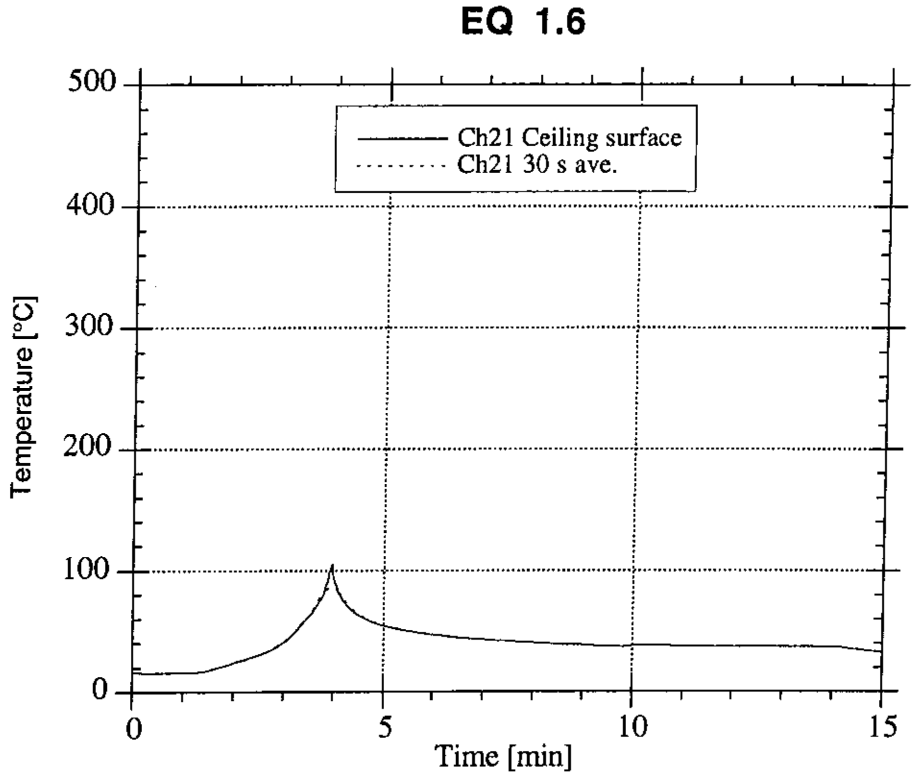
Results

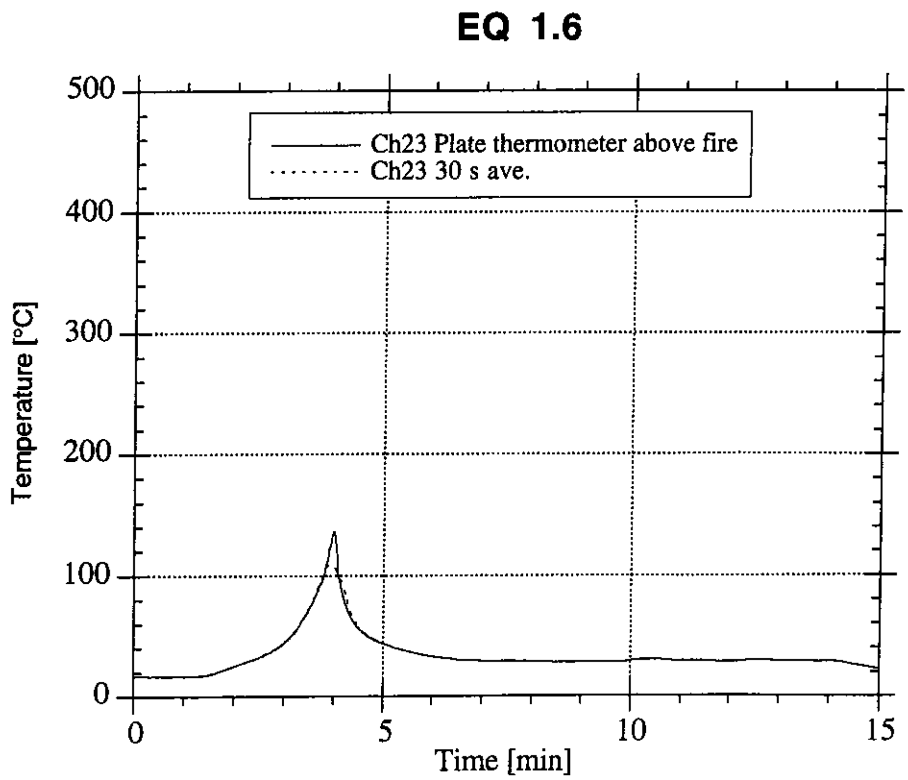
Maximum 30 second average temperatures

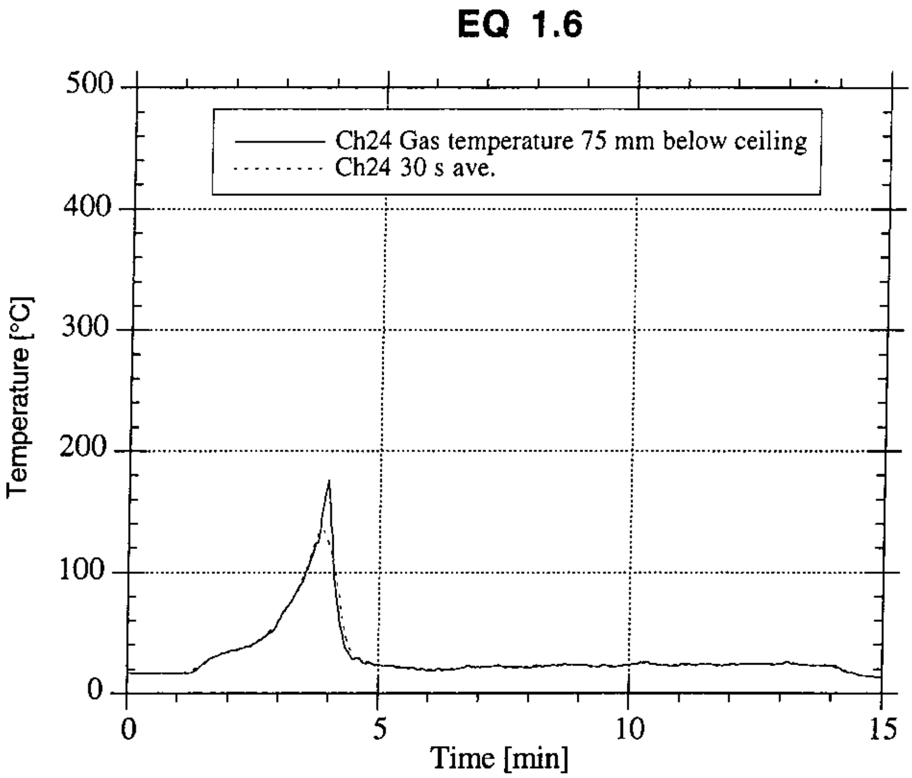
Ceiling surface above point of ignition (channel 21)	86 °C
Gas temperature at nozzle closest to point of ignition (channel 24)	109 °C
Plate thermometer above point of ignition (channel 23)	136 °C

Damages to mattresses

	Seat	Backrest
Sofa 1	5 %	60 %
Sofa 2	0 %	0 %
Sofa 3	0 %	0 %


EQ 1.6
Ch21 Ceiling surface
Ch21 30 s ave.
Temperature [°C]
Time [min]
500
400
300
200
100
0
0
5
10
15


EQ 1.6
Ch23 Plate thermometer above fire
Ch23 30 s ave.
Temperature [°C]
Time [min]
500
400
300
200
100
0
0
5
10
15


EQ 1.6
Ch24 Gas temperature 75 mm below ceiling
Ch24 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]

Test EQ 1.7 Date: January 11, 1995

Test conditions

Fire scenario: Open public space, 5 m ceiling height, ignition between 4 sprinklers

Combustibles: 4 sofas

Sprinkler type: Grinnell F950, 74 °C solder link, K=80, RTI=104

Spacing: 4 m

Water flow preset to 1 bar and 322 l/min with 4 sprinkler open.

Average system pressure during test: 0,92 bar

Water flow per nozzle: 107 l/min

Average flux density: 6,7 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
03:34	Fire spreads to sofa 2
05:51	Fire spreads to sofa 3
05:52	Fire spreads to sofa 4
05:57	First sprinkler activates
06:14	Second sprinkler activates
06:19	Third sprinkler activates
06:44	Fire intensity decreases
07:30	1,5 - 2 m flames in the backrests of the outer sofas
16:00	Sprinkler turned off
17:00	Fire extinguished manually

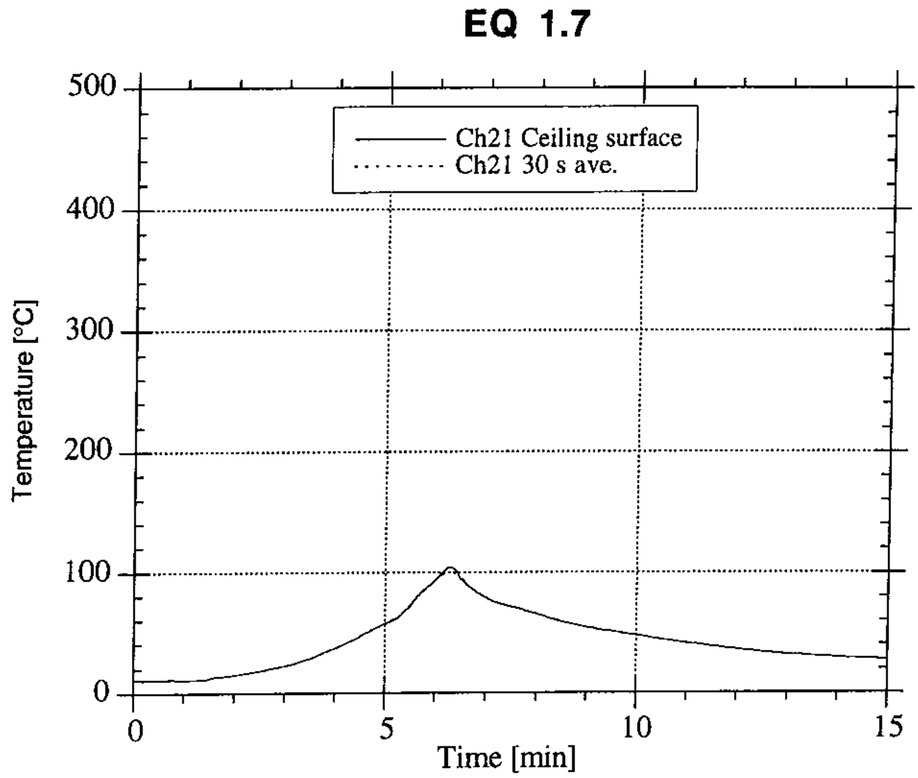
Results

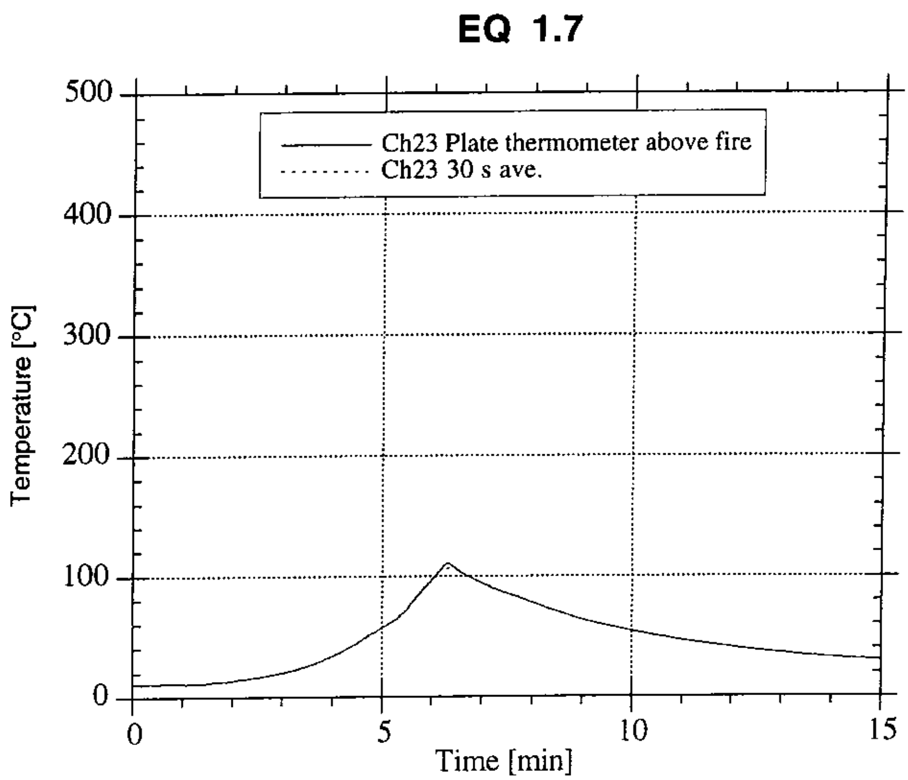
Maximum 30 second average temperatures

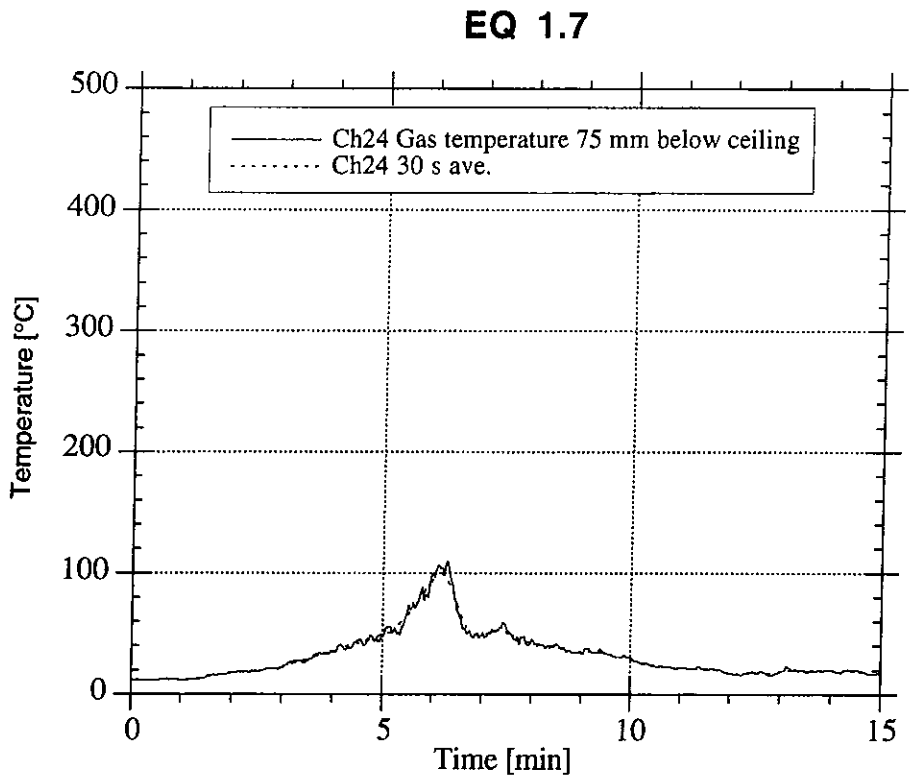
Ceiling surface above point of ignition (channel 21)	100 °C
Gas temperature at nozzle closest to point of ignition (channel 24)	100 °C
Plate thermometer above point of ignition (channel 23)	107 °C

