Fire behaviour of beds and upholstered furniture - an experimental study (Second test series) Part 1

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FIRE BEHAVIOUR OF BEDS AND UPHOLS-TERED FURNITURE- AN EXPERIMENTAL STUDY (Second Test Series)

Part 1

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CONTENTS

ABSTRACT

A series of twelve full scale experiments with upholstered furniture and beds has been carried out. Ten experiments were performed inside an extensively equipped compartment with a door opening. In order to study the influence of the room on the fire development two experiments were carried out in the open outside the compartment. One experiment in the room was made with restricted ventilation simulating a room with only a small window open. During the experiments measurements were made of temperatures, heat fluxes, rate of heat release and smoke production. The concentrations of oxygen, carbonmonoxide, carbondioxide and nitrogen oxides in the combustion gases were also measured.

Results from one experiment, a sofa with filling of standard polyurethane and cover of 100% acrylic fibres is presented in detail. From the rest of the experiments the temperature-time curves and the rate of heat release curves are given. The flame spread rates for the tests with mattresses and beds, determined from videofilms of the tests, are presented. Conclusions that can be drawn from the results are that the covering material of the furniture plays an important role in the development of a fire. It is possible to produce upholstery materials that are difficult to ignite even with very powerful ignition sources. The room has a measureable influence on the fire development when the release of energy exceeds 1 MW.

An attempt is made to compare simple theoretical models for room fires with experimental results. A correlation equation based on regression analysis by J. Quintiere for assumption of the temperature in the hot upper layer in the room is applied to the experiments and gives good agreement with the experimental results. A number of models for determining flashover are also utilized and the results are in consistency with the experience gathered during the series of experiments. The calculations presented in this report were all carried out without help from computers. A more comprehensive theoretical analysis will follow in part 2 of the report.

1. INTRODUCTION

Upholstered furniture are frequently involved in fires in domestic and institutional buildings. Often the first or second item to ignite is a piece of upholstered furniture. It is consequently important to be able to predict the behaviour of upholstered furniture in a room or compartment fire.

The series of 12 full scale experiments reported here, comprises tests with mattresses, beds, sofas and chairs, and is a continuation of the work presented in /1, 2/. A method of testing furniture items in a room is now well established. This type of testing provides important basic data for studies of fire growth in compartments and for mathematical modelling of fire development. It is also a useful instrument for ranking commercial products.

Sweden has so far no legislative demands on furniture sold neither for use in domestic areas nor in public or institutional environments. For a couple of years discussions have been going on between the authorities, the National Board for Consumer Policies, and the industries concerned, to produce guidelines regarding the ignitability of upholstered furniture for domestic purposes. A proposal for guidelines has been presented to the Ministry of Housing and they are now considering the economic consequences of the guidelines. As regards public environments some sort of regulation can be anticipated in the future, the time aspect is however difficult to predict.

The results from the study presented here can be a tool in deciding what steps should be taken in improving the fire safety for people inside buildings as concerns fires involving upholstered furniture.

2. TEST CONFIGURATION AND INSTRUMENTATION

The experiments were performed with full size furniture inside a small compartment, but still of full scale dimensions. The test room was extensively equipped with instruments for collecting physical and chemical data (cf. figure 1).

Work is going on within ISO to standardize this type of room test. A proposal for standard has been published by the Swedish National Testing Institute in Borås /3/. In USA ASTM has published a similar proposal for standard /4/. This indicates that at least within a couple of years we will have a standardized room fire test. This ought to facilitate comparisons between tests performed at different laboratories and in different countries.

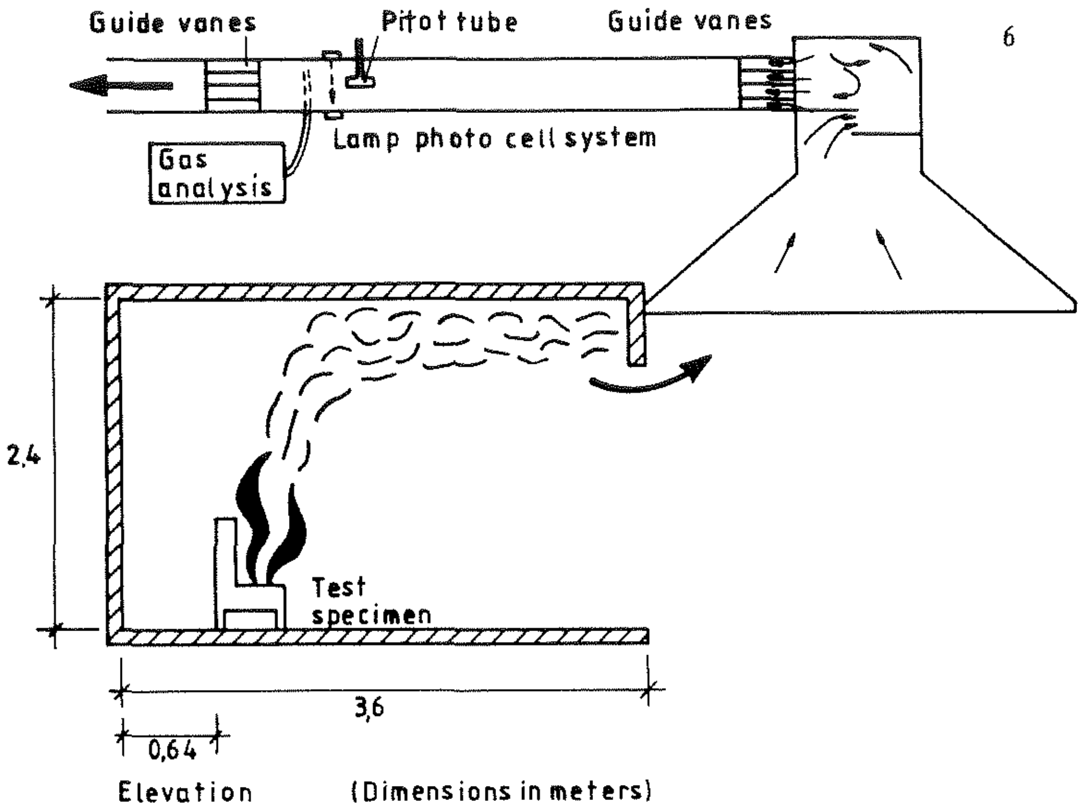

Figure 1 Test configuration for full scale room tests

2.1 Test Compartment

The experiments 1-10 were conducted in a room with the internal dimensions of 2.4 m x 3.6 m and a height of 2.4 m. The room has an opening, in the middle of one of the short sides, with a width of 0.8 m and a height of 2.0 m. The surrounding constructions are made of lightweight concrete with a thickness of 0.15 m.

2.2 Instrumentation

The test compartment was instrumented for measurement of temperature, heat flux, mass burning rate, rate of heat release, smoke production, mass flow of hot gases out of the room and for analysis of the combustion products.

2.2.1 Temperature

Gas temperatures were measured with thermocouples of Chromel Alumel with a diameter of 0.25 mm. Surface temperatures were measured with thermocouples welded to thin copper discs.

Temperatures were measured in the upper part of the doorway, along a vertical profile in the room, on the floor, in the duct and outside the room (ambient temperature). The positions of the thermocouples are given in figures 2-4 (channels 1-9).

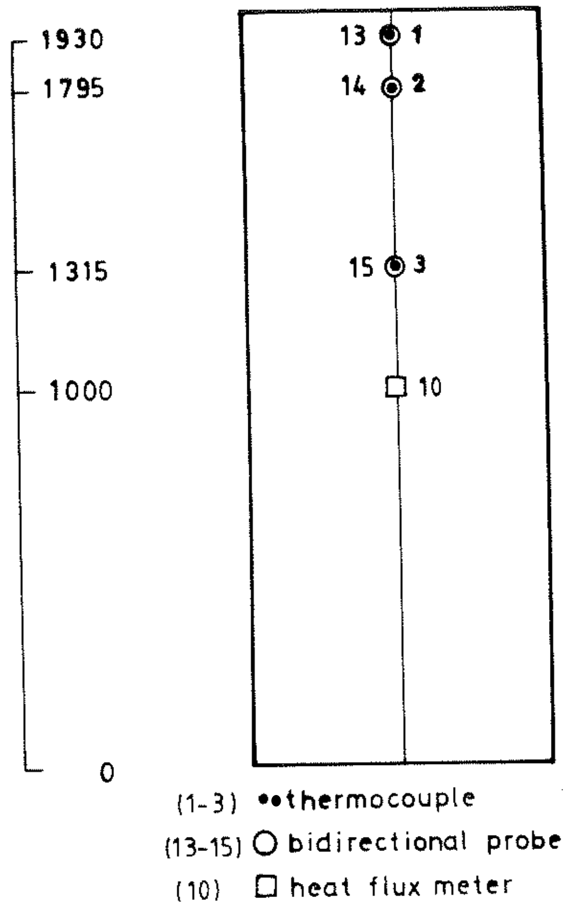

Figure 2 Positions of instruments in the doorway (distances in mm)

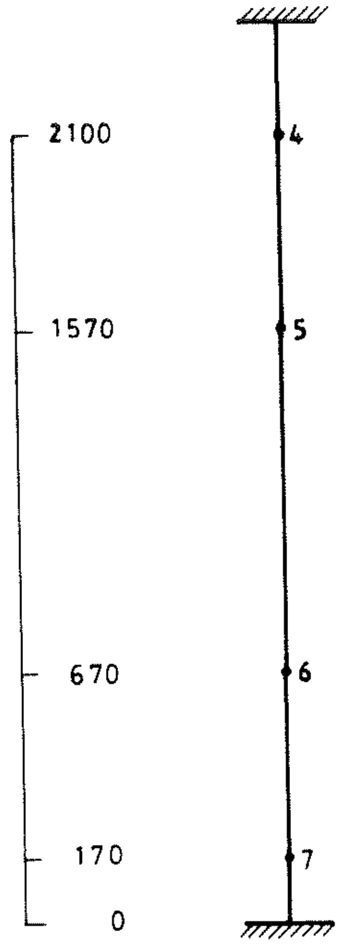

Figure 3 Positions of thermocouples along a vertical profile inside the room. the location of the vertical profile is given in figure 4 (distances in mm)

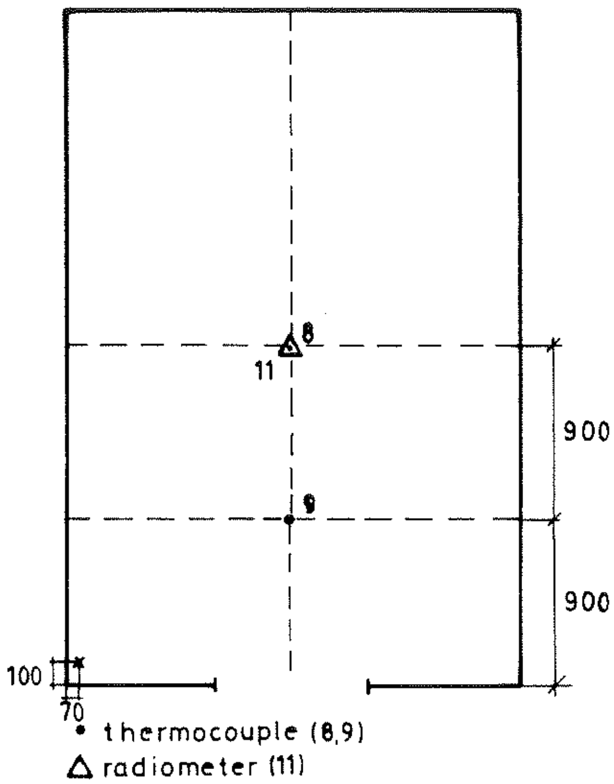

Figure 4 Positions of instruments on the floor
x represents the location of the vertical profile with thermocouples (distances in mm)

2.2.2 Heat Flux

During the tests measurements were made of total heat flux (convection and radiation) and of pure radiation. The total heat flux was measured with a Gardon-type instrument called Medtherm heat flux meter. The radiation was measured with the Medtherm heat flux meter equipped with a sapphire window.

Total heat flux measurements were made in the centre of the ceiling, in one of the side walls and in the doorway looking into the room. Radiation was measured in the centre of the floor.

The actual positions of the meters are given in figure 2, 4 and 5 (channels 10-12).

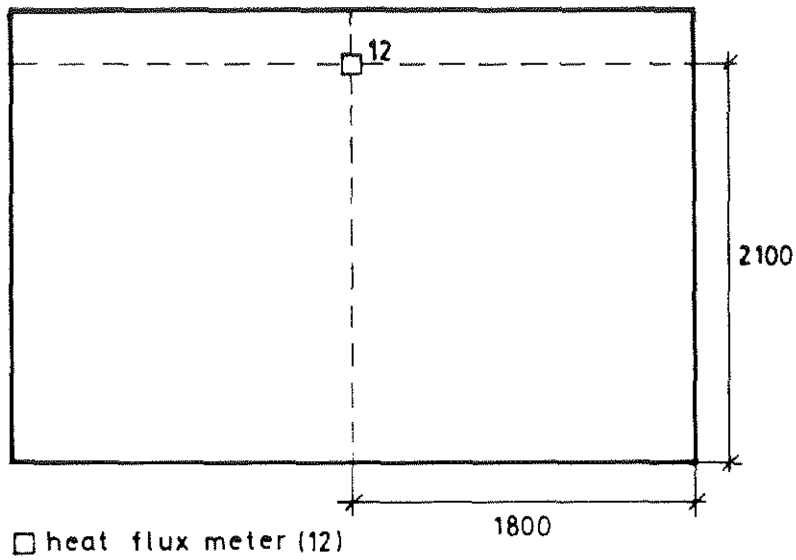

Figure 5 Position of heat flux meter in the side wall (distances in mm)

2.2.3 Burning Rate

The tested specimen was placed on a weighing platform using three loadcells under the floor of the test compartment. The accuracy of the weighing equipment is estimated to 20-50 g.

2.2.4 Rate of Heat Release

All smoke and combustion gases emerging from the test compartment are collected in a hood just outside the room. The hood is, via an exhaust duct connected with the ordinary evacuation system, figure 1.

The rate of heat release (RHR) was determined by the technique of measuring oxygen consumption. The oxygen concentration is measured in the exhaust duct by a paramagnetic analyser with an accuracy of ±0.1 vol% oxygen. The mass flow is determined by a pitot tube of the type bi-directional probe /5/ and a thermocouple in the centre of the exhaust duct at a distance from the hood where the velocity profile is ensured to be fully developed. Guide vanes are installed in the exhaust duct to obtain a fully developed velocity profile at a rather short distance from the hood and baffles are mounted inside the hood to ensure good mixing of the fire gases.

2.2.5 Smoke Production

The optical density of the smoke was determined by measuring the absorbtivity of the combustion gases in the duct, by a system consisting of a lamp, a lens system, an aperture and a photocell as in figure 6.

The lamp is a tungsten halogen lamp working at a colour temperature of 2900 ±100 K (Osram halo stars; 64410; 6V; 10W). The photocell has a spectral sensitivity according to the CIE photopic curve (United Detector Technology; PIN 10 AP).

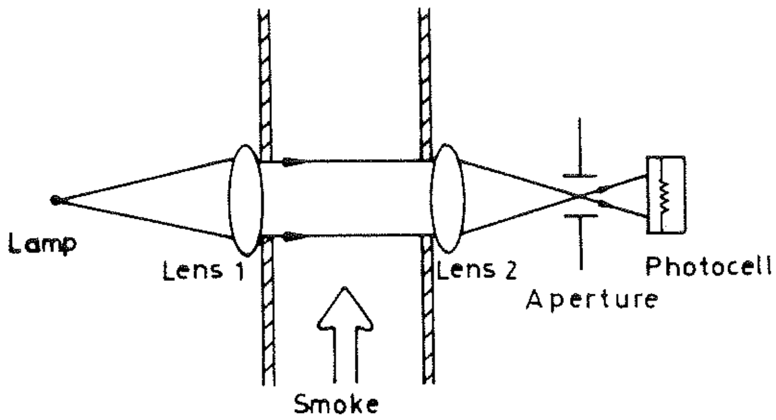

Figure 6 Measuring system for determination of smoke absorbtivity

2.2.6 Gas Analysis

The fire gases were continuously analysed for content of carbonmonoxide (CO), carbondioxide (CO_2), nitrogen oxides (NO_x), hydrocarbons (CH_x) and oxygen (O_2). The gas samples are taken in the exhaust duct as shown in figure 1.

