Fire & Rescue NSW

Fire research report

Residential Sprinkler Research

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Preface

This research report describes a study that investigated the performance and efficacy of two sprinkler system designs with respect to occupant tenability and safe egress in simulated residential fires. The study addresses a recommendation from the NSW Coroner's Court to provide a cost-effective and fit-for-purpose sprinkler system in all Class 2 and Class 3 buildings. For the purposes of this report, such systems are referred to as residential sprinkler systems.

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Executive Summary

Background

The focus of this fire research program was to undertake testing to support a Proposal for Change (PFC) to mandate fire sprinkler systems in the 2019 National Construction Code (NCC) for new Class 2 and Class 3 shared residential accommodation buildings up to 25 metres in effective height. The evidence gathered aims to deliver the life safety objectives of the NCC through the mandatory installation of fire sprinkler systems in a more reliable and cost-effective manner. This was recommended by NSW Deputy Coroner Hugh Dillon following the inquest into the death of Connie Zhang, the life-changing injuries to Ginger Jiang, and the inquiry into the 6 September 2012 fire at Unit 53, Tower B, 4 West Terrace, Bankstown, as follows:

> ***To the Minister for Planning (NSW) and the General Manager of the Australian Building Codes Board (ABCB):***
>
> *That the Department of Planning (NSW) and the ABCB conduct research (jointly or individually), in consultation with Fire & Rescue NSW and the Australasian Fire and Emergency Service Authorities Council, into the offsetting of costs associated with installing fit-for-purpose sprinkler systems in new Class 2 and 3 buildings through the possible reform of other fire safety requirements.*

The research subsequently conducted by Fire & Rescue NSW, supported by Fire Protection Association Australia (FPA Australia), Australasian Fire and Emergency Service Authorities Council (AFAC) and CSIRO, is a direct response to this recommendation. The research program is based on the principle that automatic suppression in the form of fire sprinkler systems provides the most reliable form of life safety and should be mandated in all new Class 2 and Class 3 residential buildings in a cost-effective manner.

Methodology

The methods of analysis and evaluation included an extensive literature review which was undertaken by CSIRO, and the design of an adaptable, representative and re-usable live burn structure that was suitable for the testing of sprinkler systems in varying configurations, including that which reflected the floor layout of Unit 53, Tower B, 4 West Terrace, Bankstown. The tests were carried out at the CSIRO Reaction to Fire Laboratories in North Ryde, Sydney.

FRNSW and its research partners developed two fit-for-purpose sprinkler concepts for Class 2 and Class 3 buildings not more than 25 metres in effective height: one based on tapping from the domestic water supply and one based on tapping from the hydrant system.

The fire research testing program consisted of 14 full-scale 'live' burn events as a means of comparison between two cost-effective, efficient and reliable residential sprinkler systems. The two systems were individually designed by two separate sprinkler design and installation companies.

The sprinklers were installed inside a purpose-built 'test assembly' constructed from timber framing over which structural plywood was installed, then lined with 16mm fire-rated plasterboard on the walls and ceiling. Construction was typical in both materials and dimensions, including standard-sized windows and doors. The floorplan was in an incomplete full-scale replica of the Bankstown apartment.

The 'Domestic' system was based on water taken from the domestic supply and delivered in polyethylene piping in accordance with Australian Standard 2118.5 using standard sprinkler heads at industry (code) accepted spacings. The 'Hydrant' system was based on a dedicated supply of water taken from the hydrant using larger diameter metal piping in accordance with Australian Standard 2118.4 and using the same standard sprinkler heads and code accepted spacings.

Fire load within the structure consisted of 'stylised' furniture for the majority of tests with deviation from the stylised furniture amounting to a 'kitchen' fire using overheated cooking oil as the fire source. The stylised furniture consisted of 2 x 2 seater sofa frames made from mild steel. Six blocks of polyurethane were used as the sofa cushions for each test. Included in the stylised furniture was a small side table and a larger coffee sized table. On top of each table was fixed a matching sheet of plywood as an added fuel load.

A bedroom fire was included in the testing regime using the same stylised furniture used in the 11 living room fires.

The fuel load was generally placed in the corner of the living room, and included a small wooden crib on top of a small tray of heptane as the area of ignition. The fire was started with a propane burner.

Test Results

The results of the 13 sprinklered tests revealed a consistency in sprinkler activation times and temperature at the time of activation.

In relation to the effects of sprinklers on heat and atmospheric tenability, sprinklers had a significant effect on both aspects within the structure.

Aside from time to sprinkler activation and spray patterns, a focus on temperature and atmospheric tenability was important. Sprinkler heads operated effectively and as expected in all tests.

In a ***non-sprinklered*** benchmark burn of the test apartment, the toxicity limit (Fractional Effective Dose (FED_{asp}) of 0.3 – one of the agreed tenability criteria – was reached at 3 minutes 50 seconds in the bedroom with the bedroom door closed, while temperatures likely to result in flashover (918°C at ceiling height above the ignition point) were achieved in 3 minutes 42 seconds.

By comparison, during the sprinklered tests: the sprinklers successfully operated in all tests; the peak temperatures were all well below flashover; and the highest temperature reached was 372°C at ceiling height above the ignition point. A toxicity level of FED_{asp} 0.3 was not achieved until an earliest mark of 14 min 42 s in the closed bedroom.

The other agreed tenability criterion – a temperature above 65°C at 1.6 metre height – was not exceeded significantly in all but one test. In all tests, 65°C was not exceeded at 1 metre.

Recommendations

Based on the results of tests undertaken in this fire research program and within the limitations of the number and type of scenarios tested, it is clear the activation of automatic fire sprinklers significantly improves the tenability of occupants in the event of a fire. The improvement in temperatures and atmospheric toxicity also significantly improves conditions for firefighters, resulting in a safer operating environment at the time of fire brigade intervention. It is therefore recommended that:

1. The two tested concept designs be finalised and used to support a Proposal for Change to the 2019 National Construction Code that mandates sprinklers in new Class 2 and Class 3 shared residential accommodation buildings up to 25 metres in effective height.

2. Further fire research be undertaken by FRNSW and its research partners to develop and test cost-effective and reliable sprinkler systems for application in other residential structures, particularly Class 1 buildings.

3. Develop and implement a public education program to reinforce the “Get out, stay out, call Triple Zero (000)” message as pertaining to sprinklered homes.

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1. INTRODUCTION

As a result of a tragic unit fire in Bankstown, NSW in September 2012, the NSW Coroner's Court (Dillon, 2012) recommended that the NSW Department of Planning and Environment and the Australian Building Codes Board (ABCB), in consultation with Fire and Rescue NSW (FRNSW), find avenues to provide a cost effective and fit-for-purpose sprinkler system in new Class 2 and Class 3 buildings, i.e. commercial residential accommodation and multi-unit complexes. A task group was established to undertake a research project to address the recommendations. It included:

- Mr John Clampett, Consultant
- Fire & Rescue New South Wales (FRNSW)
- The Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- Mr Bill Lea – IMEA Pty Ltd
- Mr Mark Cummings – Eclipse Fire Pty Ltd

The objective of the research was to develop a fire sprinkler system that is cost effective (ideally cost neutral) and is suitable for installation into residential buildings (apartments, flats, hotels etc.) up to 25 metres in effective height, which are classified as Class 2 and Class 3 buildings in the Building Code of Australia or National Construction Code (NCC). The 25-metre height benchmark is stipulated in the NCC, with some limited variances, as the level from which sprinklers are mandatorily installed in buildings. There are numerous, and an ever-increasing number, of residential projects that are below 25 metres in effective height.

The project consisted of several stages, including:

1. A literature review undertaken by the CSIRO.
2. The design of an adaptable, representative and re-burnable test structure suitable for testing the sprinkler systems at the fire testing facility at CSIRO in North Ryde, NSW.
3. The design of two cost-effective, efficient and reliable residential sprinkler systems.
4. A survey of insurance companies to determine savings/cost offsets if a sprinkler system is installed when not required. Included in this is a development of a suitable design fire and a performance bench mark.
5. Development of a testing methodology/regime for testing the performance of the alternative sprinkler options.
6. The undertaking of an initial test burn program by FRNSW consisting of 14 tests at the CSIRO North Ryde facility.

This report details the results of the initial test program completed in February–May 2017.

Literature review by CSIRO

CSIRO undertook a review of the available literature (Abraham & Webb, 2017) to determine what work has already been undertaken in this area. The review added to the body of knowledge of the task group, prevented repetition of work, determined what additional testing is required, and helped to design a suitable test program to demonstrate an acceptable level of fire safety which would be achieved within the building in adopting a low-cost sprinkler system.

The scope covered:

- Review of current test methods for sprinkler approvals.
- Review of experimental fire tests for sprinkler effectiveness.
- Review of fire loads for residential occupancies.
- The change in fire loads in residential occupancies over time.
- Work done on stylised fire scenarios and fuel configurations.
- Review and modelling of case studies of fire events involving residential occupancies.
- Tests comparing sprinkler-protected and non-sprinkler-protected fires.
- Flaming ignition sources used in fire tests.
- Acceptance criteria for sprinkler fire tests.

The literature review (Abraham & Webb, 2017) found that most sprinklers in use around the world have been approved based on the sprinkler approval standards developed by Underwriter Laboratories (2012) and FM Global (FM 2030, 2009). Factory Mutual Research Corporation (FMRC) conducted a series of fire tests to investigate sprinkler performance in a typical flame-initiated residential fire scenario (Kung, Haines, & Green Jr, 1978). The study demonstrated that links (sprinkler head bulbs) that are more sensitive than the commercial links are essential in providing adequate life safety and property protection in residential fires. Adequate water application to the corner of the room where the fire source was located, and to the walls, was found to be critical in controlling such a fire.

The US National Fire Protection Authority (NFPA) conducted research to test the performance of alternative sprinkler designs in controlling the development of fire in single family dwellings (Cote, 1983). The criteria used to evaluate the effectiveness of using the ‘quick response’ sprinkler heads are listed as:

- Sprinkler system effectiveness

- Fire control
- Tenability criteria.

BRANZ conducted studies to investigate the cost and cost-effectiveness of domestic sprinkler systems built to the New Zealand standard NZS 4515:1995 (C Duncan, 2001). The report outlines a low-cost, multi-purpose sprinkler system that fulfils its objective by reducing loss of life, injury and property damage due to fire in residential buildings.

Test structure design

The re-burnable test structure was designed and built by FRNSW in consultation with the CSIRO and Galea's Engineering. The rig consists of a series of four moveable floor modules measuring 3.6 metres by 3.6 metres wide, with the floor surface sitting approximately 400 millimetres off the ground. Two centre expansion modules measure 3.6 metres by 1.2 metres wide to create a floor assembly area of 7.2 metres by 8.4 metres, or 60.48 square metres. The floor modules consist of a steel rectangular hollow section (RHS) sub-frame set on four heavy-duty caster wheels to allow for manoeuvrability. On top of the RHS sub-frame sits three layers of differing materials starting with 16 mm particle board, followed by 16 mm fire-resistant gypsum board and then a layer of 16 mm fibre-cement sheeting. The layers provide stability and protection of the sub-floor equipment from fire.

Each floor module has the ability to be individually levelled by way of threaded adjustment points in each corner. Within each adjustment point is the ability to insert a load cell as a means of measuring mass loss during fire testing. The floor modules are assembled using a simple nut and bolt system along each side. Once in place, the floor modules are lowered onto the adjustable feet and load cell and levelled using a dumpy level. Each floor module has a series of hatches allowing for access to the adjustment points and securing points. These hatches also serve as drainage points for water during the sprinkler tests.

The re-burnable unit was constructed in place above the levelled floor assembly at the CSIRO test facility in North Ryde, NSW. The unit replicates the full-sized layout of a two-bedroom, open plan home unit with a main entrance opening to a small kitchen, a lounge area which has a sliding-door opening opposite to the main entrance, and a small hallway leading to the bedrooms and bathroom. The unit represents the floorplan of the Bankstown unit that was subject to the Coronial Inquiry, although limitations in space at the CSIRO facility meant the complete floor plan could not be replicated.

The frame of the unit was constructed from Oregon timber, with the walls lined with plywood bracing, over which 16 mm fire resistant gypsum board panels were used to line the internal walls and ceiling. The structure contains a standard solid timber, single leaf entry door and three standard internal doors. Low-height aluminium glazed sliding doors were installed adjacent to the main living area, and a 7 mm perspex sheet was used to cover the window opening in the main bedroom (Bedroom 1). Ceiling heights were 2.4 m and bulkheads above doors were set at 2.1 m. The layout is detailed in Figure 3.

Figure 1 View of the floor assembly

Figure 2 View of the burn unit

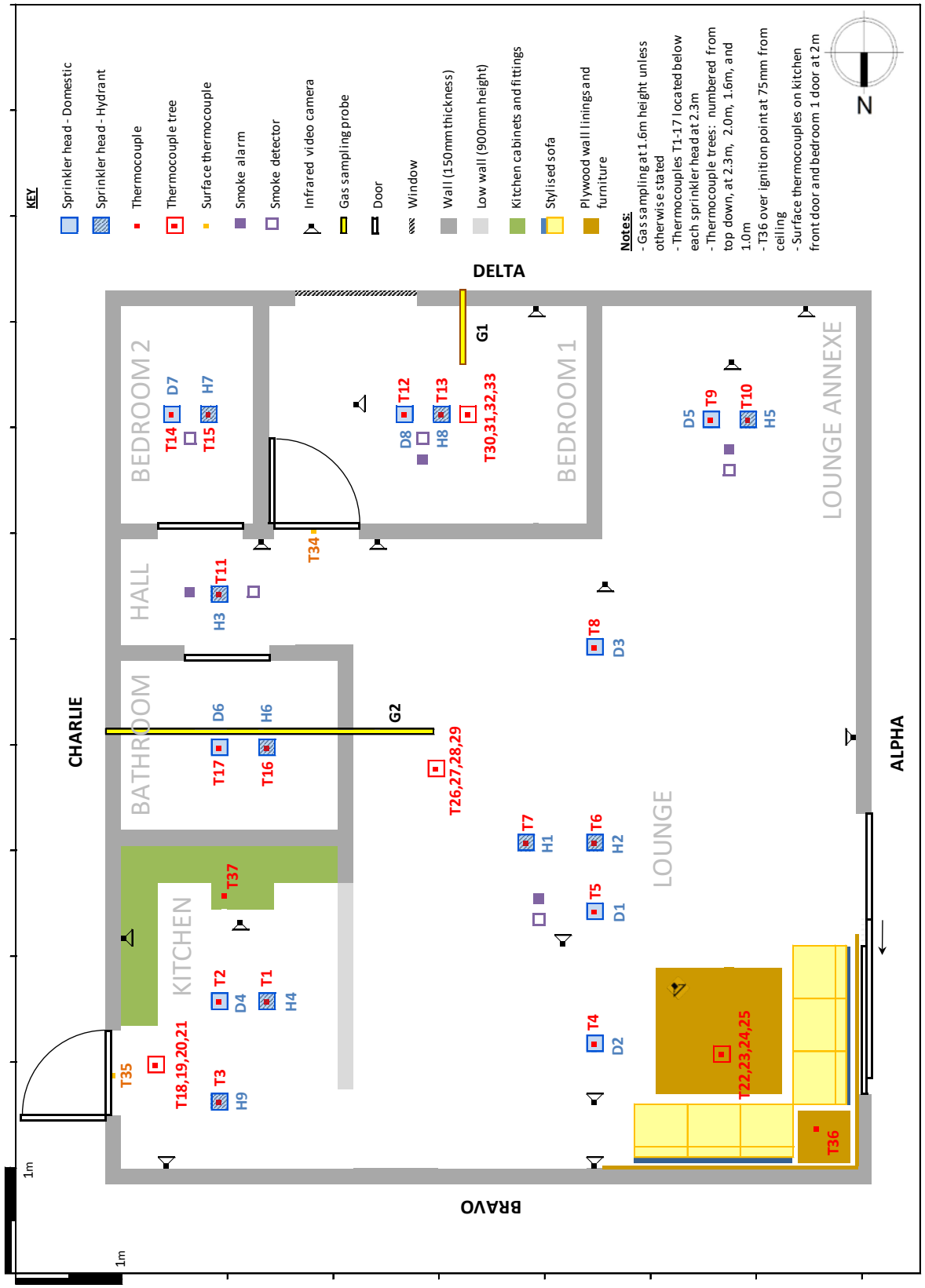

Figure 3 Layout of the burn unit

Sprinkler system designs

Two sprinkler systems were used during the testing: one is a modified Domestic system based on AS 2118.5 (Part 5) (Standards Australia, 2008a) and the other is a residential (Hydrant serviced) system based on modified AS 2118.4 (Part 4) (Standards Australia, 2012) system. The sprinkler heads used for both systems were identical, and were a rapid response, domed-plate concealed, pendant-type sprinkler head with a discharge coefficient (K-factor) of 4.9. The temperature rating for the cover plate is 59°C and for the sprinkler bulb is 68°C (see Appendix B). There were eight sprinkler heads installed for the Domestic, Part 5 system (designated ‘D’) in locations as detailed in Figure 3, and nine for the Hydrant, Part 4 system (designated ‘H’).

Figure 4 Photo showing the two sprinkler systems. To the left is the 25 mm polyethylene piping of System 1 (Domestic), and to the right is the 50 mm steel piping of System 2 (Hydrant).

1.3.1 System 1: Domestic potable water supply design

Fire System Design & Certification Pty Ltd (FSD) proposed a low-cost, AS2118.5 (Standards Australia, 2008a) compliant sprinkler system for installation in all new residential buildings under 25 metres in effective height.