Damages to mattresses

	Seat	Backrest
Sofa 1	95 %	98 %
Sofa 2	25 %	92 %
Sofa 3	Slightly burnt	62
Sofa 4	0 %	90


EQ 1.7
Ch21 Ceiling surface
Ch21 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]


EQ 1.7
Ch23 Plate thermometer above fire
Ch23 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]



EQ 1.7
Ch24 Gas temperature 75 mm below ceiling
Ch24 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]

Test EQ 1.8 Date: February 3, 1995

Test conditions

Fire scenario: Ventilated corner public space, 2,5 m ceiling height.

Combustibles: 3 sofas and plywood lining 3,6 m out from the corner

Sprinkler type: Grinnell F950, 74 °C solder link, K=80, RTI=104

Spacing: 4 m (half distance, 2 m to corner walls)

Water flow preset to 1 bar and 80 l/min with 1 sprinkler open.

Average system pressure during test not known due to measurement failure

Water flow per nozzle: 82 l/min

Average flux density: 5,1 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
02:26	Intermittent flames to the ceiling
02:45	Steady flames to the ceiling
03:12	Sprinkler closest to the corner activates
03:20	0,1 m high flames at ignition source
10:20	5 cm high flames at ignition source
13:12	Sprinkler turned off, fire extinguished manually

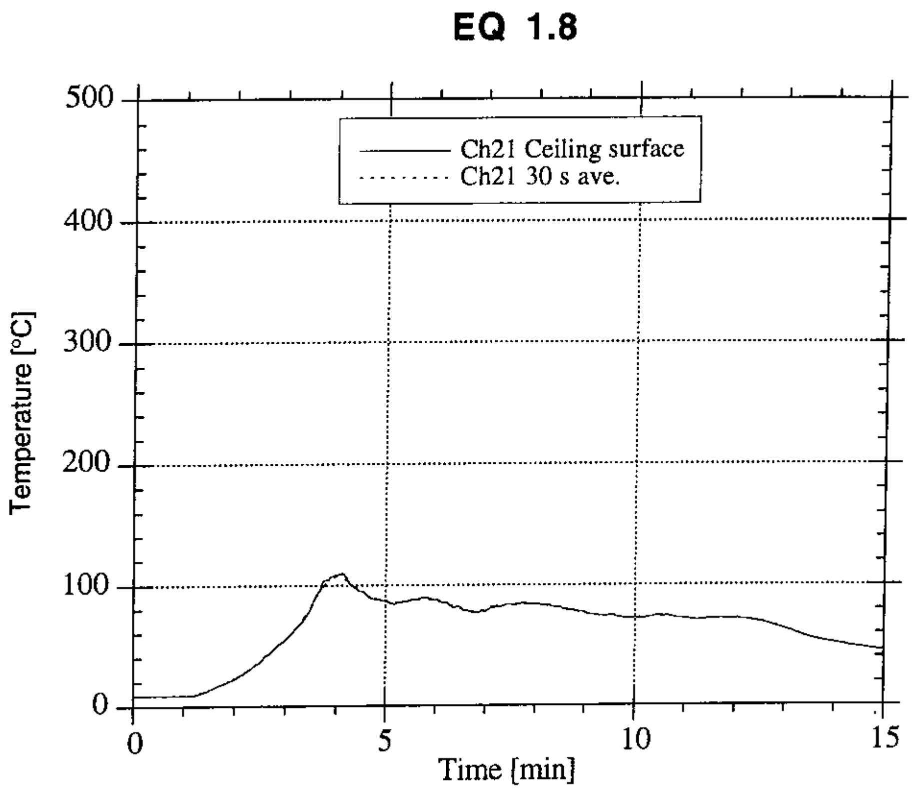
Results

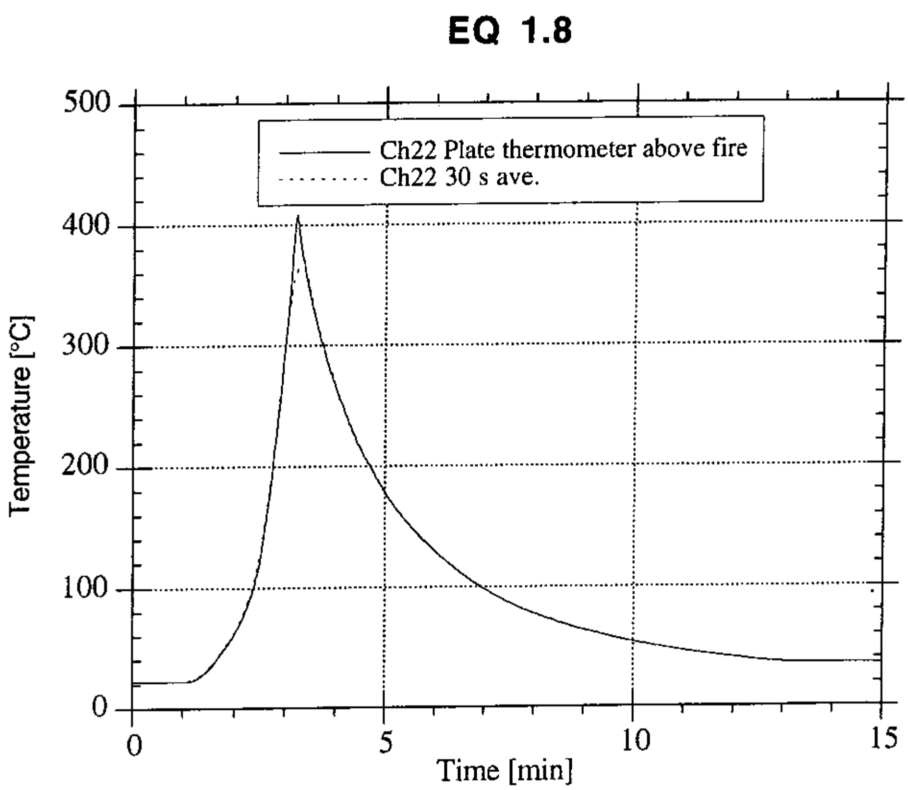
Maximum 30 second average temperatures

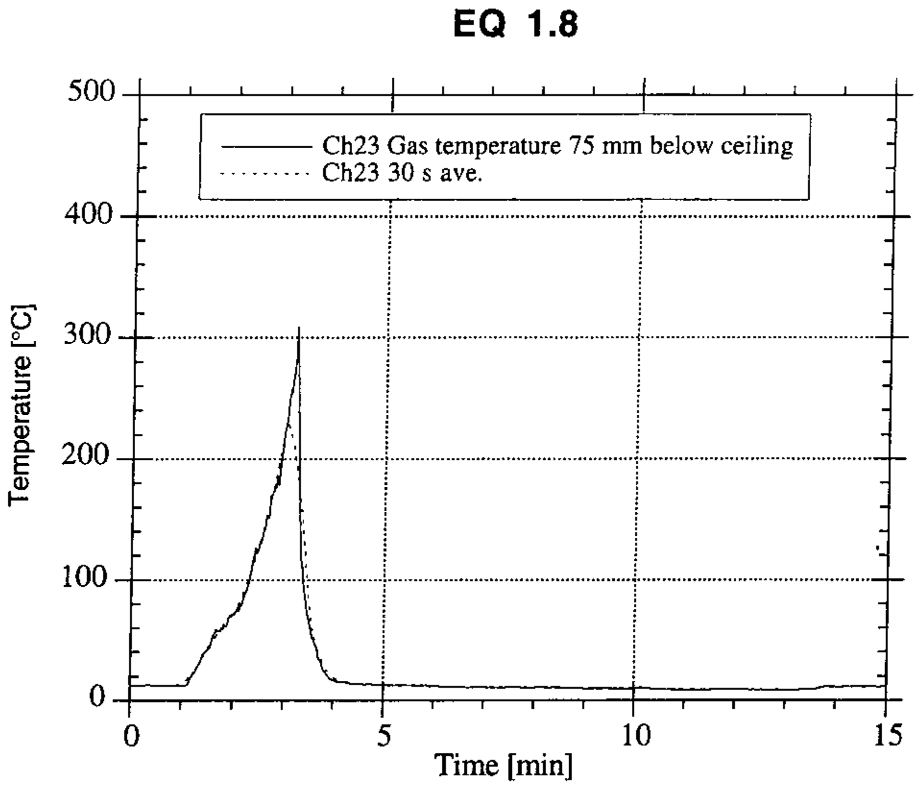
Ceiling surface above point of ignition (channel 21)	256 °C
Gas temperature at nozzle closest to point of ignition (channel 23)	229 °C
Plate thermometer above point of ignition (channel 22)	366 °C

Damages to mattresses

	Seat	Backrest
Sofa 1	< 1 %	2 %
Sofa 2	0 %	0 %
Sofa 3	0 %	0 %


EQ 1.8
Ch21 Ceiling surface
Ch21 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]


EQ 1.8
Ch22 Plate thermometer above fire
Ch22 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]


EQ 1.8
Ch23 Gas temperature 75 mm below ceiling
Ch23 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]

Test EQ 1.9 Date: February 7, 1995

Test conditions

Fire scenario:	Open public space, 5 m ceiling height, Ignition between 2 sprinklers
Combustibles:	4 sofas
Sprinkler type:	Grinnell F950, 74 °C solder link, K=80, RTI=104
Spacing:	4 m

Water flow preset to 1 bar and 160 l/min with 2 sprinkler open.

Average system pressure during test: 1 bar

Water flow per nozzle: 82 l/min

Average flux density: 5,1 mm/min

Test record

Min:s	Observation
00:00	Start of logging
01:00	Ignition
03:28	Fire spreads to sofa 2
03:40	Fire in sofas 1 and 2 spreads towards sofa 3
05:15	Fire spreads to sofa 3
05:52	Fire spreads to sofa 4
05:24	First sprinkler activates
05:26	Second sprinkler activates
07:00	Flames 2 m high, pool fires below sofas 1, 2 and 3
08:00	Backrests of sofas 1 and 2, burnt out towards sofa 3, large pool fire below sofa 3
09:30	Backrests of sofa 3, burnt out towards sofa 1
12:45	Flames 0,1 m high in backrests of sofas 2 and 3
14:24	Sprinkler turned off by mistake
14:40	Sprinkler turned on, fire size was not affected by the pause
15:25	Sprinkler turned off, fire extinguished manually