The CO and CO_2 were analysed with an IR analyser from Infrared Industries (IR702), the NO_x with a chemiluminescence instrument (Beckman 952), the CH_x with an IR instrument (Scott Emission Analyzer) and the O_2 with a paramagnetic analyser (Siemens Oxymat 2).

The fire gases were filtered to remove the soot particles and chilled by passing a cooler, immersed in an ice-water mixture before analysis.

2.3 Ignition Sources

Two flaming ignition sources were used in the experiments.

The beds and mattresses were ignited by a 40 g wooden crib (figure 7), constructed according to NT Fire 007 /6/. The crib was positioned 0.5 m from the head end of the bed along the centre-line.

In the experiments with sofas and chairs a liquid fuel burner with 0.1 l heptane was used. The heptane is poured onto a bottom layer of water. The burner is a square formed trough with a 0.18 m side. With the given amount of fuel, the burner has an output of about 20 kW for 2.5-3 minutes. The burner is positioned in front of the sofa at the left side when looking in at the sofa through the doorway.

The crib was chosen as ignition source for the experiments with mattresses and beds as it has previously been used in a large number of tests with beds and mattresses in reduced scale and in those tests proved to give reproducible ignition.

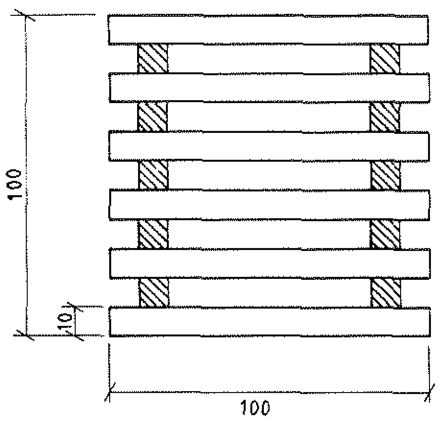

Figure 7 The 40 g wooden crib, according to NT Fire 007, used as ignition source for beds and mattresses. It is constructed of 8 pieces of pine wood, 10 x 10 mm^2 and 100 mm long. The pieces are put together as shown in the figure /6/

3. TEST SPECIMENS

Experiments were performed with sofas, chairs, mattresses and beds. To get reproducible fire scenarios and clearly defined and measureable reactions to variations in the main parameter, i.e. material selection, the test furniture was full-scale mock-up models. The test specimens were made from materials commonly used in furnishings. All material, but the bedding, was purchased directly from the producer. The bedding was bought from an ordinary shop.

The tested piece of furniture was placed at the far end of the room, 0.64 m from the wall opposite the door, see figure 1.

3.1 Furniture Construction

Sofa

The sofas were full-scale mock-up models of a sofa for three persons designed with loose cushions on a steel frame, figure 8. The seat cushion was 0.65 x 1.8 x 0.12 m^3 and the back cushion 0.42 x 1.8 x 0.12 m^3. The seat was 0.3 m from the floor at the front and 0.24 m at the back.

Chair

The chairs were full-size mock-up models made from particle board with loose cushions at the seat and back. The design is the same as for the sofa, see figure 8. The particle board was covered with aluminium foil to delay the ignition of the base construction. The seat cushion was 0.65 x 0.55 x 0.12 m^3 and the back cushion was 0.42 x 0.55 x 0.12 m^3. The seat was 0.3 m from the floor at the front and 0.24 m at the back.

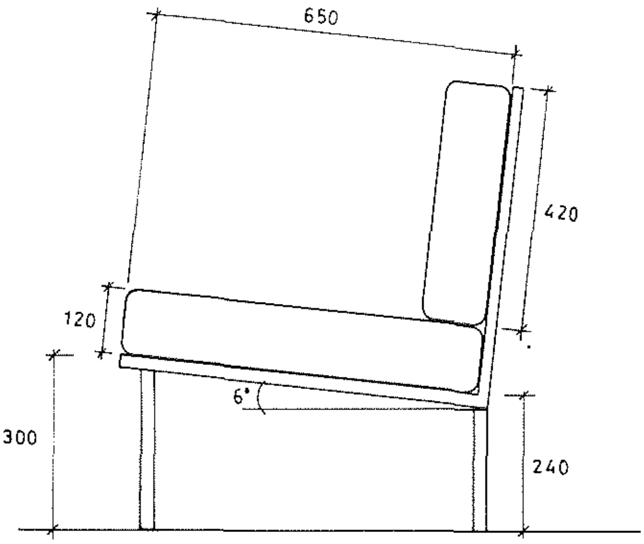

Figure 8 Design and dimensions of the full scale mock-up sofa (length 1.8 m) and chair (width 0.55 m) (dimensions in mm)

Bed

The bedbase consisted of a metal frame with an interior of metal springs. The bedbase had the dimensions 0.9 x 1.9 m^2 and the height above the floor was 0.3 m. The tested mattresses had the size 0.9 x 2.0 x 0.1 m^3.

3.2 Component Materials

The component materials were commonly available materials intended for domestic purposes. One mattress was however made of flame retardant treated polyurethane with a flame retardant treated cotton cover. This mattress is mainly intended for use in institutional areas. The component materials are described in tables 1-3.

Table 1: Material for mattresses

Filling materials	
1. Standard polyurethane (T 3545 G),	density = 35 kg/m^3
2. Flame retardant treated high resilient polyurethane (HR 35),	density = 35 kg/m^3
Cover materials	
1. Cotton (100%).	weight = 135 g/m^2
2. Flame retardant treated cotton.	weight = 260 g/m^2

Table 2: Material for bedding

Sheet: Cotton (100%)	weight	= 180 g/m^2
Quilt: Filling: polyesterfibre,	weight	= 200 g/m^2
Cover: viscose,	weight	= 110 g/m^2

Table 3: Materials for sofas and chairs

Filling materials		
1. Standard polyurethane (T 3065 G),	density	= 30 kg/m^3
2. Flame retardant treated polyurethane (T 3540 DG),	density	= 35 kg/m^3
Cover materials		
1. Acrylic (100%),	weight	= 300 g/m^2
2. Wool-viscose (61%-39%),	weight	= 540 g/m^2

4. TEST PROGRAMME

Three types of tests were conducted within this series of twelve full scale experiments. The tests are presented in table 4.

Nine experiments were performed as normal room-experiments with the furniture items inside a well-ventilated standardized test compartment (tests 1-9). To study the influence of the ventilation one experiment was made with restricted ventilation (test 10). Full scale experiments with furniture have traditionally been conducted in a room as their normal use is in rooms of limited size. To determine the influence of the room on the development of the fire, two experiments were conducted in the open outside the room (tests 11 and 12).

4.1 Well-Ventilated Room Tests

A series of nine full scale experiments (tests 1-9) were conducted in a standardized well-instrumented test compartment with one door open to achieve good ventilation. The series comprised two experiments with a bare mattress on a bed-base, two experiments with a made-up bed with sheets and quilt, two experiments with two chairs and three experiments with sofas. The materials are specified in tables 1-3.

Table 4: Tests

Test No	Type of test specimen	Initial weight (kg)	Ignition source	Filling material	Cover material
1	Mattress	6.0	Wood crib	Standard polyurethane	Cotton
2	Mattress	6.4	Wood crib + liquid fuel burner	Flame retardant treated high resilient polyurethane	Flame retardant treated cotton
3	Made-up bed	8.4	Wood crib	Standard polyurethane	Cotton (and sheet and quilt)
4	Made-up bed	8.8	Wood crib	Flame retardant treated high resilient polyurethane	Flame retardant treated cotton (and sheet and quilt)
5	Sofa	8.2	Liquid fuel burner	Standard polyurethane	Acrylic
6	Sofa	8.9	Liquid fuel burner	Flame retardant treated polyurethane	Acrylic
7	Sofa	9.3	Liquid fuel burner	Standard polyurethane	Wool-viscose
8	Two chairs (distance 0.3 m)	5.1	Liquid fuel burner	Standard polyurethane	Acrylic
9	Two chairs (distance 0.15 m)	5.1	Liquid fuel burner	Standard polyurethane	Acrylic
10	Sofa (restricted ventilation)	8.2	Liquid fuel burner	Standard polyurethane	Acrylic
11	Mattress (open configuration)	6.0	Wood crib	Standard polyurethane	Cotton
12	Sofa (open configuration)	8.2	Liquid fuel burner	Standard polyurethane	Acrylic

For material specifications see tables 1-3

4.2 Room Test with Restricted Ventilation

One room experiment (test 10) was conducted with restricted ventilation. This was achieved by shutting off the lower half of the door with a non-combustible board: the open upper half simulating an open window. The experiment was performed with a sofa similar to the sofa in the experiments 5 and 12. The intention with this test was to study what influence the change in ventilation has on the development of the fire and on the composition of the combustion products.

4.3 Tests Conducted Outside the Room in "Open Configuration"

Two tests were conducted on a weighing platform under the hood outside the room (tests 11 and 12). This enables totally free flow of air from three sides and approximately free flow of air from the fourth side. One of the experiments, test 12, was made with a similar sofa as in tests 5 and 10, and the other experiment, test 11, with a similar mattress as in test 1.

The two experiments in open configuration give an indication of how the room influences the fire and how intense the fire can get before the influence from the room becomes significant.

5. TEST RESULTS

During the series of experiments a large amount of data was generated and collected. All data cannot be reported but examples of all kinds of collected data will be given. This is achieved by reporting all data from test 5 and selected data from the rest of the experiments. Visual observations from the experiments are reported in appendix. During the experiments measurements were made of temperature, heat flux, mass burning rate, rate of heat release, smoke production and mass flow of hot gases out of the room. An analysis of the combustion products was also made.

5.1 Temperatures

Temperatures were measured on nine locations inside the test compartment. How the temperatures were measured and where is reported in section 2.2.1 and in the figures 2-4.

5.1.1 Mattresses and Beds

In figure 9 the temperature-time curves are given for tests 1, 3 and 4. Test 1 is a bare mattress on a bed-base and test 3 is a similar mattress with bedding (sheets and quilt). The addition of bedding increases the temperature in the upper part of the room by approximately 100°C and shortens the duration of the experiment by four minutes.

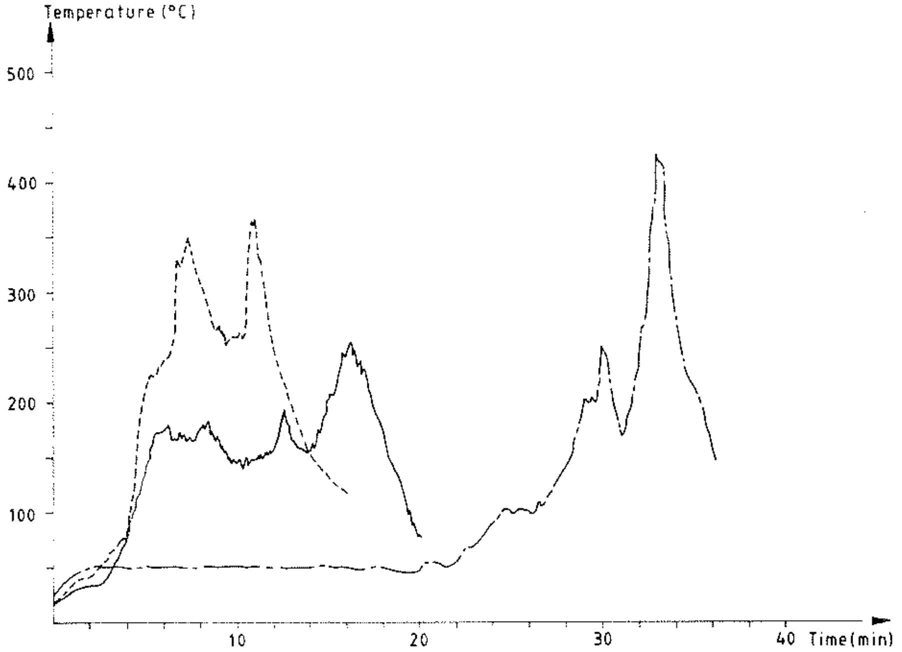

Figure 9 The temperature in the hot upper layer as a function of time for the tests: 1 (standard mattress), 3 (bed, standard materials) and 4 (bed, flame retardant treated materials). For material specifications see tables 1-4. The temperature was measured by thermocouple number 4 (see figure 3)
—— test 1
---- test 3
--- test 4

The temperature-time curve from test 2 is not presented as sustained combustion never was achieved during the test and hence never gave an increase in the room temperature.

In test 4 with flame retardant treated mattress and standard bedding the temperature in the upper part of the room is 50°C for the first 20 minutes and then increases to 400°C during a short period towards the end of the test, figure 9.

5.1.2 Sofas

The temperature measurements in the tests with sofas made of different materials, see figure 10, show that the choice of both filling and covering material influences the temperature level in the room. The cover material gives by far the largest influence, the change in filling material gives a minor contribution. The maximum temperature in the upper part of the room is decreased by 100°C and the course of the fire is prolonged by 1.5 minutes, when the filling is changed from standard polyurethane foam to a flame retardant treated quality. By changing the cover from acrylic to a wool-viscose blend the temperature was decreased by 350°C. The results show that the lower part of the room is warmer for the standard polyurethane filling and acrylic cover than with the improved materials.

By improving the cover material the build-up period of the fire is extended about ten minutes. The temperature on the floor is also decreased, by approximately 200°C, when the cover material is improved.

In figure 10 the hot layer temperature is given for test 10 with restricted ventilation. Compared to the results from test 5 (normal ventilation) it is found that the peak temperature in the room is 200°C lower and of longer duration. The floor temperature is lowered 100°C.

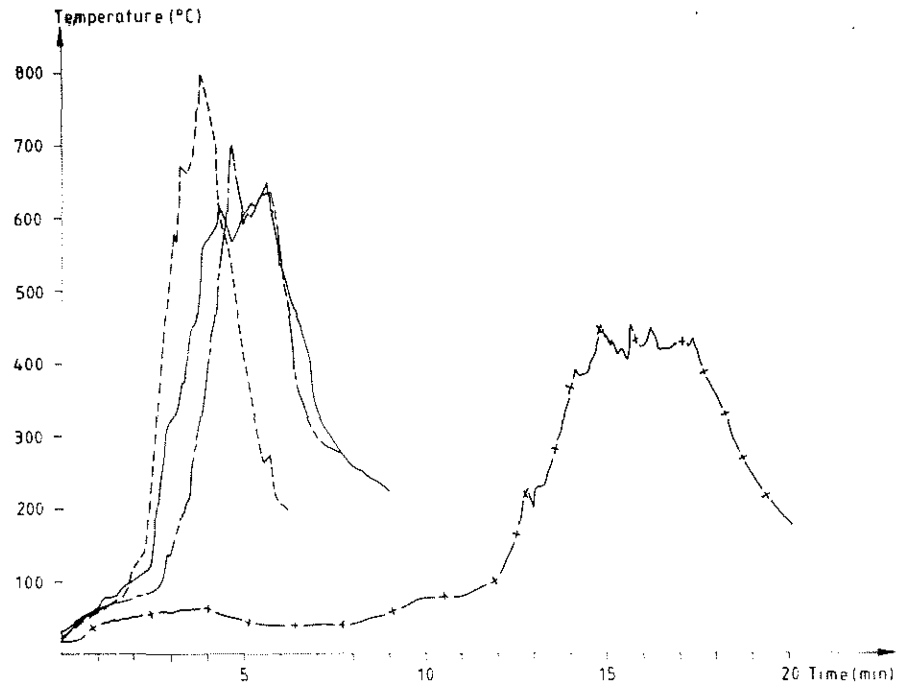

Figure 10 The temperature in the hot upper layer as a function of time for the tests: 5 (sofa, standard polyurethane with acrylic cover), 6 (sofa, flame retardant treated polyurethane with acrylic cover), 7 (sofa, standard polyurethane with wool-viscose cover) and 10 (sofa, restricted ventilation, standard polyurethane with acrylic cover). For material specifications see tables 1-4. The temperature was measured by thermocouple number 4 (see figure 3)
--- test 5 --- test 7
-·- test 6 —— test 10

The temperatures of the gases leaving the room are given for test 5 in figure 12. The curves show temperature levels which are comparable to those inside the room, figure 11.

