Effectiveness of sprinklers in residential premises:
Section 4: Benchmark tests

Project report number 204505

Dr Corinne Williams
and R Harrison

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4 Benchmark tests

4.1 Introduction

The purpose of this stage of the overall project is to establish benchmark tests for UK conditions to support the further development of BS DD 251 and 252 and to assess the performance of residential sprinklers in fire test conditions.

Two British Standards Draft for Development, DD 251 (systems) [British Standards Institution 2000] and 252 (components) [British Standards Institution 2002] have been produced. They are of a provisional nature and were issued as DDs instead of full British Standards because it was recognised at the time by the experts that UK experience needed to be gained with residential sprinklers.

The requirements and recommendations of these DDs were based on the best technical information available to the experts at the time of writing and were a consensus of opinion from the experts. The two main technical knowledge gaps concern

a) Detailed UK experience in the performance of available residential sprinkler product in appropriate fire scenarios.

b) Establishing the benchmark fire test for DD 252 for UK conditions.

The DD 252 fire test essentially involves burning a stylised, representative fuel package of simulated furniture and wall and ceiling linings arranged inside a simulated residential 'room' with door openings and with two installed sprinkler heads. There are two open doorways and near the opening of one doorway is a third dummy sprinkler head. The sprinkler system performance is determined by its performance in controlling the fire for a period of time measured after sprinkler operation, as measured by the gas temperatures being limited to specified values and the dummy sprinkler head not operating.

Any UK experience gained and/or technical data produced will be submitted to the British Standards sprinkler technical committee for consideration when the DDs are reviewed.

4.2 Previous work

Currently, the available residential sprinkler heads have been predominantly developed, manufactured and approved in the USA. A previous report [Kung et al 1982] has described a summary of the USA history of research and standards development in residential sprinklers.

Previous experimental research work [Kung et al 1982, Bill et al 2001, Bell 2001] and approvals standards [National Fire Protection Association NFPA 13R and 13D, 1999,

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Factory Mutual Research Corporation, Approved Standard, Underwriters Laboratory Inc, UL1626] in the USA have been examined. Recent FRS data from the UK Cleckheaton fire demonstrations [Purser et al 2000 and 2001] and Swedish experimental research [Arvidson 2000, 2000, 2001] and have also been taken into account. The design of the Benchmark fire test series was based on this previous work and BS DD 252. Some USA experimental work has been published since the DD 252 was drafted [Bill et al 2001 and Bell 2001].

4.3 Selection and examination of residential sprinkler heads

Available US approved residential sprinkler models have been identified using Websites and manufacturers' literature, and samples of 15 mm pendent models obtained from various residential sprinkler manufacturers via residential sprinkler industry members of the Project Steering Group.

The water delivery patterns to the walls and floor of these sprinkler heads were measured and evenness of water delivery patterns to the floor and walls was assessed by qualitative examination. Four sprinkler models were then selected for examination in the fire tests as described in Table 4.1.

Sprinkler number	Metric K-factor (US K-factor)
1	80.7 (5.6)
2	56.2 (3.9)
3	62 (4.3)
4	43.2 (3.0)

Table 4.1 Sprinklers selected for fire tests

4.3.1 Water distribution tests

Water delivery patterns of sprinklers 1 to 4 have been qualitatively and quantitatively assessed. Measurements of horizontal and vertical water distributions have been measured using a method similar to procedures given in DD 252. This has enabled an assessment to be made of both the floor and vertical water distribution patterns produced from each single sprinkler head. The water distribution tests used measuring containers which were similar to those recommended in DD 252. Prior to detailed measurement, 'splash patterns' produced by each sprinkler spray on the floor of the test facility were observed and analysed.

Appendix 4A shows photographs of the layout measuring containers for the water distribution tests.

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4.3.1.1 Horizontal distribution tests

Each single sprinkler was installed in a test cell of 6 m by 7 m (including 6 m by 1 m hood). The distance from the top of the measuring containers to the ceiling was 2.5 m. Each sprinkler was installed with its deflector plate 35 mm below the ceiling. Figure 4.1 shows the arrangement for the floor distribution tests.

Two water flow rates were examined to achieve a nominal water coverage of 4.0 and 2.8 mm/min. This equates to a flow rate of 64 and 44.8 l/min and collected in 36, 265 mm by 366 mm by 100 mm deep measuring containers. The collection time was 360 s.

Qualitative findings about sprinklers 1 to 4 from visual observations were as follows:

- Sprinkler 1 gave a reasonably even water delivery pattern at the higher water flow rate and a less even pattern at the lower water flow rate.
- Sprinkler 2 gave a less even water delivery pattern at both water flow rates. There appeared to be less water directly beneath the sprinkler.
- Sprinkler 3 gave the most even water delivery pattern at both water flow rates.
- Sprinkler 4 produced a 'star' shaped water delivery pattern, throwing most of the water to the four corners of the test area. This was observed to be the most uneven water distribution of these sprinklers. There appeared to be less water directly beneath the sprinkler.

Quantitative results of the water distribution measurements for sprinklers 1 to 4 are contained in Appendix 4B.

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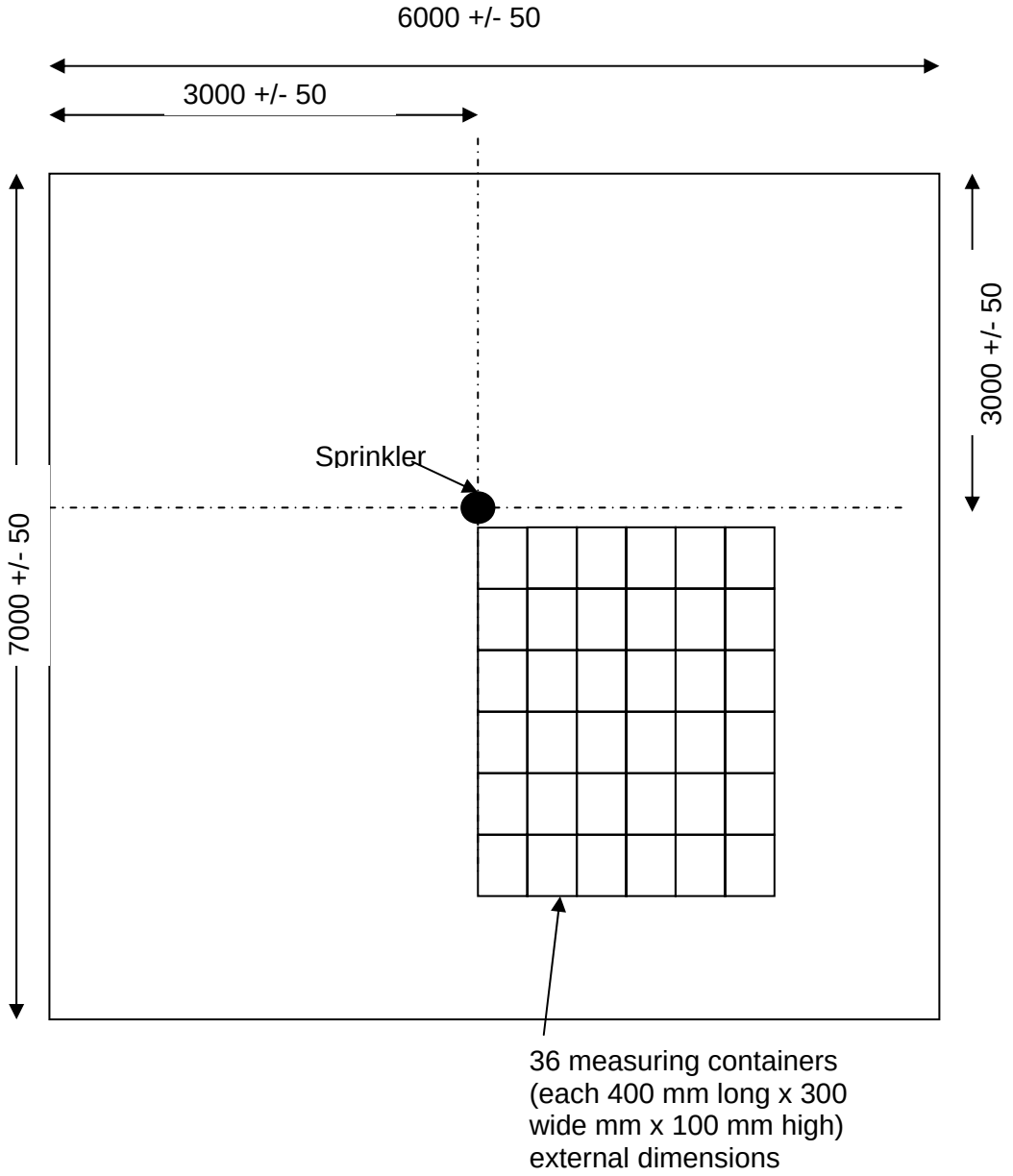

Figure 4.1 Plan of layout of horizontal distribution tests (dimensions in mm)

4.3.1.2 Vertical distribution tests

A single sprinkler was installed in a test cell 6 m by 7 m (including 6 m x 1 m hood). The distance of the topmost container from the ceiling was 175 mm.

Figures 4.2 to 4.4 show the arrangement for the vertical distribution tests.

Water was supplied through the sprinkler at a constant flow rate and collected in measuring containers which were in two vertical arrays of eight containers in different

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locations beneath the spray. Each container was 342 m long by 210 mm wide by 225 mm high. The duration of each test was 900 s.

A single water flow rate was examined to achieve a nominal water coverage of 2.8 mm/min. This equates to a flow rate of 44.8 l/min.

Quantitative results of the water distribution measurements for sprinklers 1 to 4 are contained in Appendix 4B.

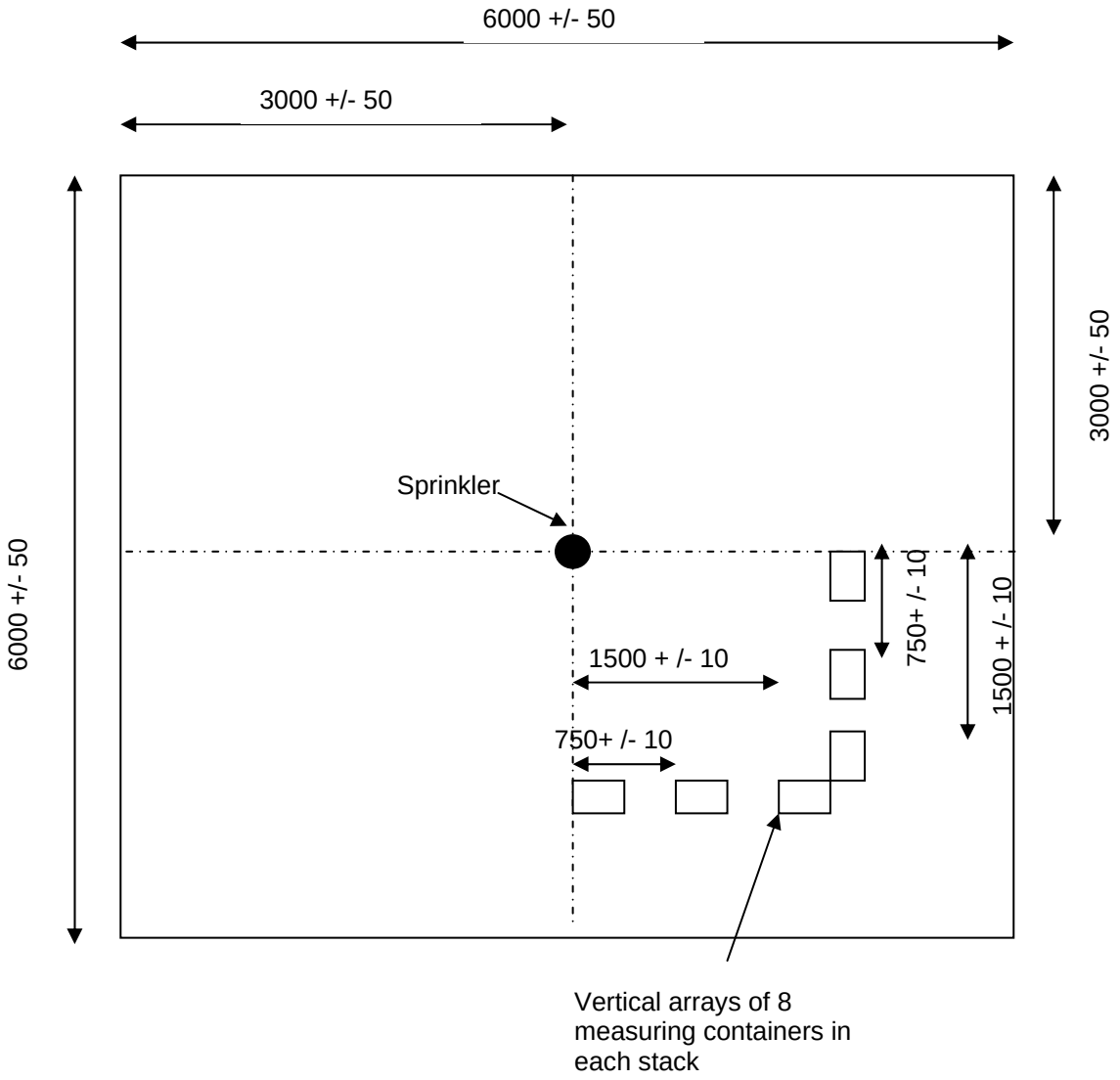

Figure 4.2 Plan view of layout for vertical distribution tests (dimensions in mm)

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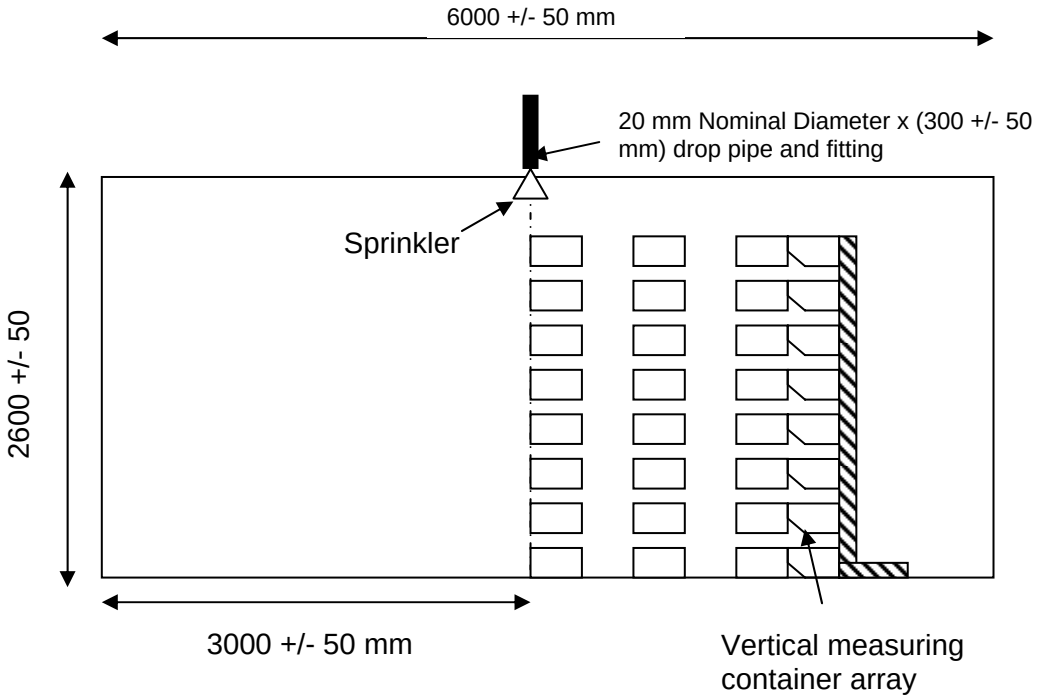

Figure 4.3 Section of layout for vertical distribution tests

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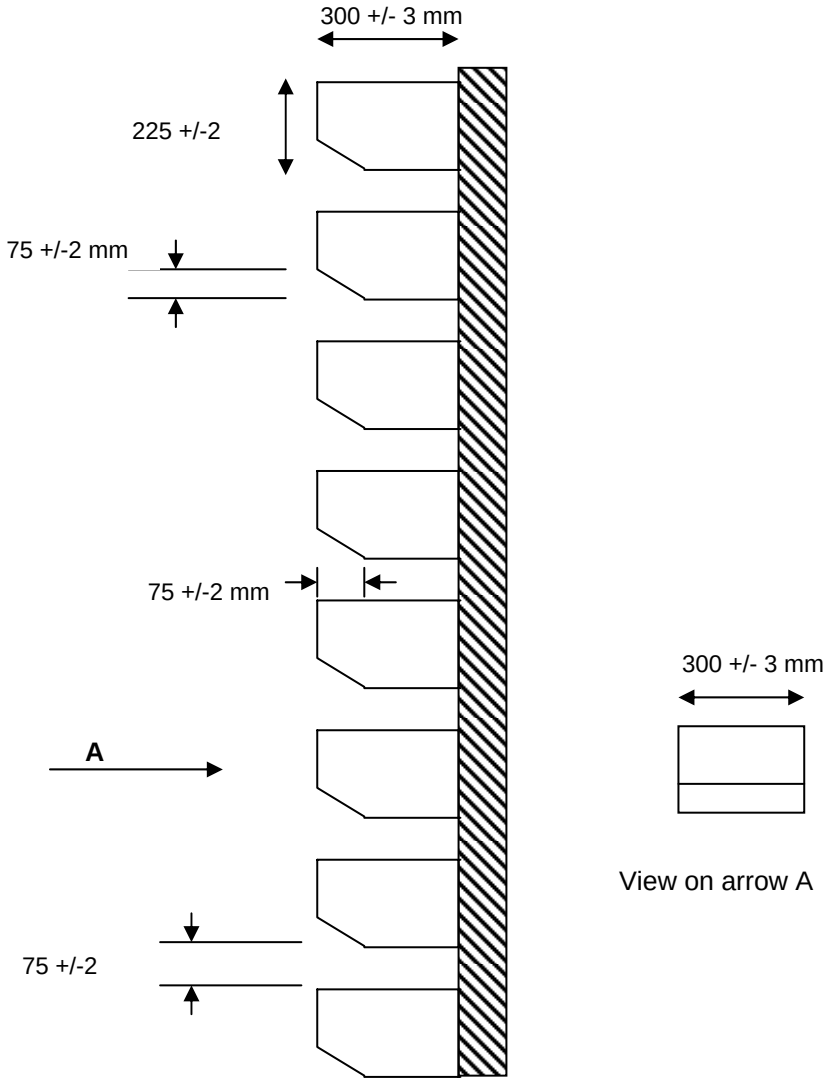

Figure 4.4 Section of vertical measuring container array

4.4 Selection of fuel package

Previous work in the USA to assess the performance of residential sprinklers has used 'real' fuel items, such as chairs, sofas, etc as the fuel source. This work has demonstrated that poor repeatability between tests is possible when using 'real' fuels, due to variability in construction and conditioning of the fuel load. It has been demonstrated that a simulated stylised furniture package can produce a more repeatable fire source.

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Also, DD 252 recommends the use of a simulated stylised furniture package as part of a fuel load for a fire test to assess residential sprinklers. Therefore, a simulated furniture fuel package has been used for the series of Benchmark tests.

The materials need to be tightly specified, e.g. foam (dimensions, density, chemical type, FR or non-FR, additives) and wood (e.g. dimensions, number of ply, treated/untreated).

The fuel package in DD 252 consists of:

- Two polyether foam sheets (non-flame retardant)[Note 1] attached to a wooden frame.
- Four plywood sheets (non-flame retardant) as a wall lining material[Note 2].

The ignition package in DD 252 consists of:

- A wood crib consisting of eight layers of wood sticks.
- The crib is placed on top of a steel tray containing commercial grade heptane.

Appendix 4C contains photographs showing a wooden crib, a wooden frame backing stand for the foam sheets and the steel tray.

Various UK suppliers of the above materials (e.g. foam manufacturers) were contacted to select and obtain suitable products which were used in the Benchmark tests. Specifications for the foam sheet, heptane and plywood are available in Appendix 4D.

Note 1. It should be noted that within Approved Document B (Fire safety), guidance on wall lining materials states that only Class 1 materials (e.g. wallpaper) are allowed to be used for residential rooms above 4 m^2 in area. Untreated plywood sheet is a Class 3 material and the plan area of the experimental facility for the Benchmark tests is > 4m^2 and therefore would not be acceptable under the current guidance in the UK. However, for the Benchmark tests, it was proposed to use untreated plywood as a wall lining, as development work for this fuel package demonstrated that this would provide a suitable fire challenge to the residential sprinklers.

Note 2. It should be noted that new UK domestic and residential furniture is FR treated. However, for the Benchmark tests, it was proposed that non-flame retardant (non-FR) treated polyether foam sheets should be used. Again, this was because the use of non-FR treated foam was used in the development work to produce a suitable fire challenge to residential sprinklers.

4.4.1 Conditioning

Experience from previous work has demonstrated the importance of conditioning the fuel package. Variation in the tolerance limits for the conditioning of the fuel package can lead to variations in the flammability characteristics of the fuel. Therefore, the same conditioning procedures for reaction to fire tests for building products as described in British Standard BS EN 13238 [British Standards Institution 2001] has been applied to the fuel package for the Benchmark tests.

BS EN 13238 document recommends that test specimens shall be conditioned at a temperature of (23 +/- 2) ^{0}C and a relative humidity of (50 +/- 5) %.

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For materials such as non-FR treated wood, a minimum conditioning period of 4 weeks was recommended. For flame retardant (FR) treated wood a minimum conditioning period of 2 months was recommended. All other products require a minimum conditioning period of 2 weeks.

4.5 Apparatus

The Benchmark tests were based upon the design of test apparatus, fuel arrangement and procedures described in the fire test in the DD 252. The performance of the selected residential sprinklers were assessed using the fuel package in different arrangements and locations within the experimental facility, a corner fire test and wall fire test (see section 4.7.7).

4.5.1 The experimental facility

The experimental facility is described in outline in DD 252. The facility consists of a fire test room with dimensions which are dependent on the maximum sprinkler spacing. The room dimensions are:

- Length of twice the maximum sprinkler spacing (2 x L).
- Width of the sprinkler spacing (L).
- Ceiling height of 2.5 m.

An experimental facility was built inside the BRE Cardington Laboratory. It is essentially a "residential room" and consists of 12 mm thick plasterboard sheets attached to a wooden frame. The dimensions of the assembled version of the fire test room were 4 m by 8 m by 2.5 m high. Ceramic fibre board was attached to the ceiling of the experimental facility.

Figures 4.5 to 4.9 show a schematic diagram and photographs of the experimental facility, respectively.

The test room has two open doorways 0.90 m wide and 1.00 m wide (see Figure 4.8). The lintels in the doorways are 0.3 m deep and are detachable, when necessary.

It has been found from previous work that the materials inside the room need to be dry and that the temperature and relative humidity needs to be controlled. Before the start of each test, it was ensured that the room, wall panels, floor and fuel package were dry. The room temperature was (20 + /- 10) ^{0}C for all of the Benchmark tests. The relative humidity inside the room was (55 +/- 15) % for the majority of the tests.

4.5.2 Sprinkler system

A suitable sprinkler system was installed in the experimental facility. Two residential sprinkler heads of the same type were installed inside the experimental facility at a spacing of 4 m. There were 'dummy' sprinklers located within the experimental facility, which were not connected to the water supply. However, each 'dummy' sprinkler had 70 ml of water inside a short length of attached 3/4" pipework. These dummy sprinklers were positioned near one of the open doorways (see Figure 4.5). One dummy sprinkler was located outside the doorway according to the guidance given in DD 252. The other

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dummy sprinkler was located inside the doorway as specified in the Factory Mutual Research Centre (FMRC) fire test [Bill et al 2001].

The sprinklers were installed in accordance with the manufacturer's instructions. After Test 1, air bleed valves were located in the sprinkler pipework, close to the sprinkler heads, to remove air from the system prior to the test.

4.5.3 Fuel package and layout

Suitable materials for the ignition and fuel packages have been identified and purchased for the fire tests, from UK suppliers.

Figures 4.5 to 4.7 show the positions and arrangements of the fuel and ignition packages within the experimental facility for a corner fire test, a wall fire test and a test where the fuel load was located beneath a sprinkler, respectively. The fuel package, based on the DD 252 consisted of:

a) Two polyether foam sheets glued to a wooden backing board and bolted to a wooden frame. DD 252 states that the foam sheets should have dimensions of 925 mm by 1000 mm by 75 mm thick. DD 252 also states that the foam sheets should overlap the top of the frame by 150 mm and the sides of the frame by 125 mm. However, after discussions with the technical experts on the Project Steering Group, it became apparent that this overlap of foam should be wrapped around and fixed to the wooden frame. This wrapping of the foam is not stated in DD 252. As inconsistencies could occur in the wrapping of the foam sheet, it was agreed by to use the current approach used in the USA [Bill et al 2001, Bell 2001] to cut the foam samples flush to the wooden backing board. Therefore, the size of the foam sheets used for the Benchmark tests were 775 mm by 865 mm by 75 mm thick.

b) Four plywood sheets, each of dimensions 2500 mm high by 1220 mm wide by 12 mm thick, as a wall lining material.

The fuel package was conditioned accordance to the guidance described in section 4.4.1.

The ignition package consisted of:

i) Eight layers of pinus silvestris sticks, each 38 mm by 38 mm by 305 mm to make a timber crib. The wood sticks were spaced 50 mm apart. The wood crib had nominal dimensions 305 mm by 305 mm by 305 mm.

ii) The crib was placed on a steel tray 300 mm by 300 mm by 100 mm deep containing 200 ml of commercial grade heptane floating on 25 mm depth of water.

iii) The foam sheets were ignited using two cotton wicks each 150 mm long and with a diameter of 6 mm, soaked in 100 ml of heptane. Each wick was placed on a 150 mm long fire brick at the corner of the foam sheet.

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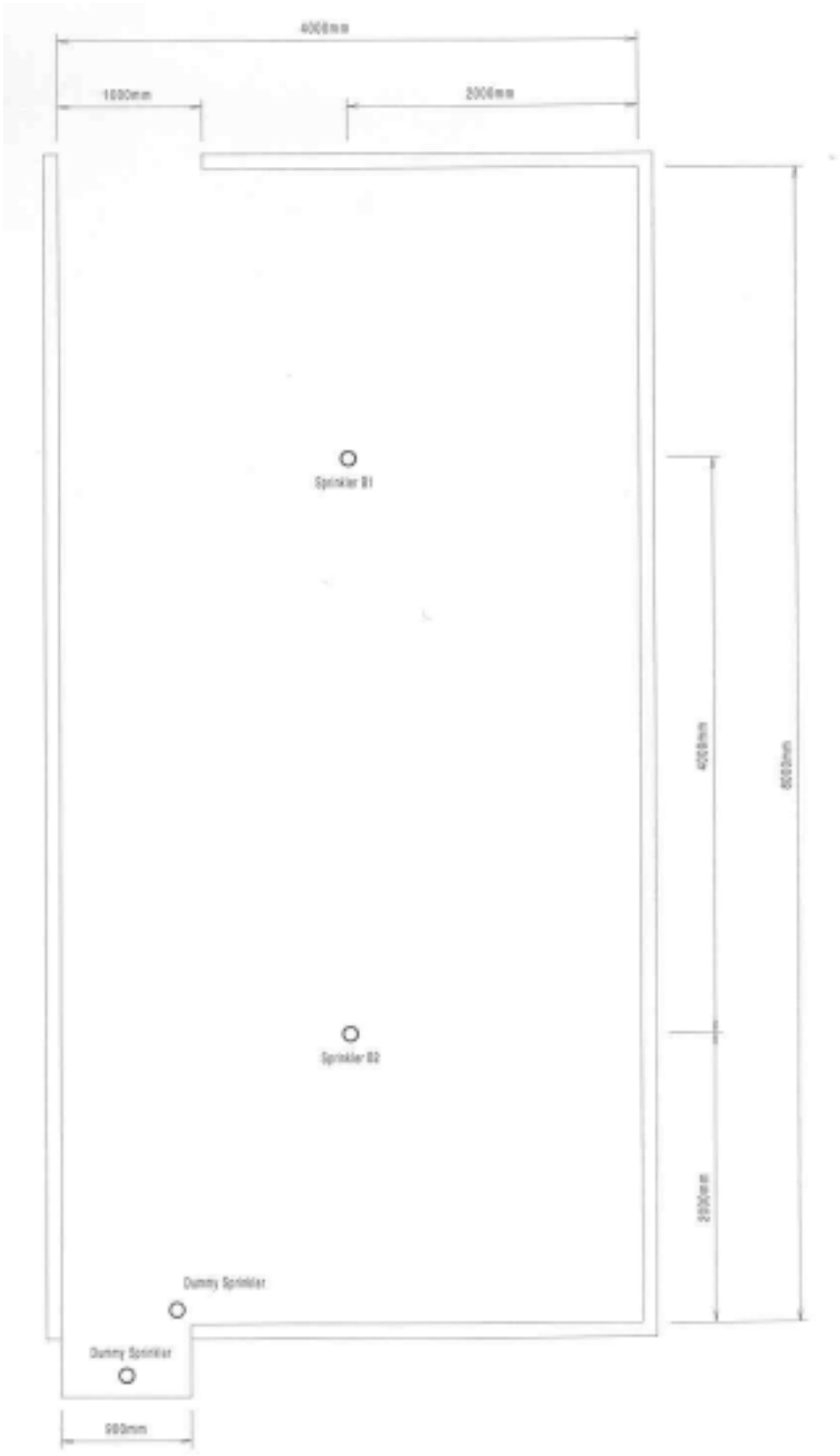

Figure 4.5 Schematic diagram of experimental facility

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Figure 4.6 Exterior of the experimental facility

Figure 4.7 Interior of the experimental facility

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Figure 4.8 Experimental facility showing both doorways

Figure 4.9 Exterior view of experimental facility showing one doorway

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4.6 Instrumentation

4.6.1 Temperatures

The gas temperatures in the experimental facility were measured using 1.5 mm diameter mineral insulated chromel/alumel (K-type) thermocouples. Some additional readings were taken with 3.0 mm diameter mineral insulated type K thermocouples.

Thermocouples were installed 75 mm below the ceiling next to each sprinkler head, in the centre of the room and over the centre of the wood crib. There were also thermocouples, in a line over the centre of the wood crib, embedded 6.5 mm into the ceiling and at the ceiling surface. A thermocouple was also located 1.6 m above the floor in the centre of the room.

Figure 4.10, Table 4.2 give details of the thermocouple and sprinkler locations.

Locations A and E (above crib)	**Position**
A/E 1	1.5 mm diameter, embedded 6.5 mm above the ceiling
A/E 2	1.5 mm diameter, embedded 6.5 mm above the ceiling
A/E 3	1.5 mm diameter, at ceiling surface
A/E 4	1.5 mm diameter, at ceiling surface
A/E 5	1.5 mm diameter, 75 mm below ceiling
A/E 6	1.5 mm diameter, 75 mm below ceiling
A/E 7	3 mm diameter, 75 mm below ceiling
Location B1 (sprinkler)	**Position**
B1.S	1.5 mm diameter, 75 mm below ceiling, 200 mm south of sprinkler
B1.N	1.5 mm diameter, 75 mm below ceiling, 200 mm north of sprinkler
	3 mm diameter, 75 mm below ceiling, 200 mm north of sprinkler
Location B2 (sprinkler)	**Position**
B2.S	1.5 mm diameter, 75 mm below ceiling, 200 mm south of sprinkler
B2.N	1.5 mm diameter, 75 mm below ceiling, 200 mm north of sprinkler
	3 mm diameter, 75 mm below ceiling, 200 mm north of sprinkler
Location C (centre of room)	**Position**
C1	1.5 mm diameter, 75 mm below ceiling
C2	1.5 mm diameter, 1.6 m above floor
Location D (doorway)	**Position**
D1 (Test 1)	1.5 mm diameter, 75 mm below ceiling, 200 mm south of sprinkler
D1 (Test 2 onwards)	1.5 mm diameter, adjacent to dummy sprinkler bulb inside door
D2	1.5 mm diameter, 75 mm below ceiling, 50 mm outside door
D3 (Test 7 onwards)	1.5 mm diameter, adjacent to dummy sprinkler bulb outside door
Column 1	**Position**
Bare wire column (various heights)	1 m from end wall (West) and 1 m from side wall (South)
Column 2	**Position**
Bare wire column (various heights)	1 m from end wall (West) and 1 m from side wall (North)

Table 4.2 Locations and positions of the thermocouples inside the experimental facility

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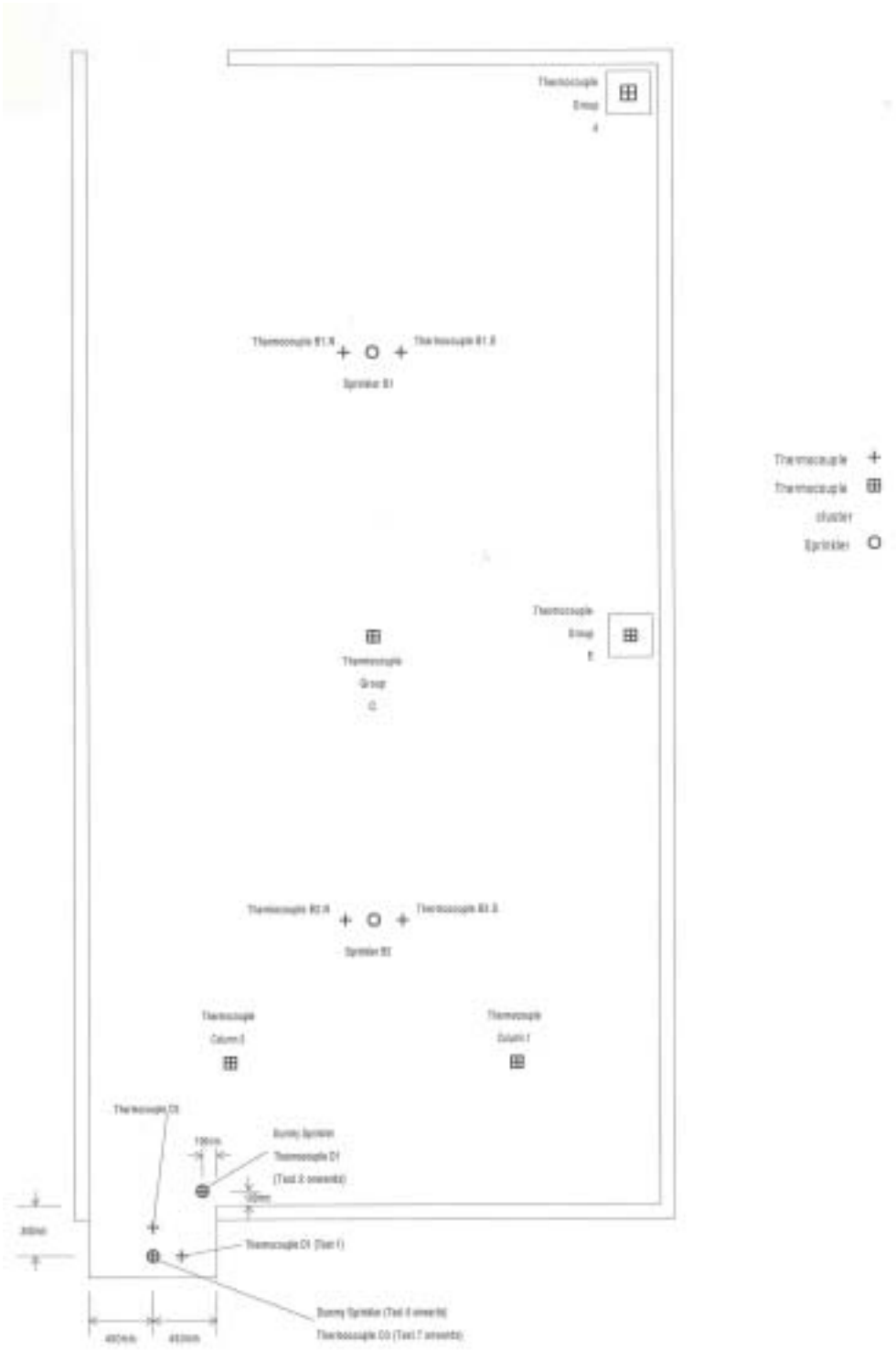

Figure 4.10 Sprinkler and Instrumentation location

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4.6.2 Sprinkler water flow rate

The sprinkler water flow rate was measured using a calibrated 0-500 l/min electronic turbine flow meter and the water pressure was measured using a calibrated pressure gauge.

4.6.3 Humidity measurement

The relative humidity inside the test room was measured using a suitable humidity meter.

4.6.4 Data recording

All instrument readings were recorded using an automatic data logger. The data was then stored directly onto the hard disc of a PC lap top computer in terminal emulation mode. The data was then be processed and transferred into an EXCEL spreadsheet, from which the data was further processed and analysed.

4.6.5 Visual, video and photographic records

Visual observations of each test were made. These included burning characteristics of the fuel, smoke behaviour and the effect of the sprinkler spray on the fuel source and hot gases.

Camcorder video and selected stills photography were also carried out.

4.6.6 Additional measurements

In addition to the instrumentation recommended in DD 252, there were two columns of bare wire K-type thermocouples (columns 1 and 2), with exposed measuring junctions formed from 0.2 mm diameter wire. Figure 4.10 and Table 4.2 show the locations of the thermocouple columns.

There were also additional thermocouples located next to each sprinkler head and at locations used to determine pass/fail criteria for the test, see Table 4.2.

4.7 Experimental method

4.7.1 Parameters of interest

The parameters which may influence the performance of a residential sprinkler in the fire test scenario are as follows.

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Sprinkler

The residential sprinkler parameters are:

- 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

The fuel package parameters are:

- Location of fuel relative to sprinkler spray
- Fuel material properties
- Fuel dimensions
- Fuel package arrangement
- Conditioning of fuel package.

Test room

The test room parameters are:

- Dimensions (height, width, length)
- Openings (size, position)
- Initial temperature and humidity of air in room.

4.7.2 The series of test fires

A series of Benchmark fire tests (including repeat tests) was carried out to examine the effect of varying parameters on the performance of residential sprinklers.

Table 4.3 shows the series of test fires. This series included seven tests to characterise the fuel package (e.g. in terms of heat release rate, etc) in a free burn without the sprinklers. These data will be used to enable comparisons to be made with the characteristics of the fuel packages developed in the USA. A series of 18 Benchmark fire tests (including repeat tests) were carried out to examine the effect of varying parameters on the performance of residential sprinklers.

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Series of unsprinklered calorimetry fires	
Test	**Fuel**
Cal 1	Wood crib
Cal 2	Two foam sheets (each 925 mm by 1000 mm by 75 mm)
Cal 3	Repeat of Test Cal 2
Cal 4	Fuel package for corner test (foam sheets, 925 mm by 1000 mm by 75 mm)
Cal 5	Repeat of Test Cal 4 (without plywood wall lining)
Cal 6	Two foam sheets (each 775 mm by 865 mm by 75 mm)
Cal 7	Fuel package for corner test (foam sheets, 775 mm by 865 mm by 75 mm)

Series of Benchmark tests				
Test	**Sprinkler number**	**Nominal delivered water density for a single operating sprinkler, or two operating sprinklers, as appropriate (mm/min, mm/min)**	**Fuel layout**	**Lintel**
1*	3	4, 3	Corner test	No
2	3	4, 3	Corner test	No
3	4	4, 3	Corner test	No
4	2	4, 3	Corner test	No
5	1	4, 3	Corner test	No
6	3	4, 3	Wall test	No
7	4	4, 3	Wall test	No
8	2	4, 3	Wall test	No
9	3	4, 3	Wall test	No
10	2	4, 3	Corner test	No
11	3	4, 3	Corner test	Yes
12**	3	4, 3	Wall test	Yes
13	3	4, 3	Wall test	Yes
14	4	4, 3	Beneath sprinkler B1	No
15	3	3, 2.8	Corner test	No
16	3	3, 2.8	Corner test	No
17	2	3, 2.8	Corner test	No
18	2	4, 3	Corner test	No

*air not bled from sprinkler system prior to test
** no temperature data recorded

Table 4.3 The series of fire tests

4.7.3 Parameter variation

The sprinkler deflector plate position relative to the ceiling, yoke arm orientation, type and sprinkler spacing were fixed.

The floor to ceiling height of the test room, the doorway opening sizes and position and the conditioning of the fuel package were also fixed.

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4.7.4 Sprinkler type and model

A residential pendent type sprinkler was used for the series of Benchmark tests. Four selected residential sprinkler models were examined.

4.7.5 Sprinkler spacing and coverage

The spacing between the sprinkler heads was fixed at 4 m. The current maximum sprinkler spacing in DD 251 is 4 m. The coverage per sprinkler was 16 m^2.

4.7.6 Sprinkler water flow rate

The majority of tests were carried out with a sprinkler water flow rate of 64 +/- 2 l/min through a single operating sprinkler and a flow rate of 96 +/- 2 l/min through two operating sprinklers. This equates to a delivered water density of 4 mm/min through a single sprinkler and 3 mm/min through two sprinklers.

For selected tests, a flow rate of 48 +/- 2 l/min through a single operating sprinkler and a flow rate of 91+/- 2 l/min through two operating sprinklers were examined. This equates to a delivered water density of 3 mm/min through a single sprinkler and 2.85 mm/min through two sprinklers. This reduced flow rate of 3 mm was based on that used in previous work in the USA [Bill et al 2001]. This flow rate was deliberately chosen for scientific reasons and is lower than that allowed in DD 252 for one sprinkler operating.

4.7.7 The fuel package arrangement and position of fuel relative to sprinkler spray

The fuel package was positioned in three locations within the test room. A corner fire test and a wall fire test were carried out for each sprinkler model examined. For one particular test, the fuel package was positioned directly beneath a sprinkler. Figures 4.11 to 4.13 show schematic diagrams of the fuel layout for the corner, wall and fuel beneath sprinkler configurations, respectively.

4.7.8 Presence of a lintel in doorways of the experimental facility

For the majority of fire tests, no lintels were present in the open doorways of the experimental facility. Hence, the floor to ceiling height of the open doorways was 2.5 m.

For selected tests, a 0.3 m deep lintel was located in the open doorways

4.7.9 Thermal response characteristics of sprinkler

The residential sprinklers used were quick response with one value of nominal operating temperature (68°C).