The primary objective of this type of sprinkler system is to *"provide a level of protection against injury or loss of life"* (Standards Australia, 2008a), such as by preventing flashover and by increasing the likelihood of occupants safely evacuating the building.

Such a system would be connected to the potable water supply and installed only in sole-occupancy units (SOUs). Each SOU would effectively be a separate system independent from each other. It is proposed that the sprinkler system would be installed by licensed plumbers in conjunction with the installation of the potable water infrastructure. The system would be designed to provide a flow of at least 100L/min in excess of the requirements of the potable demand. In some instances, a potable water pump/s will be required to achieve the necessary pressure at the point of discharge for the sprinklers to operate as required. To ensure reliability, these pumps could be connected to the supply side of the main switch, similar to conventional fire pumps.

1.3.2 System 2: Internal hydrant water supply design

The second system proposed essentially identifies the use of residential sprinklers that reticulate on each floor level no differently to an existing residential sprinkler layout. However, the water supply would not be independently provided to the town mains via its own infrastructure, but connected to a fire hydrant system riser, provided under existing NCC requirements.

The sprinkler water supply would be completed to the current requirements of AS2419.1-2005 for the fire hydrant system, except for a couple of small deviations:

a. The system mains would be provided with some form of system flow indicator to notify of the operation of a sprinkler flow condition. This is most likely achieved with a flow switch located before the system mains branch to respective areas.
b. The flow requirements of the sprinkler system and the hydrant system would not be aggregated together. Therefore, any installed fire hydrant pump (almost all installed

fire hydrant systems will include the use of a pump) would not increase in duty from current design requirements.

The water supply is reticulated throughout the building in the 100NB pipe sizing currently required by AS 2419. These pipes are typically located in the fire stairs to rise up the building to the upper level.

The dedicated (not shared) sprinkler water supply would commence at a branch connection into this fire hydrant riser for each protected floor level. There is no proposal to provide isolation valves or equipment indications at these floor branch locations due to the limited modification of residential sprinkler systems, nor the need for floor level indication for mechanical or occupant warning systems. This reduces the complexity of the system and minimises installation costs.

As the existing pressure requirements for fire hydrants operating in Class 2 buildings is 700 kPa, this pressure is significantly high enough to utilise an economical pipe sizing throughout the floor to each sprinkler location.

Insurance survey

One of the areas highlighted for possible savings and a possible payback period for the installation of sprinklers was in the area of insurance. It was decided in the first instance to undertake a review of the property insurance aspect only.

Alan Wilson Insurance Brokers (AWIB) agreed to undertake a survey of the leading insurance companies to determine what discounts, if any, would be available for Class 2 and 3 buildings up to 25 metres in effective height that are currently not required by the NCC to be equipped with sprinklers. The results of this survey are to be reported elsewhere.

Test scenarios

An initial series of 14 tests was selected by the steering group to cover a range of scenarios and conditions of interest. This is not an exhaustive series, but was chosen to be representative, given the number of tests able to be run within the set timeframe and budget. A description for each scenario is given in Section 3.

Table 1 Sprinkler test configurations

TEST	SPRINKLER SYSTEM	ORIGIN	SCENARIO AND CONDITIONS
1	Domestic	Lounge NW corner	UL-based corner test, external doors open, internal closed, corner located crib shielded by plywood-backed foam
2	Hydrant	Lounge NW corner	UL-based corner test, external doors open, internal closed, corner located crib shielded by plywood-backed foam
3	Domestic	Lounge centre	Centre Lounge, stylised furniture (2 x two-seater sofas and coffee table), external doors open, internal closed
4	Domestic	Lounge NW corner	UL-based corner test, external doors open, Internal doors closed, single sprinkler (UL location) only
5	Hydrant	Lounge NW corner	Corner fire, stylised furniture, all doors closed
6	Domestic	Lounge NW corner	Corner fire, stylised furniture, all doors closed
7	Domestic	Lounge NW corner	Corner fire, external doors closed, internal doors open
8	Domestic	Bedroom 1 NW corner	Bedroom fire, door closed, Gas sampling at 1 m and 1.6 m
9	Domestic	Kitchen stove	Kitchen oil fire, external doors closed, internal doors open
10	Hydrant	Lounge NW corner	Corner fire, real furnishings, doors closed
11	Domestic	Lounge NW corner	Corner fire, real furnishings, doors closed
12	Domestic	Lounge NW corner	Corner fire, stylised furniture, external doors open, Bedroom door open
13	Domestic	Lounge NW corner	Corner fire, real furniture, external doors closed, Bedroom door open
14	None	Lounge NW corner	Real furnishings, external doors open, Bedroom door closed.

2. MATERIALS AND METHODS

2.1 Fire ignition and extinguishment

The test fires were initiated using a timber crib, which had been conditioned at 104 ± 5°C for at least 24 hours prior to testing. The crib was removed from the conditioning oven and bagged 4 hours before testing. The crib is constructed from 38 mm x 38 mm x 300 mm Oregon (Douglas fir) timber batons nailed together in layers to form a 300 mm x 300 mm square stack.

In Tests 1–4, a four-layer stack was used, weighing approximately 3 kg. For subsequent tests, the crib was expanded to six layers, weighing approximately 4.3 kg.

The crib was placed above a steel tray containing 250 ml of heptane or kerosene, and 500 ml of water. The heptane mixture was lit using a blow torch at the start of ignition. Fires were extinguished by firefighters at the end of each test using a CO_2 extinguisher or water hose, as appropriate.

2.2 Fuel packages and test materials

In most of the tests, stylised furniture pieces were used as the fuel package for the test fires. These consisted of a steel-framed plywood coffee table (1.2 m x 1.2 m square), a steel-framed plywood side table (500 mm x 500 mm square), and two steel-framed polyurethane padded sofas (1.5 m long). A bed was stylised using the existing steel framing for the sofas, with the polyurethane foam blocks representing the mattress foam. The foam used was a general-purpose, medium-density (26–27 kg/m^3), polyurethane foam from Dunlop Foams (Product ID. MA26-160), which is commonly used in seat cushions, bed settees and arm overlays. The foam was cut to 300 mm x 300 mm x 75 mm sections. Six foam sections were used to cover each sofa. In tests where the ignition crib was positioned under the side table between the stylised sofas, an extra foam piece was used as an armrest. All foam pieces were conditioned at 23-25°C and 55-65%RH for at least 48 hours prior to testing.

In the real furniture tests, two-seater sofas were purchased from a bulk furniture store and used in place of the stylised pieces. In Test 14, salvaged furniture and furnishings from a charity shop were used to provide a large fuel load to demonstrate fire development in a non-sprinklered residence.

2.3 Performance criteria

The main objective of the test program was to evaluate the performance of the sprinkler systems in terms of occupant life safety or tenability in the room of fire origin and in the adjacent bedroom. The main factors affecting tenability in a sprinkler-controlled residential fire are convective heat, smoke toxicity and obscuration. In this study, we focused on temperatures and smoke constituents as they were readily quantifiable measures in the test environment. The criteria observed are summarised in Table 2 and detailed in APPENDIX A Tenability Criteria.

Table 2 Tenability criteria observed in the test program

CRITERION	Measured at	Threshold
Convective heat	1.6 m	65°C
Fractional Effective Dose of convective heat, FED_{heat}	1.6 m	0.3
Fractional Effective Concentration of irritant gases causing impaired escape, FEC_{esc}	1.6 m	0.3
Fractional Effective Concentration of irritant gases causing incapacitation, FEC_{inc}	1.6 m	0.3
Fractional Effective Dose of asphyxiant gases causing incapacitation, FED_{asp}	1.6 m	0.3

2.4 Instrumentation

Temperatures within the unit were measured via 37 *N*-type thermocouples (measurement range -270°C to 1260°C) which were installed 100 mm below each sprinkler head, at four tree locations at heights of 0.6 m, 1 m, 1.6 m and 2.3 m from the floor, above the NW corner ignition point 75 mm below the ceiling, and in the oil pan during the Kitchen fire (See Figure 3).

Two pad-type *K* thermocouples measured the surface temperatures of the Bedroom 1 door and of the main exit door near the Kitchen, which represents the SOU door. Ambient test conditions were monitored via a weather station (Vaisala Weather Transmitter WXT520) positioned inside the unit before testing and outside the unit during fire testing. The device measures atmospheric air temperature, air velocity, relative humidity and air pressure. All temperature and atmospheric data were captured via a data acquisition system (DataTaker DT85) sampling at 12 channels per second.

Ten infrared digital video cameras were installed throughout the unit to provide video footage of the tests. In addition, up to three portable digital cameras in protective casings were used to provide additional views of the fires.

Two Gasmet DX4000 gas analyser units were used to monitor and analyse the gas levels within the fire compartments. A library of 41 gases, including CO, HCN, CO2, O2, HCl, HBr, HF, SO2, NO2, acrolein and formaldehyde, was included in the analyses, which utilises Fourier Transform Infrared (FTIR) spectroscopy. The full list of gases and tenability limits used in the calculations is listed in APPENDIX A Tenability Criteria. Two high-temperature sampling

probes were placed at a height of 1.6 metres at two locations within the unit: one in the Lounge room along the path of egress and the other in the main Bedroom (Bedroom 1). Gases were sampled every five seconds and heated to a temperature of 180°C. In the Bedroom fire test (Test 8), the Lounge room probe was moved to Bedroom 1 to measure gas concentrations at a height of 1 metre.

The unit was thoroughly ventilated, dried and background tested between tests to enable a clean air environment as the baseline.

2.5 Data analysis

The atmospheric data acquired via the thermocouples, weather station and FTIR gas analyser units were processed using Microsoft Excel 2010. Tenability limits due to irritant and asphyxiant gases, and convective heat were calculated using the formulae presented by Purser (2010), detailed in APPENDIX A Tenability Criteria.

2.6 Study limitations

Although this study was limited due to time and cost considerations, care has been taken to design a robust program of tests. Each scenario was tested only once.

Weather and ambient conditions were a factor in the testing. The testing was undertaken in North Ryde, Sydney in the autumn season where temperatures and wind velocities varied between tests. While test articles have been conditioned prior to testing, the tests were carried out under real conditions, which were uncontrolled.

Smoke obscuration, radiant heat flux, and mass loss were not measured in this test series. Further, only two gas analysers were available for gas monitoring and hence measurements were limited to the two locations at 1.6 metres. Sprinkler coverage and flow rates were not measured.

Only one sprinkler head design was used in the testing. This is detailed in Appendix B.

3. RESULTS

The 14 tests were completed over a 15-week period between February and May 2017. In this section, we present a description of each set-up, the results, and our observations for each test. An analysis of the overall results is presented in Section 4.

3.1 Test 1: UL-based corner test, Domestic system, Ventilated

3.1.1 Test Description

Test 1 was conducted on 24 February 2017. The conditions during testing are summarised in Table 3 below.

Table 3 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 1.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.03 (0.03)	0.05 (0.03)
Air temp (ºC)	25.40 (0.00)	25.02 (0.17)
Relative humidity (%)	65.99 (0.70)	67.60 (0.80)
Air pressure (mBar)	1014.98 (0.04)	1014.73 (0.10)

This test was based on the UL 1626 Standard for Residential Sprinklers for Fire Protection Service (Underwriters Laboratory, Inc., 2012). The ignition crib was located in the NW corner of the unit, adjacent to the sliding door, and was surrounded by plywood-backed foam blocks. The arrangement is pictured in Figure 5 and detailed in Figure 6. In this test, the external doors were open and the Bedroom 1 door was closed. The fuel under the crib was a 1:2 mixture of kerosene and water.

The fire source and distance to the sprinkler heads was to the UL specifications in this test; however, the room dimensions and configuration differ. The objective of the test was to set a baseline for comparison of future tests, and against prior published data.

The pressure at the meter was set at 250 kPa, the minimum pressure that would be available for a typical residential apartment complex. With the sprinkler set-up, there were only two charged sprinkler heads in operation with this test: D1, which was specifically located to be in accordance with the sprinkler distance with the UL test; and D3, which is located in accordance with the AS 2118.5 (Standards Australia, 2008b) layout. All other sprinkler heads were made inoperable.

The test duration was approximately 12 minutes.

Figure 5 View of the ignition point and surrounding props in Test 1

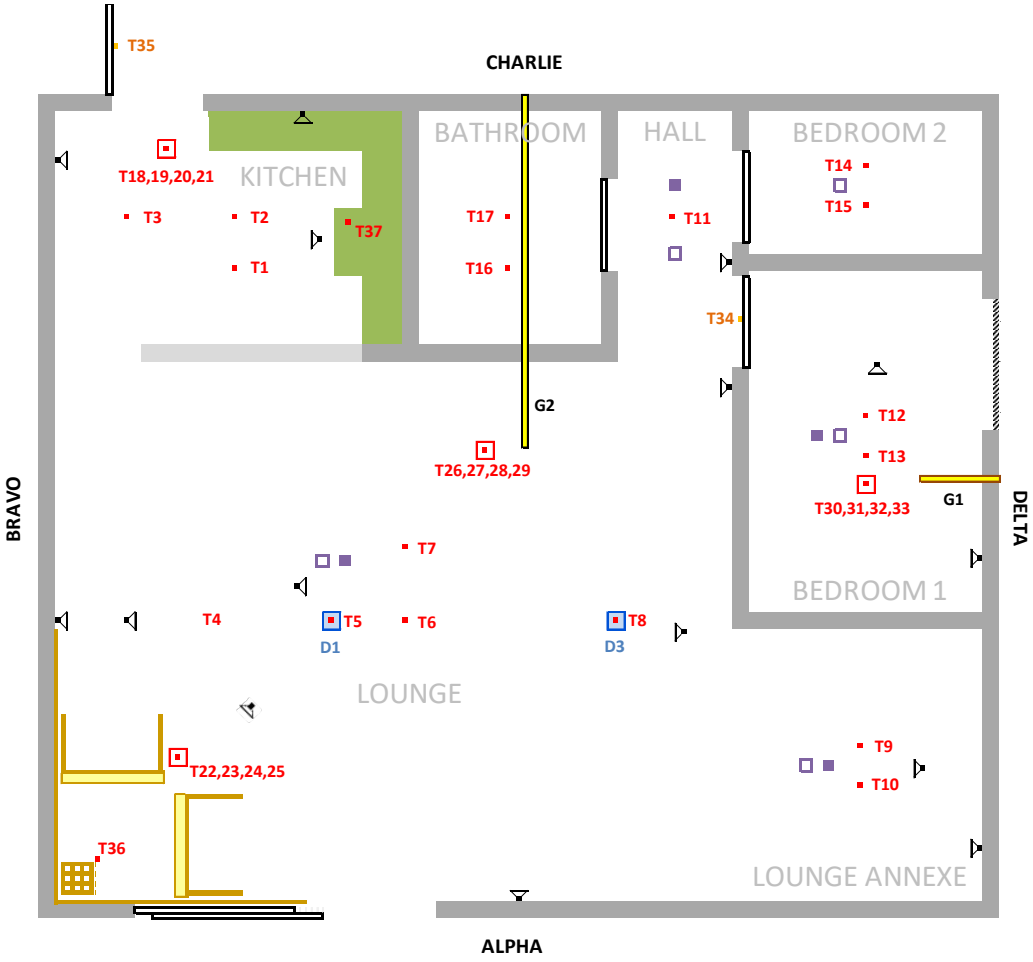

Figure 6 Map showing the Test 1 arrangement

3.1.2 Results

Fire size and fuel consumption

In Test 1, the peak flame height was approximately 2 metres (Figure 7). The foam pads surrounding the ignition crib were fully consumed during the test; however, the crib itself and the plywood surrounds remained intact (Figure 8).

Activations

The sprinklers activated at 1 min 23 s (D1) and 1 min 33 s (D3) after ignition. The peak temperatures reached at the sprinkler heads upon activation were 100.3°C and 96.4°C for D1 and D3, respectively.

Figure 7 View of the test fire before sprinkler activation

Figure 8 Views of the timber crib and foam panels at the end of Test 1

Temperatures

The maximum temperature reached in the unit was 333°C at T22, the thermocouple at 2.3 m located near the ignition point. This peak occurred at 2 min 55 s after ignition.

The temperature at the Kitchen door at 1.6 m (T20) peaked above 100°C (105°C at 3 min 20 s) and was elevated above 65°C between 2 min 05 s and 4 min 50 s. At this location, a FED_{heat} of 0.3 is reached at 8 min 25 s after ignition. At a height of 1 metre (T21), the temperature remains below 65°C for the duration of the test, with the FED_{heat} only reaching 0.03 at this location.

At the Lounge centre, the temperatures did not exceed 65°C during the test at 1.6 m (T28) or at 1 m (T29) and the FED_{heat} did not exceed 0.05.

In the Bedroom, temperatures remained ambient, with a peak of 26.6°C at 1.6 m (T32).