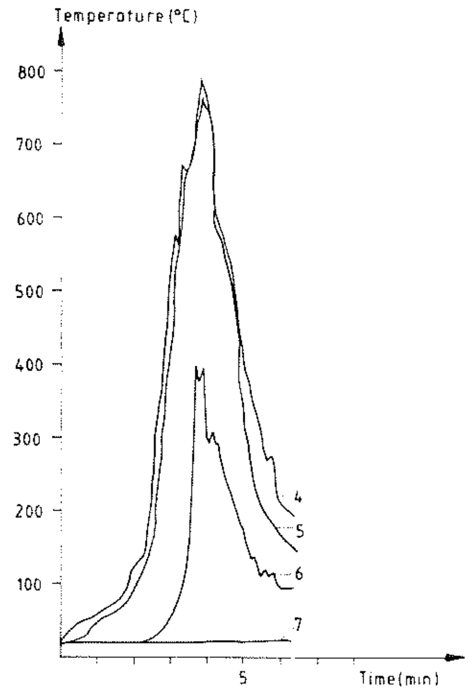

Figure 11 Temperature-time curves for test 5 (sofa, standard polyurethane with acrylic cover) showing temperatures inside the room along the vertical profile presented in figure 3. For material specifications see tables 1-4. The numbers of the curves refer to the thermocouples in figure 3

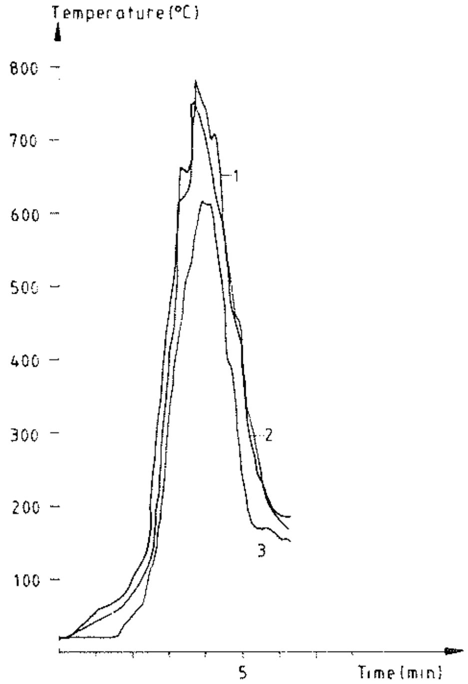

Figure 12 Temperature-time curves for test 5 (sofa, standard polyurethane with acrylic cover) showing temperatures along the vertical profile in the doorway. The profile is presented in figure 2. For material specifications see tables 1-4. The numbers of the curves refer to the thermocouples in figure 3

5.1.3 Chairs

In figure 13 the temperature-time curves are given for tests 8 and 9, with two chairs. In test 8 the distance between the chairs was 0.3 m but this proved to be too long to give ignition of the second chair. Hence the curve in figure 13 gives the temperature for one burning chair.

The distance between the chairs was shortened to 0.15 m in test 9. This gave ignition of the second chair approximately 3 min 40 s after ignition of the first chair.

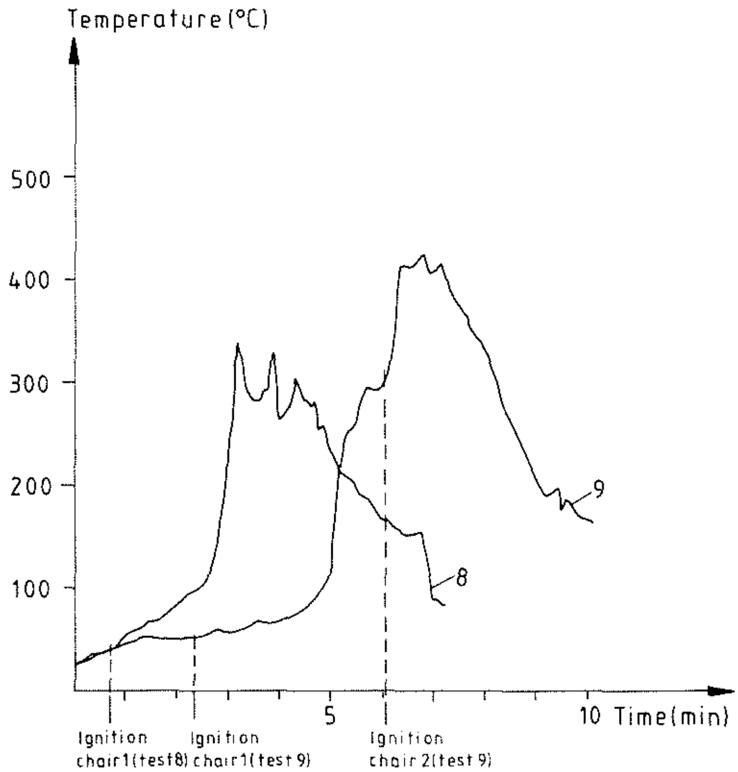

Figure 13 The temperature in the hot upper layer as a function of time for the tests: 8 (two chairs, distance 0.3 m, standard polyurethane, acrylic cover) and 9 (two chairs, distance 0.15 m, standard polyurethane, acrylic cover). For material specifications see tables 1-4. The temperature was measured by thermocouple number 4 (see figure 3)

Unfortunately, the burner was not adequately placed in test 9, this giving a longer time to ignition of chair 1 than in test 8. The ignition time is prolonged by about 1 min 40 s. If this is taken into account a comparison of the temperature-time curves for the two tests show that the contribution from the first burning chair is the same in both tests and that the second chair increases the peak temperature by approximately 100°C.

5.2 Heat Flux and Irradiance

The heat flux curves from test 5 are presented in figure 14. The curves give the total heat flux to the ceiling, to the upper part of the side-wall and out through the doorway. There is also one curve for the irradiance to the floor.

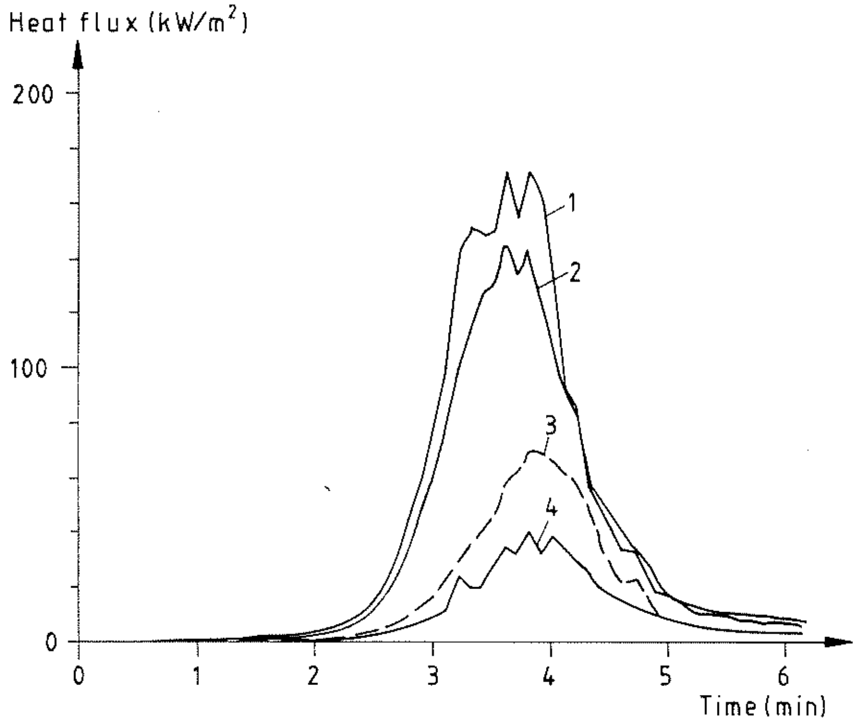

Figure 14 Heat flux (——) and irradiance (---) as a function of time for test 5 (sofa, standard polyurethane with acryclic cover). For material specifications see tables 1-4. Curve 1 = ceiling, 2 = wall, 3 = floor and 4 = = doorway, for exact positions see figures 2, 4 and 5

Table 5: Peak Irradiance to the Floor

Test No	Peak Irradiance (kW/m^2)
1	3
2	- (no sustained combustion)
3	11
4	10
5	69
6	60
7	15
8	5
9	13
10	25
11	- (open configuration)
12	- (open configuration)

The results from the other experiments show roughly the same relations between the different measurements. These results are not fully reported here, only the peak irradiances to the floor are presented in table 5. The peak irradiance to the floor is reported because it can be used as an indication to whether flashover has occurred or not. *See paragraph 6.2.*

5.3 Mass Burning Rates

The tested furniture was placed on a weighing platform and the mass loss was registered continuously. A typical mass loss curve is presented in figure 15. The mass loss curves can be used in two ways. By assuming a value for the effective heat of combustion, ΔH_{eff}, the rate of heat release (RHR) can be calculated as

$$RHR = \dot{m} \cdot \Delta H_{eff} \qquad (1)$$

RHR = rate of heat release (kW)
$\dot{m}$ = mass loss rate (kg/s)
ΔH_{eff} = effective heat of combustion (kJ/kg)

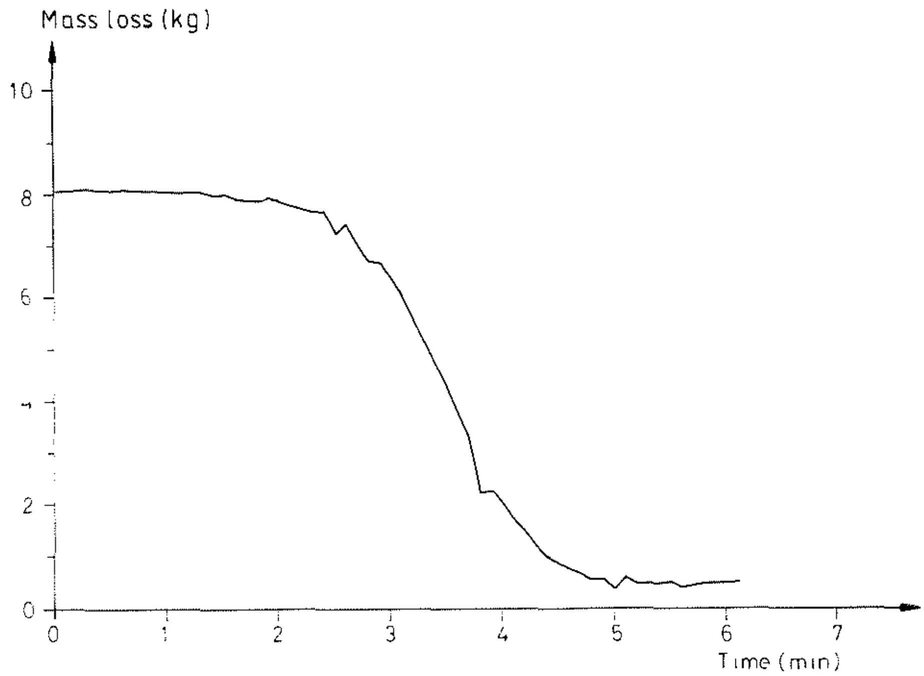

Figure 15 The mass loss curve for test 5 (sofa, standard polyurethane with acrylic cover)

A major problem with this method is that values for ΔH_{eff} for the combinations of materials used in upholstered furniture are not well known. This fact makes it more tempting to use the

RHR-results from the oxygen depletion measurements for calculating ΔH_{eff}. This has been done and the results are presented in table 6. Two values are given for each combination of materials, the average value for the experiment and the value arrived at when the RHR reaches its peak value.

The values range from 18.4 MJ/kg to 26.7 MJ/kg. With one exception, test 7, the average values are lower than the value arrived at near the maximum of RHR.

These experimentally determined values for heat of combustion are generally higher than values found in the literature for corresponding materials.

Table 6: Experimentally Determined Values for Effective Heat of Combustion

Test No	ΔH_{eff} near peak RHR MJ/kg	ΔH_{eff} average MJ/kg
1	23.1	21.6
2	-	-
3	20.8	20.5
4	-	-
5	24.8	21.6
6	24.2	22.9
7	21.7	26.7
8	22.4	21.8
9	23.4	20.5
10	22.2	20.3
11	22.0	19.9
12	23.3	18.4

5.4 Rate of Heat Release

The rate of heat release (RHR) was determined by using the technique of oxygen consumption. This technique is based on the fact that the energy released per unit oxygen consumed is close to a constant for complete combustion of most fuels of interest in compartment fires. This constant is 13.1 MJ/kg oxygen consumed or 17.2 MJ/m^3 oxygen consumed at 25°C, with an accuracy of 5% or better /7/. The technique requires that all smoke and gases from the test room are collected in a hood and are exhausted via a duct where the oxygen concentration and the gas flow are measured.

The RHR can according to Parker /8/ be calculated as:

$$RHR = \dot{V}_f (x^{\circ}_{O_2} - x^{e}_{O_2}) \frac{E}{\alpha} \qquad (2)$$

RHR = rate of heat release (kW)
$\dot{V}_f$ = volume flow of air and combustion products through the

duct at 25°C and 1 atm (m^3/s)

$x^e_{O_2}$ = ambient oxygen concentration (vol%)

$x^s_{O_2}$ = measured oxygen concentration in the duct (vol%)

E = energy released per unit oxygen consumed = 17.2 MJ/m^3 (at 25°C)

α = expansion factor for the fraction of air that was depleted of its oxygen = 1.1.

An alternative is to use the mass burning rates and known values of heat of combustion to calculate the RHR, this method is described in 5.3.

The results of the RHR-calculations are presented in figures 16 to 26. The time difference between the curve calculated from mass loss and the oxygen consumption curve is due to the time constant for the gas analysis system. The time constant is approx. 30 s. The values of $\Delta H_{e..}$ presented in figures 16-26 were chosen so that the curves calculated from mass loss measurements gave results in good agreement with the results from oxygen consumption measurements.

In test 4 the oxygen measuring device failed and hence the ordinary calculations of RHR could not be carried out. Therefore only the values based on mass burning rates are presented in figure 18.