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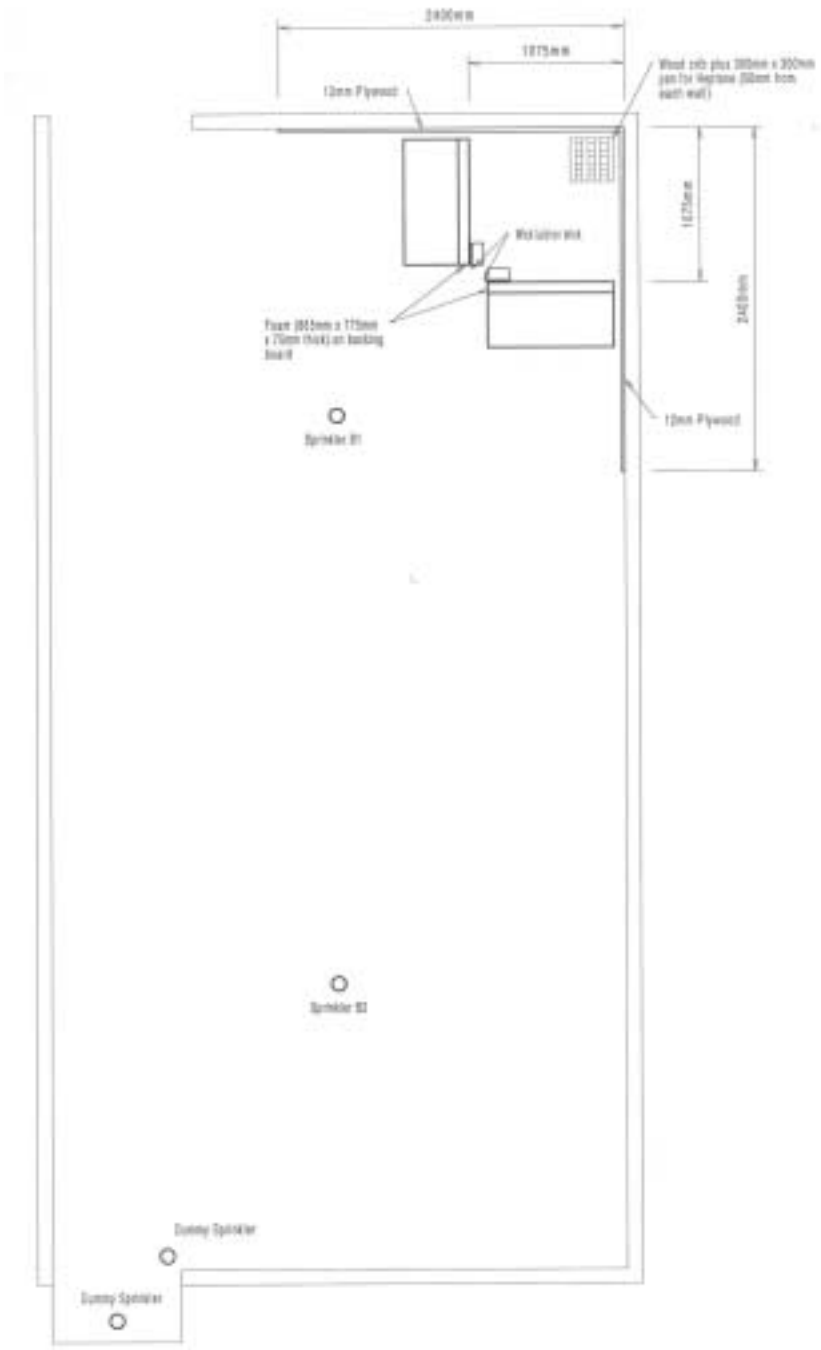

Figure 4.11 Schematic diagram of experimental facility and layout for corner configuration

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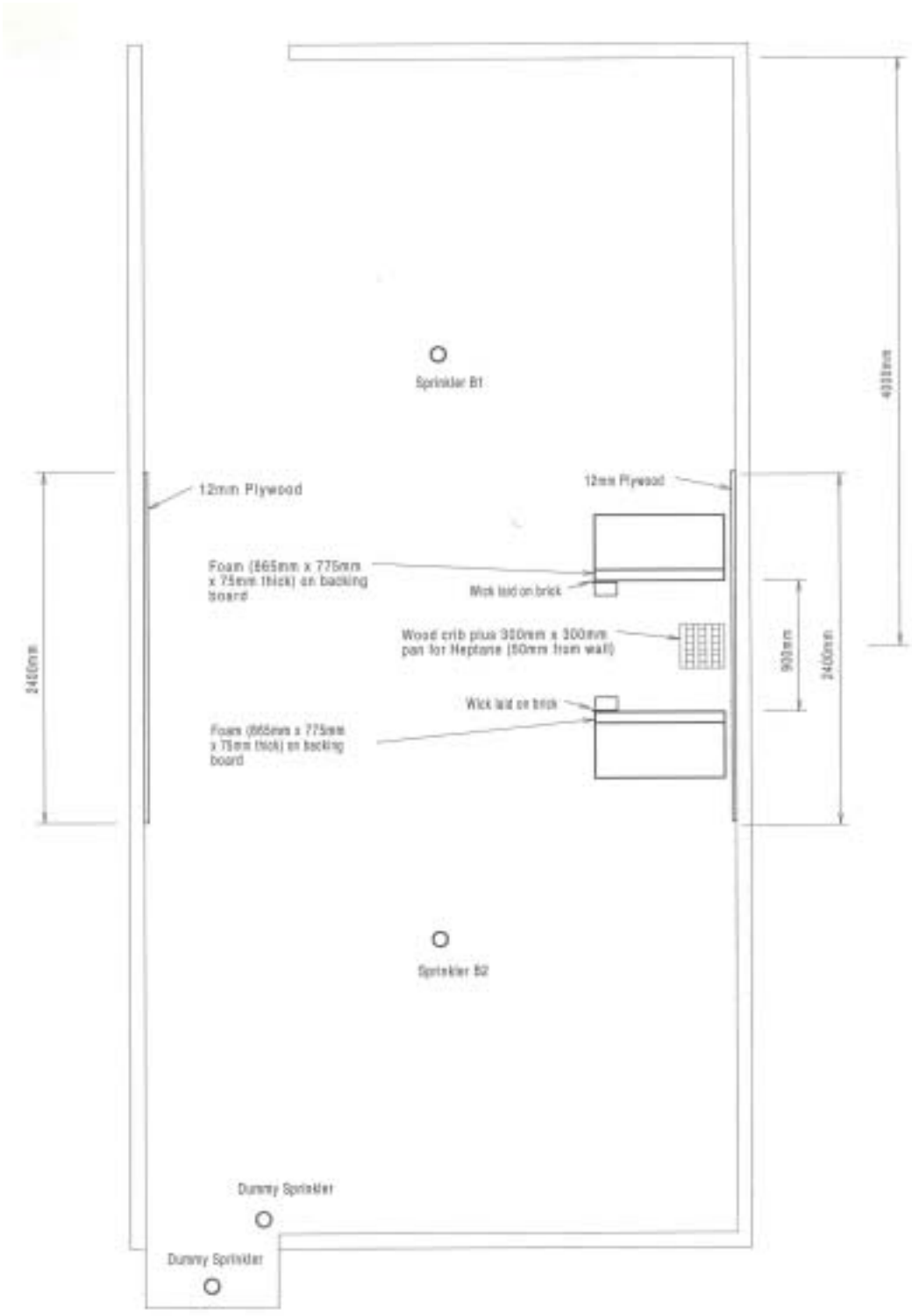

Figure 4.12 Schematic diagram of experimental facility and layout for wall configuration

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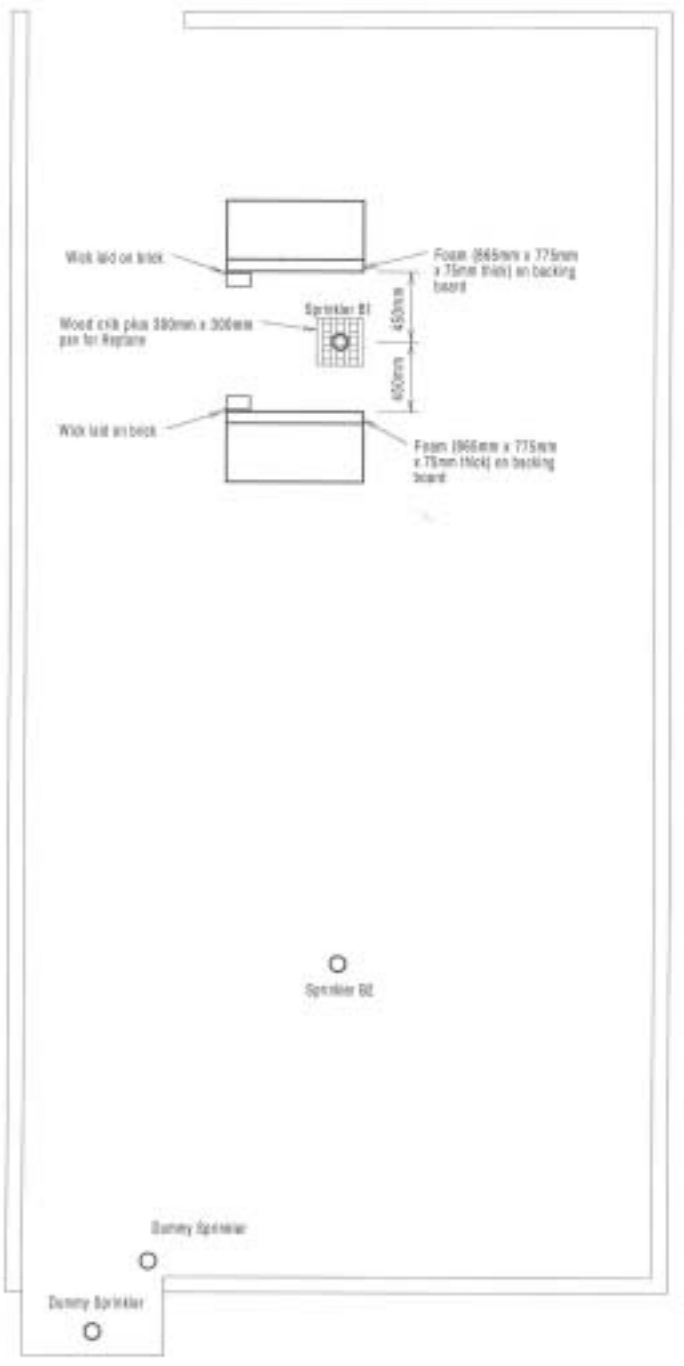

Figure 4.13 Schematic diagram of experimental facility and layout for fuel beneath sprinkler configuration

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4.8 Acceptance criteria

The acceptance criteria for the series of Benchmark tests was based on those described in DD 252. These are described as follows:

The residential sprinkler shall be capable of controlling the test fires for a period of 10 minutes, measured from first sprinkler operation, when tested in accordance with the procedures described in DD 252.

The acceptance criteria for the Benchmark fire tests are:

a) Temperatures with the experimental facility shall be limited to the values given in Table 4.4 within the period of 10 minutes.

b) The third 'dummy' sprinkler, positioned near the open doorway, shall not operate within the period of 10 minutes.

75 mm below underside of ceiling	320
1.6 m above floor	95
1.6 m above floor	55 (for not more than any 120 s interval)
Ceiling temperature - embedded 6.5 mm above the underside of the ceiling	260

Table 4.4 Fire test maximum allowable temperatures

4.9 Experimental procedure for each fire test

The following procedure was carried out for each Benchmark fire test:

1) The fuel and ignition packages were suitably conditioned.

2) Before attaching any materials in the test room, it was ensured that the floor, walls and ceiling of the test room were dry (i.e. no visible moisture and no standing water).

3) The fuel and ignition package were positioned accordingly.

4) Data recording of the water flow rate and stopwatches were started two minutes before ignition of the fuel.

5) Data recording of temperatures were started one minute before ignition of the fuel.

6) The heptane in the tray and the wicks were ignited simultaneously.

7) Air temperatures, sprinkler operating times and water flow rates were recorded.

8) The flow through the first sprinkler to operate was sufficient to provide the nominal discharge density required for a single sprinkler area of coverage. If two sprinklers operated, the pump speed was adjusted so that the required nominal discharge density for two operating sprinklers was achieved.

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The nominal discharge density was calculated using the following equation

$$D = \frac{Q}{a}$$

where

D = nominal discharge density (mm/min)

Q = flow into area of coverage (l/min)

a = area of coverage (m^2)

9) The test was terminated after 10 minutes from operation of the first sprinkler.

4.10 Results of Benchmark tests

Appendix 4B contains the results of the horizontal and vertical water distribution tests for the sprinklers used in the Benchmark tests.

Appendix 4E shows graphs of temperature with respect to time at each location for the Benchmark tests. It also includes graphs of the measured sprinkler water flow rate with respect to time for each test.

Appendix 4F shows selected graphs of heat release with respect to time for the unsprinklered free burns to characterise the fuel package.

Table 4.5 shows some of the key results (e.g. sprinkler operation times) of the series of Benchmark tests in the experimental facility.

Appendix 4C shows selected photographs of the series of fire tests.

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Test	Time of operation of sprinkler B1 from ignition (s)	Time of operation of sprinkler B2 from ignition (s)	Time of operation of 'dummy' sprinkler inside doorway (s)	Time of operation of 'dummy' sprinkler outside doorway (s)	Pass/Fail according to DD 252	Pass/Fail according to FMRC test
1	53	69	Not installed	Time unknown	Fail	Fail
2	82	Did not operate	Did not operate	Not installed	Pass	Pass
3	73	Did not operate	Did not operate	Not installed	Pass	Pass
4	67	Did not operate	Did not operate	Not installed	Pass	Pass
5*	79	Did not operate	Did not operate	Not installed	Pass	Pass
6	122	126	135	Did not operate	Pass	Fail
7	123	127	Did not operate	Did not operate	Pass	Pass
8	112	114	Did not operate	Did not operate	Pass	Pass
9	111	131	122	Did not operate	Pass	Fail
10	57	131	137	Did not operate	Pass	Fail
11	63	Did not operate	Did not operate	Did not operate	Pass	Pass
12	107	133	Did not operate	Did not operate	Pass	Pass
13	98	103	Did not operate	Did not operate	Pass	Pass
14	71	Did not operate	Did not operate	Did not operate	Pass	Pass
15	68	Did not operate	148	Did not operate	Pass	Fail
16	78	Did not operate	168	Did not operate	Pass	Fail
17	66	104	100	145	Fail	Fail
18	66	134	138	165	Fail	Fail

*This corner test involved sprinkler type 1 and only one sprinkler operated. If two sprinklers of this type operated, this would give an operating pressure of less than 0.5 bar, less than the minimum allowed in DD 251. Therefore, a wall test was not attempted with this sprinkler type.

Table 4.5 Some selected results from the Benchmark tests

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4.11 Discussion

4.11.1 Unsprinklered fires to characterise fuel package

The fuel package specified in DD 252 was characterised in a series of seven tests in a free burn without sprinklers (see Table 4.3). Both the component parts and the total fuel package of the corner fire test were characterised in terms of rate of heat release.

Figures 4F.1 and 4F.2 show the rate of heat release for the total fuel package of the corner fire test for different sizes of foam sheet (see section 4.4.3). Figure 4F.1 shows that for the size of foam sheet given in DD 252 (which is not wrapped around the wooden frame), the heat release of the fuel package rises sharply to a peak of approximately 5 MW. Figure 4F.2 shows that for the smaller size of foam sheet used in the Benchmark fire tests, the heat release rises sharply to a peak of approximately 2.5 MW. The size of each foam sheet used in the Benchmark tests is approximately 25% smaller in area to the unwrapped size of foam sheet given in DD 252. However, the peak heat release rate of the fuel package is reduced by 50% using the smaller size of foam sheet. This demonstrates that the fire size is highly sensitive to the size of the foam sheet used and, hence, the challenge to a sprinkler in a residential fire test. The size of the foam sheets could have a significant effect on whether a sprinkler will pass or fail a residential sprinkler fire test.

4.11.2 Sprinkler model

Four different models of pendent type residential sprinkler were used in the series of Benchmark fire tests. In general, all of the sprinkler models provided extensive wetting of the plywood wall lining material for all of the fire tests carried out. Therefore, the plywood did not significantly contribute to the fire load in any of the tests carried out. The unsprinklered free burns have demonstrated that the wall lining material can provide a significant contribution to the overall fire load. Also, the sprinklers were all reasonably effective in extinguishing the wood crib for the majority of the fire tests carried out.

The performance of each sprinkler model is described as follows.

4.11.2.1 Sprinkler 1 - Corner test

Sprinkler 1 was only used for the corner fire test (Test 5). This is because the bore size of the sprinkler was such that if two heads operated (as in a wall fire test) the pressure at each head would be less than the minimum allowed within DD 251 (i.e. 0.5 bar).

Sprinkler 1 performed well when used for the corner fire test and produced a technical pass using the acceptance criteria given in DD 252 or the FMRC fire test [Bill et al 2001]. Only one sprinkler operated and there was extensive wetting of the plywood wall lining and the wood crib. Figure 4E.32 shows that the temperature of the gases above the crib reached a peak of approximately 150^0C. However, this Figure also shows that the fire continued to grow after operation of the sprinkler, prior to the foam sheets burning out.

4.11.2.2 Sprinkler 2 – corner test

Sprinkler 2 was used for both the corner and wall fire tests.

For the corner fire tests the performance of sprinkler 2 was borderline. This particular test was repeated three times. In general, this sprinkler provided extensive wetting of the plywood wall lining, but not the wood crib or foam sheets. In Test 4, only one sprinkler operated. However, in Tests 10 and 18, two sprinklers operated. Table 4.5 shows that this sprinkler produced a technical pass using the criteria given in DD 252 and the FMRC fire test [Bill et al 2001] for one test (Test 4), a technical fail for another test (Test 18) and a both a pass and a fail for another test (Test 10). The failures were due to the dummy sprinklers operating. Figures 4E.24, 4E.72 and 4E.128 show that for each test, the fire continued to grow after operation of the first sprinkler, providing a peak temperature of approximately 200-250^{0}C above the crib. The temperature begins to fall after approximately 3 minutes from ignition due to the foam sheets burning out. The performance of the sprinkler appears to be dependent on differences in the fire growth curves.

4.11.2.3 Sprinkler 2 – wall test

For the wall fire test, sprinkler 2 performed well. Two sprinklers operated for the wall test. The sprinklers provided extensive wetting of the plywood wall lining, foam sheets and wood crib. Figure 4E.56 shows that the sprinkler effectively controlled the fire on operation of the sprinklers. Table 4.5 shows that this sprinkler produced a technical pass using the criteria given in DD 252 and the FMRC fire test.

4.11.2.4 Sprinkler 3 – corner test

Sprinkler 3 was used for the corner and wall fire tests. Test 1 is not included in the analysis in the section due to issues relating to ignition of the fuel package and air within the sprinkler system.

Sprinkler 3 performed well when used for the corner fire test and produced a technical pass using the acceptance criteria given in DD 252 or the FMRC fire test. Only one sprinkler operated and there was extensive wetting of the plywood wall lining and the wood crib. Figure 4E.9 shows a typical temperature profile of the gases above the crib, which reached a peak of approximately 160^{0}C. Figure 4E.32 also shows that the sprinkler controlled the fire after operation of the sprinkler, prior to the foam sheets burning out.

4.11.2.5 Sprinkler 3 – wall test

Sprinkler 3 performed reasonably well for the wall test. This test was repeated twice. For both tests two sprinklers operated and provided extensive wetting of the plywood wall lining and wood crib. Figures 4E.40 and 4E.64 show that the sprinkler effectively controlled the fire on operation of the sprinklers. However, Table 4.5 shows that this sprinkler produced a technical pass using the criteria given in DD 252 but a fail on the FMRC fire test, as the dummy sprinkler inside the doorway operated (Tests 6 and 9).

4.11.2.6 Sprinkler 4 – corner test

Sprinkler 4 was used for the corner, wall and fuel beneath sprinkler fire test.

Sprinkler 4 performed well when used for the corner fire test and produced a technical pass using the acceptance criteria given in DD 252 and the FMRC fire test. Only one sprinkler operated and there was extensive wetting of the plywood wall lining and the wood crib. Figure 4E.16 shows a typical temperature profile of the gases above the crib, which reached a peak of approximately 160^0C. This Figure also shows that the sprinkler controlled the fire after operation of the sprinkler, prior to the foam sheets burning out.

4.11.2.7 Sprinkler 4 – wall test

For the wall fire test sprinkler 4 performed well. Again, two sprinklers operated for the wall test. The sprinklers provided extensive wetting of the plywood wall lining, foam sheets and wood crib. Figure 4E.48 shows that the sprinkler effectively controlled the fire on operation of the sprinklers. Table 4.5 shows that this sprinkler produced a technical pass using the criteria given in DD 252 and the FMRC fire test.

4.11.2.8 Fuel package beneath sprinkler test

The guidance in DD 252 allows for the fuel package to be positioned in a location achieving the lowest water application rates based on the water distribution tests. Therefore, for one particular test (Test 14), the fuel package was located directly beneath sprinkler 4. The water distribution tests highlighted that sprinkler 4 delivered less water directly beneath the sprinkler head.

As the fuel load was directly beneath the sprinkler, the thermocouples used to determine acceptance criteria above the crib were redundant due to the sprinkler spray cooling the thermocouple junctions.

Table 4.5 shows that this sprinkler produced a technical pass using the criteria given in DD 252 and the FMRC fire tests, as none of the dummy sprinklers operated. However, visual observations showed that the sprinkler spray had little effect on the fuel package. The foam sheets burnt to completion and the wood crib continued to burn after the test was terminated. Figure 4E.100 shows that the temperature of the gases at the open doorway continued to rise after operation of the sprinkler. Conditions within the test room appeared to be dependent on the amount of fuel available beneath the spray.

4.11.3 Sprinkler water flow rate

Figures 4E.9 and 4E.104 show graphs temperatures above the crib with sprinkler 3 operating at a delivered density of 4 mm/min and 3 mm/min respectively. Comparison of these graphs show that the temperature of the gases above the crib peaked at approximately 160^0C for a water delivery of 4 mm/min and peaked at approximately 240^0C for a water delivery of 3 mm/min. The fire continued to grow after operation of the sprinkler for the reduced water flow rate test (Test 15). There appeared to be less water interacting with the fuel package for the reduced water flow rate test.

The dummy sprinkler inside the test room operated for the reduced water flow rate test and hence, produced a technical fail using the procedures given in FMRC fire test method. However, the second sprinkler in the test room did not operate. As this could

have been an anomalous result, this test was repeated (Test 16). The repeat test gave the same result. The non-operation of the second sprinkler may have been due to a stagnant air zone close to the sprinkler head.

The effect of reducing the sprinkler flow rate was also examined using sprinkler 2 (Test 5 and 17). Comparison of Figures 4E.32 and 4E.120 shows that the peak temperature above the crib was approximately 160^0C for a water delivery of 4 mm/min, whereas for a water delivery of 3 mm/min a peak temperature of approximately 250^0C was reached. The reduced flow rate test produced a technical fail for both the procedures given in DD 252 and the FMRC fire test. This was due to both dummy sprinklers operating.

In general, reducing the sprinkler water flow rate caused the sprinkler to provide less control of the fire.

4.11.4 Location of fuel package

4.11.4.1 Corner fire test

In general, the configuration of the foam sheets used in the corner tests provided significant shielding from the sprinkler spray. Hence, for the majority of tests, the foam sheets burnt to completion. The fires was generally controlled by a single sprinkler, however, the foam sheets tended to burn out after approximately 3 minutes. The corner fire tests were generally controlled by the amount of available fuel.

4.11.4.2 Wall fire test

For the wall fire tests the foam sheets were generally more exposed to the sprinkler spray due to there being little shielding from the spray. Therefore, on operation of the sprinklers, the foam sheets tended to be extinguished. For this configuration, two sprinklers operated for all the fire tests as the fuel load was equidistant from each sprinkler head. The fire growth curve of the wall test was different to the growth curve of the corner test due to the configuration of the foam sheets.

4.11.4.3 Fuel package beneath sprinkler

For the particular test with the fuel package beneath the sprinkler, the spray had little effect on the fuel package. An increased fuel load beneath the sprinkler could have given rise to a different result. This is an important result which will be further examined in the Experimental Programme (see section 5) on the tenability of conditions within the room of origin.

4.11.5 Effect of lintels in the doorways

The presence of a lintel within the open doorways tended to deepen the smoke layer within the test room. However, visual observations showed that the smoke flowing through an open doorway beneath the lintel caused the hot smoky gases to bypass the dummy sprinkler located outside the test room. This has important implications for the applicability of the test method.

The presence of a lintel also prevented the operation of the dummy sprinkler inside the test room which had operated in an identical test without the lintel (see Table 4.5 for Tests 9 and 13). This effect is likely to be due to the lintel creating a ‘stagnant’ air zone

around the dummy sprinkler inside the door. This 'stagnant' air zone is likely to affect the response of the dummy sprinkler.

4.12 Recommended changes and additions to DD 252

In carrying out the Benchmark fire tests a number of issues relating to the procedures given in DD 252 have been identified. The following changes and additions to the fire test in DD 252 are recommended:

- Test 1 was carried out without the air in the sprinkler system being removed. This resulted in there being a significant delay (approximately 5 to 7 s) between the operation of the sprinkler and water being delivered to the test room. Therefore, it is recommended that air bleed valves are located in the sprinkler pipework to remove air from the system prior to the test.
- DD 252 should state that the pipework connected to the dummy sprinkler should contain a small quantity of water (e.g. 70 ml).
- The sprinkler yoke arm orientation is not specified in DD 252. This was taken to be parallel to the longer length of the experimental facility for the Benchmark tests. This should be specified in DD 252.
- DD 252 does not specify the method for ignition of the foam sheets. The Benchmark tests used cotton wicks soaked in heptane to ignite the foam sheets, as used in the USA. This method of ignition should be used in DD 252.
- The ignition source used to light the cotton wicks in Test 1 was a rag soaked in heptane on a 1m long rod. This ignition source caused direct ignition of the foam sheets as the cotton wicks were lit. This resulted in a much quicker fire growth curve compared to the other Benchmark fire tests and resulted in the sprinkler failing the test.
- To achieve a more repeatable fire test it is recommended that the cotton wicks should be made longer to avoid direct ignition of the foam sheets when igniting the wicks. A less obtrusive ignition source is also recommended.
- DD 252 should state that the wooden crib and the cotton wicks should be ignited simultaneously.
- The metal tray on which the wood crib is placed is the same size as the wood sticks. It is recommended that an additional lip is added to the tray to provide stability to the crib.
- DD 252 states that the moisture content of the wood crib should be (6 +/- 1%). This is only achievable if the crib is oven dried. The moisture content of the crib used in the Benchmark tests was (10 +/- 2 %), using the procedures given in BS EN 13238 [British Standards Institution 2001]. The moisture content of the wood crib in DD 252 should be reviewed.
- The weight of the wood crib in DD 252 is given to be (5750 +/- 250) grams. This is incorrect. The weight of the wood crib should be specified as (8250 +/- 250) grams.

- The foam sheets used in DD 252 should be cut flush to the wooden backing board to remove uncertainties in the wrapping procedure (which is not stated in DD 252). The size of the foam sheet should be 775 mm by 865 mm by 75 mm thick.
- DD 252 is not specific on the exact requirements of the wooden backing board and frame on which the foam sheet is located. It is recommended that the foam sheets are glued to a sacrificial backing board which is bolted to the wooden frame. This will enable the wooden frame to be used for a number of fire tests. The method of gluing and the type of glue should be specified in DD 252.
- The presence of a lintel in the doorways of the test room should be reviewed.
- DD 252 does not clearly specify the locations of the thermocouples used for the fire test. The location and number of thermocouples used in the Benchmark tests were taken from the work carried out in the USA. DD 252 should include a specific instrumentation diagram.
- It is recommended that additional backup thermocouples are located in positions which are used to determine the acceptance criteria in case of failure during a test.
- The plywood wall lining sheets should be 12 mm thick instead of 10 mm thick as specified in DD 252, as 12 mm is a standard thickness from suppliers of plywood.
- It is recommended that the ceiling of the test room is lined with ceramic fibre board ('supalux') instead of acoustic tiles as specified in DD 252. The ceiling of the test room needs to be non-combustible. Ceramic fibre board provides the most cost effective and efficient material.
- DD 252 states that the humidity in the test room should be (60 +/- 10) %. This is not always possible to achieve on humid/wet days. DD 252 also states that the air temperature within the test room should be (25+/- 5)^{0}C. This may also not be easy to achieve. These tolerances should be reviewed.

4.13 Summary and general conclusions of Benchmark tests

Two British Standard Drafts for Development, DD 251 (systems) and 252 (components) have been published. They are of a provisional nature and were issued as DDs instead of full British Standards because it was recognised by the experts at that time that UK experience needed to be gained with residential sprinklers.

The purpose of conducting a series of experimental Benchmark tests was to establish a benchmark fire test for UK conditions to support the further development of BS DD251 and 252 and to assess the performance of residential sprinklers in fire test conditions.

The DD 252 fire test essentially involves burning a stylised, representative fuel package of simulated furniture and wall and ceiling linings arranged inside a simulated residential 'room' with door openings and with two installed sprinkler heads. There are two open doorways and near the opening of one doorway is a third dummy sprinkler head. The sprinkler system performance is determined by its performance in controlling the fire for a period of time measured after sprinkler operation, as measured by the gas temperatures being limited to specified values and the dummy sprinkler head not operating.

A new experimental facility was built and instrumented. It was essentially a "residential room" with dimensions of 4 m by 8 m by 2.5 m high with two open doorways 0.90 m wide and 1.00 m wide with detachable lintels in the doorways 0.3 m deep. A suitable sprinkler system was installed in the experimental facility. Two residential sprinkler heads of the same type were installed inside the experimental facility at a spacing of 4 m. There were 'dummy' sprinklers located within the experimental facility, which were not connected to the water supply. One dummy sprinkler was located outside the doorway according to the guidance given in DD 252. Another dummy sprinkler was located inside the doorway as specified in the USA FMRC fire test.

Available residential sprinkler heads were obtained and these were characterised using vertical and horizontal water distribution measurements. Four were chosen for further study in the fire tests.

Suitable UK materials were obtained for the fuel package given in DD 252. The fuel package in DD 252 consists of: two polyether foam sheets (non-flame retardant) each attached to a wooden frame, a wall lining of four plywood sheets (non-flame retardant) and an ignition package. The ignition package in DD 252 consists of a wood crib consisting of eight layers of wood sticks placed on top of a steel tray containing commercial grade heptane.

Elements and the whole fuel package arrangement were characterised using seven calorimetry fires in free burns without sprinklers.

A series of eighteen fire tests was conducted, including repeat tests, based on the procedures given in DD 252 to examine the effect of varying parameters on the performance of residential sprinklers. The parameters investigated were: sprinkler model (four 15 mm pendent types), location of fuel package within sprinkler spray (wall, corner and directly beneath sprinkler configurations), the effect of the presence of 0.3 m lintels (with and without), sprinkler water flow rate (3mm/min and 4 mm/min).

The general conclusions of the Benchmark tests are:

- A number of issues relating to the procedures given in DD 252 have been proposed and
- 18 changes and additions to the fire test in DD 252 are recommended.

4.14 References for Benchmark tests

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Appendix 4A – Water distribution arrangements

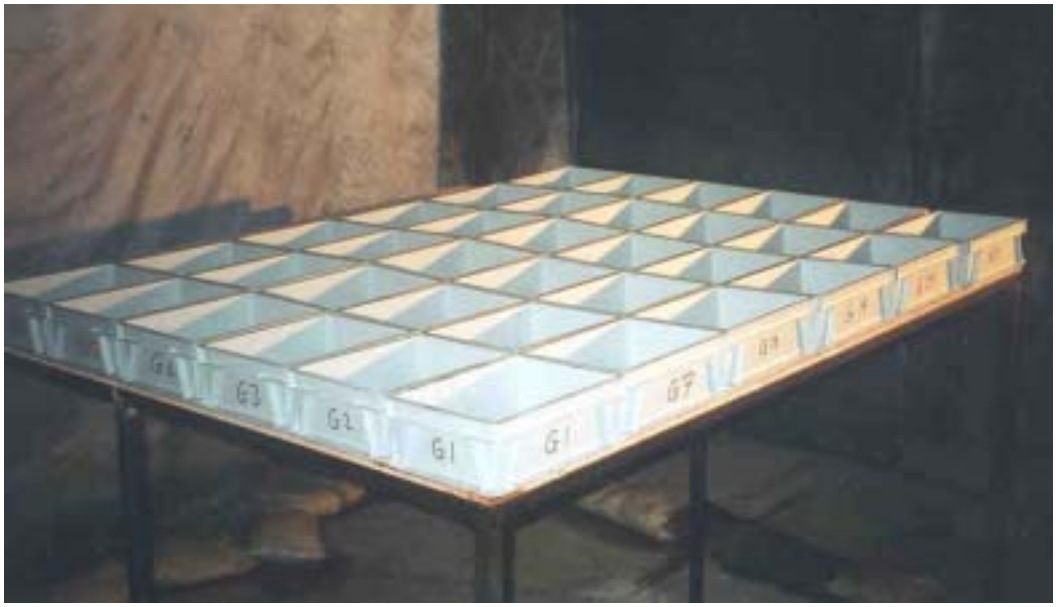


Figure 4A.1 Horizontal water distribution arrangement

Figure 4A.2 Single container for water distribution tests

Figure 4A.3 Single vertical water vertical distribution arrangement

Figure 4A.4 View of part of water distribution arrangement

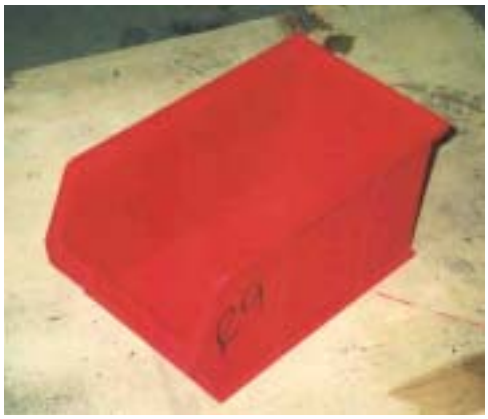
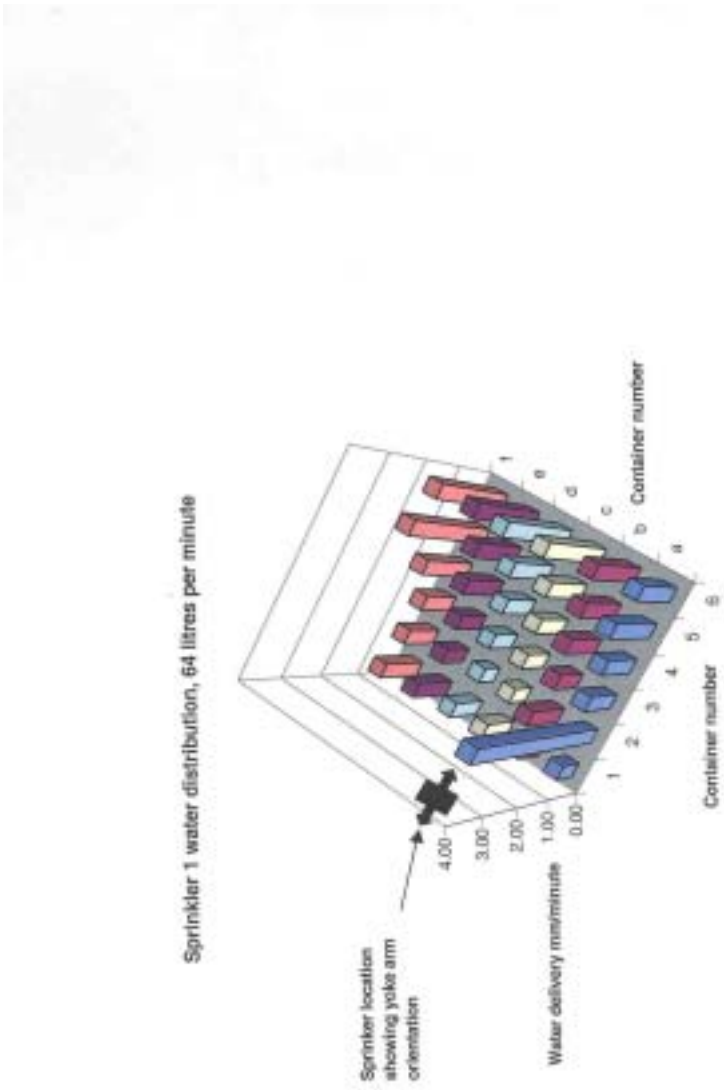


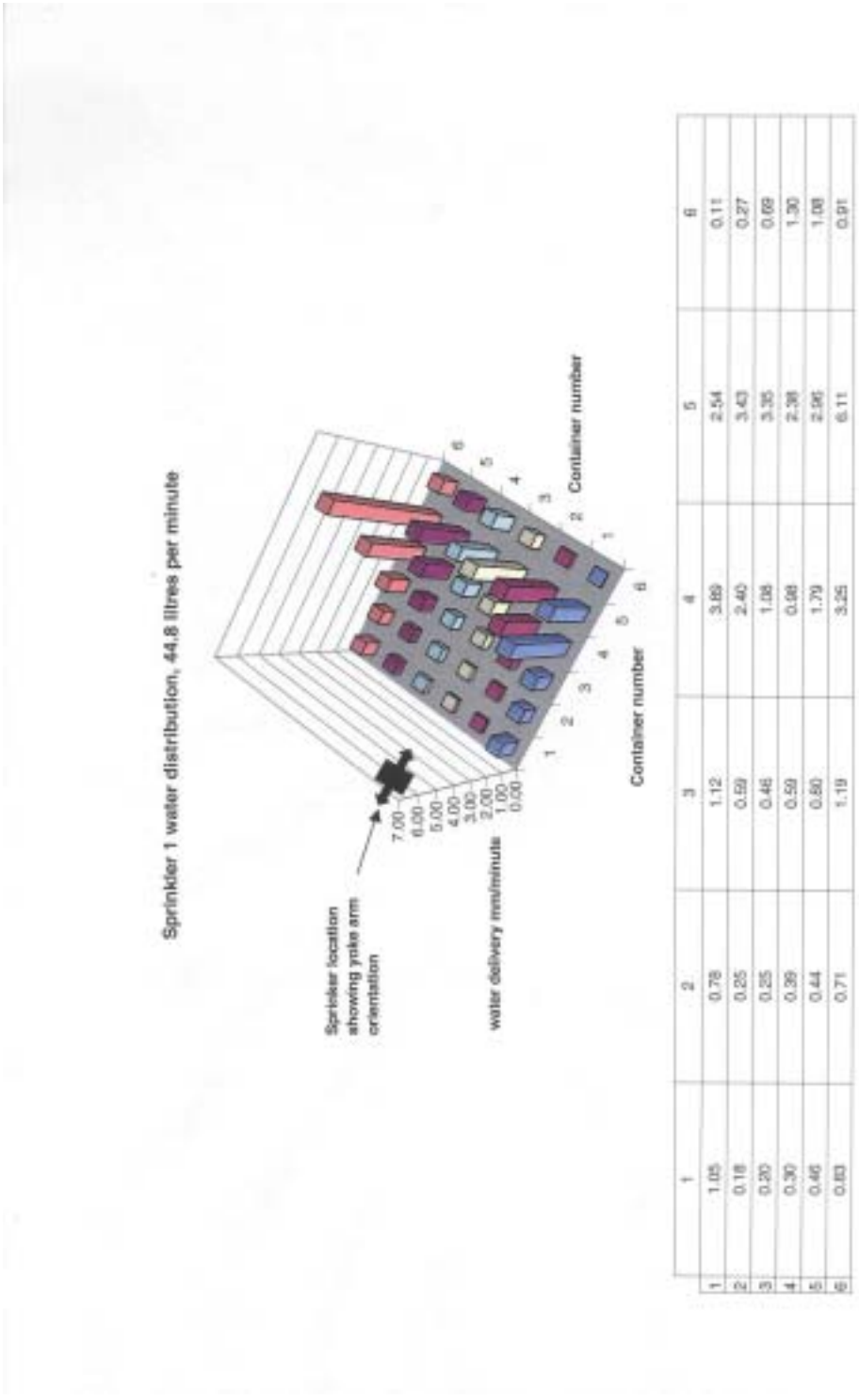
Figure 4A.5 Single container for vertical water distribution tests

Appendix 4B – Water distribution measurements

Figure 4B.1 Sprinkler 1 water distribution, 64 litres per minute

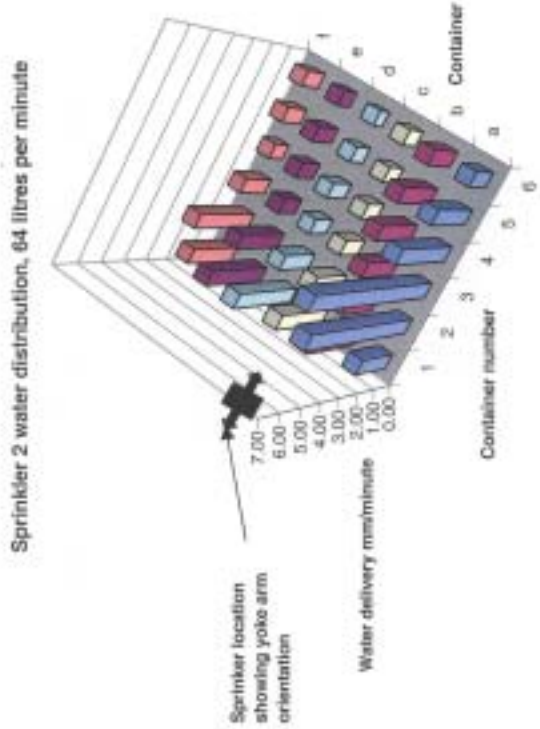


	1	2	3	4	5	6
a	0.55	3.78	0.92	1.03	1.47	1.26
b	0.71	1.06	0.78	1.06	1.24	1.53
c	0.85	0.55	0.75	0.91	1.21	1.93
d	0.63	0.48	0.73	0.91	1.28	2.09
e	1.01	0.67	0.76	1.12	1.35	1.92
f	1.08	0.89	0.89	1.38	2.27	2.02



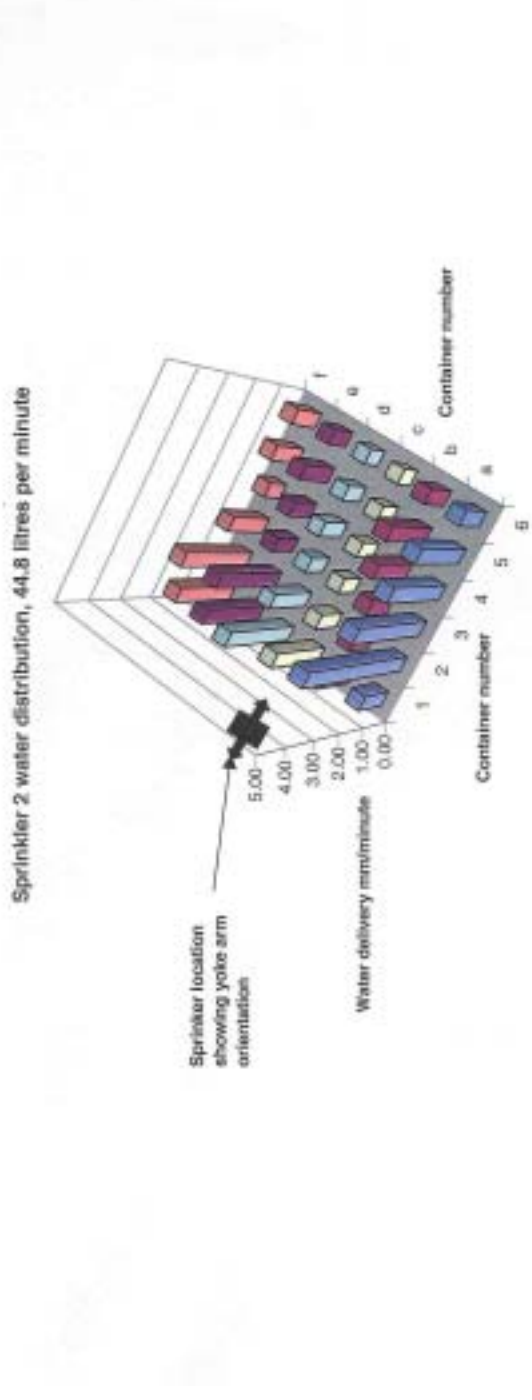
	1	2	3	4	5	6
1	1.05	0.78	1.12	3.69	2.54	0.11
2	0.18	0.25	0.59	2.40	3.43	0.27
3	0.20	0.25	0.46	1.08	3.35	0.69
4	0.30	0.39	0.59	0.68	2.38	1.30
5	0.46	0.44	0.80	1.79	2.95	1.08
6	0.83	0.71	1.19	3.25	6.11	0.91

Figure 4B.2 Sprinkler water distribution, 44.8 litres per minute



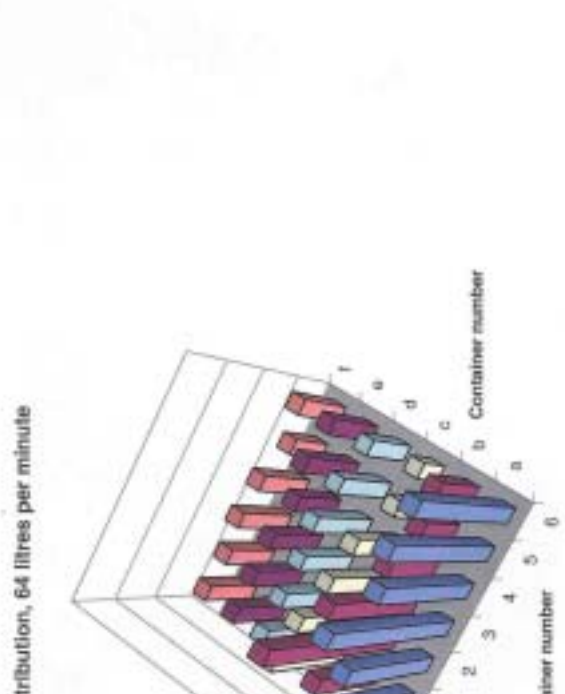
	1	2	3	4	5	6
a	1.83	5.66	6.53	3.09	2.22	1.16
b	2.66	1.81	1.81	2.15	2.04	1.44
c	2.56	1.67	1.12	0.96	0.86	0.83
d	3.07	1.65	0.99	1.06	0.82	0.55
e	2.86	2.27	0.98	0.98	1.10	0.73
f	2.25	2.79	1.37	0.76	1.05	0.96

Figure 4B.3 Sprinkler 2 water distribution, 64 litres per minute



	1	2	3	4	5	6
a	1.01	4.01	2.93	2.36	2.06	0.89
b	1.42	0.82	0.91	1.49	1.77	0.96
c	1.92	0.89	0.71	0.73	0.69	0.60
d	2.45	1.47	0.75	0.94	0.75	0.60
e	2.17	2.31	0.83	0.89	1.21	0.76
f	2.04	2.45	1.38	0.66	1.08	0.98

Figure 4B.4 Sprinkler 2 water distribution, 44.8 litres per minute



	1	2	3	4	5	6
a	1.97	2.72	3.82	2.98	3.37	3.28
b	1.93	3.90	2.73	1.58	1.17	1.33
c	2.20	2.02	1.70	1.54	0.83	0.73
d	1.51	1.53	1.53	1.72	1.56	1.26
e	1.44	1.44	1.44	1.28	1.56	1.38
f	1.37	1.28	1.46	1.37	0.99	1.30

Figure 4B.5 Sprinkler 3 water distribution, 64 litres per minute

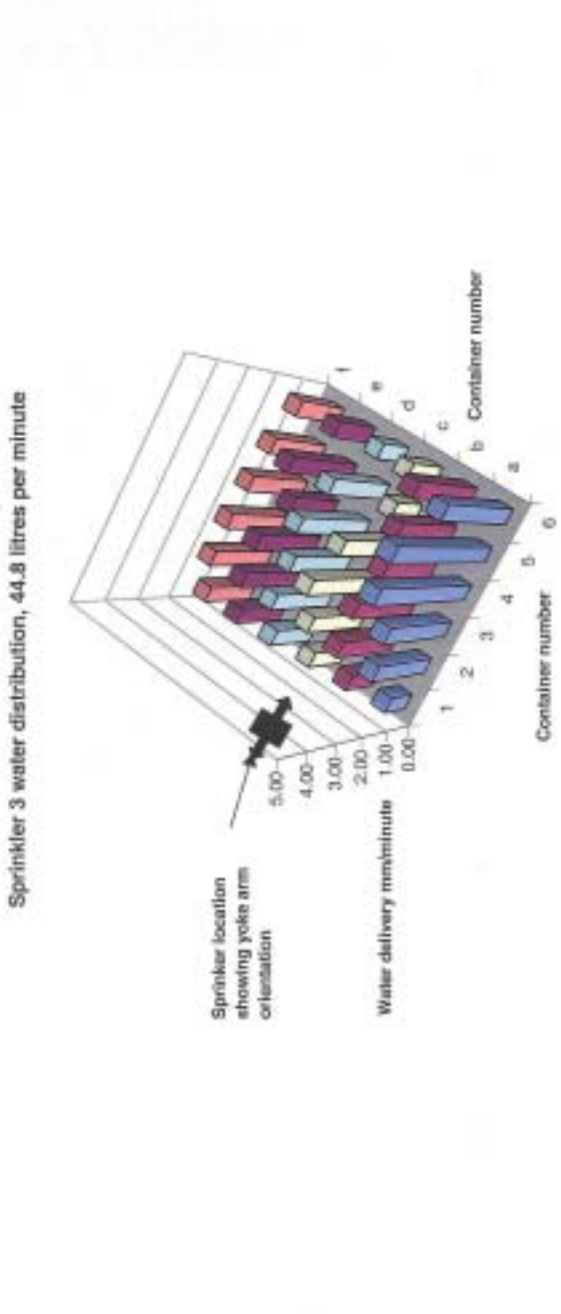
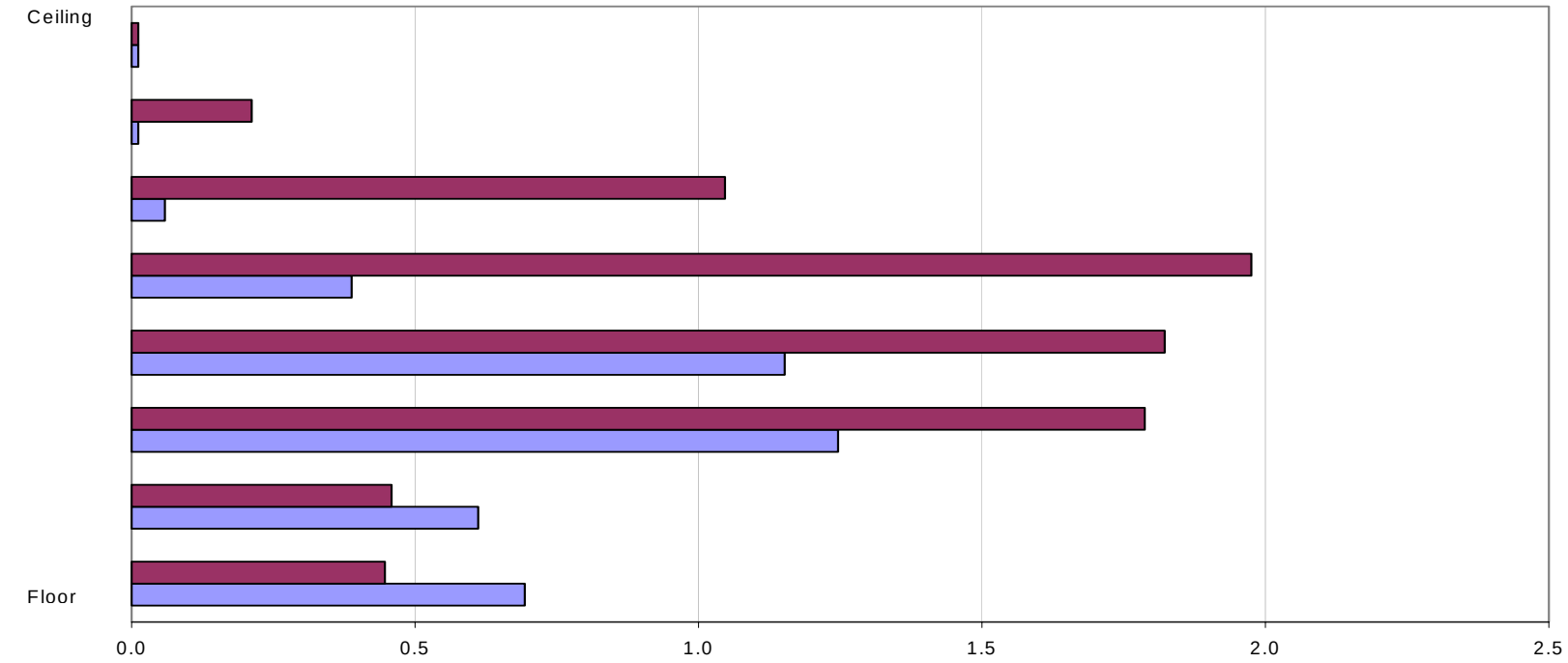