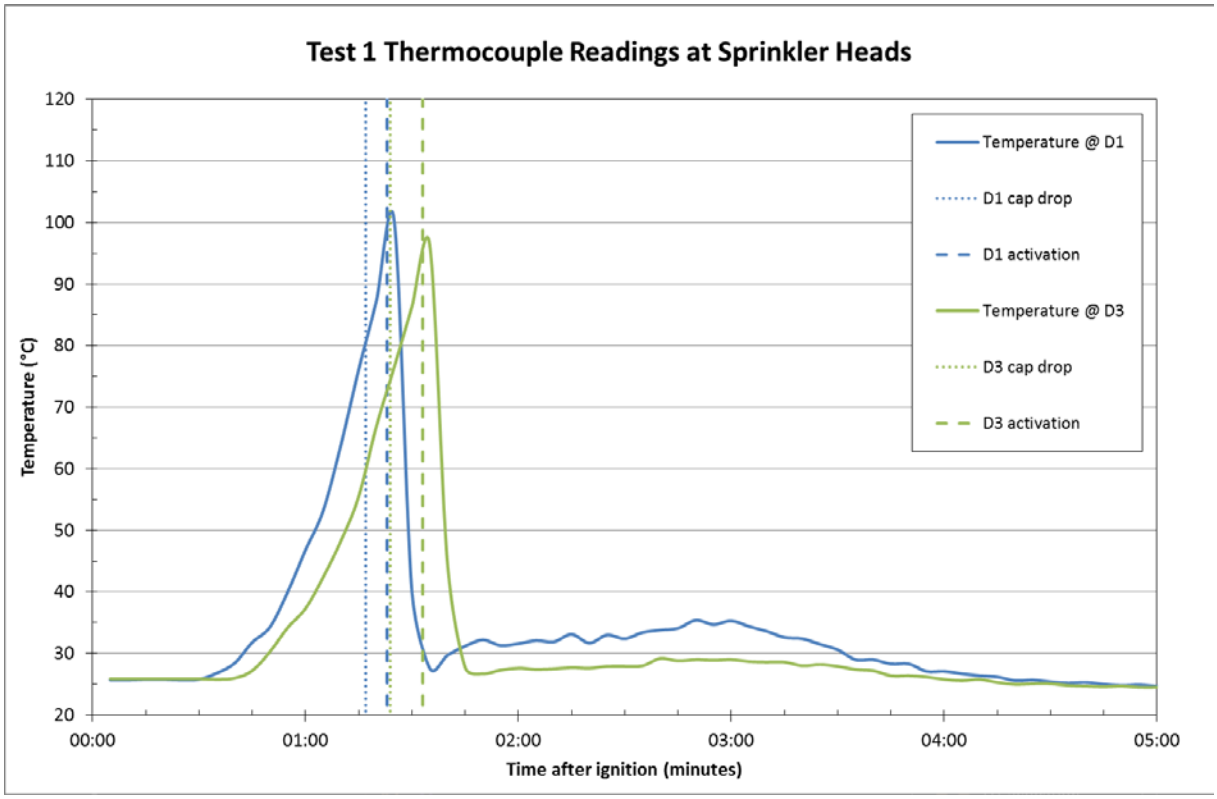

Figure 9 Sprinkler head activation times and temperatures for Test 1

Smoke toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to a level that would cause impaired escape for vulnerable persons (FEC_{esc} 0.3) at 1 min 42 s, peaking at 0.89 at 4 min 10 s after ignition, and remaining mostly above 0.3 for the duration of the test. Conditions in the Lounge would have caused vulnerable persons to become incapacitated due to the irritant concentrations (FEC_{inc} >0.3) for the time between 2 min 16 s

and 4 min 44 s after ignition. The tenability limit for incapacitation due to asphyxiant concentrations FED_{asp} 0.3 was not reached during this test.

In Bedroom 1, FEC_{esc}, FEC_{inc} and FED_{asp}, peaked at fractional values of 0.07, 0.03 and 0 respectively.

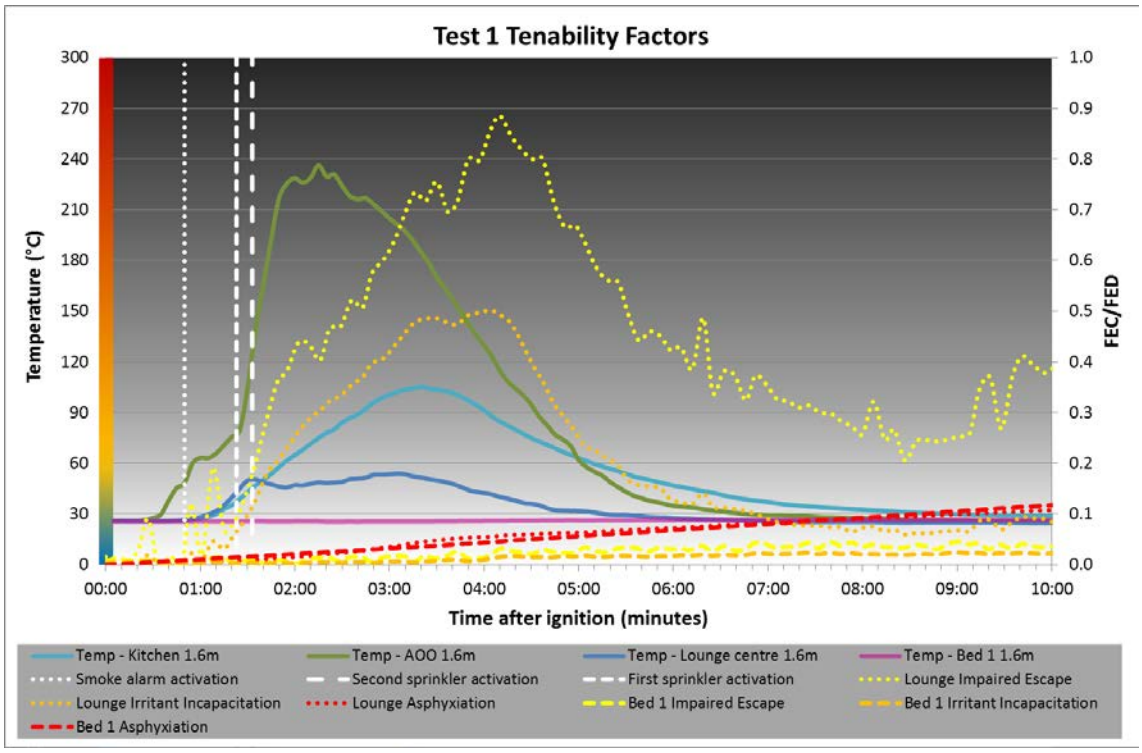

Figure 10 Chart showing timing of activations and tenability factors for Test 1

Table 4 Summary of Test 1 event timings

TIME AFTER IGNITION	EVENT
50 s	First smoke alarm activation
1 min 23 s	First sprinkler activation (D1)
1 min 33 s	Second sprinkler activation (D3)
1 min 42 s	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
2 min 5 s – 4 min 50 s	Temperature at Kitchen doorway (1.6 m) elevated above 65°C
2 min 16 s – 4 min 44 s	Irritant incapacitation FEC_{inc} >0.3 at G2 (Lounge)
3 min – 3 min 40 s	Temperature at Kitchen doorway (1.6 m) elevated above 100°C
8 min 25 s	Temperature at Kitchen doorway (1.6 m) reaches FED_{heat} 0.3
12 min 13 s	Test end – fire extinguished

3.1.3 Observations

The following observations were noted from the data:

- With only two sprinkler heads operating, the fire was controlled and did not spread.
- The temperatures and products of combustion did continue to develop for a period of approximately two minutes after the sprinkler heads operated.
- Once the sprinkler heads activated, temperatures throughout the unit, other than in the area of fire origin, remained safe for evacuation. While the temperature at 1.6 m in the Kitchen area near the main entry did rise above the tenability threshold, a brief exposure is unlikely to cause significant injury to an escaping occupant.
- At a height of one metre above floor level, temperatures were well below tenability limits.
- While escape impairment and irritant incapacitation thresholds were reached in the Lounge room along the egress path, the tenability limit for asphyxiant incapacitation was not reached.
- Temperatures and smoke conditions in the closed Bedroom remained tenable for the duration of the test. Data indicates that an occupant remaining in the Bedroom would have been safe for the duration of the test.
- The pressure supplied at the meter of 250 kPa, in the context of the specifications of this test, provided enough water flow and pressure to generate the above results.

3.2 Test 2: UL-based corner test, Hydrant system, Ventilated

3.2.1 Test Description

Test 2 was conducted on 3 March 2017. The conditions during testing are summarised in Table 5 below.

Table 5 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 2.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.07 (0.05)	0.08 (0.04)
Air temp (ºC)	23.13 (0.11)	22.92 (0.14)
Relative humidity (%)	83.02 (0.30)	85.09 (1.05)
Air pressure (mBar)	1011.04 (0.05)	1010.78 (0.08)

This test was identical to Test 1 in configuration and method, except for the sprinkler system tested. As in Test 1, the ignition crib was located in the NW corner of the unit and was

surrounded by plywood-backed foam blocks. The arrangement is pictured in Figure 11 and detailed in Figure 12. In this test, the external doors were open and the Bedroom 1 door was closed. The fuel under the crib was a 1:2 mixture of kerosene and water.

The pressure at the meter was set at 700 kPa, the minimum pressure required in the Standard. With the sprinkler system set up, there were seven charged sprinkler heads in operation with this test: H1, which was specifically located to be in accordance with the sprinkler distance with the UL test; and H3, H4, H5, H6, H7, and H8.

The test duration was approximately 8 minutes.

Figure 11 View of the test arrangement for Test 2

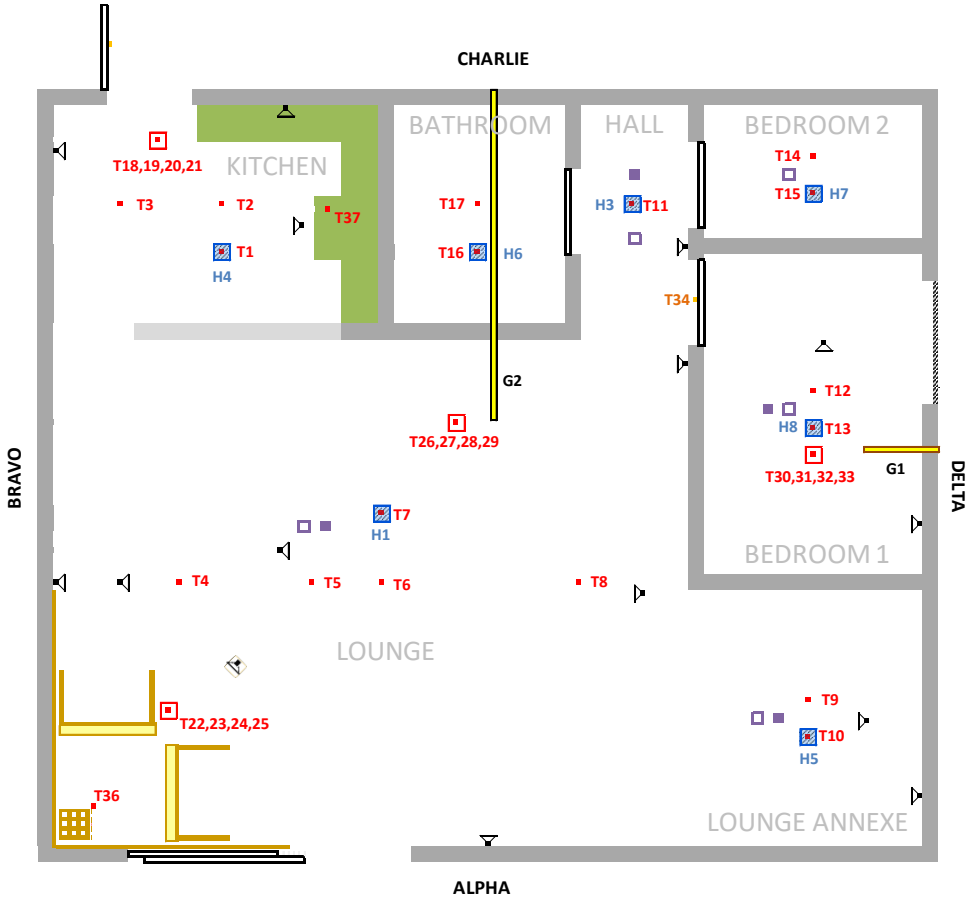

Figure 12 Map showing the Test 2 arrangement

3.2.2 Results

Fire size and fuel consumption

As in Test 1, the peak flame height in Test 2 was approximately 2 metres (Figure 13). Similarly, the foam pads surrounding the ignition crib were fully consumed during the test; however, the crib itself and the plywood surrounds remained intact (Figure 14).

Activations

There were two sprinkler activations during this test. H1 in the Lounge centre activated at 1 min 20 s and H4 in the Kitchen activated at 1 min 21 s after ignition. The peak temperatures reached at the sprinkler heads upon activation were 93.3°C and 98.2°C for H1 and H4, respectively. Note the 10 second delay in temperature drop after the H4 activation. Interestingly, the cover for the sprinkler head in the Lounge annexe (H5) dropped at 1 min 25 s at a temperature of 80.1°C; however, this sprinkler head did not activate during the test.

Figure 13 View of the test fire before sprinkler activation

Figure 14 View of the ignition point at the end of Test 2

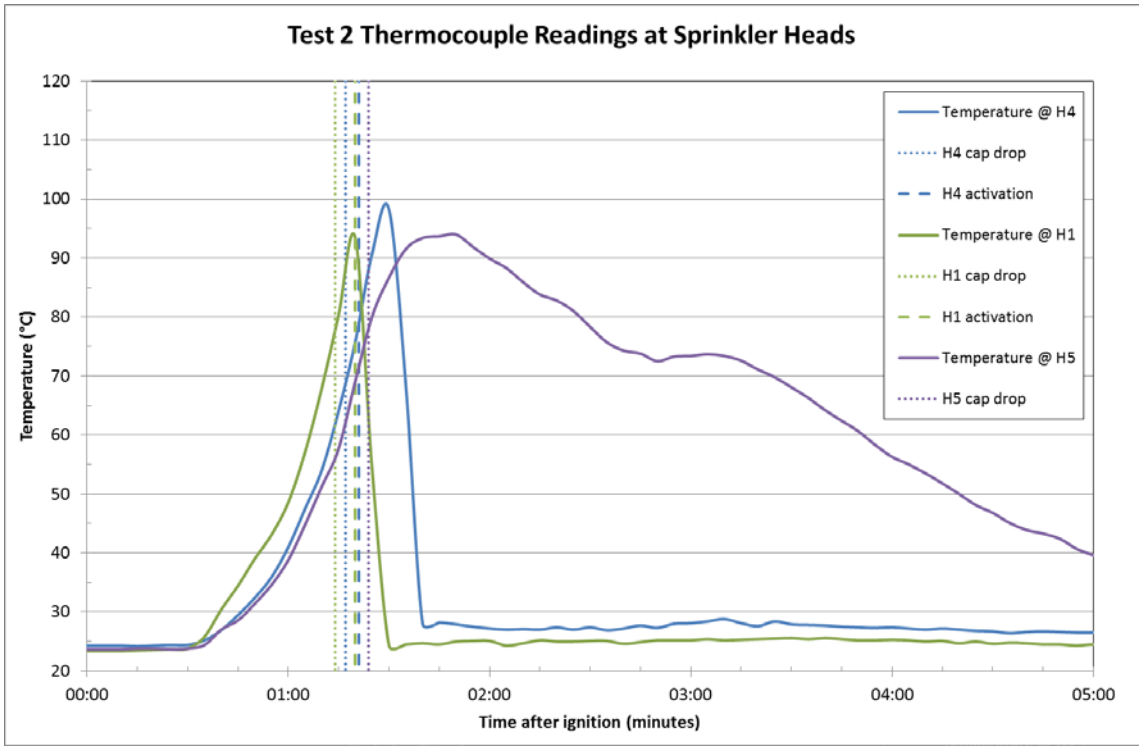

Figure 15 Sprinkler head activation times and temperatures for Test 2

Temperatures

The maximum temperature reached in the unit was 254°C at T24, the thermocouple at 1.6 m located near the ignition point. This peak occurred at 1 min 50 s after ignition.

The temperatures at all other locations within the unit at 1.6 m and below remained below tenability limits.

In the Bedroom, temperatures remain ambient, with a peak of 24.5°C at 1.6 m (T32).

Smoke toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to a level that would cause impaired escape for vulnerable persons (FEC_{esc} > 0.3) at 2 min 35 s, and remained above that level until the test end. FEC_{inc} was not reached, peaking at 0.26. FED_{asp} was not reached during this test, remaining at 0 for the test duration.

In Bedroom 1, FEC_{esc}, FEC_{inc}, and FED_{asp} were not reached during the test, with the fractional values peaking at 0.22, 0.06, and 0, respectively.

