Effectiveness of sprinklers in residential premises:

Section 5: Experimental programme

Project report number 204505

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Contents

5 Experimental programme

5.1 Introduction

The purpose of the Experimental programme was to examine and quantify the effectiveness of residential sprinklers in particular to life safety in the room of fire origin.

Currently, the available residential sprinkler heads have been predominantly developed, manufactured and approved in the USA. Original research into the performance of residential sprinkler heads was carried out by Factory Mutual in the USA in the 1970s. Further research has continued in the USA and other countries outside the UK since that time.

In 1998, detailed measurements were taken by FRS [Purser 2000, Purser 2001] in six demonstration fires carried out by Kirklees Metropolitan Council, West Yorkshire Fire and Civil Defence Authority and Wormald Fire Systems in sprinklered and unsprinklered two-storey maisonettes inside a tower block in Cleckheaton, West Yorkshire, UK. These demonstrated the effectiveness of residential sprinklers in living room, bedroom and kitchen scenarios and showed that the fire atmospheres were survivable, in terms of heat and toxic products, in the sprinklered cases, including in the room of fire origin. The fires chosen were flaming fires and unshielded fuels. These fires could be considered as a pilot experimental study.

5.2 Acceptance criteria

The effectiveness of the residential sprinklers in both the House and Compartment fires was primarily assessed particularly in the room of origin by their ability to control:

a) tenability, i.e.

- whether the cumulative effect of asphyxiating gases remained below two critical values (determined from a Fractional Effective Dose (FED) model derived from carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2) concentrations at head height)
- whether the cumulative effect of convective heat (determined from a FED model derived from head height gas temperatures) remained below a critical value
- whether the optical density per metre remained below a critical value

b) and the amount of fuel burnt (area).

5.2.1 Toxicity effect

The Fractional Effective Dose is calculated [Purser 2003] for each room using the recorded concentrations of O_2, CO_2 and CO. Concentrations of other gases present e.g. hydrogen cyanide were not measured.

The threshold values of FED of asphyxiating gases (FED_{AG}) are:

$FED_{AG} \geq 1$	Loss of consciousness through asphyxiation
$FED_{AG} \geq 2$	Death [Purser 2003]

5.2.2 Temperature effects

The Fractional Effective Dose for convective heat was calculated [Purser 2003] for each room using the recorded temperatures. Radiative heat was not measured

The threshold value FED for convective heat (FED_H) is:

$FED_H \geq 1$	Extreme pain resulting in incapacitation [Purser 2003]

In addition, for wet fire atmospheres, an additional temperature threshold value is that in a saturated atmosphere above 60^0C people cannot breathe properly [Purser 2003].

5.2.3 Visibility

Incapacitation by smoke obscuration is concentration related. The optical density per metre (OD/m) is calculated from the measured % transmittance using the relationship

$$OD/m = \frac{1}{L} \times Log_{10}(T_o / T) \qquad \{7.1\}$$

where L = optical path length, T_O = initial transmittance (100%), T = transmittance during test.

Visibility for each of the locations is calculated as the reciprocal of OD/m.

The threshold values for OD per m, applicable to the rooms, are:

OD/m ≥ 0.2	Irritation to eyes and respiratory system due to particulate matter suspended in air.
OD/m ≥ 0.5	Ability to locate exits likely to be impaired. An optical density of 0.5 per metre approximates to a visibility of 2 m.

5.3 House fires

5.3.1 Introduction

The first phase of the Experimental Programme was a series of house fires. Details of the experimental facility, instrumentation, experimental method, results and conclusions are described, as follows.

5.3.2 The experimental facility

The BRE house facility was utilised. The facility is a two-storey detached house with a loft conversion built within the BRE Cardington Laboratory. The house is of traditional design. The ground floor comprises a lounge/dining area (7.58 m by 3.5 m) which is currently divided into two by a 30-minute fire resisting partition wall, a kitchen (3.4 m by 2.2 m) and a hallway. The ground floor could be converted into open plan by removing the lounge/hall wall. The first floor comprises two bedrooms (4.2 m by 3.5 m and 3.5 m by 3.4 m) and a bathroom area (2.2 m by 2.0 m). The ceiling height on the ground and first floors is 2.4 m. There are various doors and windows. The house also includes a loft conversion [BRE 2002].

Salient features of the loft conversion are as follows. The ceiling height in the loft room is lower than in normal practice (approximately 2 m to the ridge). There is a straight flight of conventional tread stairs up to the loft room. A fire-resisting cut off door at the head of the stairs separates the loft from the rest of the house.

Figure 5.1 shows a photograph of the exterior of the house facility and Figure 5.2 is a schematic diagram showing the internal layout of the house.

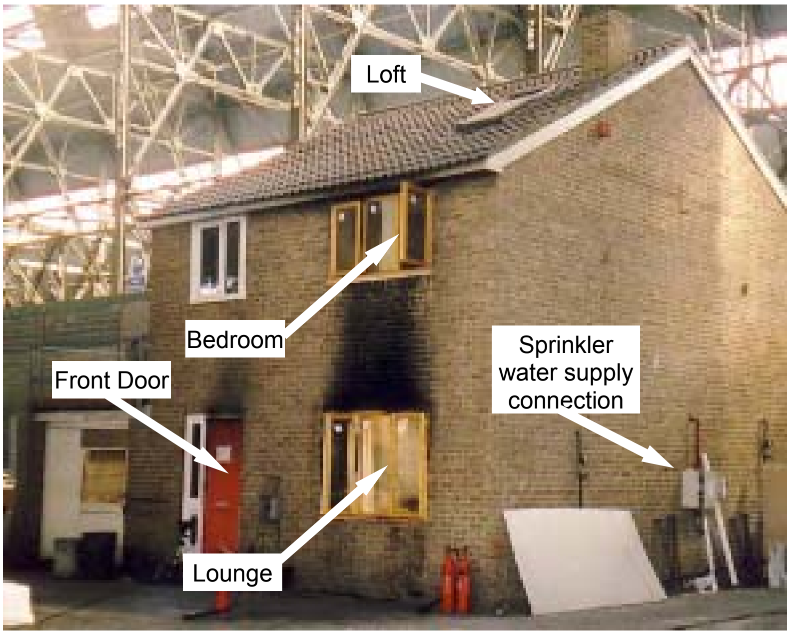


Figure 5.1 The experimental facility

Figure 5.2 Schematic diagram showing the internal layout of the house and instrument locations

5.3.3 The sprinkler system

The house facility has a domestic sprinkler system. The design and installation of the system was consistent with BS DD 251 [BRE 2002, British Standards Institution, 2000].

5.3.4 The fuel arrangement

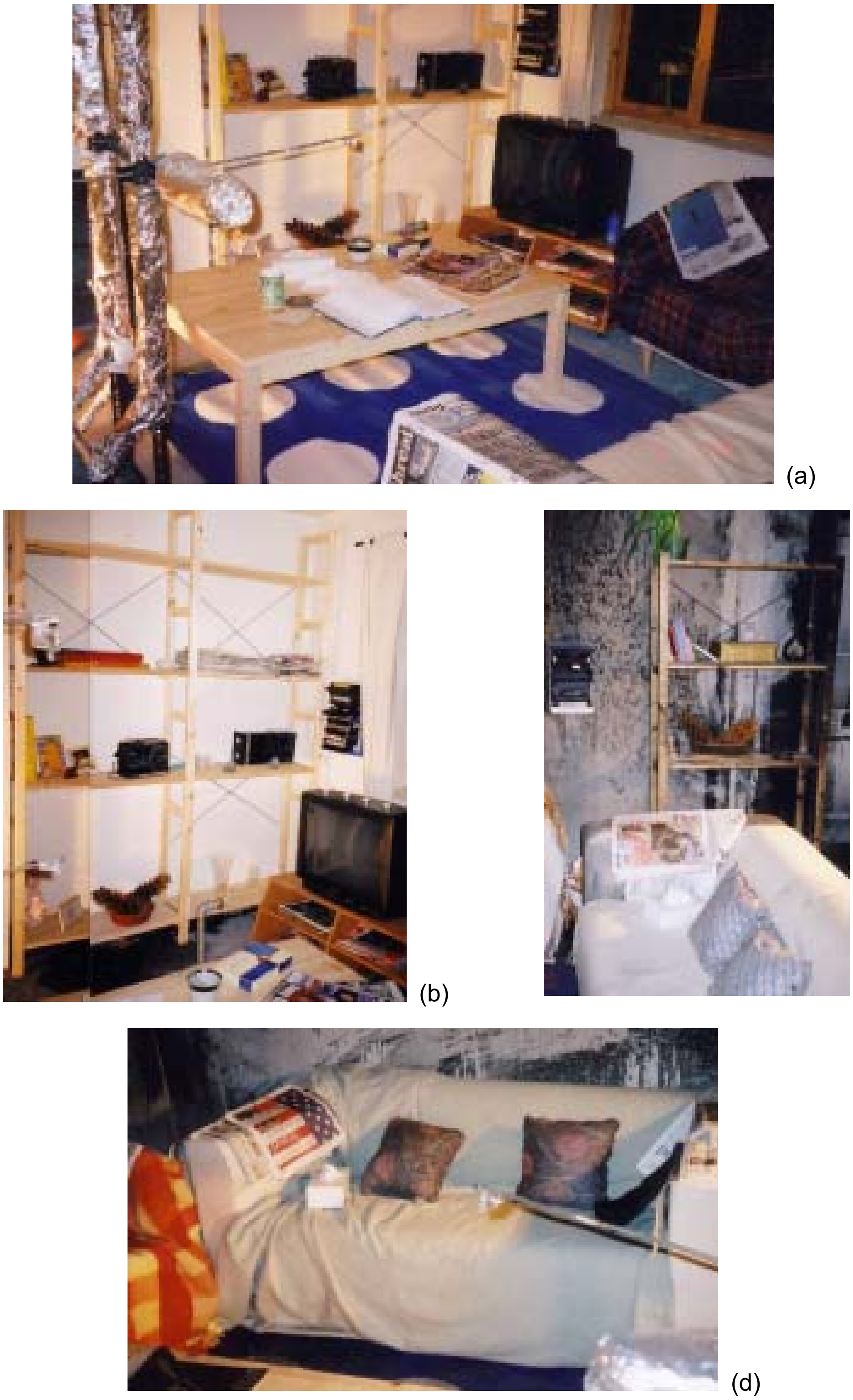
The chosen fire scenario was a lounge fire and hence the fire load arrangement was representative of the contents of a lounge. The fire load arrangement was similar to that used for a previous demonstration domestic fires project and a well-ventilated front room fire video [BRE]. The main items were new 'IKEA' type furniture. This type of furniture is widely available and used by young families or first-time buyers.

The main items for the conventional lounge arrangement were: a three-seater sofa, two armchairs, a coffee table, a rug, two shelving units, a pair of tab top curtains, a television and television table. The open plan lounge arrangement had an additional shelving unit. The televisions were second-hand and European. Sundry items included new candles, second-hand newspapers, magazines, chair throws, cushions, magazine rack, videos and various ornaments.

Figure 5.3 shows photographs of the lounge fuel arrangement: Figure 5.3(a) is a view from the lounge door towards the television, Figure 5.3(b) is a double shelving unit next to the television, Figure 5.3(c) is an additional shelving unit for the open plan lounge arrangement and Figure 5.3(d) is a view of the sofa from in front of double shelving unit. Figure 5.4 shows a schematic of the lounge furniture arrangement(s).

The fuel was conditioned prior to each test and the house was allowed to dry out between tests.

The ignition source was a lit tea light candle placed under the front left-hand corner of the television, when facing the television screen, see Figure 5.5. The tea light was pre-burnt for 60 s prior to being placed under the corner of the television.



(a) (b) (c) (d)

Figure 5.3 Photographs showing the lounge furniture arrangement(s)

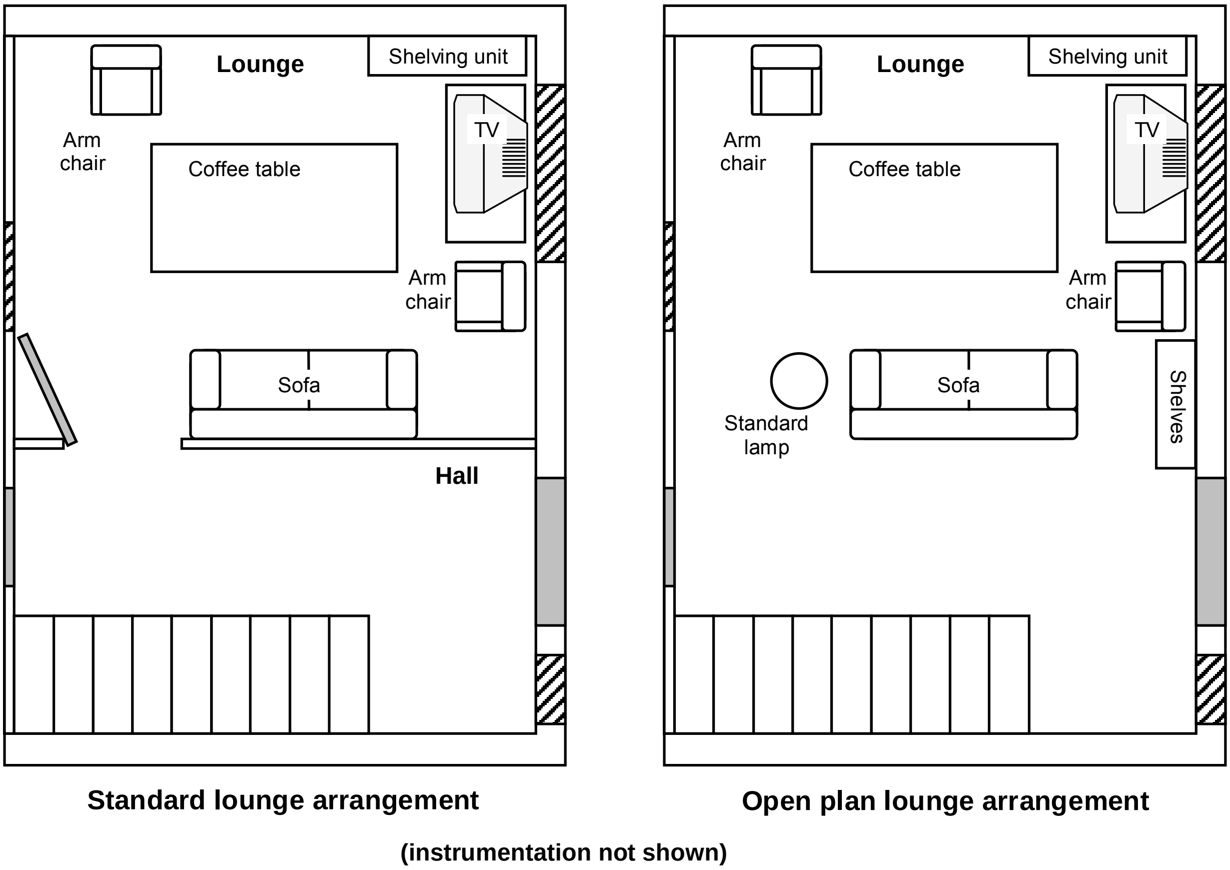


Figure 5.4 Schematic diagram showing the standard and open plan lounge furniture arrangements

Figure 5.5 Ignition source

5.3.5 Fire detection

Fire detection consisting of pairs of ionisation and optical fire alarms was installed inside the house, in locations as shown in Figure 7.2, in the lounge, hall, landing and loft. Smoke alarms were replaced after every test.