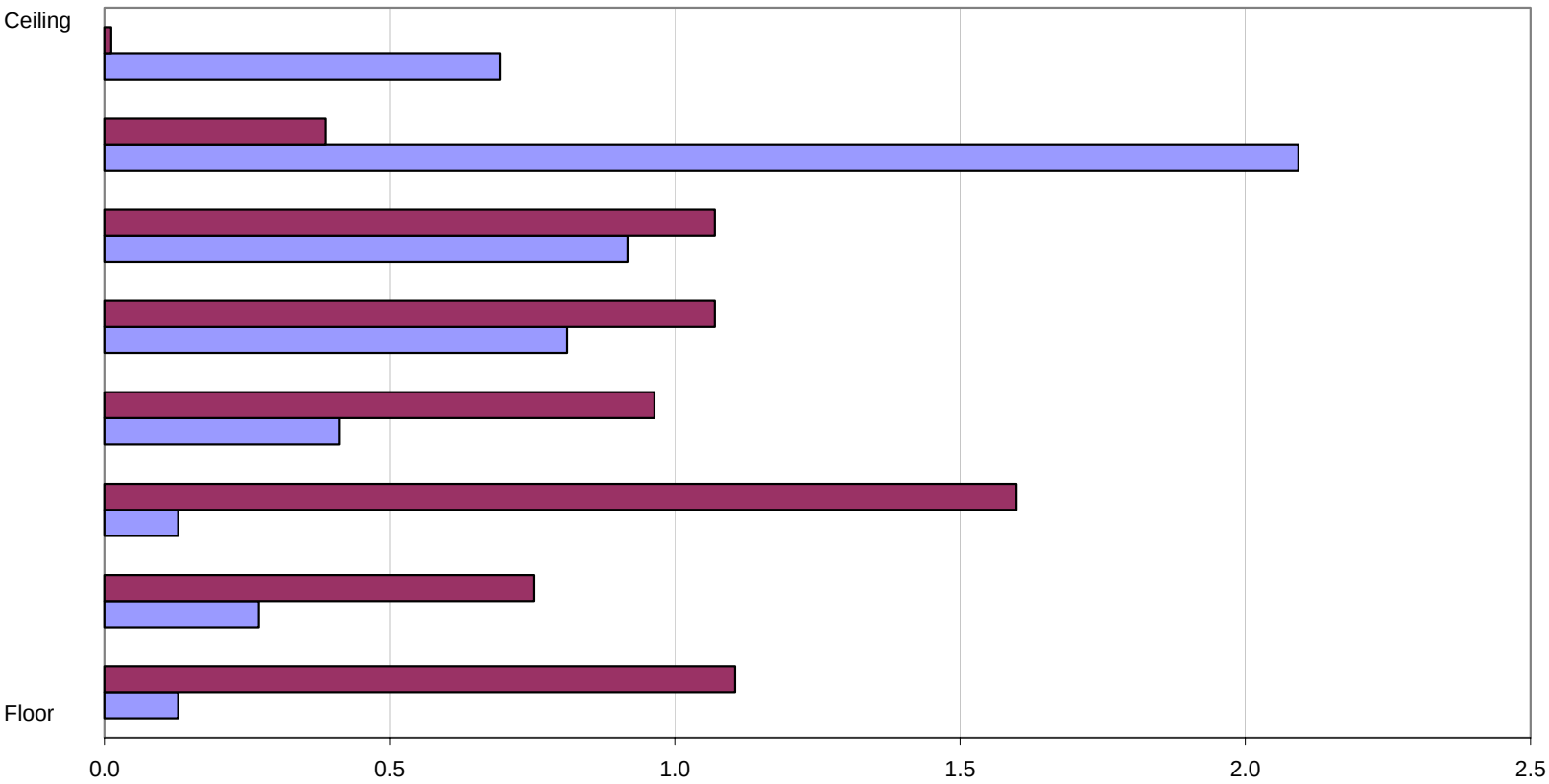
Figure 4B.6 Sprinkler 3 water distribution,44.8 litres per minute



	1	2	3	4	5	6	7	8
Bins 9-16	0.45	0.46	1.79	1.82	1.98	1.05	0.21	0.01
Bins 1-8	0.69	0.61	1.25	1.15	0.39	0.06	0.01	0.01

Delivery [mm/min]

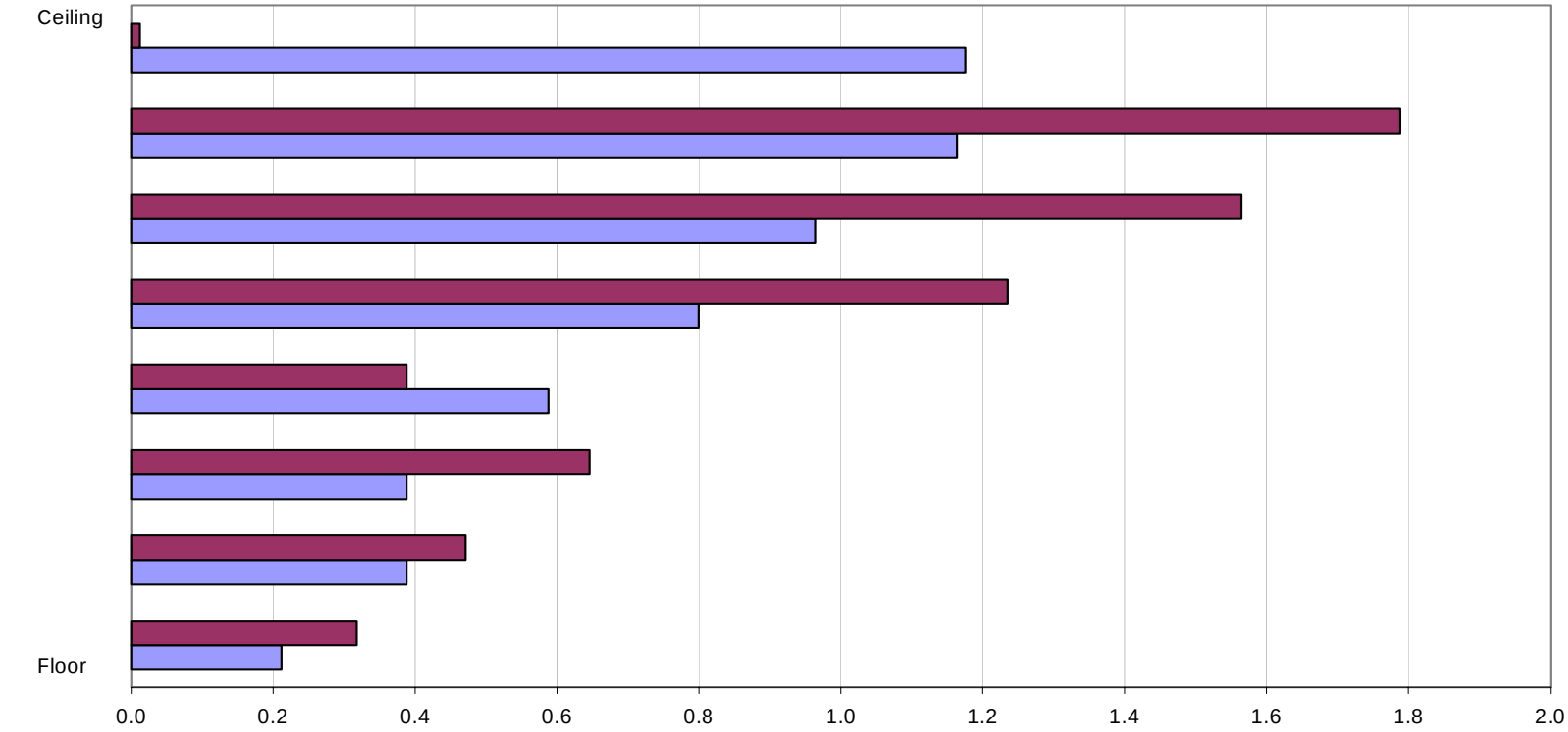
Figure 4B.7 Sprinkler 1 - vertical water distribution, 44.8 litres per minutes



	1	2	3	4	5	6	7	8
Bins 9-16	1.11	0.75	1.60	0.96	1.07	1.07	0.39	0.01
Bins 1-8	0.13	0.27	0.13	0.41	0.81	0.92	2.09	0.69

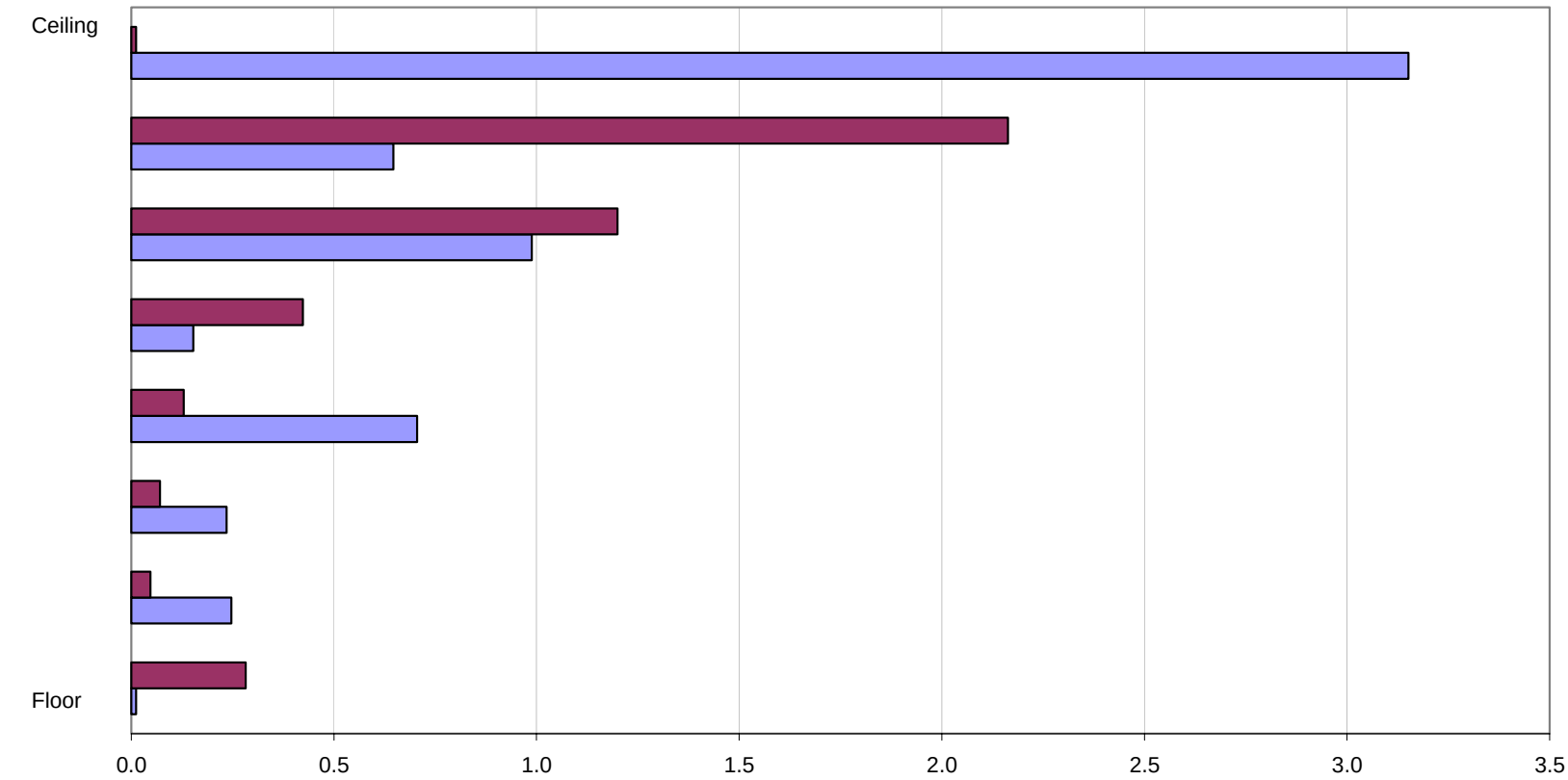
Delivery [mm/min]

Figure 4B.8 Sprinkler 2 - Vertical water distribution, 44.8 litres per minutes



	1	2	3	4	5	6	7	8
Bins 9-16	0.32	0.47	0.65	0.39	1.23	1.56	1.79	0.01
Bins 1-8	0.21	0.39	0.39	0.59	0.80	0.96	1.16	1.18

Figure 4B.9 Sprinkler 3 - Vertical distribution, 44.8 litres minutes



	1	2	3	4	5	6	7	8
Bins 9-16	0.28	0.05	0.07	0.13	0.42	1.20	2.16	0.01
Bins 1-8	0.01	0.25	0.24	0.71	0.15	0.99	0.65	3.15

Figure 4B.10 Sprinkler 4- Vertical water distribution, 44.8 litres per minute

Appendix 4C – Selected photographs of tests

Figure 4C.1 A timber crib on a steel tray

Figure 4C.2 A backing stand for the foam sheets

Figure 4C.3 The steel tray

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Figure 4C.4 Unsprinklered free burn of a corner test

Figure 4C.5 Fuel package layout for a corner test (Test 16)

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Figure 4C.6 Fuel package after test (Test 16)

Figure 4C.7 Fuel package for a wall test (Test 6)

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Figure 4C.8 Fuel package after a wall test (Test 6)

Figure 4C.9 Typical smoke flow from a door

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Figure 4C.10 Lintel in open doorway

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Appendix 4D – Specifications for materials

PRODUCT TECHNICAL DATA

PRODUCT	:	CFT HLB 22
DESCRIPTION	:	A flexible polyurethane foam which has a high load bearing capacity providing optimum protection in packaging applications.
APPLICATIONS	:	The physical properties of this foam make it ideal for cushion packaging, case inserts and padding applications.
PROPERTIES	:	
COLOUR	:	Grey
DENSITY (Kg/m3)	:	20 - 24
TENSILE (Kga Min)	:	140
ELONGATION OF BREAK (%)	:	> 100
COMPRESSION SET (%)	:	15 Max
NOMINAL HARDNESS (ASTM D3574-81 TEST B1)		65 + 10lb (Force at 25% compression)

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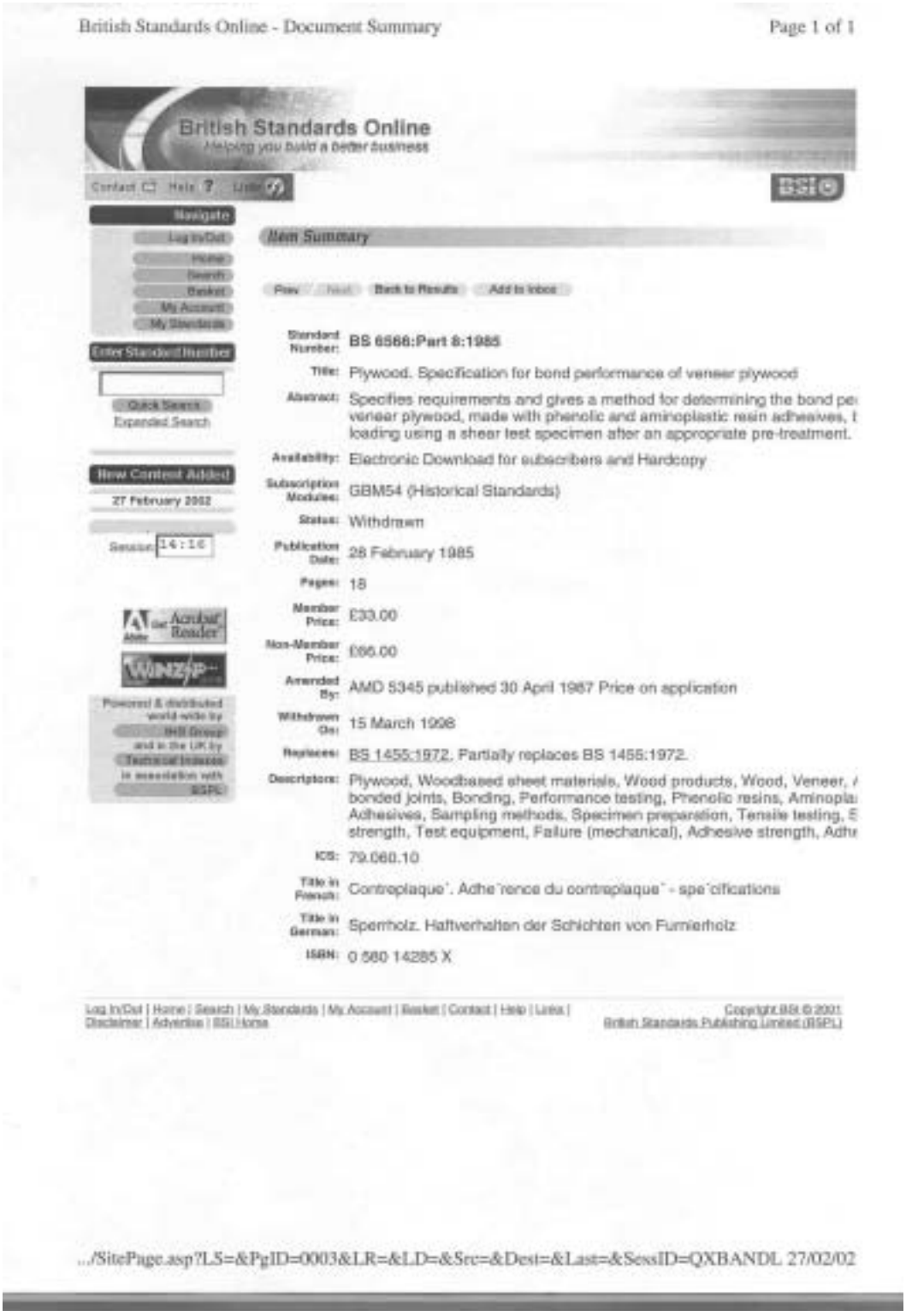

British Standards Online - Document Summary Page 1 of 1

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Item Summary

Prev Next Back to Results Add to Inbox

Standard Number: BS 6566:Part 8:1985

Title: Plywood. Specification for bond performance of veneer plywood

Abstract: Specifies requirements and gives a method for determining the bond pe veneer plywood, made with phenolic and aminoplastic resin adhesives, t loading using a shear test specimen after an appropriate pre-treatment.

Availability: Electronic Download for subscribers and Hardcopy

Subscription Modules: GBM54 (Historical Standards)

Status: Withdrawn

Publication Date: 28 February 1985

Pages: 18

Member Price: £33.00

Non-Member Price: £66.00

Amended By: AMD 5345 published 30 April 1987 Price on application

Withdrawn On: 15 March 1998

Replaces: BS 1455:1972. Partially replaces BS 1455:1972.

Descriptors: Plywood, Woodbased sheet materials, Wood products, Wood, Veneer, / bonded joints, Bonding, Performance testing, Phenolic resins, Aminopla Adhesives, Sampling methods, Specimen preparation, Tensile testing, S strength, Test equipment, Failure (mechanical), Adhesive strength, Adh

ICS: 79.060.10

Title in French: Contreplaque˙. Adhe˙rence du contreplaque˙ - spe˙cifications

Title in German: Sperrholz. Haftverhalten der Schichten von Furnierholz

ISBN: 0 580 14285 X

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Specifications of plywood material

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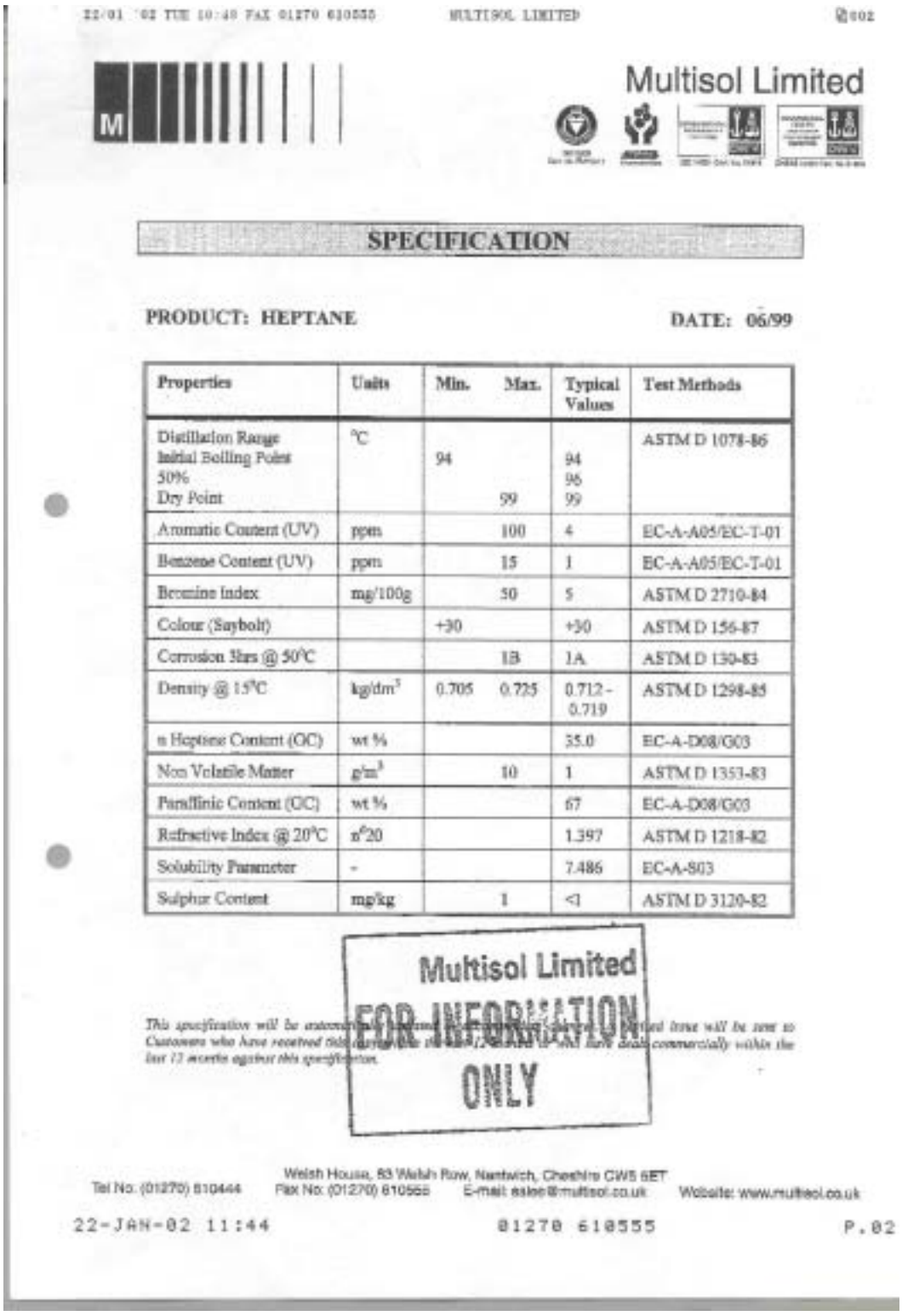

22/01 '02 TUE 10:40 FAX 01270 610555 MULTISOL LIMITED 002

Multisol Limited

SPECIFICATION

PRODUCT: HEPTANE **DATE: 06/99**

Properties	Units	Min.	Max.	Typical Values	Test Methods
Distillation Range Initial Boiling Point 50% Dry Point	°C	 94	 99	 94 96 99	ASTM D 1078-86
Aromatic Content (UV)	ppm		100	4	EC-A-A05/EC-T-01
Benzene Content (UV)	ppm		15	1	EC-A-A05/EC-T-01
Bromine Index	mg/100g		50	5	ASTM D 2710-84
Colour (Saybolt)		+30		+30	ASTM D 156-87
Corrosion 3hrs @ 50°C			1B	1A	ASTM D 130-83
Density @ 15°C	kg/dm³	0.705	0.725	0.712 - 0.719	ASTM D 1298-85
n Heptane Content (GC)	wt %			35.0	EC-A-D08/G03
Non Volatile Matter	g/m³		10	1	ASTM D 1353-83
Paraffinic Content (GC)	wt %			67	EC-A-D08/G03
Refractive Index @ 20°C	n°20			1.397	ASTM D 1218-82
Solubility Parameter	-			7.486	EC-A-S03
Sulphur Content	mg/kg		1	<1	ASTM D 3120-82

Multisol Limited
FOR INFORMATION
ONLY

This specification will be automatically [illegible] issue will be sent to Customers who have received this [illegible] commercially within the last 12 months against this specification.

Welsh House, 83 Welsh Row, Nantwich, Cheshire CW5 5ET
Tel No: (01270) 610444 Fax No: (01270) 610555 E-mail: sales@multisol.co.uk Website: www.multisol.co.uk

22-JAN-02 11:44 01270 610555 P.02

Specification of heptane

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Appendix 4E – Graphs of temperature versus time for Benchmark tests

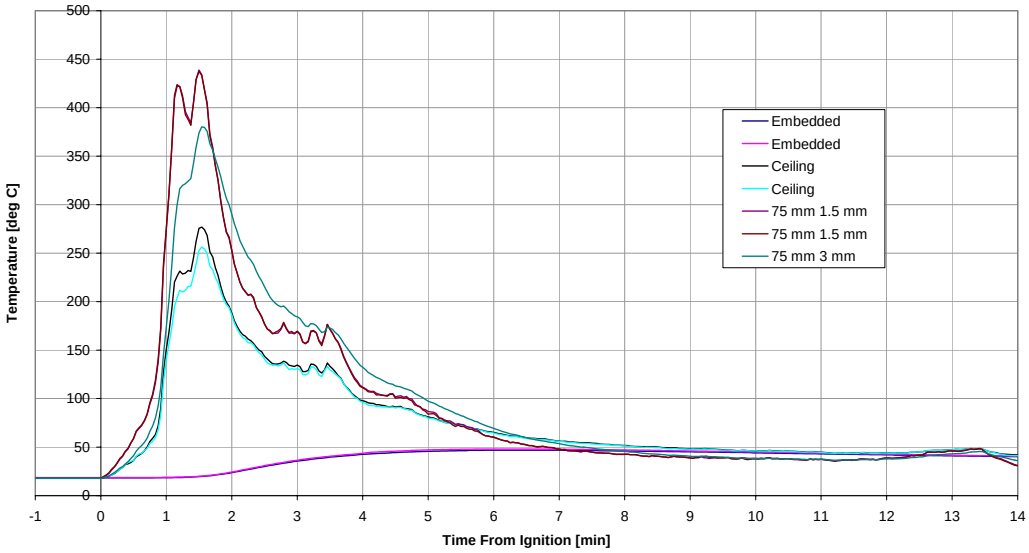

Figure 4E.1 Test 1 Temperatures above crib

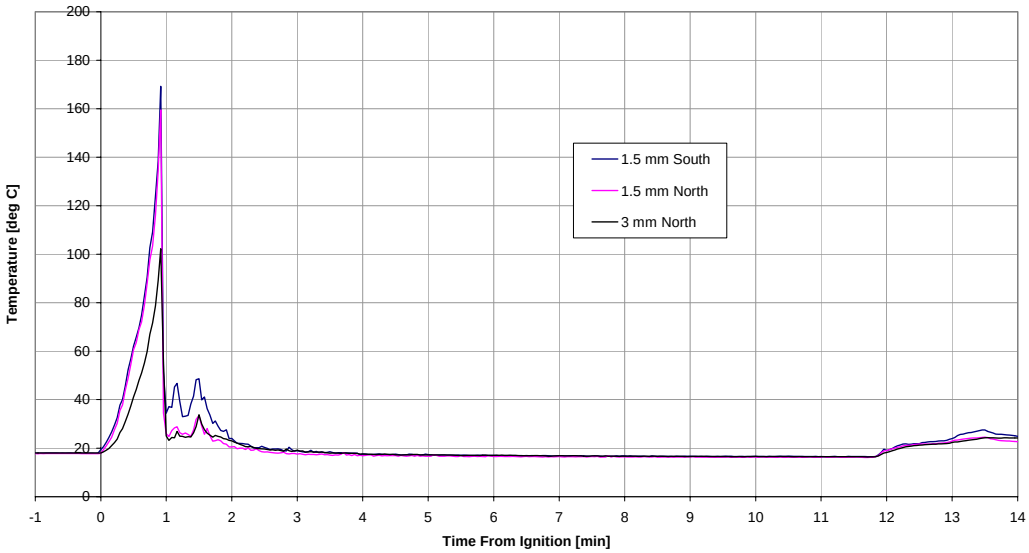

Figure 4E.2 Test 1 Temperatures at sprinkler B1

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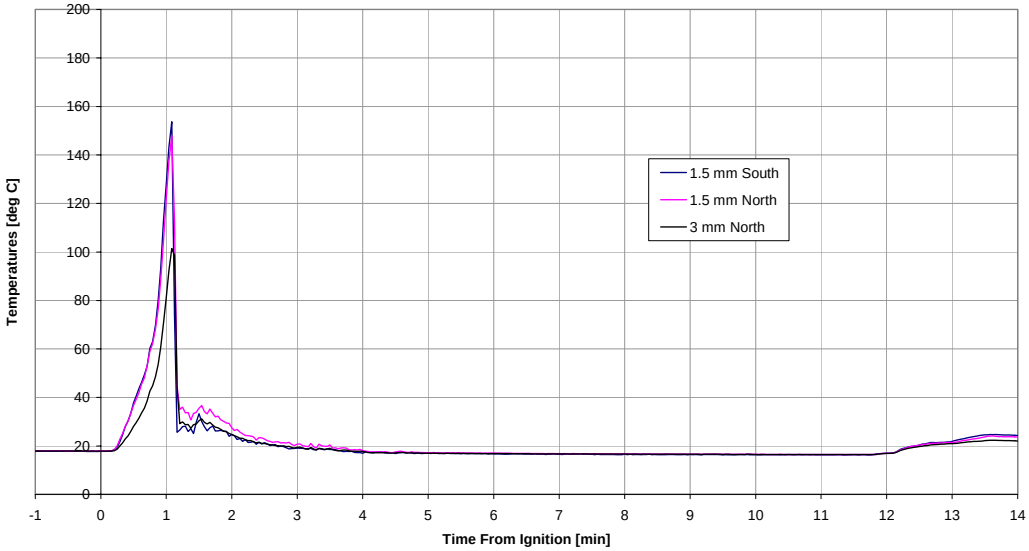

Figure 4E.3 Test 1 Temperatures at sprinkler B2

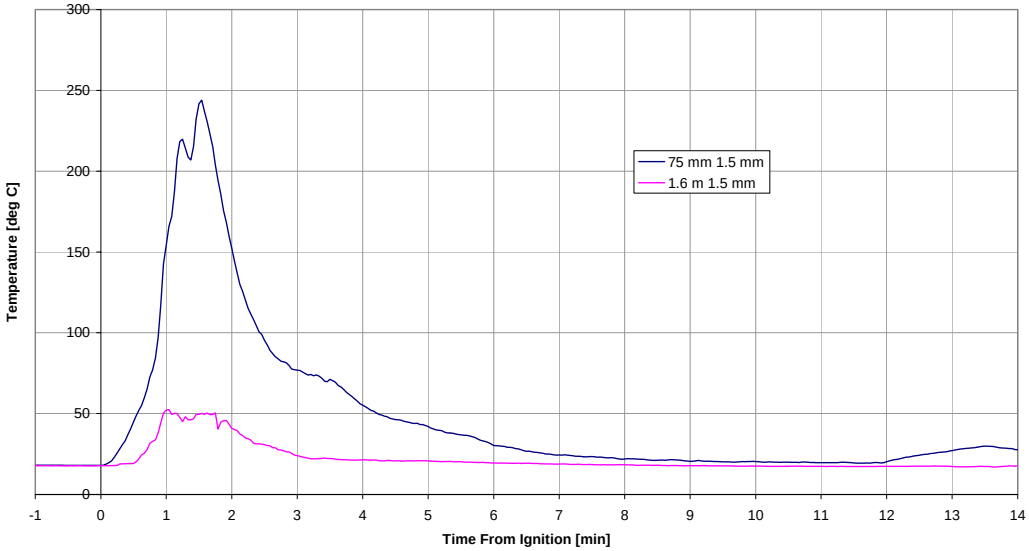

Figure 4E.4 Test 1 Temperatures at centre of room

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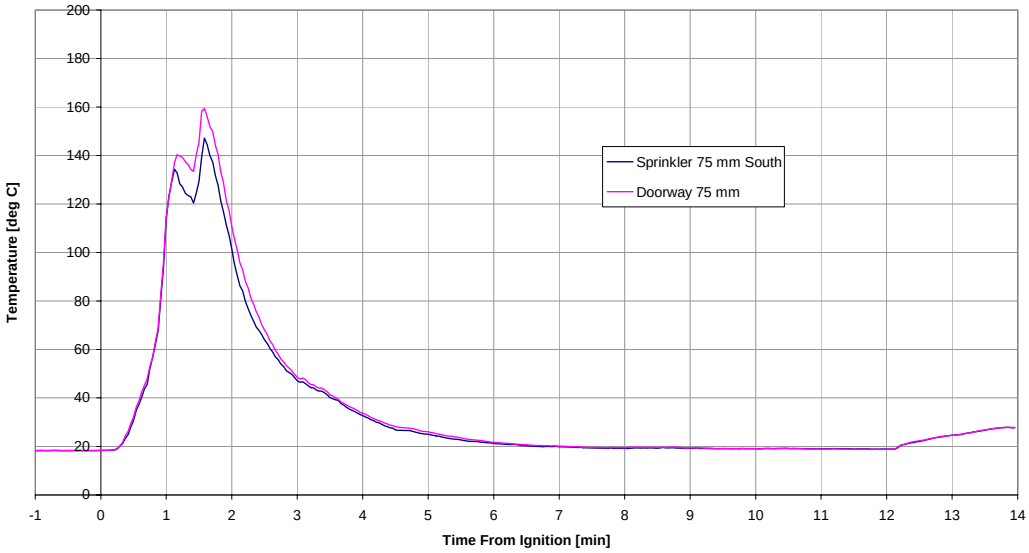

Figure 4E.5 Test 1 Temperatures at doorway

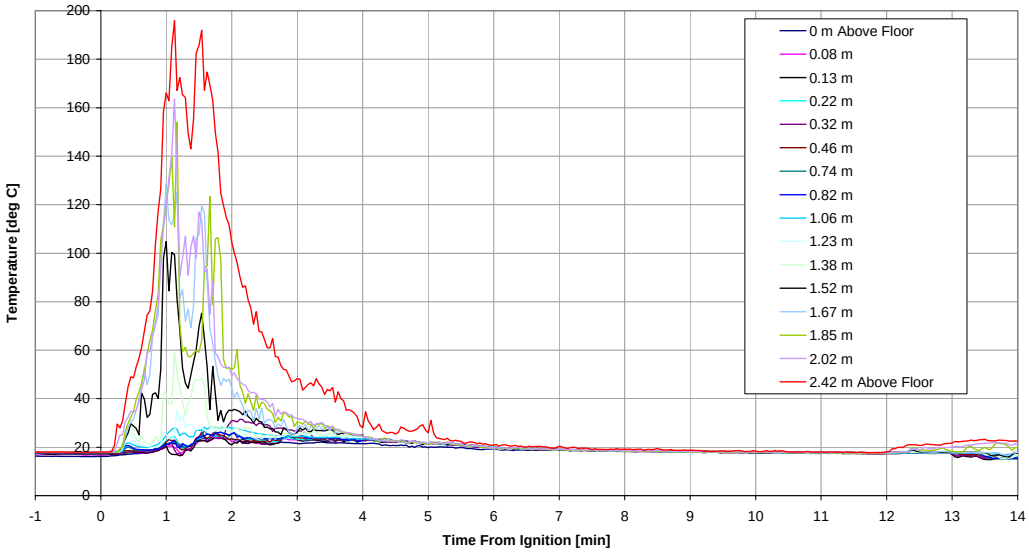

Figure 4E.6 Test 1 Temperatures at column 1

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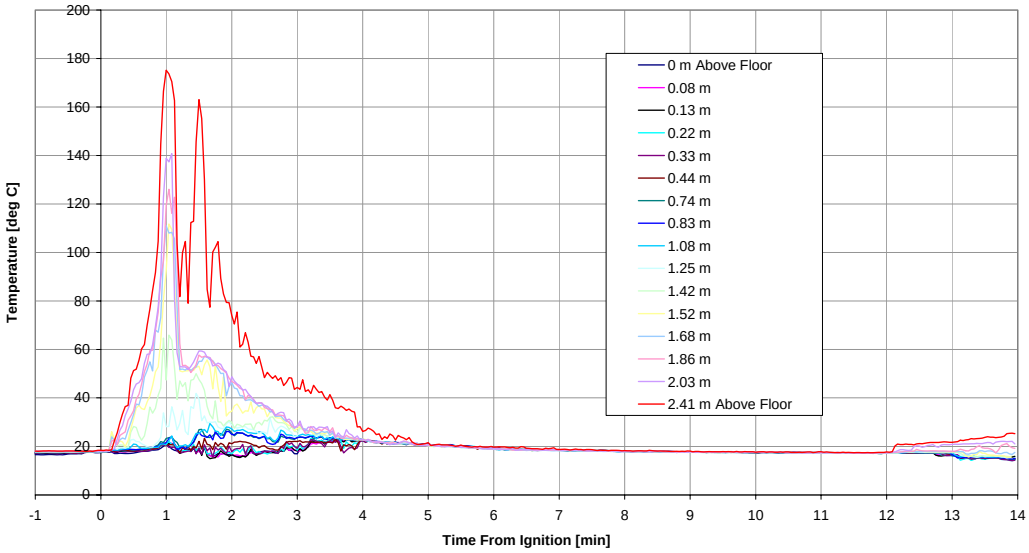

Figure 4E.7 Test 1 Temperatures at column 2

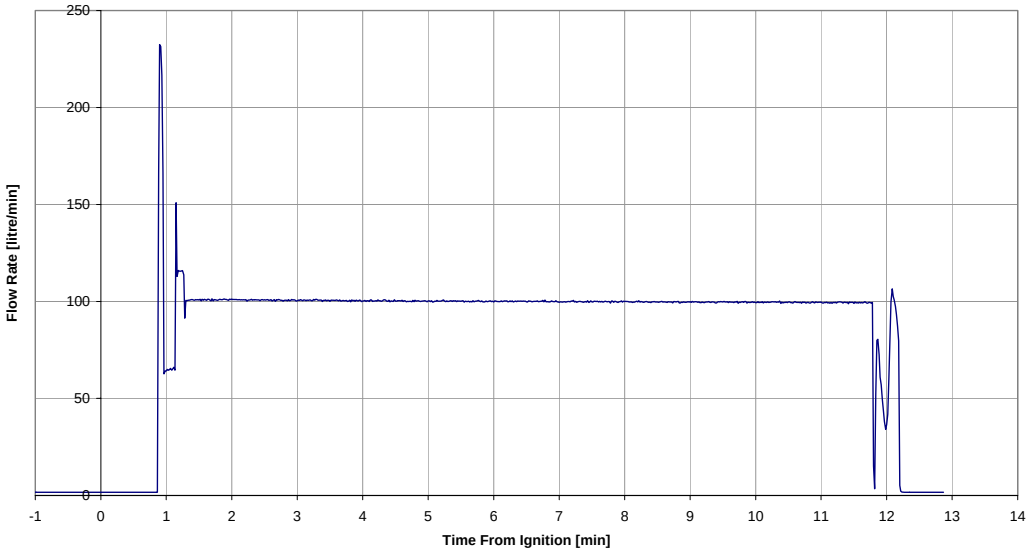

Figure 4E.8 Test 1 Sprinkler water flow rate

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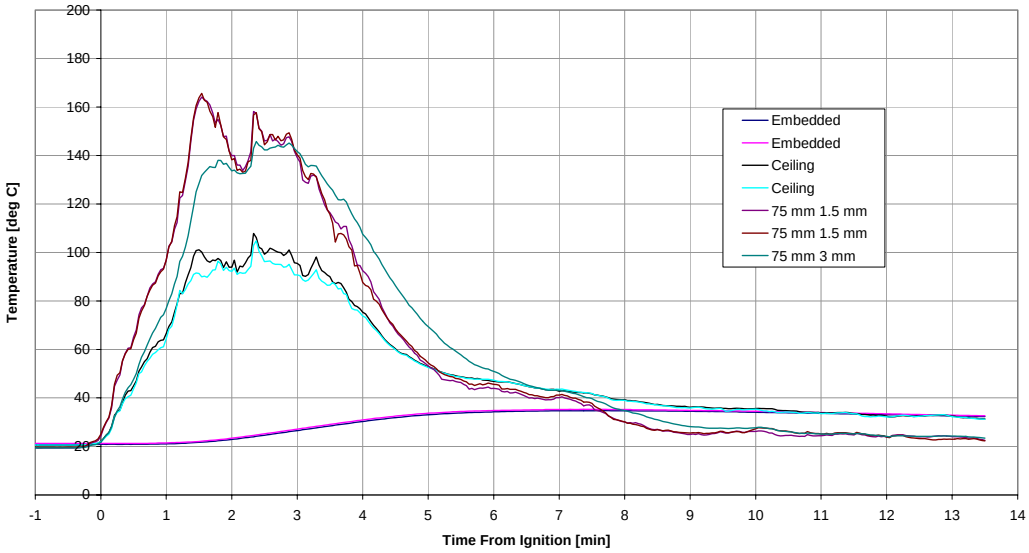

Figure 4E.9 Test 2 Temperatures above crib

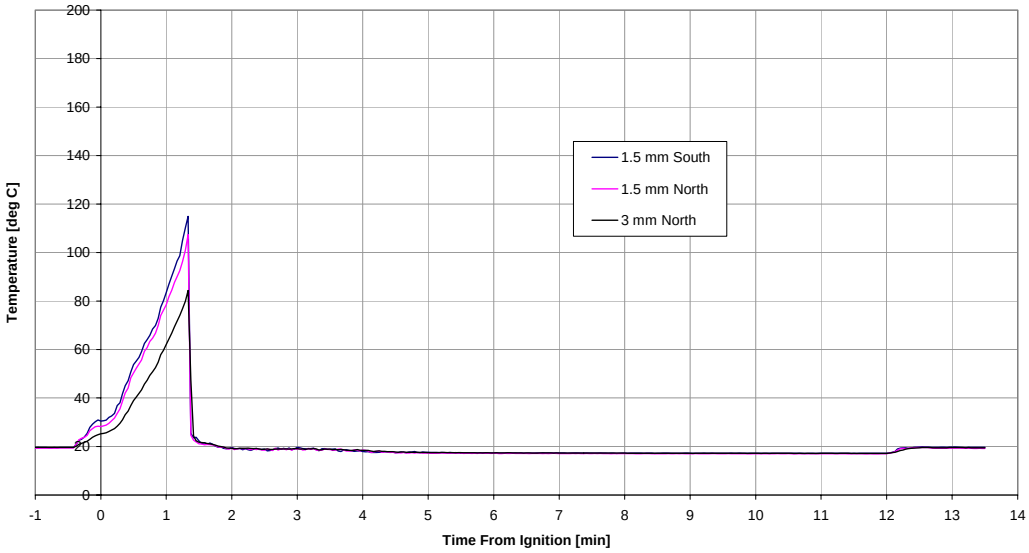

Figure 4E.10 Test 2 Temperatures at sprinkler B1

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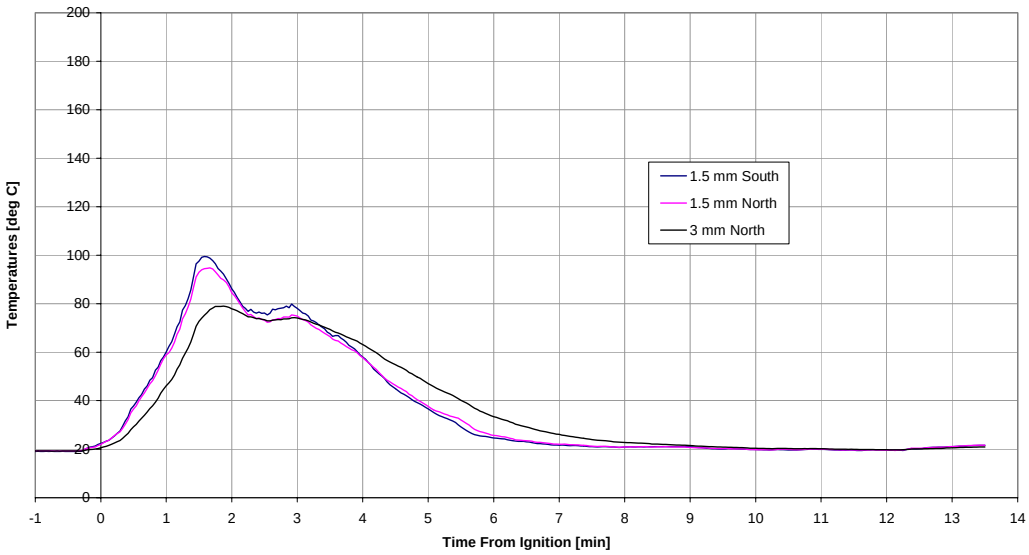