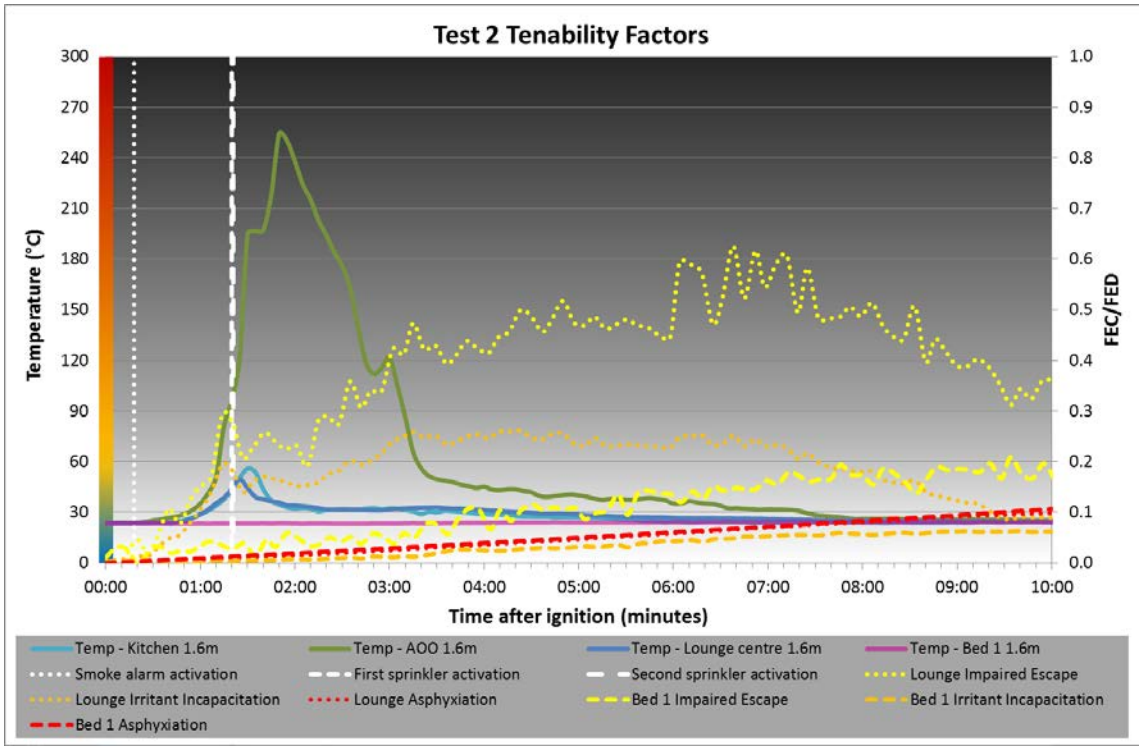

Figure 16 Chart showing timing of activations and tenability factors for Test 2

Table 6 Summary of Test 2 event timings

TIME AFTER IGNITION	EVENT
18 s	First smoke alarm activation
1 min 20 s	First sprinkler activation (H1)
1 min 21 s	Second sprinkler activation (H4)
2 min 35 s	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
8 min 20 s	Test end – fire extinguished

3.2.3 Observations

The following observations were noted from the data:

- With only two heads operating, the fire was controlled and did not spread significantly.
- The temperatures throughout the apartment dropped significantly upon activation of the sprinkler heads, with temperatures along the path of egress remaining below tenability thresholds.

- Once the sprinkler heads activated, the majority of the unit, other than the area of the living room nearest the fire source, the temperatures at 1.6 m were safe.
- After smoke alarm activation, there is 137 seconds before the threshold for impaired escape is reached in the Lounge room at 1.6 metres. This should give an able person ample time to escape the premises. Conditions in the closed Bedroom also remained tenable throughout the test.
- After sprinkler activation, the temperatures recorded in Test 2 were significantly lower than in Test 1 except for the bedrooms, where there was an insignificant difference.
- Data indicates that an occupant remaining in the Bedroom would have been safe for the duration of the test.
- The pressure supplied at the meter of 700 kPa, in the context of the specifications of this test, provided enough water flow and pressure to generate the above results.

3.3 Test 3: Lounge centre test, Domestic system, Ventilated, Stylised furniture

3.3.1 Test Description

Test 3 was conducted on 10 March 2017. The conditions during testing are summarised in Table 7 below.

Table 7 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 3.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.06 (0.04)	0.04 (0.02)
Air temp (ºC)	21.35 (0.14)	21.50 (0.00)
Relative humidity (%)	63.30 (1.02)	62.95 (1.00)
Air pressure (mBar)	1009.70 (0.02)	1009.78 (0.04)

In this test, the ignition crib was located in the centre of the Lounge room, underneath a stylised coffee table. The coffee table was surrounded by two stylised sofas. The arrangement is pictured in Figure 17 and detailed in Figure 18. In this test, the external doors were open and the internal doors were closed. The fuel under the crib was a 1:2 mixture of heptane and water. There were seven sprinkler heads in operation in this test: D2, D3, D4, D5, D6, D7, and D8. The pressure at the meter was set at 250 kPa. All other sprinkler heads were made inoperable.

The test duration was approximately 10 minutes.

3.3.2 Results

Fire size and fuel consumption

In Test 3, the peak flame height was approximately 1.5 metres (Figure 19). The fire spread to the southern Lounge. Of the six foam blocks representing the sofa cushions, the three seat cushions, and approximately half of the three back cushions were consumed (Figure 20).

Activations

There were four sprinkler activations in this test, which occurred within a period of 14 seconds. D3 and D2 in the Lounge activated at 1 min 55 s and 1 min 58 s, respectively. They were followed by D4 in the Kitchen at 2 min 5 s, and D5 in the Lounge annex at 2 min 9 s. The peak temperatures reached at the sprinkler heads upon activation were 86.7°C, 91.8°C, 80.9°C, and 85.9°C.

Figure 17 Photo showing the test arrangement for Test 3

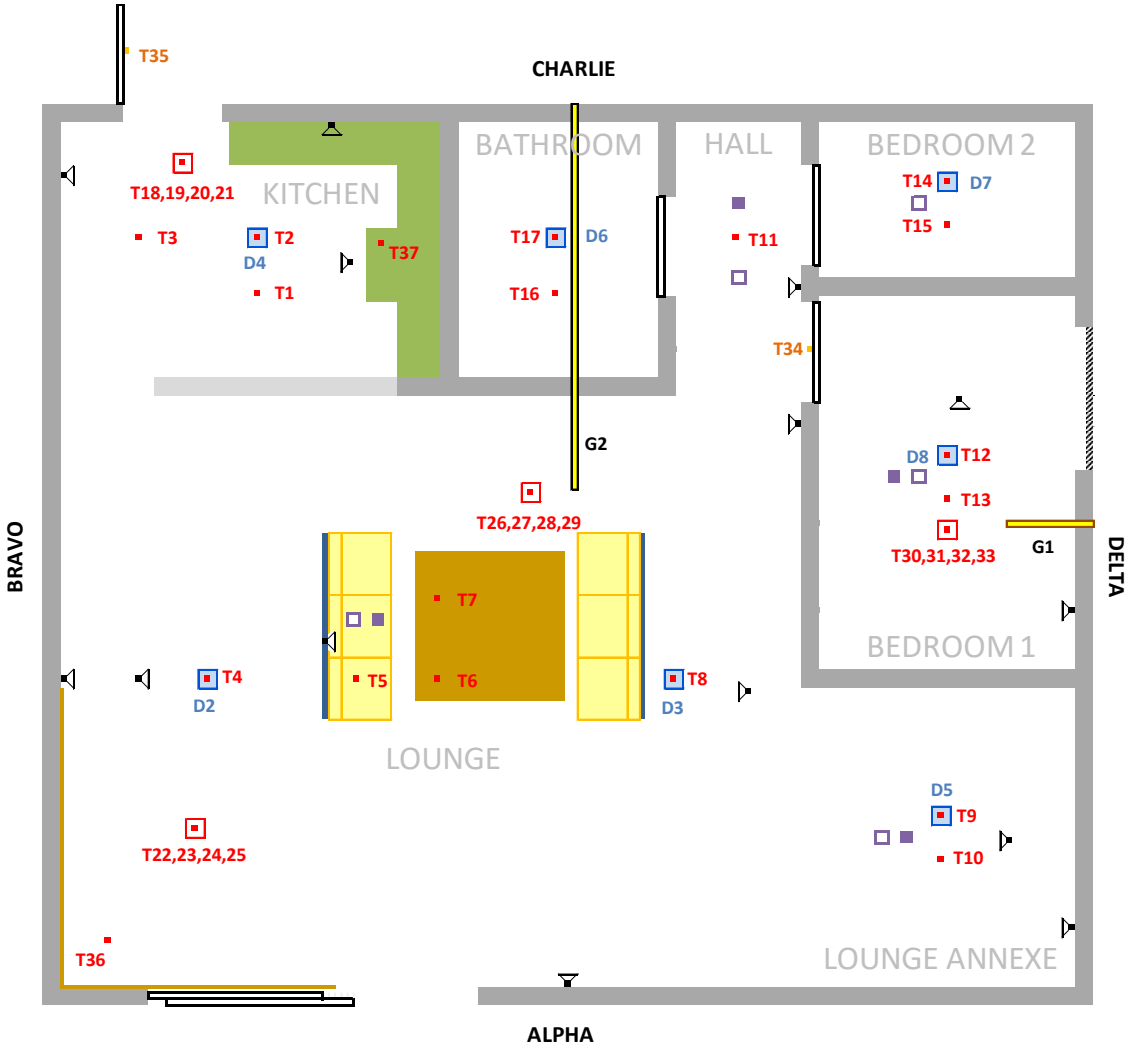

Figure 18 Map showing the Test 3 arrangement

Figure 19 View of the test fire before sprinkler activation

Figure 20 View of the test furnishings at the end of Test 3

Temperatures

The maximum temperature reached in the unit was 248°C at T7, the thermocouple positioned above the coffee table. This peak occurred at 2 min 10 s after ignition.

Along the paths of egress, the temperatures measured at 1.6 m at the Lounge centre T28 and Lounge corner T24, rose above 65°C at 2 min 35 s and 3 min 5 s, respectively. They remained elevated for a period of 4 to 5 ½ minutes. The cumulative heat tenability limits at those locations were reached at 6 min and 6 min 50 s, respectively.

In the Bedroom, temperatures remained ambient, with a peak of 23°C at 1.6 m (T32).

Smoke toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to a level that would cause impaired escape for vulnerable persons (FEC_{esc} > 0.3) at 2 min and 50% of the population (FEC_{esc} = 1) at 3 min 19 s after ignition. Irritant incapacitation FEC_{inc} 0.3 was reached at 2 min 23 s and remained above this level for the test duration. FED_{asp} was not reached at this location.

In Bedroom 1, the threshold for impaired escape due to irritant concentrations (FEC_{esc} > 0.3) was reached at 6 min 5 s after ignition. FEC_{inc} 0.3 and FED_{asp} 0.3 were not reached during the test, with the fractional values peaking at 0.2, and 0.08, respectively.

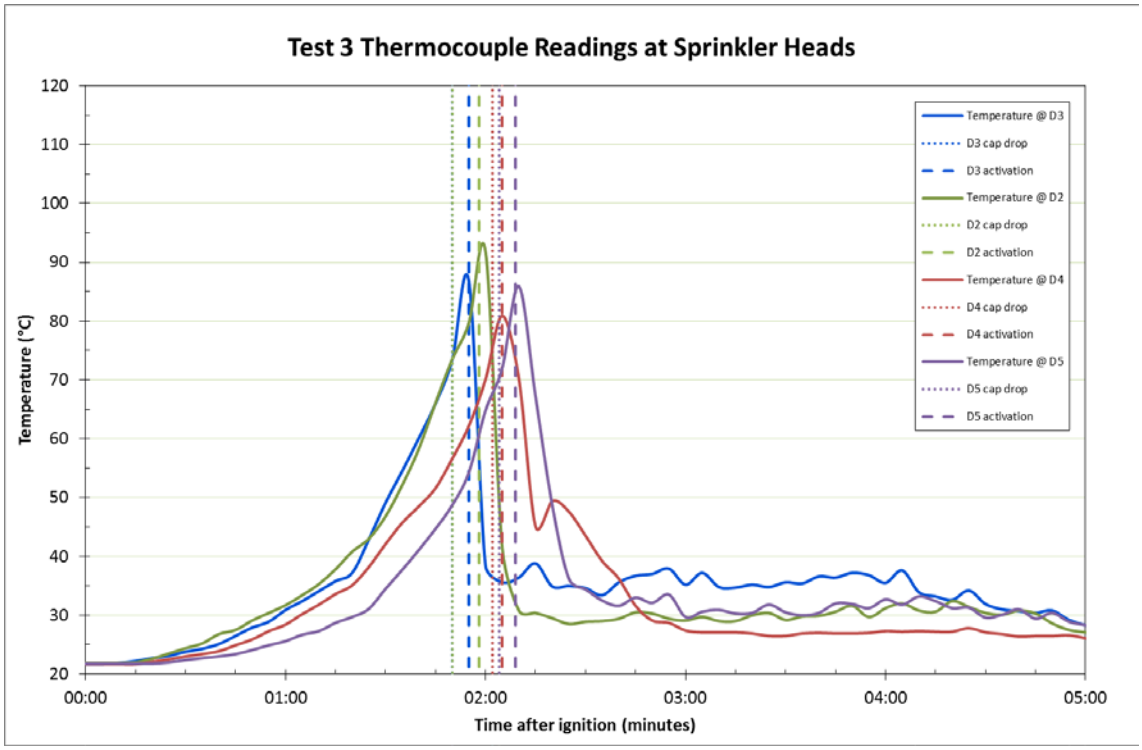

Figure 21 Sprinkler head activation times and temperatures for Test 3

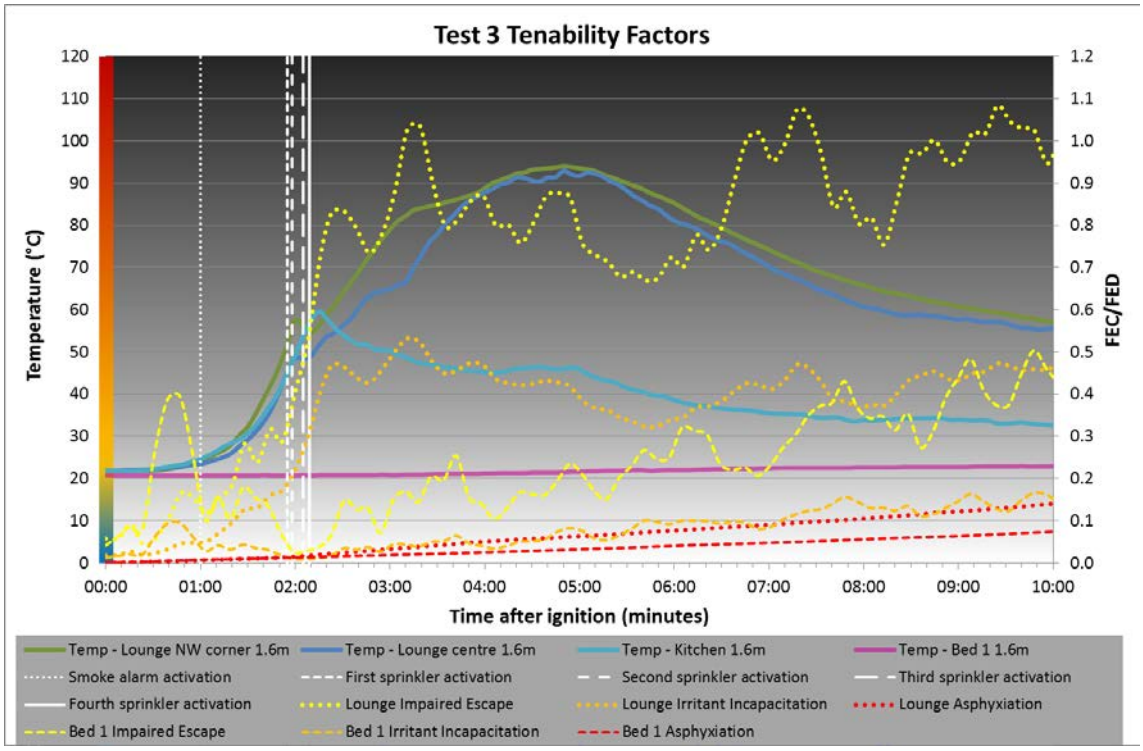

Figure 22 Chart showing timing of activations and tenability factors for Test 3

Table 8 Summary of Test 3 event timings

TIME AFTER IGNITION	EVENT
1 min	First smoke alarm activation
1 min 55 s	First sprinkler activation (D3)
1 min 58 s	Second sprinkler activation (D2)
2 min	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
2 min 5 s	Third sprinkler activation (D4)
2 min 9 s	Fourth sprinkler activation (D5)
2 min 23 s	Irritant incapacitation FEC_{inc} >0.3 at G2 (Lounge)
2 min 35 s – 8 min 5 s	Temperature at Lounge corner (T24) elevated above 65°C
3 min 5 s – 7 min 25 s	Temperature at Lounge centre (T28) elevated above 65°C
3 min 19 s	Impaired escape FEC_{esc} >1 at G2 (Lounge)
6 min	Temperature at Lounge corner reaches FED_{heat} 0.3
6 min 5 s	Impaired escape FEC_{esc} >0.3 at G1 (Bedroom)
6 min 50 s	Temperature at Lounge centre reaches FED_{heat} 0.3
10 min 19 s	Test end – fire extinguished

3.3.3 Observations

The following was observed from the data:

- With four heads operating the fire was controlled, did not flash over and did not spread beyond the southern sofa.
- With the fire source situated directly between two sprinkler heads, these activated almost simultaneously (3 seconds difference) and overall, with four sprinklers activated, the sprinkler system effectively delivered enough water to prevent the fire from spreading.
- The temperatures throughout the apartment dropped significantly in the area directly adjacent to the activating sprinkler heads, but ceiling temperatures continued to rise for approximately another 90 seconds before dropping. The products of combustion did continue to increase after the sprinkler heads operated.
- Once the sprinkler heads activated, in most of the unit other than the area of the living room nearest the fire source, the temperatures at 1.6m were still tenable and for anyone sheltering in the Bedroom with the door closed, the conditions were tenable for the duration of the test.

- At 1.6 metres height, the temperature along the egress path through the Lounge room was elevated for a four-minute period between 3 mins and 7 mins after ignition. Further, the thresholds for irritant-induced escape impairment and incapacitation were reached in this area. The combined effects may have made it difficult for an occupant to safely egress from the bedrooms after the sprinkler activation. At a crawling height of 1 metre, an escaping occupant would have been safe.
- Data indicates that an occupant remaining in the Bedroom would have been safe for the duration of the test.