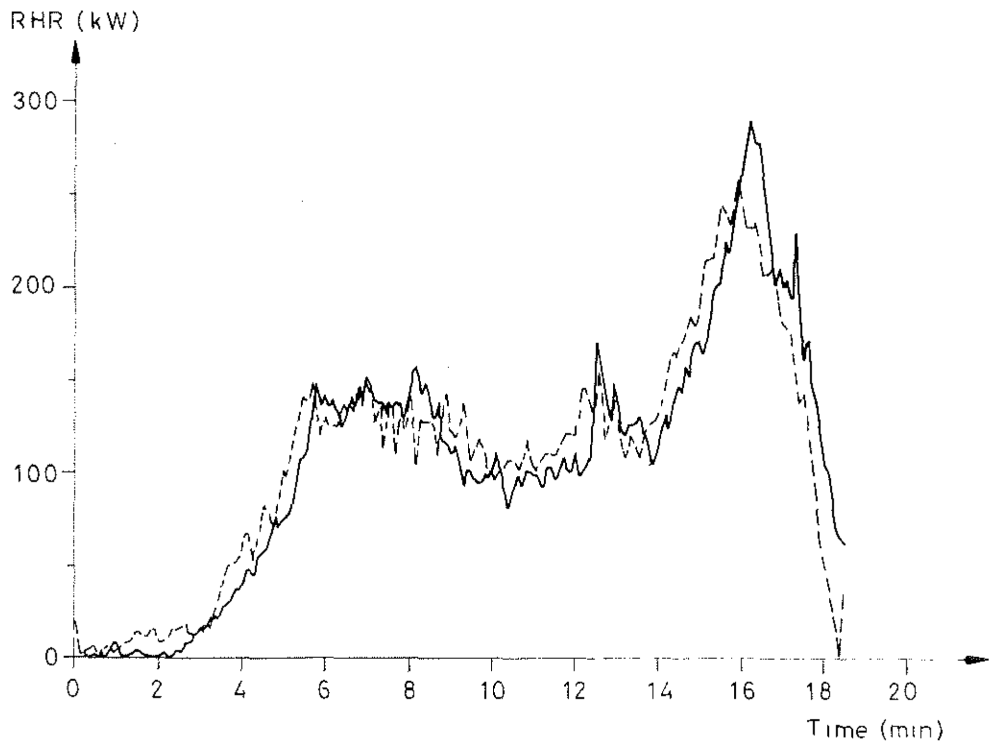

Figure 16 RHR curves for test 1 (mattress, standard polyurethane)
—— calculated from measured oxygen consumption
--- calculated from measured mass loss with $\Delta H_{e..}$ = 22 MJ/kg

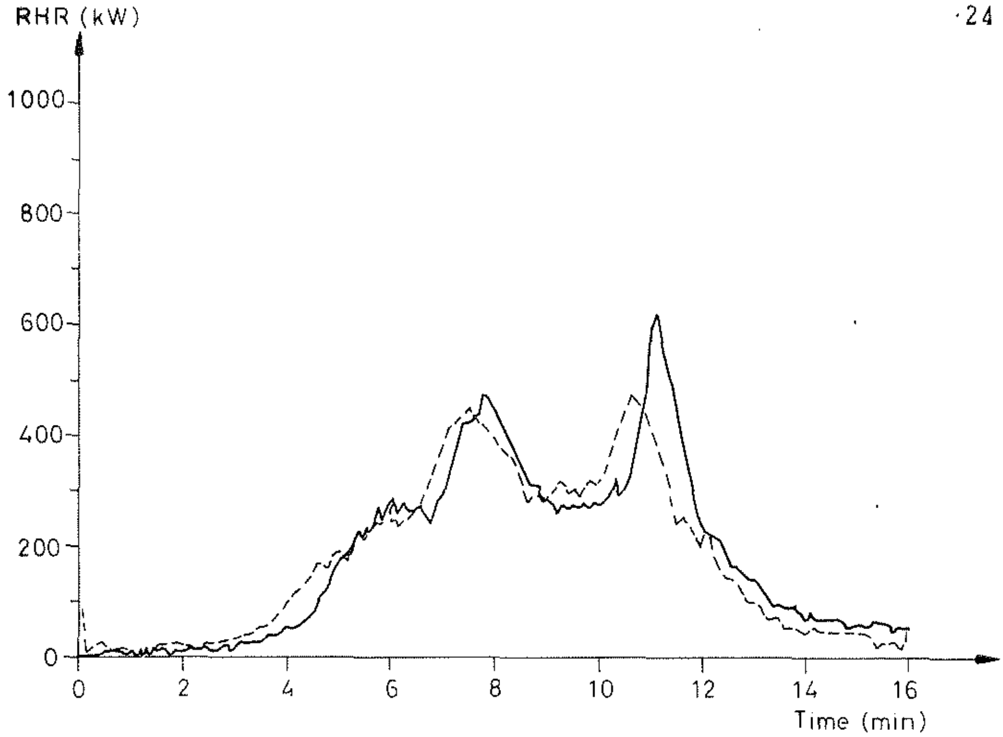

Figure 17 RHR curves for test 3 (bed, standard polyurethane and bedding)
—— calculated from measured oxygen consumption
--- calculated from measured mass loss with
$\Delta H_{e..}$ = 20 MJ/kg

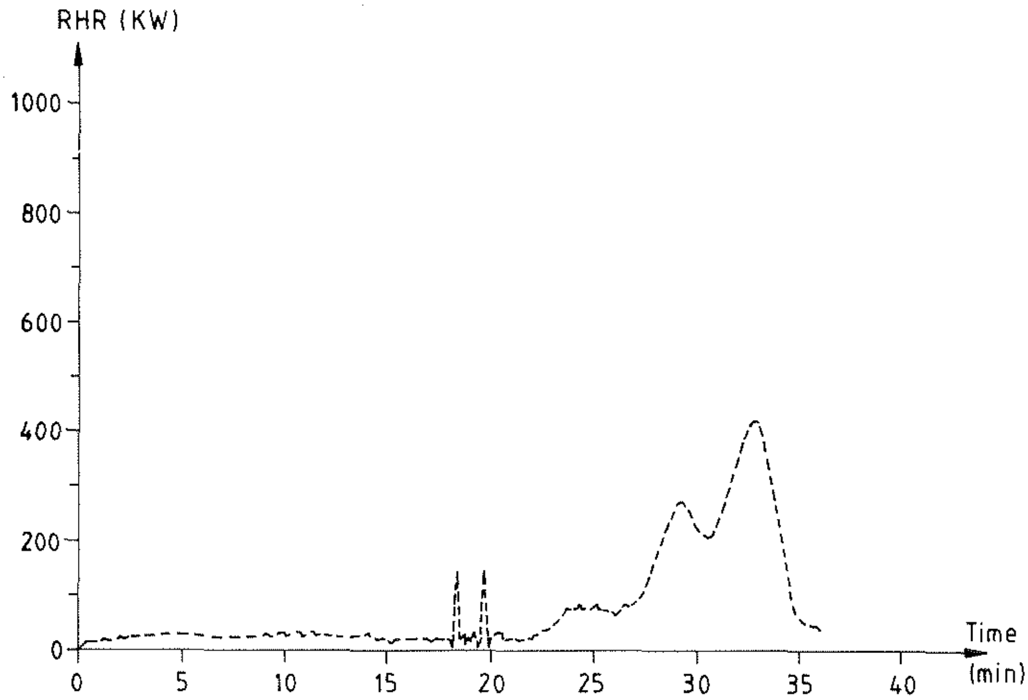

Figure 18 RHR curves for test 4 (bed, flame retardant treated high resilient polyurethane and bedding)
--- calculated from measured mass loss with
$\Delta H_{e..}$ = 20 MJ/kg

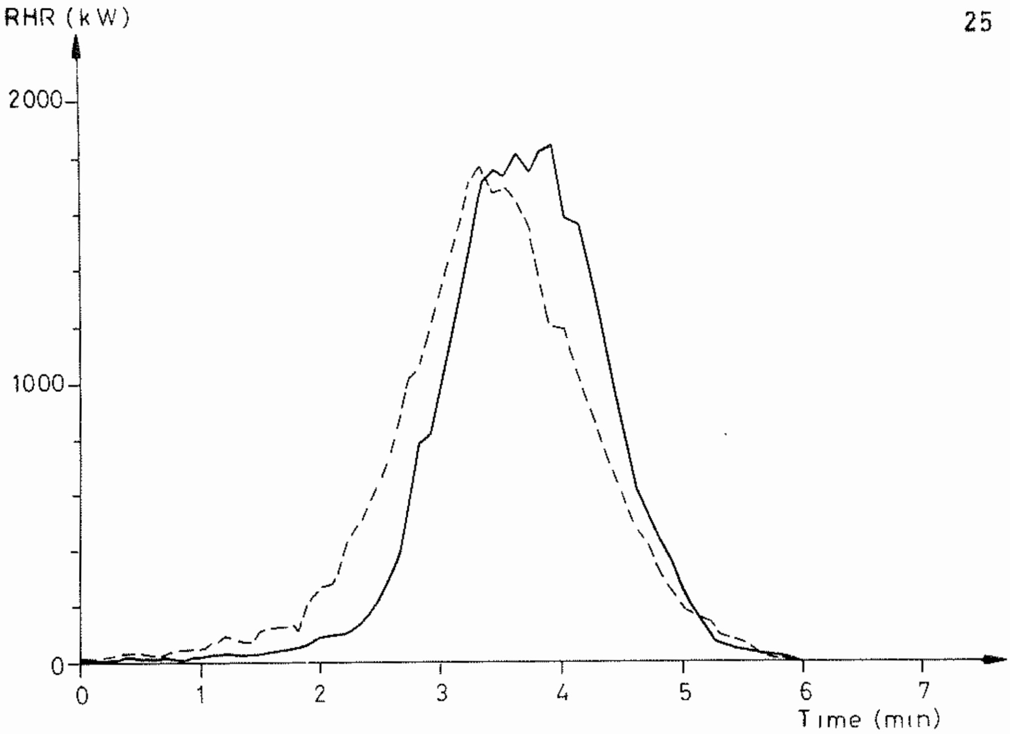

Figure 19 RHR curves for test 5 (sofa, standard polyurethane with acrylic cover)
—— calculated from measured oxygen consumption
--- calculated from measured mass loss with $\Delta H_{e..}$ = 24.6 MJ/kg

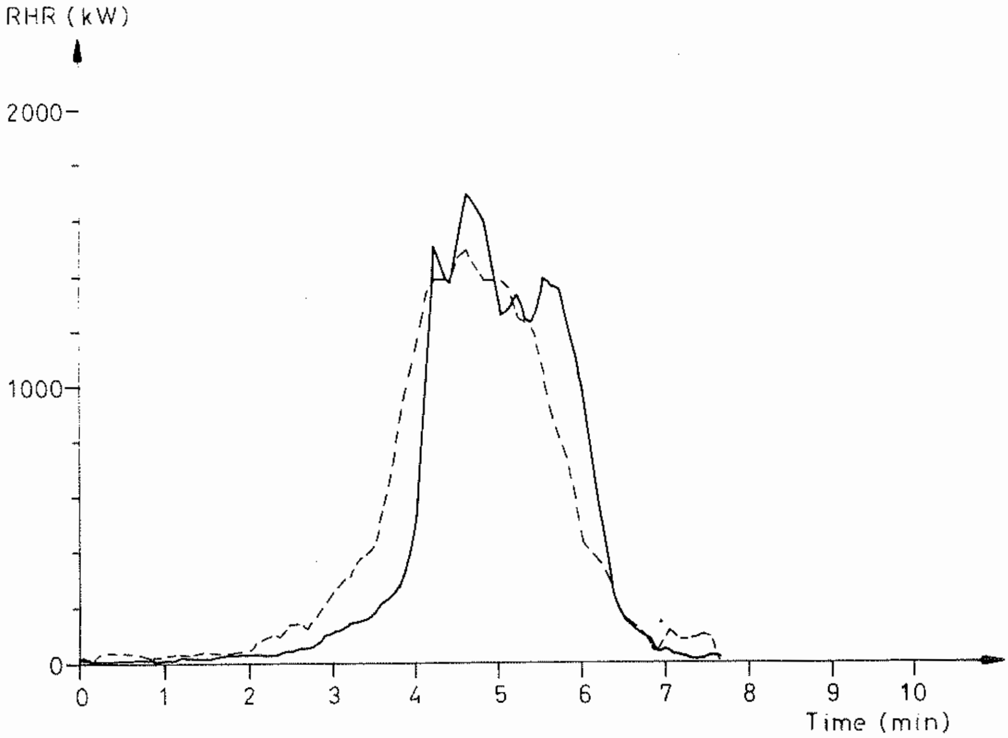

Figure 20 RHR curves for test 6 (sofa, flame retardant treated polyurethane with acrylic cover)
—— calculated from measured oxygen consumption
--- calculated from measured mass loss with $\Delta H_{e..}$ = 24.6 MJ/kg

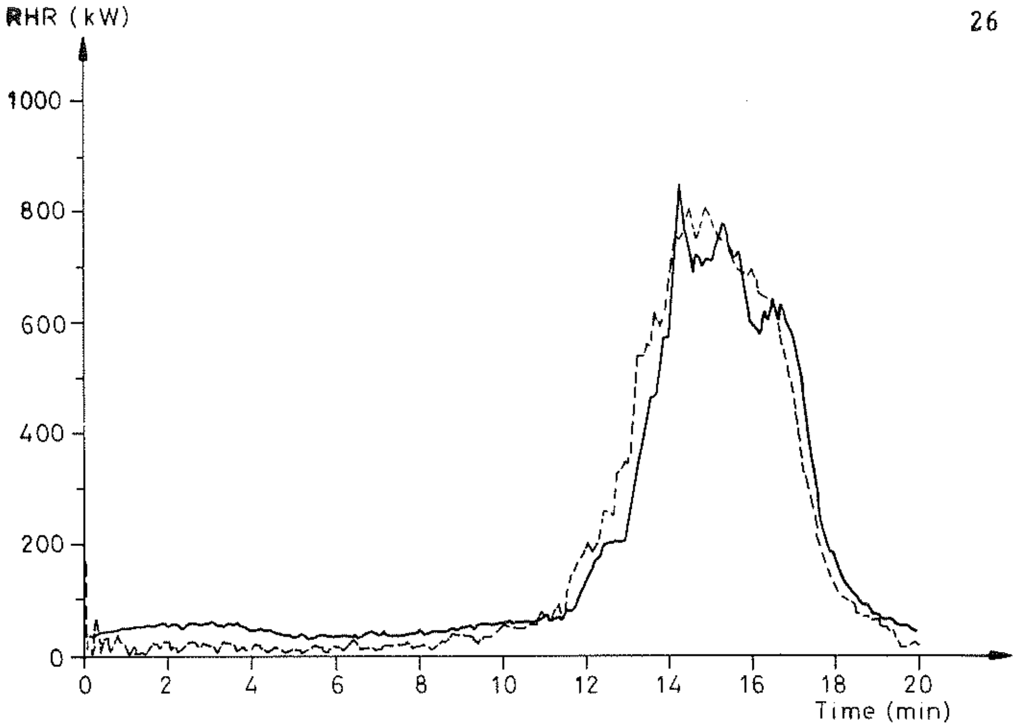

Figure 21 RHR curves for test 7 (sofa, standard polyurethane with wool-viscose cover)
—— calculated from measured oxygen consumption
--- calculated from measured mass loss with ΔH_{eff} = 24.6 MJ/kg

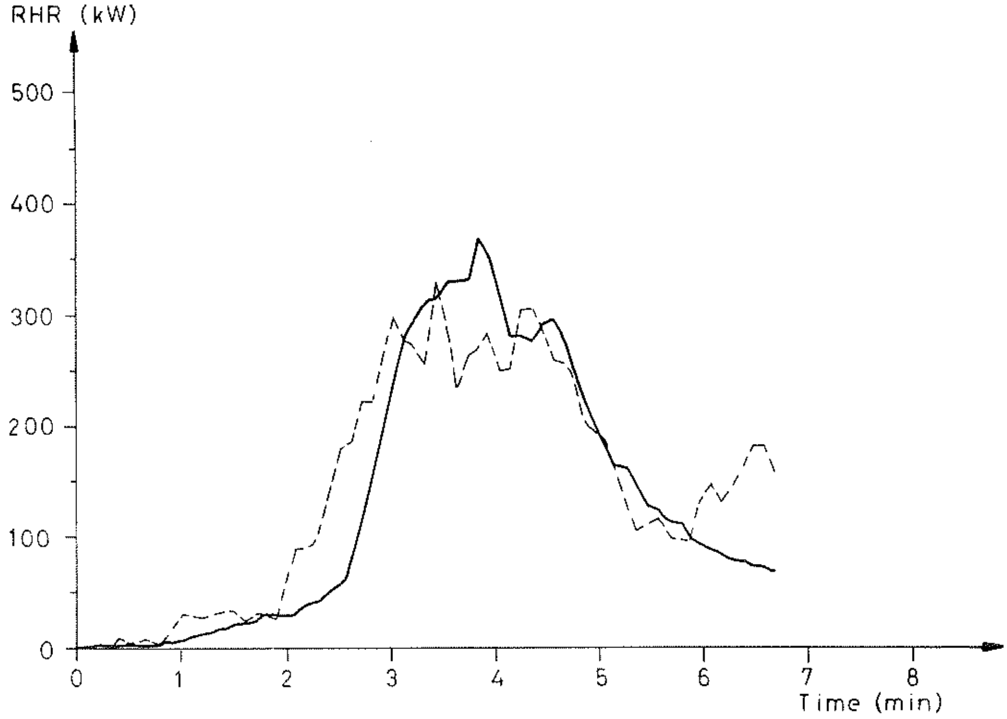

Figure 22 RHR curves for test 8 (two chairs, standard polyurethane with acrylic cover)
—— calculated from measured oxygen consumption
--- calculated from measured mass loss with ΔH_{eff} = 22 MJ/kg