Figure 4E.11 Test 2 Temperatures at sprinkler B2

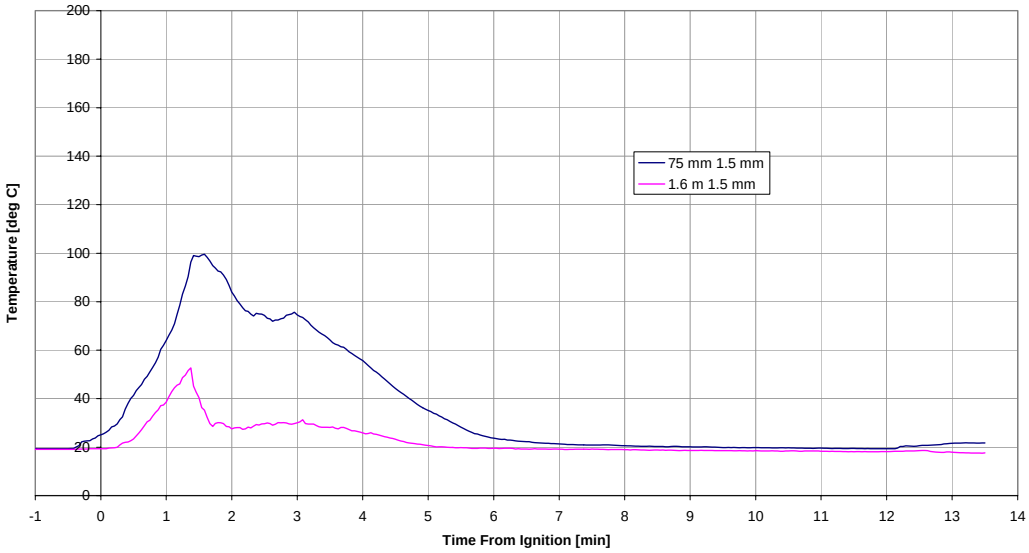

Figure 4E.12 Test 2 Temperatures at centre of room

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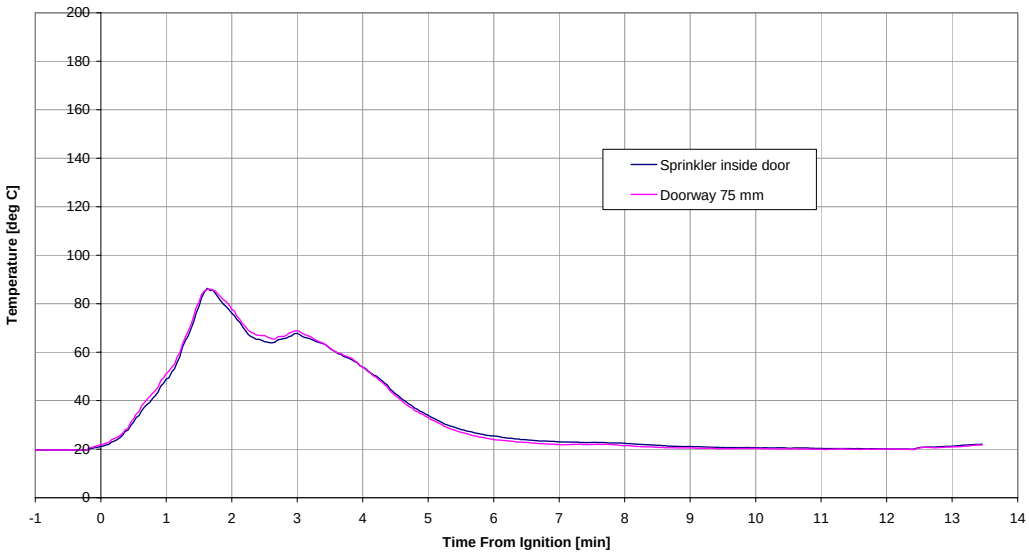

Figure 4E.13 Test 2 Temperatures at doorway

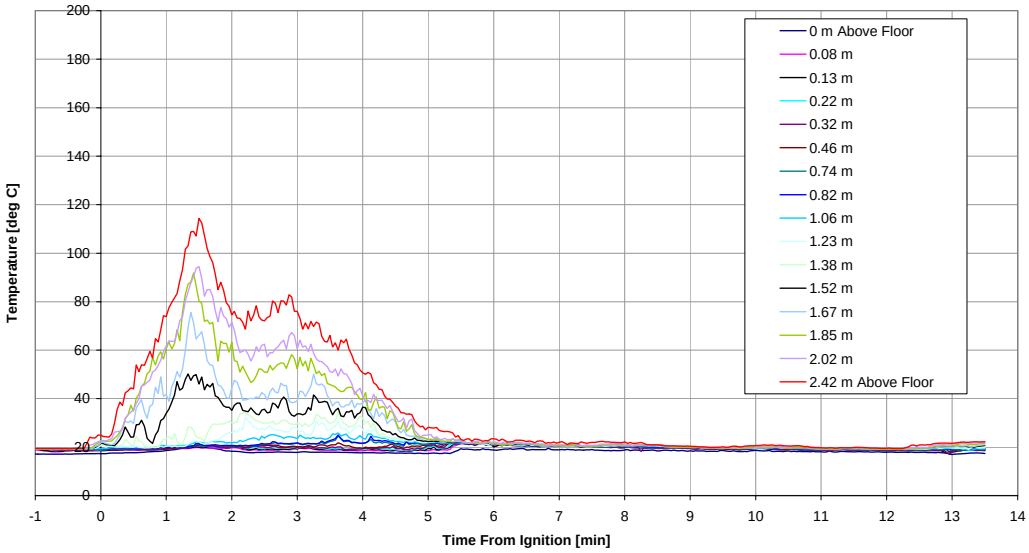

Figure 4E.14 Test 2 Temperatures at column 1

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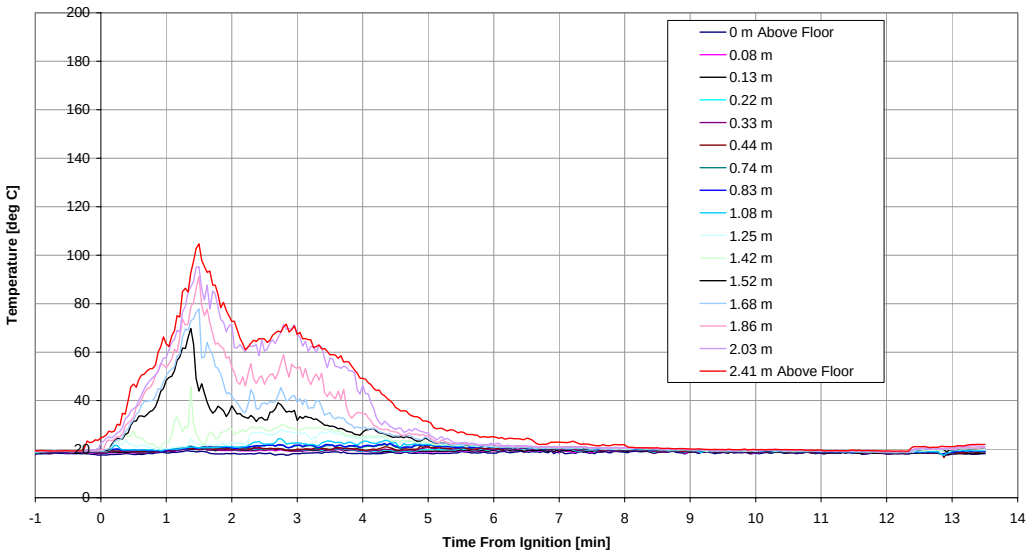

Figure 4E.15 Test 2 Temperatures at column 2

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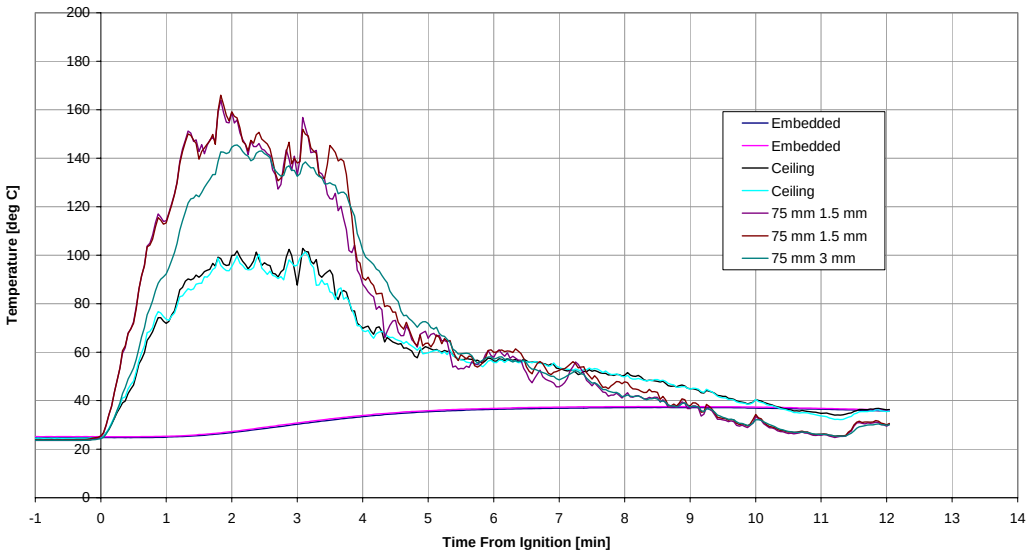

Figure 4E.16 Test 3 Temperatures above crib

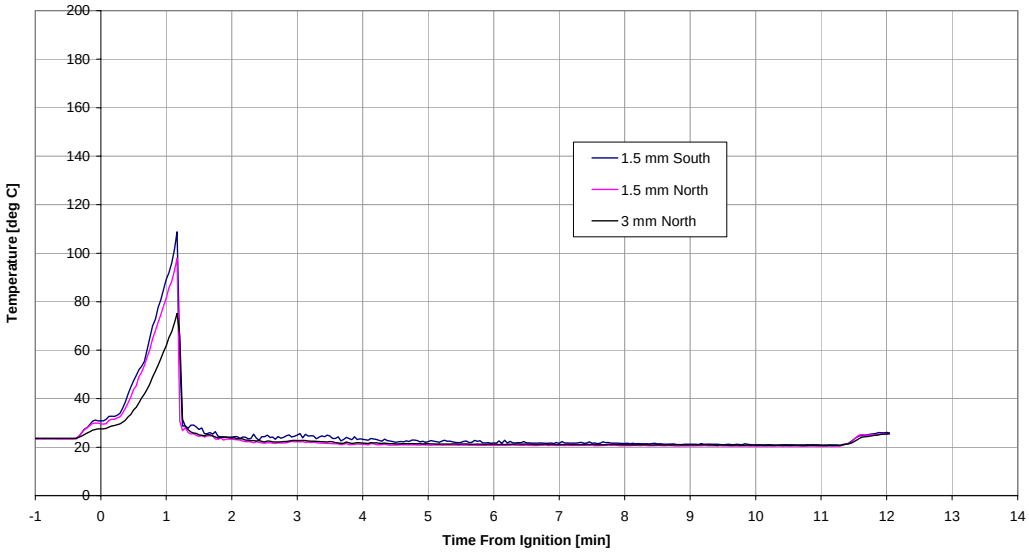

Figure 4E.17 Test 3 Temperatures at sprinkler B1

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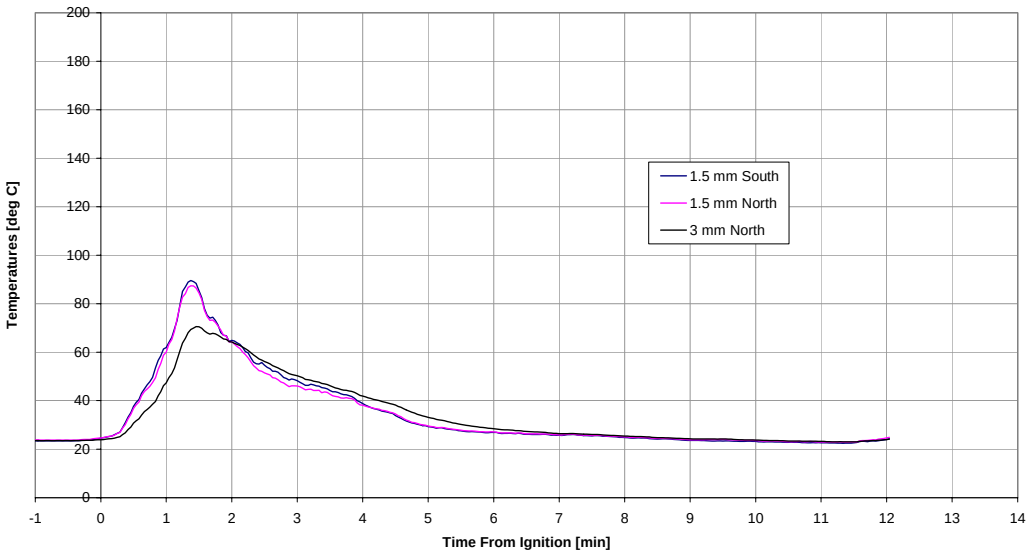

Figure 4E.18 Test 3 Temperatures at sprinkler B2

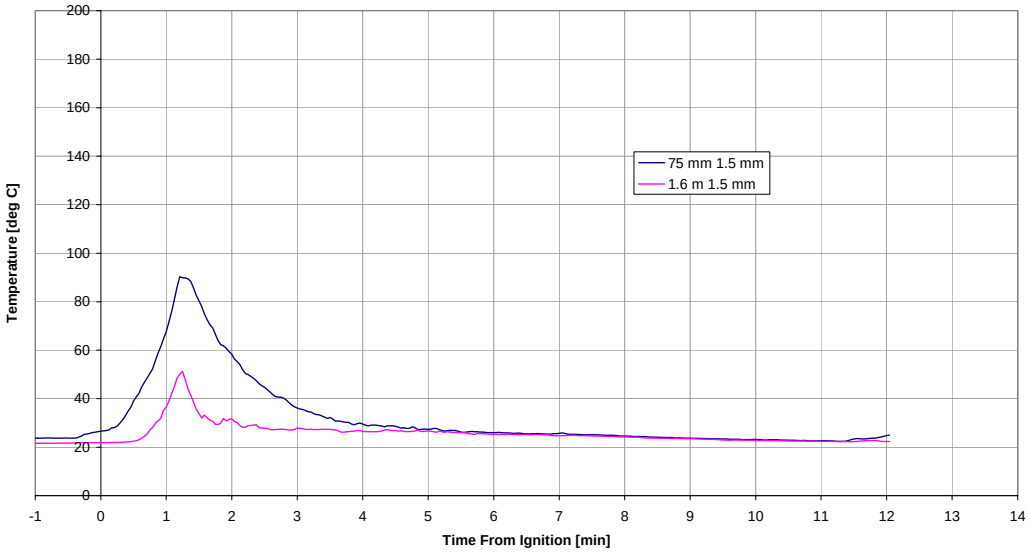

Figure 4E.19 Test 3 Temperature at centre of room

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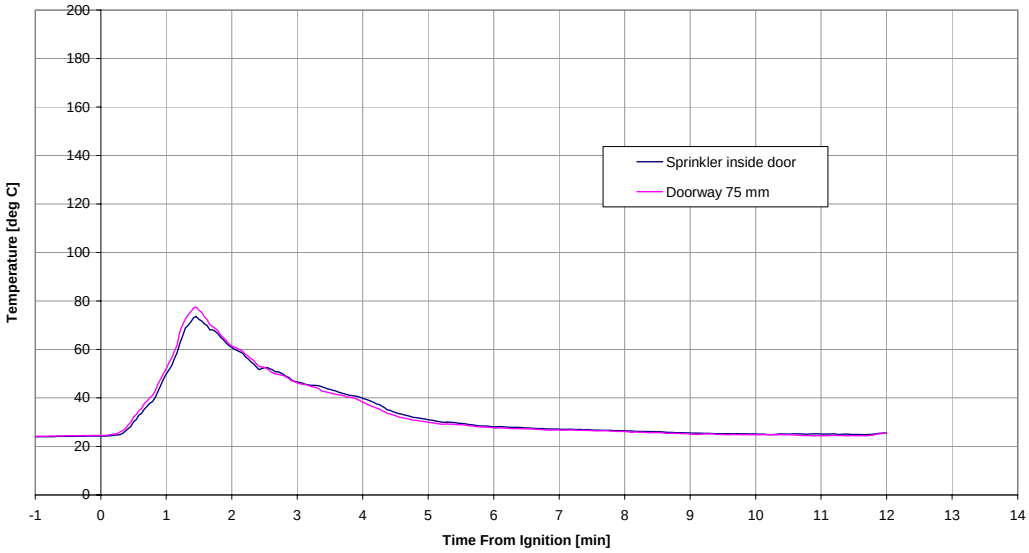

Figure 4E.20 Test 3 Temperatures at doorway

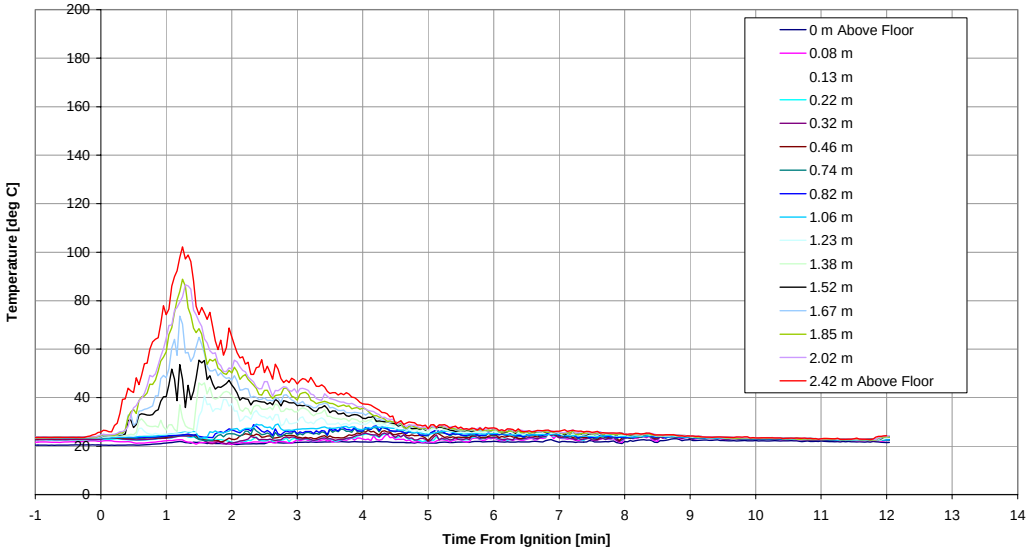

Figure 4E.21 Test 3 Temperatures at column 1

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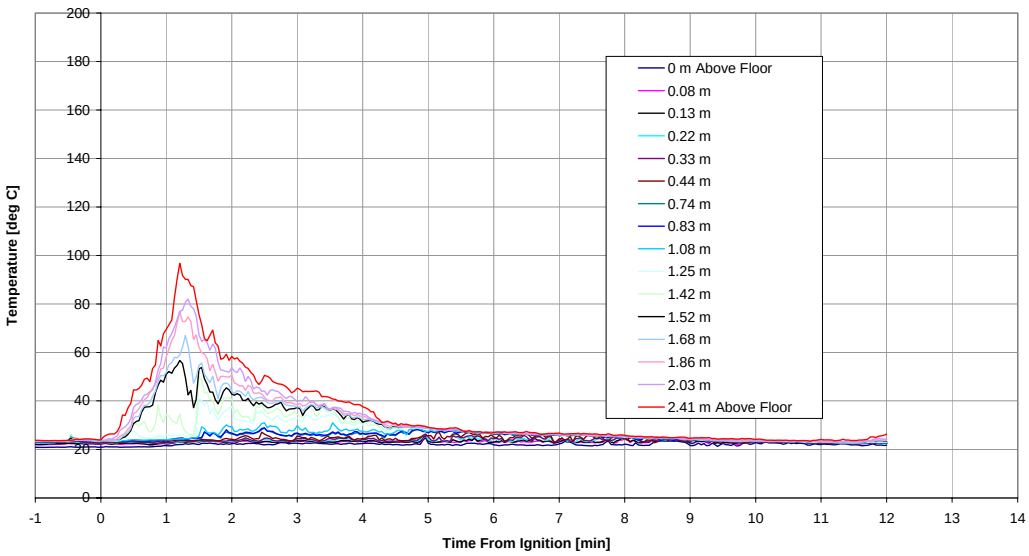

Figure 4E.22 Test 3 Temperatures at column 2

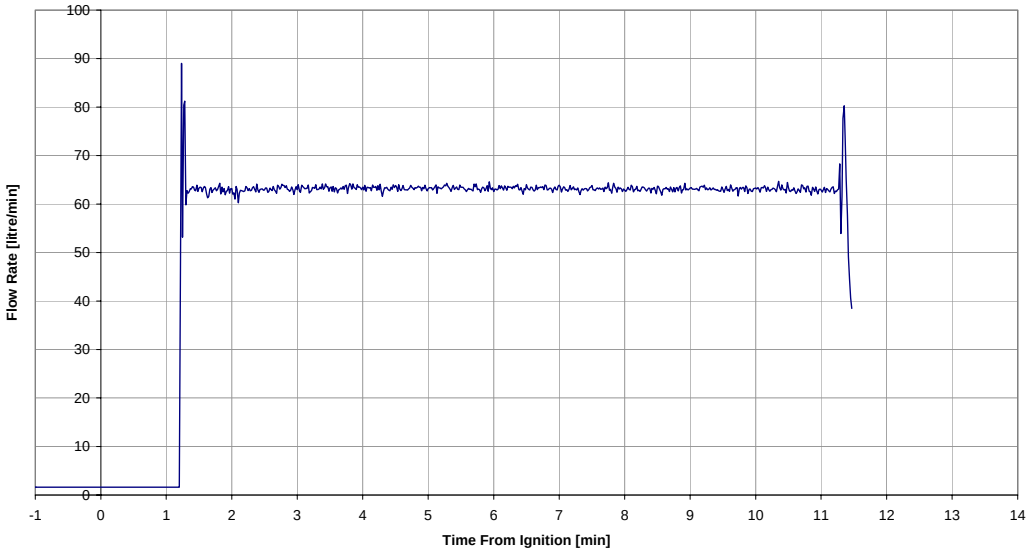

Figure 4E.23 Test 3 Sprinkler water flow rate

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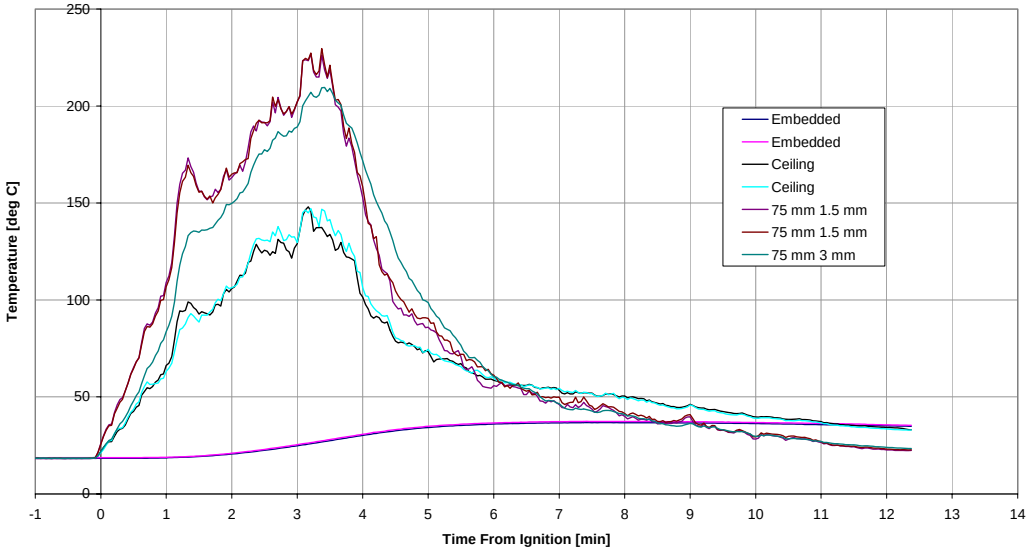

Figure 4E.24 Test 4 Temperatures above crib

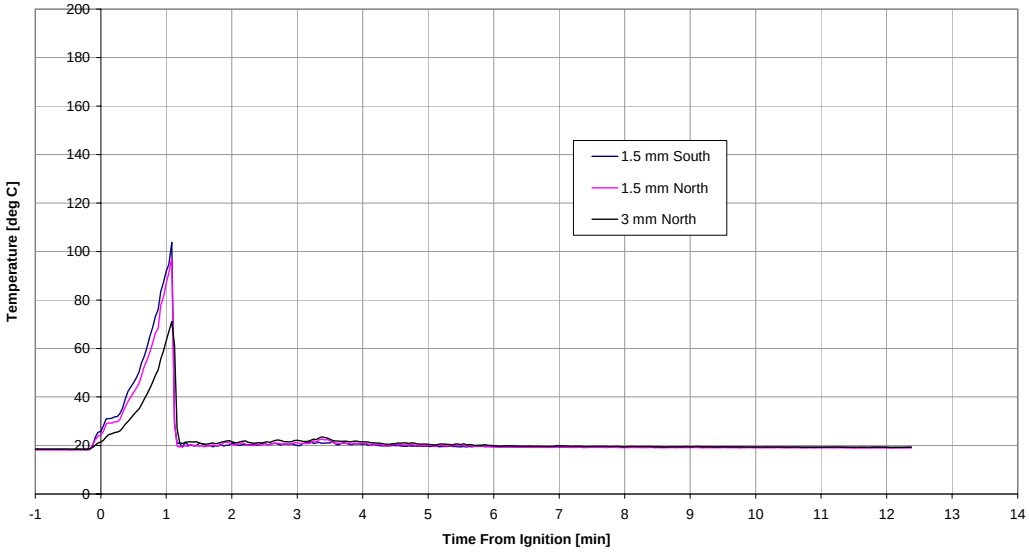

Figure 4E.25 Test 4 Temperatures at sprinkler B1

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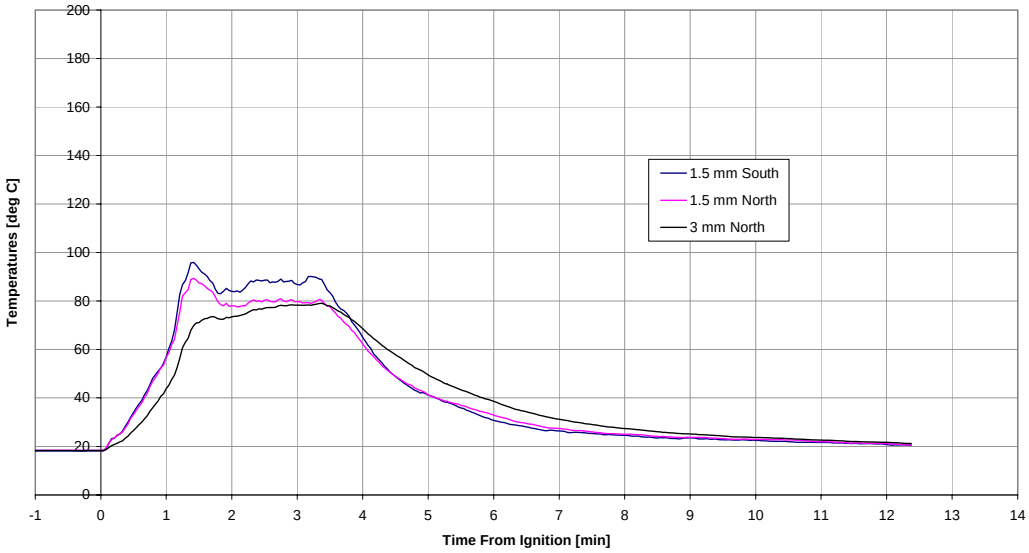

Figure 4E.26 Test 4 Temperatures at sprinkler B2

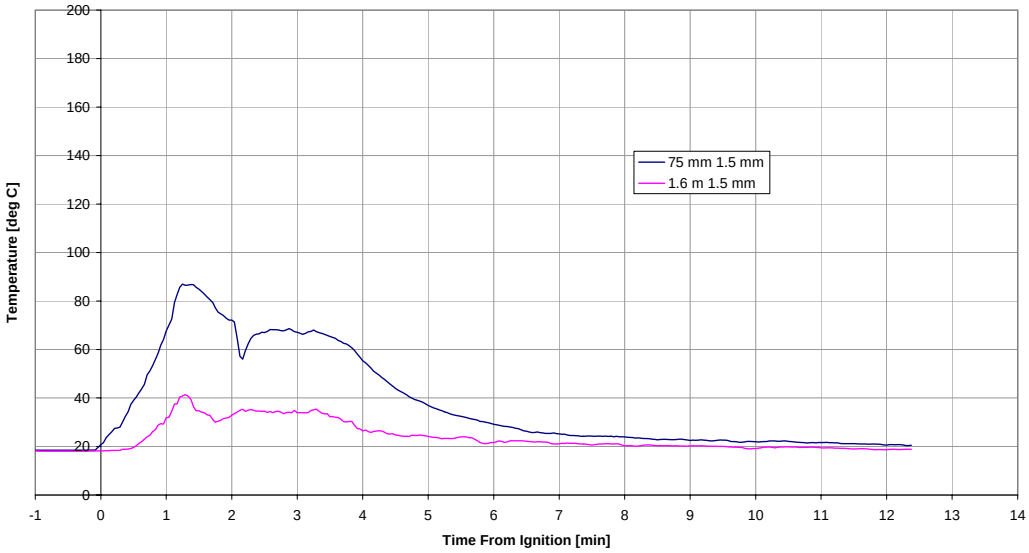

Figure 4E.27 Test 4 Temperatures at centre of room

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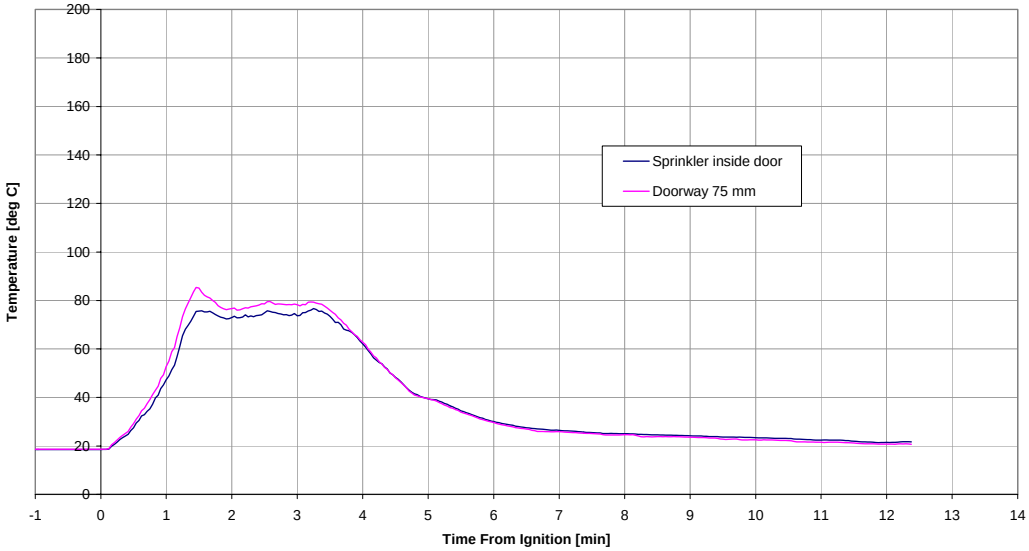

Figure 4E.28 Test 4 Temperatures at doorway

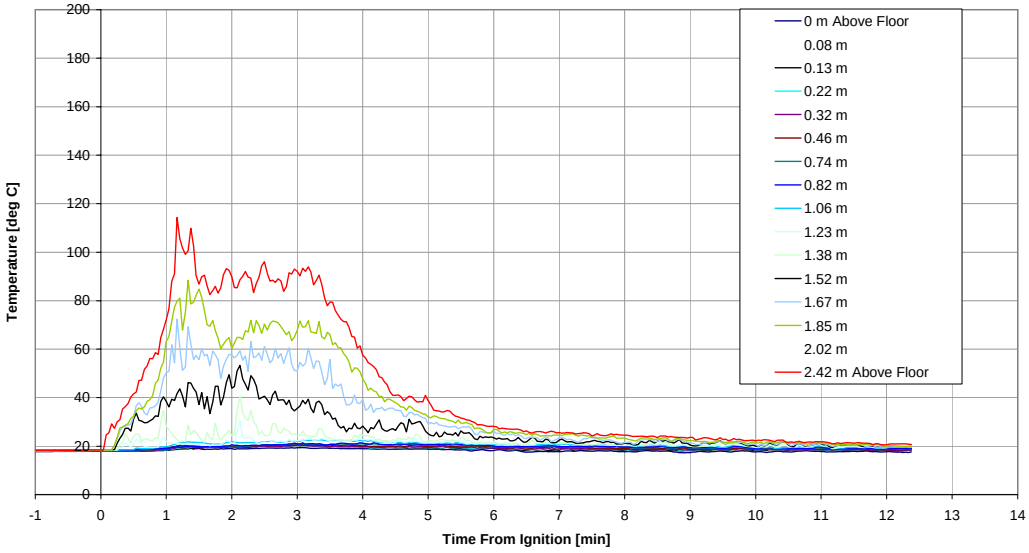

Figure 4E.29 Test 4 Temperatures at column 1

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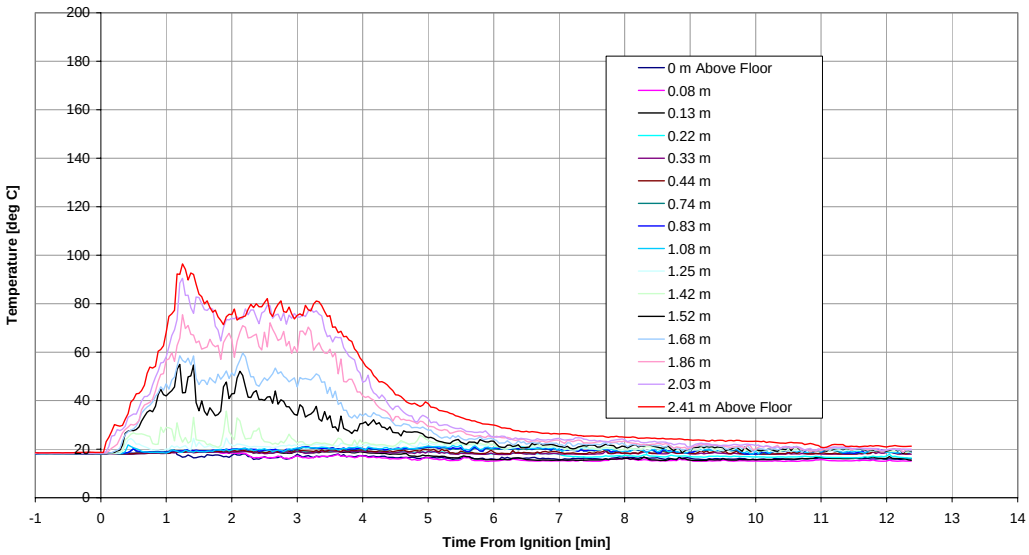

Figure 4E.30 Test 4 Temperatures at column 2

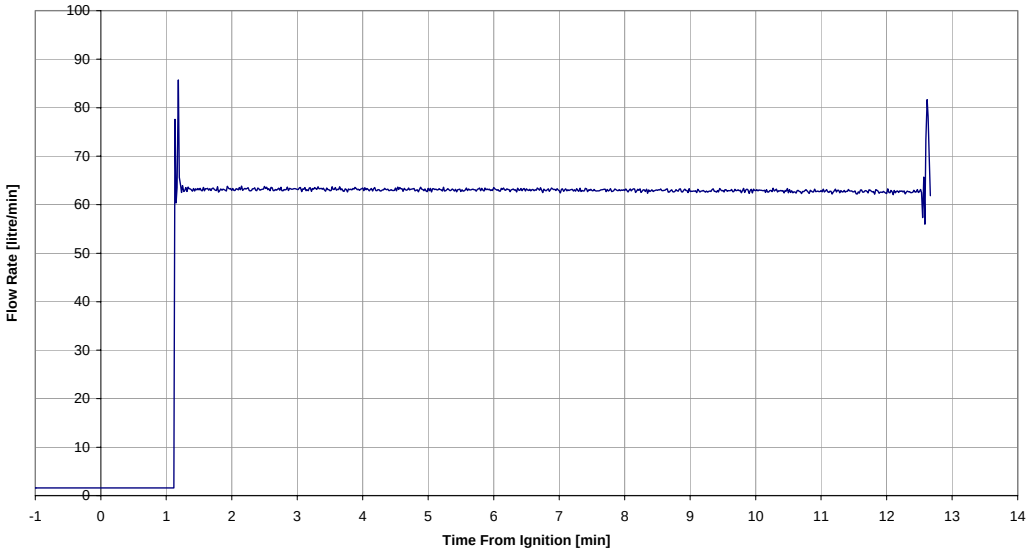

Figure 4E.31 Test 4 Sprinkler water flow rate

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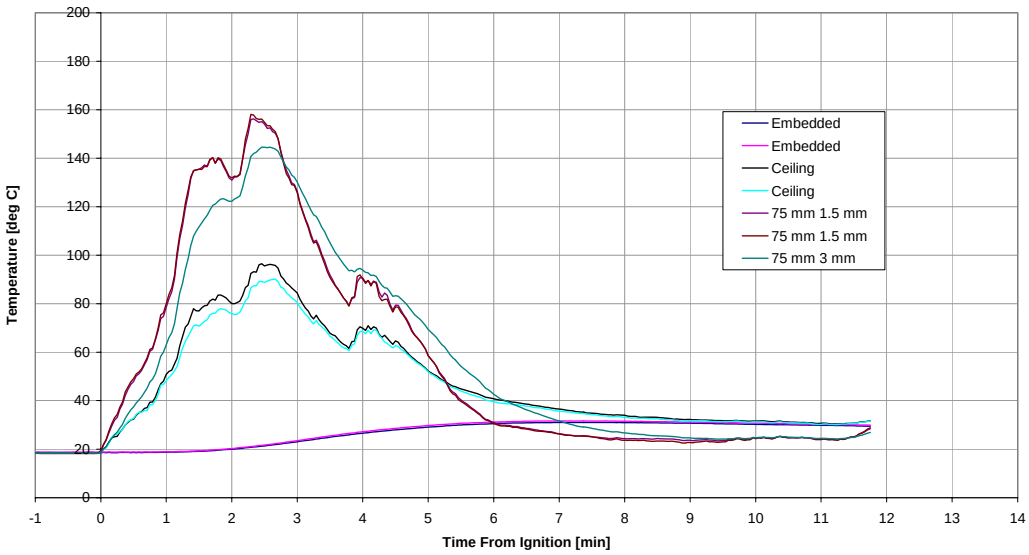

Figure 4E.32 Test 5 Temperatures above crib

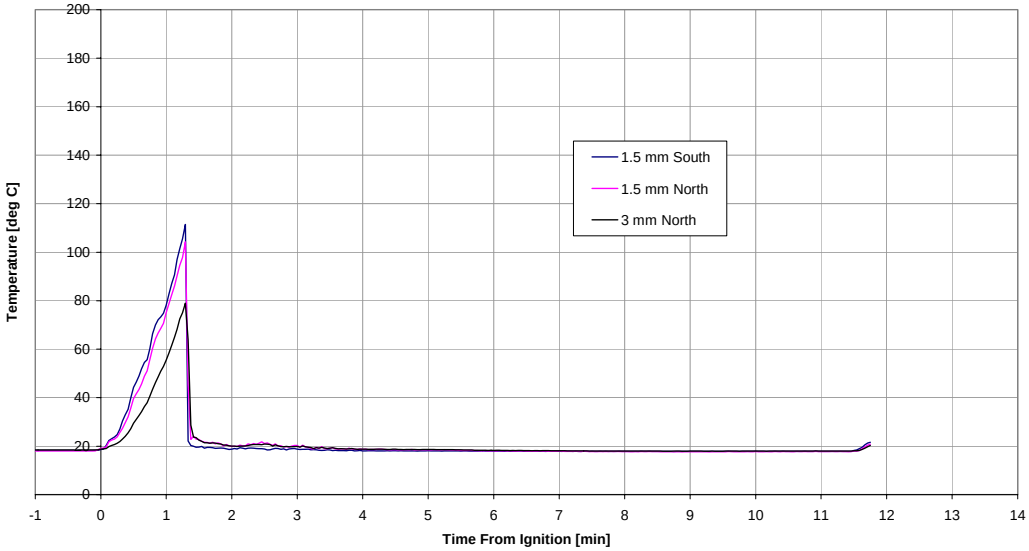

Figure 4E.33 Test 5 Temperatures at sprinkler B1

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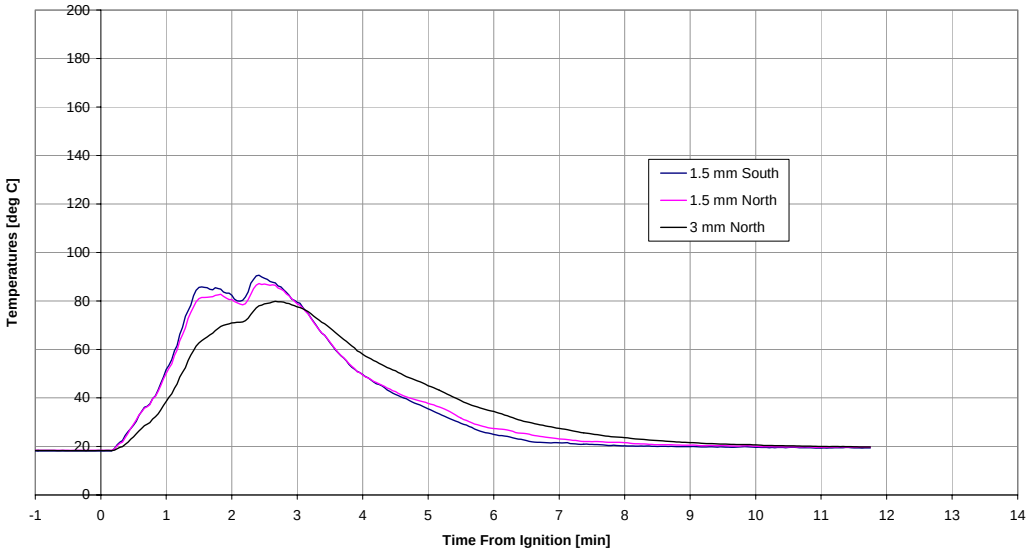

Figure 4E.34 Test 5 Temperatures at sprinkler B2

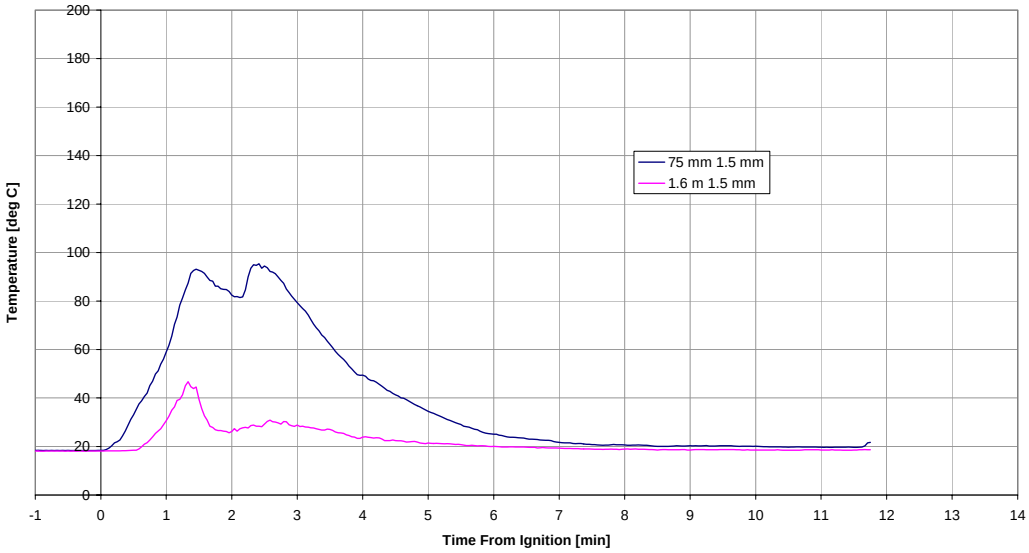

Figure 4E.35 Test 5 Temperatures at centre of room

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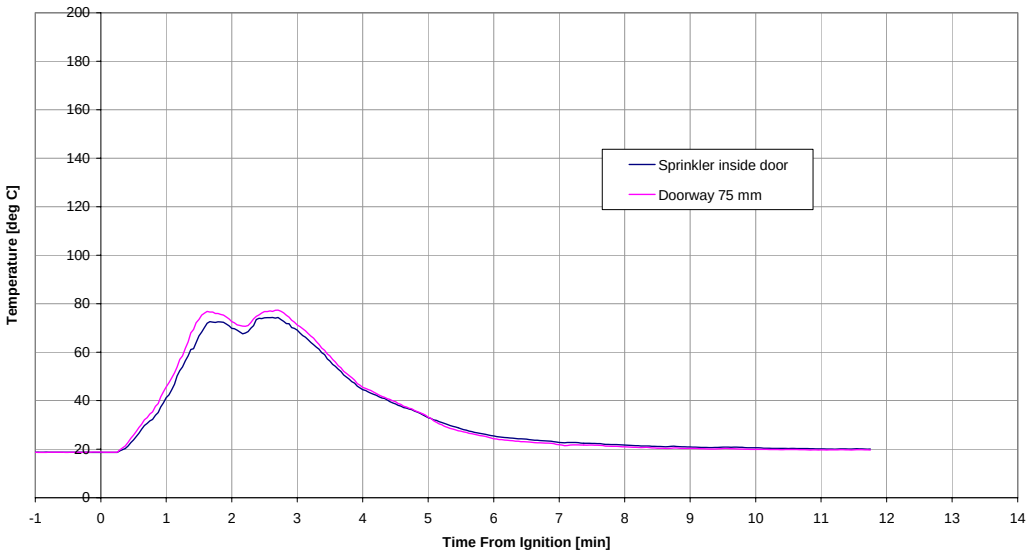