3.4 Test 4: UL-based corner test, Domestic system, Ventilated, Stylised furniture

3.4.1 Test Description

Test 4 was conducted on 16 March 2017. The conditions during testing are summarised in Table 9 below.

Table 9 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 4.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.07 (0.04)	0.04 (0.02)
Air temp (ºC)	23.17 (0.04)	23.40 (0.00)
Relative humidity (%)	87.75 (0.24)	86.64 (0.50)
Air pressure (mBar)	1006.11 (0.07)	1005.77 (0.05)

In this test, the ignition crib was located in the NW corner of the Lounge room, underneath a stylised coffee table. The coffee table was surrounded by two stylised sofas with a plywood side table placed in the corner between them. The arrangement is pictured in Figure 23 and detailed in Figure 24. In this test, the external doors were open and the internal doors were closed. The fuel under the crib was a 1:2 mixture of heptane and water.

There was one sprinkler head in operation in this test: D1. The pressure at the meter was set at 250 kPa, providing 48 kPa at the head. All other sprinkler heads were made inoperable.

The test duration was approximately 50 minutes.

Figure 23 Photo showing the test arrangement for Test 4

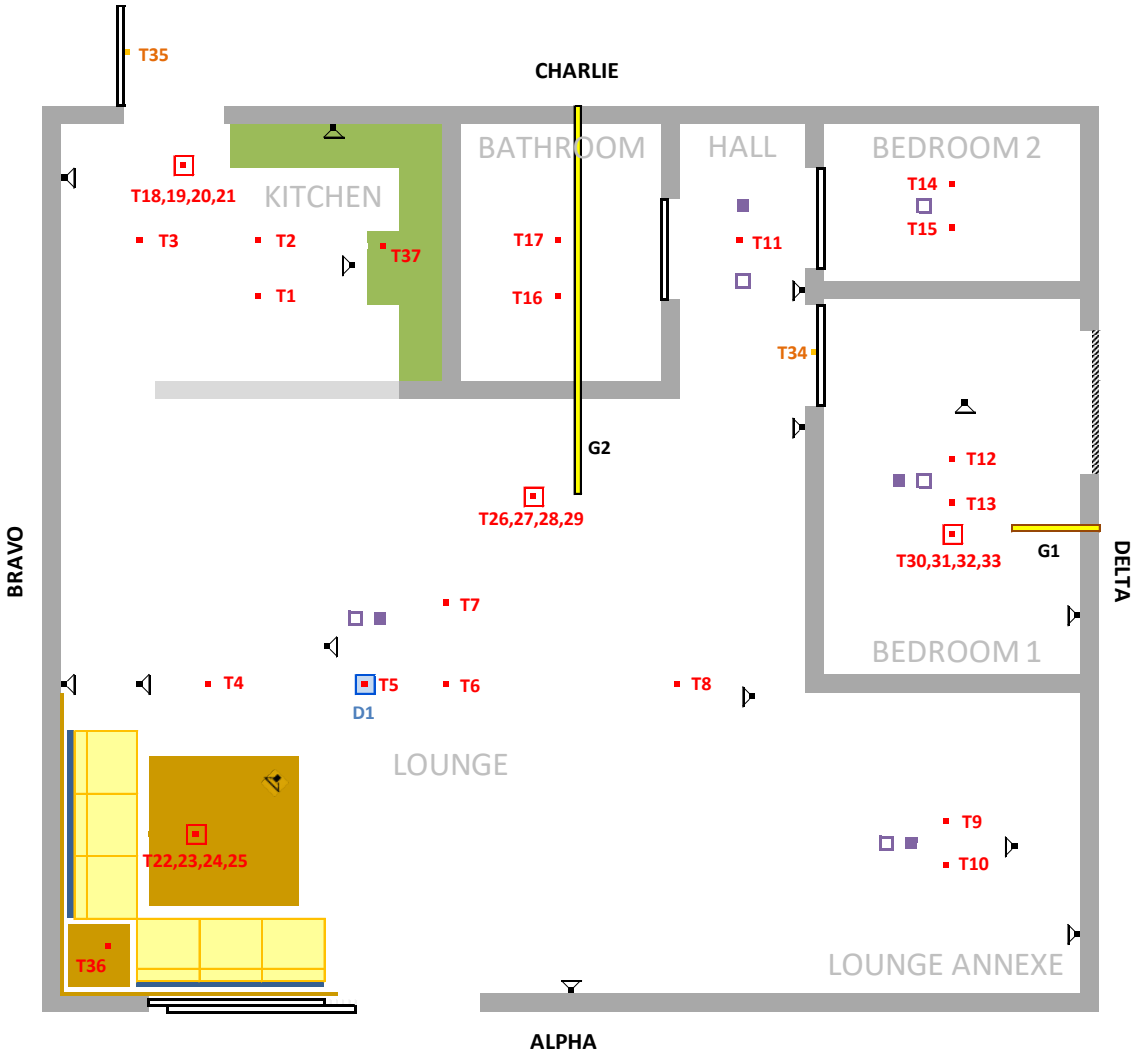

Figure 24 Map showing the Test 4 arrangement

3.4.2 Results

Fire size and fuel consumption

In Test 4, the peak flame height was approximately 1.5 metres (Figure 25). The fire spread to the northern sofa. Of the seven foam blocks representing the sofa cushions (including arm rest), approximately four blocks were fully consumed with the remaining blocks partially consumed (Figure 26).

Figure 25 Views of the test fire before sprinkler activation

Figure 26 View of the test furnishings at the end of Test 4

Activations

The single sprinkler head (D1) available in this test activated at 1 min 51 s, which was 50 seconds after the first smoke alarm activation. The peak temperature at the sprinkler head was 95°C.

Temperatures

The maximum temperature reached in the unit was 372.2°C at T36, the thermocouple positioned above the ignition point. This peak occurred at 1 min 59 s after ignition. The temperature fell to below 100°C at 4 min 8 s after ignition.

Along the paths of egress, the temperature measured at 1.6 m at the Lounge centre T28 only briefly rose above 65°C between 2 min 03 s and 2 min 14 s. The cumulative heat tenability limits were not reached in the Lounge room or Bedroom during the test.

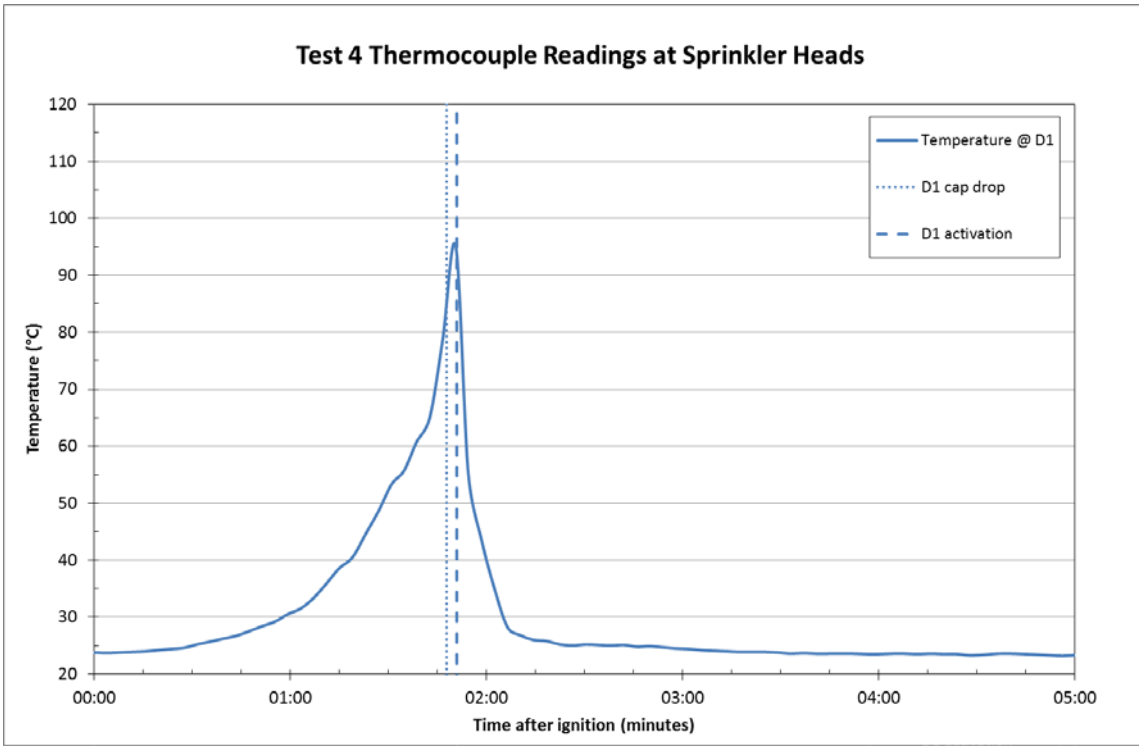

Figure 27 Sprinkler head activation times and temperatures for Test 4

Smoke Toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to a level that would cause impaired escape for vulnerable persons (FEC_{esc} > 0.3) at 1 min 27 s and 50% of the population (FEC_{esc} = 1) at 2 min 31 s after ignition. Irritant incapacitation FEC_{inc}

0.3 was reached at 2 min 7 s and rose above FEC_{inc} = 1 at 10 min 51 s. FED_{asp} 0.3 was reached 12 min 58 s.

In Bedroom 1, the tenability limit for escape due to irritant concentrations (FEC_{esc} > 0.3) was reached at 10 min 44 s after ignition. FEC_{inc} was not reached during the test; however, the cumulative asphyxiant gas concentrations rose to a FED_{asp} > 0.3 in 31 min 39 s.

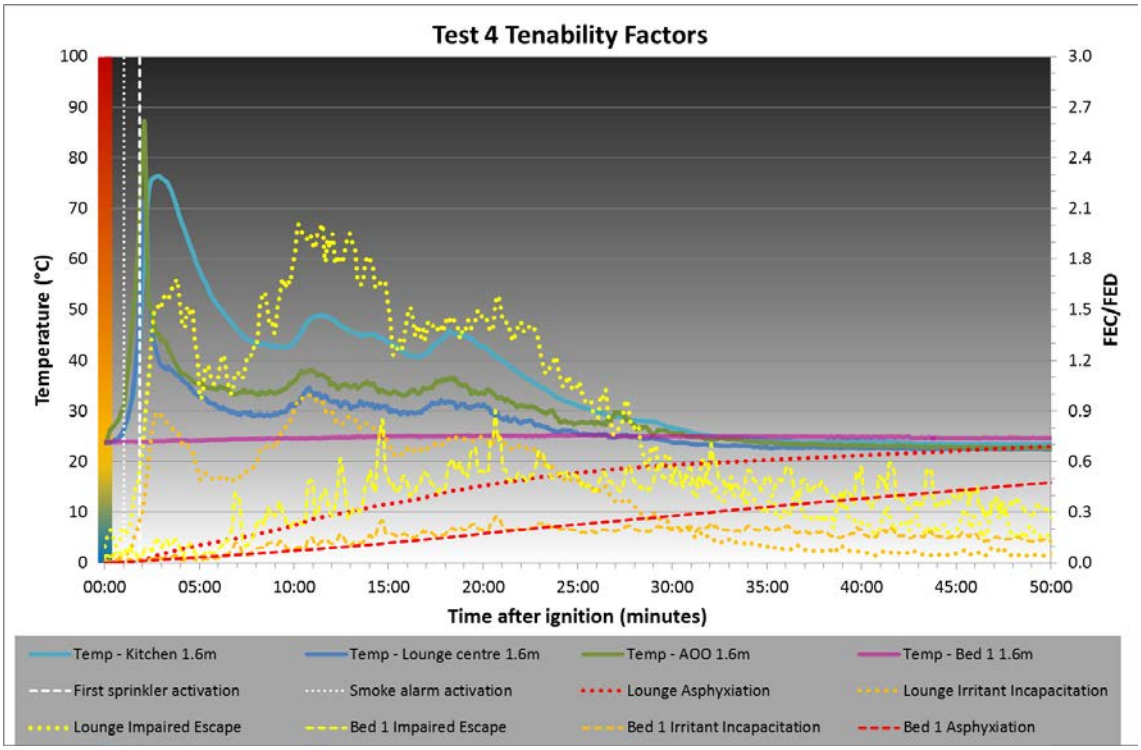

Figure 28 Chart showing timing of activations and tenability factors for Test 4

3.4.3 Observations

The following was observed from the data:

- With only one head operating at the edge of the assumed coverage area, the fire was controlled, did not flash over and did not spread beyond the northern sofa.
- With an increased fire load, a significantly shielded fire placed at the edge of the sprinkler's assumed coverage area, and only one available sprinkler head, the system effectively delivered enough water to prevent the fire from spreading, preventing flashover and providing tenable temperature conditions in most of the apartment.
- The temperatures throughout the apartment dropped significantly upon the activation of the sprinkler head.

- At 1.6 metres height level, it would have been possible for an occupant to safely egress from the bedrooms after the sprinkler activation. The temperatures on the egress path through the Lounge room and Kitchen were only briefly elevated above 65°C.
- At a height of 1 metre, all temperatures in any part of the apartment were below the tenability criteria of 65°C except for the area of fire origin.
- The FED_{asp} for the Lounge room remained under 0.3 for approximately 13 minutes.
- The FED_{asp} for Bedroom 1 remained under 0.3 for approximately 31 minutes.
- This data indicates that an occupant remaining in the Bedroom with the door closed would have been safe for a period of at least 31 minutes before possibly becoming incapacitated from smoke inhalation.
- The pressure of 48 kPa supplied to the furthest possible sprinkler head in accordance with the data sheet, in the context of the specifications of this test, provided enough water flow to generate the above results.

Table 10 Summary of Test 4 event timings

TIME AFTER IGNITION	EVENT
1 min 1 s	First smoke alarm activation
1 min 27 s	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
1 min 51 s	First sprinkler activation (D1)
2 min 7 s	Irritant incapacitation FEC_{inc} >0.3 at G2 (Lounge)
2 min 3 s – 2 min 14 s	Temperature at Lounge centre T28 elevated above 65°C
2 min 11 s – 4 min 16 s	Temperature at Kitchen door T20 elevated above 65°C
2 min 31 s	Impaired escape FEC_{esc} >1 at G2 (Lounge)
10 min 44 s	Impaired escape FEC_{esc} >0.3 at G1 (Bedroom 1)
10 min 51 s	Irritant incapacitation FEC_{inc} >1 at G2 (Lounge)
12 min 58 s	Asphyxiant incapacitation FED_{asp} >0.3 at G2 (Lounge)
31 min 39 s	Asphyxiant incapacitation FED_{asp} >0.3 at G1 (Bedroom 1)
50 min	Test end – fire extinguished

3.5 Test 5: Corner test, Hydrant system, Non-ventilated, Stylised furniture

3.5.1 Test Description

Test 5 was conducted on 28 March 2017. The conditions during testing are summarised in Table 11 below.

Table 11 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 5.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.02 (0.02)	0.07 (0.04)
Air temp (ºC)	22.60 (0.00)	22.61 (0.19)
Relative humidity (%)	74.95 (0.28)	77.20 (1.14)
Air pressure (mBar)	1008.4 (0.01)	1008.22 (0.10)

In this test, the ignition crib was located in the NW corner of the Lounge room under a stylised plywood side table, which was placed in the corner between two stylised sofas. The arrangement is pictured in Figure 29 and detailed in Figure 30. In this test, the internal and external doors were closed. The fuel under the crib was a 1:2 mixture of heptane and water.

Figure 29 Photo showing the test arrangement for Test 5

There were seven sprinkler heads in operation in this test: H2, H3, H4, H5, H6, H7 and H8. The pressure at the meter was set at 700 kPa. All other sprinkler heads were made inoperable.

The test duration was approximately 45 minutes.