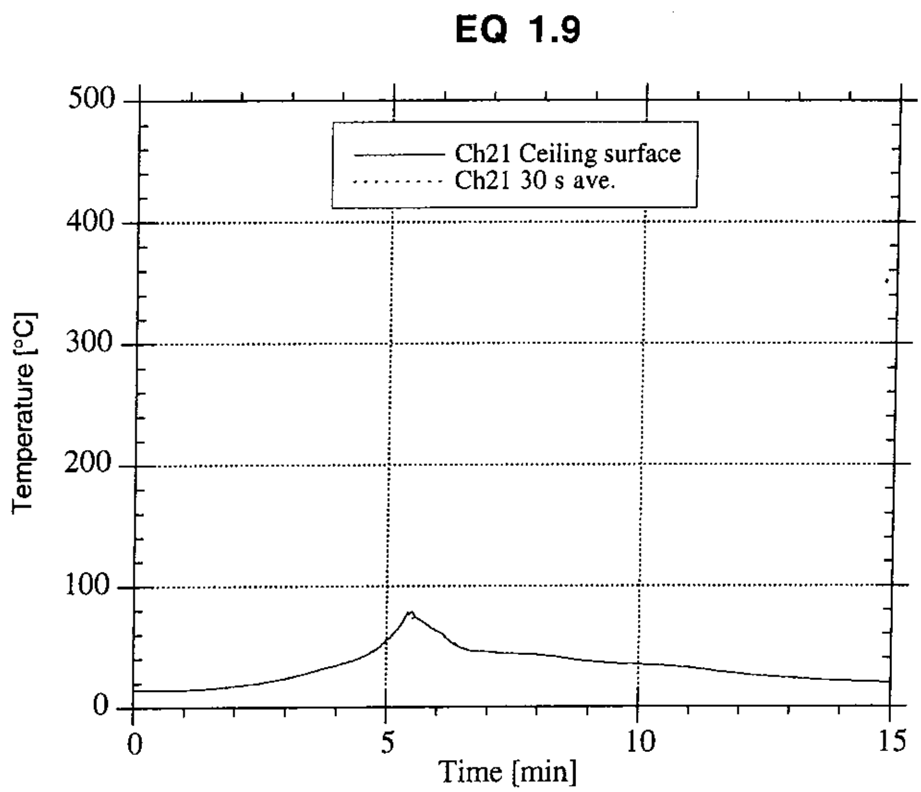
Results

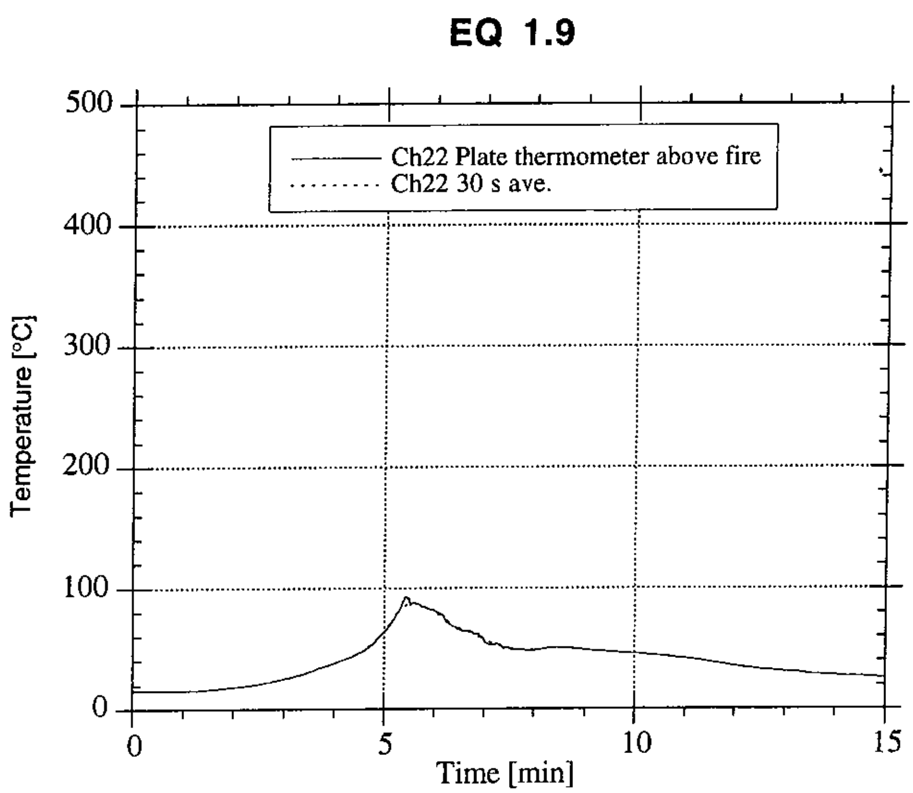
Maximum 30 second average temperatures

Ceiling surface above point of ignition (channel 21)	74 °C
Gas temperature at nozzle closest to point of ignition (channel 23)	92 °C
Plate thermometer above point of ignition (channel 22)	88 °C

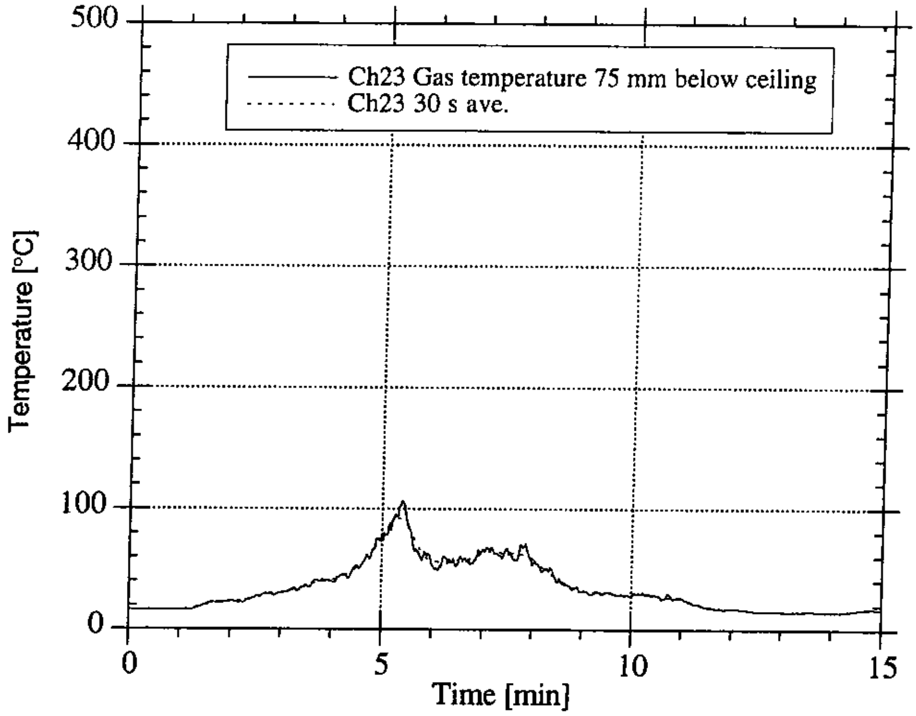
Damages to mattresses

	Seat	Backrest
Sofa 1	40 %	82 %
Sofa 2	0 %	81 %
Sofa 3	1 %	77 %
Sofa 4	0 %	< 1 %


EQ 1.9
Ch21 Ceiling surface
Ch21 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]


EQ 1.9
Ch22 Plate thermometer above fire
Ch22 30 s ave.
Temperature [°C]
500
400
300
200
100
0
0
5
10
15
Time [min]

EQ 1.9

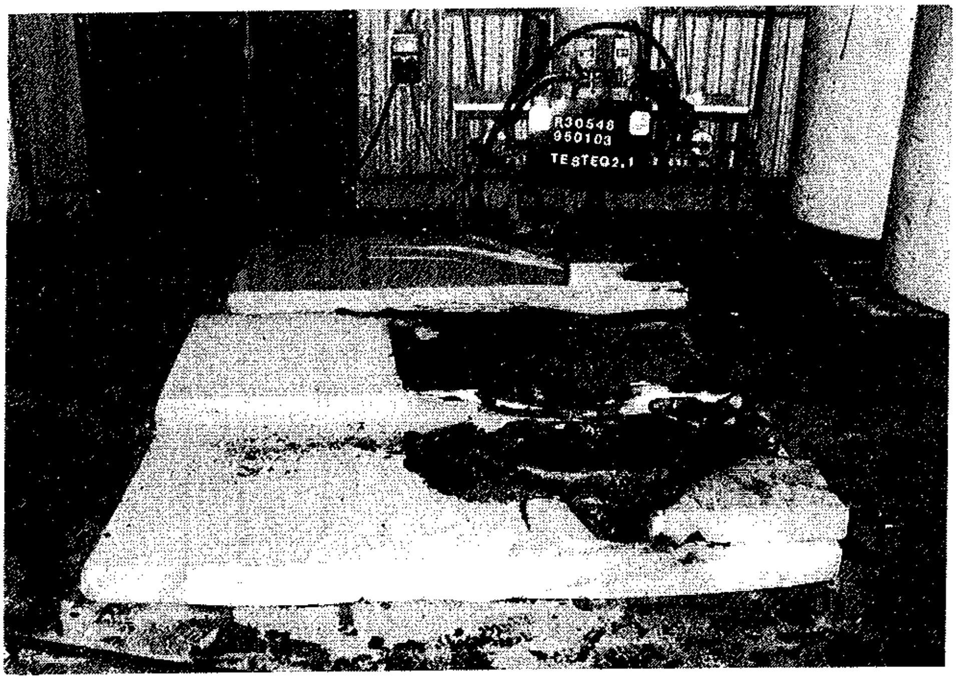


500
400
300
200
100
0
Temperature [°C]
0
5
10
15
Time [min]
Ch23 Gas temperature 75 mm below ceiling
Ch23 30 s ave.

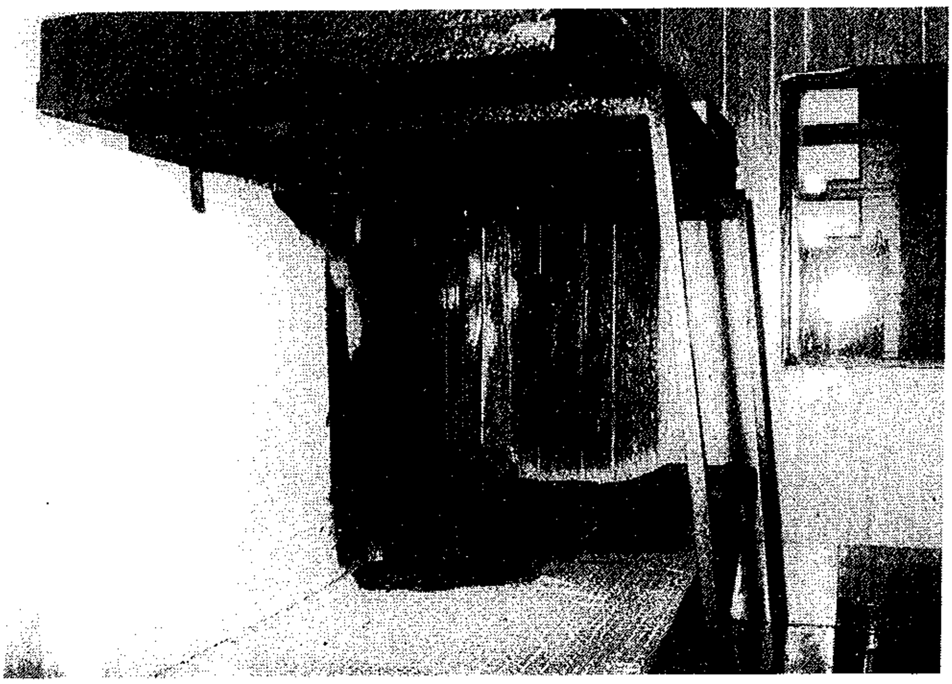
Appendix C

Pictures from test series 2 and 1

Fire tests to establish acceptance criteria for systems equivalent to SOLAS II/2/12 in 12 m^2 cabin and corridor and in public spaces with 2,5 and 5 m ceiling height

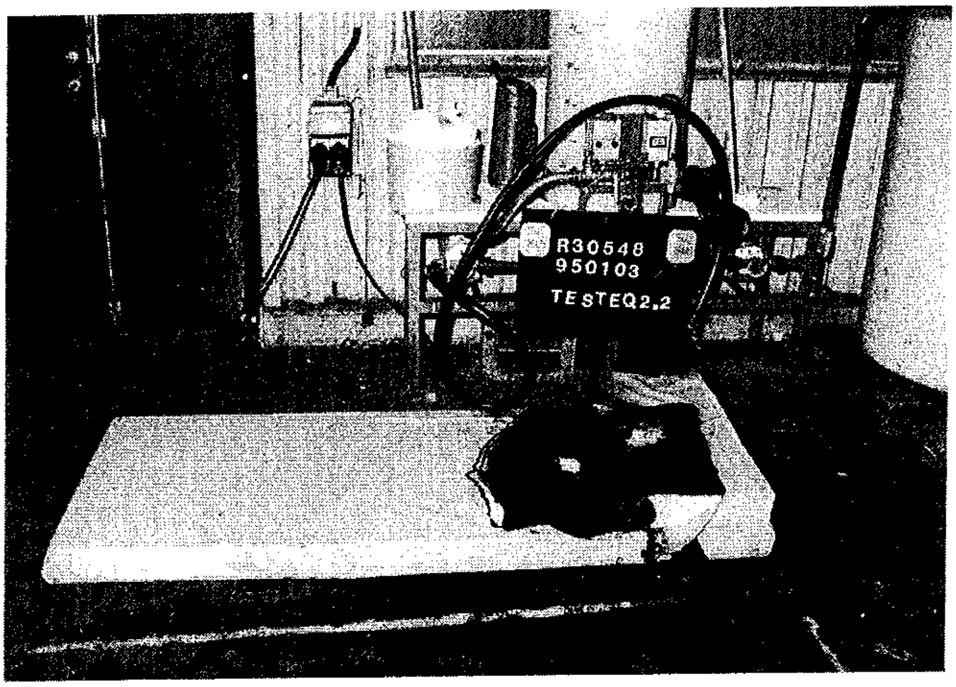


Picture 1 *Test EQ 2.1. Fire started in lower left side bed, water pressure 0,75 bar. Picture shows from top to bottom, upper mattress and pillow, backrest and lower mattress and pillow.*

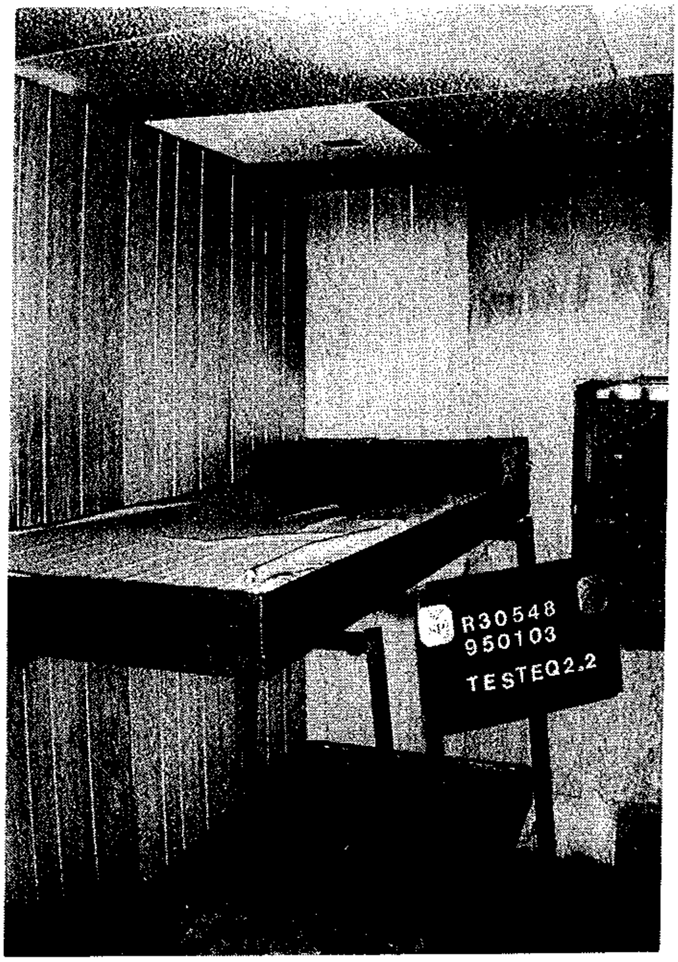


Picture 2 *Test EQ 2.1. View of left side bed inside cabin, backrest, lower mattress and pillow. Note the rear wall lining damage*