5.3.6 Instrumentation

Instrumentation was installed inside the experimental facility. Measurements included:

- Gas temperatures at strategic locations
- Relative humidity inside the test facility
- Concentrations of carbon monoxide, carbon dioxide and oxygen at strategic locations
- Smoke optical densities/visibility at strategic locations
- Sprinkler water flow rate
- Time of sprinkler(s) operation
- Time of smoke alarm activation
- Visual observations, video and photographs
- Amount of fire damage.

Figure 5.2 shows the locations of each item of instrumentation.

The instrumentation is described as follows.

5.3.6.1 Sprinkler water flow rate

The sprinkler water flow rate during sprinklered fire tests was measured using a calibrated 0 - 500 l/min electronic turbine flow meter.

5.3.6.2 Humidity measurement

The relative humidity inside the lounge was measured immediately prior to each test using a suitable humidity meter.

5.3.6.3 Gas temperatures

Gas temperatures were measured using 1.5mm diameter chromel/alumel K-type thermocouples. Three types of temperature measurements were made:

a) thermocouples measuring room gas temperatures were installed in a column at specified intervals from floor to ceiling in the lounge, hall, landing, bedroom and loft (referred to as a ‘thermocouple tree’)

b) thermocouples measuring the gas temperature were installed adjacent to sprinkler glass bulbs, and

c) thermocouples measuring near ceiling gas temperatures were installed in the lounge at a distance of 25 mm below ceiling.

Thermocouple locations are shown in Figure 5.2 and exact locations are included in Appendix 5A.

5.3.6.4 Gas concentrations

The relative concentrations of O_2, CO_2, and CO were measured at strategic locations within the house, as shown in Figure 5.2, as follows:

a) CO_2 and CO at heights of 1 m and 1.6 m in the lounge, 1 m in the loft room and 1.6 m in the main bedroom.

b) O_2 at heights of 1 m and 1.6 m in the lounge and 1.6 m in the main bedroom.

c) Optical density at heights of 1 m and 1.6 m in the lounge, 1.6 m in the main bedroom, 1.6 m in the hallway, 1 m in the loft and 1.6 m on the first floor landing.

All the distances above are measured above the floor and in the centre of each room.

The O_2 analysers were of the paramagnetic type and the CO and CO_2 analysers used an infra red absorption technique. All analysers were calibrated prior to each test.

5.3.6.5 Optical density per metre

The effect of smoke production on visibility was assessed using FRS optical density meters. These consist of optically coupled transmitter/receiver pairs aligned axially and mounted on a rigid metal support frame, see Figure 5.6. The optical density meters were calibrated using a range of neutral density filters.

The received light intensity was measured at strategic locations within the house, as shown in Figure 5.2, at 1 m and 1. 6 m in the lounge, 1.6 m in the ground floor hallway, 1.6 m in the first floor landing, 1.6 m in the main bedroom and 1 m in the loft. All these distances are measured above the floor.

The recorded optical transmittance was subsequently used to calculate (i) Optical Density per metre, and (ii) effective visibility (in m).

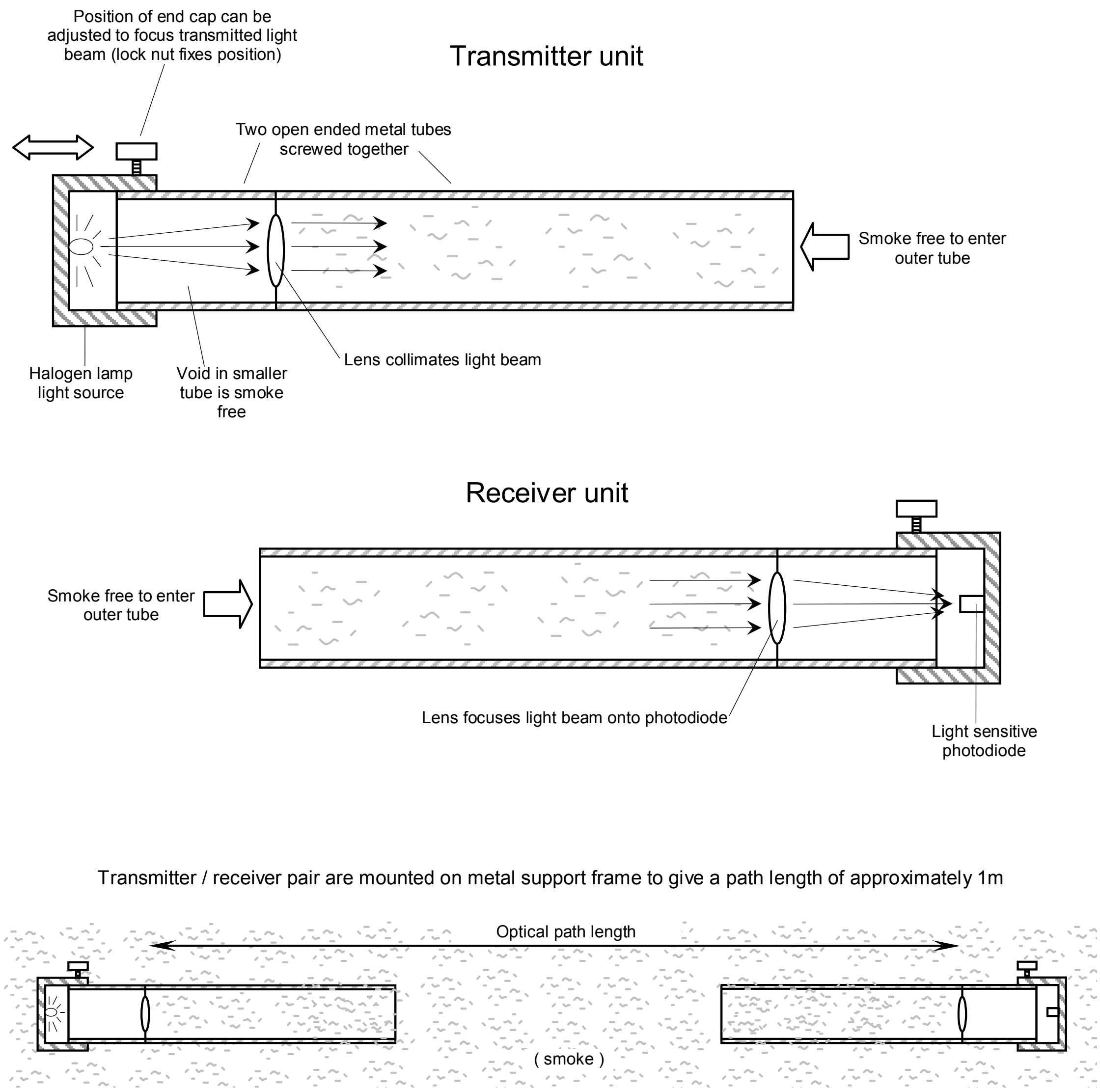


Figure 5.6 Schematic of optical density meter

5.3.6.6 Data acquisition

Two types of data acquisition systems were used for recording the instrument readings:

(1) Solatron automatic logger – used to record the water flow rate and all of the thermocouple tree temperatures, logged at 2.5 s intervals.

(2) Data Shuttle logger – used to record all other measurements, logged at 0.5 s intervals.

5.3.6.7 Visual, video and photographic records

Camcorder video footage was recorded at five locations in the house facility during the fires, as shown in Figure 5.2. In addition, for Tests 1-5 and 8, a thermal imaging camera was used to record 'infra-red images' of the lounge. Selected stills photography was carried out.

Also, visual observations of key events during each fire were made.

5.3.7 Experimental method

5.3.7.1 Parameters of interest

The parameters that may influence the performance of a residential sprinkler in the fire scenario, include those shown in Table 5.1:

Table 5.1 Parameters of interest

Residential sprinkler parameters
• Model • Type (e.g. pendent, sidewall, recessed, etc) • Deflector plate depth below/above ceiling • Spacing between sprinkler heads • Bore size (K-factor) • Yoke arm orientation • Thermal response characteristics (Response Time Index, and nominal operating temperature) • Water flow rate • Initial starting water pressure
Fuel package parameters
• Location of fuel relative to sprinkler spray • Location of fuel in test room (wall, corner, middle) • Fuel material properties • Fuel dimensions • Fuel package arrangement • Conditioning of fuel package • Smouldering or flaming fire • Fire growth.
Test room parameters
• Dimensions (height, width, length) • Door or window openings (size, position) • Initial temperature and humidity of air in room

5.3.7.2 The test programme

The House fires test programme comprised eight fires. The experimental matrix is shown in Table 5.2. Tests 1 to 5 concern the standard lounge arrangement and Test 6, 7 and 8 concern the open plan lounge arrangement. Test 8 was a repeat of Test 7.

Table 5.2 Experimental matrix for the House fires

Test number	Lounge door configuration	Sprinkler water flow rate (l/min)	Sprinkler yoke arms orientation relative to lounge window	Sprinkler type
Standard lounge arrangement				
1	Open	0	n/a	n/a
2	Open	60	90^{O}	A
3	Closed	0	n/a	n/a
4	Closed	60	45^{O}	A
5	Open	60	90^{O}	B
Open plan lounge arrangement				
6	n/a	84	n/a	n/a
7	n/a	84	90^{O}	A
8 (repeat of 7)	n/a	84	90^{O}	A

5.3.7.3 Sprinkler type/model

One model of a pendent type residential sprinkler model, designated sprinkler A, was selected for use in the house fires based on its performance in the Benchmark tests. This sprinkler had a metric K-factor of 70.6 (US K-factor of 4.9).

At the recommendation of the project experimental working group, a second sprinkler, designated sprinkler B, based on a poorer performance in the Benchmark tests, was used for Test 5. This sprinkler had a metric K-factor of 56.2 (US K-factor of 3.9).

5.3.7.4 Sprinkler orientation

The sprinkler orientation was fixed as yoke arms parallel to the lounge window, except for Test 4, when the yoke arms were 45^0 to the lounge window.

5.3.7.5 Fixed parameters

The residential sprinklers used were quick response, i.e. RTI < 50, with one value of nominal operating temperature (68^0C).

The sprinkler positions were fixed, see Figure 5.2. For the open plan lounge arrangement, the distance between the two lounge sprinklers was 2.9 m.

The distance of the fuel arrangement was fixed, relative to the position of the sprinkler spray. The fire scenario was fixed as a lounge scenario, a tea light and television fire which was a shielded flaming fire.

5.3.7.6 Sprinkler water flow rate

The water flow rate of the first sprinkler in operation was fixed at either 0 l/min (no sprinkler in operation) or 60 l/min (Tests 2, 4, 5). For two sprinklers in operation the water flow rate was fixed at 84 l/min, 42 l/min per sprinkler (Tests 7, 8). For two sprinklers in operation, for sprinkler A, the minimum operating pressure would be less than the 0.5 bar specified in DD 251.

5.3.7.7 Ventilation conditions

The ventilation conditions were as follows:

- All the windows on the front of the house were modern double-glazed units, including the lounge, main bedroom and loft windows.
- Inside the lounge, there was a chimney and two low-level air bricks on the window wall. The lounge window was closed during all fires but there were trickle ventilators in the lounge window.
- For the standard lounge arrangement, the non fire-resisting lounge door was either fully open or closed.
- The door of the main bedroom was partially open to give an effective gap of approximately 0.5 m.
- The back bedroom and bathroom windows were partially open; the back bedroom door was closed and sealed with foil tape and the bathroom/landing door was closed.
- The dining room doors were nominally closed but access was needed during the fires. The kitchen/hallway and kitchen/dining room doors were closed and sealed with foil tape.
- All other remaining doors and windows were closed.

5.3.7.8 Two storey dwelling house with open plan lounge and loft conversion

In the case of a loft conversion to an existing two-storey dwelling house it is considered adequate to provide means of escape by the provision of a primary escape route supplemented by an assisted escape route from the habitable rooms at second floor level.

When following this approach, it would normally be necessary to upgrade existing stairway enclosures by making existing doors self-closing and by replacing any conventional glass with fire resisting glass. If the stairway is not a full enclosure at one or more levels in the house, then additional doors and partitions necessary to complete the enclosure would need to be provided.

However, it has been suggested that a combination of early warning from a fire detection system and suppression of the fire using a sprinkler system, when considered as a whole, could have the potential to provide a similar level of safety for the occupants of the house as would be provided by a self-closing door of undetermined fire resistance and thereby provide for unaided escape to the final exit (i.e. the front door).

Equally, if the occupants of the room on the new second floor found their primary escape route blocked, sprinkler protection might also extend the period for which the occupants of the second floor could await assisted escape via the second floor escape window.

Tests 6, 7 and 8 attempted to address the two-storey house with open plan lounge and loft conversion scenario.

5.3.7.9 Experimental procedure for each fire test

The following experimental procedure was carried out for each fire:

1. The fuel was suitably conditioned.
2. It was ensured that the inside of the house was dry.
3. The furniture was positioned.
4. The gas analyser pumps were switched on.
5. The data logging systems were started and a stopwatch was started.
6. The five photographic videos and thermal imaging video (when present) were started in sequence.
7. The water pump was switched on, for sprinklered fires.

8. The water flow rate data logger system was started, for sprinklered fires.
9. The tea light candle was lit 60 s prior to ignition and a count down started.
10. The lit tea light was placed close to the television at ignition, a klaxon was sounded and the remainder of the stopwatches and a large digital timing clock was started.
11. The fire was allowed to develop and relevant measurements made.
12. For sprinklered fires, the flow through the first sprinkler to operate was sufficient to provide the nominal density of discharge required for a single sprinkler area of coverage. When two sprinklers operated, the pump speed was adjusted so that the required nominal discharge density for two operating sprinklers was achieved.
13. At the end of test a klaxon was re-sounded.

The order of steps 4, 5, 6 were sometimes interchanged.

5.3.8 Results of the House fires

The following data are presented in Appendix 5A.

- Graphs of temperature against time at each location
- Graphs of % optical transmittance against time at each location uncorrected for path length
- Graphs of O_2, CO_2 and CO concentrations against time for each location. These have been adjusted to take into account lag time (the time taken for the gas to be drawn through the tubing from the sampling point into the measuring region of the analyser)
- Graphs of sprinkler water flow rate against time
- Humidity readings and temperature inside the fire room prior to each fire
- Optical and ionisation smoke detector activation times and
- Visual observations.

Photographic video, thermal imaging video (for Tests 1-5 and 8) and stills photographs are available for before, during and after each fire.

Appendix 5B contains selected damage assessment photographs.

Appendix 5C contains graphs of optical density per metre, visibility and fractional effective dose against time at each location.

Appendix 5D contains summary graphs of temperatures at head height, FED_{AG} and FED_H against time in each room. These are provided to allow easier comparison of the variation of those parameters between tests. The FEDs were extrapolated, where necessary, to 30 minutes from the test start.

Figure 5.7 is a bar chart of the key event timings in the room of origin in the house fires.