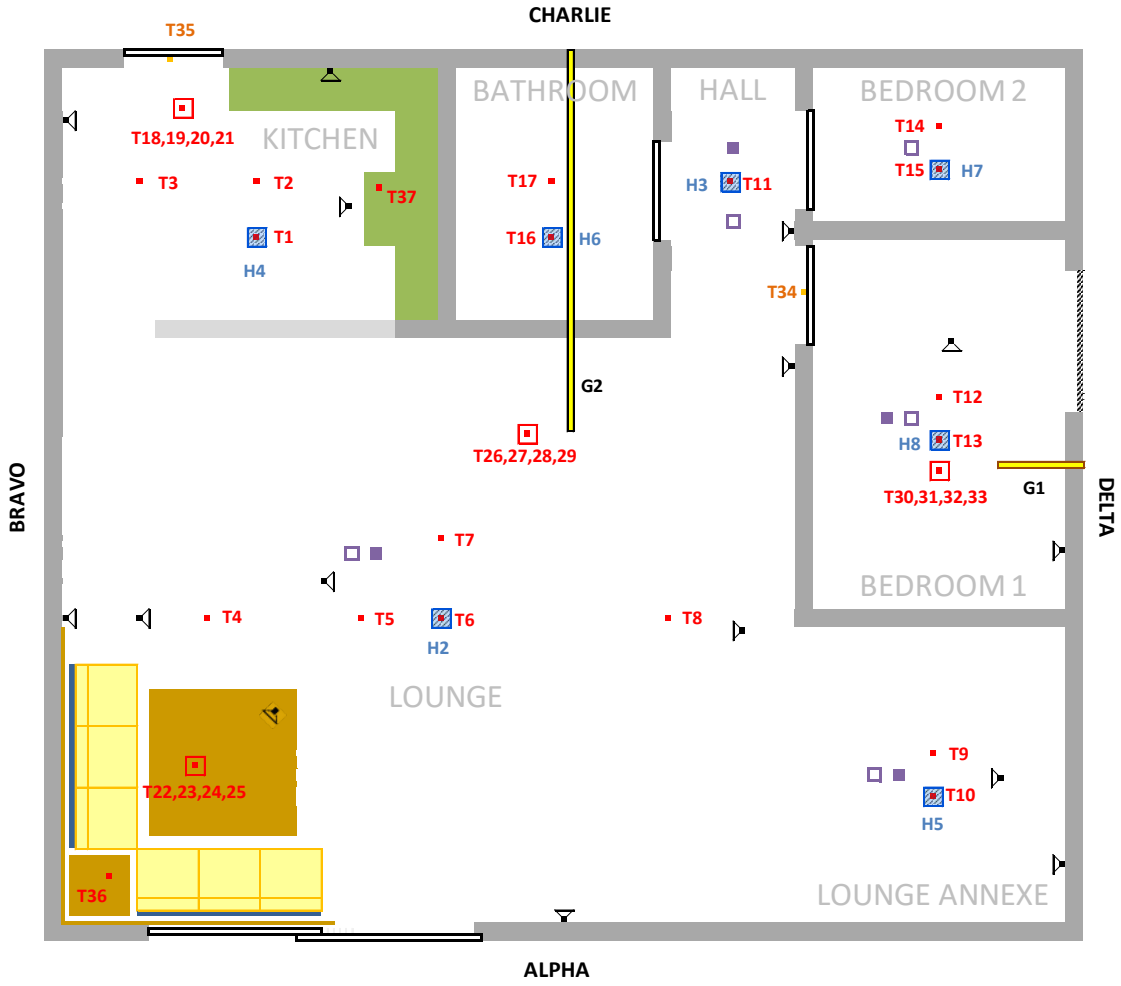

Figure 30 Map showing the Test 5 arrangement

3.5.2 Results

Fire size and fuel consumption

In Test 5, the peak flame height was approximately 1.5 metres (Figure 31). The fire spread to both sofas. The two arm rests were consumed as well as four foam blocks from the northern sofa, while one block was partially consumed from the western sofa (Figure 32).

Figure 31 Views of the test fire before sprinkler activation

Figure 32 View of the test furnishings at the end of Test 5

Activations

One sprinkler head (H2) activated at 1 min 35 s, which was 19 seconds after the first smoke alarm activation. The peak temperature at the sprinkler head was 85.9°C.

Temperatures

The maximum temperature reached in the unit was 343.6°C at T36, the thermocouple positioned above the ignition point. This peak occurred at 1 min 39 s after ignition. The temperature fell to below 100°C at 4 min 2 s after ignition.

Along the paths of egress, the temperatures measured at 1.6 m remained below 65°C for the duration of the test, peaking at 48°C in the Kitchen, 34.6°C in the Lounge room, and 23.7°C in Bedroom 1. The cumulative heat tenability limits were not reached in both the Lounge or Bedroom during the test.

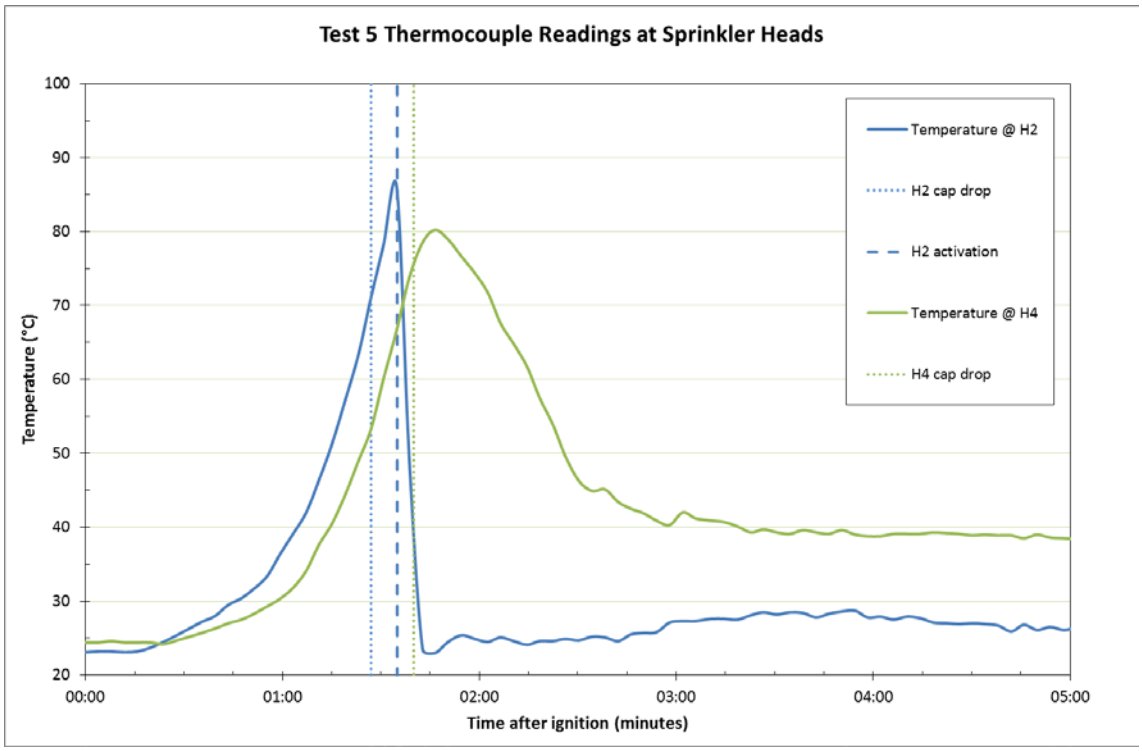

Figure 33 Sprinkler head activation times and temperatures for Test 5

Smoke Toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to FEC_{esc} > 0.3 at 1 min 43 s and FEC_{esc} > 1 at 3 min 43 s after ignition. Irritant incapacitation FEC_{inc} 0.3 was reached at 2 min 39 s and rose above FEC_{inc} = 1 at 6 min 29 s. FED_{asp} 0.3 was reached 9 min 48 s, and FED_{asp} 1 at 19 min 44 s.

In Bedroom 1, FEC_{esc} > 0.3 was reached at 26 min 53 s after ignition and peaked at 0.8 at test end. FEC_{inc} > 0.3 was reached at 34 min 50 s, peaking at 0.46 by test end. The cumulative asphyxiant gas concentrations rose to FED_{asp} > 0.3 in 37 min 53 s, reaching 0.4 at test end.

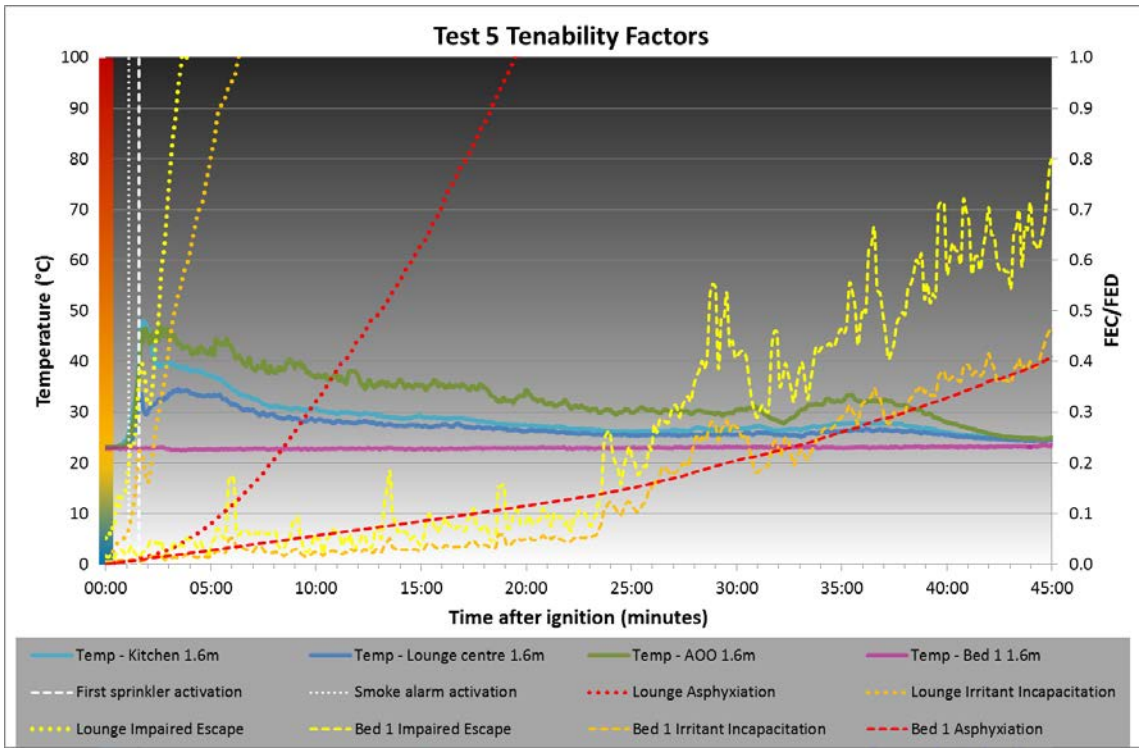

Figure 34 Chart showing timing of activations and tenability factors for Test 5

Table 12 Summary of Test 5 event timings

TIME AFTER IGNITION	EVENT
1 min 6 s	First smoke alarm activation
1 min 35 s	First sprinkler activation (H2)
1 min 43 s	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
2 min 39 s	Irritant incapacitation FEC_{inc} >0.3 at G2 (Lounge)
3 min 43 s	Impaired escape FEC_{esc} >1 at G2 (Lounge)
6 min 29 s	Irritant incapacitation FEC_{inc} >1 at G2 (Lounge)
9 min 48 s	Asphyxiant incapacitation FED_{asp} >0.3 at G2 (Lounge)
19 min 44 s	Asphyxiant incapacitation FED_{asp} >1 at G2 (Lounge)
26 min 53 s	Impaired escape FEC_{esc} >0.3 at G1 (Bedroom 1)
34 min 50 s	Irritant incapacitation FEC_{inc} >0.3 at G1 (Bedroom 1)
37 min 53 s	Asphyxiant incapacitation FED_{asp} >0.3 at G1 (Bedroom 1)

45 min	Test end – fire extinguished

3.5.3 Observations

The following was observed from the data:

- With only the one head operating the fire was controlled, did not flash over and did not spread significantly.
- The sprinkler system effectively delivered enough water to prevent the fire from developing and consuming the two sofas. The temperatures throughout the apartment dropped significantly upon the activation of the sprinkler head. Temperatures at 1.6 m remained below tenability thresholds throughout the test.
- The data also indicates that at 1.6 metres at all times, before and after sprinkler activation, the conditions were tenable for the Fire Brigade to safely enter and undertake search and rescue operations.
- This data indicates that an occupant remaining in the Bedroom with the door closed would have been safe for a period of at least 35 minutes before possibly becoming incapacitated from smoke inhalation.
- The FED_{asp} for the Lounge room remained under 0.3 until 9 min 48 s into the test.
- The FED_{asp} for Bedroom 1 remained under 0.3 for approximately 38 minutes.

3.6 Test 6: Corner test, Domestic system, Non-ventilated, Stylised furniture

3.6.1 Test Description

Test 6 was conducted on 31 March 2017. The conditions during testing are summarised in Table 13 below.

Table 13 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 6.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.08 (0.07)	0.10 (0.07)
Air temp (ºC)	18.55 (0.05)	19.45 (0.24)
Relative humidity (%)	58.27 (0.71)	59.16 (0.95)
Air pressure (mBar)	1010.69 (0.07)	1010.68 (0.05)

The arrangement for this test was identical to that of Test 5. The ignition crib was again located in the NW corner of the Lounge room under a stylised plywood side table, which was placed in the corner between two stylised sofas. The arrangement is pictured in Figure 35 and

detailed in Figure 36. In this test, the internal and external doors were closed. The fuel under the crib was a 1:2 mixture of heptane and water.

Figure 35 Photo showing the test arrangement for Test 6

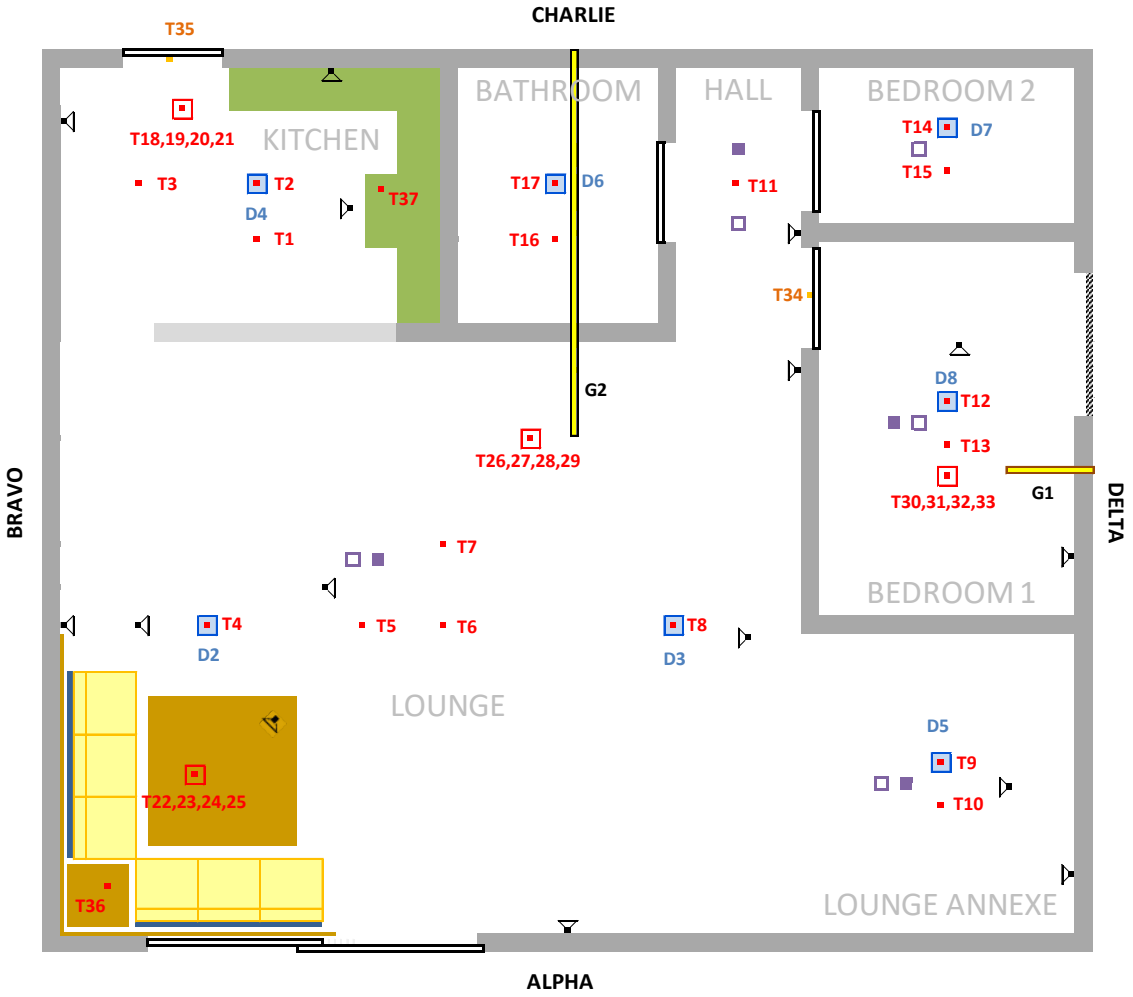

Figure 36 Map showing the Test 6 arrangement

There were seven sprinkler heads in operation in this test: D2, D3, D4, D5, D6, D7 and D8. The pressure at the meter was set at 250 kPa. All other sprinkler heads were made inoperable.

The test duration was approximately 45 minutes.

3.6.2 Results

Fire size and fuel consumption

In Test 6, the peak flame height was approximately 1 metre (Figure 37). The fire spread to both sofas. The two arm rests were consumed as well as four foam blocks from the northern sofa, and one block from the western sofa (Figure 38).

Activations

Two sprinkler heads activated during the test. D2 activated at 1 min 13 s and D3 at 2 min 37 s, 9 seconds and 93 seconds after the first smoke alarm activation, respectively. The peak temperatures at the sprinkler heads were 89°C at D2, and 117.5°C at D3.

Temperatures

The maximum temperature reached in the unit was 304.2°C at T36, the thermocouple positioned above the ignition point. This peak occurred at 2 min 15 s after ignition. The temperature fell to below 100°C at 12 min 44 s after ignition.

While the temperature at 1.6 metres remained below 65°C in Bedroom 1 and along the path of egress through the Lounge room, the temperature measured at the Kitchen door was elevated above 65°C between 2 min 46 s and 8 min 25 s, peaking at 72.2°C. The cumulative heat tenability limit (FED_{heat} > 0.3) at this location was reached at 11 min 34 s.

Smoke Toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to FEC_{esc} > 0.3 at 1 min 43 s and FEC_{esc} > 1 at 3 min 3 s after ignition. Irritant incapacitation FEC_{inc} 0.3 was reached at 2 min 15 s and rose above FEC_{inc} = 1 at 3 min 50 s. FED_{asp} 0.3 was reached at 7 min 25 s, and FED_{asp} 1 at 13 min 38 s.