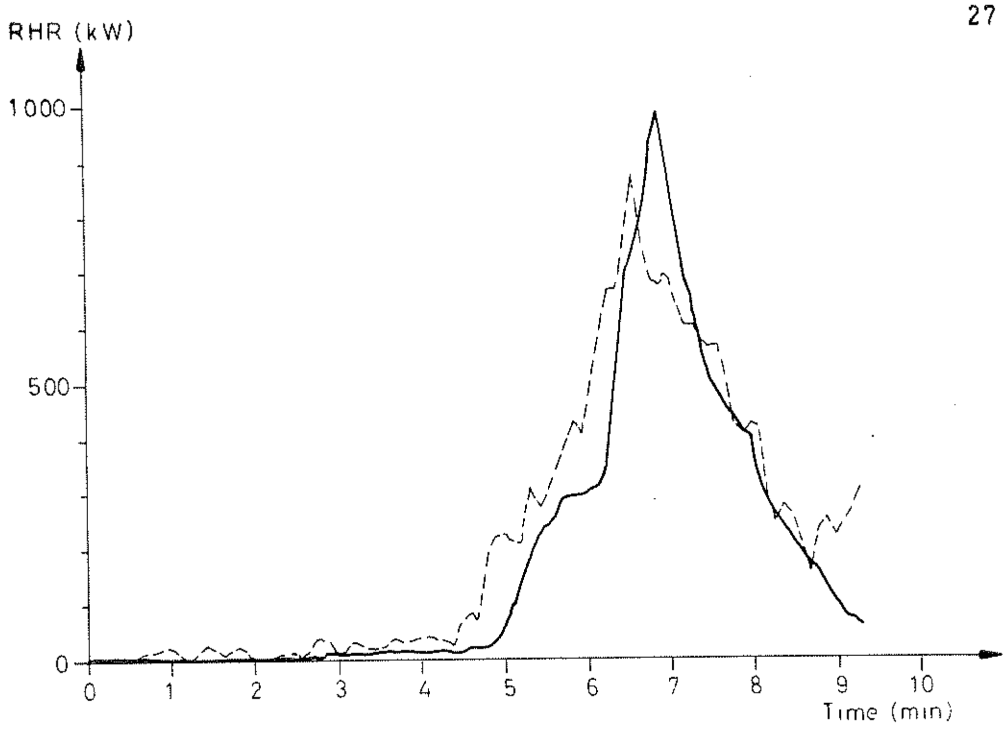

Figure 23 RHR curves for test 9 (two chairs, standard polyurethane with acrylic cover)
—— calculated from measured oxygen consumption
--- calculated from measured mass loss with ΔH_{eff} = 22 MJ/kg

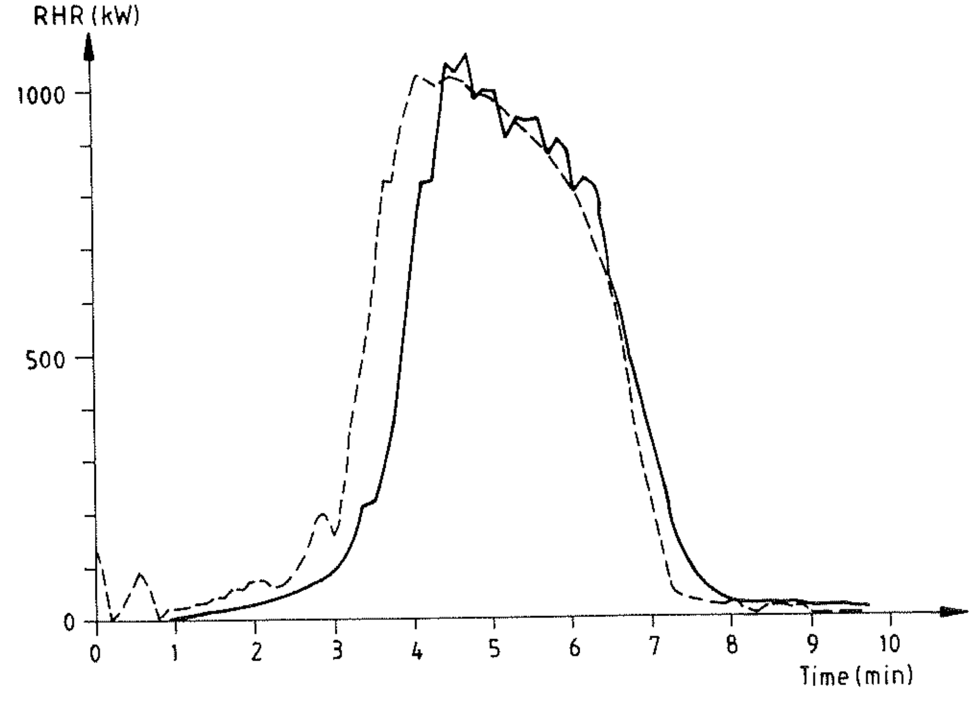

Figure 24 RHR curves for test 10 (sofa, standard polyurethane with acrylic cover, restricted ventilation)
—— calculated from measured oxygen consumption
--- calculated from measured mass loss with ΔH_{eff} = 24.6 MJ/kg

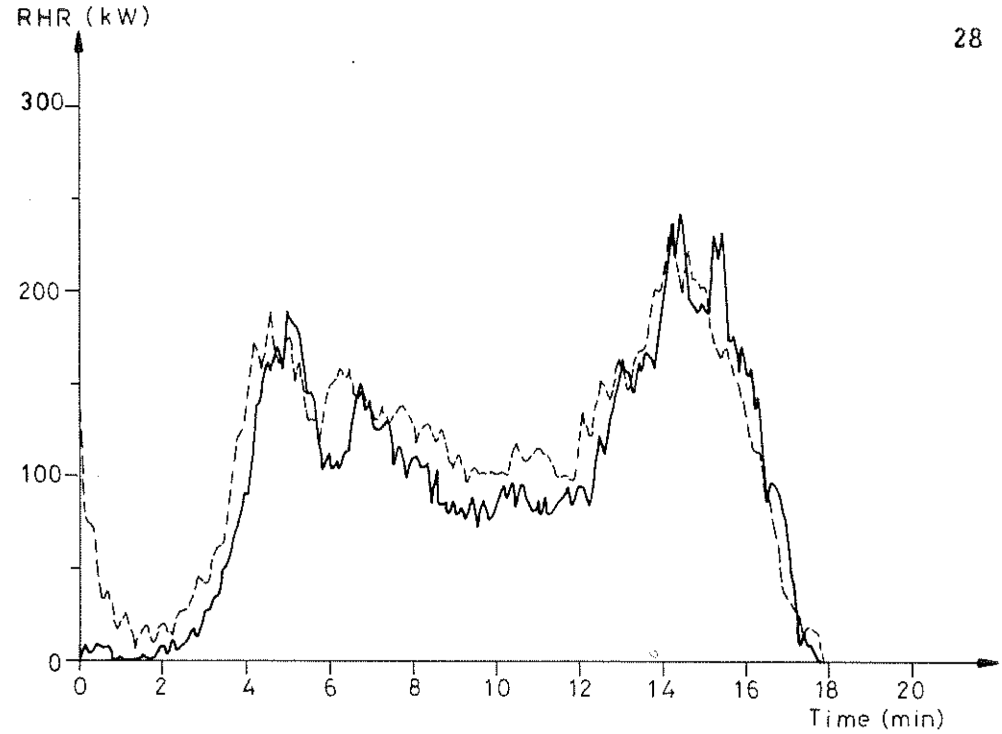

Figure 25 RHR curves for test 11 (mattress, standard polyurethane, open configuration)
—— calculated from measured oxygen consumption
--- calculated from measured mass loss with ΔH_{eff} = 22 MJ/kg

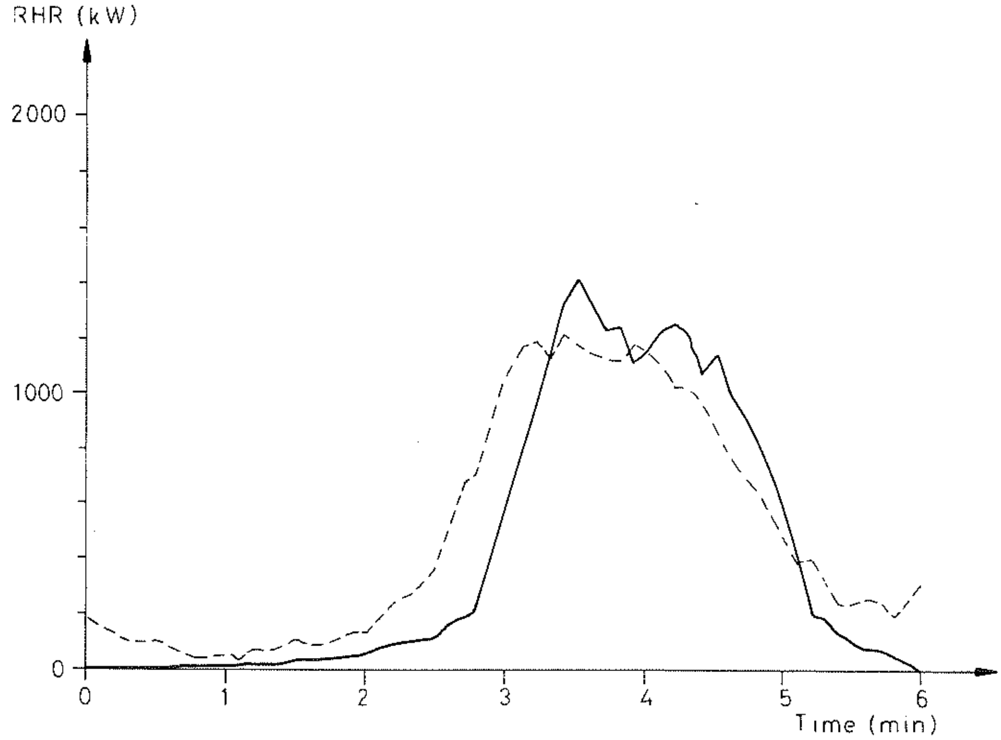

Figure 26 RHR curves for test 12 (sofa, standard polyurethane with acrylic cover, open configuration)
—— calculated from measured oxygen consumption
--- calculated from measured mass loss with ΔH_{eff} = 24.6 MJ/kg

5.5 Spread of Flame

Rates for spread of flame over full scale upholstered furniture are not easily found in the literature. In /9/ Krasny and Babrauskas present two types of flame spread data. The first is based on burn through times for trip threads suspended over the horizontal surfaces of the tested item. The second approach is to study videotapes taken during the tests. This was the same method as the one used in the experiments reported here.

To facilitate the estimation of the burning area, lines were drawn 100 mm apart on all mattresses and seat and back cushions of the sofas and the chairs.

The flame spread rates for the bare mattresses, tests 1 and 11, were easily determined. For the mattresses with bedding, tests 3 and 4, it was also possible to see the position of the flame front on the videotape.

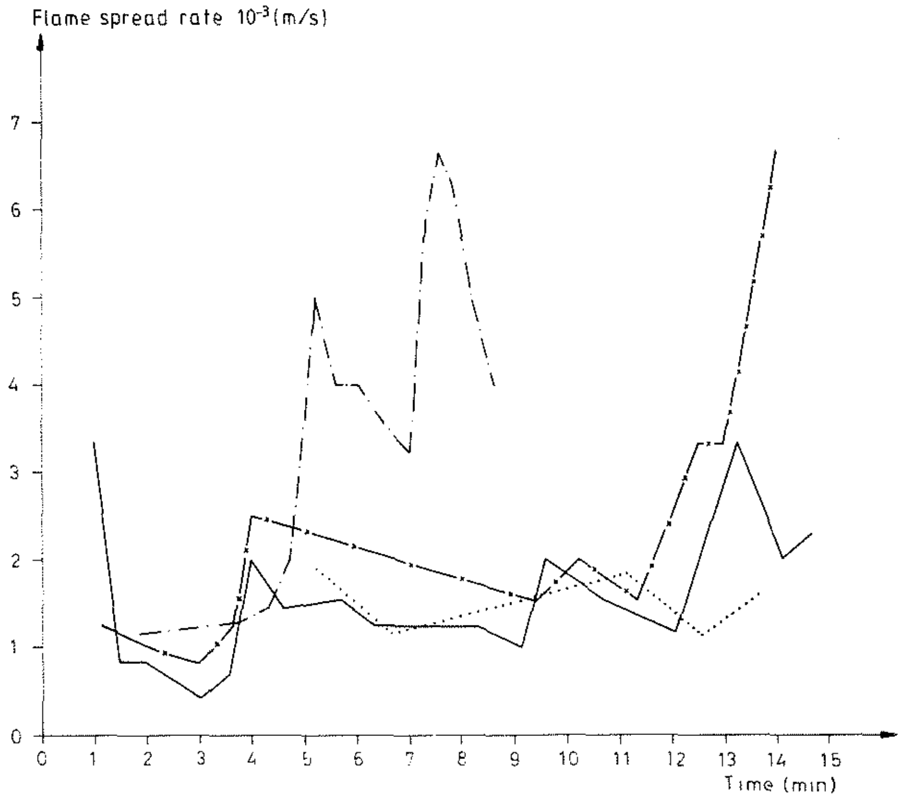

Figure 27 Flame spread rates for tests 1, 3, 4 and 11
—— test 1 ··· test 4
–·– test 3 –x– test 11

Estimating the flame spread rates for the sofas and chairs caused problems. The fire spreads horizontally along the seat and vertically up the back. The flames and smoke from the burning seat makes it difficult to study the fire spread at the back after the initial phase.

The flame spread rates for the mattresses and beds are presented in figure 27. As can be seen the rate is fairly constant over a long period of time for the bare mattress made of standard polyurethane, tests 1 and 11. It is only when the mattress is nearly consumed that the rate increases rapidly. The mattresses with bedding, the standard polyurethane, test 3, and the flame retardant treated polyurethane mattress, test 4, give the same initial flame spread rates as the bare standard mattress. In test 3 the rate increases rapidly after 4.5 min due to the fact that the quilt and sheets have ignited and act as a large ignition source upon the mattress, which now burns fiercely. In test 4 the sheets and quilt burn but ignition of the mattress is never achieved. The rate presented in figure 27 is really the values for spread of flame over the quilt.

5.6 Smoke Production

Smoke generation is one of the characteristics of uncontrolled fires which represents a threat to life safety. The measurement of smoke production is accordingly important during a full scale experiment. There are many different approaches to estimating the smoke production /10, 11, 12/. One quantity is however fundamental in all these approaches and that is the transmission of light through the smoke.

There have also been attempts by e.g. Babrauskas and Quintiere /10, 11/ to correlate results from bench-scale tests with results from full scale room experiments.

The method used in this report was presented by Rasbash /12/.