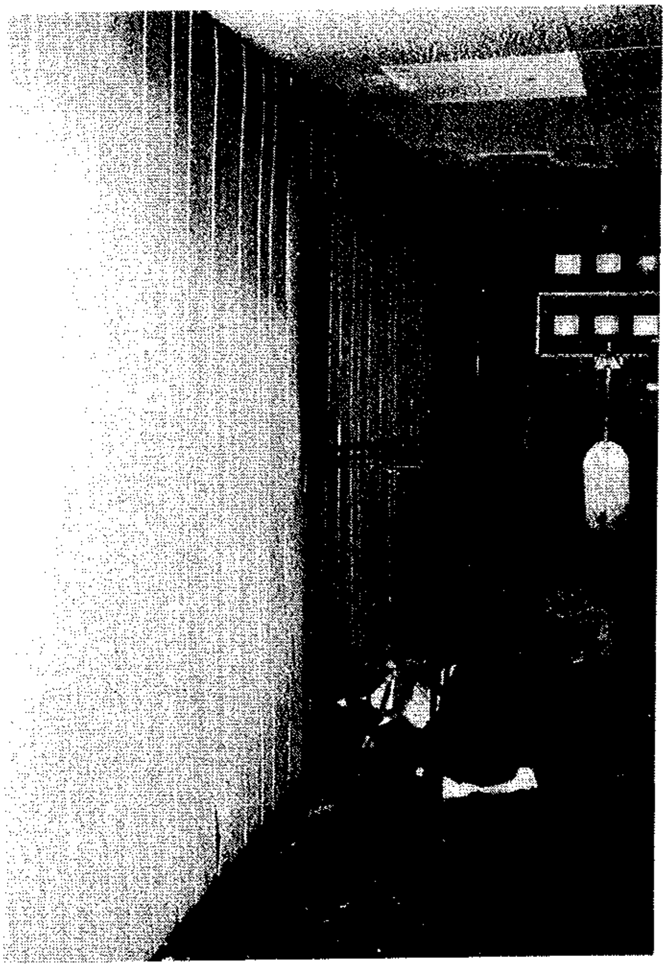
Picture 3 Test EQ 2.1. View of left side bed inside cabin, note wall lining damage.



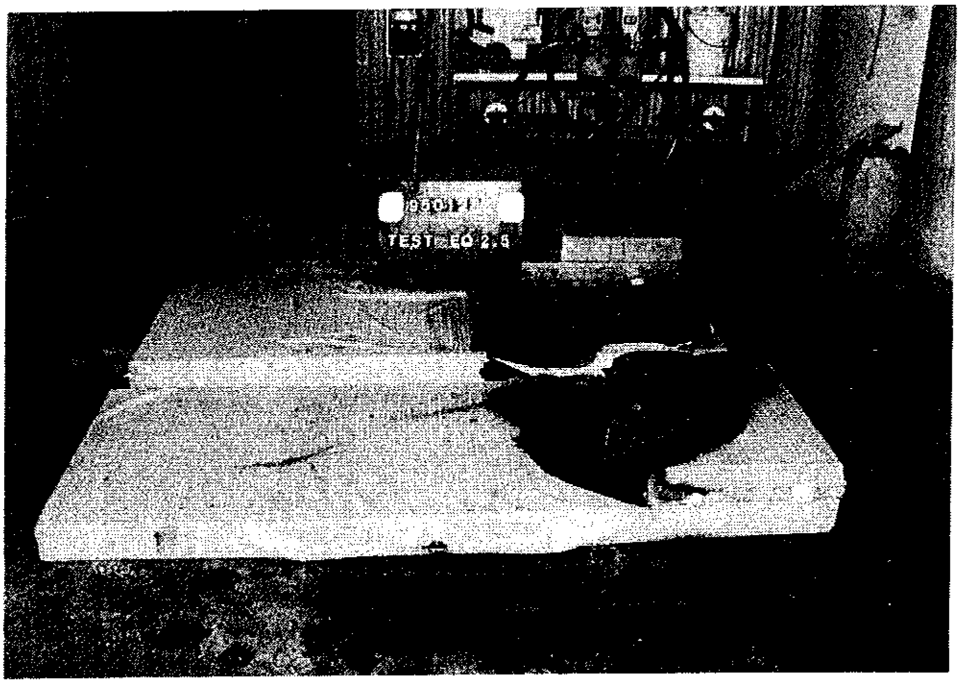
Picture 4 *Test EQ 2.2. Fire started in upper left side bed, water pressure 0,75 bar. Picture shows upper mattress and pillow.*



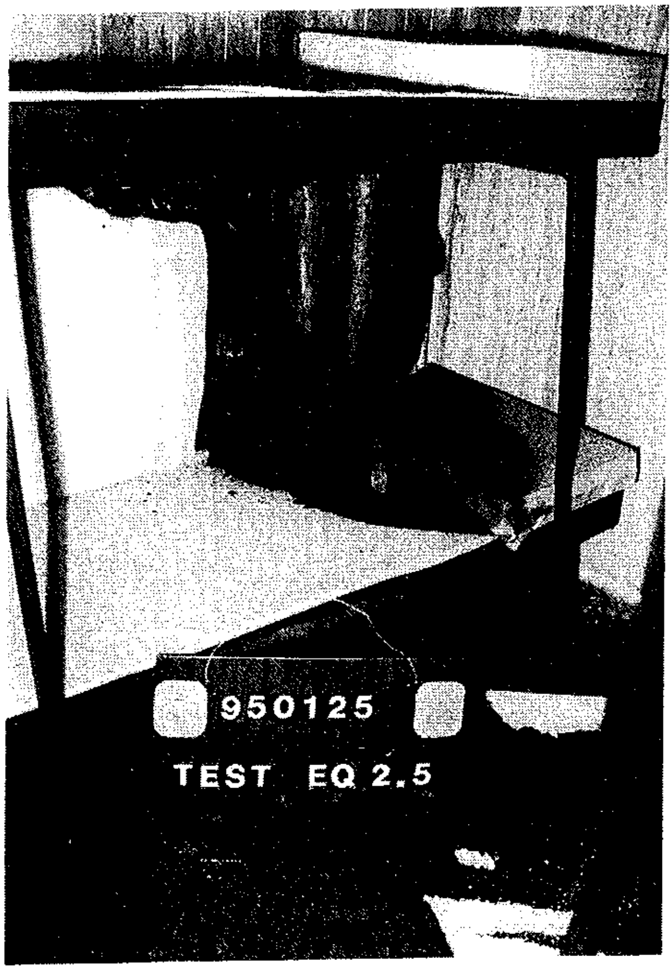
Picture 5 *Test EQ 2.2. View of left side bed inside cabin. No damage to wall lining.*



Picture 6 *Test EQ 2.3. Corridor, fire between two sprinklers, water pressure 0,75 bar. View inside corridor, note the charred wall lining and foam pieces on the floor.*

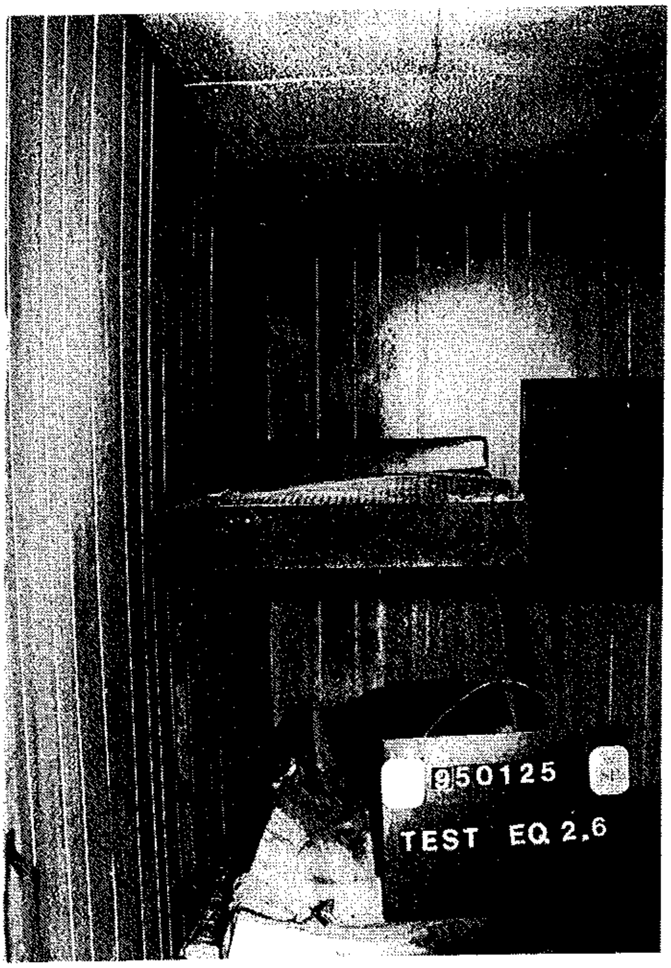


Picture 7 Test EQ 2.5. Fire started in lower left side bed, water pressure 2,2 bar. Picture shows from top to bottom, upper mattress and pillow, backrest and lower mattress and pillow.

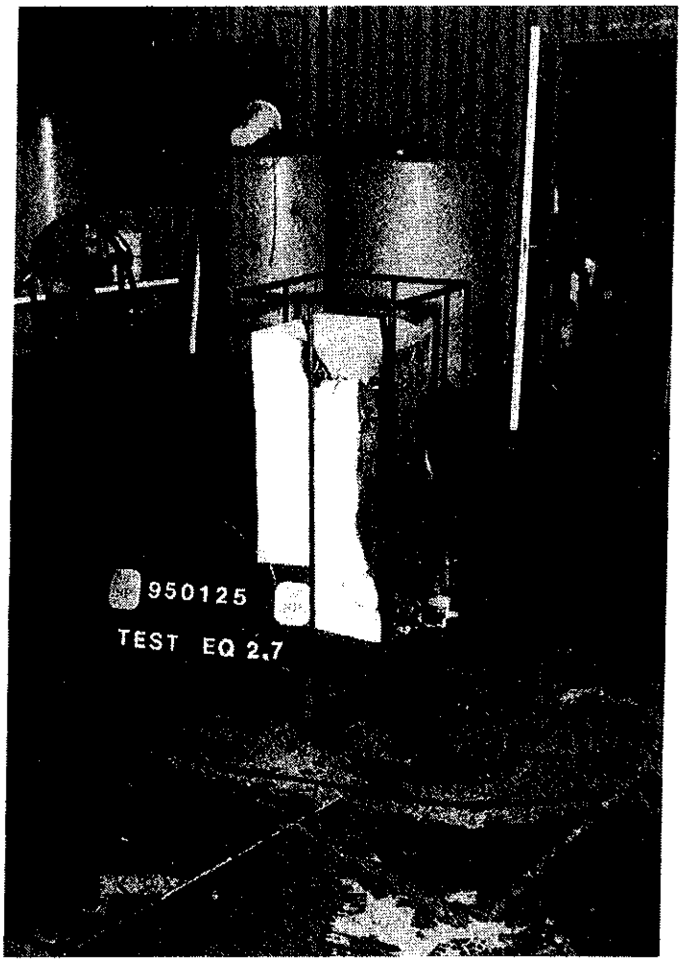


Picture 8 Test EQ 2.5 View of left side bed inside cabin, note the limited damages to mattresses and wall lining.

Picture 9 *Test EQ 2.6. Arsonist fire started in lower left side bed, water pressure 0,75 bar. Picture shows from left to right, upper mattress and pillow, backrest and lower mattress and pillow.*



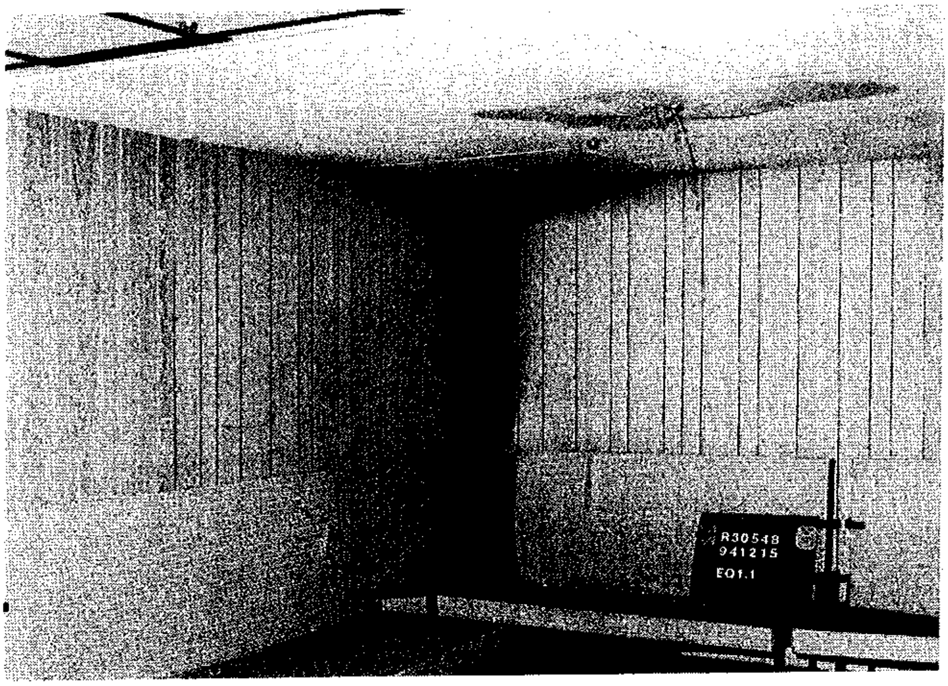
Picture 10 Test EQ 2.6. View of left side bed inside cabin, note the collapsed backrest and the abscense of damages to the wall lining.