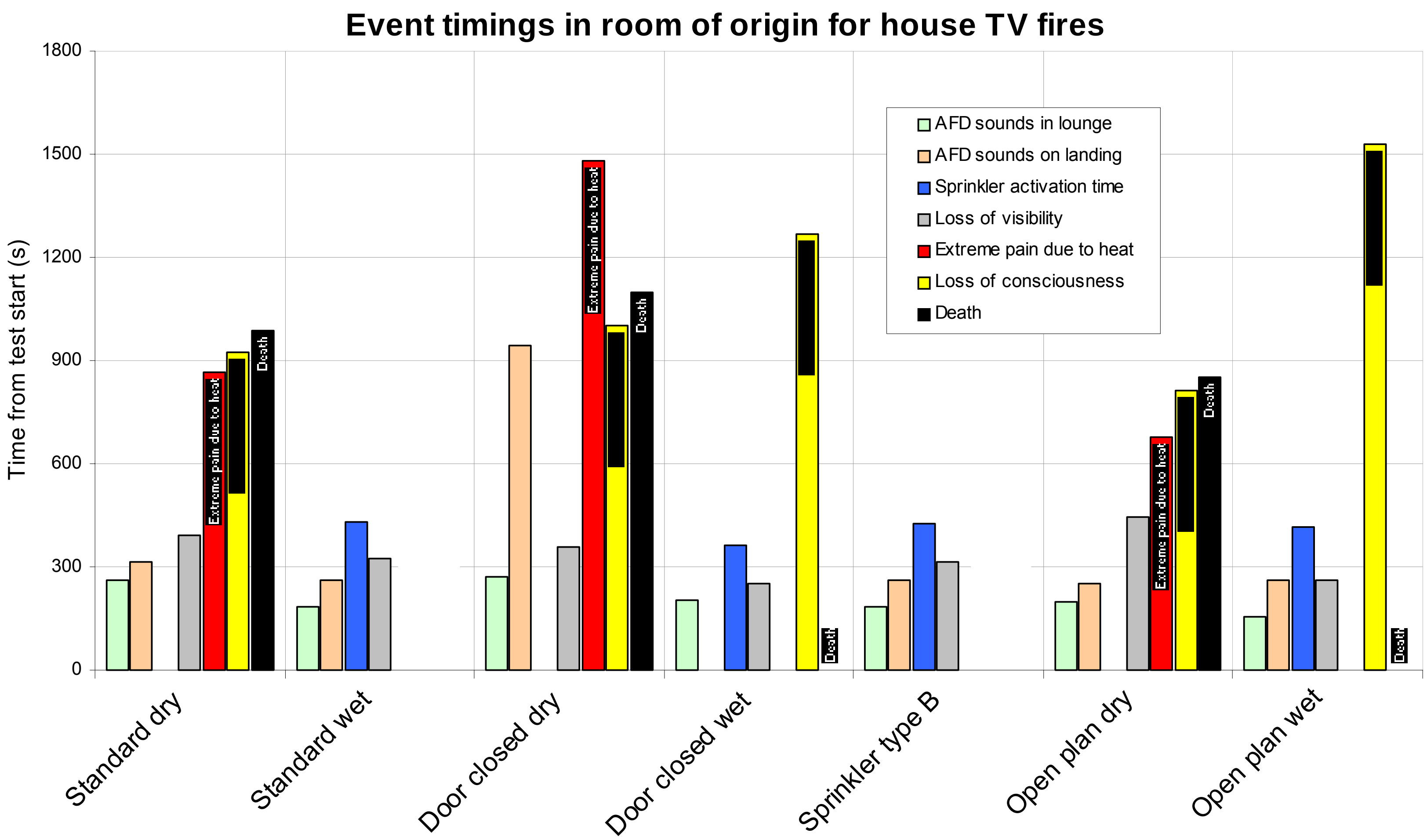


Figure 5.7 Bar chart showing timings of key events, during various house fire tests

5.3.9 Summary and conclusions of house fires

8 house lounge fires were conducted inside a two-storey house with a loft conversion, with and without sprinklers. Smoke alarms were present. Five fires were performed in a standard lounge and three with an open plan lounge arrangement. The effects of fire room door open/closed, sprinkler model, sprinkler orientation and water flow rate were studied.

The detailed conclusions of the house fires, for the conditions studied and for a duration of 30 minutes from ignition, are as follows:

1. Five realistic fires were conducted in a standard house lounge arrangement.
2. Three realistic fires were conducted for an open lounge and loft arrangement.
3. The televisions used as the initial source of fuel were found to have slightly different burning characteristics.
4. For the unsprinklered open lounge door arrangement, the conditions became unsurvivable in terms of FED_{AG} in all areas of the house apart from the loft room. For both of the sprinklered cases, the conditions remained tenable in terms of FED_{AG} throughout the house. The visibility remained tenable in the bedroom and loft and was slightly improved in the landing and hallway compared to the unsprinklered case.
5. For the unsprinklered closed lounge door arrangement, the conditions became unsurvivable in the lounge but remained tenable in the rest of the house. In the sprinklered case, the conditions were greatly improved in terms of FED_{AG} in the lounge but became untenable and conditions remained tenable throughout the rest of the house. The visibility remained tenable in all areas of the house apart from the lounge.
6. It was found that closing the lounge door had a noticeable effect on the fire size (i.e. slightly less vigorous and cooler) and considerably improved the tenability throughout the rest of the house by containing the combustion products to the room of origin.
7. It was found that the use of sprinklers, in all cases, helped to significantly reduce the FED_H in the room of origin.
8. For the unsprinklered open plan lounge arrangement, the conditions became unsurvivable in terms of FED_{AG} in all areas of the house apart from the loft room. The visibility became untenable throughout the house. In the sprinklered case, the conditions were greatly improved in terms of FED_{AG}. The conditions in the lounge became untenable but remained tenable throughout the rest of the house. The visibility conditions remained tenable in the bedroom and loft only.
9. For the sprinklered fires, examination revealed that the fire damaged area was confined to between ½ and ⅓ of the television, slight damage to the table underneath and one curtain. The walls in the lounge were relatively clean.
10. For the unsprinklered fires, examination revealed that the fire damaged area was greater than when sprinklered. For the unsprinklered door closed case, a layer of thick soot was produced on all surfaces in the lounge but the walls were clean elsewhere in the house. For the unsprinklered door open and the open plan lounge arrangement tests, there was less soot but it was observed throughout the house.

    Post test observations:

11. The sprinklers controlled but did not completely extinguish all of the fires.
12. The sprinkler spray was not evenly distributed so fires in locations of low water delivery would not be controlled to the same extent.

Note: Based on previous experiments, for television fires, the smoke release during the early stages is likely to be more irritant than has been assumed for the unsprinklered case.

The main general conclusions for the 30 minute duration of the house lounge television fires are:

- For the unsprinklered fires, the conditions in the lounge became unsurvivable/lethal 15 to 20 minutes from ignition.
- For the unsprinklered fires with the lounge door open, the conditions became unsurvivable/lethal in all the open spaces within the house.
- Closing the lounge door, maintained tenable conditions throughout the rest of the house.
- Sprinklers greatly improved conditions in the standard lounge and maintained tenable conditions in terms of toxic effects; reduced the effects of convected heat but there was little or no improvement in visibility.
- Sprinklers in the standard lounge arrangement maintained tenable conditions in terms of toxic effects throughout the house.
- For the open plan lounge arrangement, conditions became unsurvivable/lethal in all the open spaces within the house for the unsprinklered case. Sprinklers greatly improved conditions - conditions became untenable within the lounge in terms of toxic effects but remained tenable in the rest of the house including the loft room.
- The conditions in the loft room remained tenable for all tests with the loft door closed.. However if the loft door had been open the conditions would have been similar to those in the bedroom and upper circulation spaces.
- The life safety benefits of fitting smoke alarms was demonstrated. This includes the added benefits of fitting linked smoke alarms in both rooms and circulation spaces.

5.4 Compartment fires

5.4.1 Introduction

The second phase of the Experimental Programme was a series of compartment fires. Details of the experimental facility, instrumentation, experimental method, results and conclusions are described, as follows.

5.4.2 The experimental facility

The experimental facility that was used for the Benchmark tests was extended and modified and utilised for the compartment fires. It was located inside the BRE Cardington Laboratory. It consists of 12 mm thick plasterboard sheets attached to a wooden frame forming “residential rooms”. Ceramic fibre board was attached to the ceiling of the experimental facility. Figure 7.8 shows photographs of the exterior and interior of the compartment experimental facility. The internal layout of the facility and locations of the instrumentation are shown in Figure 7.9.

The experimental facility was initially configured to provide alternative fire rooms at either end each measuring 4 m by 4 m by 2.5 m high connected a middle room measuring 3.8 m by 4 m by 2.5 m high. Standard size, non fire-resisting doors were fitted externally to either end of the facility for access to the rooms during test preparation and were kept closed during fires (except for the table and kitchen fire scenarios).

Standard size, non fire-resisting, internal doors were also fitted to the internal compartment dividing walls to allow ventilation conditions to be controlled. For each fire, one end room was fitted with furniture (the room of fire origin). The other end room remained empty. In all tests, the door of the non-fire room was left fully open. Therefore, during tests in which the internal fire room door was left open, the effective enclosure volume was approximately 118 m^3. This was reduced to 40 m^3 when the fire room door was closed.

Several of the test fires required a larger fire room of size 8 m by 4 m by 2.5 m high and therefore the experimental facility was further modified.

Figure 5.8 Layout of the experimental facility

5.4.3 The sprinkler system

A suitable sprinkler system was installed in the experimental facility. For sprinklered fires, a single residential sprinkler head was located centrally inside the fire room, as shown in Figure 5.9. For the large compartment fires, two residential sprinkler heads were installed inside the fire room at a spacing of 4 m. Air bleed valves were located in the sprinkler pipework, close to the sprinkler heads, to allow the removal of air from the system prior to each test.

5.4.4 Instrumentation

Instrumentation was installed inside the experimental facility at locations indicated in Figure 5.9. Measurements included:

- Gas temperatures at strategic locations
- Relative humidity inside the test facility
- Concentrations of carbon monoxide, carbon dioxide and oxygen
- Smoke optical densities/visibility
- Sprinkler water flow rate
- Time of sprinkler(s) operation
- Time of smoke alarm activation(s)
- Visual observations, video and photographs
- Estimate of the amount of fire damage.

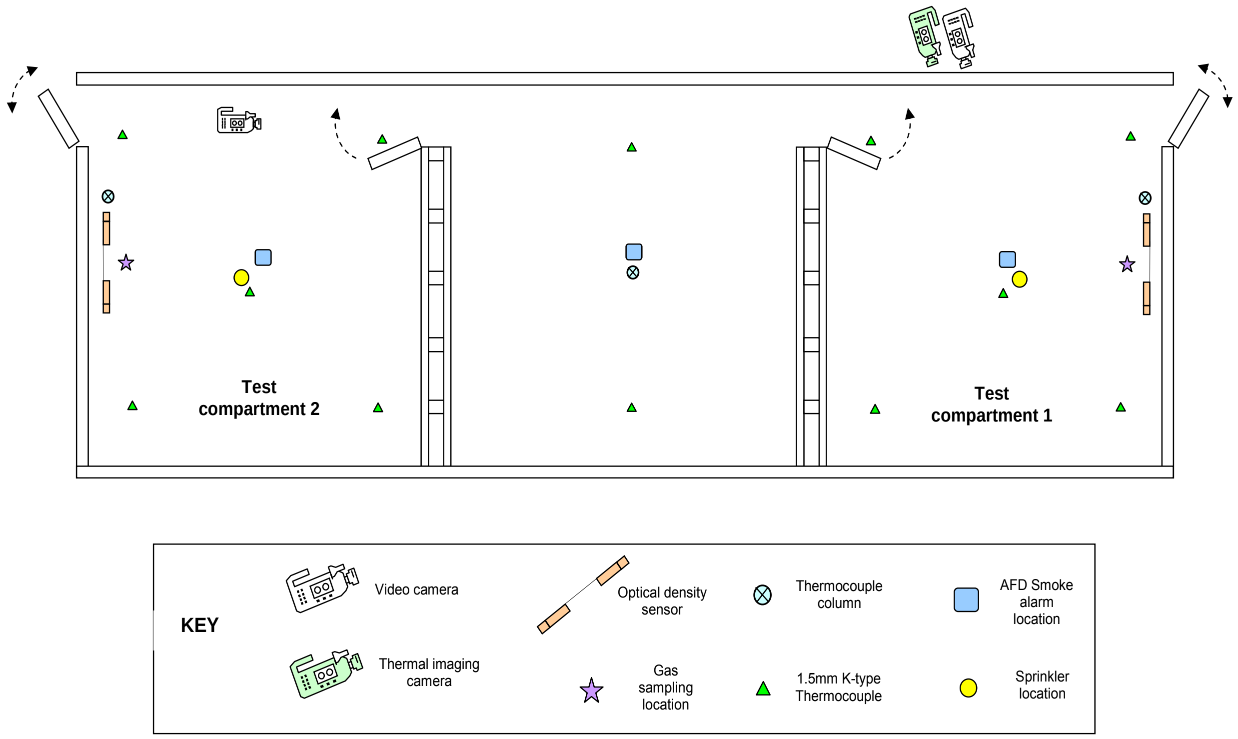


Figure 5.9 Schematic diagram showing the video and instrument locations

5.4.4.1 Sprinkler water flow rate

The sprinkler water flow rate was measured during the sprinklered fires using a calibrated 0 - 500 l/min electronic turbine flow meter.

5.4.4.2 Humidity and moisture measurement

The relative humidity inside the fire room was measured immediately prior to each test using a suitable humidity meter.

For the table fires, the moisture content of the tabletop and the wooden battens surrounding the underside of the tabletop was measured immediately prior to each test using a suitable moisture meter.

5.4.4.3 Gas temperatures

Gas temperatures were measured using 1.5 mm diameter chromel/alumel K-type thermocouples. Three types of temperature measurements were made:

d) thermocouples measuring gas temperatures were installed in a column at specified intervals from floor to ceiling in each room

e) thermocouples measuring the gas temperature were installed adjacent to the sprinkler glass bulbs, and

f) thermocouples measuring gas temperatures 25 mm below the ceiling were installed in the locations shown in Figure 7.10.

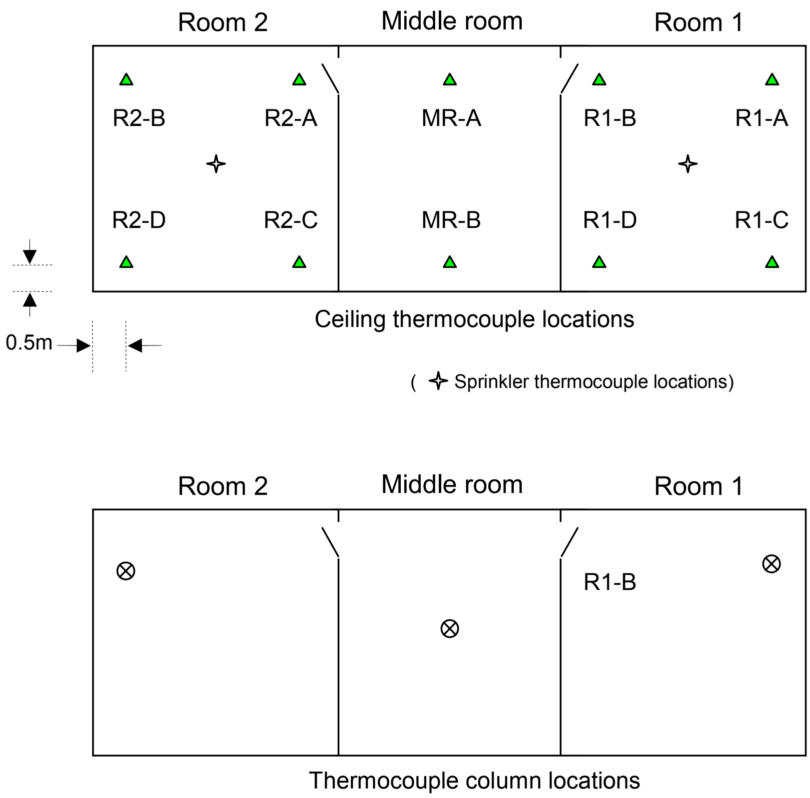


Figure 5.10 Thermocouple locations

5.4.4.4 Gas concentrations

Gas sampling lines were installed in the two end rooms (see Figure 5.9) at heights of 1.0 m and 1.6 m. During each test, the relative concentrations of O_2, CO_2, and CO were measured in the room of fire origin.