Figure 4E.36 Test 5 Temperatures at doorway

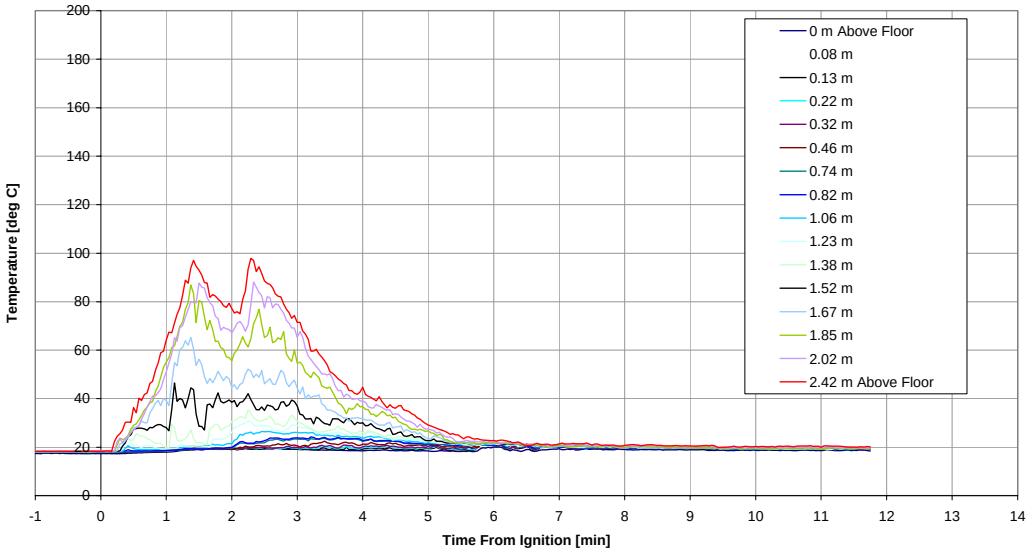

Figure 4E.37 Test 5 Temperatures at column 1

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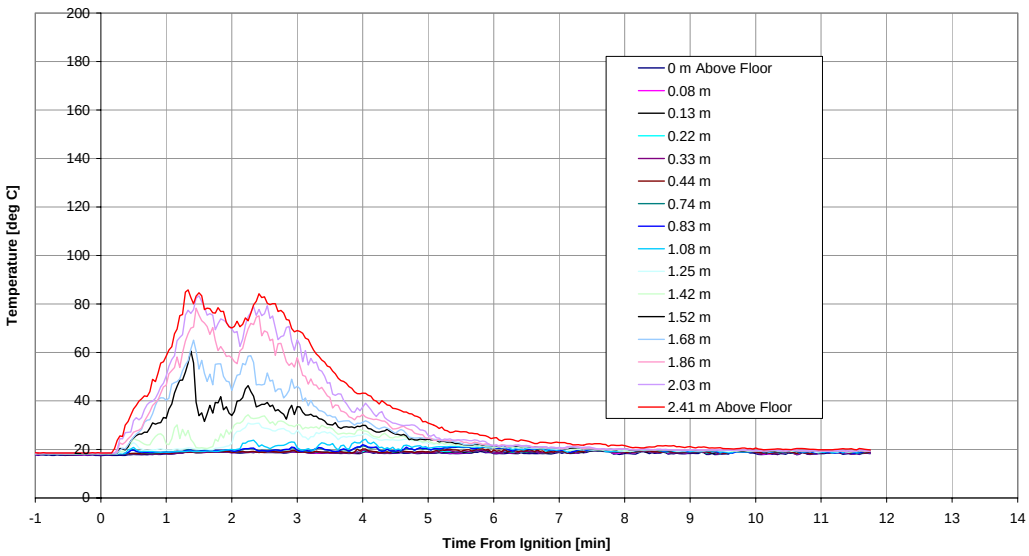

Figure 4E.38 Test 5 Temperatures at column 2

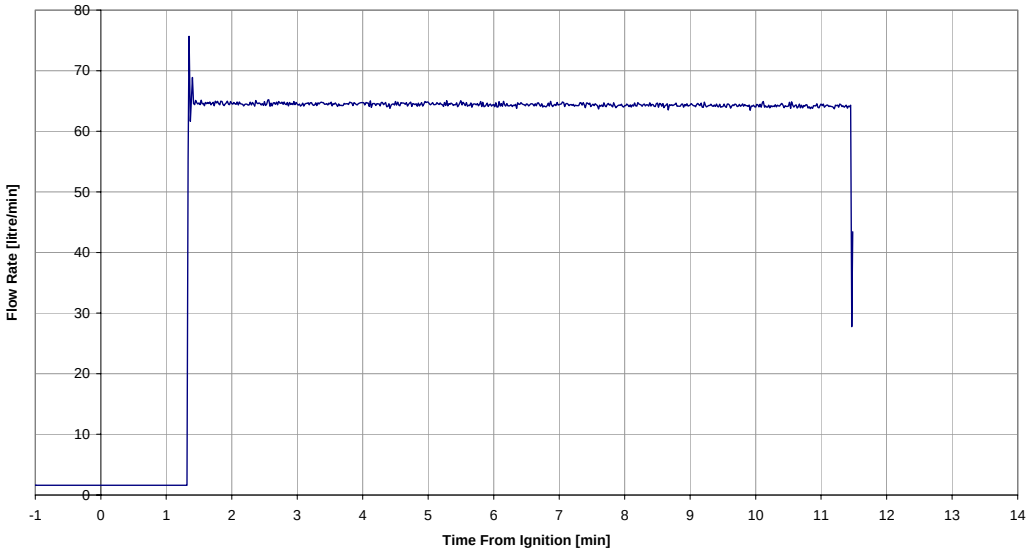

Figure 4E.39 Test 5 Sprinkler water flow rate

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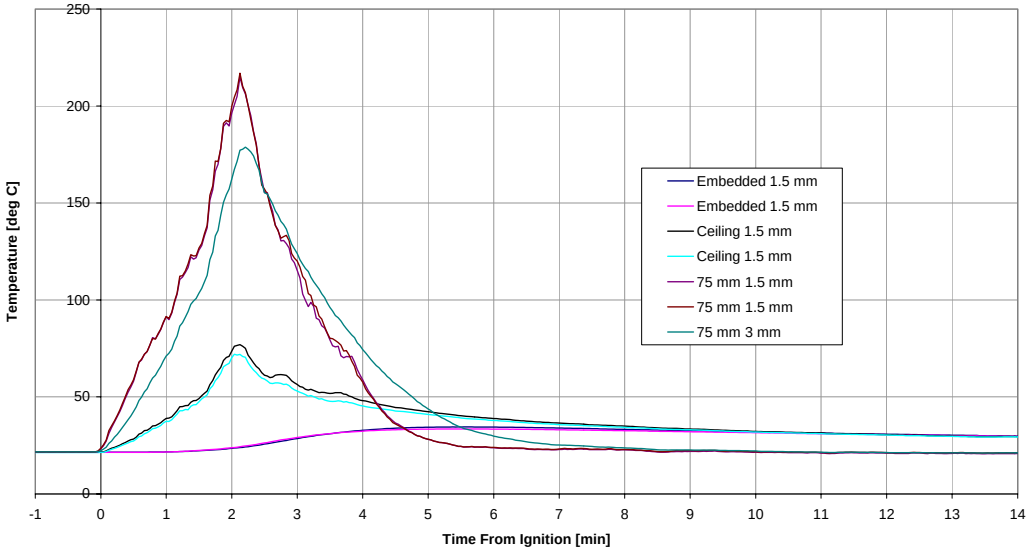

Figure 4E.40 Test 6 Temperatures above crib

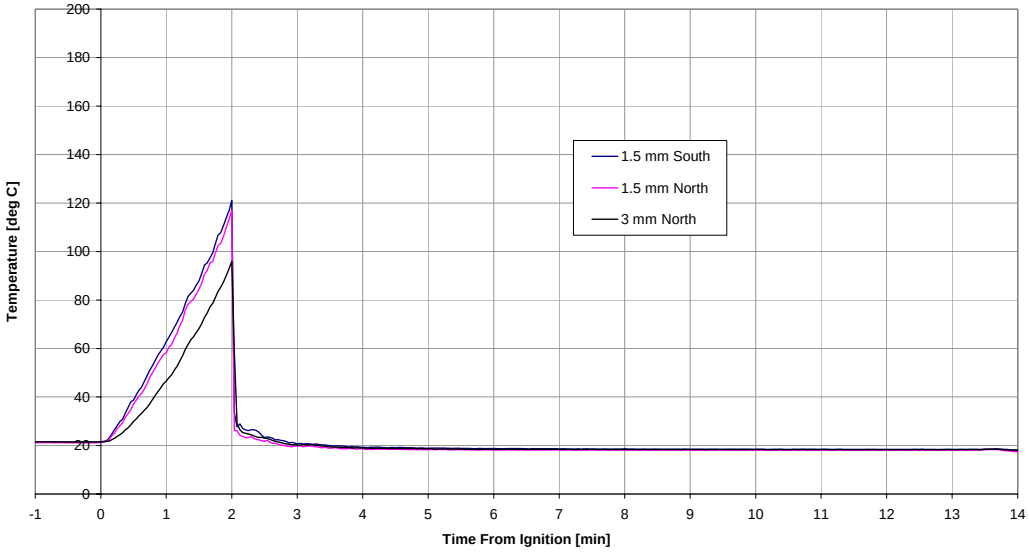

Figure 4E.41 Test 6 Temperatures at sprinkler B1

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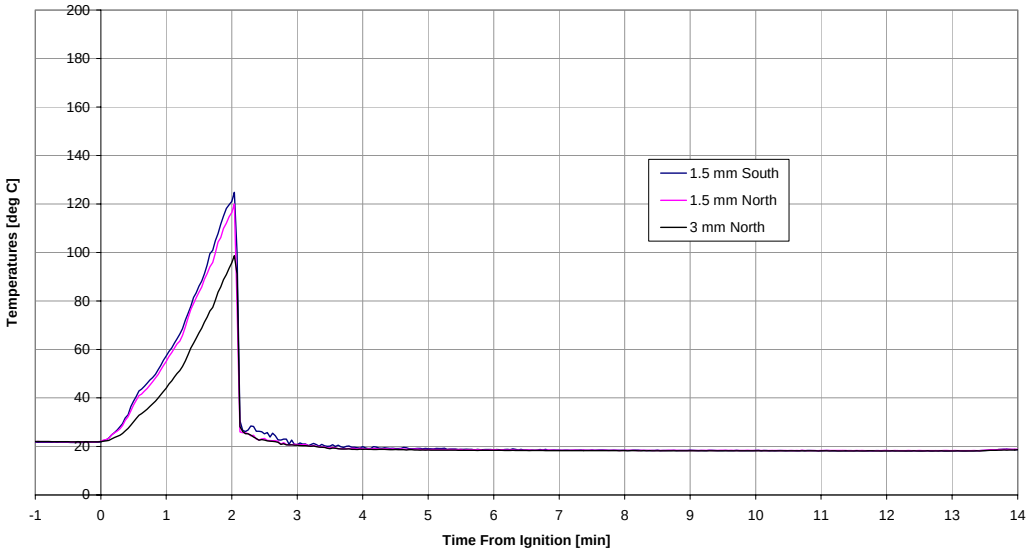

Figure 4E.42 Test 6 Temperatures at sprinkler B2

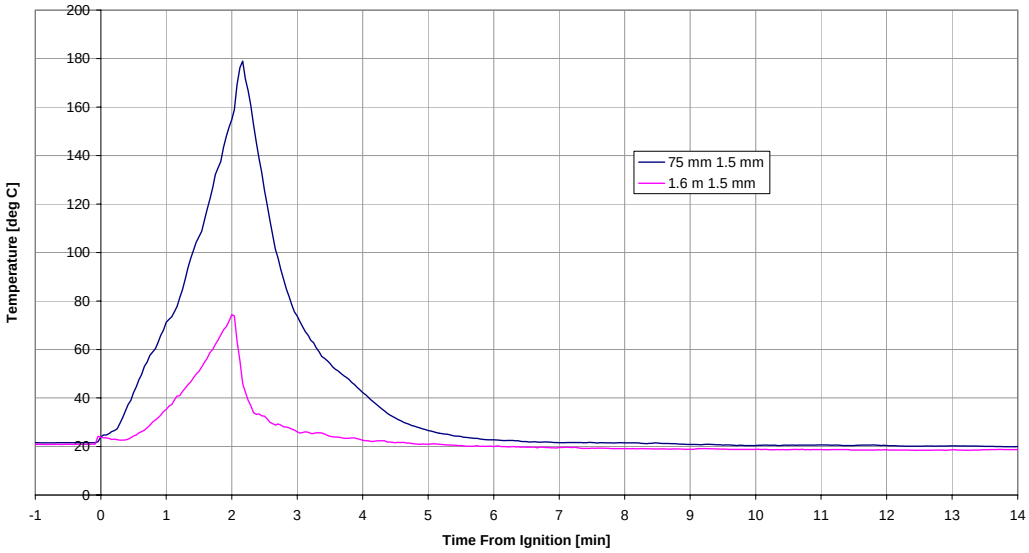

Figure 4E.43 Test 6 Temperatures at centre of room

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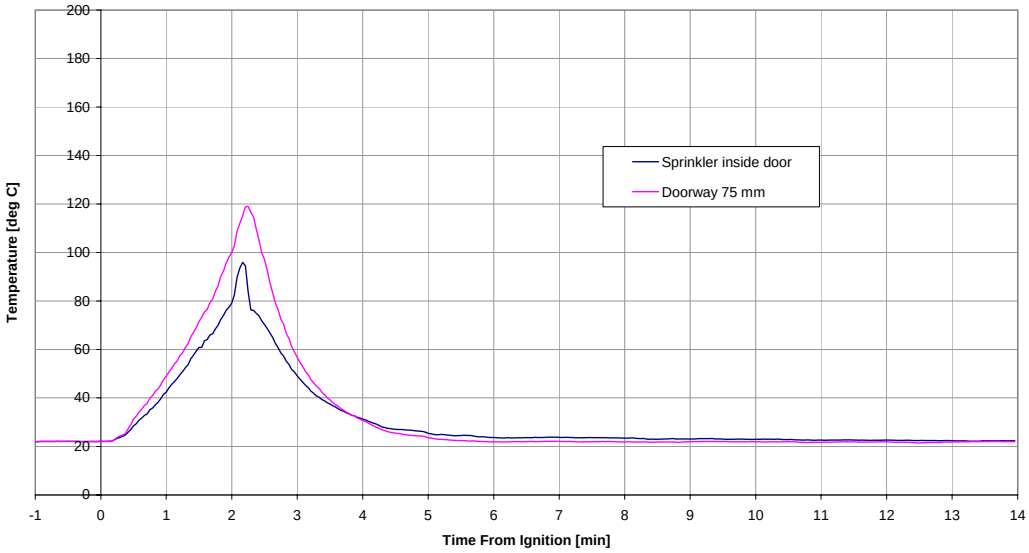

Figure 4E.44 Test 6 Temperatures at doorway

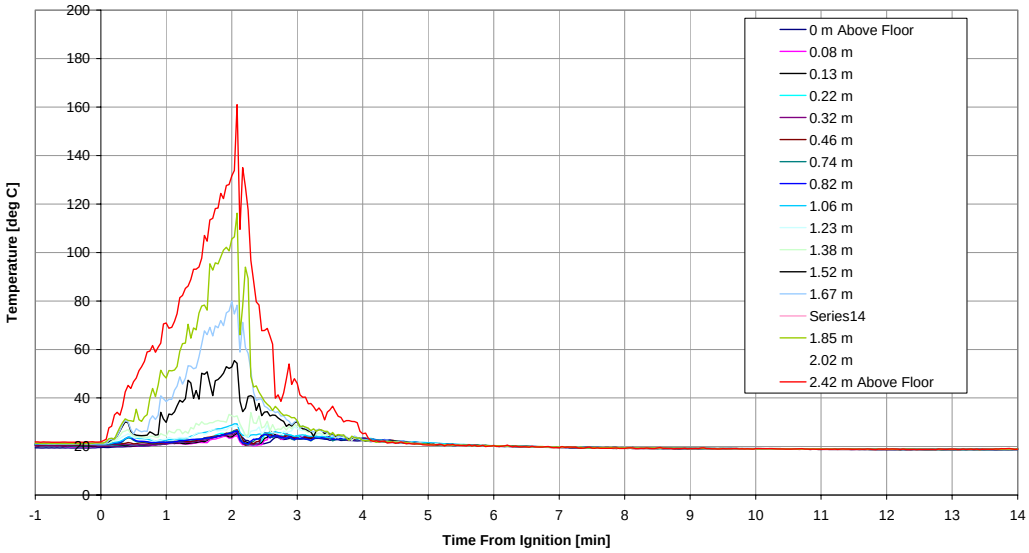

Figure 4E.45 Test 6 Temperatures at column 1

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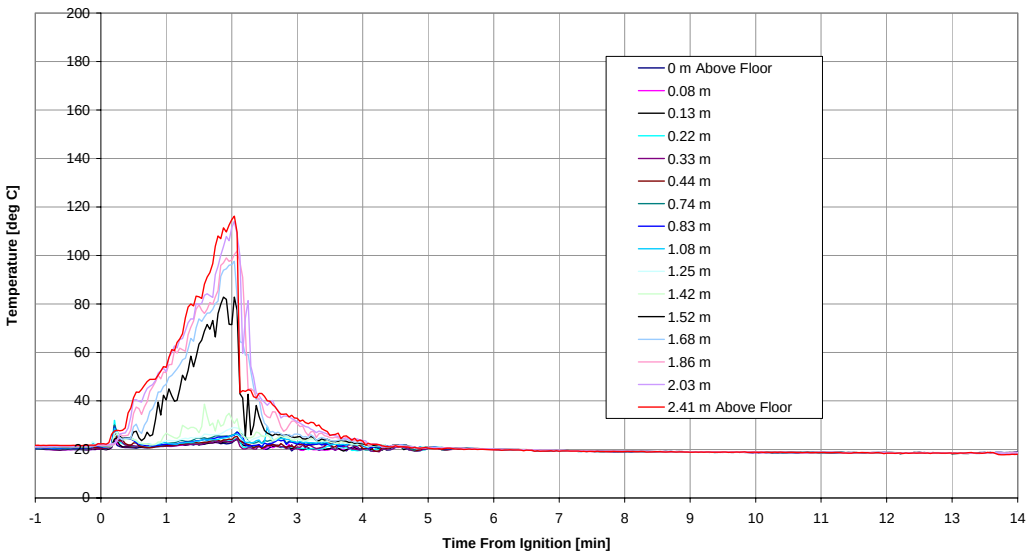

Figure 4E.46 Test 6 Temperatures at column 2

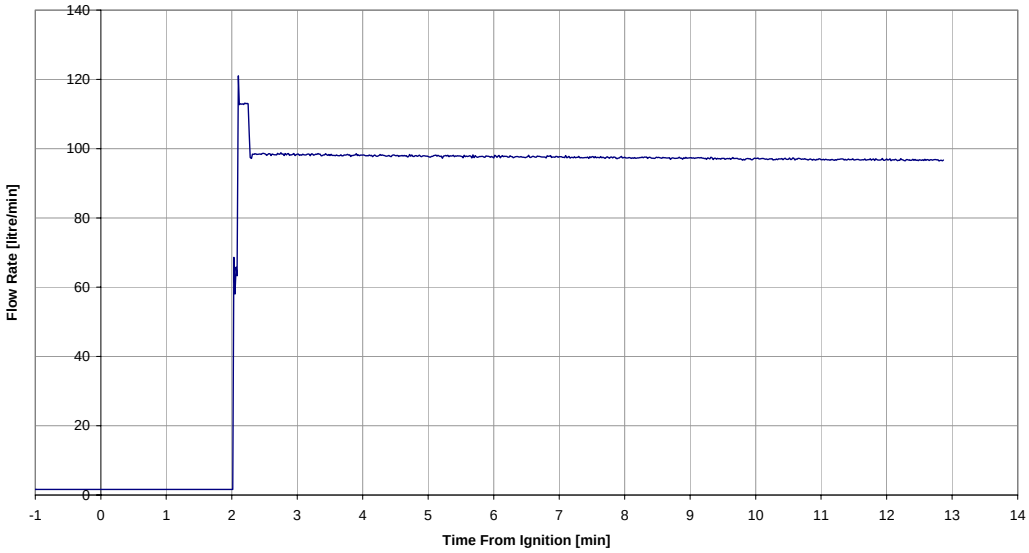

Figure 4E.47 Test 6 Sprinkler water flow rate

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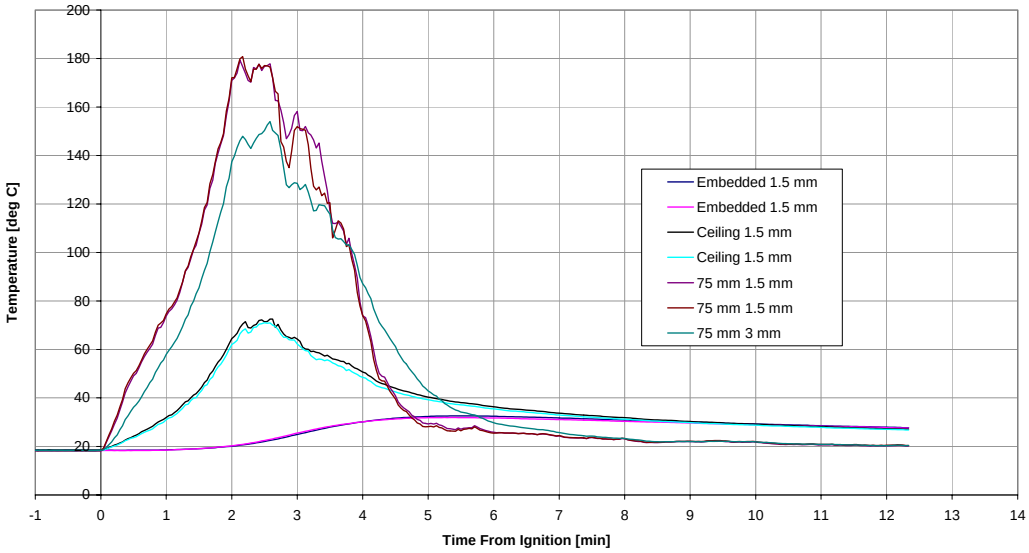

Figure 4E.48 Test 7 Temperatures above crib

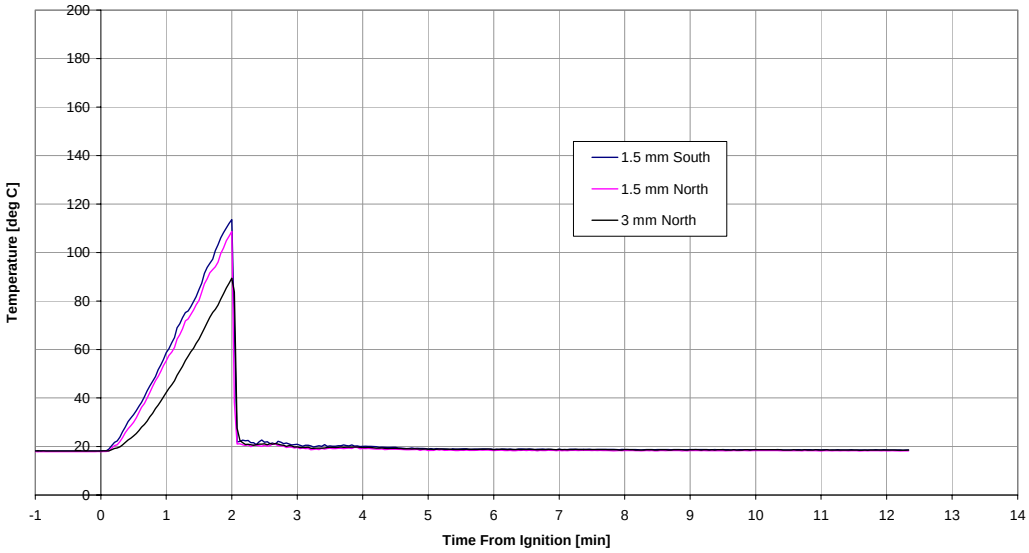

Figure 4E.49 Test 7 Temperatures at sprinkler B1

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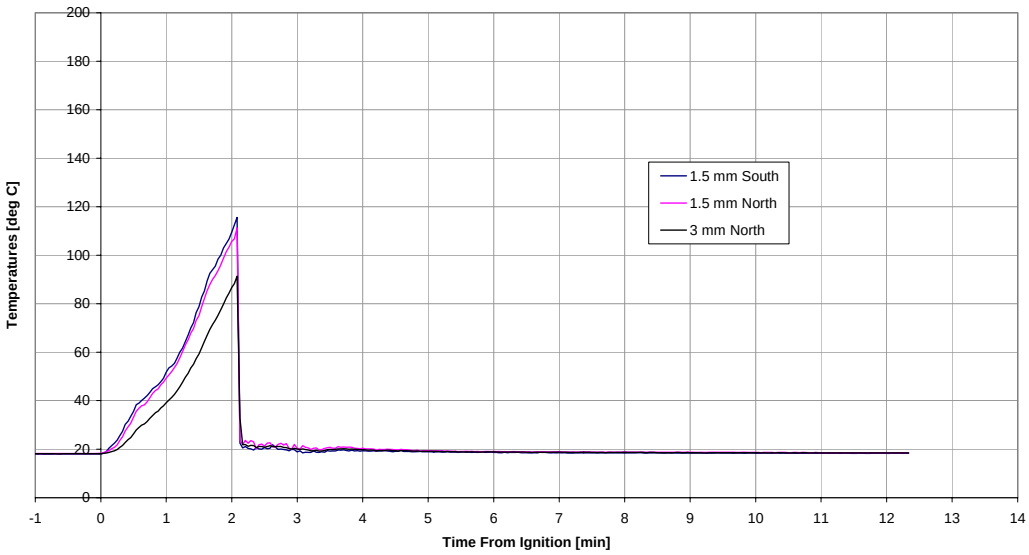

Figure 4E.50 Test 7 Temperatures at sprinkler B2

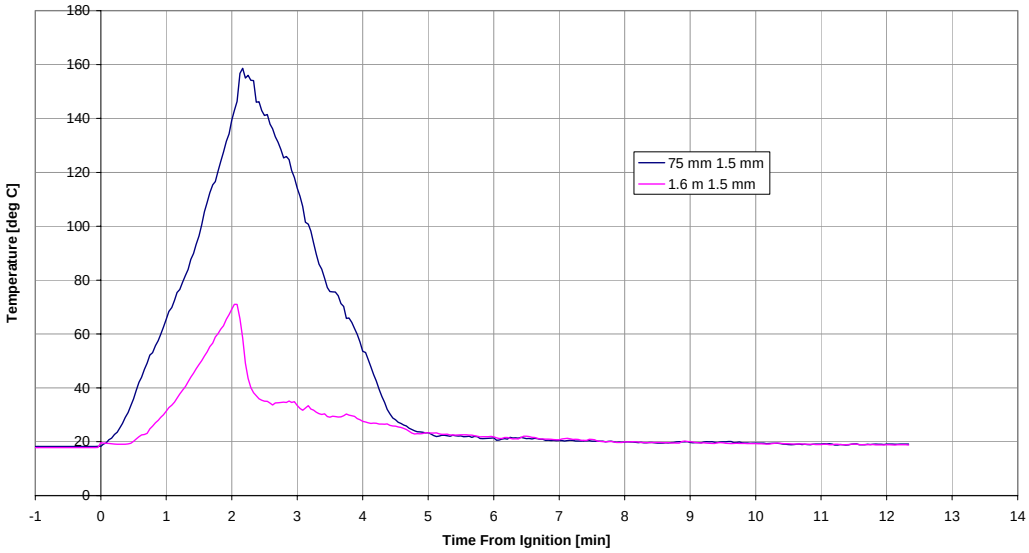

Figure 4E.51 Test 7 Temperatures at centre of room

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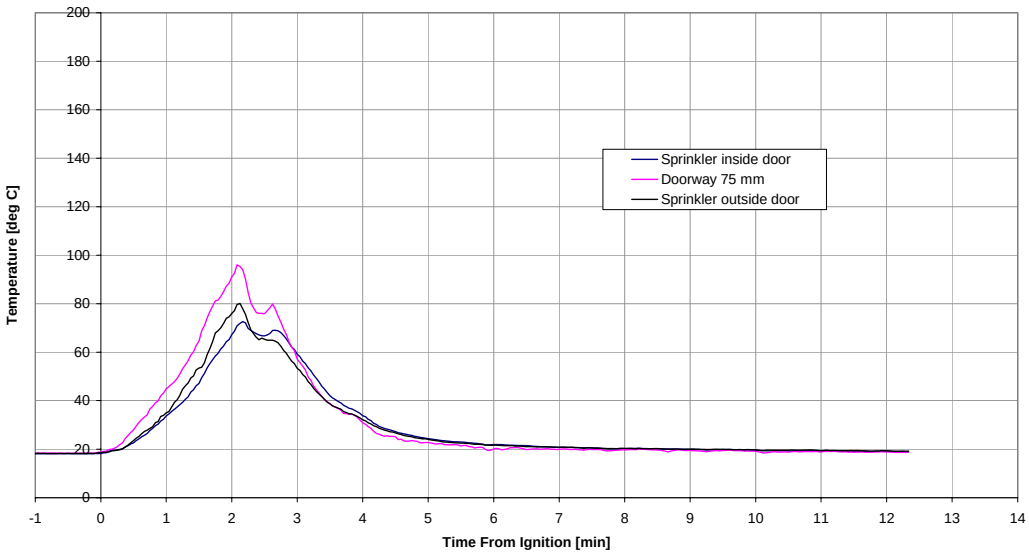

Figure 4E.52 Test 7 Temperatures at doorway

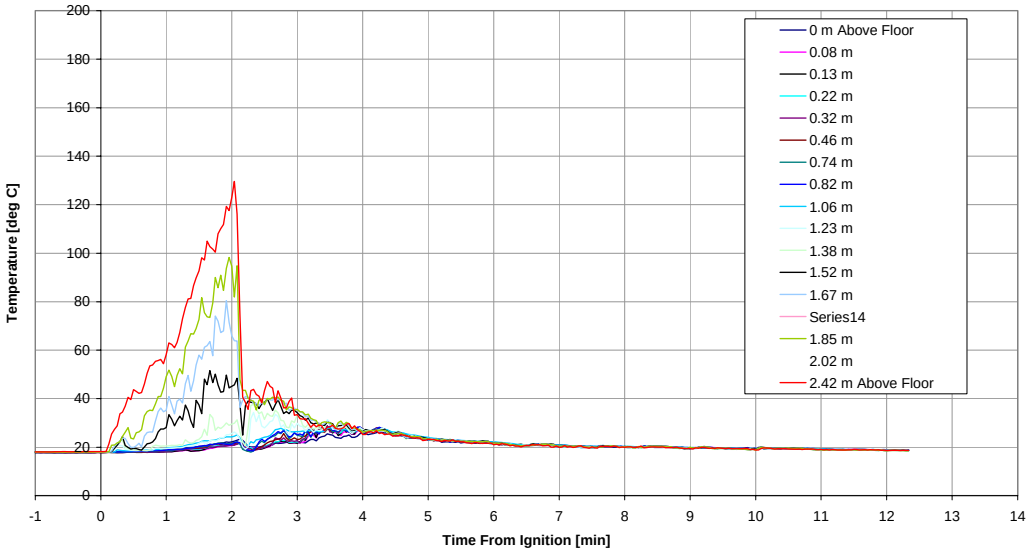

Figure 4E.53 Test 7 Temperatures at column 1

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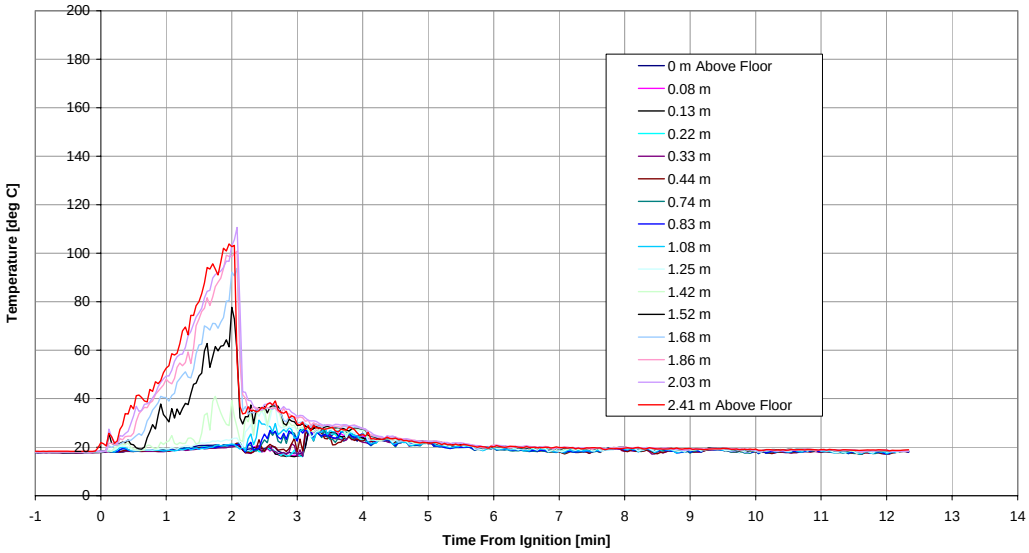

Figure 4E.54 Test 7 Temperatures at column 2

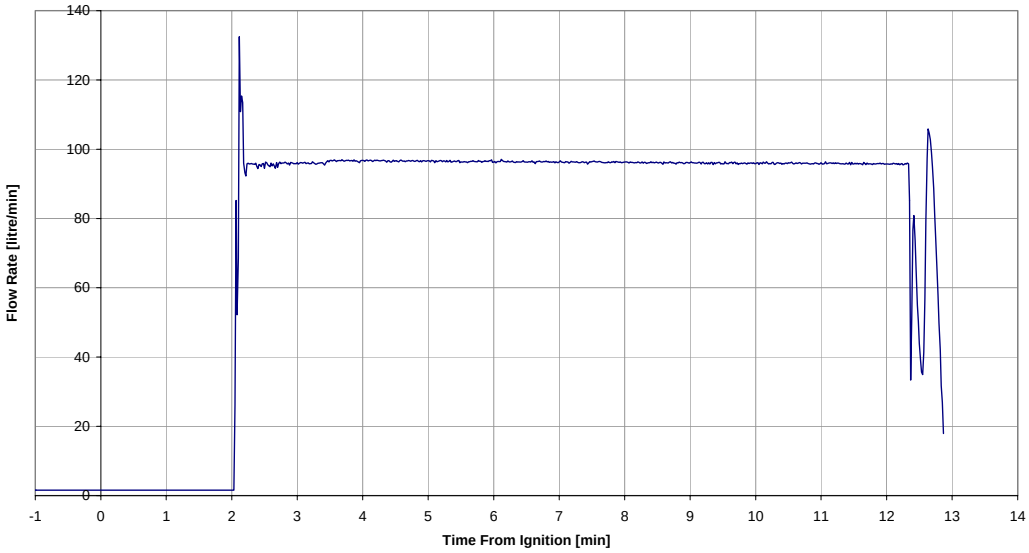

Figure 4E.55 Test 8 Sprinkler water flow rate

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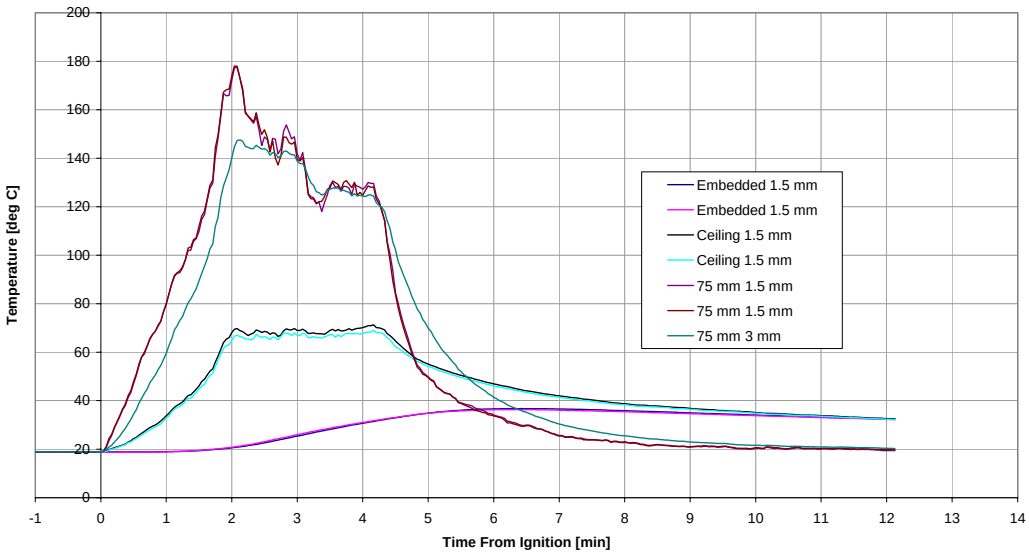

Figure 4E.56 Test 8 Temperatures above crib

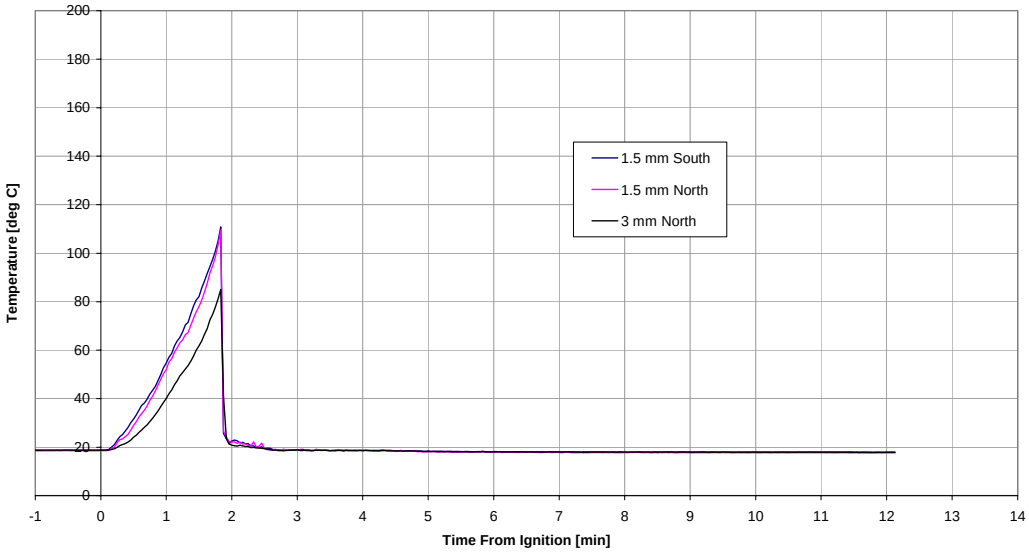

Figure 4E.57 Test 8 Temperatures at sprinkler B1

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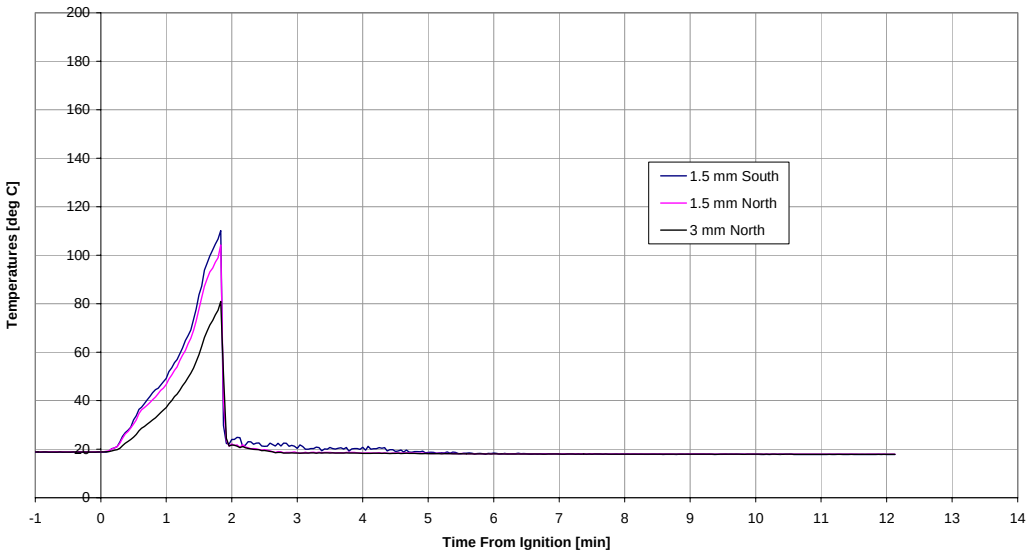

Figure 4E.58 Test 8 Temperatures at sprinkler B2

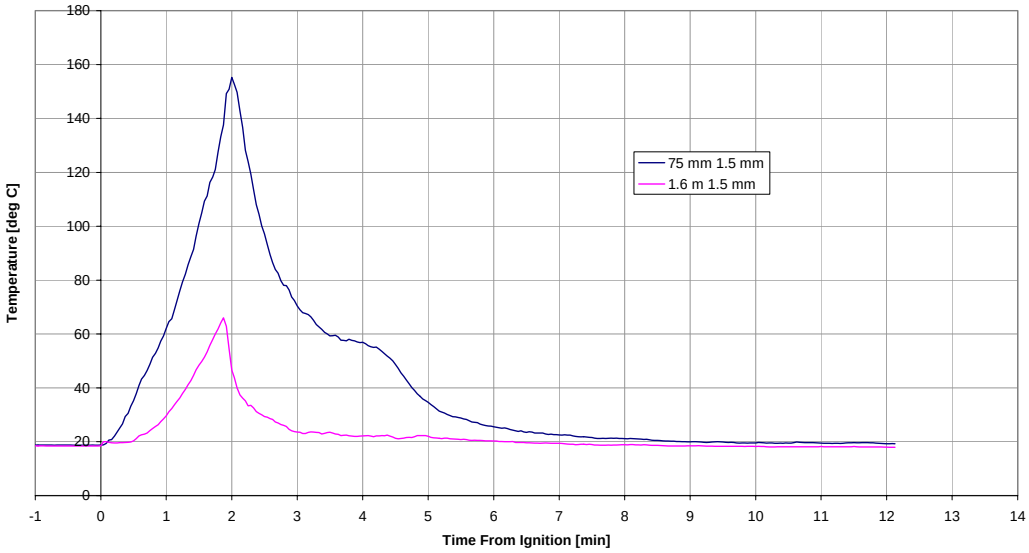

Figure 4E.59 Test 8 Temperatures at centre of room

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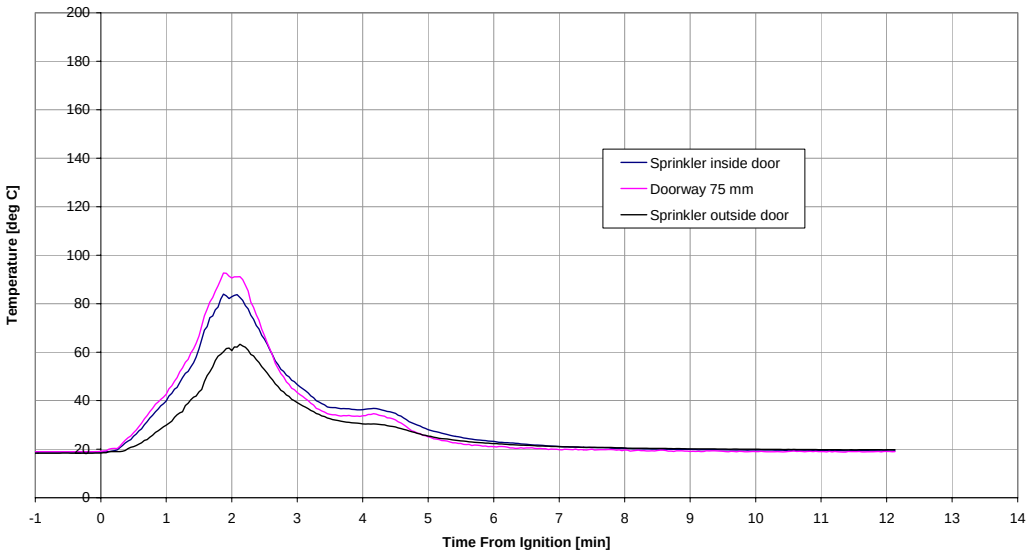

Figure 4E.60 Test 8 Temperatures at doorway

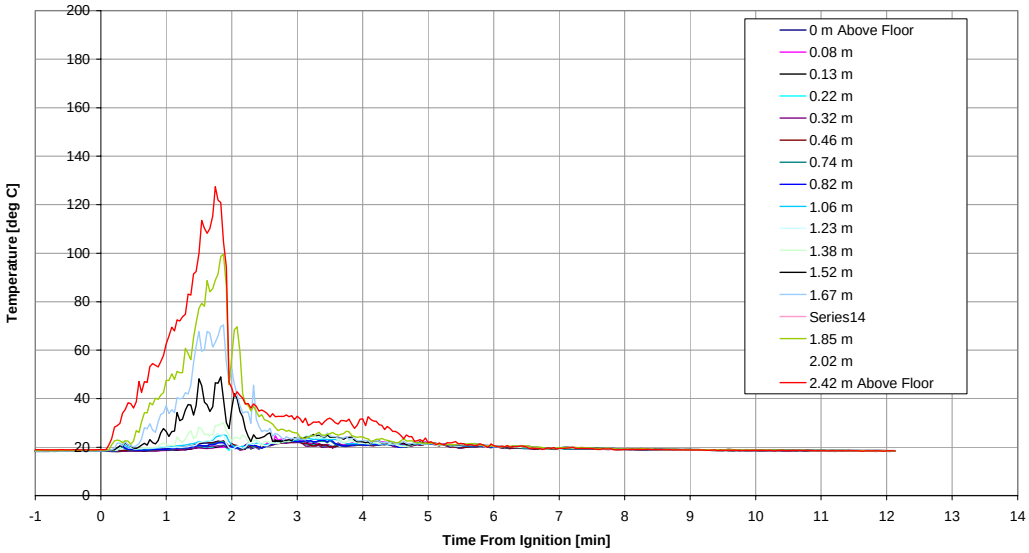

Figure 4E.61 Test 8 Temperatures at column 1

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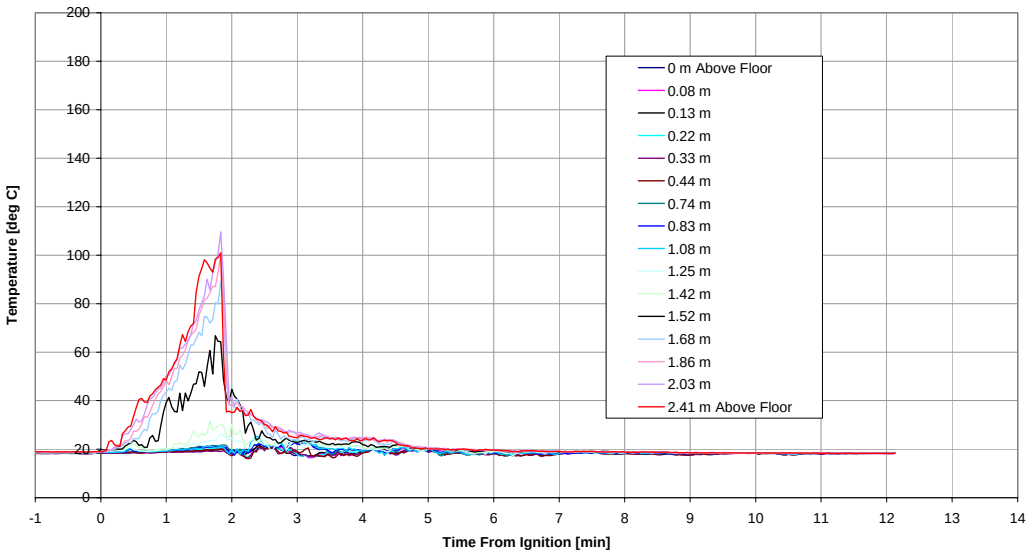