In Bedroom 1, FEC_{esc} > 0.3 was reached at 7 min 25 s and FEC_{esc} > 1 was reached at 27 min 1 s. FEC_{inc} > 0.3 was reached at 21 min 11 s, with FEC_{inc} 1 exceeded after 40 min 56 s. The cumulative asphyxiant gas concentrations rose to FED_{asp} > 0.3 in 28 min 05 s, reaching 0.73 by test end.

Figure 37 View of the test fire before sprinkler activation during Test 6

Figure 38 View of the test furnishings at the end of Test 6

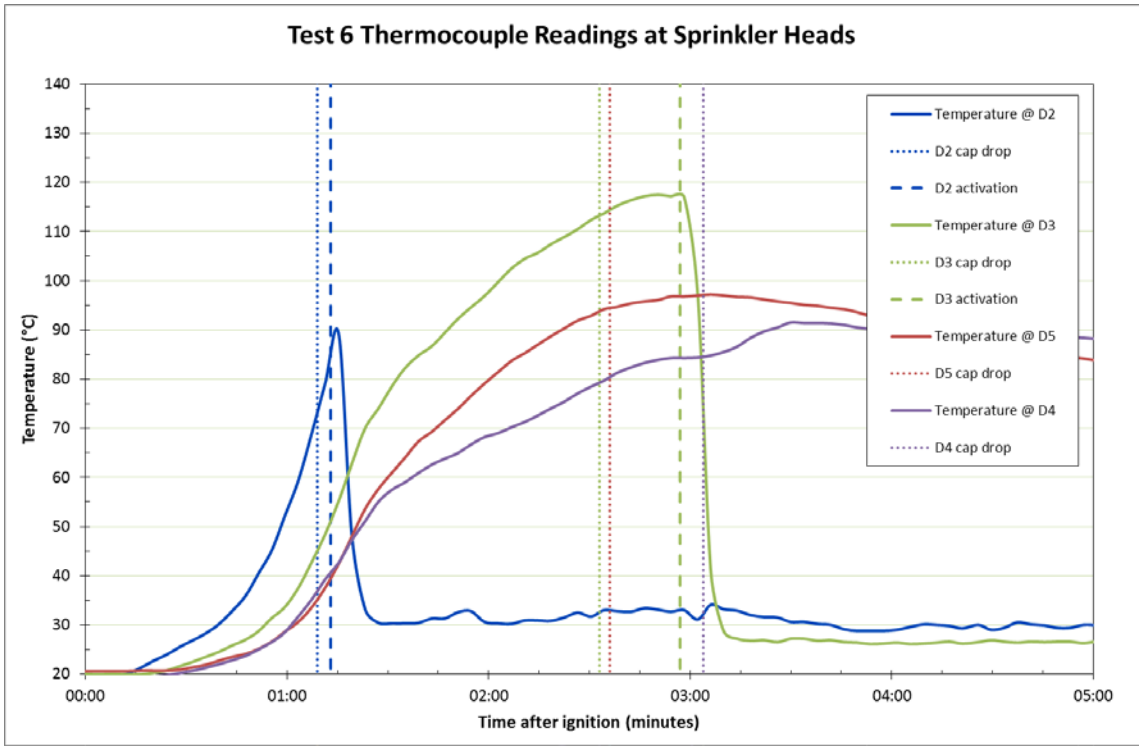

Figure 39 Sprinkler head activation times and temperatures for Test 6

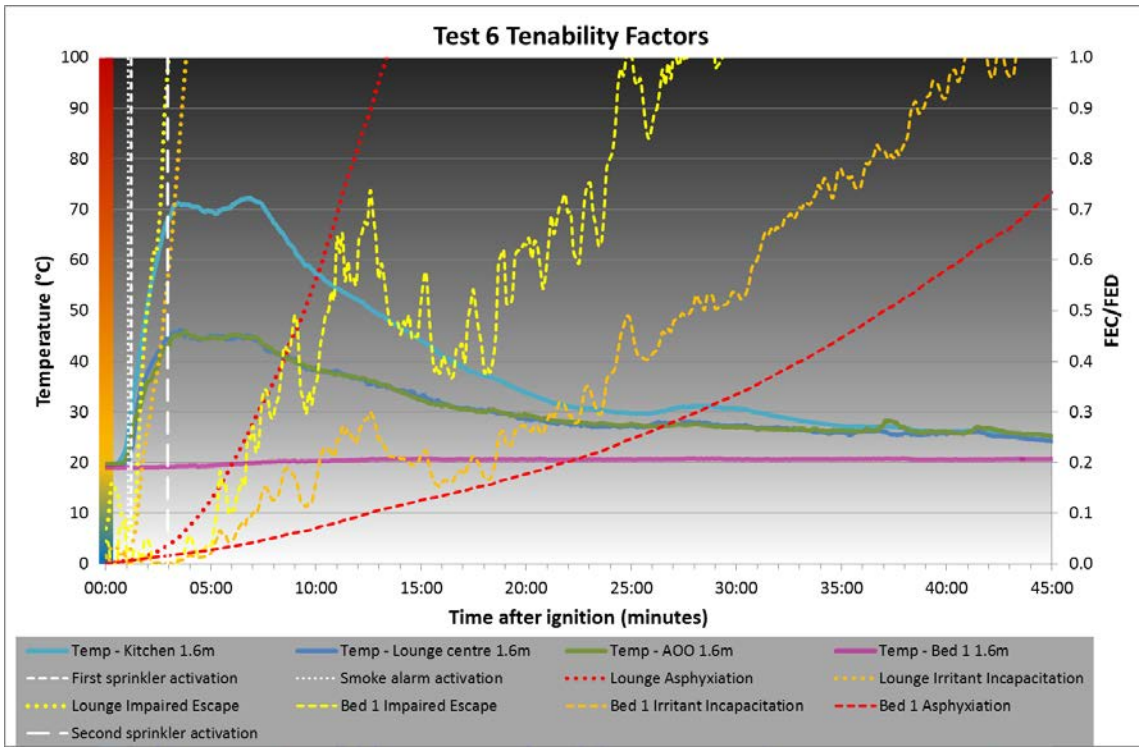

Figure 40 Chart showing timing of activations and tenability factors for Test 6

Table 14 Summary of Test 6 event timings

TIME AFTER IGNITION	EVENT
1 min 4 s	First smoke alarm activation
1 min 13 s	First sprinkler activation (D2)
1 min 43 s	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
2 min 15 s	Irritant incapacitation FEC_{inc} >0.3 at G2 (Lounge)
2 min 46 s – 8 min 25 s	Temperature at Kitchen door elevated above 65°C
2 min 57 s	Second sprinkler activation (D3)
3 min 3 s	Impaired escape FEC_{esc} >1 at G2 (Lounge)
3 min 50 s	Irritant incapacitation FEC_{inc} >1 at G2 (Lounge)
7 min 25 s	Impaired escape FEC_{esc} >0.3 at G1 (Bedroom 1)
7 min 25 s	Asphyxiant incapacitation FED_{asp} >0.3 at G2 (Lounge)
11 min 34 s	Temperature at Kitchen (T20) reaches FED_{heat} 0.3
13 min 38 s	Asphyxiant incapacitation FED_{asp} >1 at G2 (Lounge)
21 min 11 s	Irritant incapacitation FEC_{inc} >0.3 at G1 (Bedroom 1)
27 min 1 s	Impaired escape FEC_{esc} >1 at G1 (Bedroom 1)
28 min 5 s	Asphyxiant incapacitation FED_{asp} >0.3 at G1 (Bedroom 1)
40 min 56 s	Irritant incapacitation FEC_{inc} >1 at G1 (Bedroom 1)
45 min	Test end – fire extinguished

3.6.3 Observations

The following was observed from the data:

- With two heads operating, the fire was controlled, did not flash over and did not spread further along the two sofas.
- While temperatures continued to rise after the operation of the first sprinkler head, they stopped rising or dropped significantly upon the activation of the second sprinkler head.
- At 1.6 metres height level, it would have been possible for an occupant to safely egress from the bedrooms as temperatures along the egress path in the Lounge room remained below tenability thresholds.
- At a height of 1.6 metres, all temperatures in any part of the apartment were below the tenability thresholds except near the SOU door, where they were elevated for approximately 5 ½ minutes after the second sprinkler activation.
- FED_{asp} in the Lounge room remained under 0.3 until 7 min 25 s into the test.

- FED_{asp} in Bedroom 1 remained under 0.3 for 28 minutes with the bedroom door closed.
- This data indicates that an occupant in the Bedroom with the door closed would be safe from temperature and toxicity levels for at least 21 minutes before possibly becoming incapacitated due to smoke inhalation.

3.7 Test 7: Corner test, Domestic system, Non-ventilated, Stylised furniture, Bedroom door open

3.7.1 Test Description

Test 7 was conducted on 7 April 2017. The conditions during testing are summarised in Table 15 below.

Table 15 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 7.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.04 (0.04)	0.06 (0.04)
Air temp (ºC)	18.19 (0.03)	19.71 (0.46)
Relative humidity (%)	67.62 (0.79)	59.6 (1.24)
Air pressure (mBar)	1022.1 (0.00)	1021.89 (0.15)

The arrangement for this test was identical to that of Test 6, except for the ventilation characteristics. The ignition crib was again located in the NW corner of the Lounge room under a stylised plywood side table, which was placed in the corner between two stylised sofas. The arrangement is pictured in Figure 41 and detailed in Figure 42. In this test, the external doors were closed while the door to Bedroom 1 was open. The fuel under the crib was a 1:2 mixture of heptane and water.

Figure 41 Photo showing the test arrangement for Test 7

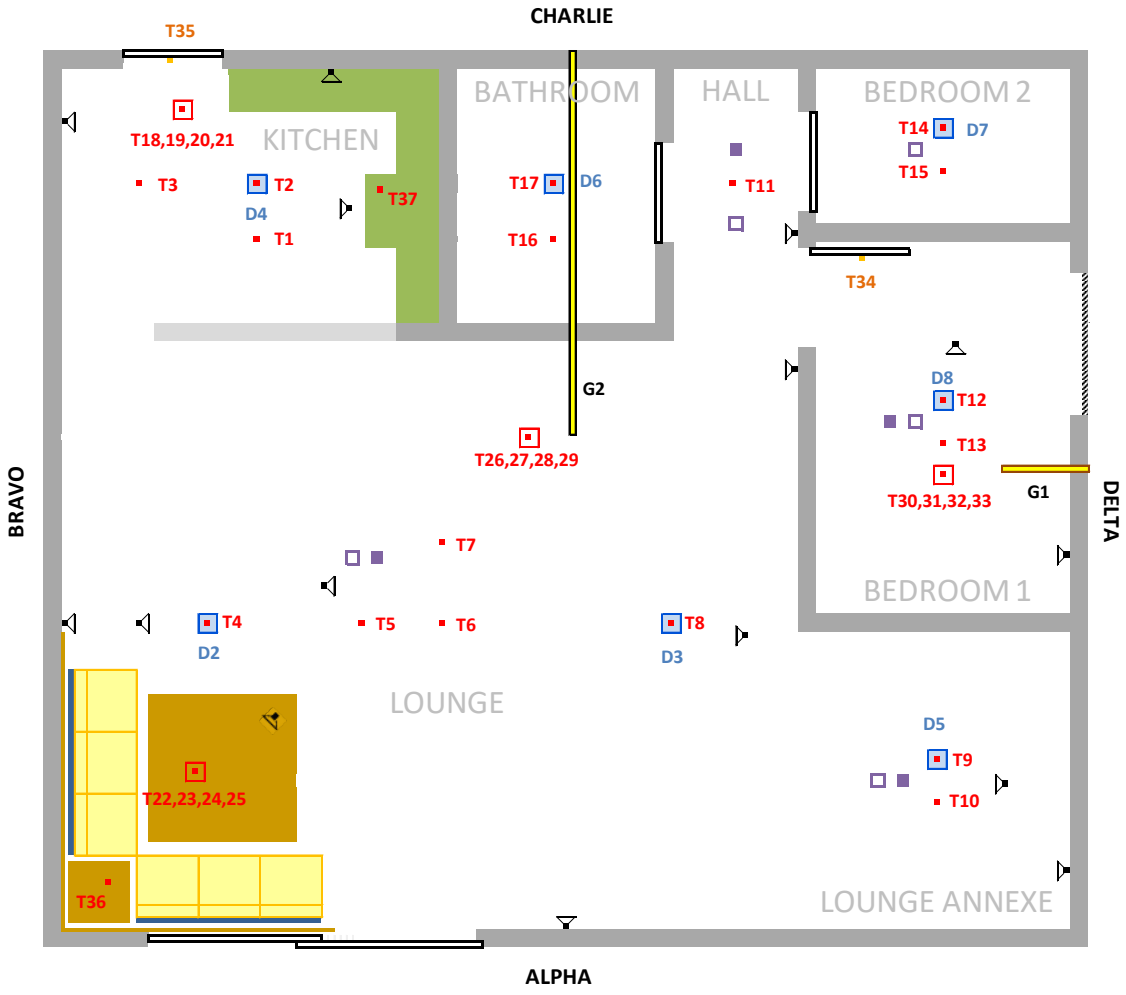

Figure 42 Map showing the Test 7 arrangement

There were seven sprinkler heads in operation in this test: D2, D3, D4, D5, D6, D7 and D8. The pressure at the meter was set at 250 kPa. All other sprinkler heads were made inoperable.

The test duration was approximately 30 minutes.

3.7.2 Results

Fire size and fuel consumption

In Test 7, the peak flame height was approximately 1.5 metres (Figure 43). The fire spread to both sofas. The two arm rests were consumed as well as approximately 1.5 foam blocks from each sofa (Figure 44).

Figure 43 View of the test fire before sprinkler activation

Figure 44 View of the test furnishings at the end of Test 7

Activations

Two sprinkler heads activated during the test. D2 activated at 1 min 18 s and D3 at 1 min 42 s, 29 seconds and 53 seconds after the first smoke alarm activation, respectively. The peak temperatures at the sprinkler heads were 89.4°C at D2, and 89.5°C at D3.

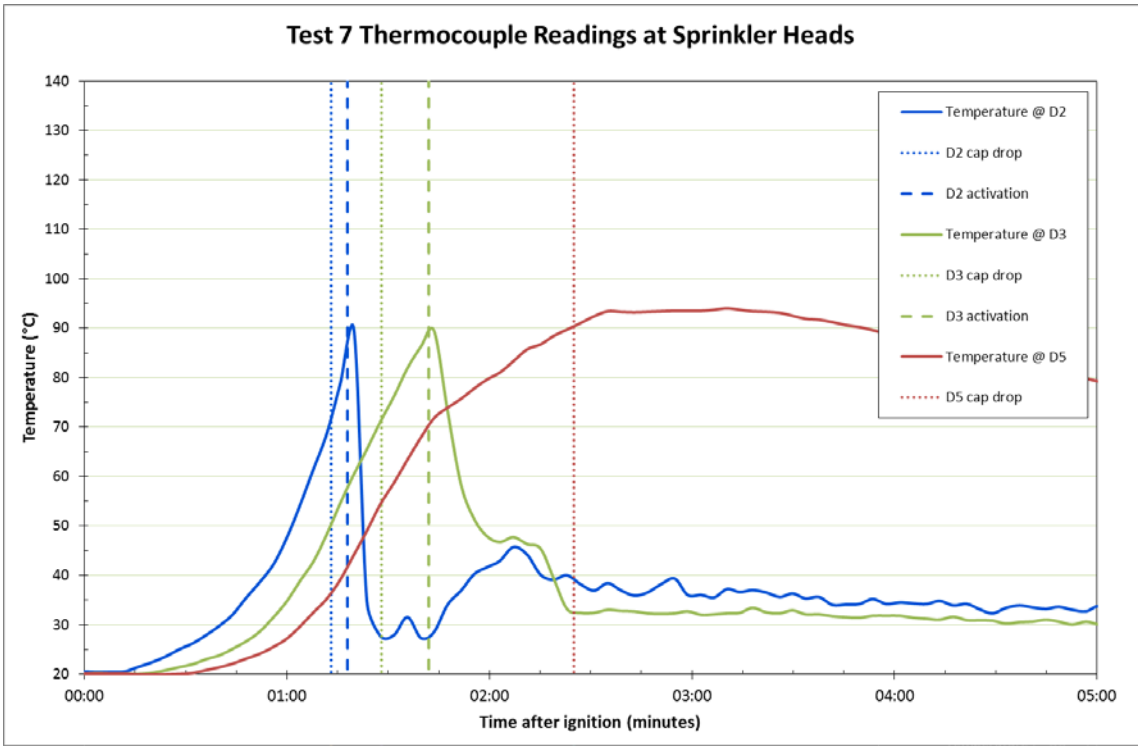

Figure 45 Sprinkler head activation times and temperatures for Test 7

Temperatures

The maximum temperature reached in the unit was 348.2°C at T36, the thermocouple positioned above the ignition point. This peak occurred at 2 min 27 s after ignition. The temperature fell to below 100°C at 12 min 32 s after ignition.

Temperatures along the paths of egress and in Bedroom 1 at 1.6 metres remained below 65°C throughout the test, peaking at 48.3°C in Bedroom 1, 43.4°C at the Lounge centre, and 60°C in the Kitchen. The cumulative heat tenability limit (FED_{heat} > 0.3) was not reached for any of the three locations.