5.4.4.5 Optical density per metre

The effect of smoke production on visibility was assessed using FRS optical density meters. These consist of optically coupled transmitter/receiver pairs aligned axially on a rigid metal support frame and calibrated using a range of neutral density filters.

Optical sensors were positioned at 1.0 m and 1.6 m above the floor in each of the end rooms. The received light intensity at each of the four locations was recorded for every test.

The recorded optical transmittance was used to calculate (i) OD/m, and (ii) visibility (m).

5.4.4.6 Automatic fire detection activation times

Smoke alarms were located in the room of fire origin and its adjacent room and connected to the data logging system to record their activation times. For the majority of tests, ionisation types were used. In addition, optical types were also used for a selected number of tests. Smoke alarms were replaced after every fire.

5.4.4.7 Sprinkler operation times

The sprinkler operation times were measured from the start of the water flow and also from the temperature drop of the thermocouple mounted close to the sprinkler head.

5.4.4.8 Data acquisition

Two types of data acquisition systems were used for recording the instrument readings:

1) Solartron automatic logger – used to record the water flow rate, alarm activations and all of the thermocouple tree temperatures, logged at 2.5 s intervals.

2) Data Shuttle logger – used to record all other measurements, logged at 1.0 s intervals.

5.4.4.9 Visual, video and photographic records

Camcorder video footage was recorded at two (and for some tests three) locations in the experimental compartment during the fires, and a thermal imaging camera was used to record ‘infra-red images’ of the fires, as shown in Figure 5.9. Also, visual observations of key events during each fire were made.

Following each fire, a visual estimate and record was made of the amount of area that was smoke and fire damaged.

5.4.5 The fuel arrangement

Five fire scenarios were studied which included three types of lounge fire, one bedroom fire and one kitchen fire. The materials inside the fire room needed to be dry and the temperature and relative humidity needed to be controlled. Before the start of each test it was ensured that the fuel package and the room were suitably conditioned.

The fire scenarios are described in detail, as follows.

5.4.5.1 The lounge fires

The fire load arrangement for the lounge fire was representative of the contents of a lounge. The fire load arrangement was similar to that used for the house fires. The main items were new ‘IKEA’ type furniture. This type of furniture is widely available and is typically used by young families or first-time buyers.

The main items for the lounge arrangement were: a three-seat sofa, one armchair, a coffee table, a rug, two shelving units, a pair of tab top curtains and a television on a television table. The televisions were second-hand. Sundry items included new candles, second-hand newspapers, magazines, chair throws, cushions, magazine rack, videos and various ornaments.

Three types of lounge fire were tested, each with nominally the same fuel arrangement but with different items used for the primary ignition source.

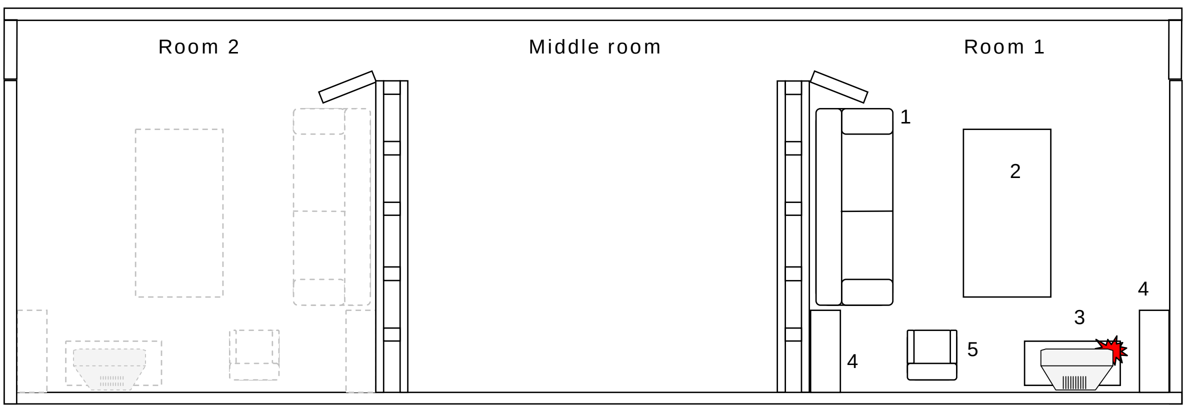
5.4.5.2 The television fire

Figure 5.11 shows the furniture arrangement for the television fire. A full list of items used is contained in Table 5.3.

The primary ignition source for this fire was a lit nightlight candle placed under the front corner of the television closest to the bookshelf. Figure 5.12 shows the location of the nightlight for a fire in room 1 and a typical photograph of fire growth up the side of the television several minutes after ignition. For each of the television fires, the nightlight was ignited and allowed to burn for 60 s prior to being placed under the corner of the television.

Table 5.3 Items used in television fires

Main items I sofa 1 chair 1 coffee table on rug Television on cabinet 2 single shelving units Magazine rack Curtain pole 2 video racks	
	Sundries
On sofa	1 large throw 2 matching cushions I handbag I box of tissues 1 newspaper on each arm
Chair	1 small throw 1 newspaper on each arm
Videos	39 needed, see below
Video rack 1 Video rack 2	10 videos 10 videos
On television table	20 glossy magazines, 5 per shelf 2 wax candles 5 videos 4 nightlights on top of television 2 nightlights to one side Television wired in places
On curtain pole	I pair of curtains
On coffee table	1 mug 3 magazines 2 coasters 1 chocolate box
Newspapers	10 kg weighed out, see below for details
Magazine rack	10 folded newspapers
Shelf unit next to television	Top shelf – 4” broad sheet, 5” tabloid newspapers Middle shelf – 14 videos, 10 CDs, 2 birds, plastic cup Bottom shelf – large vase or china owl and glass
A3 sheets of white paper	1 on camera wall 1 on sofa wall 1 under coffee table
Shelf unit next to sofa	Top shelf – plastic alarm clock, board game, small cuddly toy Middle shelf – 1 large book, two picture frames, 1 radio cassette Bottom shelf – basket containing two large fir cones



1-sofa 2-coffe table 3-small table 4-Shelving units 5-Arm chair -approximate location of ignition

Figure 7.11 Fuel arrangement for television fire (in room 1)

Figure 5.12 Television fire ignition source

5.4.5.3 The table fire

Figure 5.13 shows the furniture arrangement for the table fire. A full list of items used is contained in Table 5.4. The main components of the 'table' and the material beneath it are shown in Figure 5.14. The whole of this table arrangement except the blocks and the materials below it were replaced for each test.

The table fire comprised a simulated coffee table below which was placed a wicker magazine rack filled with newspapers and videos. Also, under the table were two stacks of four videos, four jigsaw boxes and eight loose newspapers resting vertically against the videos and boxes.

The table consisted of a single sheet of 1.2 m by 0.8 m plywood to which eight wooden battens were screwed. This 'table top' was supported on four concrete blocks (215 mm by 100 mm by 440 mm tall) to help prevent the table collapsing. Ignition was achieved by igniting a total of six scrunched up newspapers, positioned three on each side under the magazine rack, as shown in Figure 5.15. A piece of Hessian-backed carpet, of the same size as the tabletop, was positioned on the floor below the concrete blocks.

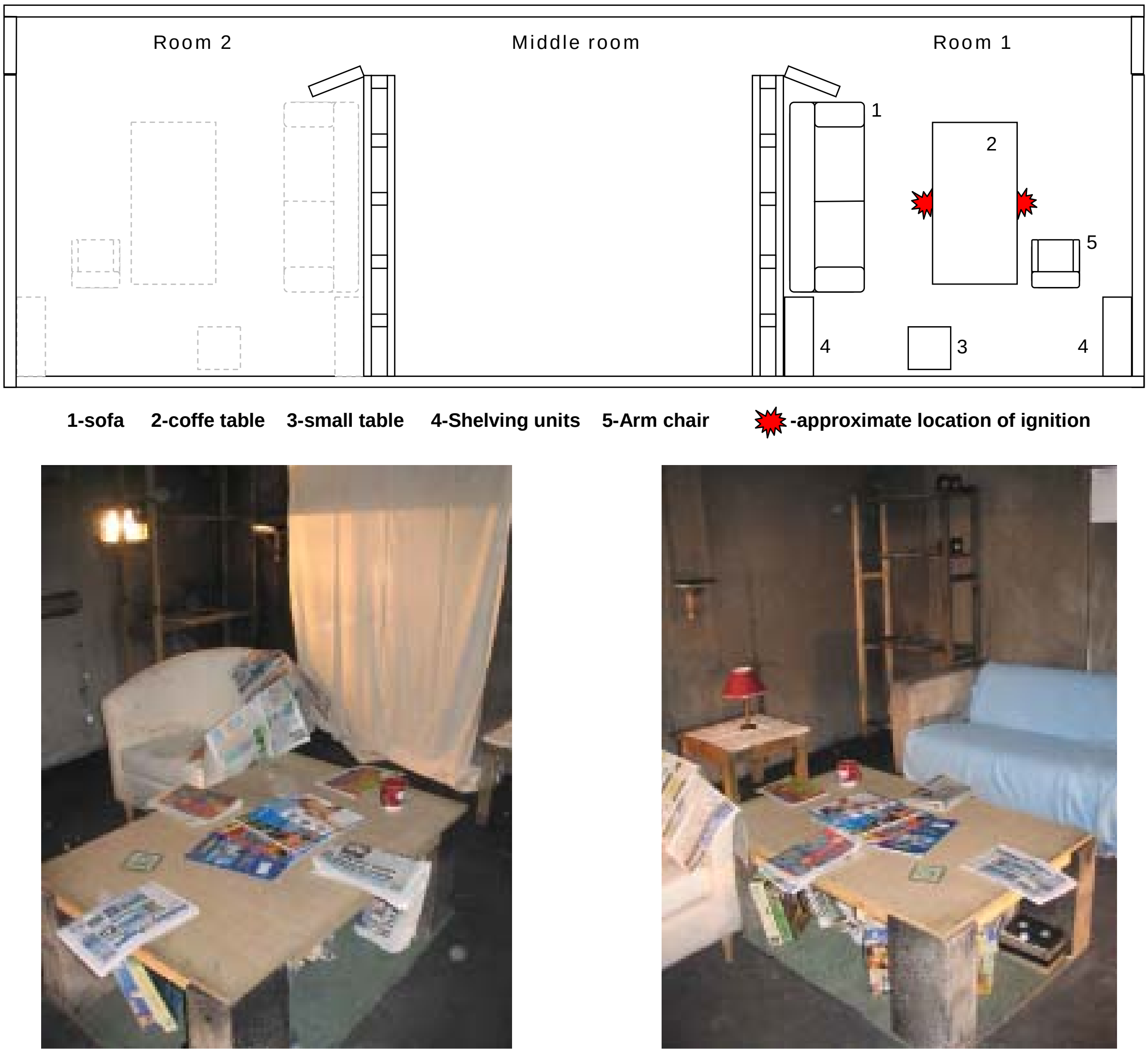


Figure 5.13 Fuel arrangement for table fire (in room 1)

Table 5.4 Items used in table fires

<table>
<tr><td colspan="2">Main items
I sofa
1 chair
1 simulated coffee table on rug
1 side table
2 single shelving units
Curtain pole
2 video shelves</td></tr>
<tr><td></td><td>Sundries</td></tr>
<tr><td>On sofa</td><td>1 large throw</td></tr>
<tr><td>Chair</td><td>1 newspapers draped over arm
1 folded newspaper on side nearest to table</td></tr>
<tr><td>Magazine rack under table</td><td>2.7 kg of newspapers
6 videos (2 of these on top)</td></tr>
<tr><td></td><td>4 off 100/1500 piece puzzle boxes
6 empty video cases (2 stacks of 3)
2 videos (1 on top of each empty case pile)
8 folded newspapers</td></tr>
<tr><td>Video racks</td><td>1 video on each</td></tr>
<tr><td>On side table</td><td>Lamp and shade on cloth</td></tr>
<tr><td>On curtain pole</td><td>1 central curtain</td></tr>
<tr><td>On coffee table</td><td>1 mug
5 magazines
1 coaster
4 folded newspapers</td></tr>
<tr><td>Shelf units</td><td>Top shelf – 2 video, 1 on each edge, 1 flat newspaper in middle
Middle shelf – 1 flat newspaper in middle</td></tr>
<tr><td>A3 sheets of white paper</td><td>1 on camera wall
1 on sofa wall
1 on bottom shelf of bookshelf</td></tr>
</table>

Plywood table top with wooden battens

Magazine rack with papers and videos

View of 'table' facing towards sofa

View of 'table' facing away from sofa

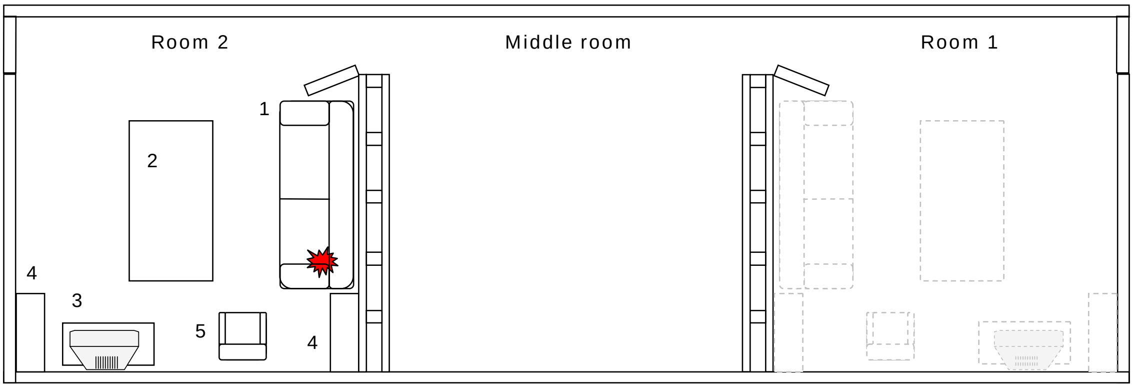
Figure 7.14 Details of table fire arrangement

Figure 5.15 Table fire ignition point

5.4.5.4 The sofa fire

The primary fuel source for this scenario was the same type of sofa used in the other lounge fires. The fuel arrangement used was similar to that used for the television fires, see Figure 5.16. A full list of items used is contained in Table 5.5.

Ignition was achieved using a lit nightlight placed below three scrunched up newspapers pressed in between the side and rear cushions of the sofa as shown in Figure 5.17. Due to the fire retardant treatment of the cushion fabric it was not always possible to achieve and maintain a consistent growing fire. In some cases, the papers burned and extinguished without the sofa catching alight. This was partially rectified by replacing the burnt paper with new additional newspaper which was then ignited.