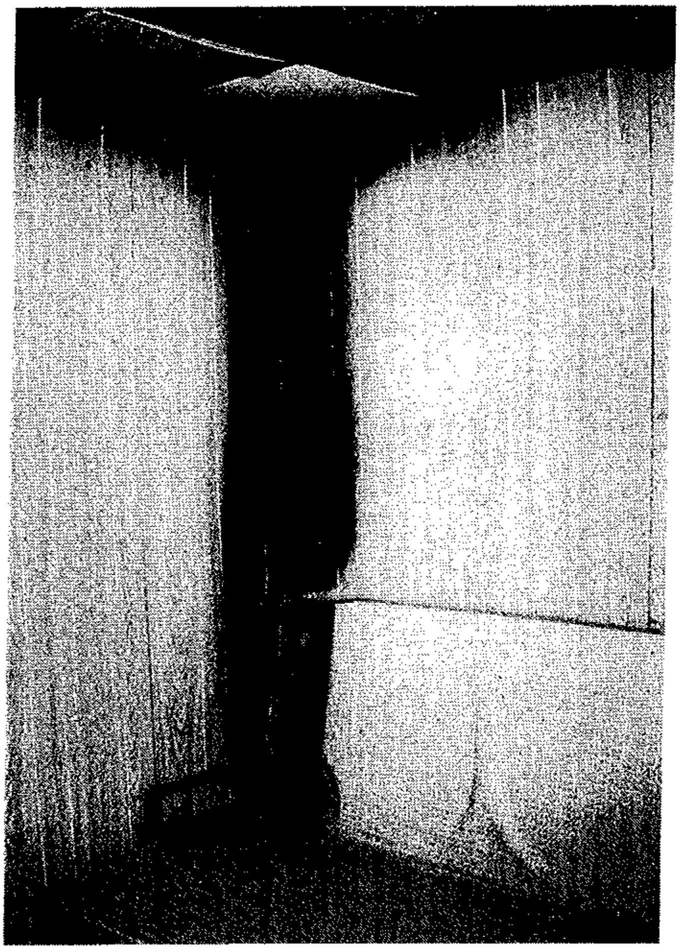
Picture 11 Test EQ 2.7. Corridor, fire under one sprinkler, water pressure 0,75 bar. Damages to pile of foam.

Picture 12 Test EQ 2.8. Corridor, fire between two sprinklers, water pressure 4 bar. View inside corridor, note the foam on the floor.

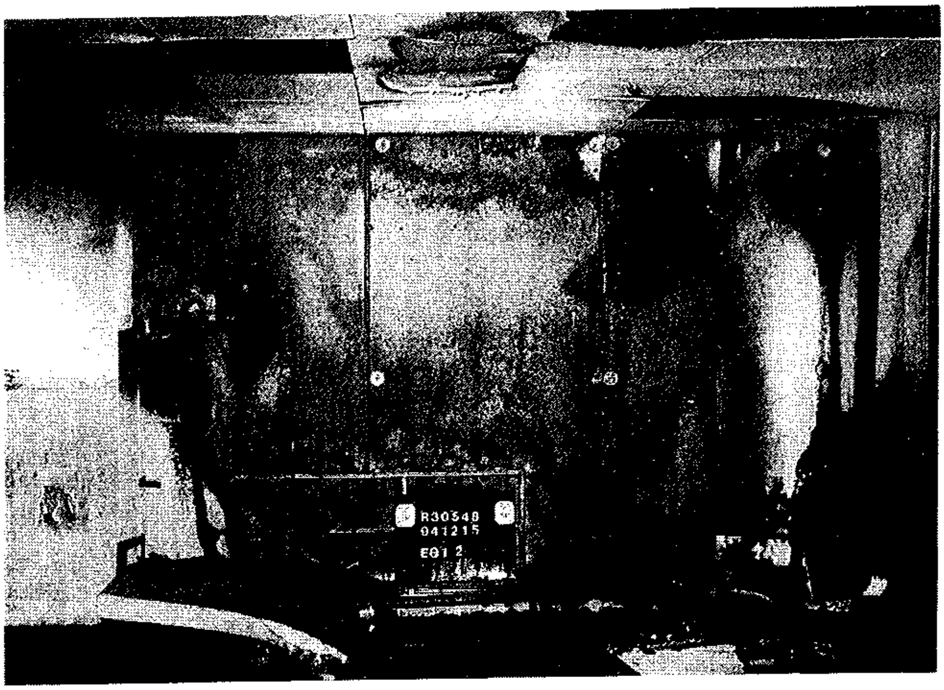
Picture 13 Test EQ 2.9. Corridor, ventilated fire between two sprinklers, water pressure 1 bar. View inside corridor, note the foam on the floor.



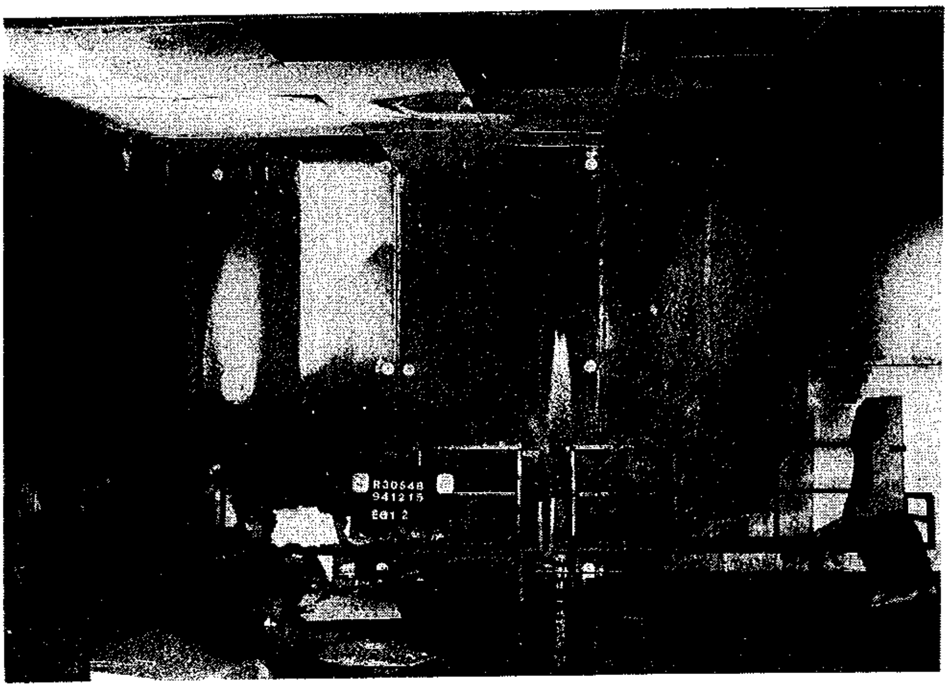
Picture 14 Test EQ 1.1. Corner public space, 2,5 m ceiling height GW DD sprinkler at 1 bar. View of corner.



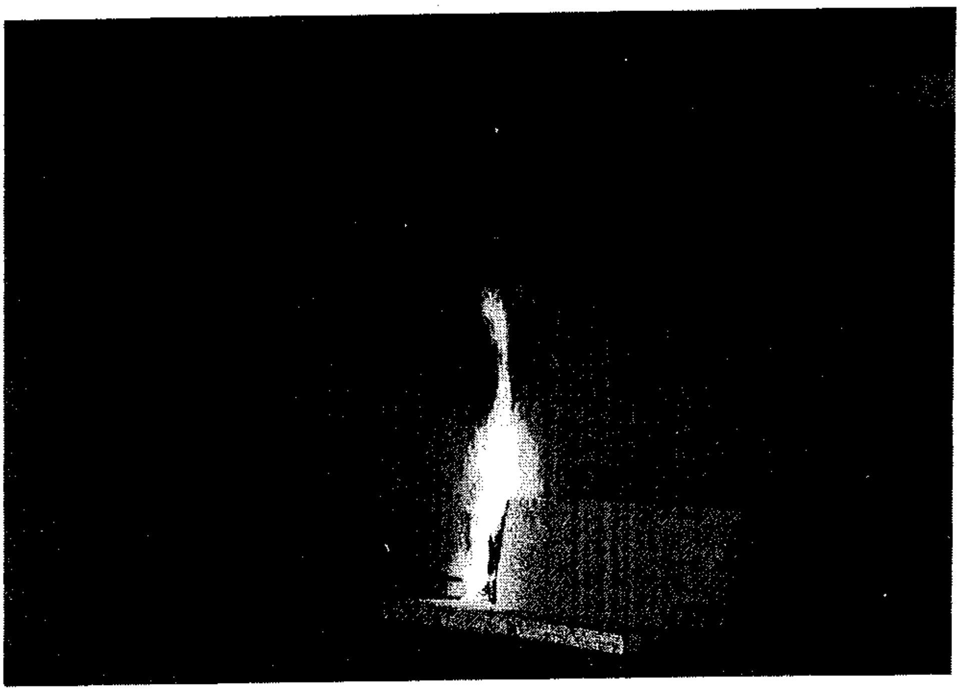
Picture 15 Test EQ 1.1. Close-up view of corner.



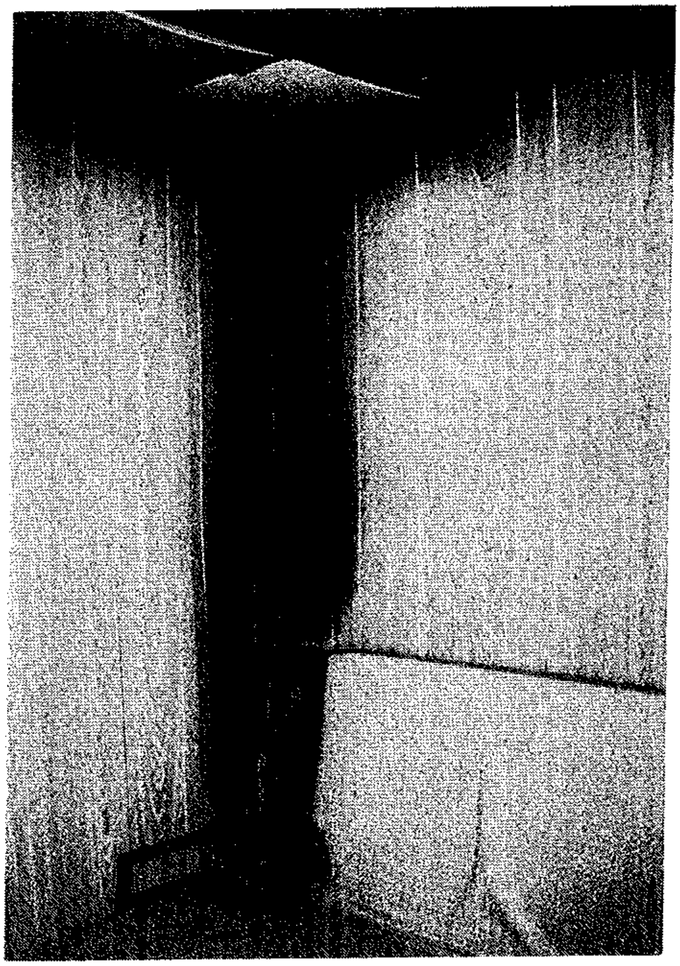
Picture 16 Test EQ 1.2. Corner public space, disabled nozzle, 2,5 m ceiling height GW DD sprinkler at 1 bar. View of corner. From left to right sofa 3, sofa 1 and sofa 2. Note the limited remains of the wall lining.



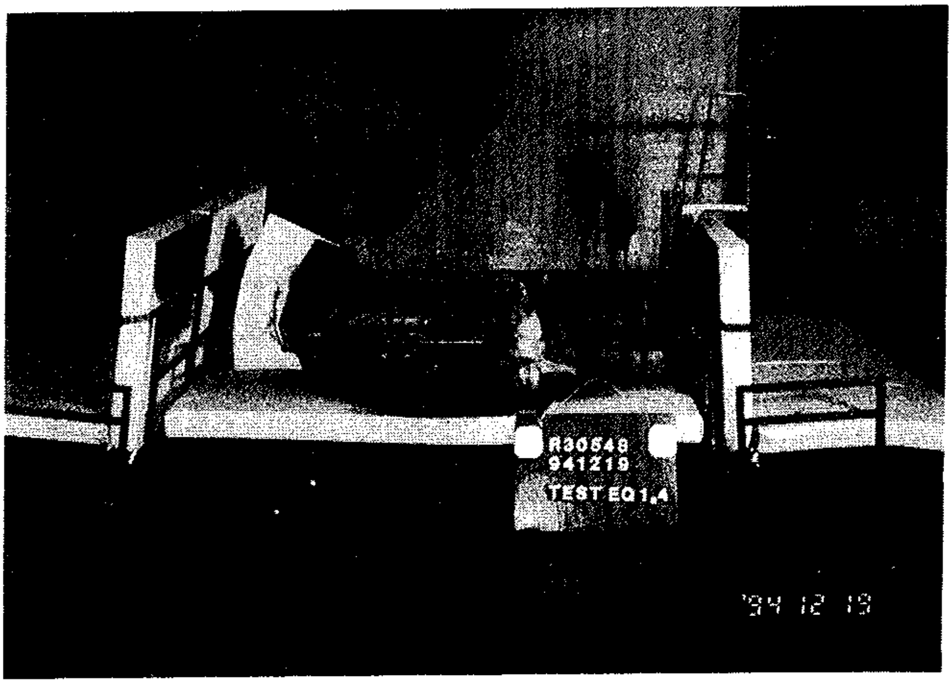
Picture 17 Test EQ 1.2. View of corner. From left to right sofa 3, sofa 1 and sofa 2.