Figure 4E.62 Test 8 Temperatures at column 2

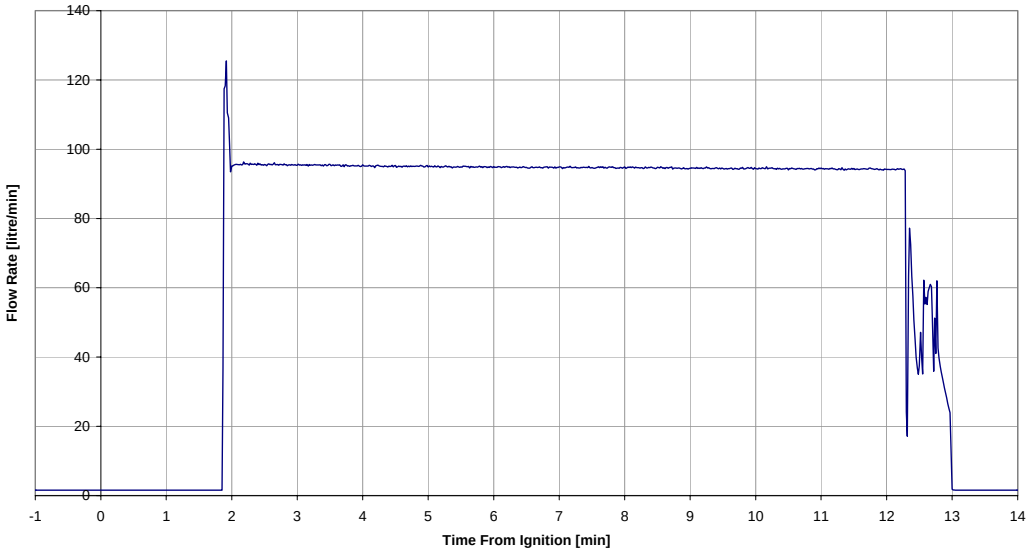

Figure 4E.63 Test 8 Sprinkler water flow rate

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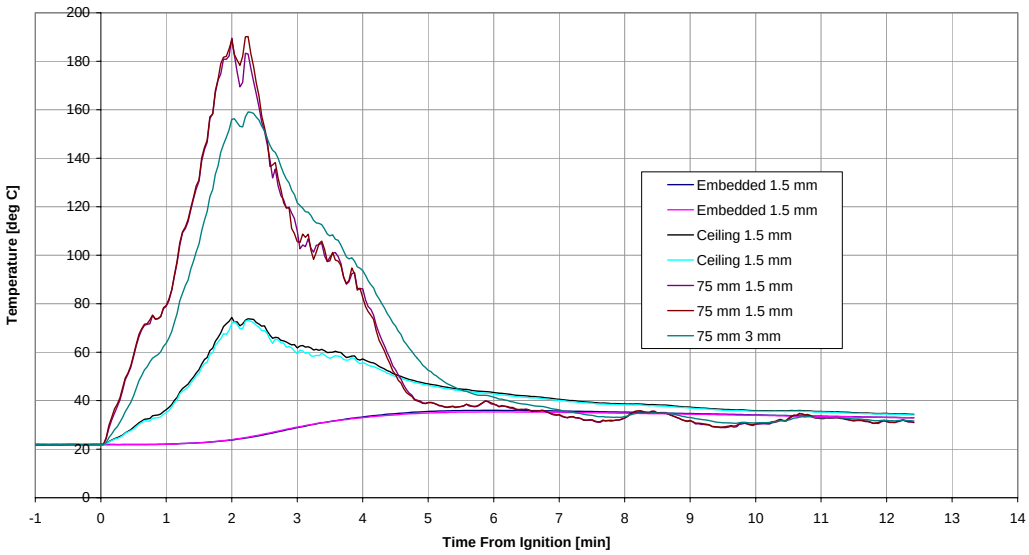

Figure 4E.64 Test 9 Temperatures above crib

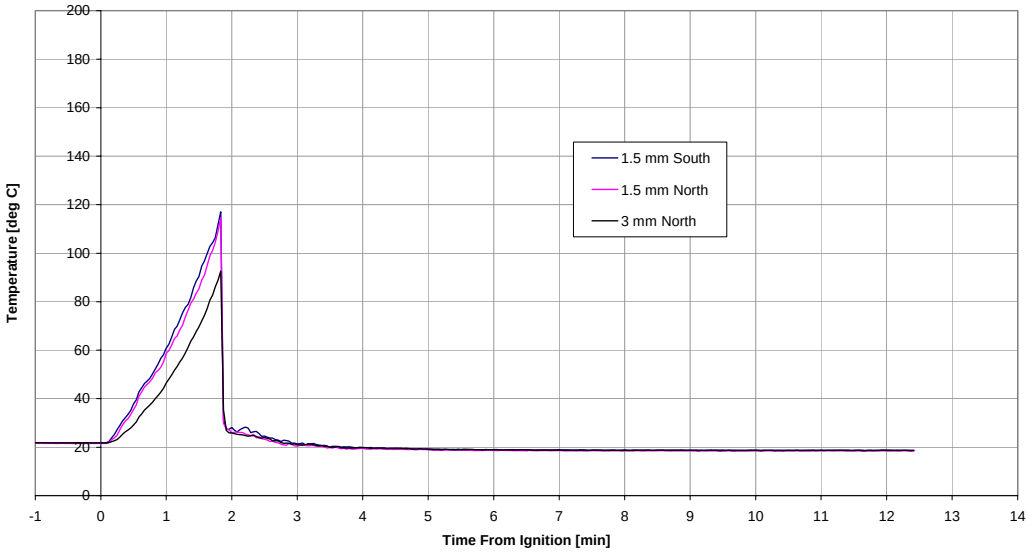

Figure 4E.65 Test 9 Temperatures at sprinkler B1

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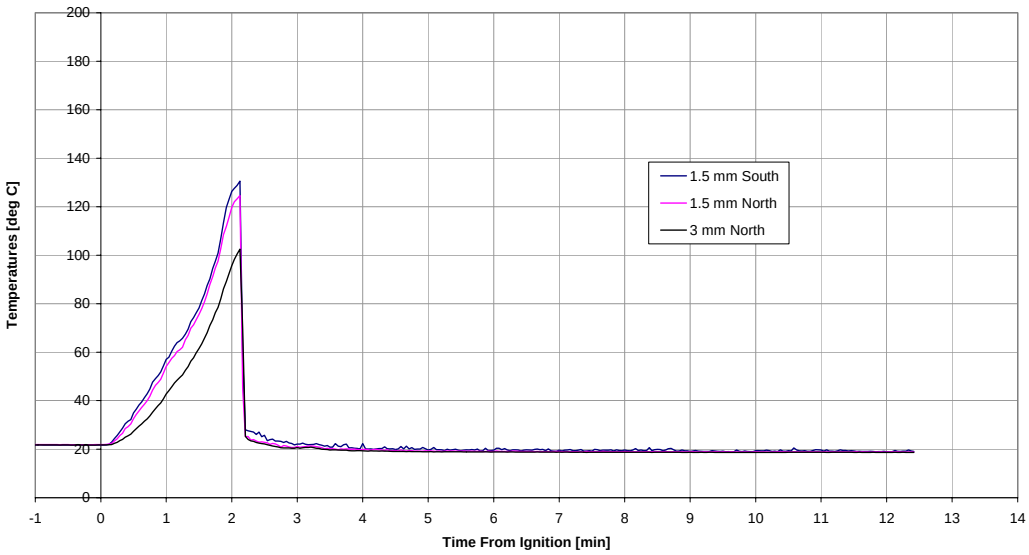

Figure 4E.66 Test 9 Temperatures at sprinkler B2

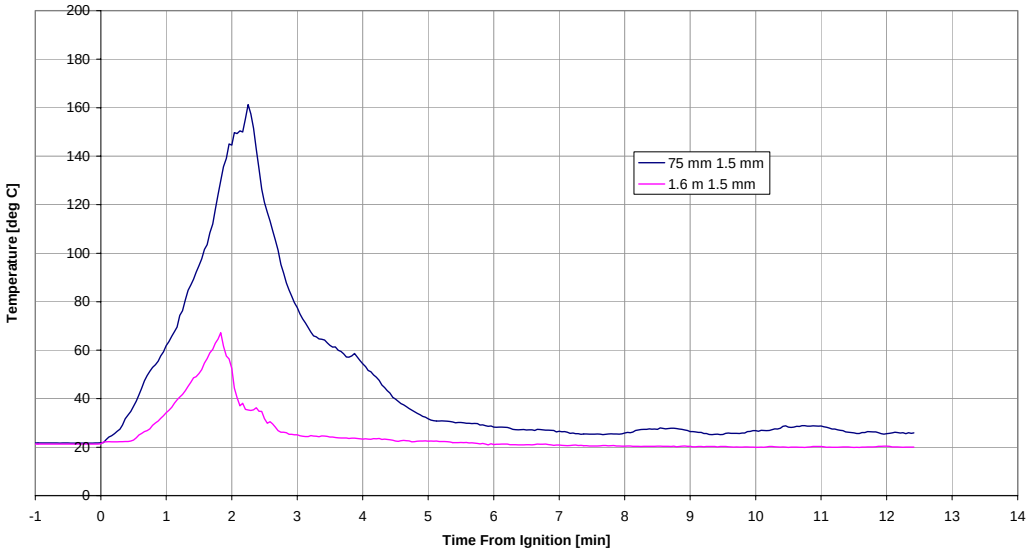

Figure 4E.67 Test 9 Temperatures at centre of room

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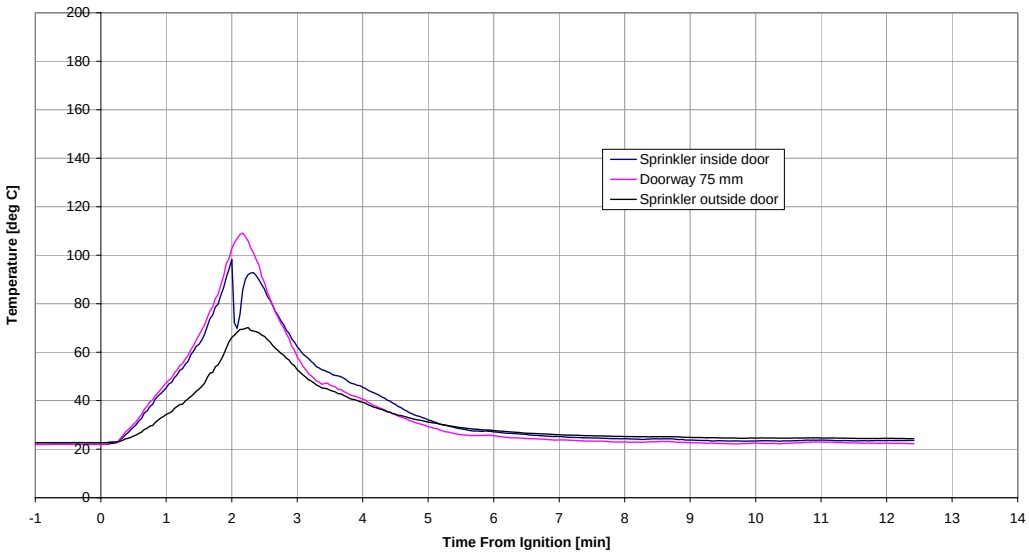

Figure 4E.68 Test 9 Temperatures at doorway

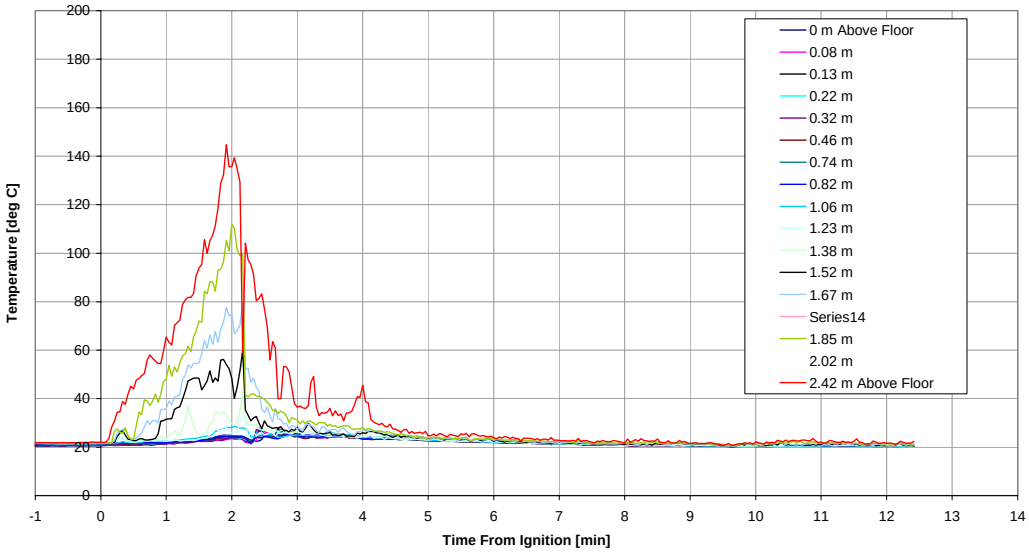

Figure 4E.69 Test 9 Temperatures at column 1

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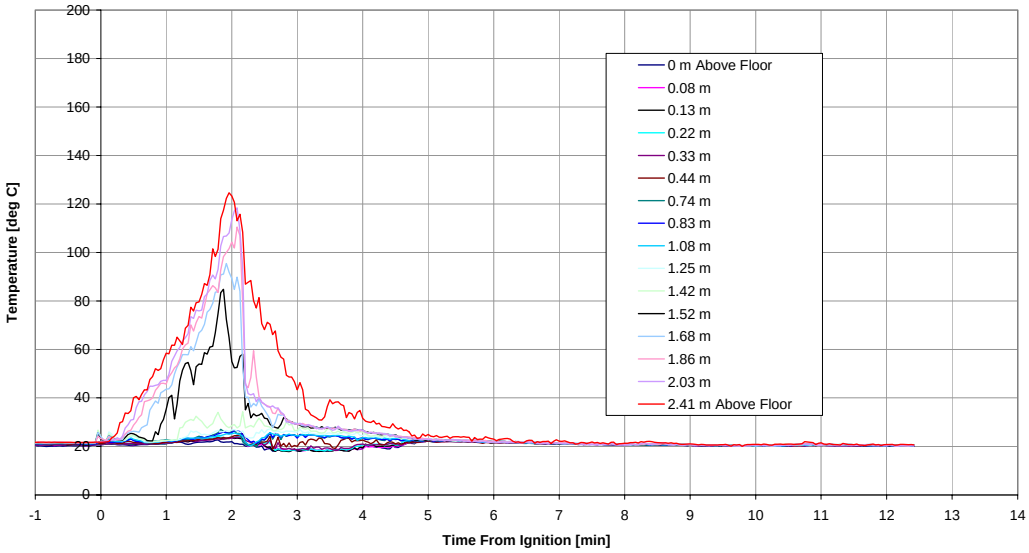

Figure 4E.70 Test 9 Temperatures at column 2

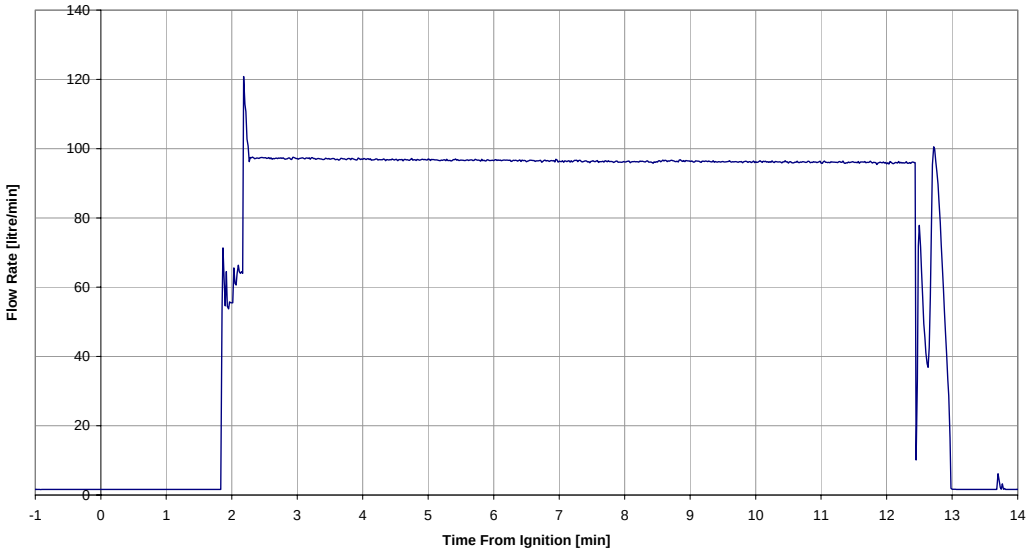

Figure 4E.71 Test 9 Sprinkler water flow rate

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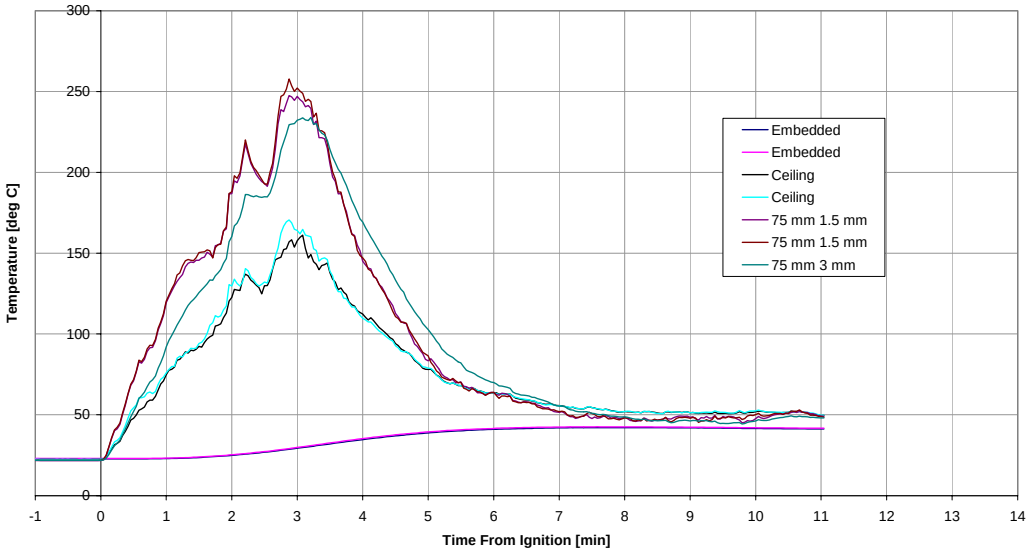

Figure 4E.72 Test 10 Temperatures above crib

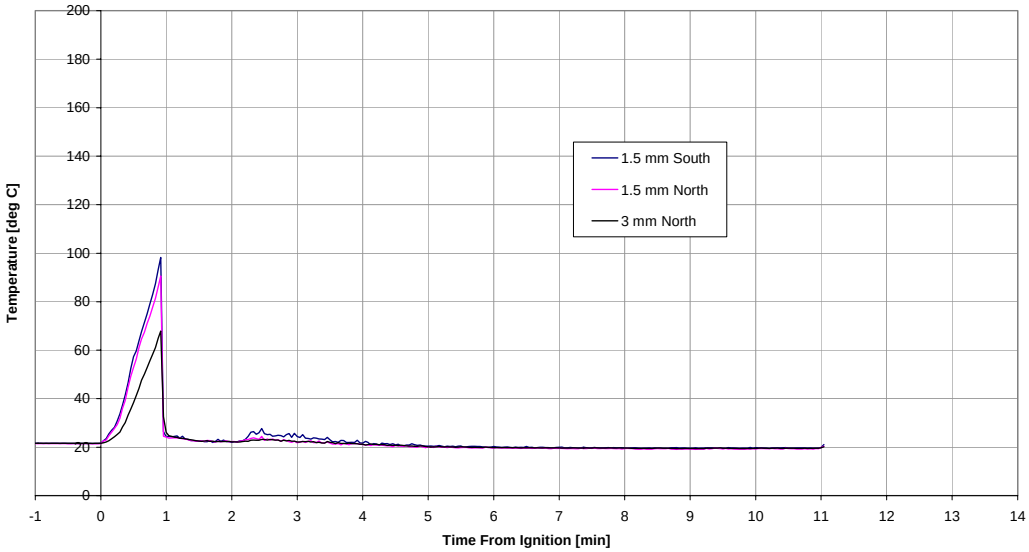

Figure 4E.73 Test 10 Temperatures at sprinkler B1

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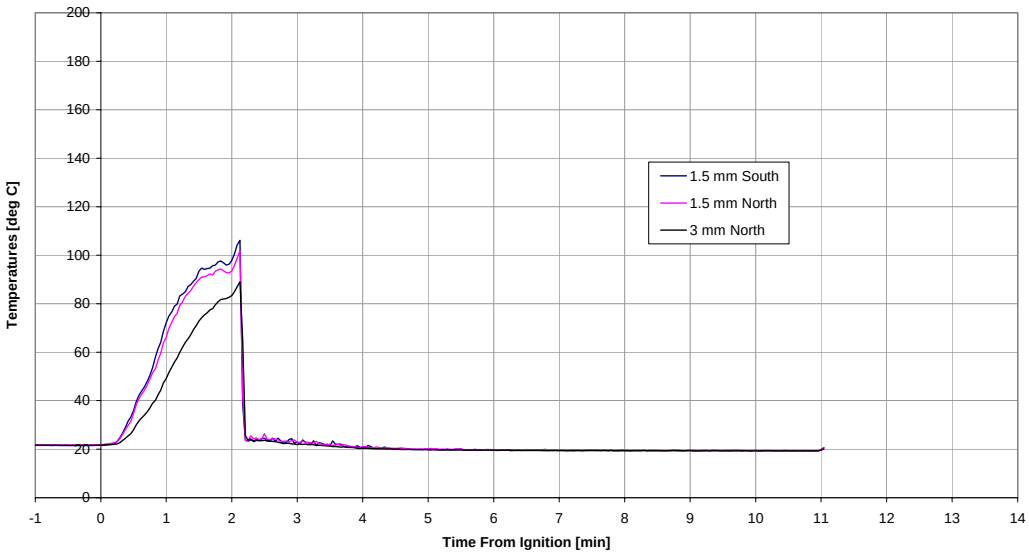

Figure 4E.74 Test 10 Temperatures at sprinkler B2

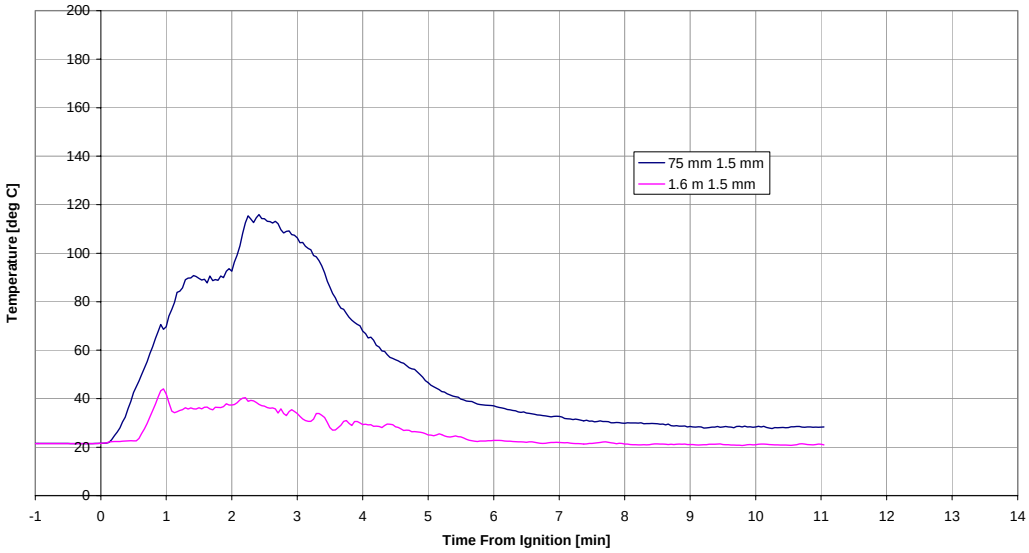

Figure 4E.75 Test 10 Temperatures at centre of room

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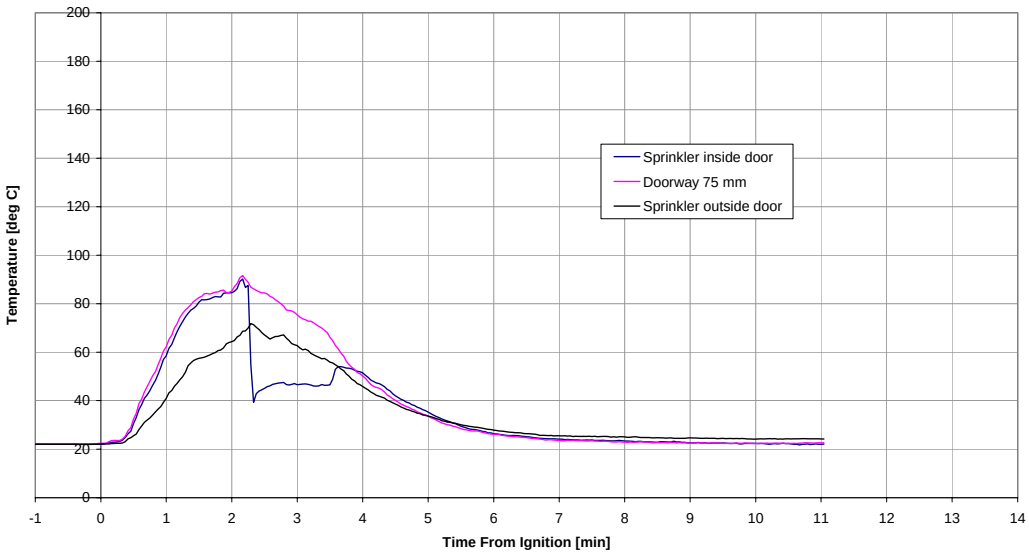

Figure 4E.76 Test 10 Temperatures at doorway

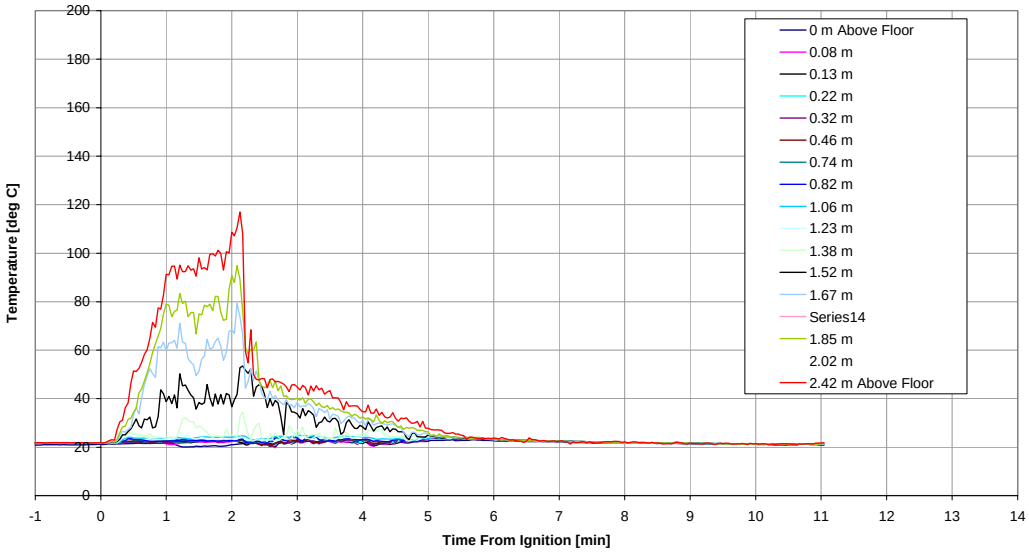

Figure 4E.77 Test 10 Temperatures at column 1

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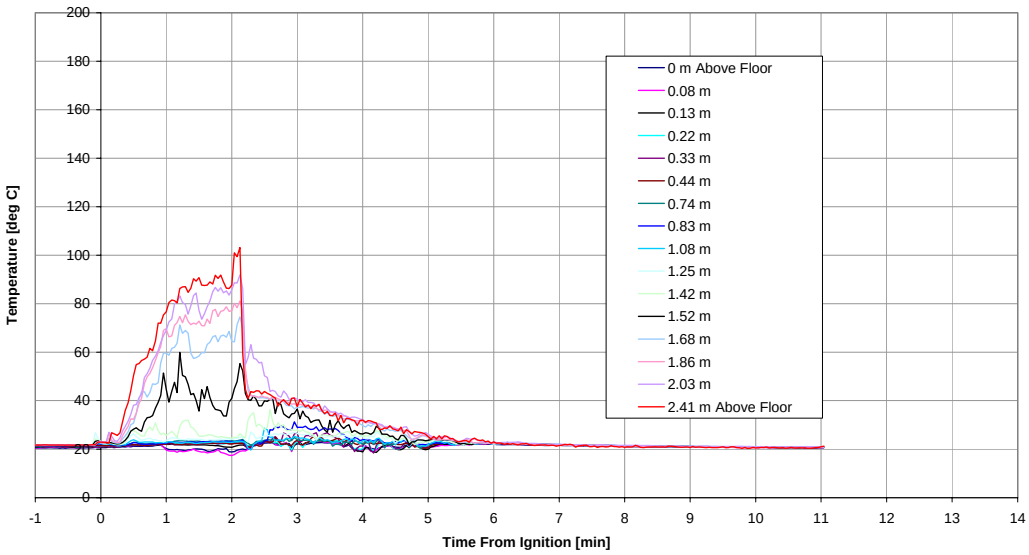

Figure 4E.78 Test 10 Temperatures at column 2

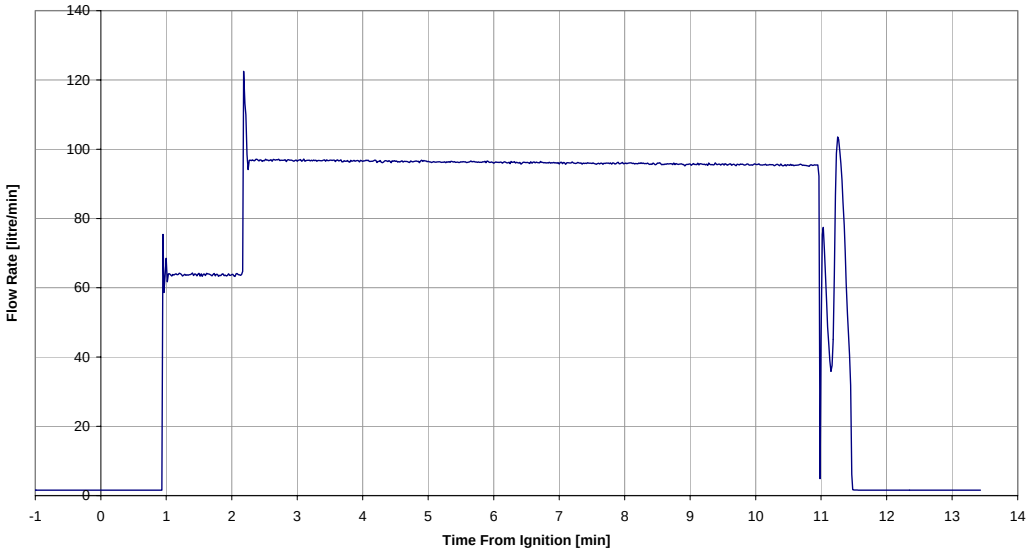

Figure 4E.79 Test 10 Sprinkler water flow rate

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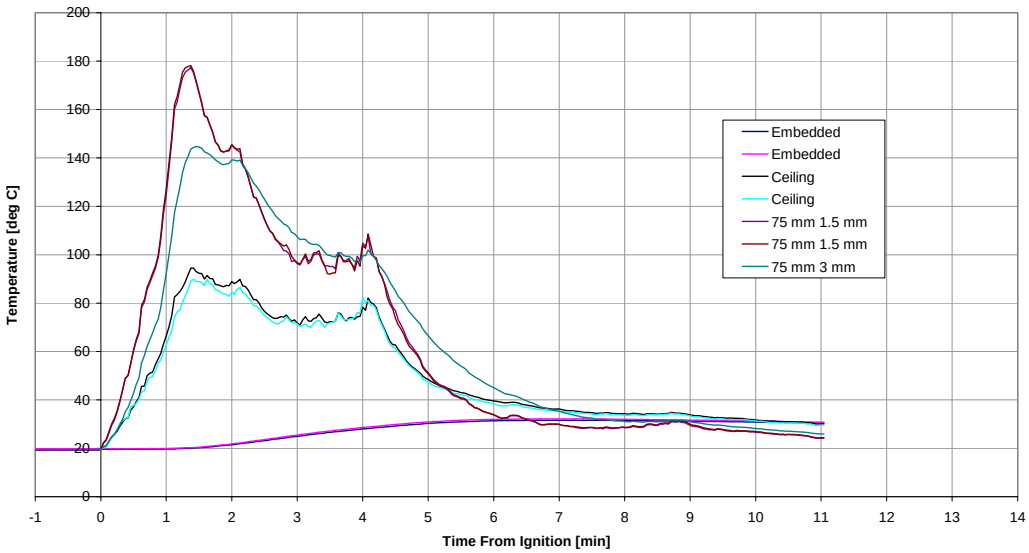

Figure 4E.80 Test 11 Temperatures above crib

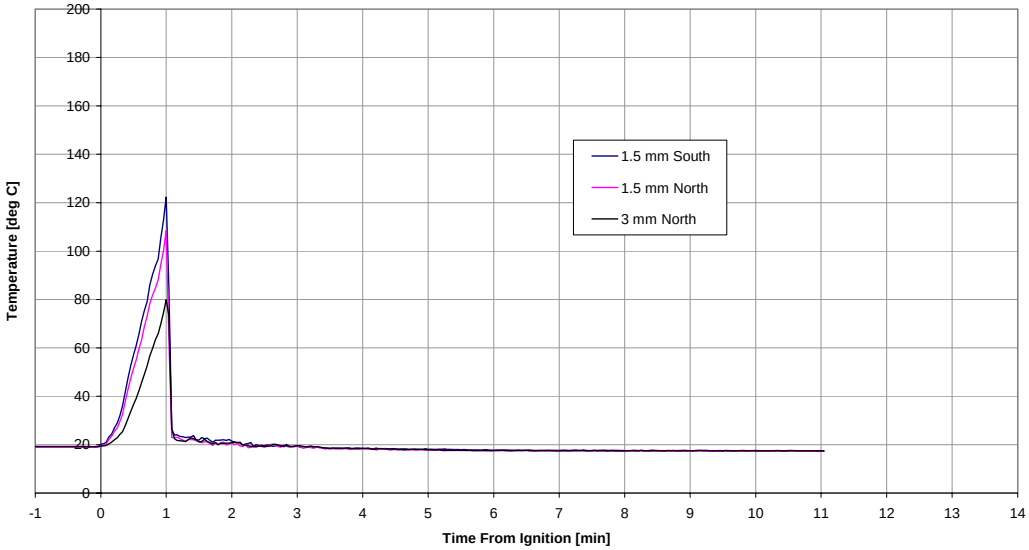

Figure 4E.81 Test 11 Temperatures at sprinkler B1

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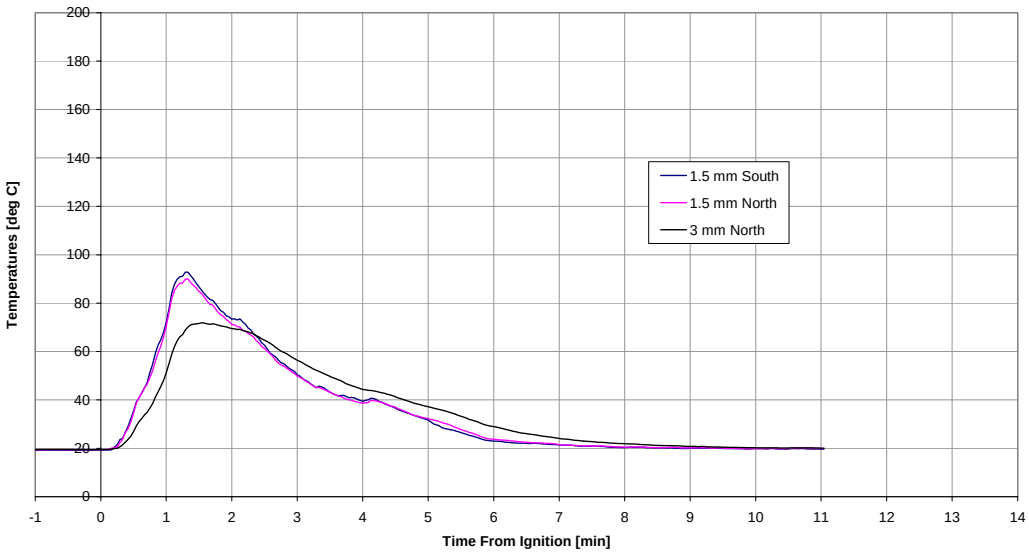

Figure 4E.82 Test 11 Temperatures at sprinkler B2

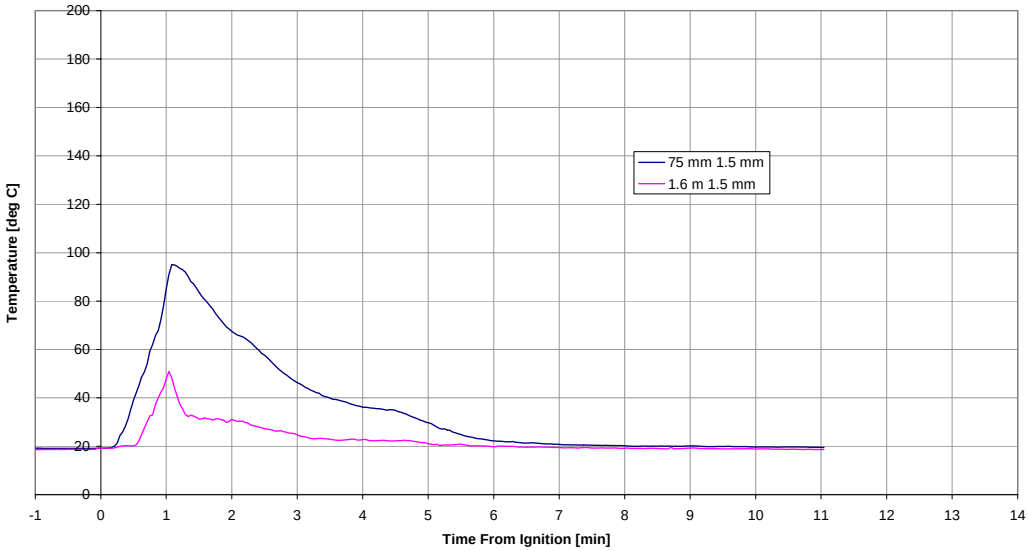

Figure 4E.83 Test 11 Temperatures at centre of room

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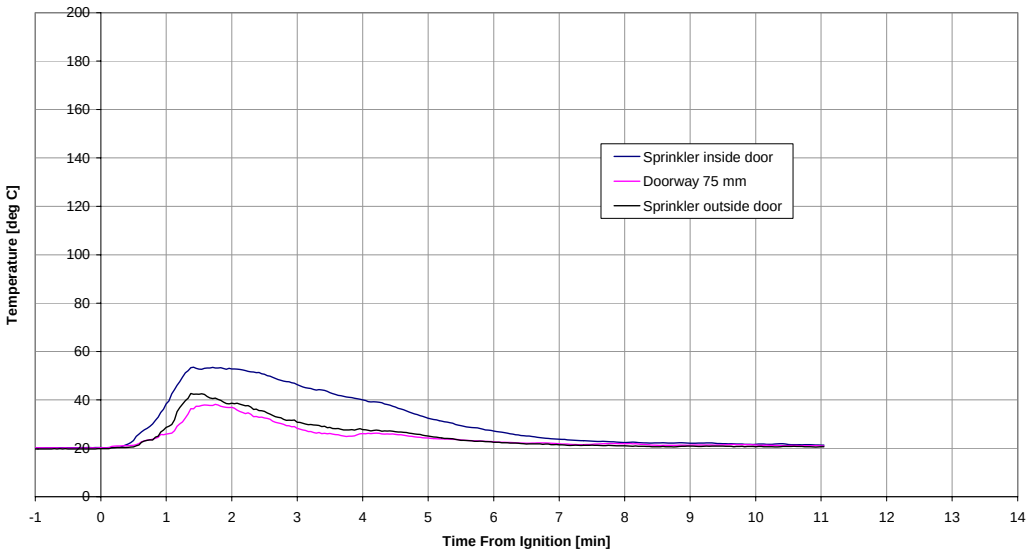

Figure 4E.84 Test 11 Temperatures at doorway

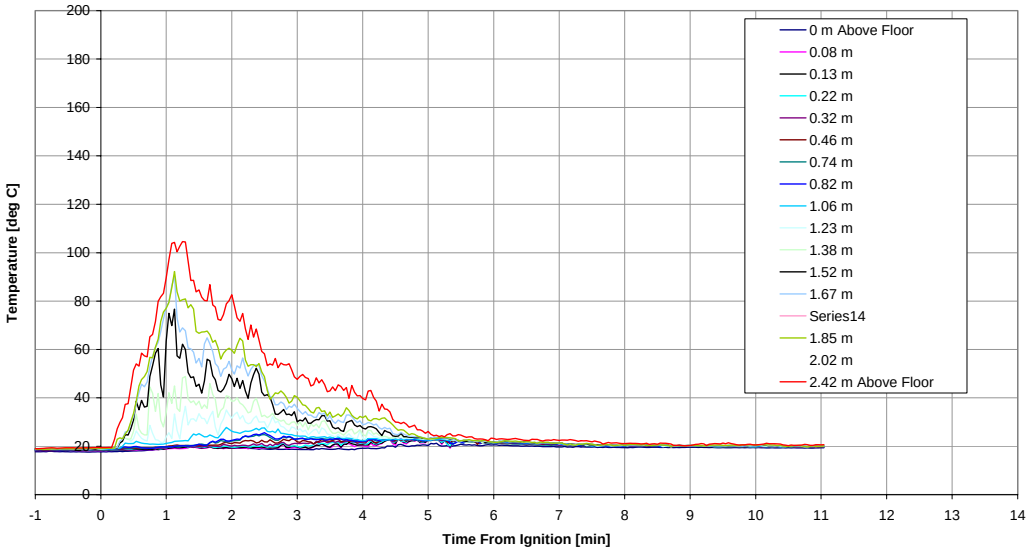

Figure 4E.85 Test 11 Temperatures at column 1

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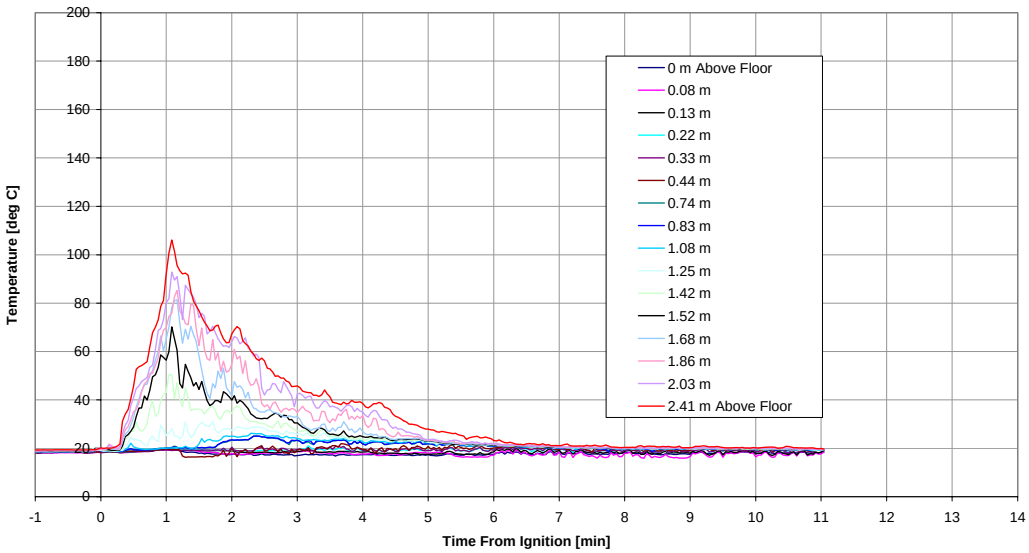