5.6.1 Calculation of Smoke Production

The transmission of light through the smoke is measured in the exhaust duct as indicated in figure 1. From the values of transmission the smokiness D_L is derived as:

$$D_L = \frac{10}{L} \log \frac{100}{T} \qquad (dB/m) \qquad (3)$$

L = pathlength of the transmitted light (m)
T = transmittance (%).

The value of D_L varies throughout the experiment and as it is influenced by the amount of air that flows through the duct it is no true estimate of the smoke generation. To overcome this the product of D_L and the volume flow $\dot{V}$ through the duct is taken as the time-dependent variable, D_{mom}

$$D_{mom} = D_L \cdot \dot{V} \qquad (dB\ m^2/s) \qquad (4)$$

$\dot{V}$ = volume flow through the duct at the temperature measured in the duct (m^3/s).

The total amount of smoke, D_{tot}, produced during an experiment, from t = 0 to t, is also of interest when judging the qualities of a product. D_{tot} is given by the formula

$$D_{tot} = \int_0^t D_L \cdot \dot{V} \, dt \qquad (dB\ m^2) \qquad (5)$$

5.6.2 Results

The time curves for D_{mom} and D_{tot} for the experiments are given in figures 28-31.

For the standard mattress in experiments 1 and 11 the results indicate that the same total amount of smoke is produced when the mattress is burned inside the room and outside. The production rate is also the same. When the mattress is supplied with sheets and quilt, test 3, D_{tot} is about the same as for the bare mattress but the smoke is produced faster and earlier.

The flame retardant treated mattress is tested with and without bedding. It was difficult to establish a propagating fire in the bare mattress - test 2 - and it just smouldered slowly most of the time. During this smouldering period only small amounts of smoke were produced at a low rate. Most of the bedding that was added in test 4 just burnt off and did not have much effect on the mattress. After 19.5 min the mattress cover was torn open, exposing the underlying foam. The smoke production increased substantially giving a large D_{tot}. Without this damage to the cover the mattress would probably not have been more damaged with the bedding than without.

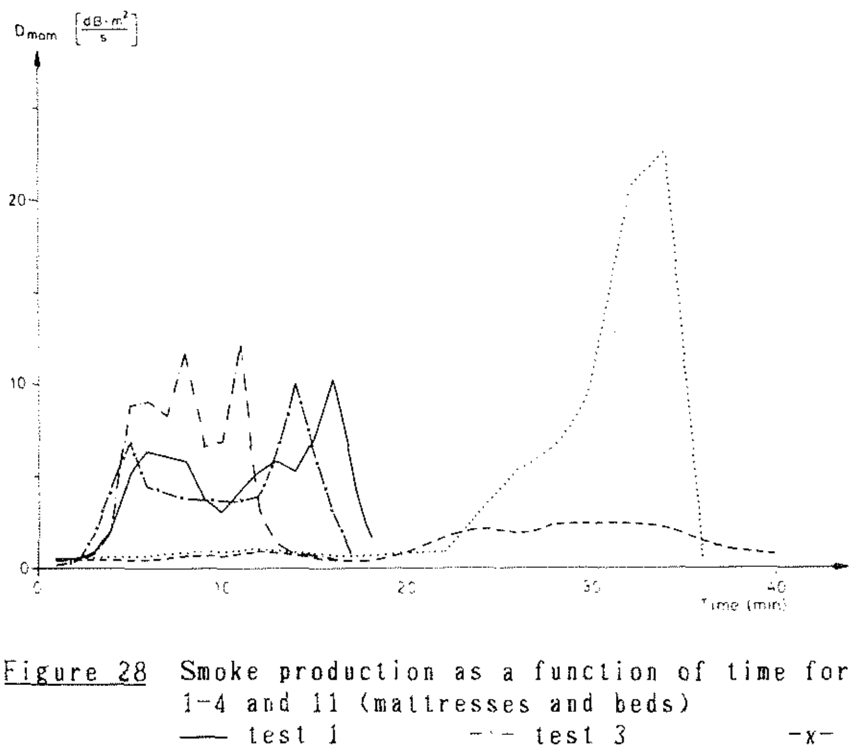

Figure 28 Smoke production as a function of time for the tests 1-4 and 11 (mattresses and beds)
—— test 1 -·- test 3 -x- test 11
--- test 2 ··· test 4

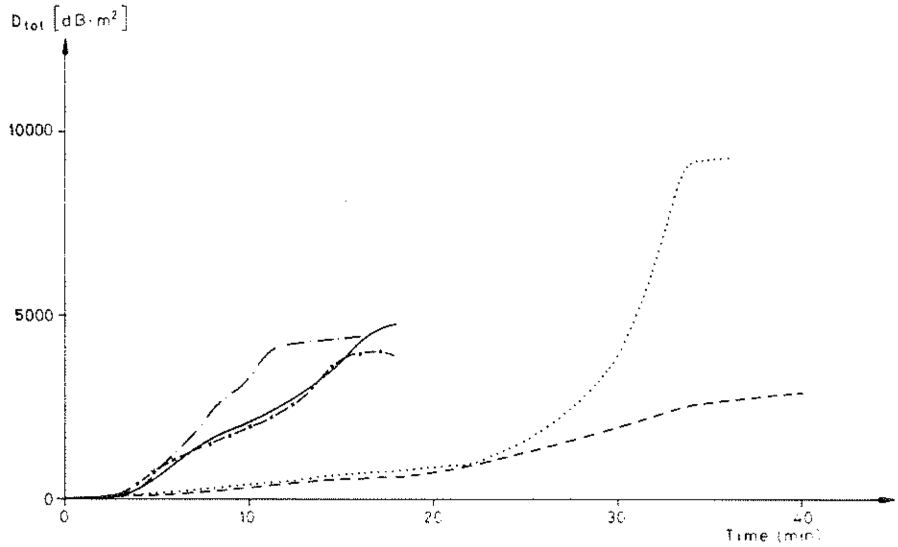

Figure 29 Total smoke production as a function of time for the tests 1-4 and 11 (mattresses and beds)
—— test 1 ··· test 4
--- test 2 -x- test 11
-·- test 3

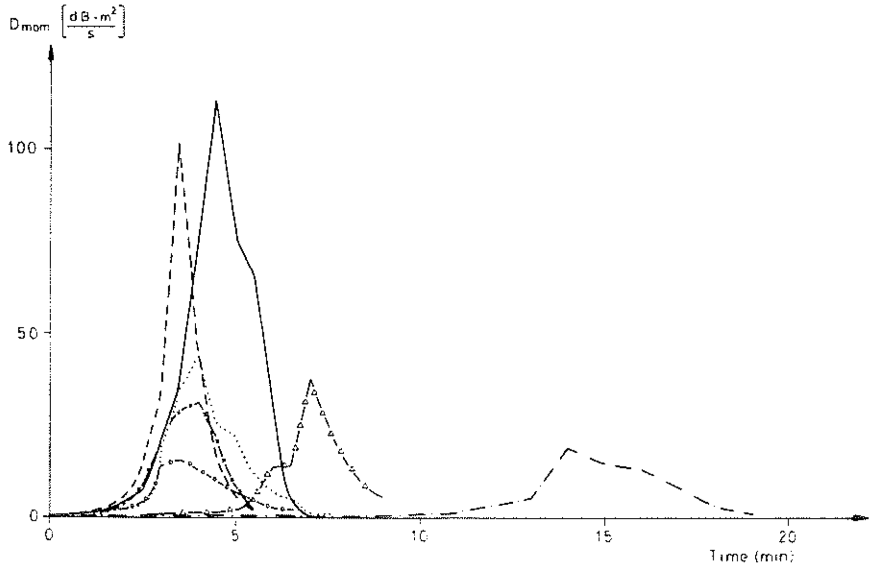

Figure 30 Smoke production as a function of time for tests 5-10 and 12 (sofas and chairs)
--- test 5 -Δ- test 9
—— test 6 ··· test 10
-·- test 7 -x- test 12
-o- test 8

Carbonmonoxide is a very dangerous gas as it is colourless, tasteless and nearly odourless. To set a limit for dangerous CO-concentration is difficult because it is the concentration of carboxyhemoglobin (COHb) in the blood that is crucial to the well-being of the exposed person, not a well specified concentration in the atmosphere.

A COHb concentration of 50% can cause unconsciousness. Lower percentages cause headache, dizziness and increase in breathing rate and pulse. A concentration of 0.15% is taken as the level where the symptoms of poisoning becomes severe /13/.

Nitrogen dioxide, NO_2, is an irritating and corrosive gas. A concentration of 80 ppm gives breathing problems after a few minutes /13/ and is taken as a dangerous level. If the concentration reaches 250 ppm the atmosphere is lethal within a very short period of time.

5.7.1 Calculations of Produced Amounts of Combustion Products

The concentrations of the combustion products are measured as vol% or ppm. To get an estimation of the produced amounts the production rates ($\dot{V}_i$) and the total volumes of produced gases (V_i) are calculated.

$$\dot{V}_i = \frac{\dot{V}_d \cdot [i]}{100} \qquad (6)$$

$$V_i = \int_0^t \dot{V}_i \, dt \qquad (7)$$

$\dot{V}_i$ = amount of gas, i, produced per second (m^3/s at 25°C, 1 atm)
V_i = total amount of produced gas, i, (m^3 at 25°C, 1 atm)

$\dot{V}_d$ = volume flow in the duct (m^3/s at 25°C, 1 atm)
[i] = volume % of gas i
t = time after ignition.

These calculations were performed for all experiments in the series, for the gases, CO, CO_2 and NO_x. In figures 32-37 the values for V_{CO}, V_{CO_2} and V_{NO_x} are given as time curves for the different experiments. From these curves, the time to dangerous concentrations in a room of a specified volume, can be estimated. In the figures the amounts necessary to give dangerous concentrations in rooms with volumes 60, 100 and 200 m^3 are indicated. The chosen levels are those given in 5.7, 8% for CO_2, 0.15% for CO and 80 ppm for NO_x.

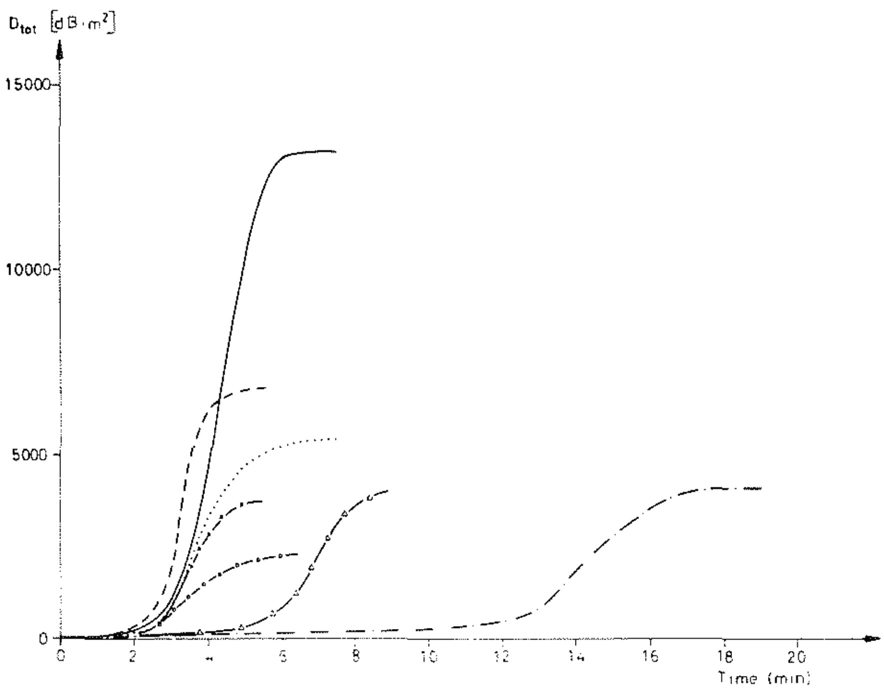

Figure 31 Total smoke production as a function of time for tests 5-10 and 12 (sofas and chairs)

--- test 5 -Δ- test 9
—— test 6 ··· test 10
-·- test 7 -x- test 12
-o- test 8

Among the sofa experiments, figures 30 and 31, the sofa in test 6 with flame retardant treated polyurethane foam as filling, is outstanding as regards smoke production. The maximum value of D_{tot} is 13150 dB m^2 which is almost twice the value for the sofa with standard polyurethane (test 5).

The experiments with chairs, tests 8 and 9, as could be expected show that two chairs produce twice as much smoke as one chair. The later start for the smoke production in test 9 is due to the position of the ignition source which gave a delayed ignition of the first chair.

5.7 *Combustion Products*

Gas analysis was performed continuously for gases known to be hazardous in a fire atmosphere, CO, CO_2 and NO_x. The O_2-concentration was also measured, primarily to give the rate of heat release from the fire but also to give an indication of when the O_2-content is so low that it becomes difficult to breath normally.

Carbondioxide is present in small amounts in normal air (0.03 vol%) and it is produced when all organic materials burn. It is difficult to set an absolute limit to when CO_2 becomes poisonous, but a study by Kimmerle /13/ implies that a concentration of 8% can be selected as hazardous.

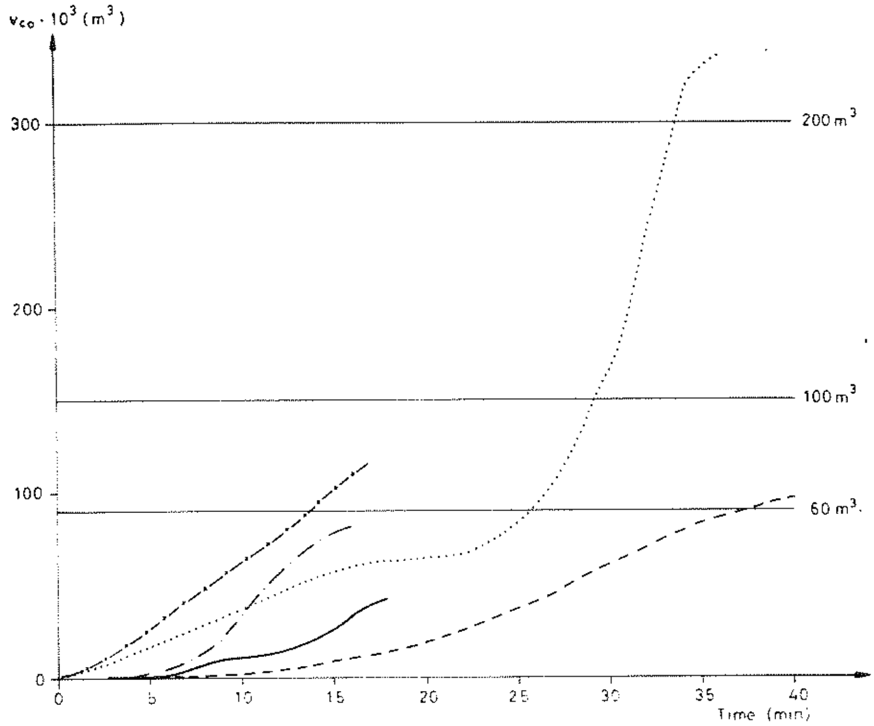

Figure 32 Total amount of CO produced for tests 1-4 and 11. Dangerous levels for rooms with volumes of 60, 100 and 200 m³ are indicated