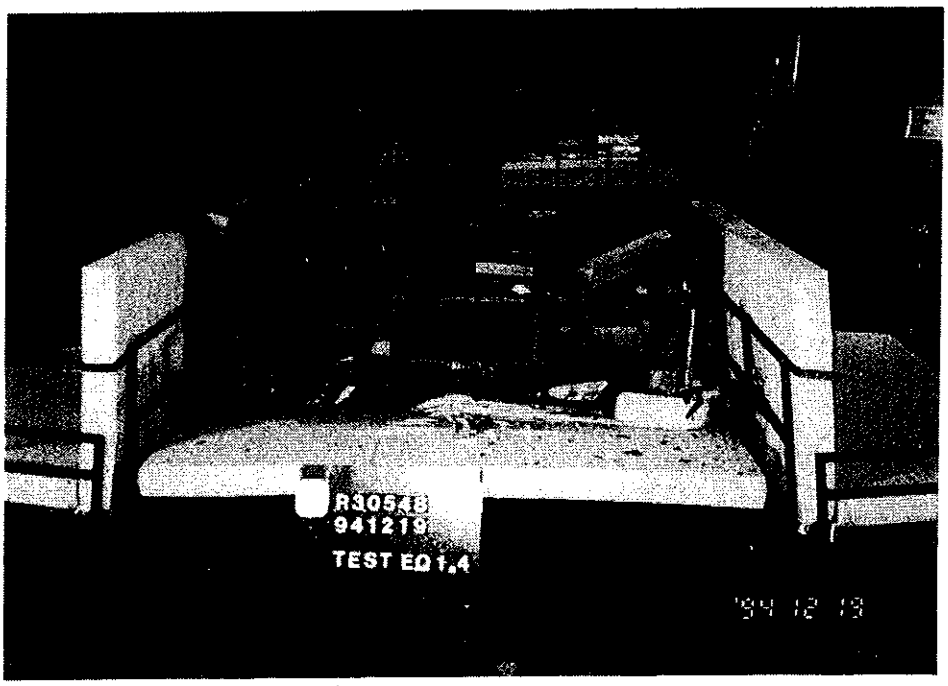
Picture 18 Test EQ 1.3. Corner public space, 2,5 m ceiling height water pressure 1 bar. Fire 1 minutes 54 seconds after ignition, 31 seconds prior to sprinkler operation.



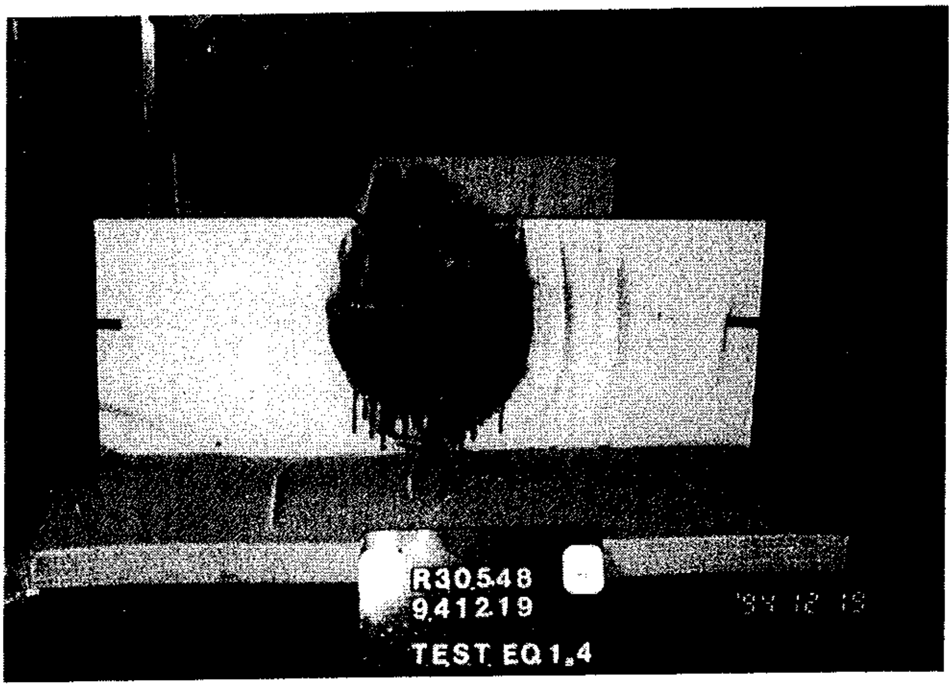
Picture 19 Test EQ 1.3. Close-up view of corner.



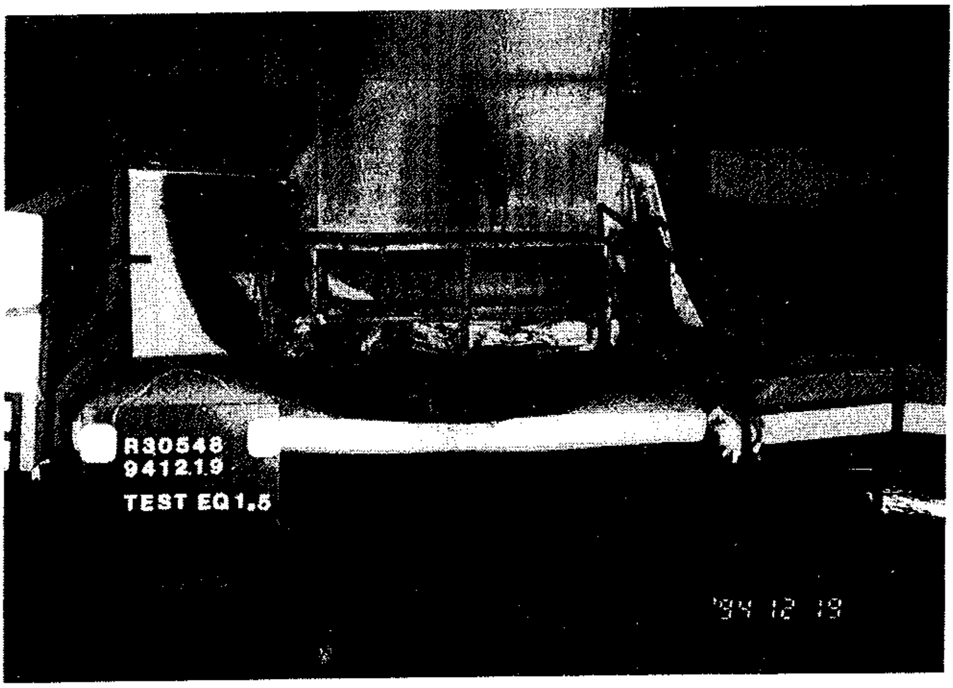
Picture 20 Test EQ 1.4. Open public space, fire between 4 sprinklers, 2,5 m ceiling height water pressure 1 bar. Sofa 1 in the front of the picture, sofa 3 to the left and sofa 4 to the right.



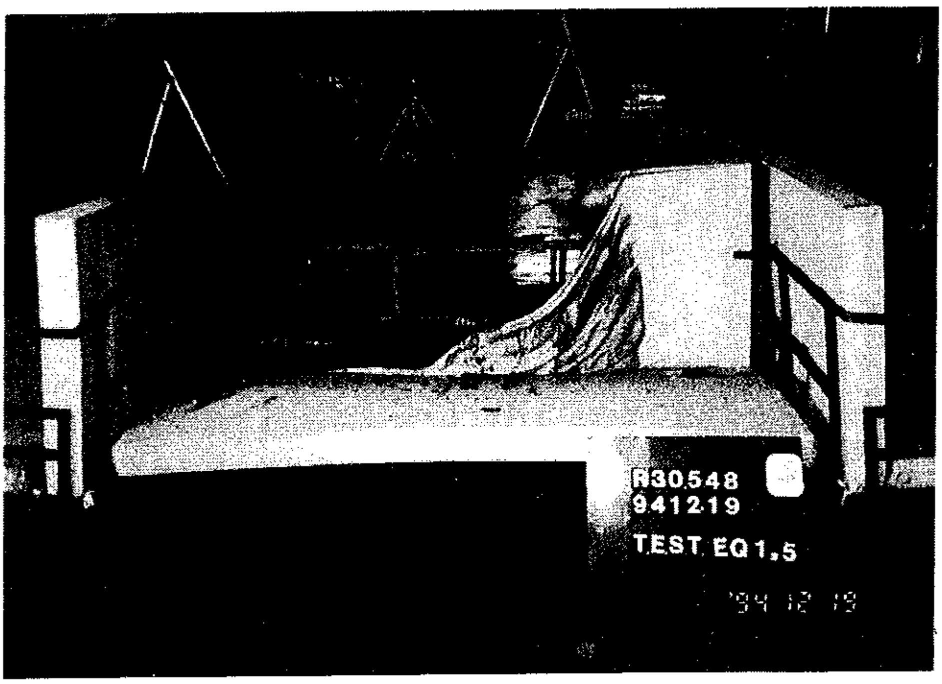
Picture 21 Test EQ 1.4. Sofa 2 in the front of the picture, sofa 4 to the left and sofa 3 to the right.



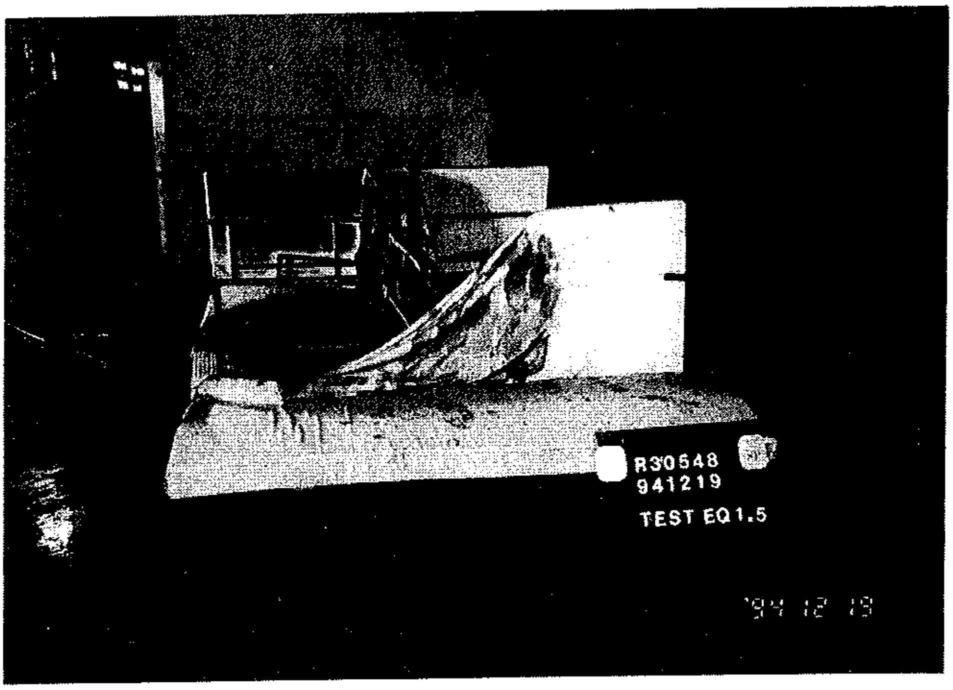
Picture 22 Test EQ 1.4. Sofa 4 in the front of the picture.



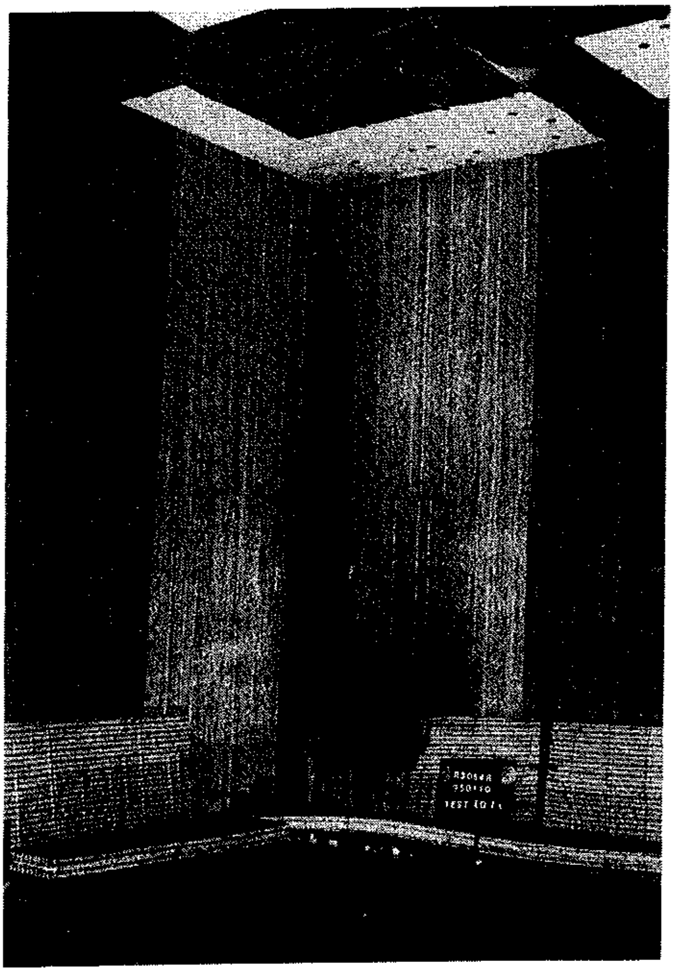
Picture 23 Test EQ 1.5. Open public space, fire between 4 sprinklers, 2,5 m ceiling height water pressure 4 bar. Sofa 1 in the front of the picture, sofa 3 to the left and sofa 4 to the right.