1-sofa 2-coffe table 3-small table 4-Shelving units 5-Arm chair -approximate location of ignition

Figure 5.16 Fuel arrangement for sofa fire (in room 2)

Figure 5.17 Sofa fire ignition source

Table 5.6 Items used in sofa fires

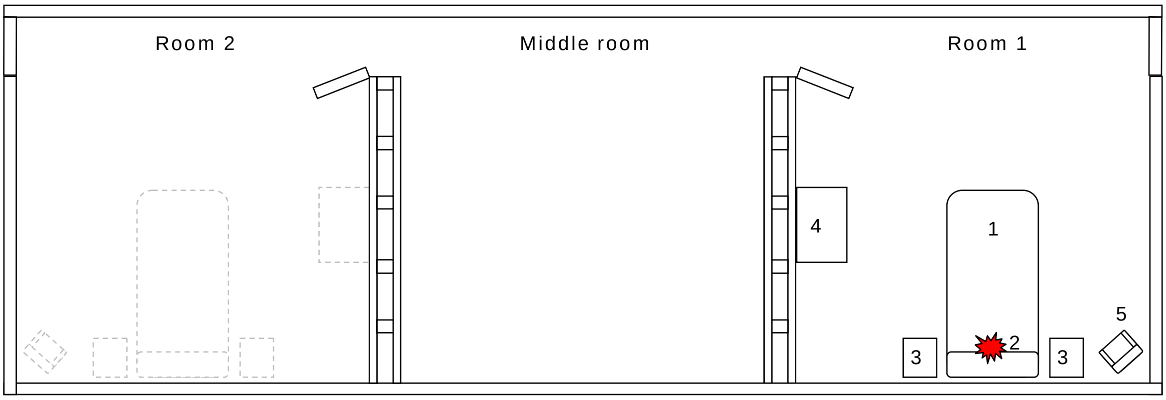
Main items 1 sofa 1 chair 1 coffee table on rug Television on cabinet 2 single shelving units Magazine rack Curtain pole 2 video racks	
	Sundries
On sofa	1 large throw, on half of sofa containing items below 1 cushion I handbag I box of tissues 1 newspaper on far side arrangement of scrunched up newspaper 2 nightlights (1 spare)
Chair	1 small throw 1 newspaper on each arm
Videos	19 needed, see below
Video rack 1 Video rack 2	10 videos empty
On television table	20 glossy magazines, 5 per shelf 2 wax candles 5 videos 2 nightlights on top of television
On curtain pole	I pair of curtains
On coffee table	1 mug 3 magazines
Newspapers	10 kg weighed out, see below for details
Magazine rack	10 folded newspapers
Shelf unit next to sofa	Top shelf – 4” broad sheet (3.8 kg), 5” tabloid newspapers (2.3 kg) Middle shelf – 14 videos, 10 CDs, 2 birds, plastic cup Bottom shelf – large vase or china owl and glass
A3 sheets of white paper	1 on camera wall 1 on sofa wall 1 under coffee table
Shelf unit next to sofa	Top shelf – board game Middle shelf – 1 large book Bottom shelf – basket containing two large fir cones

5.4.5.5 The bedroom fire

Figure 5.18 shows the bedroom fire load arrangement used for the bed fire which was representative of the contents of a bedroom. The main items were new ‘Argos’ type furniture. A full list of items used is contained in Table 5.7.

The main items for the bedroom arrangement were: a single bed, two bedside cabinets, a wicker chair and a fabric wardrobe. Sundry items included bedding, bedside table items, a rug, cushions, items of clothing on plastic hangars. The bed was made up with fitted sheets, pillow, duvet and an additional small cushion placed next to the pillow.

Ignition was achieved using a lit nightlight placed under the front edge of the pillow, close to the cushion, see Figure 5.19.



1-bed 2-pillow and cusion 3-Bed-side table 4-Fabric wardrobe 5-Wicker chair -approximate location of ignition

Figure 5.18 Fuel arrangement for sofa fire (in room 2)

Figure 5.19 Bed fire ignition source

Table 5.7 Items used in bed fires

Main items I single bed 1 wicker chair 1 bedside cabinet 1 side table 1 wardrobe 1 rug on floor on table side of bed	
	Sundries
On bed	I sheet 1 duvet with cover I pillow and pillow case 1 cushion 2 nightlight (1 spare)
Chair	1 cushion
Side table	I table cloth I lamp and shade I mug 5 small books I box of tissues
Bedside cabinet	3 newspapers 1 radio alarm clock 1 small plastic clock
Wardrobe	5 plastic hangers 5 garments order nearest to bed: 1 green top, cotton polyester 1 top 1 woolly jumper 1 cotton dress 1 pair of jogging bottoms
A3 sheets of white paper	1 on camera wall 1 on sofa wall 1 under coffee table

5.4.5.6 The kitchen fire

The oil pan fire used for this scenario was based on the arrangement used in BS EN1869:1999 [British Standards Institution 1999] for fire blanket testing. This used a 350 mm diameter pan with side walls of 100 mm supported on a metal frame 140mm tall. This arrangement was in turn located on a sheet of fire resisting board supported on concrete blocks, as shown in Figure 5.20. The remainder of the fire room was empty.

A gas burner was located underneath the pan and propane was fed to it from a cylinder located outside the experimental facility. The burner was used to heat the oil to its auto ignition temperature, nominally 360^{O}C. Three litres of new sunflower cooking oil were used for each fire. The temperature of the oil was monitored using a thermocouple connected to a display unit. To prevent the room from overheating prior to ignition of the oil, the external door of the fire room was kept open until the oil temperature reached 350^{O}C. Immediately the oil had auto-ignited, the gas burner was turned off and removed from the fire room through a small hole in the wall.

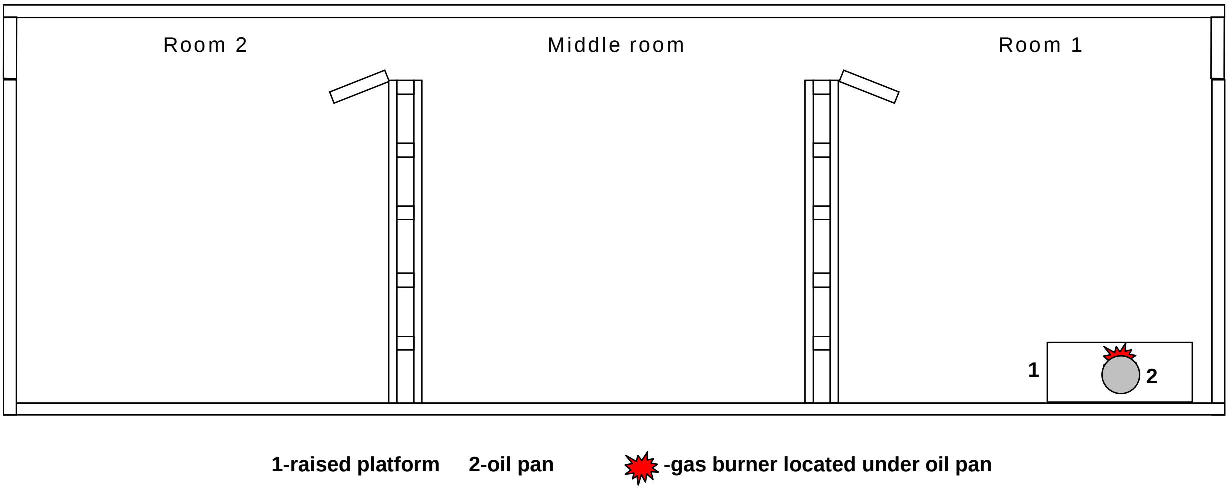


Figure 5.20 Fuel arrangement for oil pan fire (only done in room 1)

5.4.6 The large fire compartment

Following Test 20, the experimental facility was further modified by the removal of the partition wall between the middle room and room 2, to produce a larger room of 8 m by 4 m. This required a number of changes to the instrumentation, as shown in Figures 5.21 and 5.22.

In the relevant graphs, this larger compartment is simply referred to as the 'Large Compartment'.

An additional sprinkler was fitted for the large room tests.

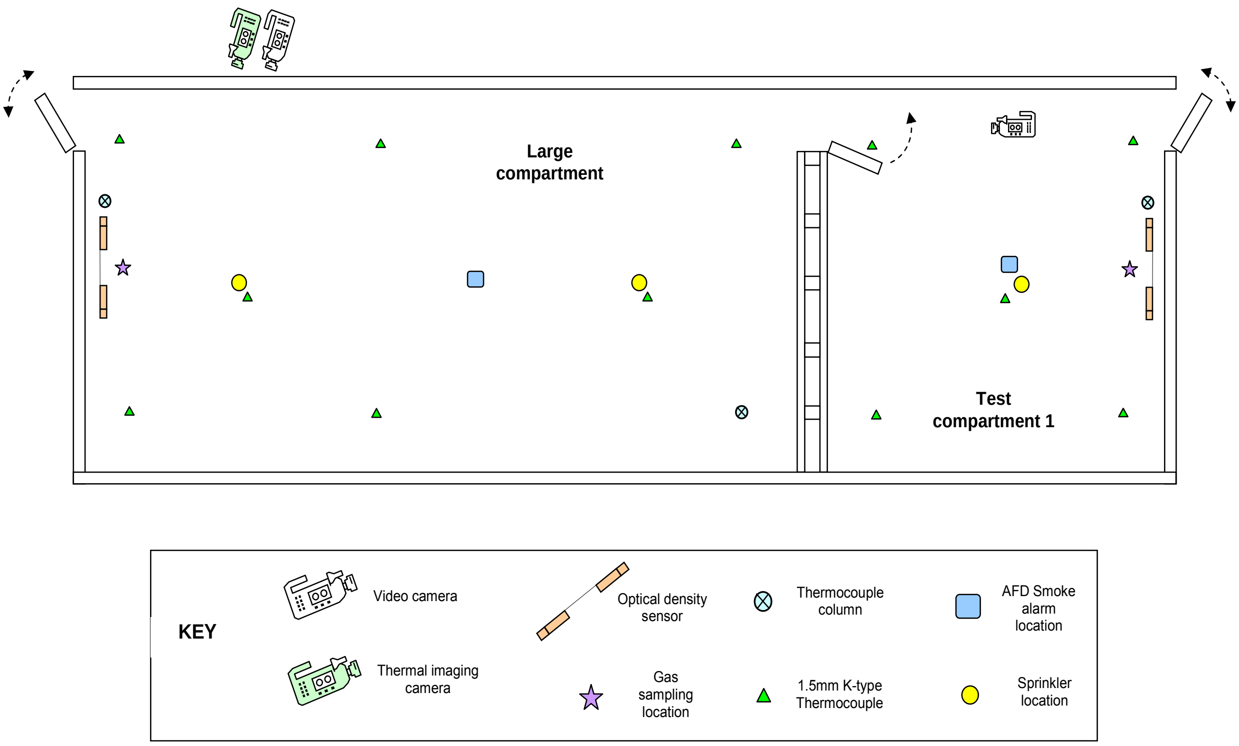


Figure 5.21 Schematic diagram showing the large compartment layout

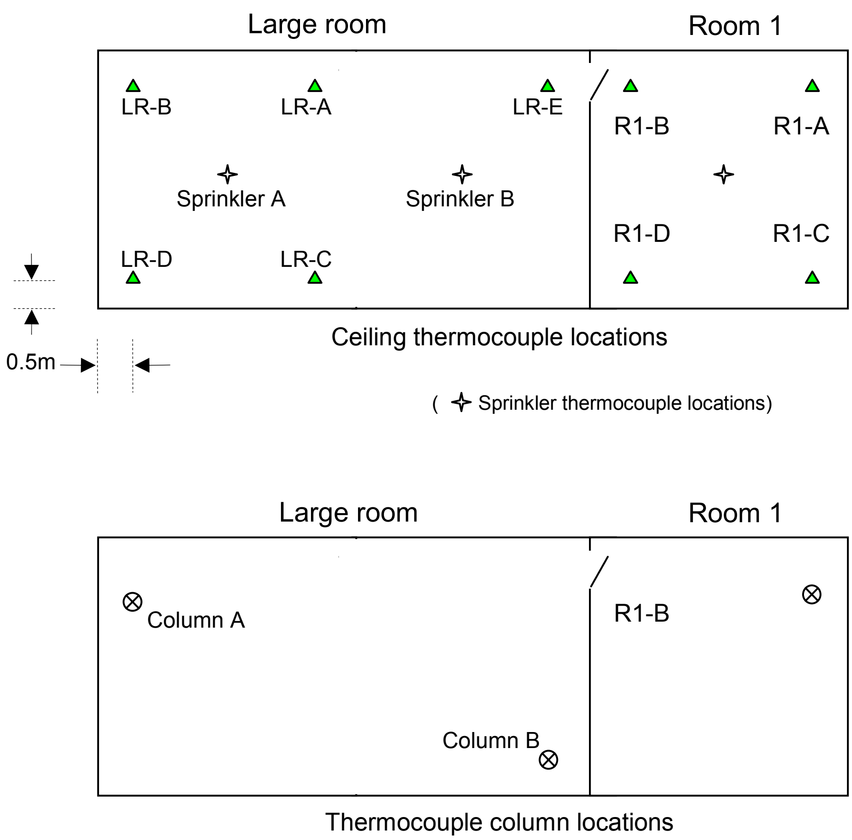


Figure 5.22 Thermocouple locations and nomenclature (for graphs)

5.4.7 Experimental method

5.4.7.1 Parameters of interest

The parameters that may influence the performance of a residential sprinkler in a fire scenario, are included in Table 5.2.

5.4.7.2 The test programme

The compartment fires test programme comprised twenty-nine fires. The experimental matrix is shown in Table 5.8.

Table 5.8 The experimental matrix for the compartment fires

Test	Fire scenario	Item first ignited	Room size (m by m)	Room	Door open or closed	Water flow rate (l/min)	Sprinkler type	Sprinkler orientation relative to long axis of facility
1	Lounge	Television	4 by 4	1	Open	0	-	-
2	Bedroom	Bed	4 by 4	2	Open	0	-	-
3	Lounge	Television	4 by 4	1	Closed	0	-	-
4	Lounge	Sofa	4 by 4	2	Open	0	-	-
5	Lounge	Sofa	4 by 4	2	Closed	0	-	-
6	Bedroom	Bed	4 by 4	1	Closed	0	-	-
7	Lounge	Television	4 by 4	2	Closed	60	A	Parallel
8	Lounge	Television	4 by 4	1	Open	60	A	Parallel
9	Lounge	Sofa	4 by 4	2	Open	60	A	Parallel
10	Lounge	Sofa	4 by 4	2	Closed	60	A	Parallel
11	Lounge	Table	4 by 4	1	Open	0	-	-
12	Lounge	Table	4 by 4	1	Open	60	A	Parallel
13	Bedroom	Bed	4 by 4	2	Closed	60	A	Parallel
14	Lounge	Table	4 by 4	1	Closed	60	A	Parallel
15	Bedroom	Bed	4 by 4	2	Open	60	A	Parallel
16	Lounge	Table	4 by 4	2	Closed	0	-	-
17	Lounge	Table	4 by 4	1	Open	60	B	Parallel
18	Lounge	Television	4 by 4	1	Open	60	B	Parallel
19	Lounge	Television	4 by 4	1	Open	60	A	Perpendicular
20	Lounge	Television	4 by 4	2	Open	42	A	Parallel
21	Lounge	Television	8 by 4	-	Open	0	-	-
22	Lounge	Table	4 by 4	1	Open	42	A	Parallel
23	Lounge	Table	8 by 4	-	Open	0	-	-
24	Lounge	Table	8 by 4	-	Open	60 for 1 or 84 for 2	A	Parallel
25	Lounge	Television	8 by 4	-	Open	60 for 1 or 84 for 2	A	Parallel
26	Kitchen	Pan of oil	4 by 4	1	Open	0	-	-
27	Kitchen	Pan of oil	4 by 4	1	Open	60	A	Parallel
28	Lounge	Television	4 by 4	1	Open	60	B	Parallel
29	Kitchen	Pan of oil	4 by 4	1	Open	60	B	Parallel

5.4.7.3 Fire scenario

Five types of fire were investigated:

a) Television fire – ignition by nightlight under front corner

b) Table fire – ignition by crumpled news papers under magazine rack

c) Sofa fire – ignition by nightlight and crumpled newspapers wedged between side and rear cushions

d) Bed fire – ignition by nightlight placed under pillow with adjacent cushion

e) Oil pan fire – auto ignition initiated by propane burner under pan.