Figure 4E.86 Test 11 Temperatures at column 2

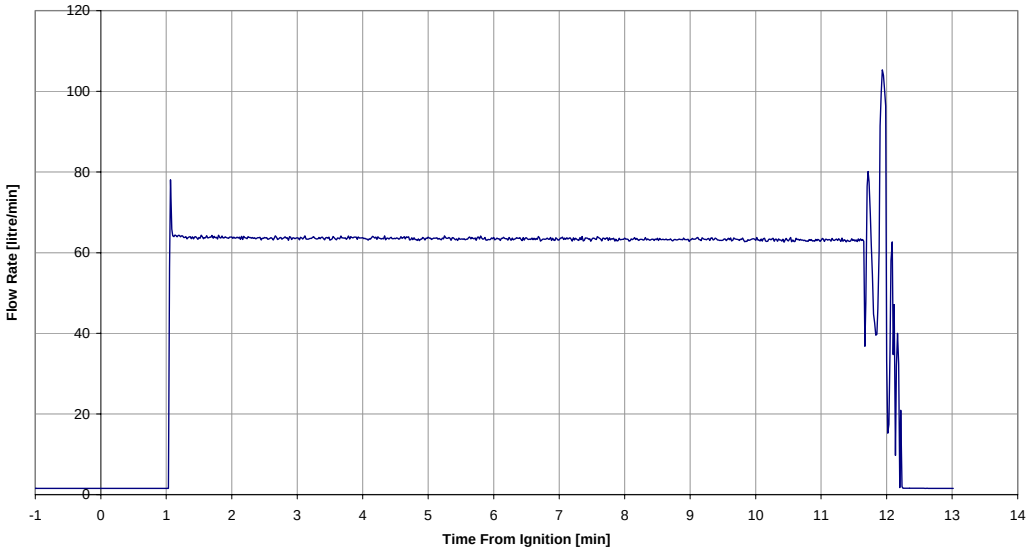

Figure 4E.87 Test 11 Sprinkler water flow rate

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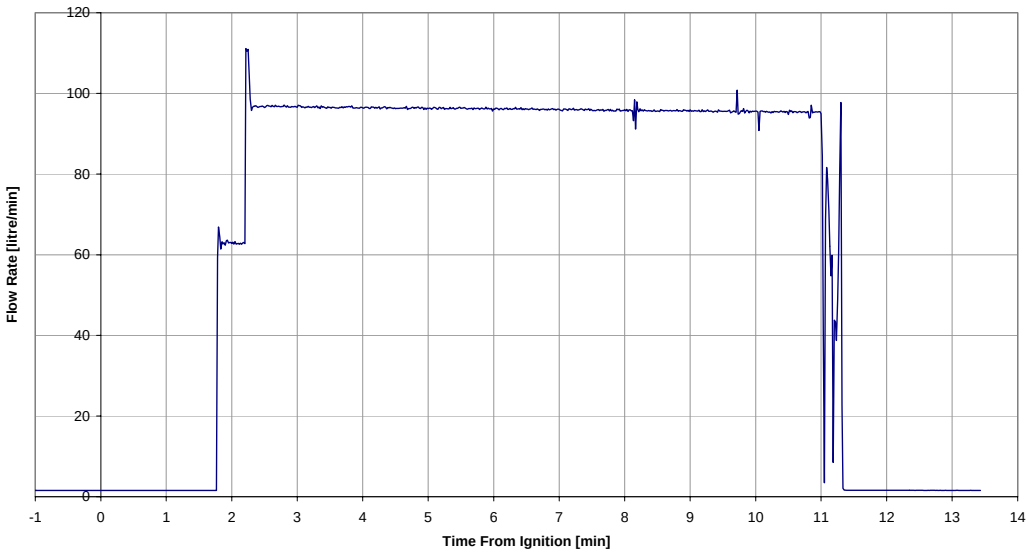

Figure 4E.88 Test 12 Sprinkler water flow rate

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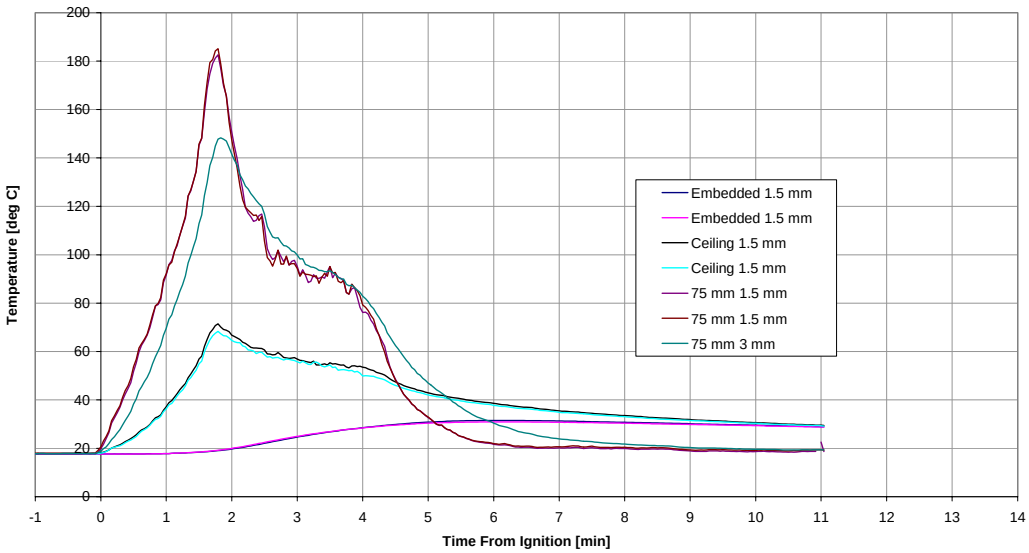

Figure 4E.89 Test 13 Temperatures above crib

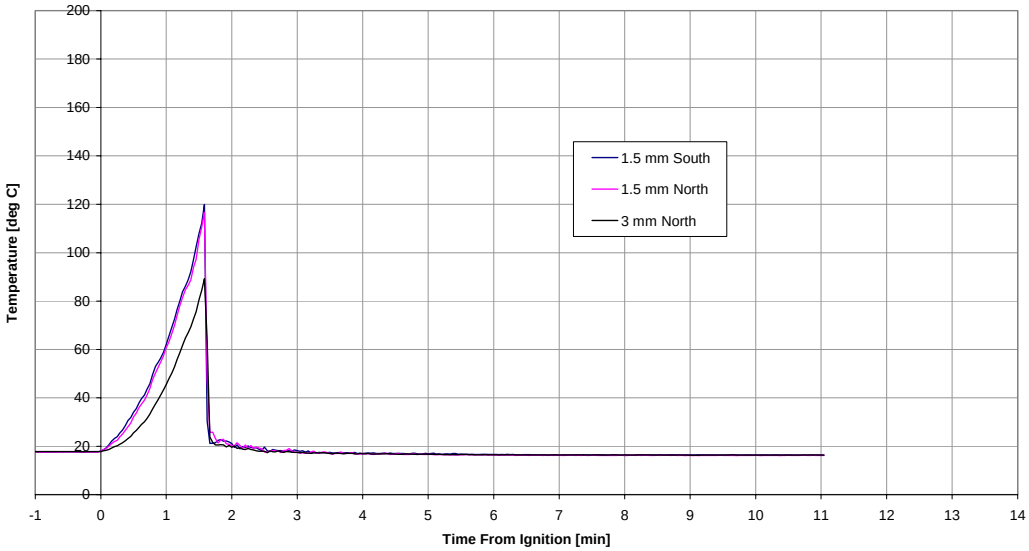

Figure 4E.90 Test 13 Temperatures at sprinkler B1

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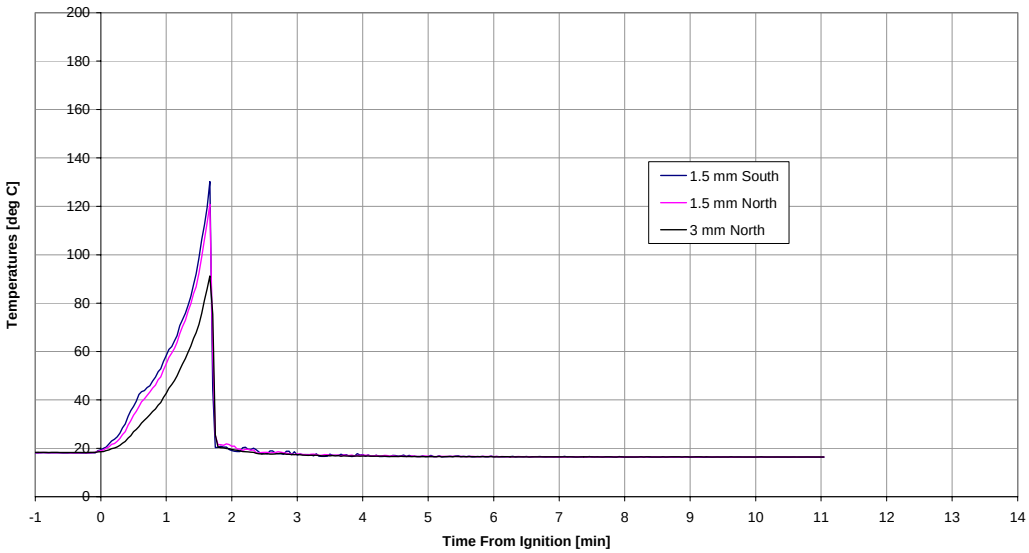

Figure 4E.91 Test 13 Temperatures at sprinkler B2

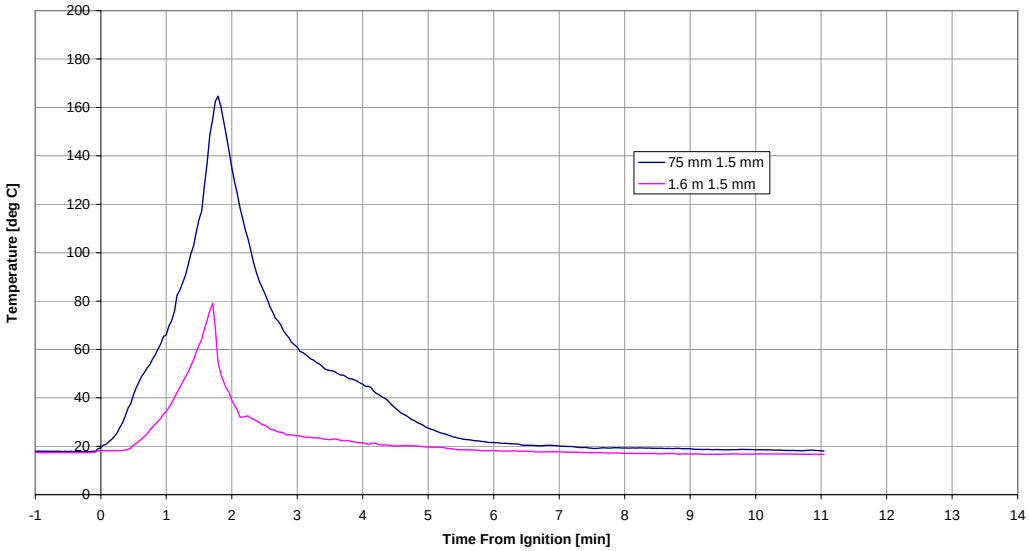

Figure 4E.92 Test 13 Temperatures at centre of room

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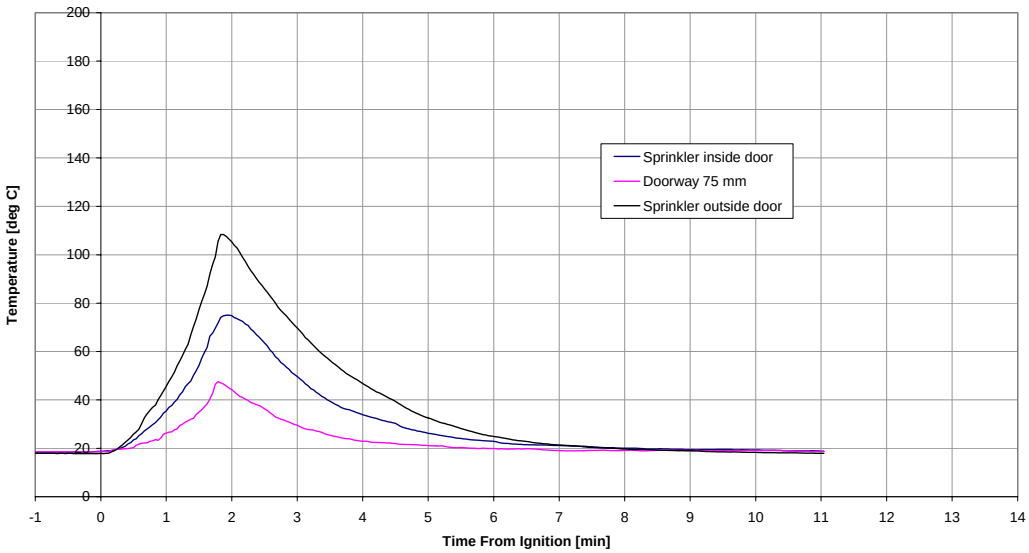

Figure 4E.93 Test 13 Temperatures at doorway

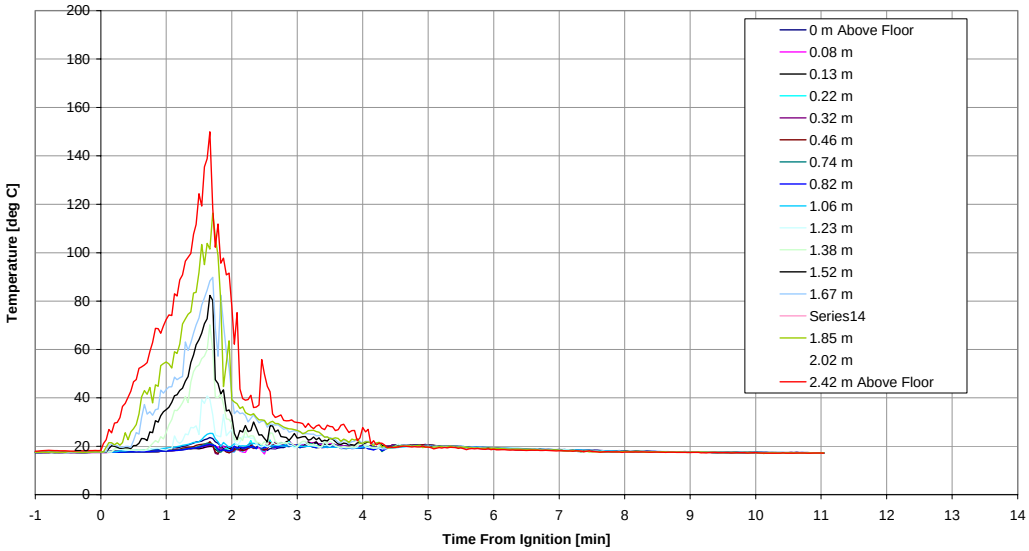

Figure 4E.94 Test 13 Temperatures at column 1

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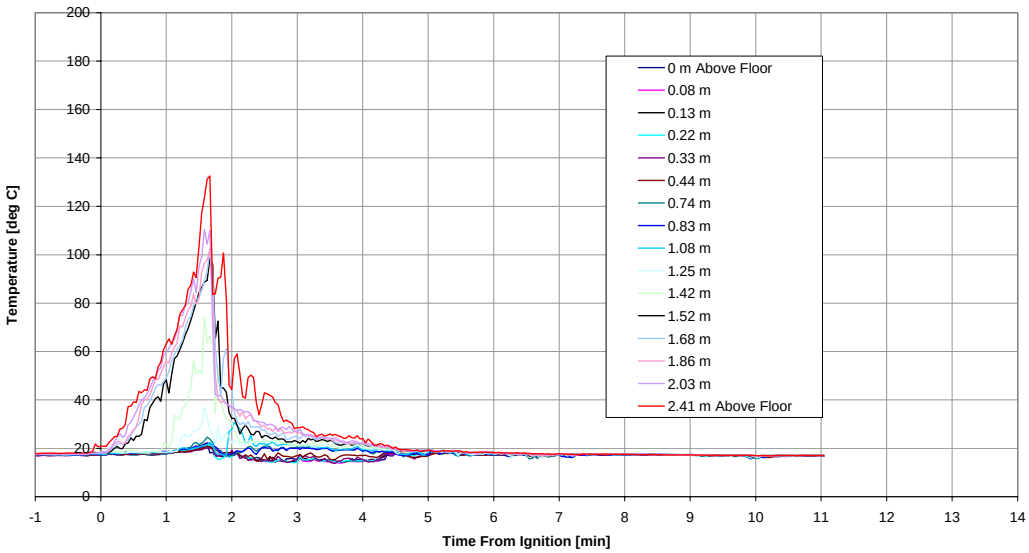

Figure 4E.95 Test 13 Temperatures at column 2

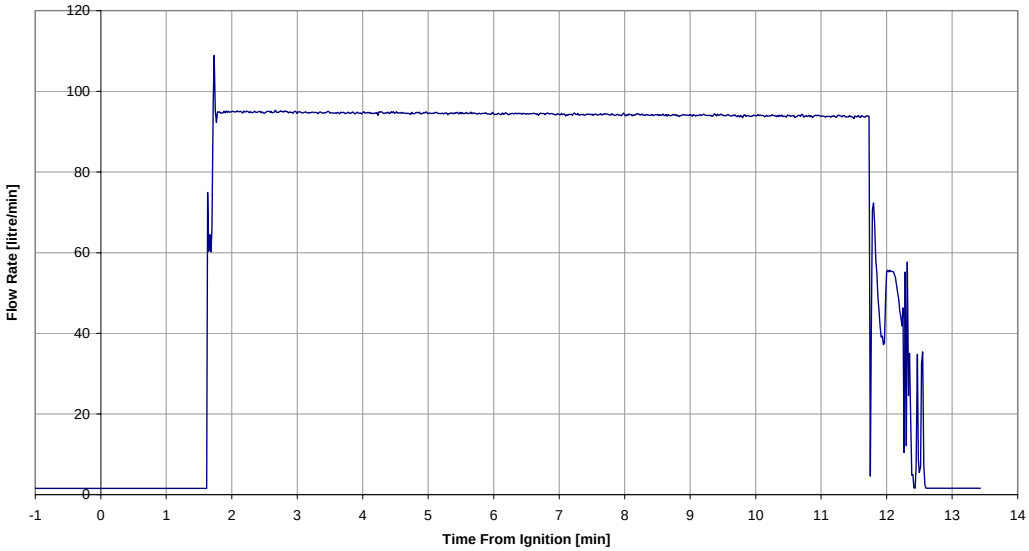

Figure 4E.96 Test 13 Sprinkler water flow rate

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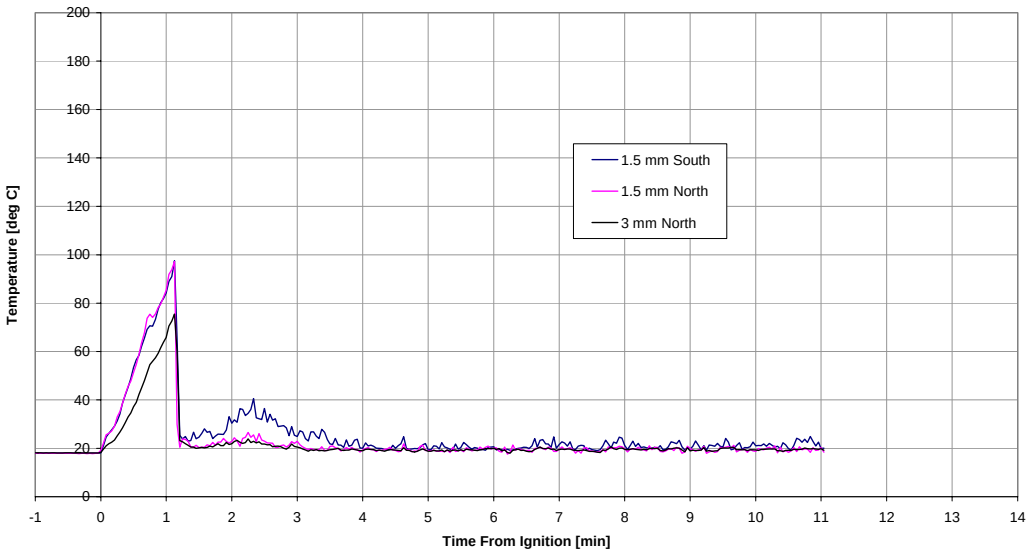

Figure 4E.97 Test 14 Temperatures above crib at sprinkler B1

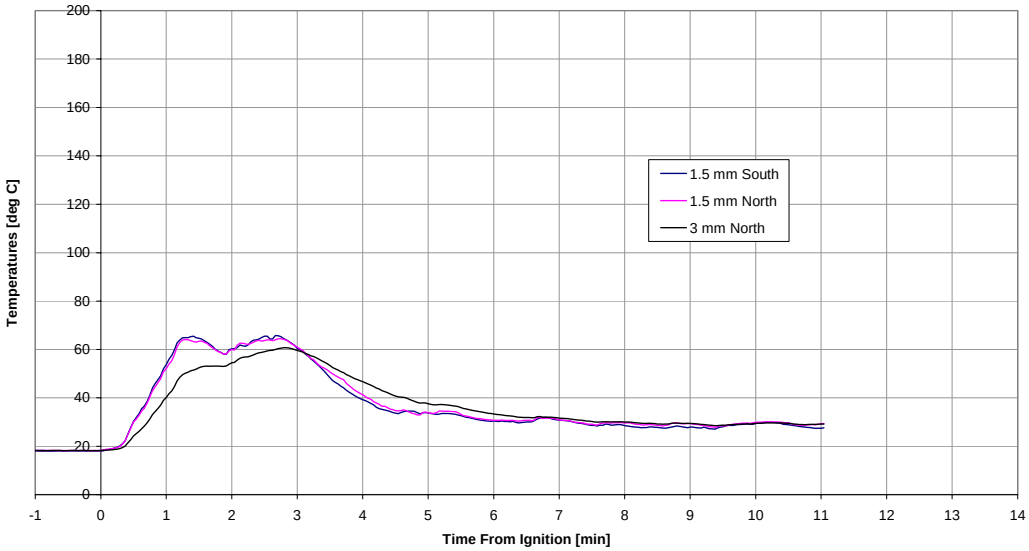

Figure 4E.98 Test 14 Temperatures at sprinkler B2

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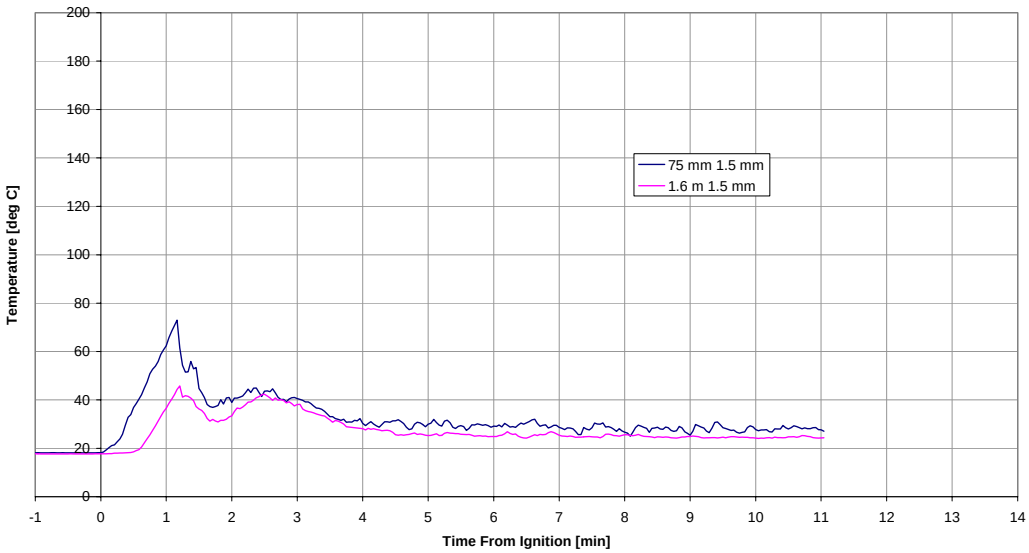

Figure 4E.99 Test 14 Temperatures at centre of room

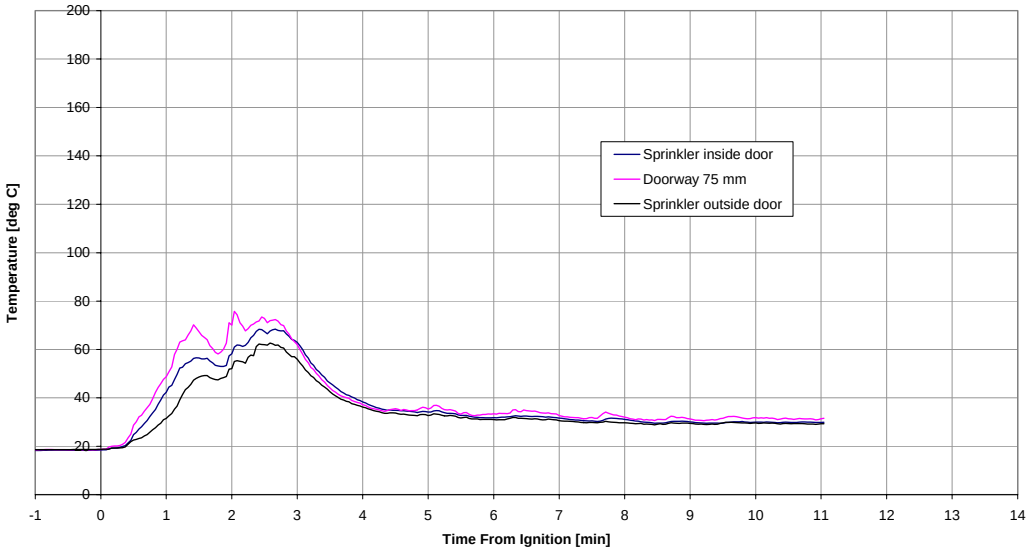

Figure 4E.100 Test 14 Temperatures at doorway

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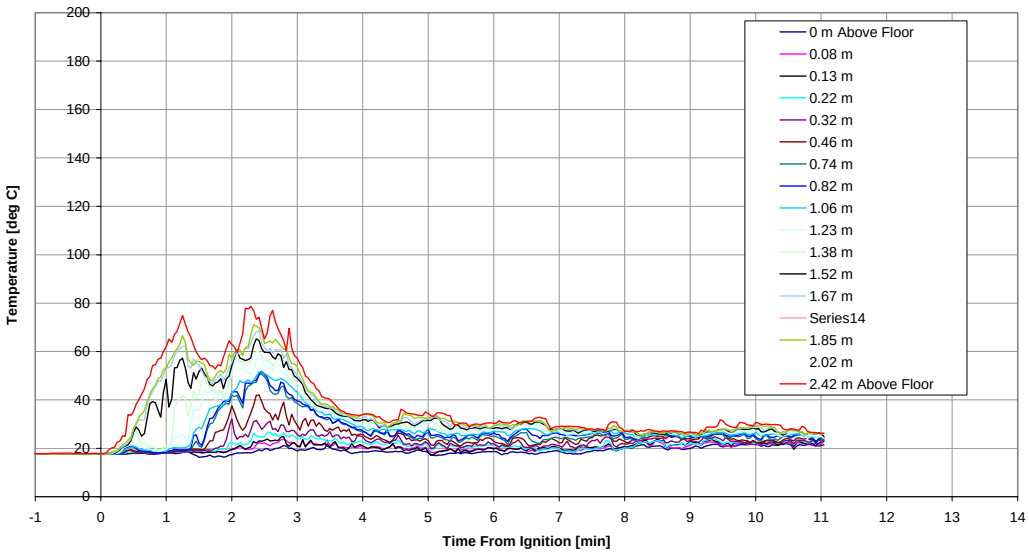

Figure 4E.101 Test 14 Temperatures at column 1

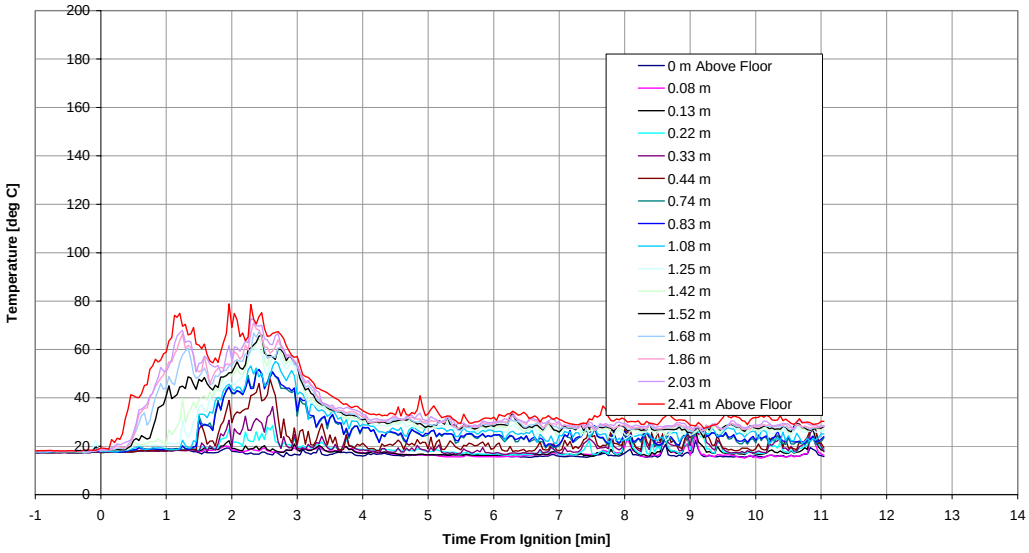

Figure 4E.102 Test 14 Temperatures at column 2

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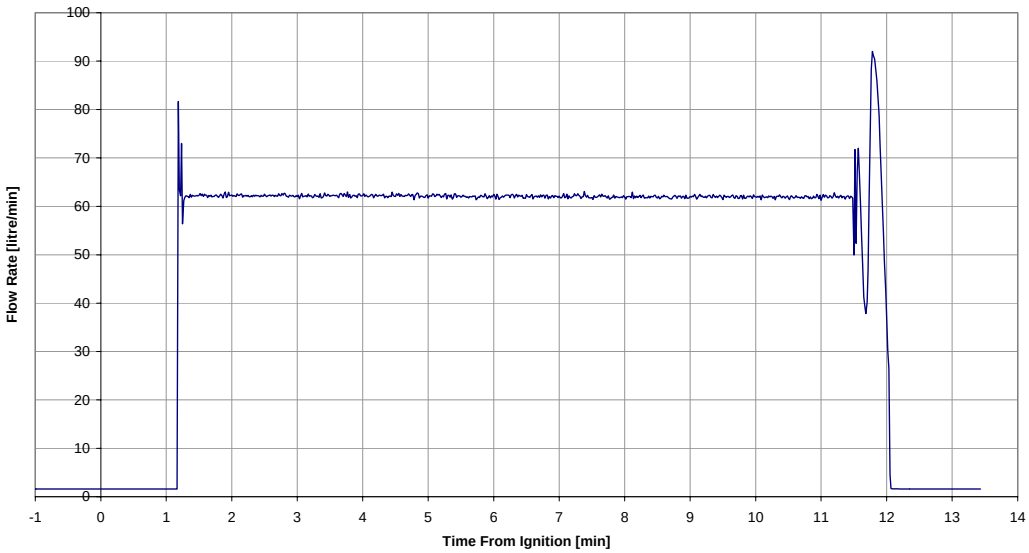

Figure 4E.103 Test 14 Sprinkler water flow rate

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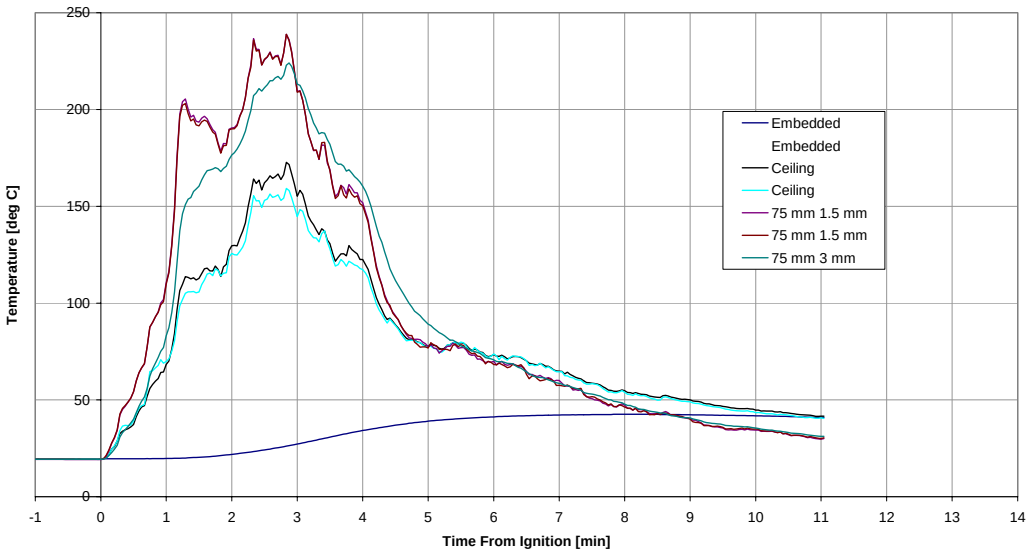

Figure 4E.104 Test 15 Temperatures above crib

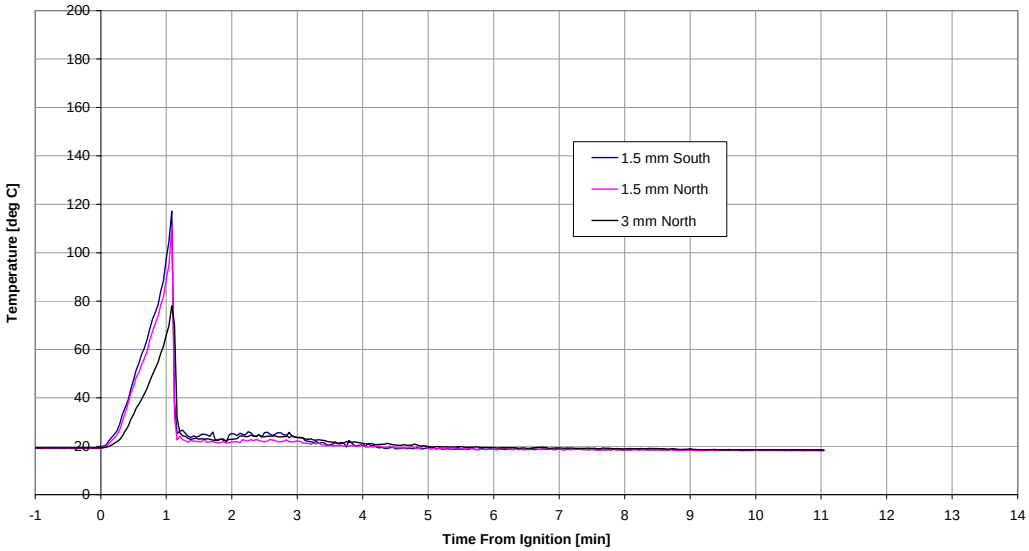

Figure 4E.105 Test 15 Temperatures at sprinkler B1

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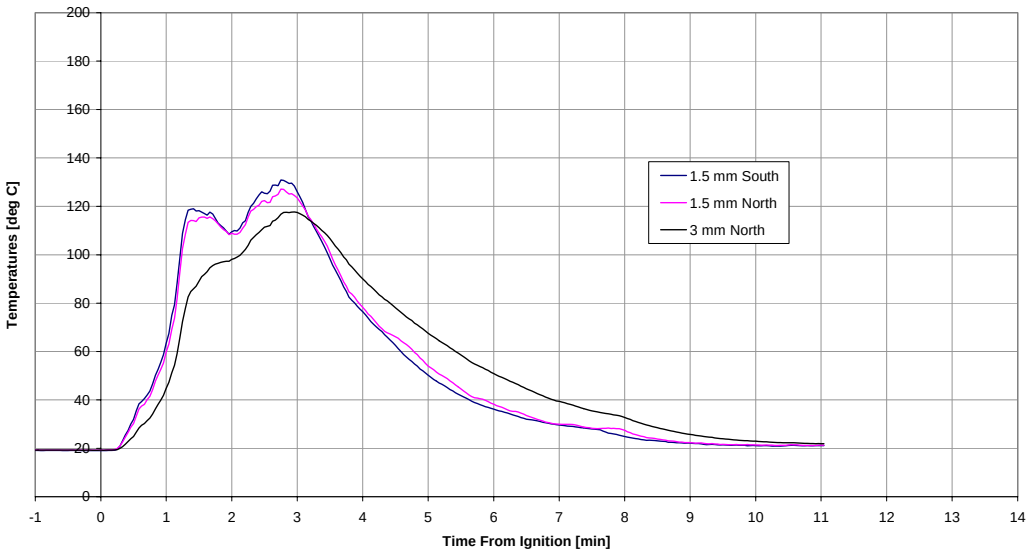

Figure 4E.106 Test 15 Temperatures at sprinkler B2

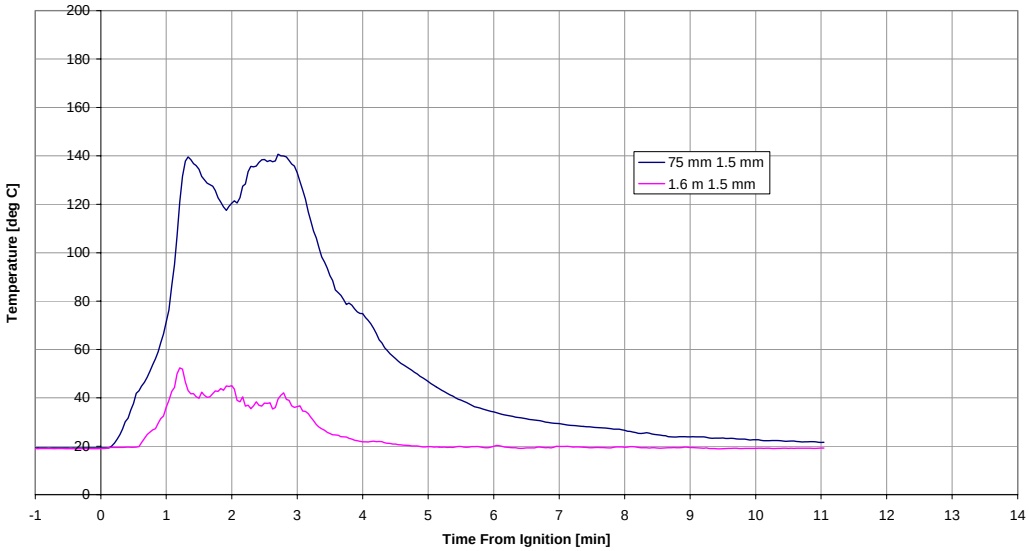

Figure 4E.107 Test 15 Temperatures at centre of room

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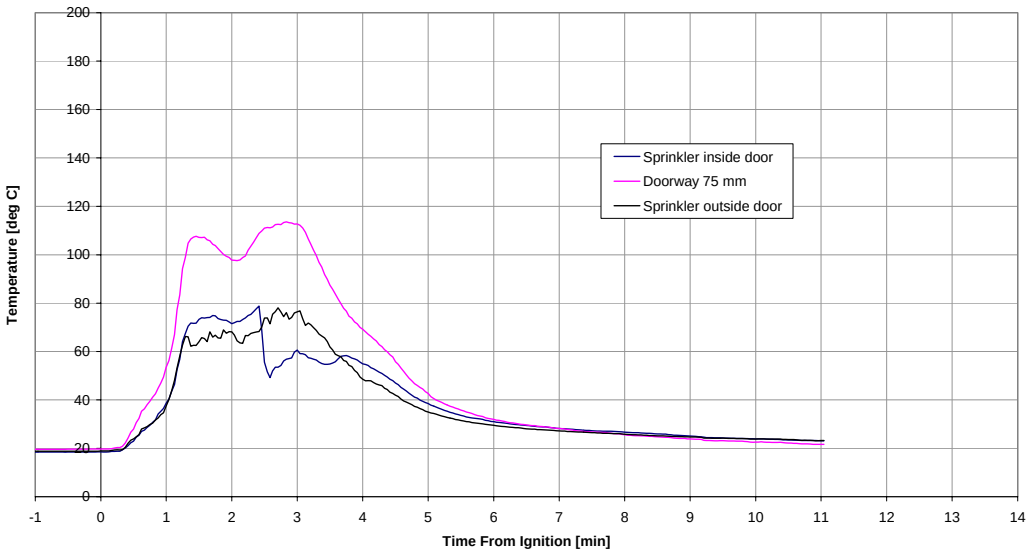

Figure 4E.108 Test 15 Temperatures at doorway

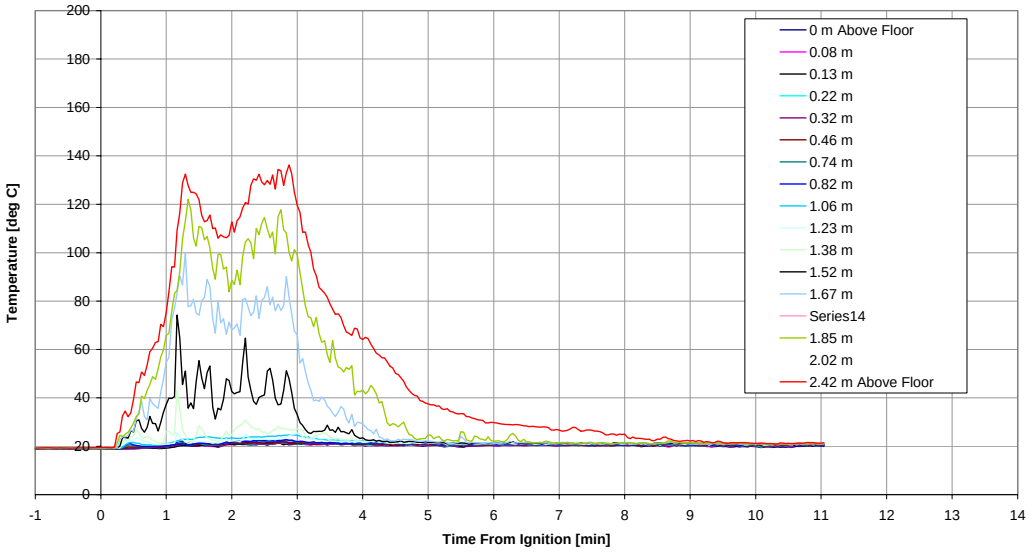

Figure 4E.109 Test 15 Temperatures at column 1

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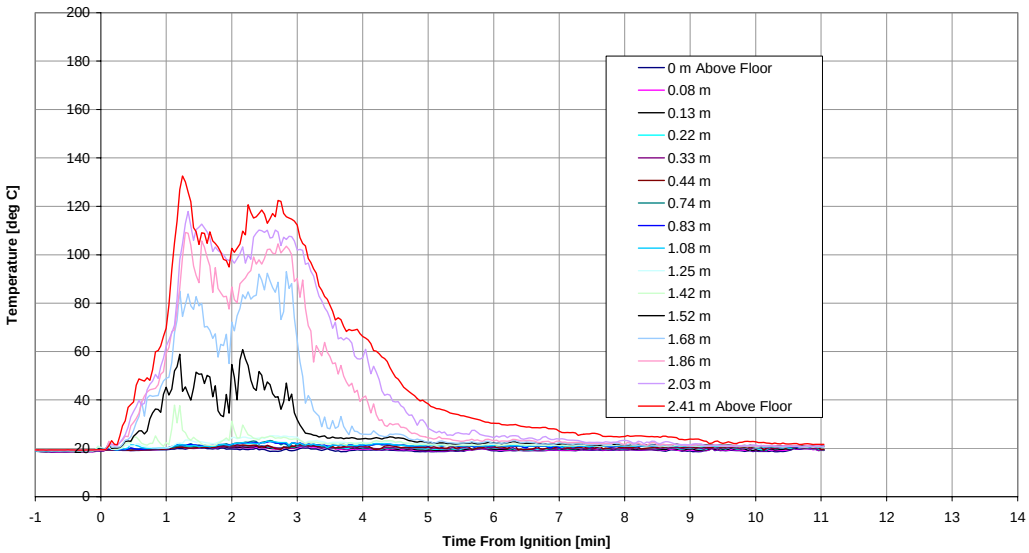

Figure 4E.110 Test 15 Temperatures at column 2

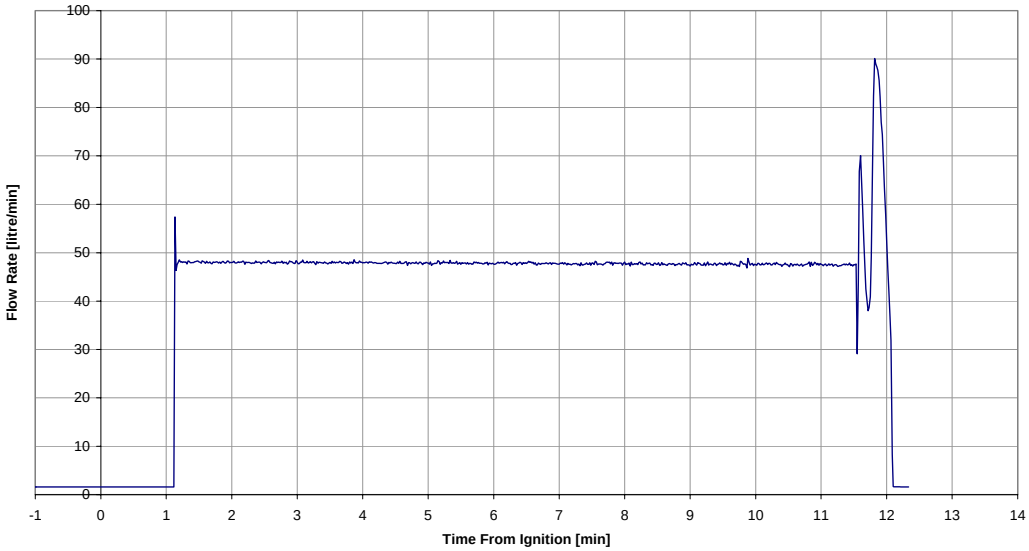

Figure 4E.111 Test 15 Sprinkler water flow rate

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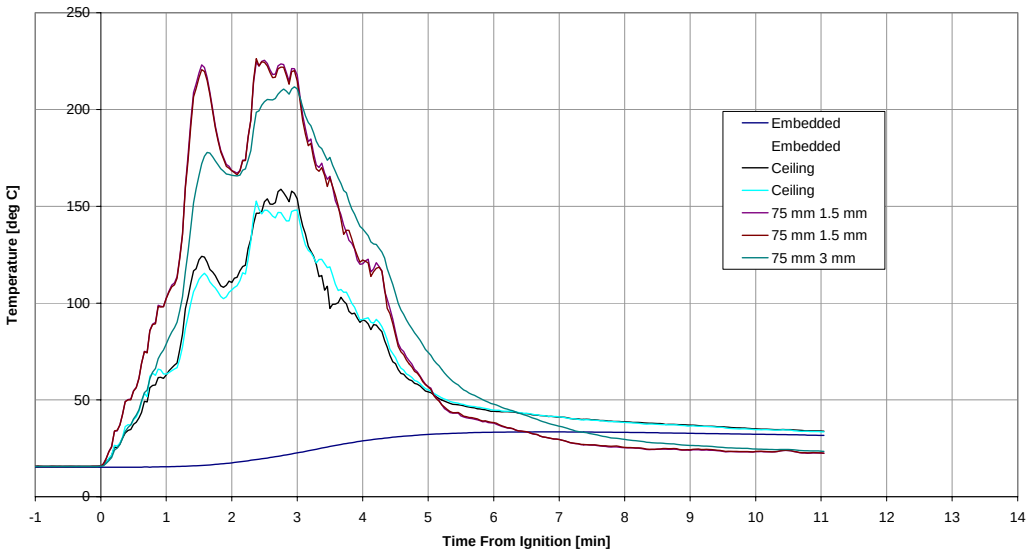