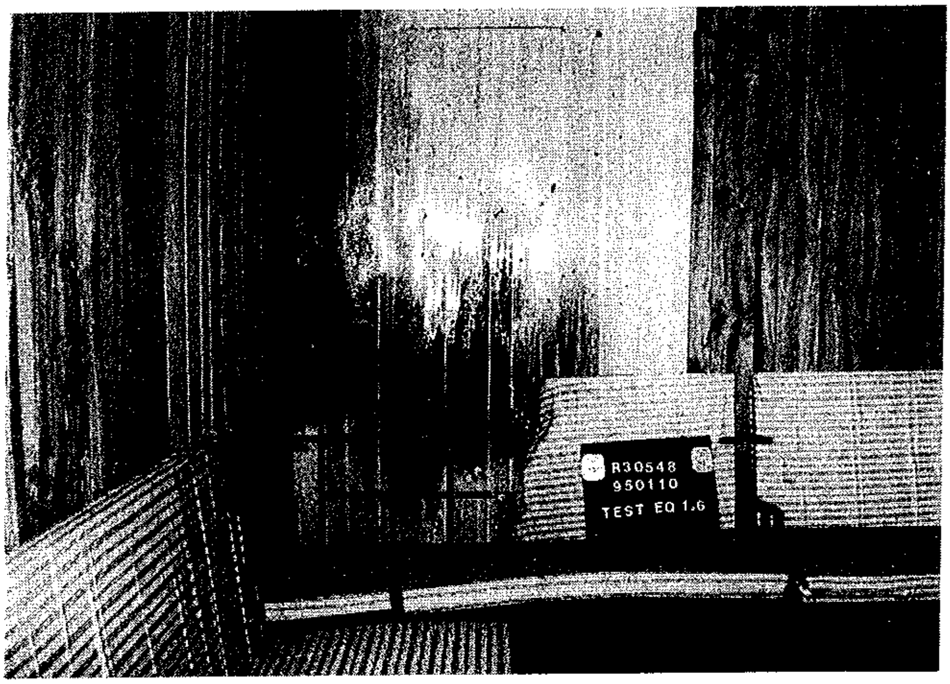
Picture 24 Test EQ 1.5. Sofa 2 in the front of the picture, sofa 4 to the left and sofa 3 to the right.



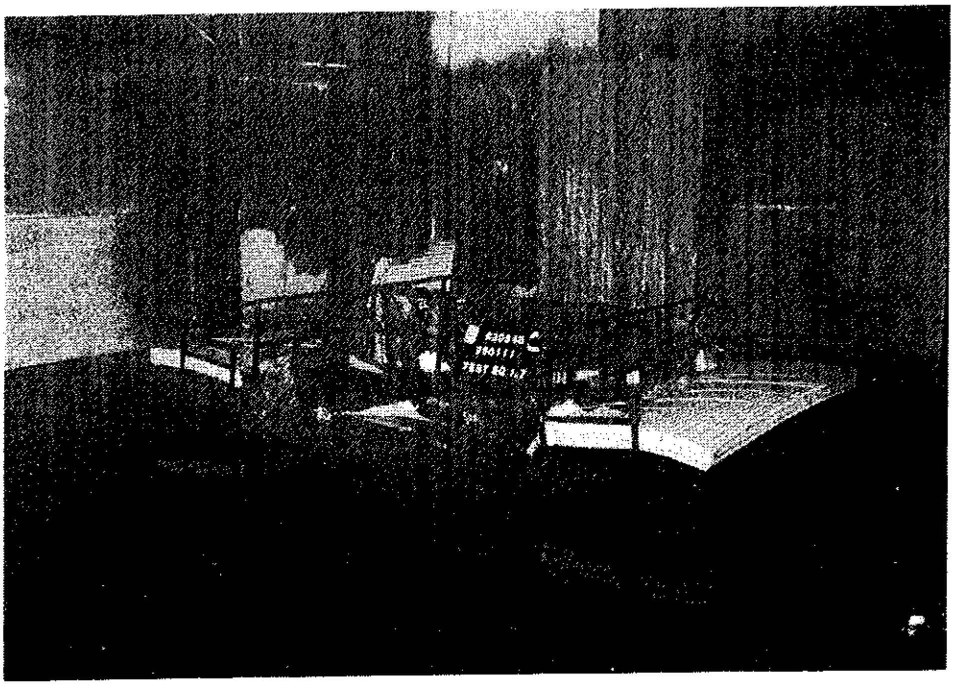
Picture 25 Test EQ 1.5. Sofa 4 in the front of the picture.



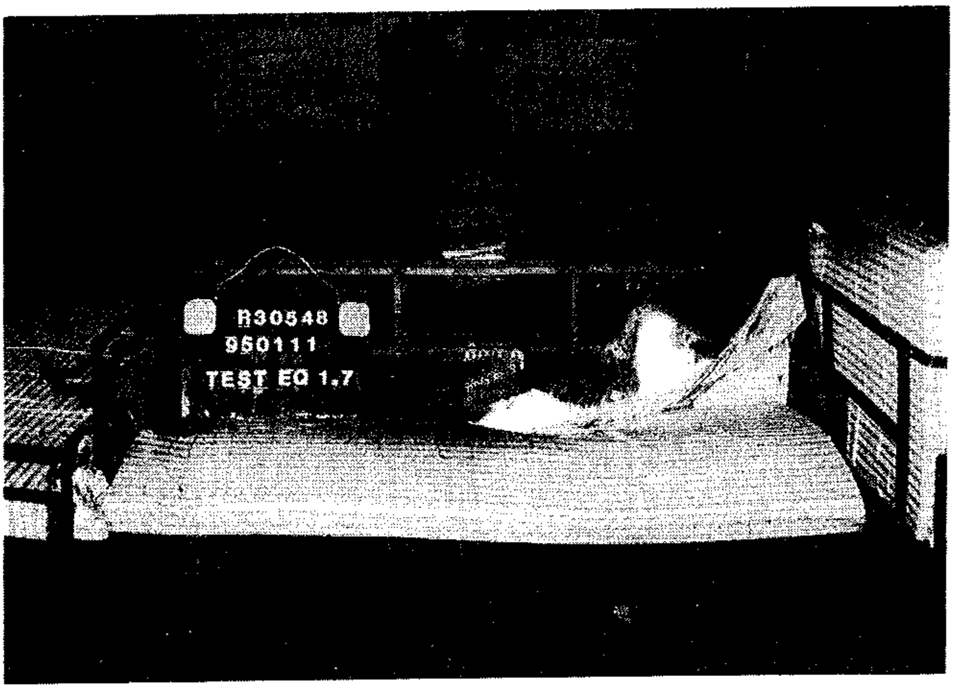
Picture 26 Test EQ 1.6. Corner public space, 5 m ceiling height water pressure 1 bar. View of corner



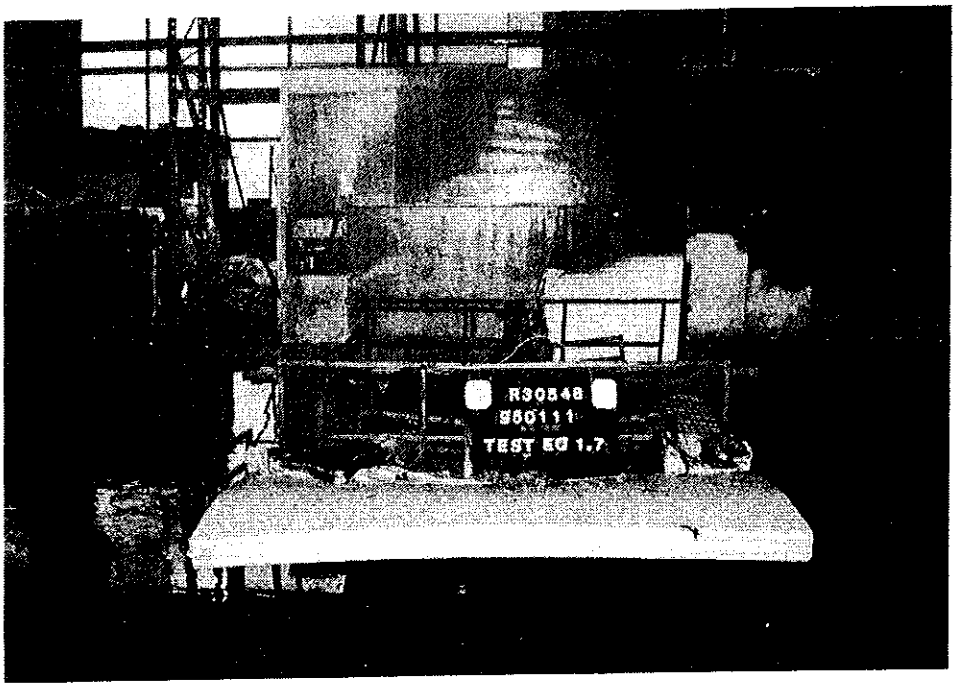
Picture 27 Test EQ 1.6. Close-up view of corner.



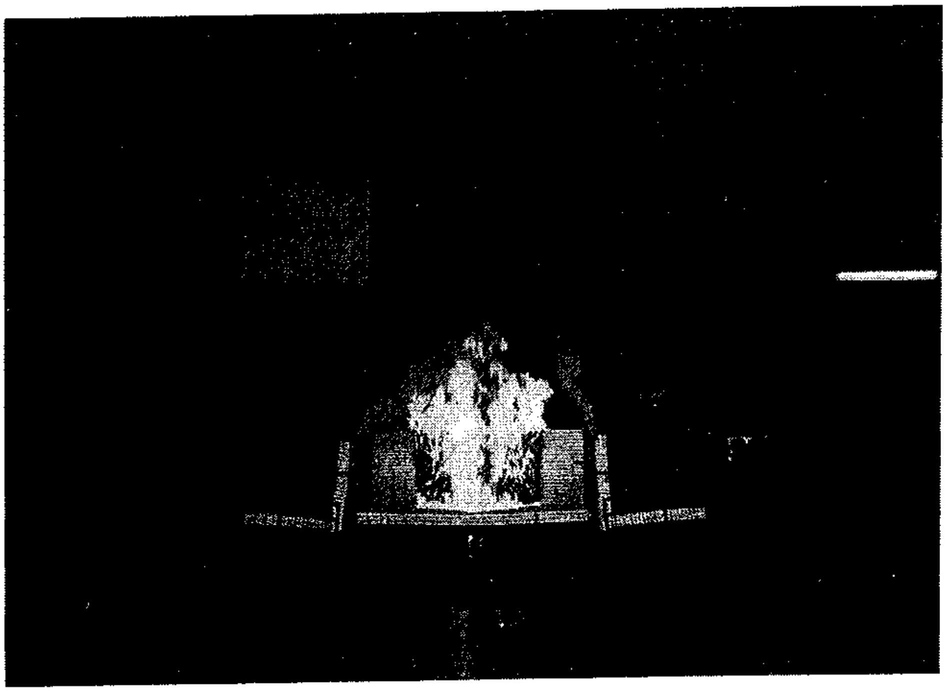
Picture 28 Test EQ 1.7 Open public space, fire between 4 sprinklers, 5 m ceiling height water pressure 1 bar. Sofa 1 in the center of the picture, sofa 3 to the left and sofa 4 to the right.



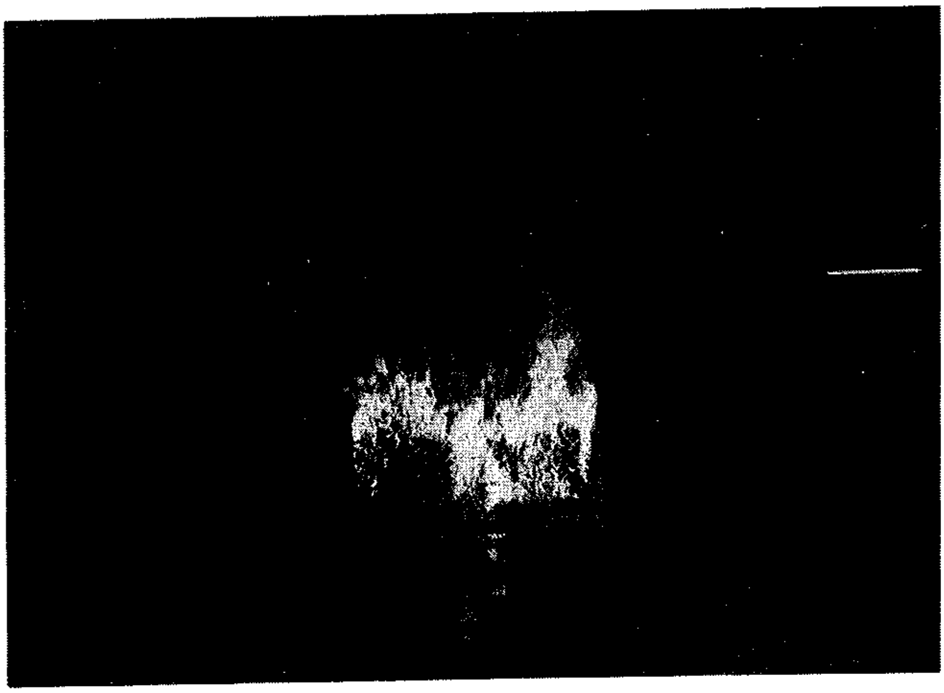
Picture 29 Test EQ 1.7 Sofa 2 in the front of the picture, sofa 4 to the left and sofa 3 to the right.