5.4.7.4 Sprinkler type/model

One model of a pendent type residential sprinkler model, designated sprinkler A, was selected for use in the compartment fires based on its performance in the Benchmark tests. This sprinkler had a metric K-factor of 70.6 (US K-factor of 4.9).

A second sprinkler, designated sprinkler B, based on a poorer performance in the Benchmark tests, referenced as sprinkler 2, was also used. This sprinkler had a metric K-factor of 56.2 (US K-factor of 3.9).

5.4.7.5 Sprinkler orientation

The sprinkler orientation was either yoke arms parallel or perpendicular to the long axis of the experimental facility.

5.4.7.6 Fixed parameters

The residential sprinklers used were quick response, i.e. RTI < 50, with one value of nominal operating temperature (68^0C).

The sprinkler positions were fixed, see Figures 5.2 and 5.9. The sprinklers were located at the centre of the ceilings of the small fire rooms, either room 1 or room 2. The spacing between the two sprinklers in the large room was 4 m and each were located 4 m from the 4 m wall and 2 m from the 8 m wall.

In each of the scenarios, the positions of the items of fuel/furniture was fixed, relative to the position of the sprinkler spray.

5.4.7.7 Sprinkler water flow rate

The water flow rate of the first sprinkler in operation was fixed at 42 l/min or 60 l/min. 42 l/min was deliberately chosen for research purposes and is lower than the minimum requirement in DD 251. For two sprinklers in operation, the water flow rate was fixed at 84 l/min, 42 l/min per sprinkler. For two sprinklers in operation, for sprinkler A, the minimum operating pressure would be less than the 0.5 bar specified in DD 251.

5.4.7.8 Ventilation conditions

The ventilation conditions during the fires were as follows:

- The non fire-resisting fire room internal door was either fully open or closed.
- The external compartment doors were closed and sealed with foil tape apart from the bottom edge.

5.4.7.9 Experimental procedure for each fire test

The following experimental procedure was carried out for the lounge, table and bedroom fires:

1. The fuel was suitably conditioned.
2. It was ensured that the inside of the experimental facility was dry.
3. The furniture was positioned accordingly.
4. The gas analyser pumps were switched on.
5. The data logging systems were started and a stopwatch was started.
6. The photographic videos and thermal imaging video (when present) were started in sequence.
7. The water pump was switched on, for sprinklered fires.
8. The water flow rate data logger system was started, for sprinklered fires.
9. A countdown to ignition was started.
10. At ignition, a klaxon was sounded and the remainder of the stopwatches and a large digital timing clock was started.
11. The fire was allowed to develop and relevant measurements made.
12. For the table fires, after 10 minutes the external door of the non-fire compartment was opened.
13. For sprinklered fires, the flow through the first sprinkler to operate was sufficient to provide the nominal density of discharge required for a single sprinkler area of coverage. When two sprinklers operated, the pump speed was adjusted so that the required nominal discharge density for two operating sprinklers was achieved.
14. At the end of test a klaxon was re-sounded.

The following experimental procedure was carried out for the kitchen fires:

1. It was ensured that the inside of the experimental facility was dry.
2. The oil pan and burner arrangement was set up.
3. The oil was poured into the metal pan.
4. Propane cylinder was positioned outside the test facility.
5. The gas analyser pumps were switched on.
6. The data logging systems were started and a stopwatch was started.
7. The photographic videos and thermal imaging video (when present) were started in sequence.
8. The water pump was switched on, for sprinklered fires.
9. The water flow rate data logger system was started, for sprinklered fires.
10. 3 litres of cooking oil were placed into the test pan.
11. A thermocouple was placed inside the test pan under the cooking oil surface.

12. A countdown to time when lit gas burner being located under test pan was started. The burner was lit with a spark igniter.
13. At 'ignition', a klaxon was sounded and the remainder of the stopwatches and a large digital timing clock was started.
14. The gas burner was placed under the pan and the external fire room door closed.
15. The oil temperature was monitored using a thermocouple.
16. Upon non-piloted ignition (typically 360^{0}C) the gas source was turned off and the burner removed from under the test pan from outside the facility.
17. The fire was allowed to continue and relevant measurements were made.
18. At the end of test a klaxon was re-sounded.

5.4.8 Results of the compartment fires

5.4.8.1 Collected data

Appendix 5E contains selected photographs of the fuel loads before, during and after the fires.

Appendix 5F contains the following:

- Visual observations
- Humidity readings and temperature inside the fire room prior to each fire
- Graphs of temperature against time at each location
- Graphs showing smoke alarm activation times
- Graphs of O_2, CO_2 and CO concentrations against time. These have been adjusted to take into account lag time (the time taken for the gas to be drawn through the tubing from the sampling point into the measuring region of the analyser)
- Graphs of % optical transmittance against time at each location
- Graphs of sprinkler water flow rate against time.

Appendix 5G contains graphs of head height temperatures, OD/m, visibility, FED_{AG} and FED_H against time in each location.

Appendix 5H contains summary graphs of temperature at head height, FED_{AG} and FED_H against time in each location for the equivalent sprinklered and unsprinklered conditions.

Figures 5.23 to 5.26 contain bar charts of the key event timings in the television, table, bed and sofa compartment fires.

Table 5.9 is a summary table and contains numerical values of key events in the compartment fires.

Notes:

1. Most of the experimental data from Test 18 were lost due to equipment problems and therefore was repeated as Test 28.
2. Tests 29 and 28 were, by necessity, both conducted in room 1. Since Test 28 was sprinklered the room could not be fully pre-conditioned as usual for Test 29.

5.4.8.2 Television fires

As found in the House fires, the growth rate and spread of the television fire was not consistent. In general, the fire was found to be relatively slow growing and smoky and tended to progress in one of two main ways:

a) flames spread up the side of the television and gradually spread to the rear section eventually igniting the curtain, or

b) flames spread mainly to the front and inside the television with insufficient progression to the rear to ignite the curtain.

In both cases, it was common for molten plastic to drip from the television onto the lower shelves causing the magazines to burn. During sprinklered tests, operation of the sprinkler was achieved in all cases although with type b) growth fires this took longer to accomplish. Some flaming was observed to continue inside the shielded portion of the television after sprinkler operation. In some cases, e.g. Test 8, sufficient flaming was maintained for the fire to grow substantially when the sprinkler system was turned off after running for 20 minutes.

5.4.8.3 Table fires

The table fire was a rapidly growing fire which was found to produce reasonably repeatable results. The table was located in the centre of the room directly under the sprinkler, in the position of lowest water delivery. During the first test, it was noted that fire became oxygen-starved and started to diminish after several minutes. It was therefore decided to open the external door of the room farthest from the fire room after 10 minutes, allowing the fire to progress. This was repeated on all subsequent table fire tests, with the exception of the ‘closed internal door’ fires.

During unsprinklered tests, the fire spread easily to the adjacent armchair and showed signs of igniting the blankets draped over the sofa before being extinguished manually. For sprinklered tests, the fuel under the table continued to burn at a subdued rate for the duration of the sprinkler operation, as it was shielded from the spray. After this, the surrounding materials were sufficiently wetted to make re-ignition unlikely for this test arrangement.

5.4.8.4 Sofa fires

The sofa fire was a slowly growing unshielded fire which did not provide consistent burning characteristics due to the fire retardant materials. Once ignition was achieved the fire tended to spread either along the back and side arm, or just along the side arm.

For one of the sprinklerd fires, Test 9, insufficient heat was generated to operate the sprinkler. In Test 10, the sprinkler did operate and appeared to extinguish the fire quickly. Examination of the sofa after the test revealed that some smouldering had continued and spread along the rear, concealed from view.

5.4.8.5 Bed fires

The bed fire was a rapidly growing unshielded fire which was found to produce reasonably repeatable results. Initially, fire growth was mainly across the width of the bed as the pillow and cushion burned. Once the duvet became involved, the fire spread along the length of the bed. For the unsprinklered tests, the fire started to spread to the items on the bedside cabinets. For the sprinklered tests, the fire was quickly extinguished after sprinkler operation.

5.4.8.6 Oil pan fires

After auto ignition of the oil, the tray fire burned steadily with a flame height of approximately 0.5m. As the oil temperature continued to rise, the flame height gradually increased and the smoke layer in the room deepened. For the sprinklered fires, after sprinkler operation, the flame height was initially observed to increase significantly. After several minutes the fire was extinguished. There was no fire spread during this test due to the absence of furniture in the room.

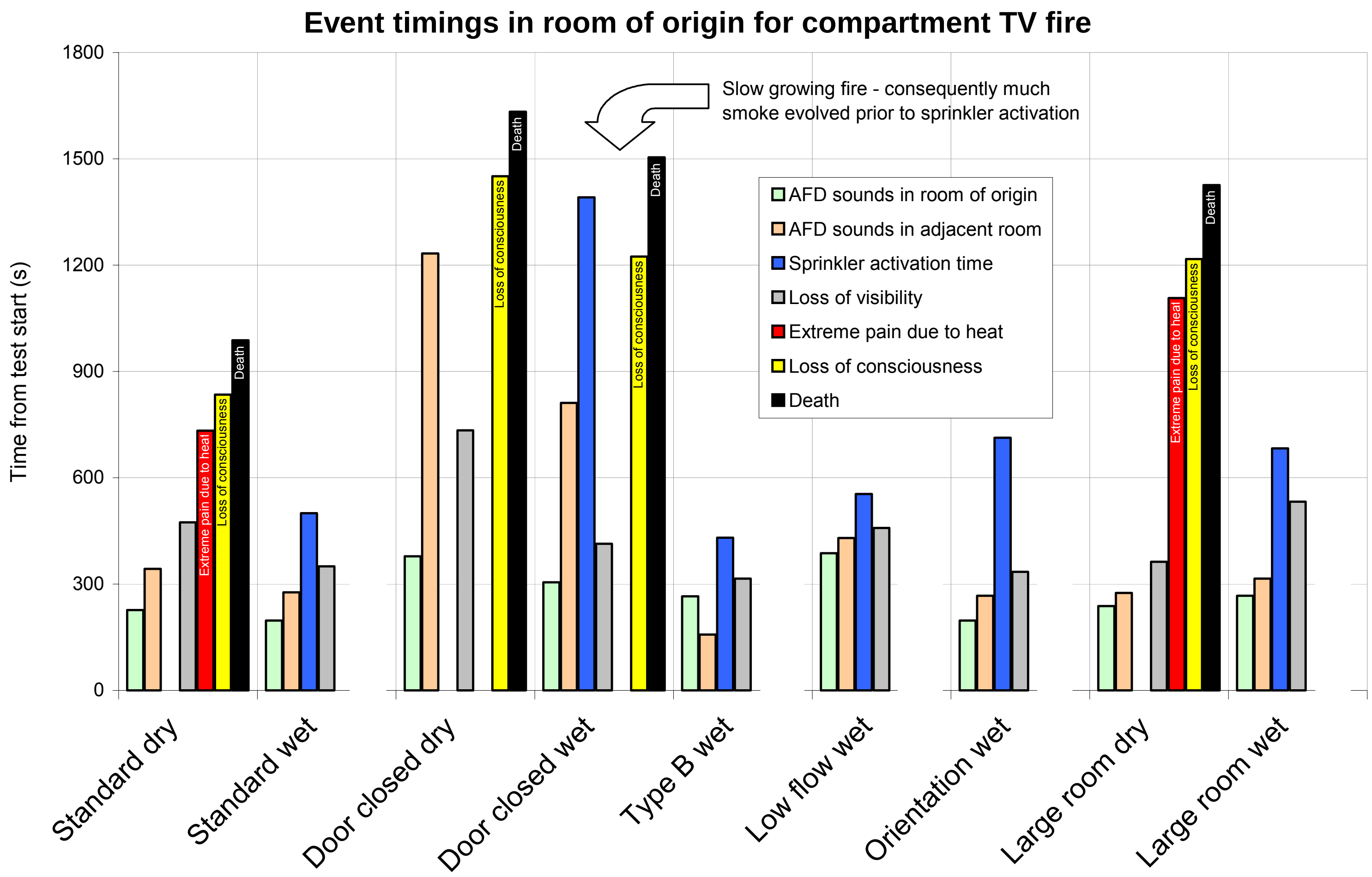

Event timings in room of origin for compartment TV fire
Time from test start (s)
0
300
600
900
1200
1500
1800
Slow growing fire - consequently much smoke evolved prior to sprinkler activation
AFD sounds in room of origin
AFD sounds in adjacent room
Sprinkler activation time
Loss of visibility
Extreme pain due to heat
Loss of consciousness
Death
Standard dry
Standard wet
Door closed dry
Door closed wet
Type B wet
Low flow wet
Orientation wet
Large room dry
Large room wet