Figure 4E.112 Test 16 Temperatures above crib

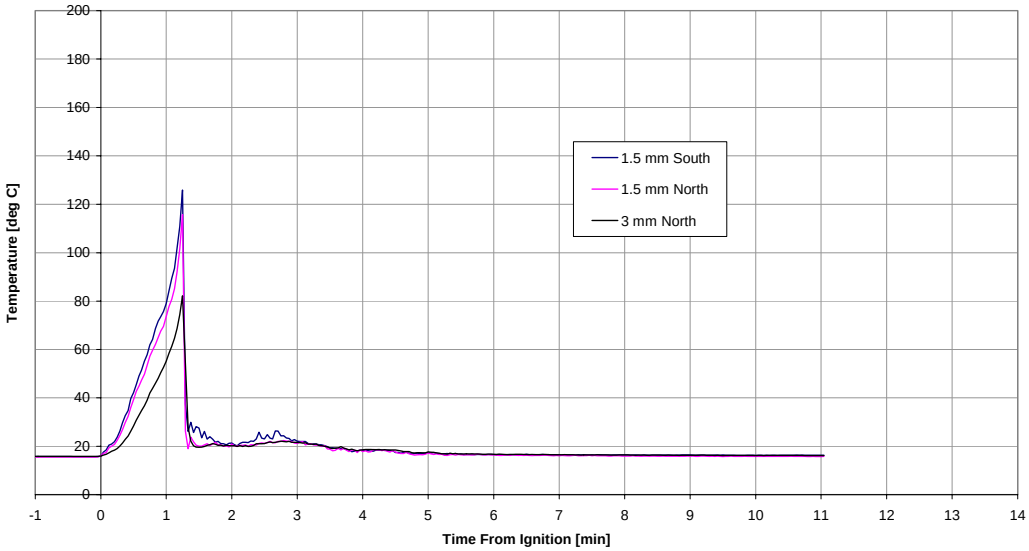

Figure 4E.113 Test 16 Temperatures at sprinkler B1

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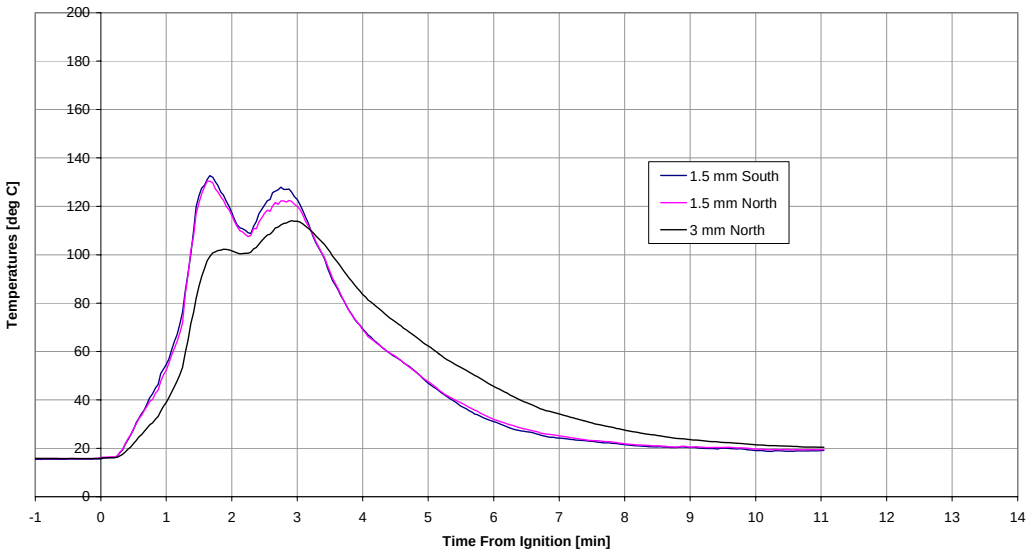

Figure 4E.114 Test 16 Temperatures at sprinkler B2

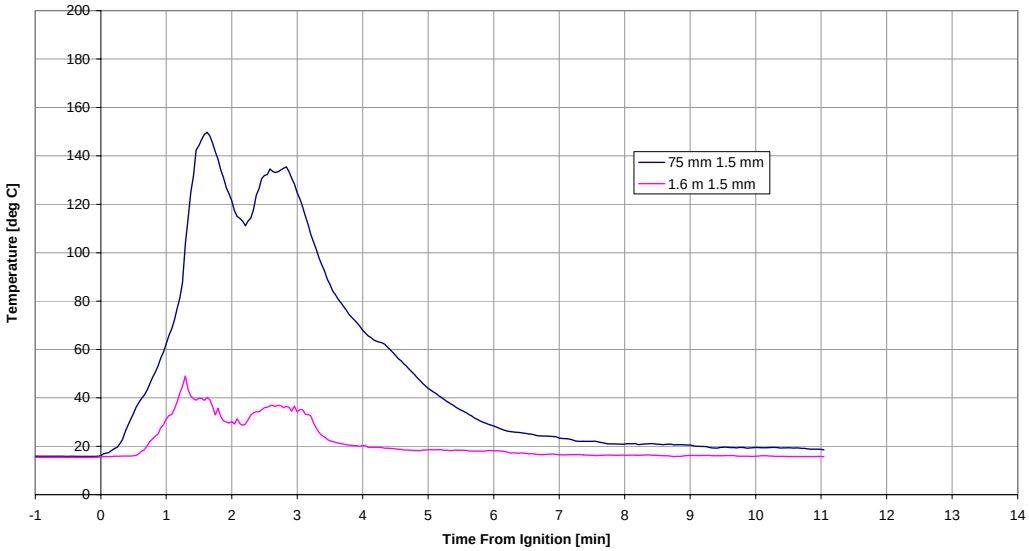

Figure 4E.115 Test 16 Temperatures at centre of room

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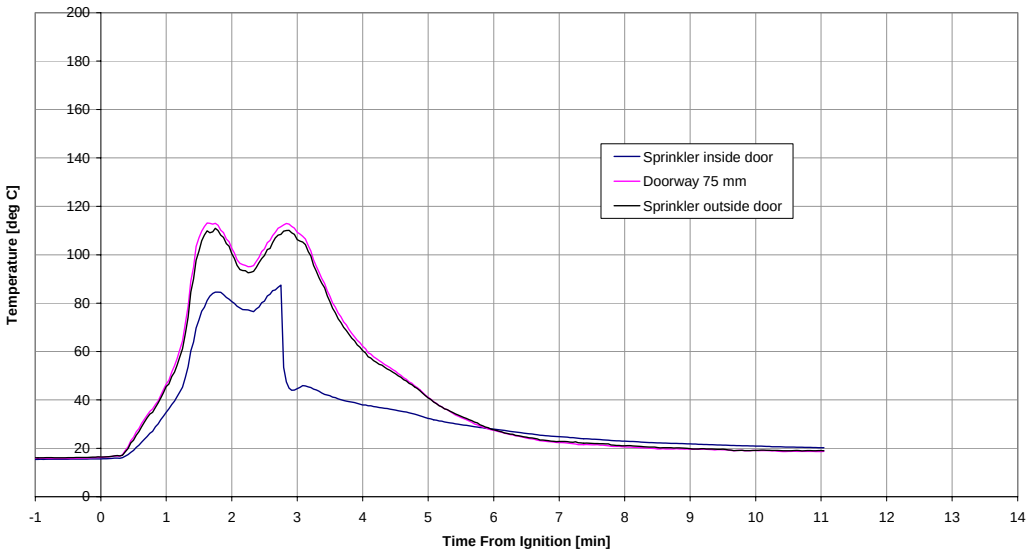

Figure 4E.116 Test 16 Temperatures at doorway

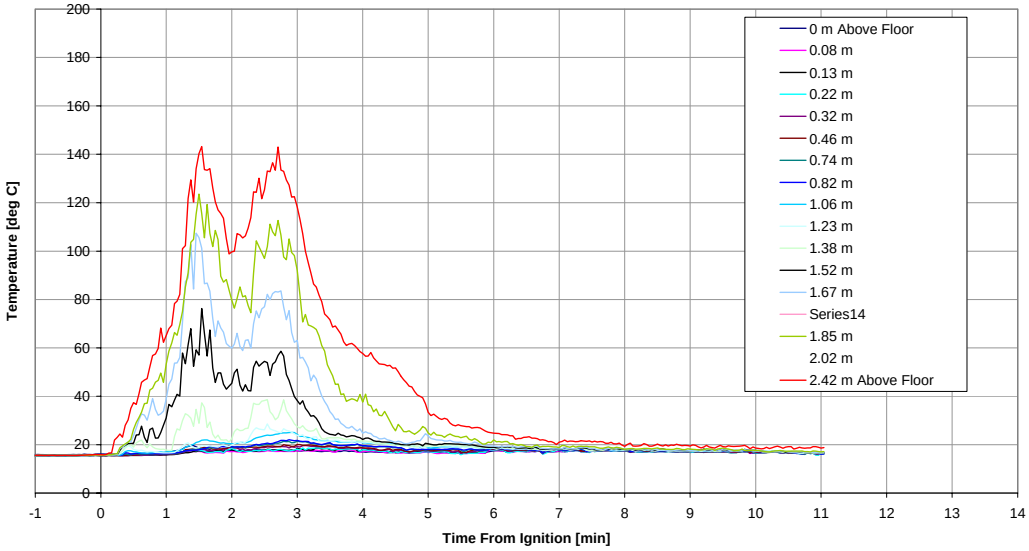

Figure 4E.117 Test 16 Temperatures at column 1

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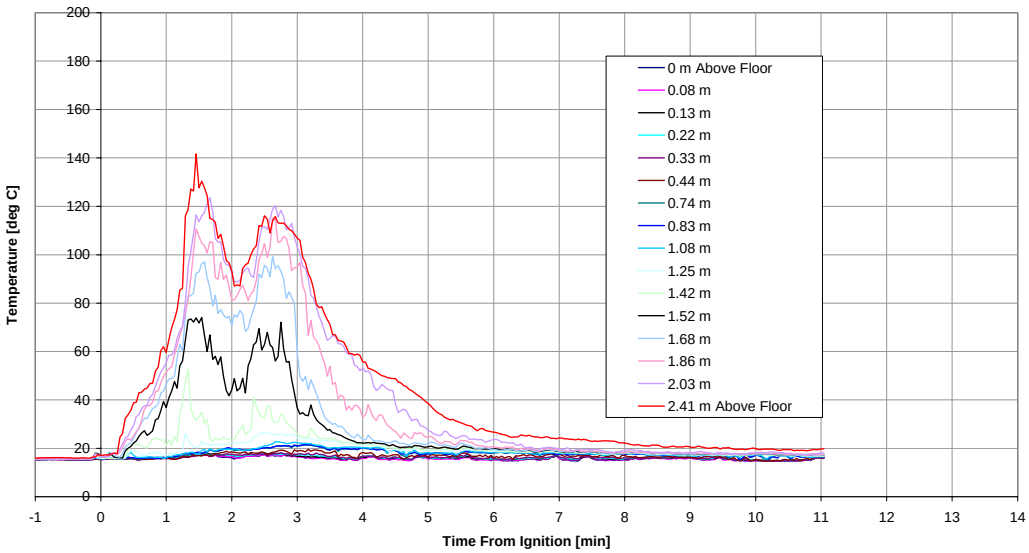

Figure 4E.118 Test 16 Temperatures at column 2

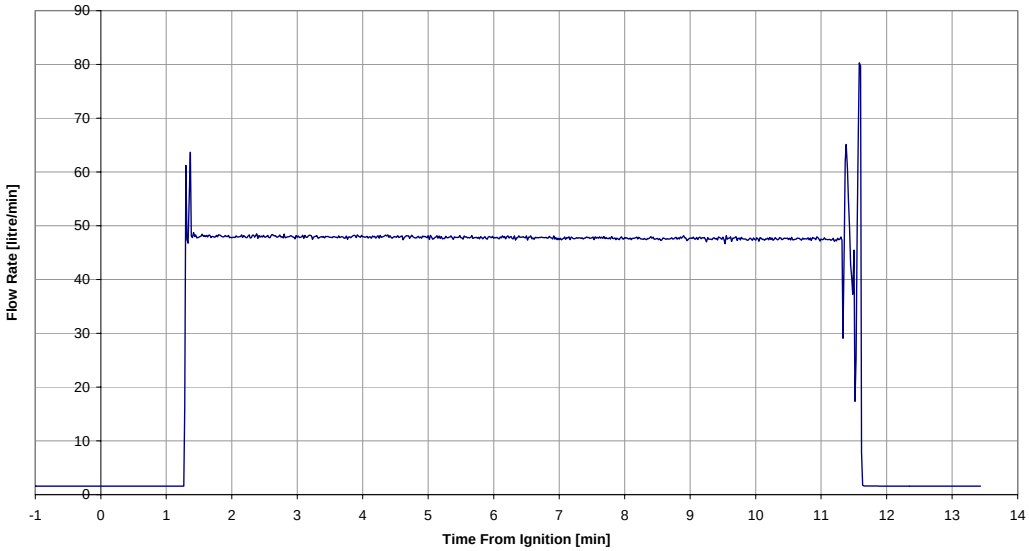

Figure 4E.119 Test 16 Sprinkler water flow rate

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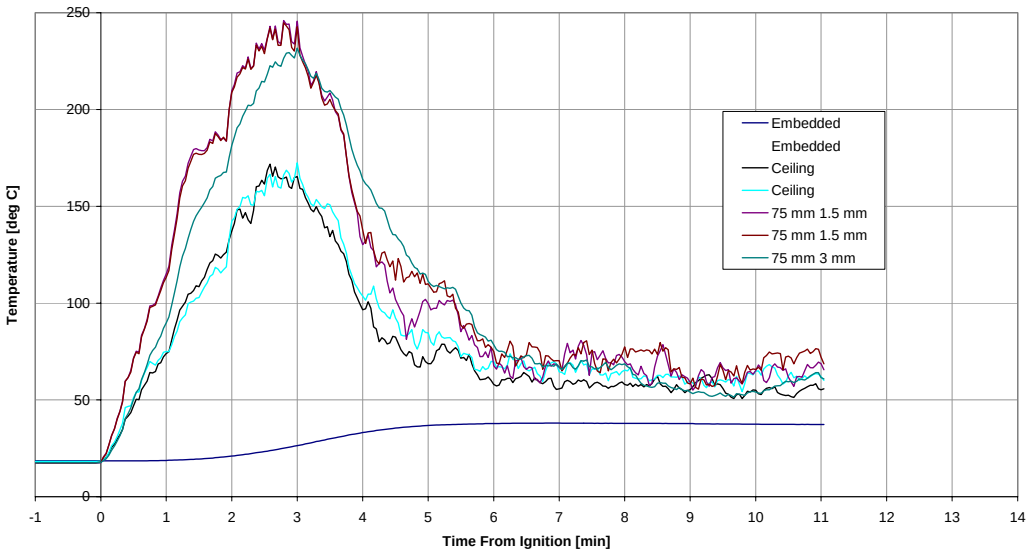

Figure 4E.120 Test 17 Temperatures above crib

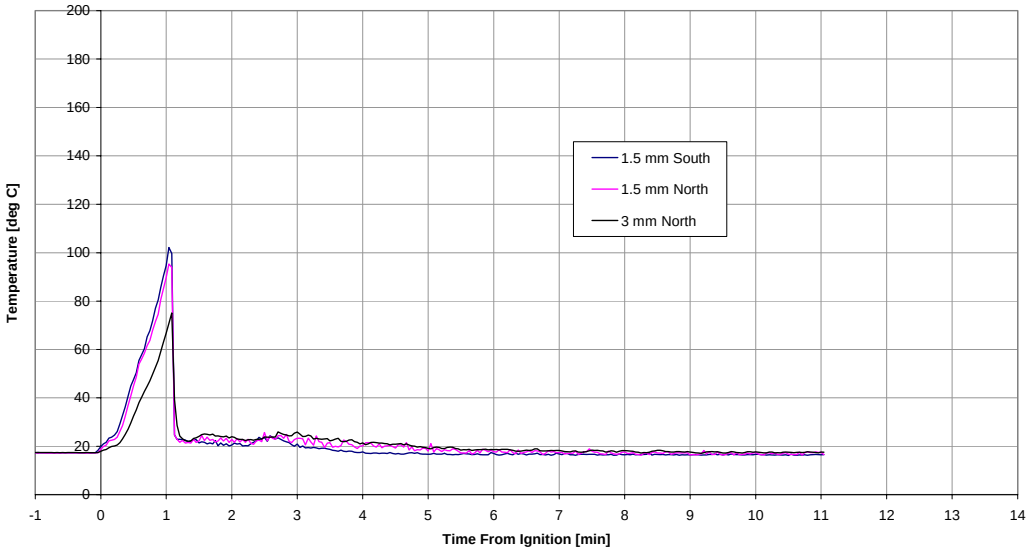

Figure 4E.121 Test 17 Temperatures at sprinkler B1

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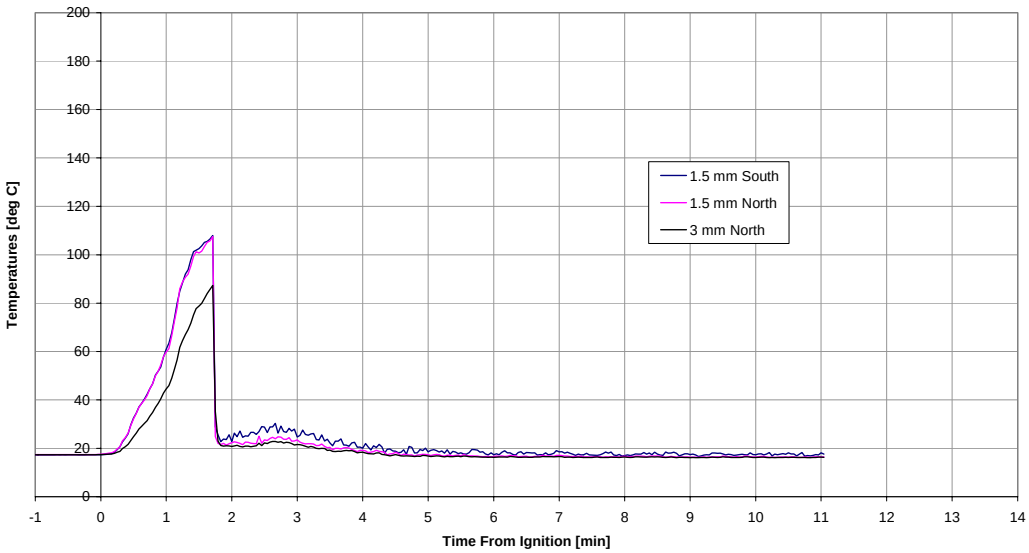

Figure 4E.122 Test 17 Temperatures at sprinkler B2

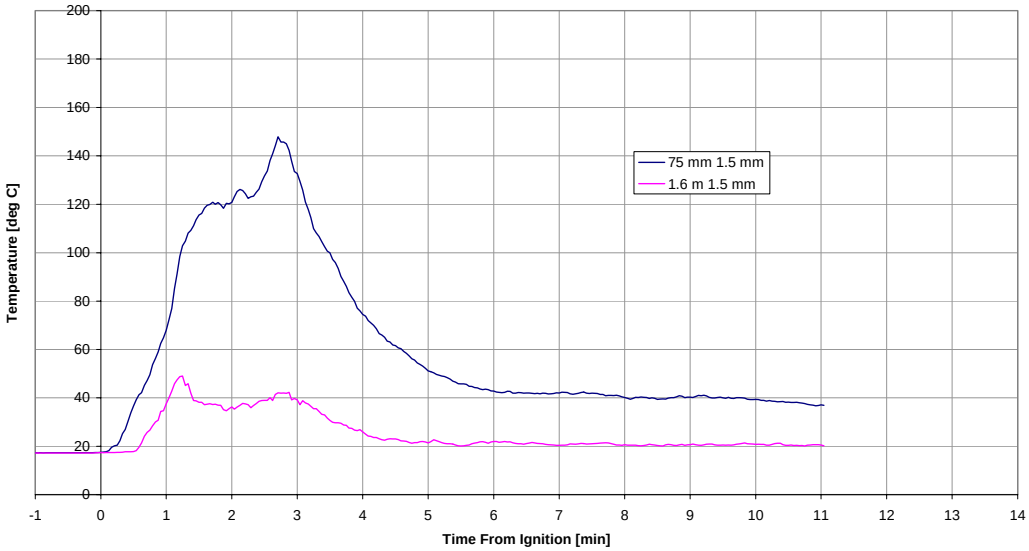

Figure 4E.123 Test 17 Temperatures at centre of room

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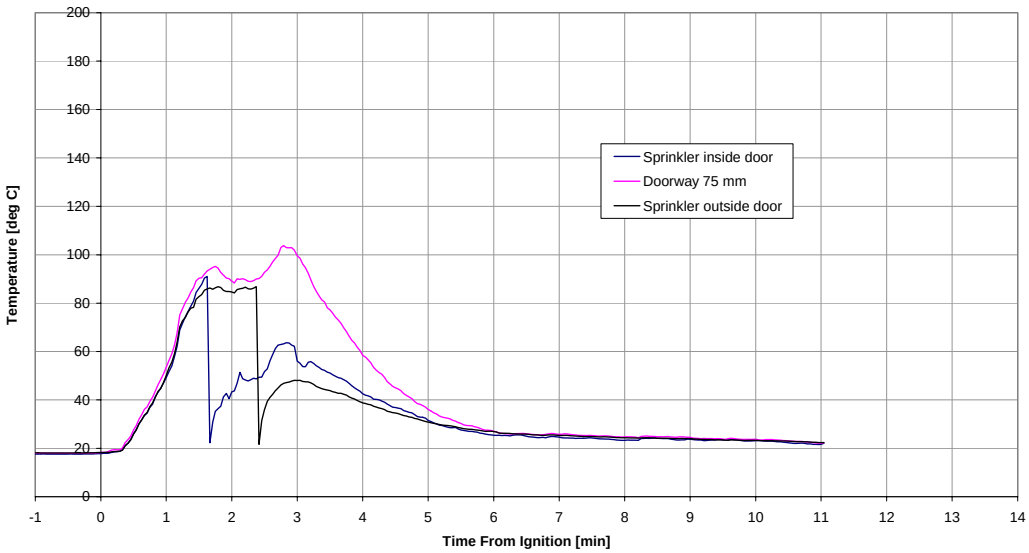

Figure 4E.124 Test 17 Temperatures at doorway

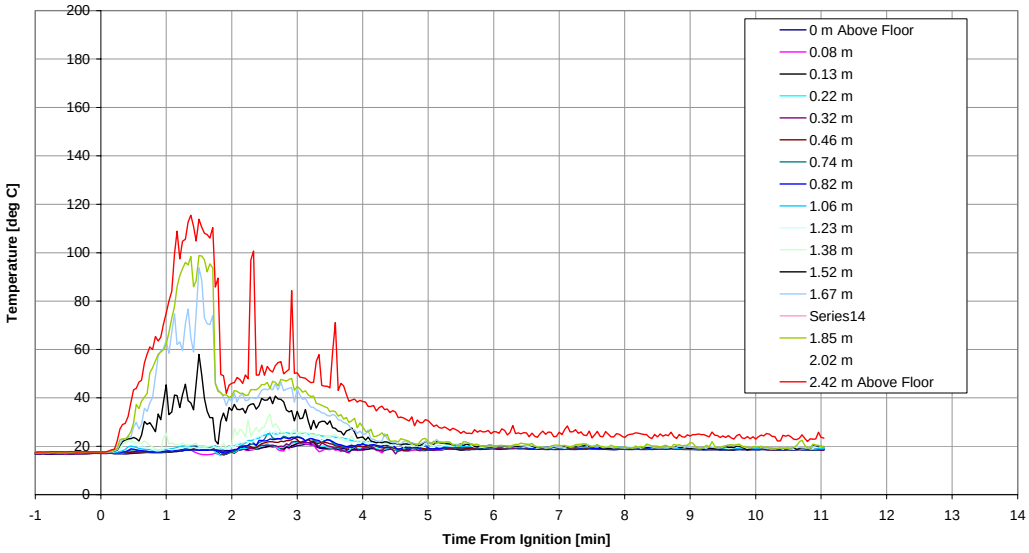

Figure 4E.125 Test 17 Temperatures at column 1

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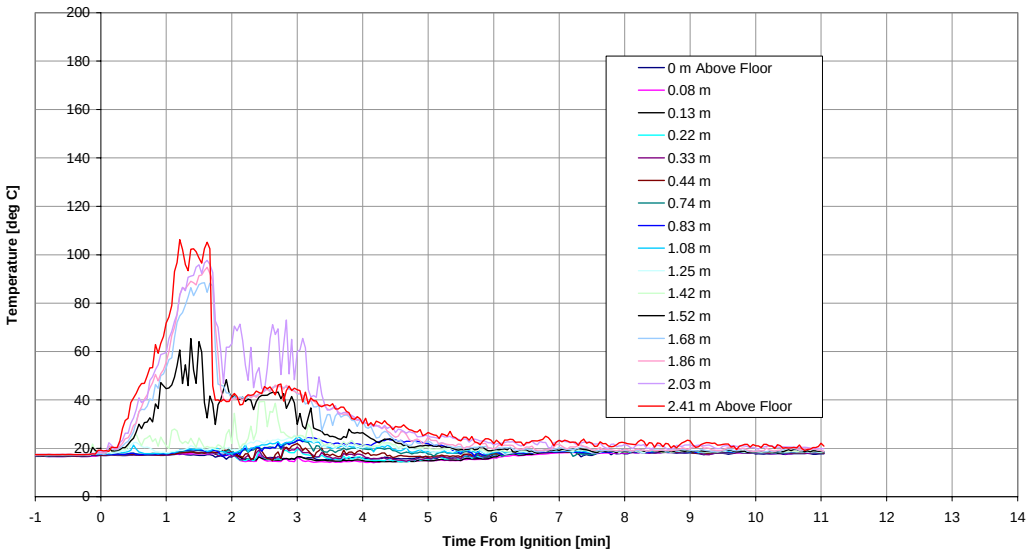

Figure 4E.126 Test 17 Temperatures at column 2

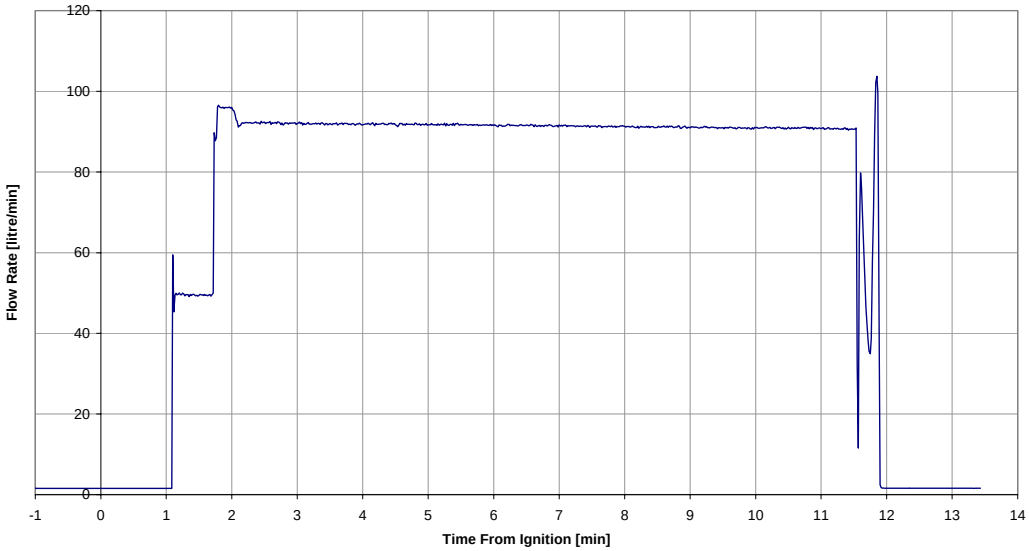

Figure 4E.127 Test 17 Sprinkler water flow rate

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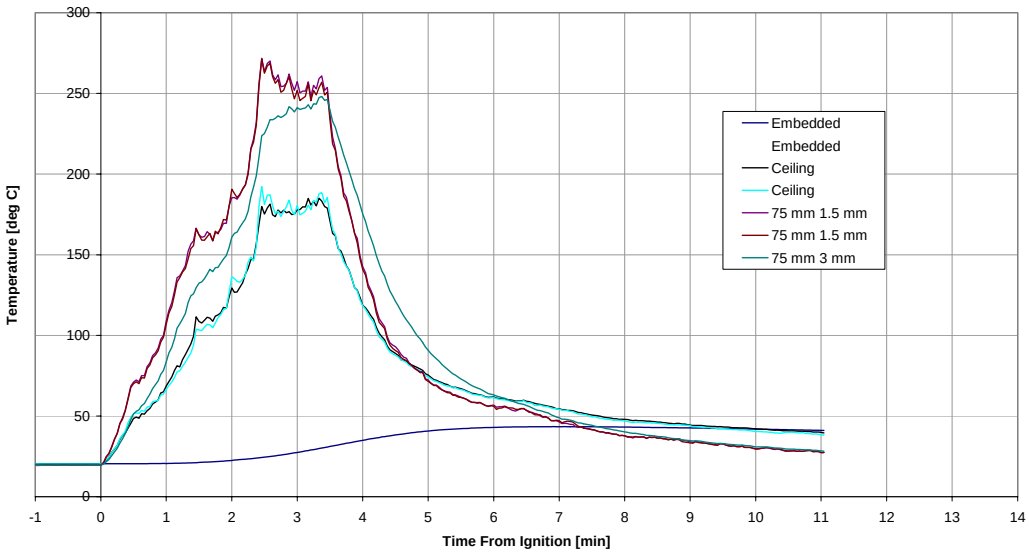

Figure 4E.128 Test 18 Temperatures above crib

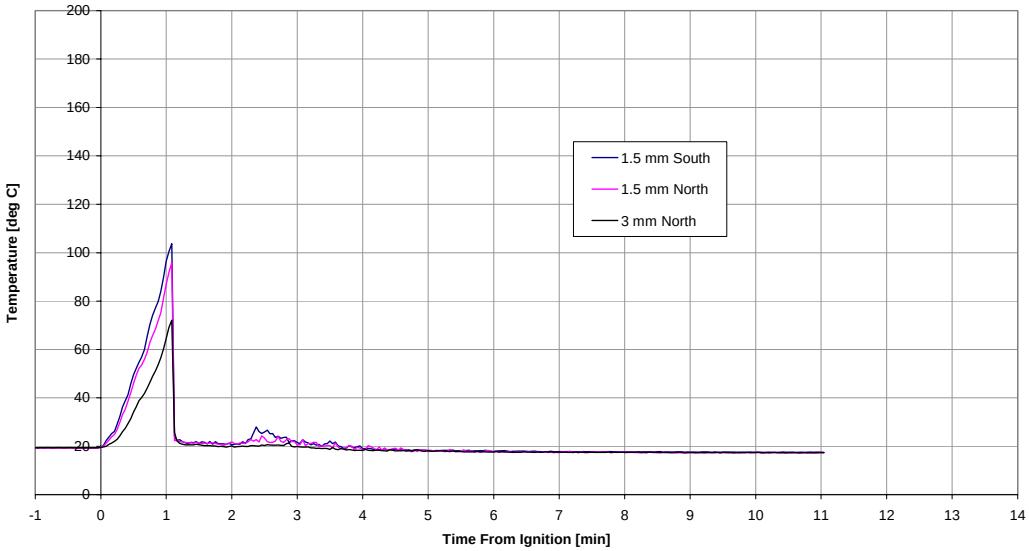

Figure 4E.129 Test 18 Temperatures at sprinkler B1

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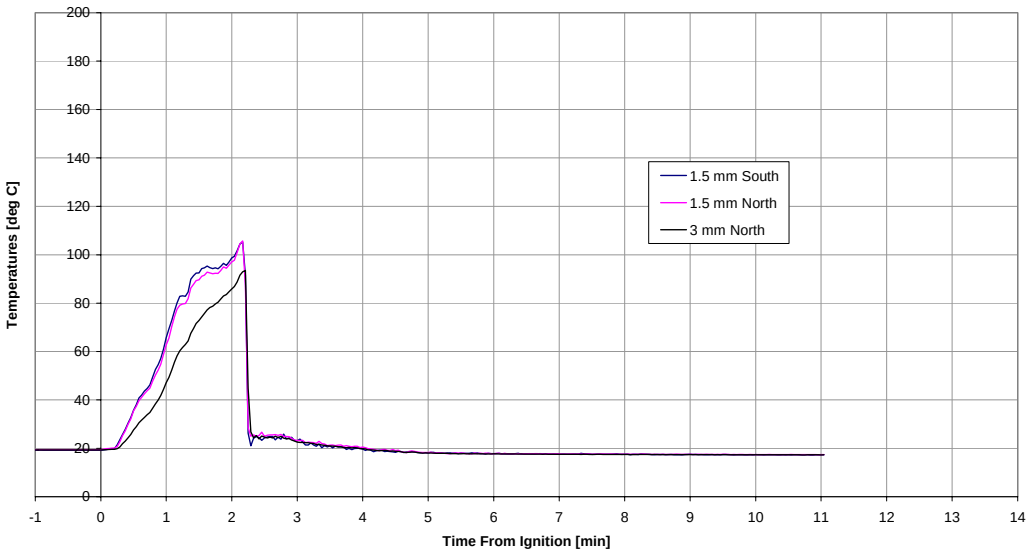

Figure 4E.130 Test 18 Temperatures at sprinkler B2

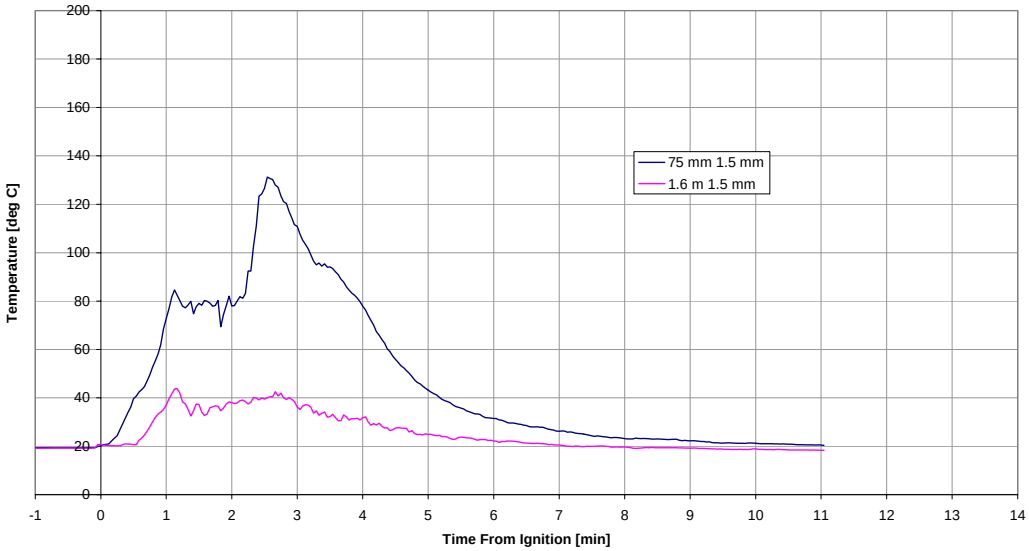

Figure 4E.131 Test 18 Temperatures a centre of room

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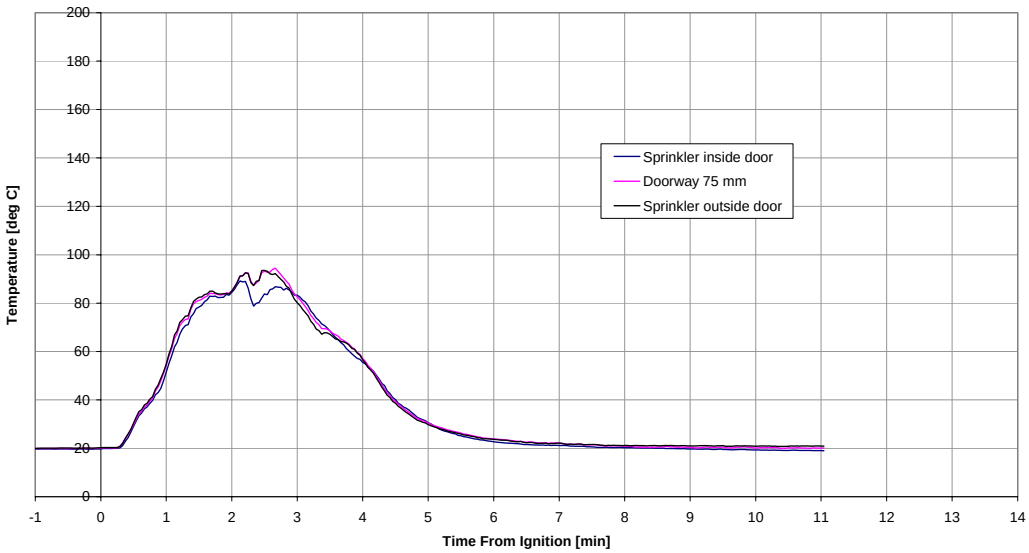

Figure 4E.132 Test 18 Temperatures at doorway

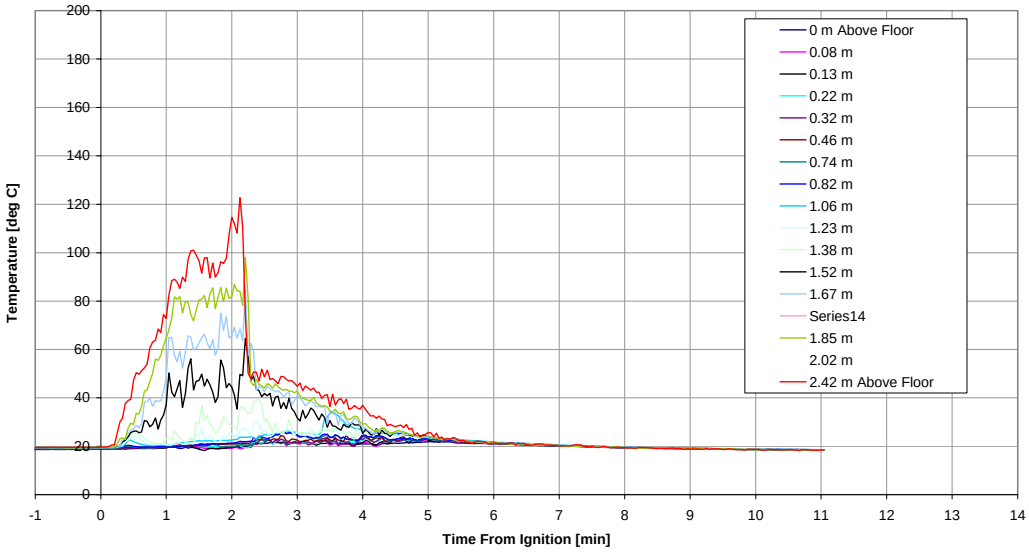

Figure 4E.133 Test 18 Temperatures at column 1

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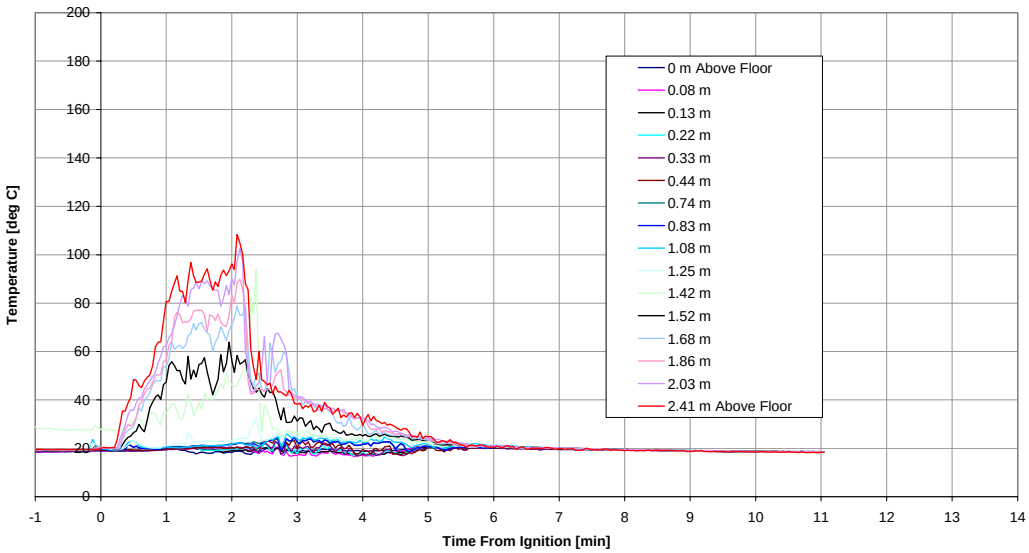

Figure 4E.134 Test 18 Temperatures at column 2

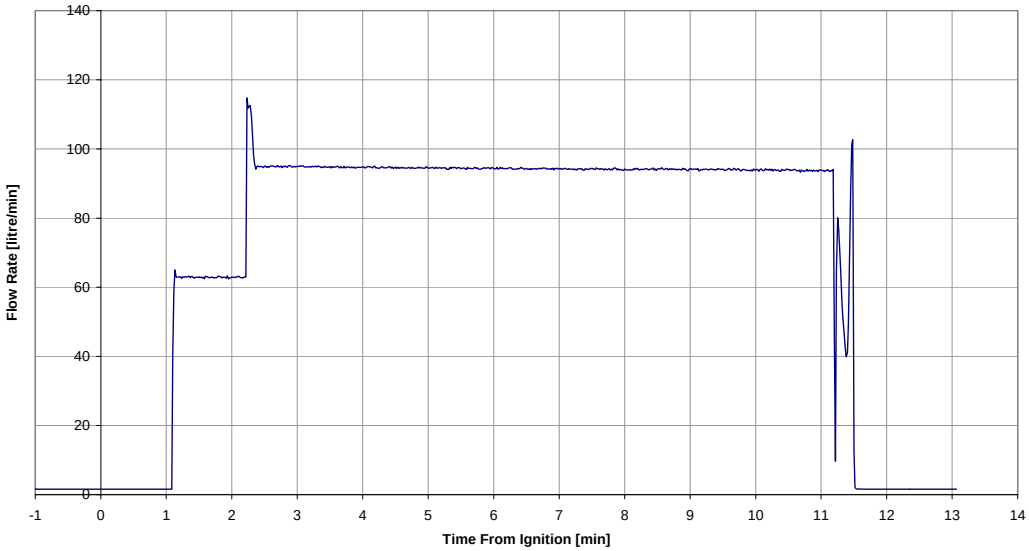

Figure 4E.135 Test 18 Sprinkler water flow rate

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Appendix 4F – Selected heat release graphs for the unsprinklered calorimetry fires for the Benchmark tests

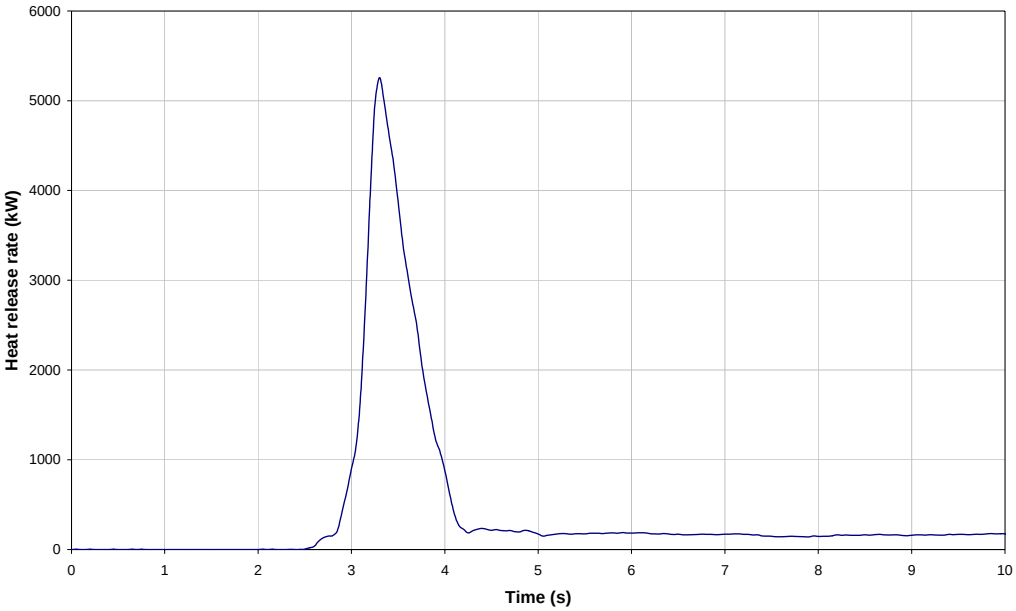

Figure 4F.1 Graph of heat release with respect to time for unsprinklered corner fire test, uncut foam sheets (925 mm by 1000 mm by 75 mm)

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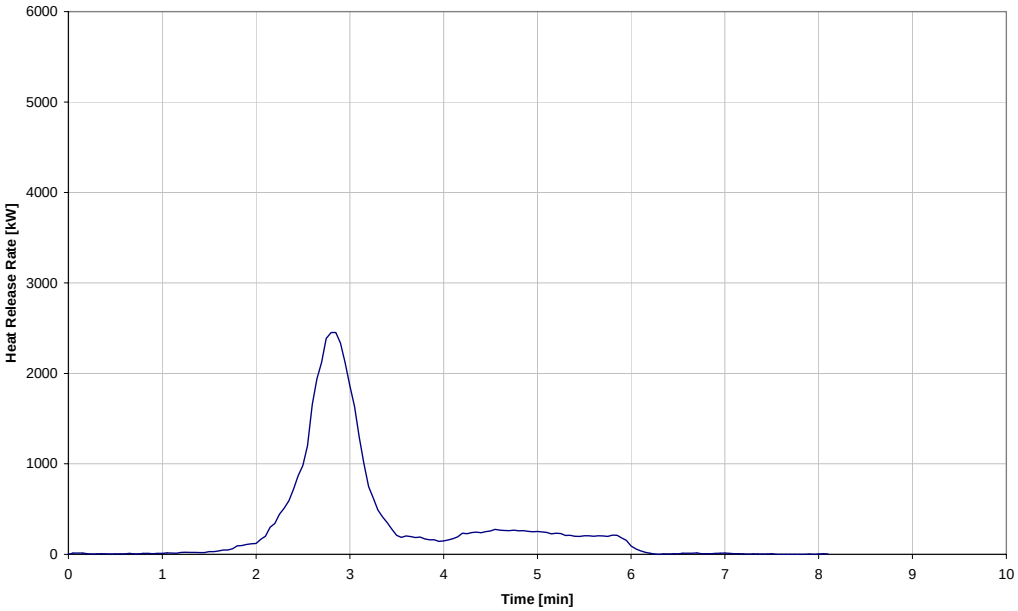

Figure 4F.2 **Graph of heat release with respect to time for unsprinklered corner fire test, cut foam sheets (775 mm by 865 mm by 75 m**

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