—— test 1
--- test 2
-·- test 3
··· test 4
-x- test 11

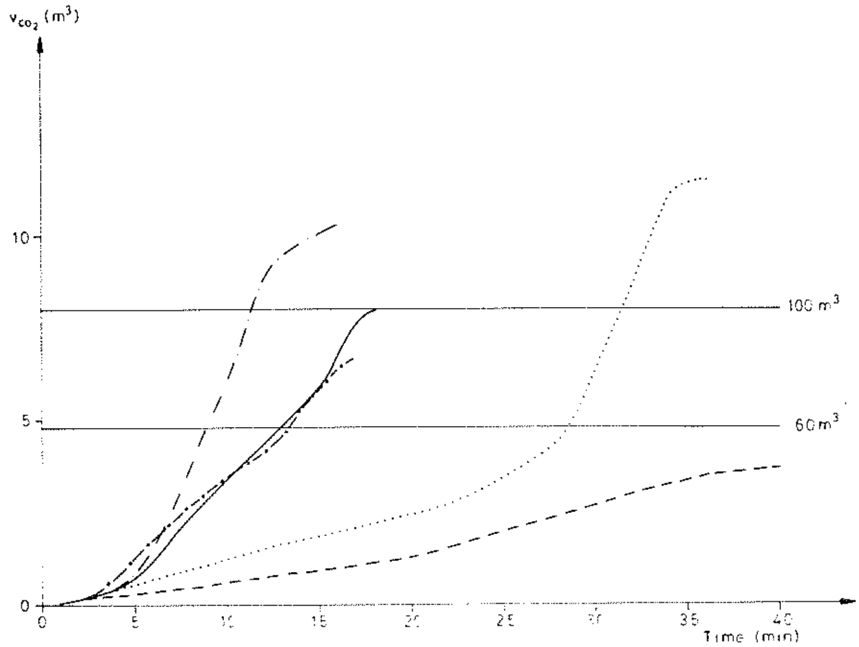

Figure 33 Total amount of CO_2 produced for tests 1-4 and 11. Dangerous levels for rooms with volumes of 60 and 100 m³ are indicated

—— test 1
--- test 2
-·- test 3
··· test 4
-x- test 11

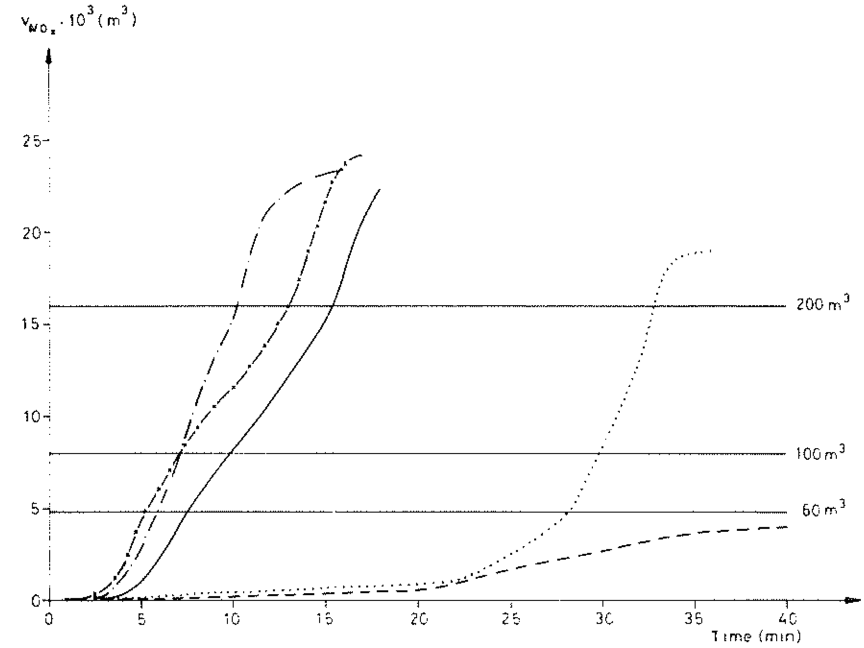

Figure 34 Total amount of NO_x produced for tests 1–4 and 11. Dangerous levels for rooms with volumes of 60, 100 and 200 m³ are indicated

—— test 1   ··· test 4

--- test 2   -x- test 11

-·- test 3

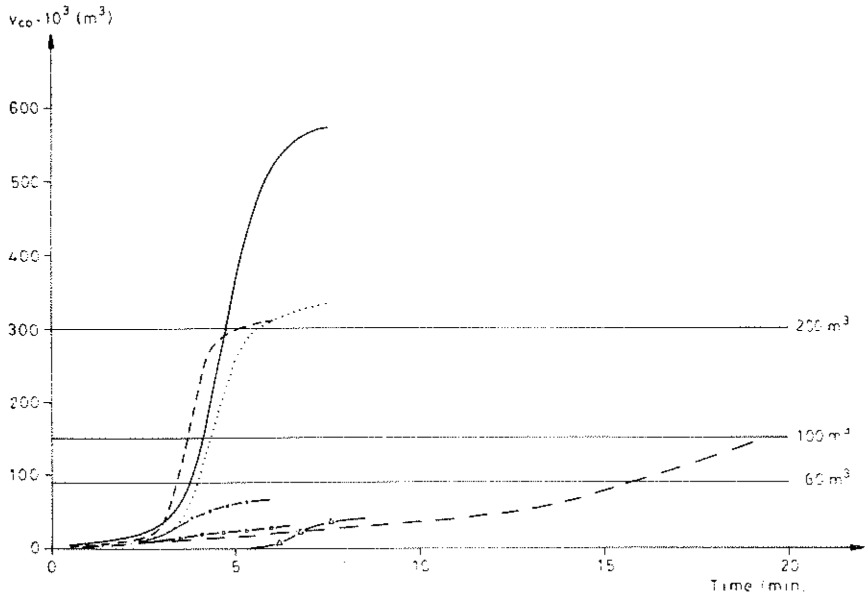

Figure 35 Total amount of CO produced for tests 5–10 and 12. Dangerous levels for rooms with volumes of 60, 100 and 200 m³ are indicated

--- test 5   -Δ- test 9

—— test 6   ··· test 10

-·- test 7   -x- test 12

-o- test 8

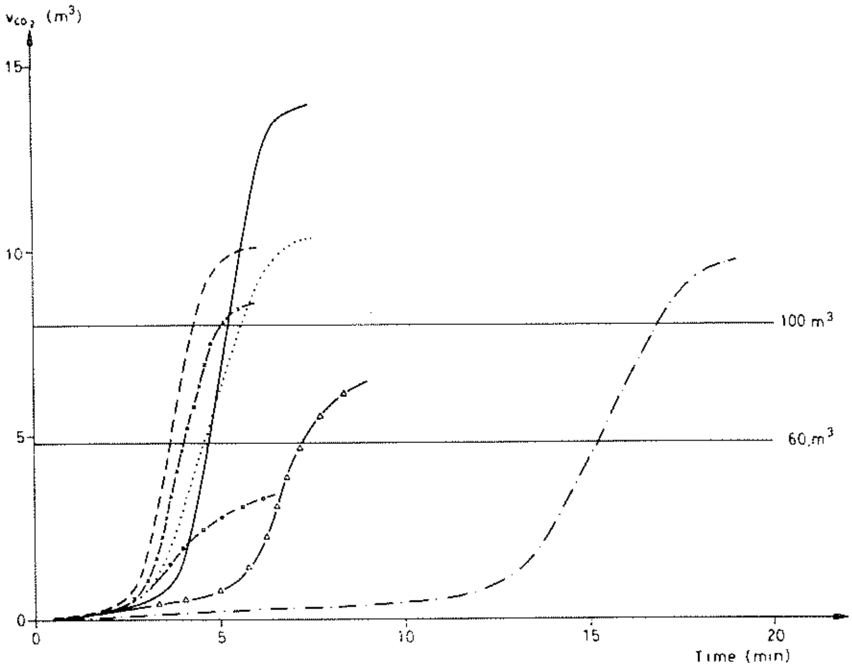

Figure 36 Total amount of CO_2 produced for tests 5-10 and 12. Dangerous levels for rooms with volumes of 60 and 100 m^3 are indicated

--- test 5	-Δ- test 9
—— test 6	··· test 10
-·- test 7	-x- test 12
-o- test 8	

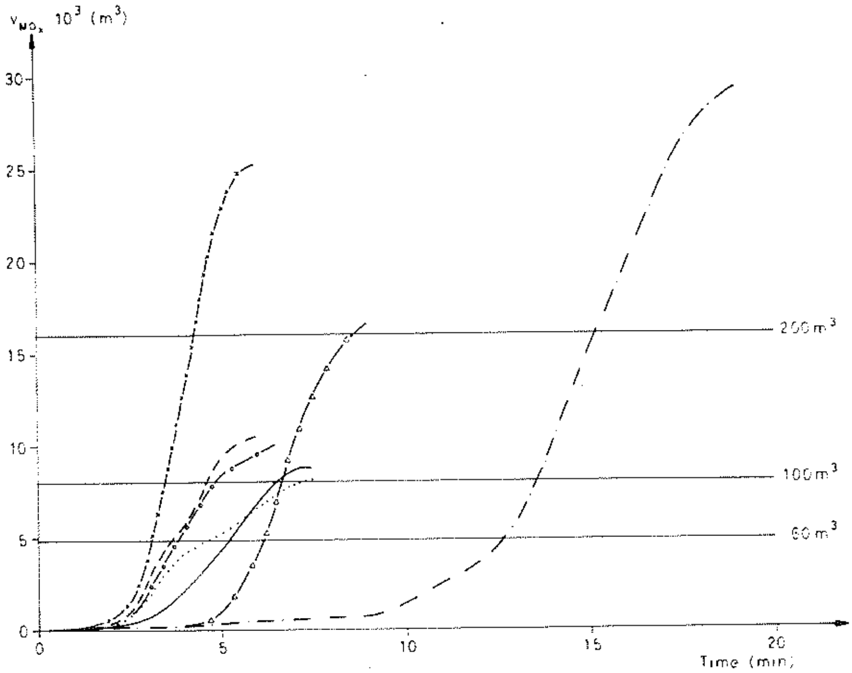

Figure 37 Total amount of NO_x produced for tests 5-10 and 12. Dangerous levels for rooms with volumes of 60, 100 and 200 m^3 are indicated

--- test 5	-Δ- test 9
—— test 6	··· test 10
-·- test 7	-x- test 12
-o- test 8	

6. SIMPLE THEORETICAL ANALYSIS

Attempts were made to apply a simple model for theoretical assumption of room temperatures to the presented experiments. A number of frequently used flashover criteria were also examined. All these approaches are simple and no computer programme was used. Simulations of tests 5 and 12 have however been made with the Harvard Computer Fire Code Mark V /14/. The results were promising but some improvement of the Harvard programme is needed to give full agreement with the experimental data. The simulations are not presented here but are published in a special report /15/.

6.1 Theoretical Assumption of Temperature in a Room Fire

In/16/ Quintiere presents a method based on regression analysis for predicting the temperature in the upper gas layer for a room fire. Necessary inputs are energy release rate, vent geometry and material properties for the compartment lining materials.

The method is based on a zone model which assumes a uniform temperature in the upper gas region, a lower region at ambient temperature and the fire plume represented as a localized heat source (see figure 38). The model is only relevant during the early stages of the fire, as long as the fire is fuel controlled.

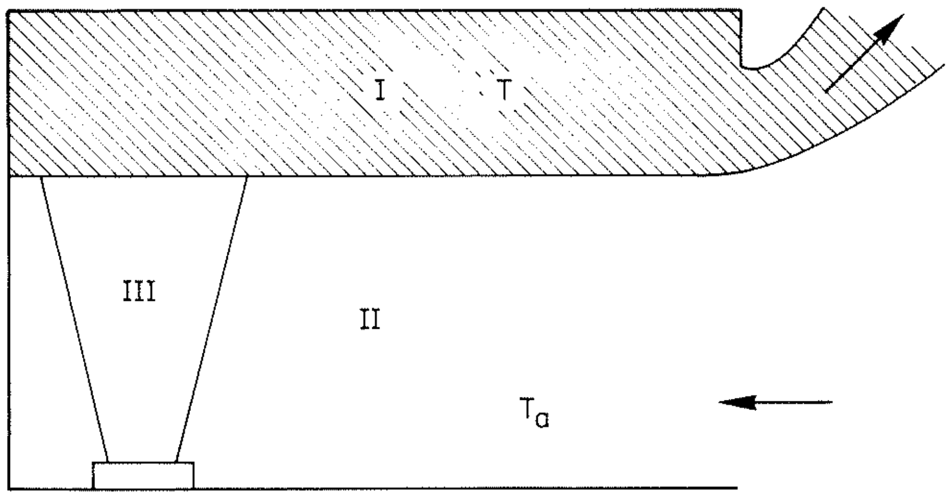

Figure 38 Main features of a zone model with I: hot upper gas layer, II: zone at ambient temperature, III: fire plume

Some background to the theory is referred here to facilitate the understanding of the procedure. Gas temperatures measured in the upper part of the room can be correlated in a power law relationship involving the energy release rate of the fire, the ventilation factor for the opening and a room geometric scale factor /17/. Further study has led to a more general correlation including parameters of the room surface area and its thermal properties /16/. Three examples employing the latter correlation will be presented here.

The temperature rise can be calculated as:

$$T - T_o = 6.85 \left[\frac{\dot{Q}^2}{(A_o\sqrt{H_o})(h_k A)}\right]^{1/3} \qquad (^\circ C) \qquad (8)$$

where

T	= temperature at time t
T_o	= initial temperature = 295 K
$\dot{Q}$	= the instantaneous rate of energy release in the compartment (kW) (also called RHR)
A_o	= area of opening into the room (m^2)
H_o	= height of the opening (m)
$A_o\sqrt{H_o}$	= the ventilation factor ($m^{5/2}$)
h_k	= effective enclosure conductance (kW/($m^2 \cdot$K))
A	= surface area of the enclosure (m^2).

The variable h_k is computed for each experimental situation taking into account the involved construction and surface materials. For method of calculation see /16/.

The constant 6.85 incorporates $g = 9.8$ m/s^2, $\rho_o = 1.2$ kg/m^3 and $c_p = 1.05$ kJ/(kg K) for the gas in the compartment. This is also clarified in /16/.

The method is applied to three of the experiments in the series presented in this report, namely test 1, a mattress, and test 5 and 10, a sofa.

As seen in figures 39 and 40 the calculated temperatures are in good agreement with the measured temperatures for tests 1 and 5. In neither case a ventilation controlled fire is reached. Calculations for test 10 gave however a somewhat different result as can be seen in figures 41 and 42. The calculated temperature-time curve gives 200°C higher temperature than the experimentally measured values, during the most intense period of the fire. This implies that the $\dot{Q}$ used in the calculations is too high. The videotape from test 10 shows that the combustion to some extent takes place outside the compartment. This is also supported by the curves in figure 42 where the measured $\dot{Q}_{max}$ is 1000 kW and the calculated $\dot{Q}_{max}$ is 650 kW. The calculated $\dot{Q}$ is achieved by using the measured temperature in the hot upper layer in the compartment as T in equation 8. The calculations show that the conditions during the test were close to ventilation controlled and therefore equation 8 is no longer valid.