Figure 5.23

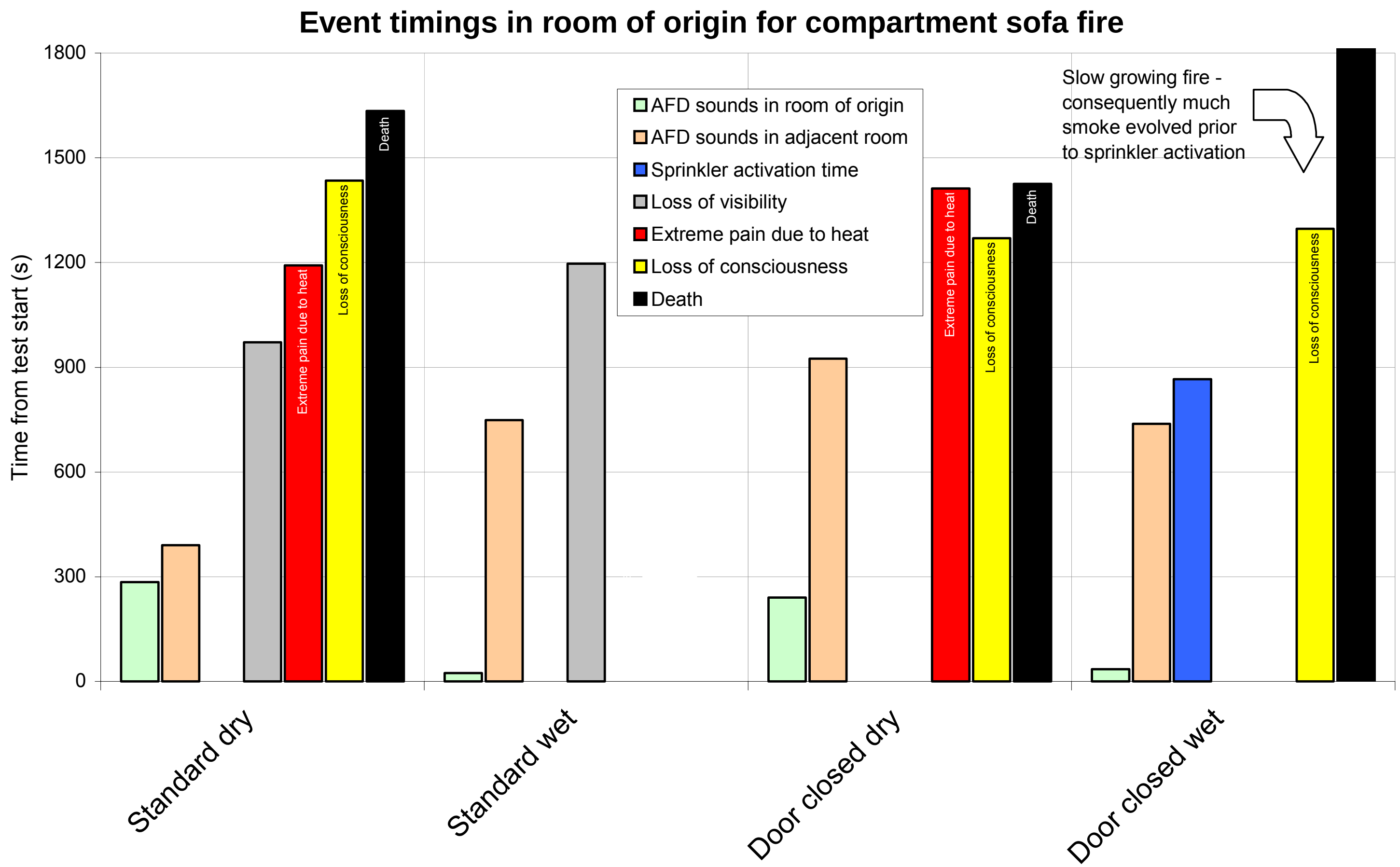
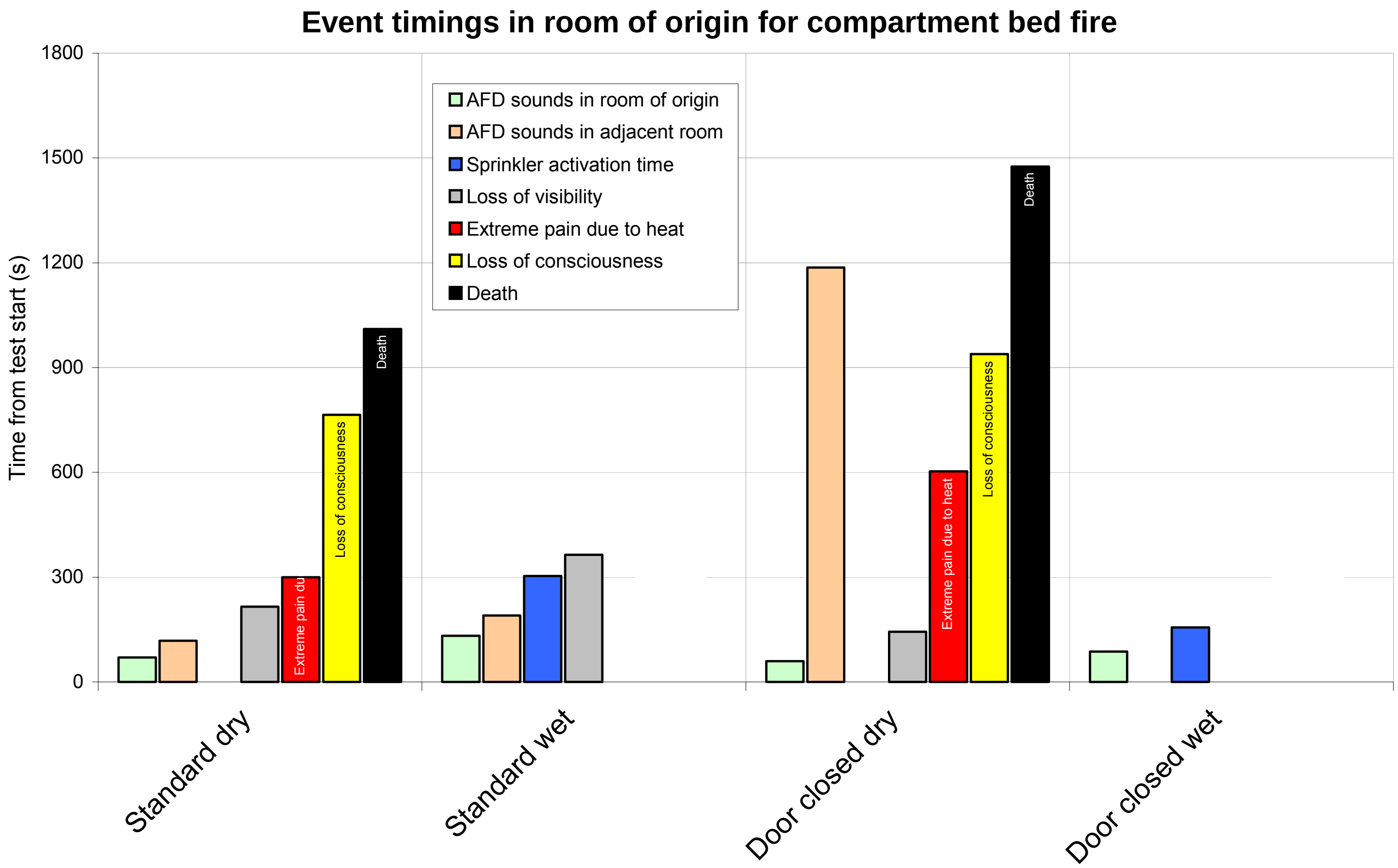


Figure 7.24 **ure**



Event timings in room of origin for compartment bed fire
Time from test start (s)
1800
1500
1200
900
600
300
0
AFD sounds in room of origin
AFD sounds in adjacent room
Sprinkler activation time
Loss of visibility
Extreme pain due to heat
Loss of consciousness
Death
Extreme pain du
Loss of consciousness
Death
Extreme pain due to heat
Loss of consciousness
Death
Standard dry
Standard wet
Door closed dry
Door closed wet

Figure 5.25

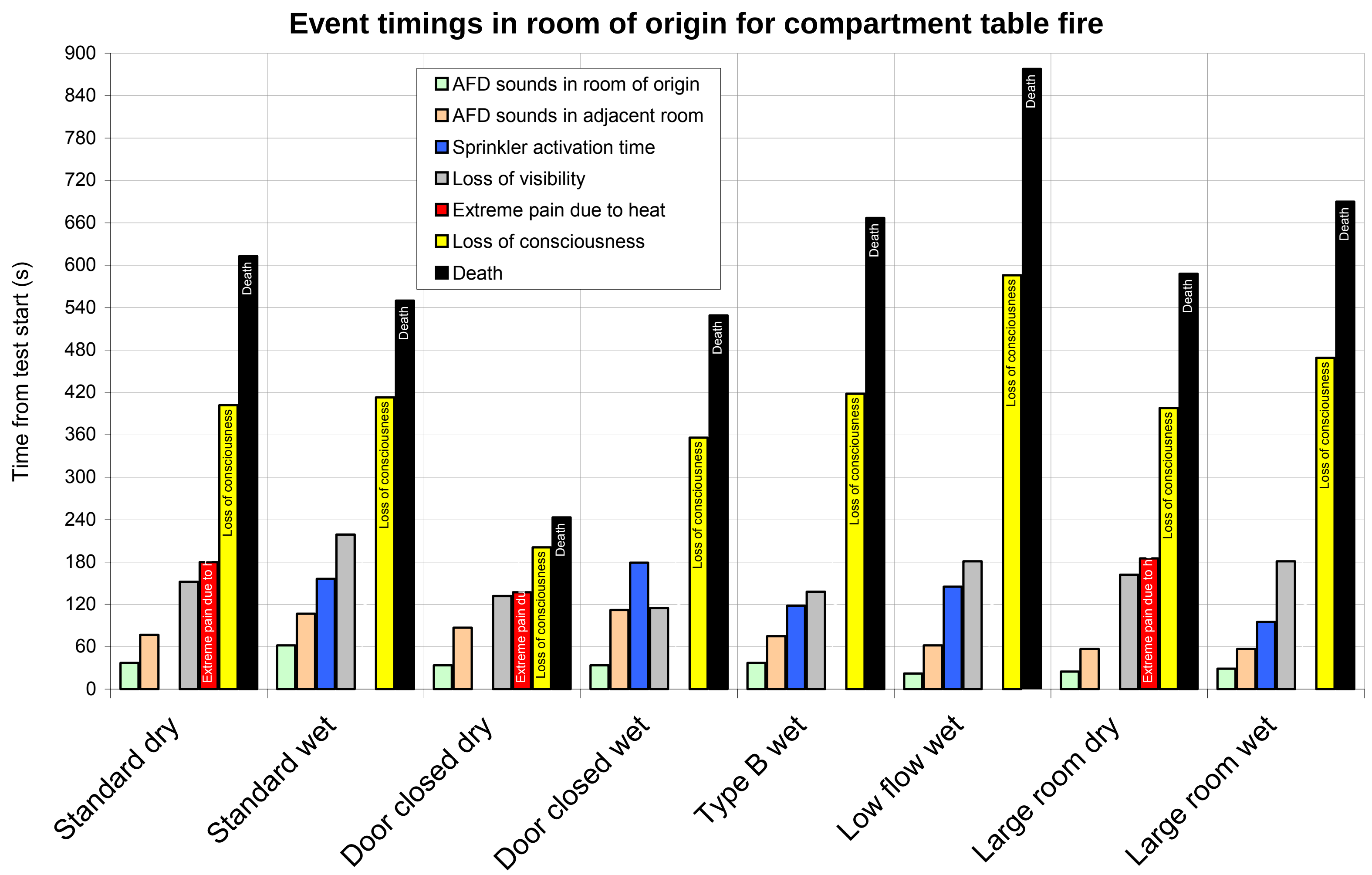

Event timings in room of origin for compartment table fire
Time from test start (s)
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
AFD sounds in room of origin
AFD sounds in adjacent room
Sprinkler activation time
Loss of visibility
Extreme pain due to heat
Loss of consciousness
Death
Standard dry
Standard wet
Door closed dry
Door closed wet
Type B wet
Low flow wet
Large room dry
Large room wet

Figure 5.26

Table 5.9

Test No.	Set-up	Wet or dry	Room of origin	Alarm activation time						Sprinkler activation		OD limit reached (OD/m > 0.5)		FED_{AG} limit @ 1.6 m reached (room of origin)		FED_H limit reached		
				R1		MR		R2		Time	Temp	R1	R2	Uncon	Death	R1	MR	R2
				ion (s)	opt (s)	ion (s)	opt (s)	ion (s)	opt (s)	(s)	(°C)	(s)	(s)	(s)	(s)	(s)	(s)	(s)
Television fires																		
1	Standard	dry	1	227	292	343	410	-	-	n/a	n/a	474	598	835	988	733	(0.62)	(0.21)
8	Standard	wet	1	197	-	277	-	-	-	500	104	350	514	(0.60)	(0.60)	(0.26)	↓	↓
3	Door closed	dry	1	378	507	1233	-	-	-	n/a	n/a	734	(1238)	1451	1633	(0.96)	↓	↓
7	Door closed	wet	2	-	-	811	-	305	-	1391	93	(0.19)	414	1224	1504	↓	↓	(0.36)
28	Type B	wet	1	157	-	265 (LR ion)				431	108	315	418LR	(0.44)	(0.44)	↓	↓	↓
20	Low flow	wet	2	-	-	430	-	387	-	554	87	589	458	(0.27)	(0.27)	↓	↓	↓
19	Orientation	wet	1	197	-	267	-	-	-	713	123	335	580	(0.84)	(0.84)	(0.14)	↓	↓
21	Large room	dry	LR	275	-	238 (LR ion)				n/a	n/a	412	363LR	1217	1426	(0.68)	1190A	1107B
25	Large room	wet	LR	315	-	267 (LR ion)				683	105	595	532LR	(0.50)	(0.50)	↓	↓	↓
Table fires																		
11	Standard	dry	1	37	47	77	82	-	-	n/a	n/a	152	206	402	613	180	365	(0.85)
12	Standard	wet	1	62	-	107	-	-	-	156	112	219	309	413	550	↓	↓	↓
16	Door closed	dry	2	-	-	87	-	34	-	n/a	n/a	(1335)	132	201	243	↓	↓	137
14	Door closed	wet	1	34	-	112	-	-	-	179	100	115	(0.05)	356	529	↓	↓	↓
17	Type B	wet	1	37	-	75	-	-	-	118	109	138	214	418	667	(0.29)	↓	↓
22	Low flow	wet	1	22	-	62 (LR ion)				145	114	181	223	586	878	(0.74)	(0.14)	(0.17)
23	Large room	dry	LR	57	-	25 (LR ion)				n/a	n/a	179	162LR	398	588	310	185A	202B
24	Large room	wet	LR	57	-	29 (LR ion)				95	97	230	181LR	469	690	↓	↓	↓
Sofa fires																		
4	Standard	dry	2	-	-	390	414	285	337	n/a	n/a	972	741	1435	(1.3)	(0.22)	(0.42)	1192
9	Standard	wet	2	-	-	749	-	24	-	dno	n/a	1197	1002	(0.53)	(0.53)	↓	↓	↓
5	Door closed	dry	2	-	-	925	dna	240	252	n/a	n/a	(0.12)	578	1270	1426	↓	↓	1412
10	Door closed	wet	2	-	-	738	-	35	-	866	100	(0.07)	476	1297	(1.34)	↓	↓	(0.18)
Bed fires																		
2	Standard	dry	2	-	-	118	136	70	107	n/a	n/a	215	159	764	1011	300	620	300
15	Standard	wet	2	-	-	190	-	132	-	303	102	(364)	295	↓	↓	↓	↓	↓
6	Door closed	dry	1	59	-	1186	-	-	-	n/a	n/a	144	(0.07)	938	(1.34)	603	↓	↓
13	Door closed	wet	2	-	-	dna	-	87	-	156	105	↓	133	↓	↓	↓	↓	↓
Oil pan fires																		
26	Standard	dry	1	108	-	649	-	-	-	n/a	n/a	1165	1297	↓	↓	(0.62)	↓	↓
27	Standard	wet	1	449	-	619 (LR ion)				1202	102	1115	1251	↓	↓	↓	↓	↓
29	Type B	wet	1	18	745	430 (LR ion) 828 (LR opt)				1336	91	1238	1411	↓	↓	↓	↓	↓

Table notation

LR	= large room
(LR ion)	= ionisation detector located in large room
(LR opt)	= optical detector located in large room
-	= measurement not made
dna	= did not activate
n/a	= not applicable
dno	= did not operate
Blue	= maximum recorded value during test time scale
Red	= time at which OD/m > 0.2 was reached.
A	= measurement in large room 'compartment A'
B	= measurement in large room 'compartment B'
↓	= lower than 0.05 OD/m, 0.25 FED_{AG}, and 0.1 FED

5.4.9 Summary and conclusions of the compartment fires

A total of twenty nine fires using sprinklered and unsprinklered realistic fuel arrays representative of residential premises were conducted inside a compartment experimental facility. These comprised five scenarios of a television, table and sofa fires in a lounge, a bed fire in a bedroom and a cooking oil pan kitchen fire. The effect of fuel type, compartment size, fire door open/closed, sprinkler model, sprinkler orientation, fuel arrangement relative to sprinkler spray and water flow rate were studied.