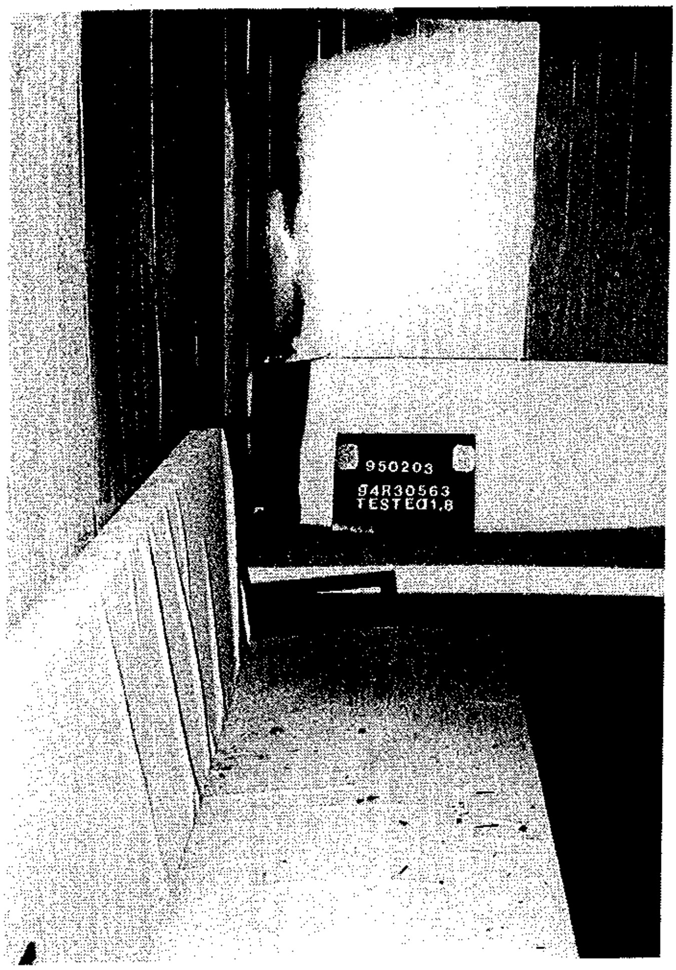
Picture 30 Test EQ 1.7 Sofa 4 in the front of the picture, sofa 1 to the left and sofa 2 to the right.



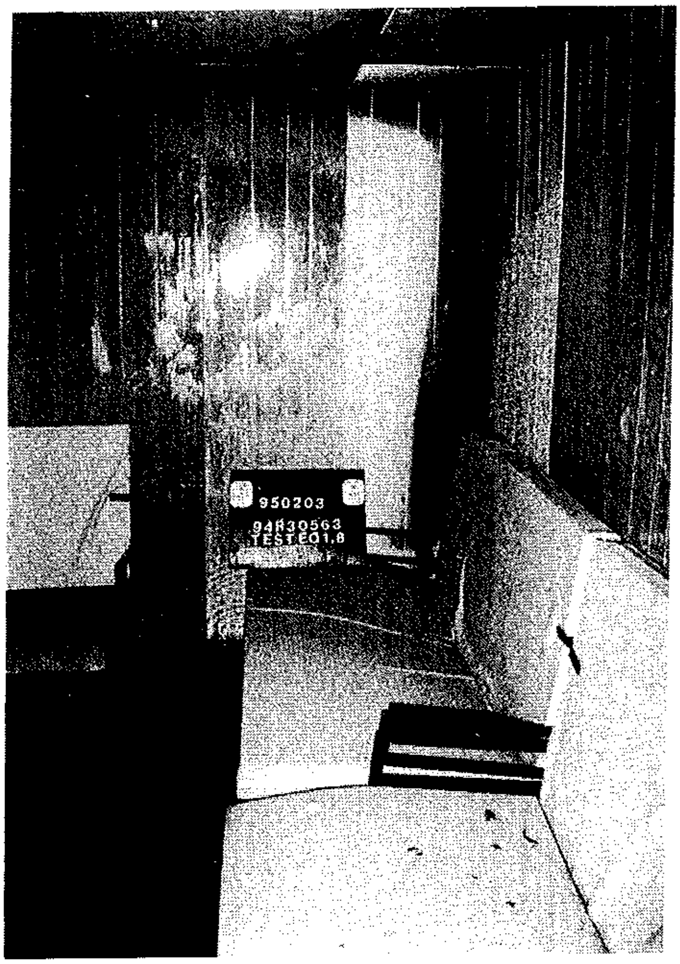
Picture 31 Test EQ 1.7 Sofa 1 in the front of the picture, time 4 minutes 10 seconds after ignition. Picture is taken prior to sprinkler operation.



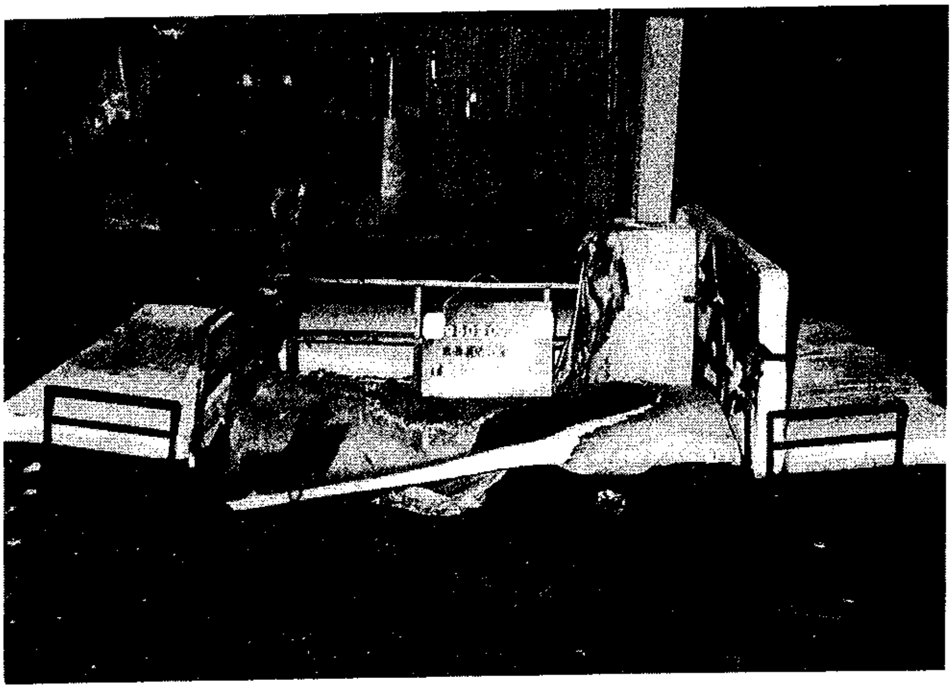
Picture 32 Test EQ 1.7 Sofa 1 in the front of the picture, time 4 minutes 57 seconds after ignition. Picture is taken when the first sprinkler operates.



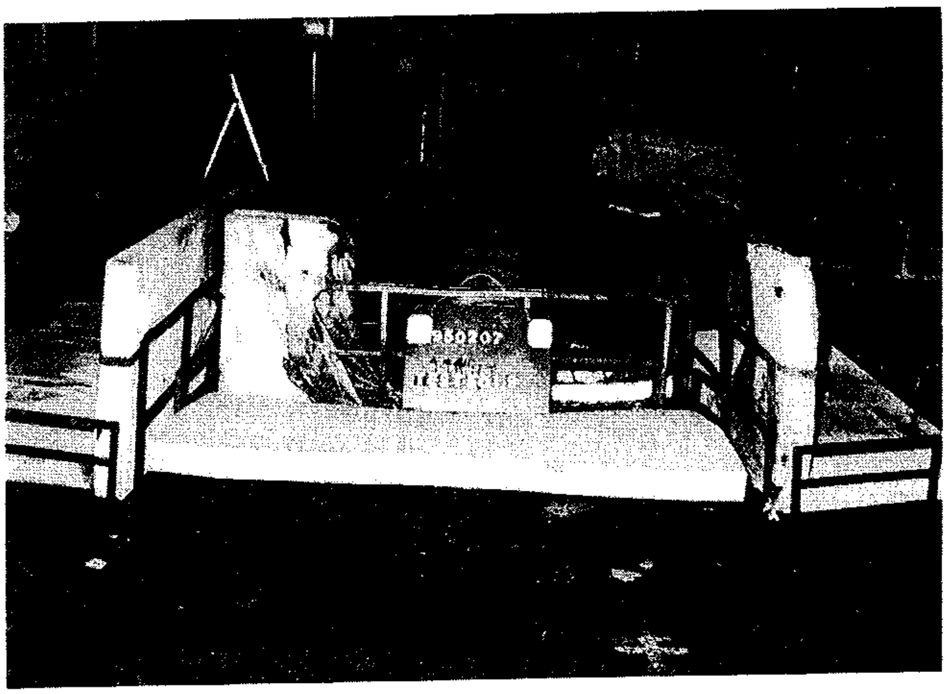
Picture 33 Test EQ 1.8. Ventilated corner public space, 2,5 m ceiling height water pressure 1 bar. View of corner with sofa 3 in front and sofa 1 in the rear.



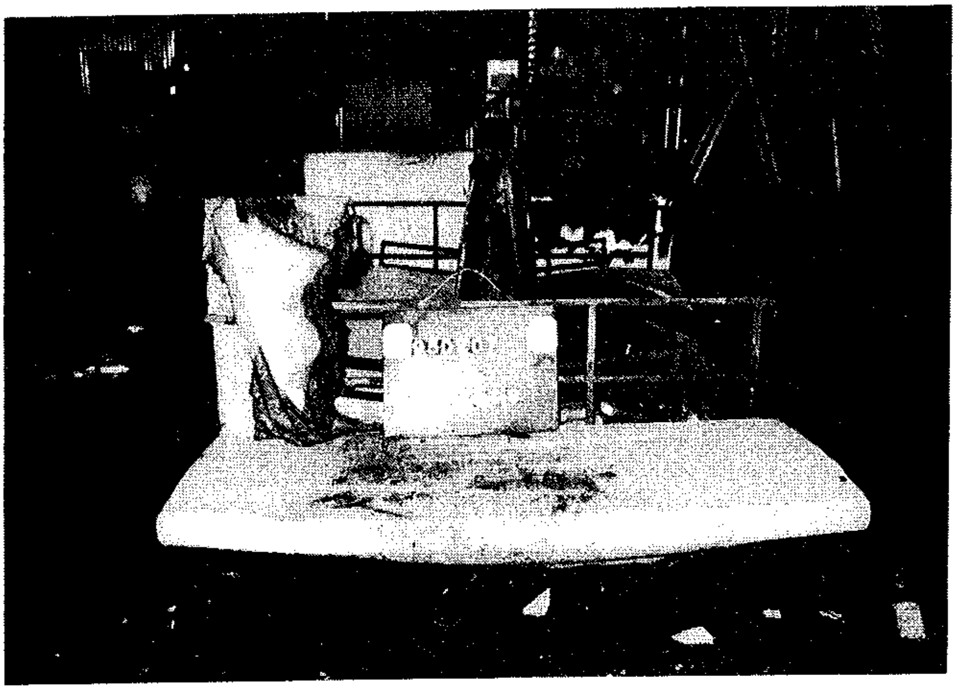
Picture 34 Test EQ 1.8. View of corner with sofa 2 in front and sofa 1 in the rear right and sofa 3 in the rear left.



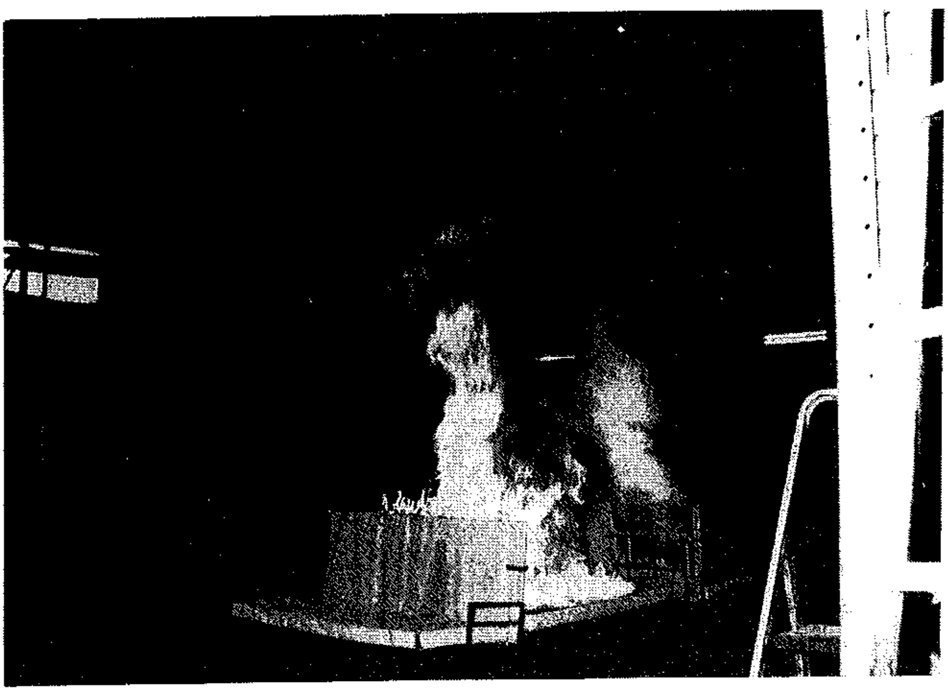
Picture 35 Test EQ 1.9. Open public space, fire between 2 sprinklers, 5 m ceiling height water pressure 1 bar. Sofa 1 in the center of the picture, sofa 3 to the left and sofa 4 to the right.



Picture 36 Test EQ 1.9. Sofa 2 in the front of the picture, sofa 4 to the left and sofa 3 to the right.



Picture 37 Test EQ 1.9. Sofa 3 in the front of the picture, sofa 2 to the left and sofa 1 to the right.



Picture 38 Test EQ 1.9. Sofa 3 to the left in the picture, time 4 minutes 45 seconds after ignition. Picture is taken when the first sprinkler operates.

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