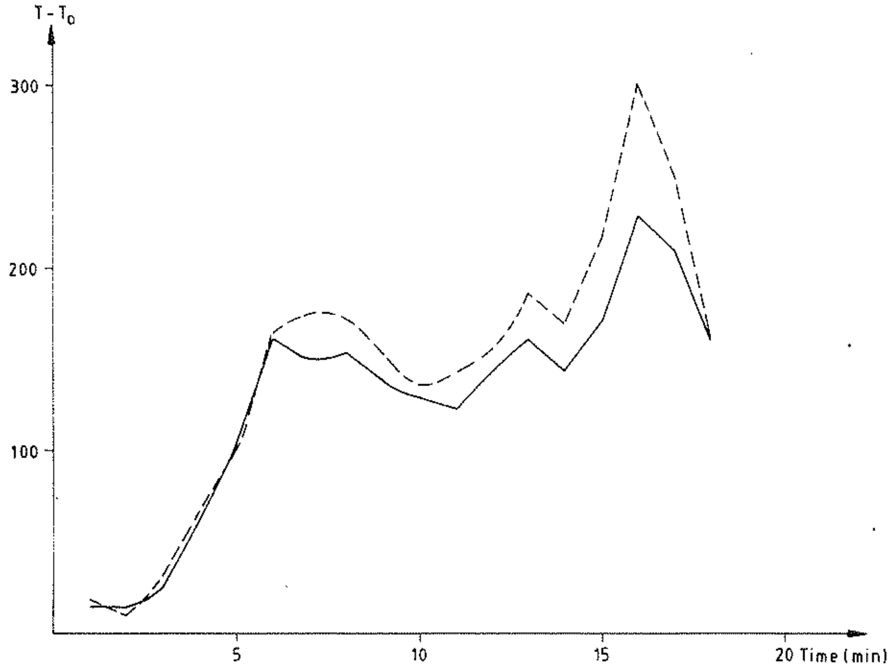

Figure 39 Comparison between temperature in the hot upper layer from the experiment (test 1, standard polyurethane mattress) and from the theoretical assumption
—— experimental
---- theoretical

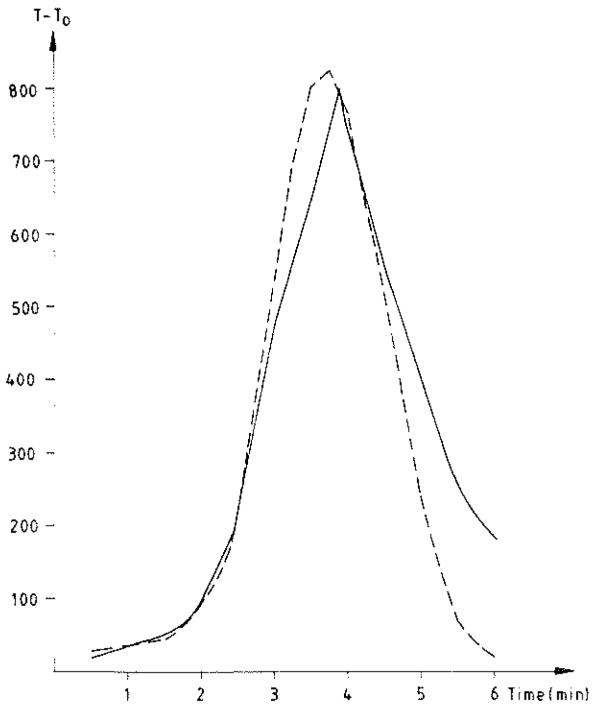

Figure 40 Comparison between temperature in the hot upper layer from the experiment (test 5, sofa, standard polyurethane and acrylic cover) and from the theoretical assumption
—— experimental
---- theoretical

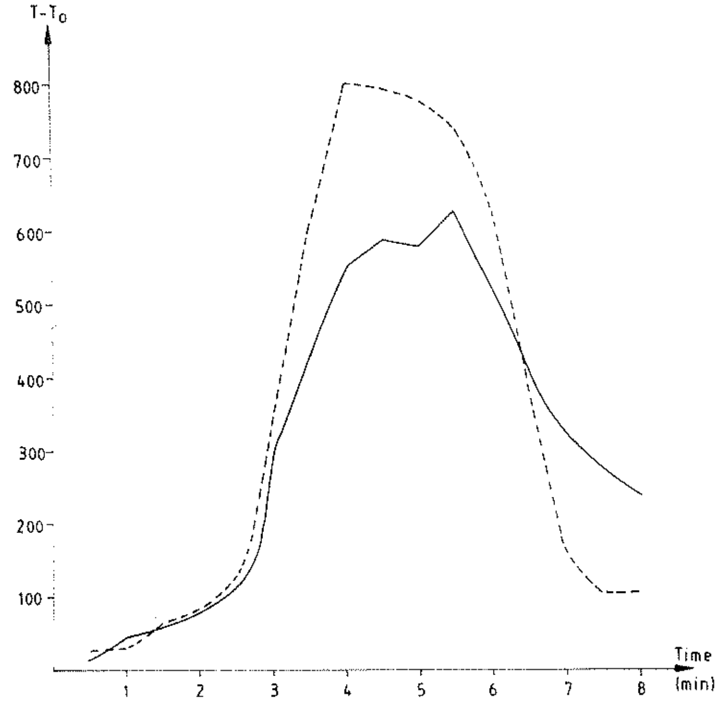

Figure 41 Comparison between temperature in the hot upper layer from the experiment (test 10, sofa, standard polyurethane with acrylic cover, restricted ventilation) and from the theoretical assumption
—— experimental ---- theoretical

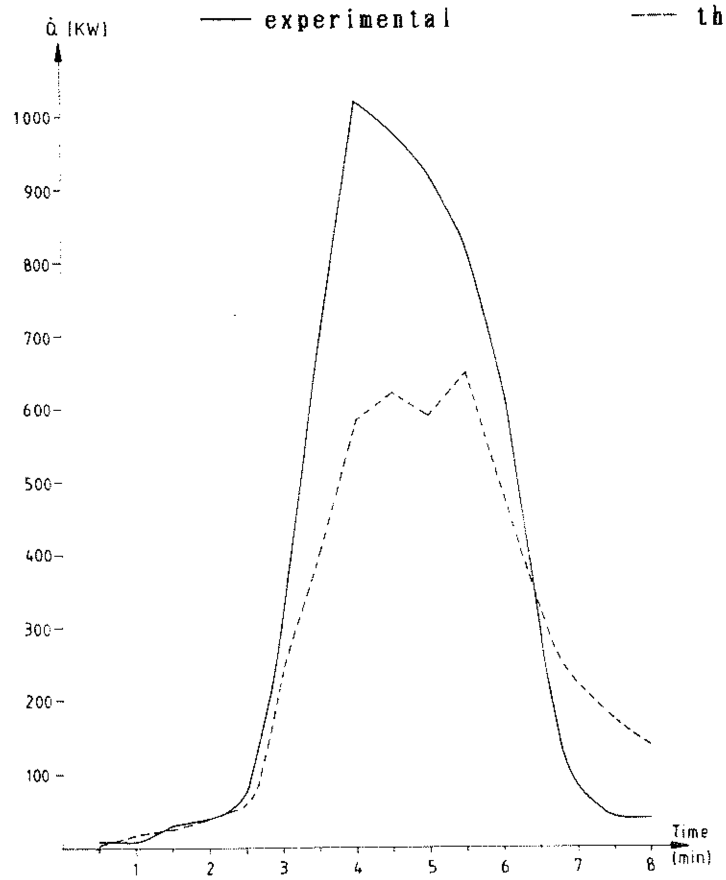

Figure 42 Comparison between the measured rate of heat release during the experiment (test 10, sofa, standard polyurethane with acrylic cover, restricted ventilation) and from the theoretical assumption
—— experimental --- theoretical

6.2 Flashover Criteria

There are a number of criteria that can be applied in assessing the hazard of a room fire to the occupants in a building. One crucial event is the onset of room flashover. At this point the room becomes filled with flames and the heat flux is sufficient to ignite other combustibles in the room. To define exactly when flashover occurs is not possible, but experimentally a compartment fire has reached the state of flashover when flames start to emerge through openings, and/or the temperature in the upper hot layer is 500–600°C /18/ and/or the heat flux to the floor is >20 kW/m² /19/.

One primary factor, in determining whether flashover in a room will occur or not, is the heat release rate of the combustibles in the room. A number of theoretical models exist that make it possible to calculate the rate of heat release required to cause flashover in a defined room. Three models will be briefly outlined here.

Babrauskas presents in /20/ a simple model for estimating the room flashover potential, only taking into account the ventilation properties of the compartment. The model considers a heat balance for the upper gas region.

$$\dot{Q} = m_a\ C(T_f - T_o) + \dot{Q}_{loss} \qquad (9)$$

$\dot{Q}$ = rate of heat release (kW)
m_a = airflow rate (kg/s)
C = heat capacity (kJ/kg K)
T_f = fire temperature
T_o = ambient temperature
$\dot{Q}_{loss}$ = heat loss rate (kW)

The airflow rate, m_a, is conventionally assumed to be

$$m_a = 0.5\ A_o\sqrt{H_o} \qquad (10)$$

A_o = opening area (m^2)
H_o = height of the opening (m).

The $\dot{Q}_{loss}$ term is hard to estimate accurately but a crude estimate can be obtained as follows. The main loss term is radiation to the floor, which is assumed to be at ambient temperature $T_o \approx$ ≈ 298 K prior to flashover. Heat is radiated and convected to the ceiling, which has warmed up somewhat, and to the upper wall surfaces. As a rough estimate, 40 percent of the total surface area is assumed to be at T_o, with the remaining fraction at the fire temperature and therefore not contributing to heat loss. This gives the following expression for the heat loss in the compartment:

$$\dot{Q}_{loss} = \varepsilon_f\ \sigma(T_f^4 - T_o^4)(0.4\ A) \qquad (11)$$

A = total surface area (m^2)
ε_f = gas emissivity
σ = Stefan-Boltzmann constant = $5.67 \cdot 10^{-11}$ kW/m²K⁴.

For practical room shapes it is found that there is some correlation between wall area and $A_o\sqrt{H_o}$. This may be in the order of $A/A_o\sqrt{H} \approx 50$. Assuming that this value can be applied and that T_f = 873 K, ε_f = 0.5 and c = 1.0 kJ/kg K gives the following expression

$$\dot{Q} = 600\ A_o\sqrt{H_o} \qquad (12)$$

Thomas /21/ uses another approach where also the area of the surrounding surfaces is taken into consideration, this equation can be written as:

$$\dot{Q} = 7.8\ A + 378\ A_o\sqrt{H_o} \qquad (13)$$

In the derivation of equation (13) the following values for experimental conditions are assumed ε_f = 0.5, T_f = 873 K and c = 1.26 kJ/kg K.

For a full description of the derivation of equation (13) see reference /21/.

The method by Quintiere for temperature assumptions in room fires presented in 6.1 can be transformed to give an estimate of the maximum heat release rate allowed to prevent flashover.for a defined enclosure. This yields the equation /16/:

$$\dot{Q} = 116(A\ A_o\sqrt{H_o})^{1/2} \qquad (14)$$

In the equations (12), (13) and (14) above the limit temperature in the hot upper layer for flashover is assumed to be 600°C. The rate of heat release for the three models are 1.36 MW, 1.20 MW and 1.17 MW respectively, which must be ragarded as a satisfying result for all the models. The experience of the experiments in the testing compartment in Borås shows flashover when the rate of heat release reaches approximately 1.0 MW.

In table 7 the times for experimentally reaching 20 kW/m², 600°C and 1.0 MW are given. As can be seen in table 7 flashover conditions were reached only in three experiments in the series reported here. The temperature criterion is fulfilled first in the three experiments that were sufficiently powerful to give flashover and shortly after the hazardous heat flux level is attained.

Table 7

Test No	Time to reach 20 kW/m² at the floor (s)	Time to reach 600°C in the upper layer (s)	Time to reach 1.0 MW (s)
1	–	–	–
2	–	–	–
3	–	–	–
4	–	–	–
5	215	195	180
6	290	260	250
7	–	–	–
8	–	–	–
9	–	–	–
10	300	255	230

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APPENDIX

Test No 1

Test specimen: Mattress
Filling: Standard polyurethane
Cover: Cotton
Ignition source: Wood crib

Time (min s)	Visual observations
0.45	The fire is spreading on the mattress.
3.50	The flame height above the mattress is 0.75 m.
4.25	The fire reaches the first of the shorter sides.
4.55	The flame height above the mattress is 1.2 m.
5.10	The fire reaches the back of the mattress.
5.15	Droplets of burning plastic from the mattress.
6.50	The fire reaches the front of the mattress.
7.10	Burning pool of molten plastic on the weighing platform.
7.45	The mattress is consumed in the ignition area.
8.20	Intense fire on the weighing platform.
8.55	The material at the nearest of the short sides falls down.
9.10	The fire is concentrated to a 0.4 m wide area across the mattress at the centre of the bed.
10.00	The flame height is 0.7 m.
11.50	The fire intensity is increasing, the flame height is 1.0 m.
12.30	Flames are reaching the ceiling, increasing smoke production.
13.30	The fire intensity is decreasing again.
15.35	The fire reaches the second of the shorter sides.
15.40	The remaining parts of the mattress are burning.
15.55	The fire area is less than 1 m^2.
17.10	The flame height is 1 m.
18.10	The whole mattress is consumed.

Test No 2

Test specimen: Mattress
Filling: Flame retardant treated resilient polyurethane
Cover Flame retardant treated cotton
Ignition source: Wood crib + liquid fuel burner

Time min s	Visual observations
1.25	Ignition of the fabric.
2.35	The wooden crib colapses.
3.00	Smoke from the mattress.
6.45	The ignition has failed and a new crib is put close to where the first attempt was made.
8.00	Smoke is emerging from beneath the mattress, probably a hole through the mattress.
10.10	The fabric round the hole is burning.
13.25	The second attempt of ignition has failed.
16.30	0.5 l methylated spirit is ignited at the bottom end of the mattress.
17.15	The fire is spreading under the mattress.
20.50	The fire is slowly spreading on top of the mattress.
21.05	No visible flame, only signs of smouldering can be seen.
23.00	Flame at the bottom end.
23.50	The mattress colapses at the middle.
25.00	Pyrolysis gases are produced and come out through the fabric.
37.00	No visible signs of combustion.

Test No 3

Test specimen: Made-up bed
Filling: Standard polyurethane
Cover: Cotton (and sheet and quilt)
Ignition source: Wood crib

Time min s	Visual observations
0.29	The sheet has ignited.
1.29	The fire is spreading in the folded part of the sheet and quilt.
2.40	The fire reaches the rear of the longer sides.
3.57	The fire reaches the front of the bed.
4.17	The flame front is 0.2 m in on the quilt.
4.42	The flame front is 0.25 m in on the quilt.
4.51	The flame front is 0.3 m in on the quilt.
4.54	The flames are impinging on the ceiling.
5.07	The flame front is 0.35 m in on the quilt. Burning droplets from the bed.
5.12	The flame front is 0.4 m in on the quilt.
5.24	The fire reaches the "head end" of the bed.
5.37	The flame front is 0.5 m in on the quilt.
5.58	The material is consumed at the point of ignition.
6.02	The flame front is 0.6 m in on the quilt.
6.30	The flame front is 0.7 m in on the quilt.
7.01	The flame front is 0.8 m in on the quilt.
7.18	The flame front is 0.9 m in on the quilt.
7.33	The flame front is 1.0 m in on the quilt.
7.49	The flame front is 1.1 m in on the quilt.
8.09	The flame front is 1.2 m in on the quilt.
8.34	The flame front reaches the "foot end" of the bed.
10.17	The remaining material is burning.
12.10	Burning material from the bed falls on the weighing platform.
16.00	All material is consumed.

Test No 4

Test specimen: Made-up bed
Filling: Flame retardant treated high resilient polyurethane
Cover: Flame retardant treated cotton (and sheet and quilt)
Ignition source: Wood crib

Time min s	Visual observations
0.30	The sheet has ignited.
2.35	The quilt has ignited.
4.00	The flame front is slowly spreading across the quilt.
10.15	0.6 m left of the quilt.
11.08	0.5 m left of the quilt.
12.35	0.4 m left of the quilt.
13.38	0.3 m left of the quilt.
16.45	The flame front reaches the "foot end" of the bed.
19.30	The mattress is torn open along its centre line.
21.30	The filling material is burning.
22.45	Burning droplets.
23.40	Increasing smoke production.
24.35	Flame beneath the mattress.
27.50	Molten material is burning on the floor.
29.15	The smoke layer has descended to 0.2 m above the bed.
29.30	The top half of the bed area is burning.
31.20	The remaining material is burning.
35.00	Charred residuals, no signs of combustion.

Test No 5

Test specimen: Sofa
Filling: Standard polyurethane
Cover: Acrylic
Ignition source: Liquid fuel burner

Time min s	Visual observations
0.27	The covering material has ignited.
0.48	The flame front reaches 0.3 m at the front.
0.50	The fire is spreading towards the back.
1.10	The flame front reaches 0.4 m at the front.
1.44	The flame front reaches 0.5 m at the front. Burning droplets.
2.00	Burning pool on the weighing platform.
3.10	The flame front reaches the far end of the sofa.
3.30	The whole room is filled with smoke.
6.00	The material is consumed.