The detailed conclusions from the compartment fires, for the conditions studied and for a duration of 30 minutes from ignition are, as follows:

For the TV fires, for the room of fire origin:

1. The televisions used as the initial source of fuel were found to have slightly different burning characteristics.
2. For the unsprinklered open lounge door arrangement, the conditions became unsurvivable. For the four sprinklered cases, the conditions remained tenable in terms of FED_{AG}.
3. For the unsprinklered door closed lounge arrangement, the conditions became unsurvivable. For the sprinklered case, the TV fire was slower growing than usual and consequently much more smoke was produced prior to sprinkler activation. This resulted in conditions becoming unsurvivable.
4. For the unsprinklered, large room, open lounge door arrangement, the conditions became unsurvivable. For the sprinklered case, the conditions remained tenable in terms of FED_{AG}.
5. For the unsprinklered cases, the first tenability criteria to be reached was visibility, then the effect of convected heat rather than incapacitation.
6. Sprinklers significantly reduced the effect of convected heat from the fire.
7. However, sprinklers did not observably improve visibility conditions.
8. The effects of the +sprinkler type, water flow rate and orientation were inconclusive due to the variability of the TV fires.

For the table fires, for the room of fire origin:

9. The table fires were found to have consistent ignition and burning characteristics.
10. For all the unsprinklered and sprinklered cases, the conditions rapidly became untenable due to convected heat and then became unsurvivable because of toxic effects.
11. Sprinklers improved conditions in terms of FED_{AG} for all cases, but still became unsurvivable, except for the sprinkler type A open door standard compartment.
12. Sprinklers significantly reduced the effect of convected heat from the fire.
13. However, sprinklers did not observably improve visibility.
14. Sprinkler type B gave a marginally better performance than sprinkler type A.
15. The lower water flow rate gave a marginally better performance than the higher water flow rate. This result needs to be treated with caution as other factors need to be considered e.g. variability of fires, water delivery in other areas of room, location of fire relative to sprinkler.

For the bed fires, for the room of fire origin:

16. The bed fires were found to have consistent ignition and burning characteristics.
17. For the unsprinklered cases, the first tenability criteria to be reached was visibility, then convected heat rather than toxic effects.
18. For the unsprinklered cases, the conditions rapidly became unsurvivable.
19. For the sprinklered tests, the conditions remained tenable in terms of FED_{AG}.
20. Sprinklers helped to significantly reduce the effect of convected heat from the fire.
21. Visibility became untenable in the sprinklered door open case but remained tenable in the door closed sprinklered case.

For the sofa fires, for the room of fire origin:

22. It was difficult to achieve consistency in burning characteristics with the 1988 Furniture Regulations compliant, nominally identical, sofas used. Therefore, it was difficult to assess the effectiveness of sprinklers.
23. For the unsprinklered cases, the first tenability criteria to be reached was visibility, then convected heat rather than toxic effects.
24. For the unsprinklered cases, the conditions became unsurvivable.
25. For the sprinklered case with the door open, the sprinkler did not operate as sustained ignition was not achieved. Sufficient smoke was produced for the visibility conditions to become untenable. This was considered a null test.
26. In the sprinklered case with the door closed, the fire was very slowly growing and so much smoke was produced before sprinkler activation and conditions became unsurvivable.

Post test observations:

27. The sprinklers controlled but did not completely extinguish all of the shielded fires.

28. The sprinklers extinguished the unshielded fires.

29. The sprinkler spray was not evenly distributed so fires in locations of low water delivery would not be controlled to the same extent.

For the oil pan fires, for the room of fire origin:

30. Neither the FED_{AG} nor FED_{H} were reached in any of the tests. However, these fires were designed so there was no opportunity for fire spread to adjacent furniture as the room was empty except for the oil pan arrangement.

31. A sprinkler extinguished the fires after a period of time.

The main general conclusions for the room of fire origin in the compartment fires for a duration of 30 minutes:

- Sprinklers significantly reduced the effect of convected heat from the fire.
- However, sprinklers did not observably improve visibility.
- Television and bed fires. Sprinklers generally greatly improved conditions in the room of fire origin and maintained tenable conditions in terms of toxic effects; reduced the effects of convected heat but had no observed improvement in visibility
- Table fires. For all the sprinklered and unsprinklered fires the conditions became unsurvivable. Sprinklers generally improved conditions in terms of toxic effects, except for one case.
- However, conditions became unsurvivable in one television and one sofa slower growing fire where a lot of smoke was produced prior to sprinkler operation and consequently conditions became unsurvivable.
- The effects of the sprinkler type, water flow rate and orientation were inconclusive.
- For all the unsprinklered fires, the conditions became unsurvivable/lethal.
- For all the unsprinklered fires, the first tenability criteria to be reached was visibility, then convected heat then toxicity effects.
- The life safety benefits of fitting smoke alarms was demonstrated. This includes the added benefits of fitting linked smoke alarms in both rooms and circulation spaces.

Based on previous experiments [Purser 2003], particularly for upholstered furniture and bedding fires, a significant contribution from cyanide would be expected. This would have the effect of reducing the FED times especially for unsprinklered fires by perhaps one minute or so.

For television fires, the smoke release during the early stages is likely to be more irritant than has been assumed, again for the unsprinklered case.

Therefore, overall, the benefits of sprinklers are likely to be more marked.

5.5 Calorimetry fires

5.5.1 Introduction

Calorimetry fires were conducted underneath a 3 m furniture calorimeter to characterise each of the four principal fuel packages used for the compartment fires: the television, table, bed and sofa fires.

5.5.2 3 m calorimeter experimental facility

The 3 m calorimeter test facility consists of a collection hood and horizontal duct which contains instrumentation to characterise the gases and particulates and through data manipulation, is able to determine the heat released by the burning specimen. The method uses oxygen depletion calorimetry and can characterise items with a nominal peak heat release of up to 2 MW.

The combustion products released by the burning items are collected in the hood. The dimensions of the hood are 3 m by 3 m by 1 m deep. On three sides a steel skirt extends 1 m downward from the base of the hood and can be lowered if required to contain the emitted fire gases. The hood is supported by four 3 m long steel legs, which are fixed to the ground.

The hood is connected to a plenum chamber with a cross-sectional area of 0.9 m^2, used to increase the mixing of the combustion gases.

A 5 m long circular exhaust duct with a diameter of 0.4 m is connected to the plenum chamber. Guide vanes located at each end of the duct produced a stabilised flow profile along it. A fan with a capacity of at least 3.5 m^3/s is connected to the duct to exhaust the combustion products. The fan is nominally run at 2.5 m^3/s.

5.5.3 Measurements and instrumentation

5.5.3.1 Exhaust gas analysis and measurements

Measurements of gas temperature and velocity, smoke density, O_2, CO and CO_2 concentration were made in the calorimeter duct.

5.5.3.2 Gas velocity

The volume flow rate of the gases passing through the duct was measured continuously using a calibrated bi-directional probe located at the centre of the duct. The pressure difference between the two chambers of the probe was measured using a differential pressure transducer.

5.5.3.3 Gas temperature

The temperature of the gases in the duct were measured using a 1.5 mm diameter, stainless steel sheathed, K-type chromel/alumel thermocouple. The thermocouple was located at the centre of the duct close to the bi-directional probe.

5.5.3.4 Gas analysis

A continuous sample of the combustion gases in the duct was drawn off so that the concentrations of O_2, CO and CO_2 could be measured. The gas sampling probe consisted of a 10 mm stainless steel tube which is supported in one wall of the duct and covers the full diameter of the duct. Gas was drawn continuously using an oil-free diaphragm pump from the duct, through a series of small holes distributed at equal intervals along the sampling probe. The sampled gas was passed through an in-line filter to remove any particulate matter and then through a PTFE sample line, down to a chiller unit, which was used to remove any moisture in the sampled gas. It was then further conditioned by passing it through 'drierite' filters to remove any residual moisture and to protect the analysis equipment from damage. At this point, the sample line was divided into two. One line was used for the measurement of O_2 and the other is used for the measurement of CO and CO_2.

A constant flow was maintained in the O_2 sample line by means of a pressure regulator and the flow rate was monitored using a rotameter. The O_2 content of the sampled gas was measured using a paramagnetic O_2 analyser. Calibration of the analyser was achieved using O_2 -free N_2 and atmospheric O_2.

The concentrations of the sampled gas are measured by CO and CO_2 specifically tuned, non-dispersive, infrared gas analysers. Calibration was achieved using O_2 -free N_2 and certified calibration gases in the range of interest.

5.5.4 Calorimetry results

Figures 5.27 to 5.30 show photographs taken before, during and after the calorimetry television, table, sofa and bed fires.

Appendix 5I contains graphs of heat release rate versus time for each of the fires and a comparison of heat release rate profiles.

5.5.5 Calorimetry discussion

The fires under the calorimeter appeared to burn more rapidly than when in the house or in the compartment fire tests. These fires had an abundant supply of clean air and hot smoke gases were removed.

The television fire was a slowly growing, shielded fire, rising to a heat release rate (HRR) of 390 kW at 859 s when the fire was manually extinguished.

The table fire was a rapidly growing, shielded fire giving a first peak of HRR of 402 kW at 174 s, when all the fuel beneath the table was burning and a second peak of HRR of 470 kW at 878 s when the wooden table top itself was burning. The fire was manually extinguished.

The bed fire was a rapidly growing, exposed fire which gave a HRR of 552 kW at 456 s, when the fire was manually extinguished.

The sofa calorimetry fire burnt evenly along the back and side arm of the sofa. This was a slowly growing fire which gave a total HRR of 425 kW at 1122 s when the fire was manually extinguished.

5.5.6 Summary and conclusions of calorimetry fires

The television, table, bed and sofa fires used in the compartment and house have been characterised in terms of HRR.

The recorded HRR rate profiles provide an indication of the burning characteristics of each fire in a well-ventilated open space. The peak values and the rates of burning observed are likely to be greater than would have occurred in the house and compartment tests. However, the results provide important benchmark data of the types of fires studied. They also give a useful insight into the growth and relative sizes of each fire that would have been difficult to obtain otherwise during the compartment tests.

90 s (1½ minutes) | 150 s (2½ minutes) | 330 s (5½ minutes)

360 s (6 minutes) | 450 s (7½ minutes) | 480 s (8 minutes)

510 s (8½ minutes) | 630 s (10½ minutes) | 780 s (13 minutes)

Figure 5.27 Photographs taken before and during television calorimetry fire

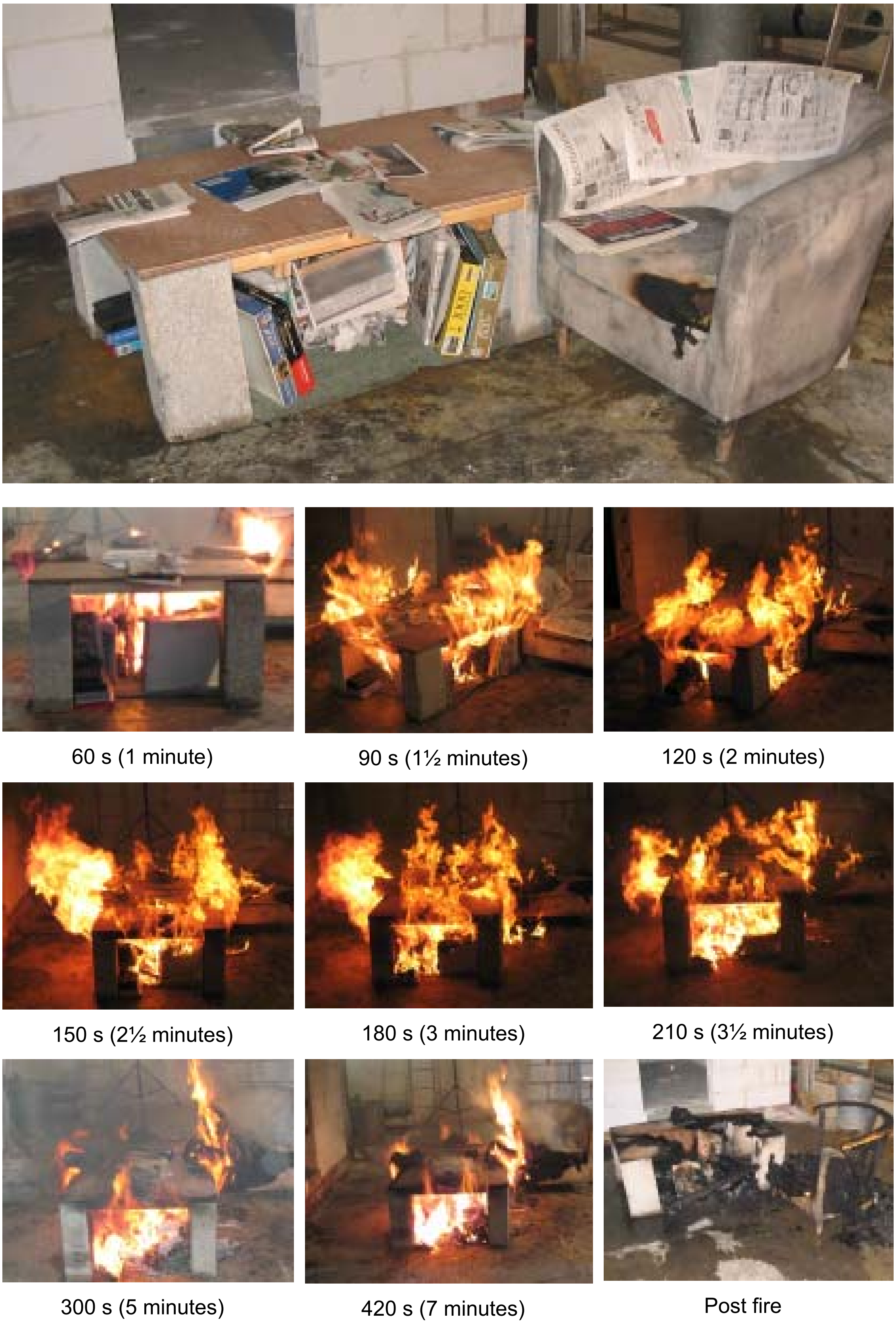


Figure 5.28 Photographs taken before, during and after table calorimetry fire

30 s (½ minute)

660 s (11 minutes)

690 s (11½ minutes)

930 s (15½ minutes)

960 s (16 minutes)

1080 s (18 minutes)

1110 s (18½ minutes)

Post fire

Figure 5.29 Photographs taken before, during and after sofa calorimetry fire

30 s (½ minute)

60 s (1 minute)

90 s (1½ minutes)

120 s (2 minutes)

150 s (2½ minutes)

180 s (3 minutes)

240 s (4 minutes)

330 s (5½ minutes)

Figure 5.30 Photographs taken before, during and after bed calorimetry fire

5.6 References

BRE, Fire in the House video and CD-ROM, March 2002

BRE, Front room fire 2 video, BREcom

British Standards Institution, BS EN 1869 Fire Blankets, 1999

British Standards Institution, BS DD 251 Sprinkler systems for residential and domestic occupancies – Code of Practice, April 2000

Purser, D, Residential sprinklers, occupant behaviour and fire safety - sprinkler effectiveness in improving escape time in domestic fires, 12th annual building control conference: Fire! Fresh thinking against the old enemy, Taunton, October 2000

Purser, D, The impact of sprinklers on escape time from fires, BRE project report number 76589, 2001

Purser, D, Toxicity assessment of combustion products, Chapter 6, SFPE Handbook

Purser, D, Private Communication, 2003

Purser, D, The impact of sprinklers on escape time from fires, BRE project report number 76589, 2001