Smoke Toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to FEC_{esc} > 0.3 at 1 min 20 s and FEC_{esc} > 1 at 3 min 35 s after ignition. Irritant incapacitation FEC_{inc} 0.3 was reached at 1 min 59 s and rose above FEC_{inc} = 1 at 4 min 46 s. FED_{asp} 0.3 was reached at 7 min 41 s, and FED_{asp} 1 at 12 min 19 s.

In Bedroom 1, FEC_{esc} > 0.3 was reached at 1 min 20 s and FEC_{esc} > 1 was reached at 4 min 6 s. FEC_{inc} > 0.3 was reached at 2 min 55 s, with FEC_{inc} 1 exceeded after 7 min 33 s. The cumulative asphyxiant gas concentrations rose to FED_{asp} > 0.3 in 17 min 45 s, reaching 0.64 by test end.

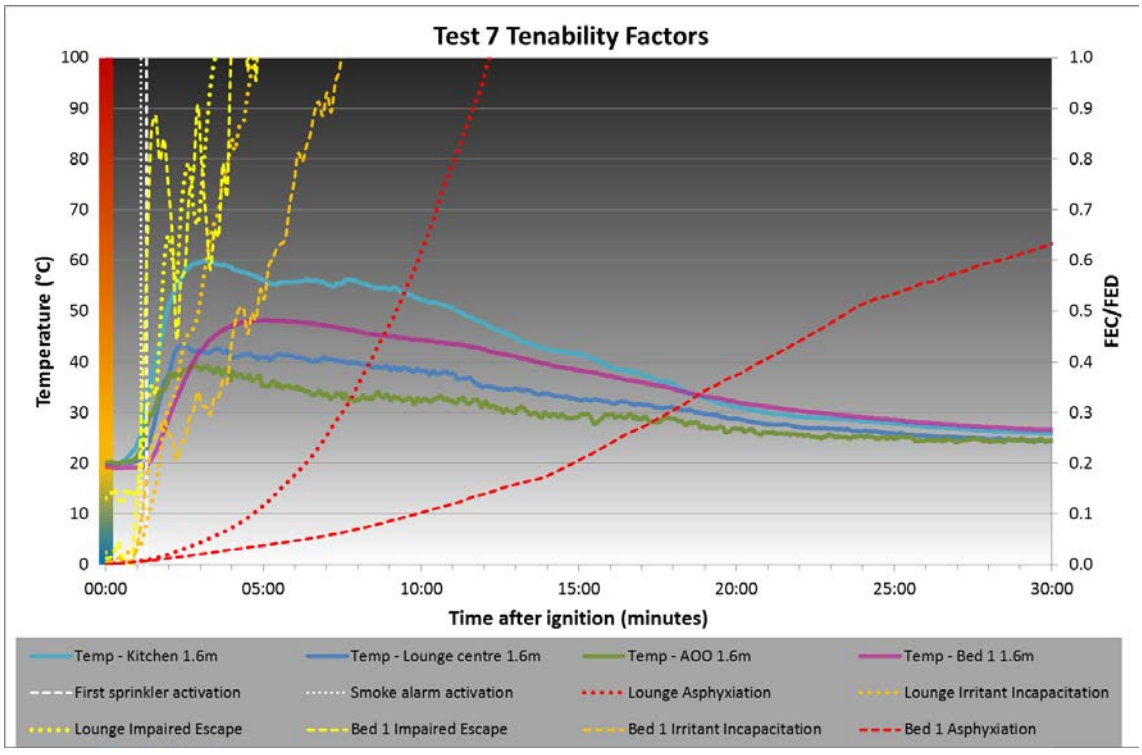

Figure 46 Chart showing timing of activations and tenability factors for Test 7

Table 16 Summary of Test 7 event timings

TIME AFTER IGNITION	EVENT
1 min 7 s	First smoke alarm activation
1 min 18 s	First sprinkler activation (D2)
1 min 20 s	Impaired escape FEC_{esc} >0.3 at G1 (Bedroom 1)
1 min 20 s	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
1 min 42 s	Second sprinkler activation (D3)
1 min 59 s	Irritant incapacitation FEC_{inc} >0.3 at G2 (Lounge)
2 min 55 s	Irritant incapacitation FEC_{inc} >0.3 at G1 (Bedroom 1)
3 min 35 s	Impaired escape FEC_{esc} >1 at G2 (Lounge)
4 min 6 s	Impaired escape FEC_{esc} >1 at G1 (Bedroom 1)
4 min 46 s	Irritant incapacitation FEC_{inc} >1 at G2 (Lounge)
7 min 33 s	Irritant incapacitation FEC_{inc} >1 at G1 (Bedroom 1)
7 min 41 s	Asphyxiant incapacitation FED_{asp} >0.3 at G2 (Lounge)
12 min 19 s	Asphyxiant incapacitation FED_{asp} >1 at G2 (Lounge)
17 min 45 s	Asphyxiant incapacitation FED_{asp} >0.3 at G1 (Bedroom 1)
30 min	Test end – fire extinguished

3.7.3 Observations

The following was observed from the data:

- With two heads operating, the fire was controlled, did not flash over and did not spread further along the two sofas.
- The temperatures throughout the unit stopped increasing upon the activation of the sprinklers.
- At a height of 1.6 metres, all temperatures in any part of the apartment were below the tenability threshold of 65°C.
- The data indicates that an occupant remaining in the Bedroom with the door open would be safe for only 2 min 55 s before possibly becoming incapacitated from smoke inhalation. Escape via the most direct egress path would have been possible prior to this.
- FED_{asp} in the Lounge room remained under 0.3 until 7 min 41 s into the test.
- FED_{asp} in Bedroom 1 remained under 0.3 for 17 min 45 s with the Bedroom door open.

3.8 Test 8: Bedroom test, Domestic system, Non-ventilated, Stylised furniture

3.8.1 Test Description

Test 8 was conducted on 12 April 2017. The conditions during testing are summarised in Table 17 below.

Table 17 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 8.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.02 (0.02)	0.06 (0.04)
Air temp (ºC)	18.94 (0.05)	18.96 (0.11)
Relative humidity (%)	65.93 (0.58)	66.7 (0.84)
Air pressure (mBar)	1017.8 (0.00)	1017.65 (0.09)

In this test, the ignition crib was located in the NW corner of Bedroom 1, underneath a stylised bed. The arrangement is pictured in Figure 47 and detailed in Figure 48. In this test, both the external and internal doors were closed. The fuel under the crib was a 1:2 mixture of heptane and water.

There were seven sprinkler heads in operation in this test: D2, D3, D4, D5, D6, D7 and D8. The pressure at the meter was set at 250 kPa. All other sprinkler heads were made inoperable.

The test duration was approximately 50 minutes.

Figure 47 Photo showing the test arrangement in Test 8

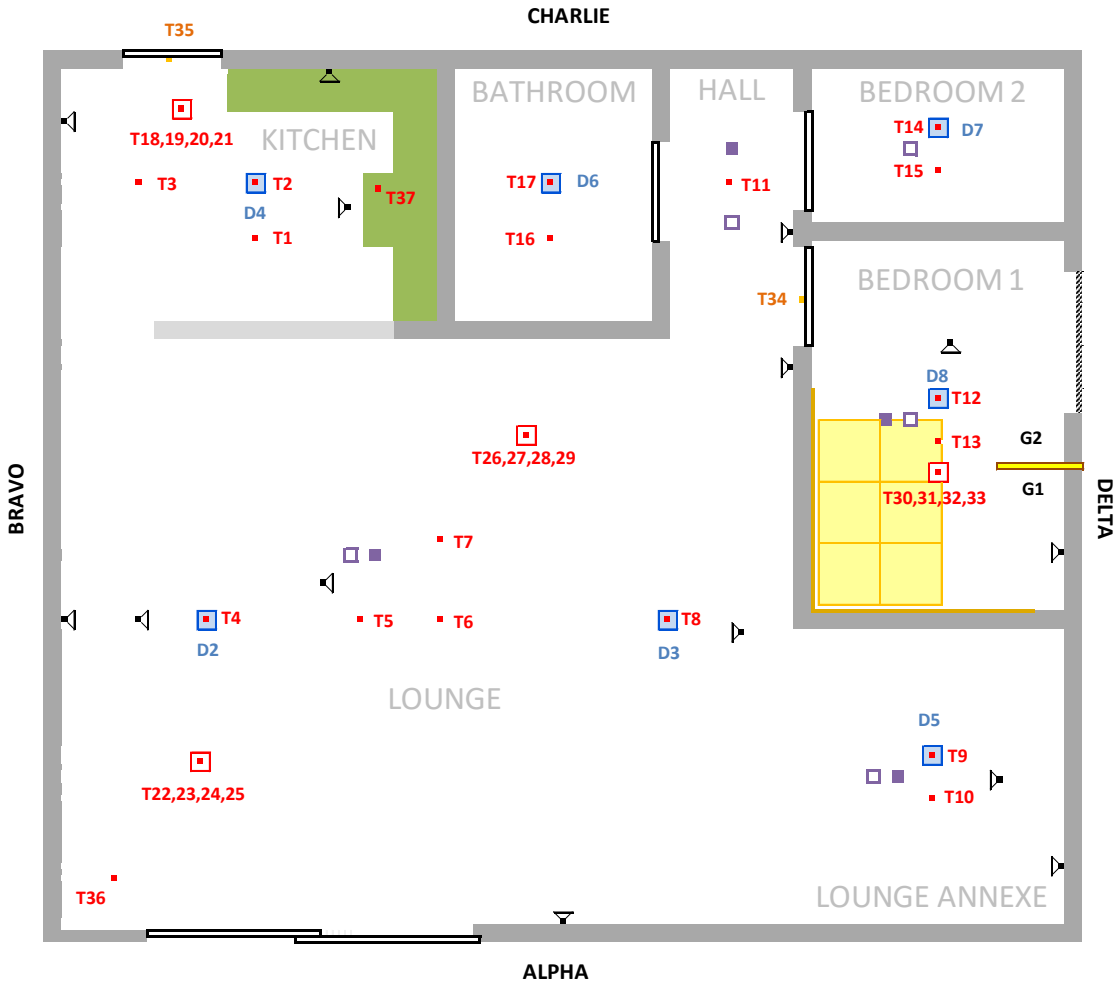

Figure 48 Map showing the Test 8 arrangement

3.8.2 Results

Fire size and fuel consumption

In Test 8, the peak flame height was approximately 2.4 metres or ceiling height (Figure 49). The fire was confined to a single foam block (Figure 50).

Figure 49 View of the test fire before sprinkler activation

Figure 50 View of the test furnishings at the end of Test 8

Activations

The Bedroom 1 sprinkler head (D8) activated after 58 seconds, 31 seconds after the room smoke alarm sounded. The peak temperature at the sprinkler head was 125.8°C.

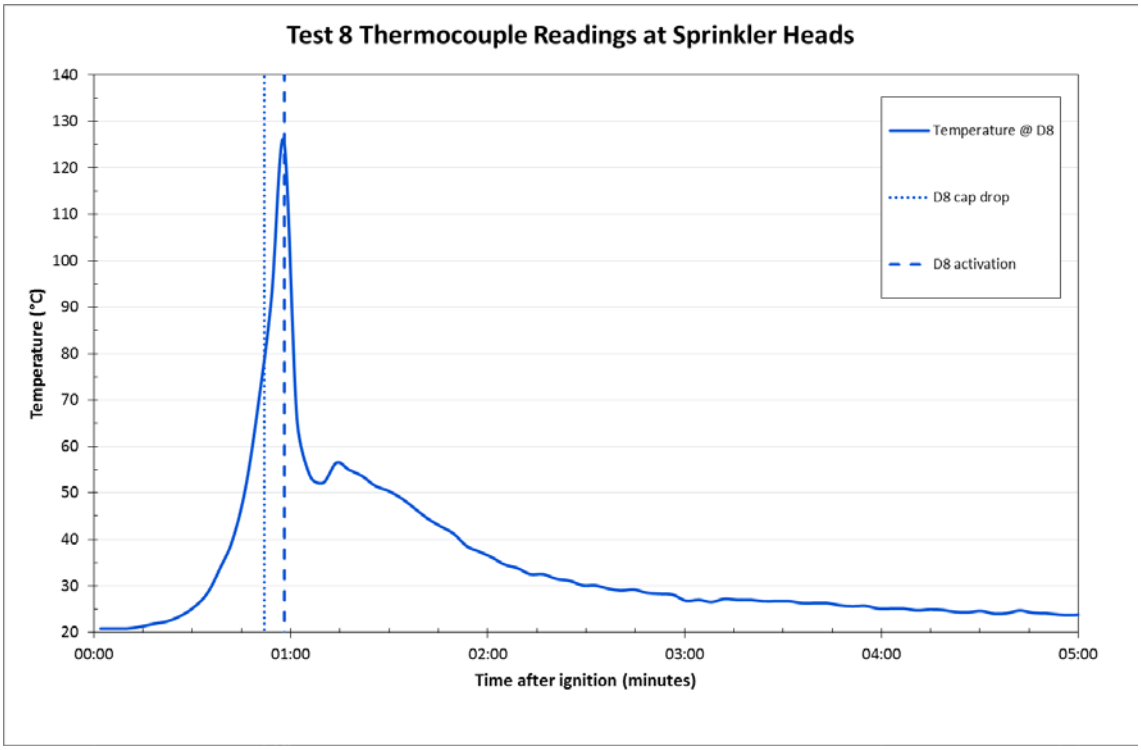

Figure 51 Sprinkler head activation times and temperatures for Test 8

Temperatures

The maximum temperature reached in the unit was 243.4°C at T30, the thermocouple positioned at the ceiling of Bedroom 1. This peak occurred at 1 min 14 s after ignition. The temperature fell to below 100°C at 1 min 46 s after ignition.

Temperatures measured at 1.6 metres remained below 65°C throughout the test, peaking at 63.1°C in Bedroom 1. The cumulative heat tenability limit (FED_{heat} > 0.3) was not reached at any location.

Smoke Toxicity

Gases were sampled at heights of 1.6 metres (G1) and 1 metre (G2) within Bedroom 1.

At 1.6 metres (G1), both FEC_{esc} > 0.3 and FEC_{inc} > 0.3 were reached in 56 seconds. FEC_{esc} 1 was exceeded in 1 min 4 s and FEC_{inc} 1 in 1 min 12 s. Asphyxiant incapacitation FED_{asp} 0.3 was reached at 3 min 59 s, and FED_{asp} 1 at 7 min 33 s.

At 1 metre (G2), FEC_{esc} > 0.3 was reached in 56 seconds, while FEC_{inc} 0.3 and FEC_{esc} 1 were reached in 1 min 4 s. FEC_{inc} 1 was exceeded in 1 min 19 s. Asphyxiant incapacitation FED_{asp} 0.3 was reached at 2 min 39 s, and FED_{asp} 1 at 5 min 26 s.

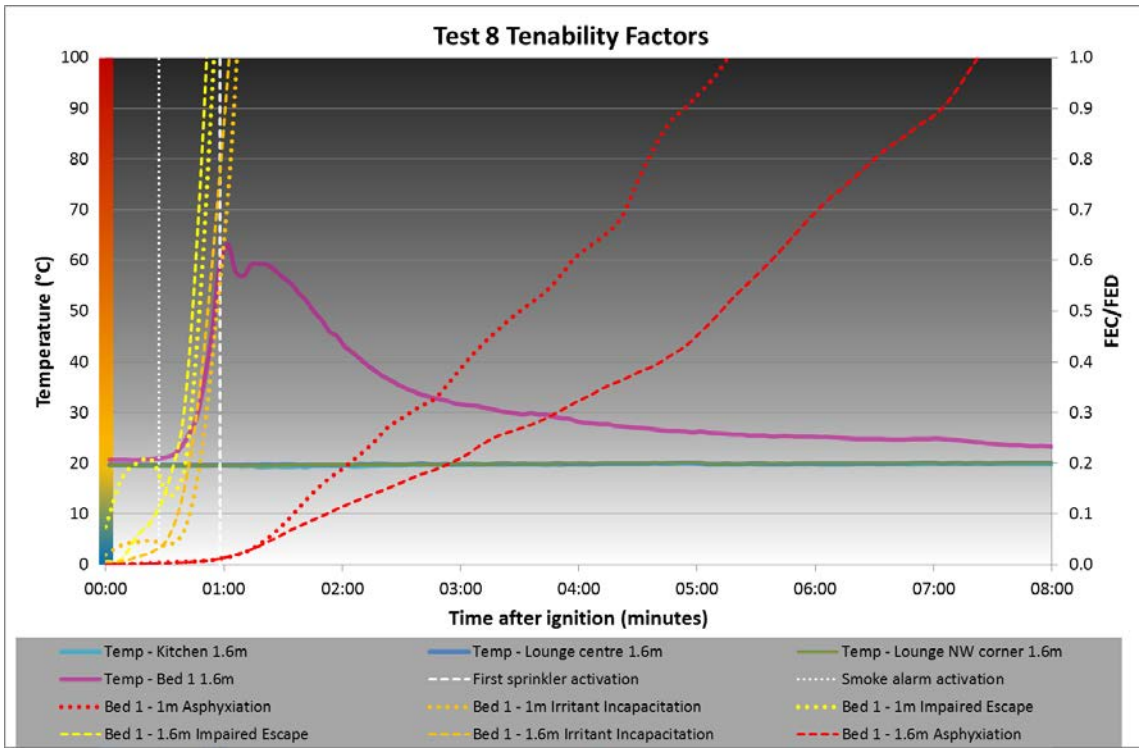

Figure 52 Chart showing timing of activations and tenability factors for Test 8

3.8.3 Observations

The following was observed from the data:

- With the one head operating, the fire was controlled, did not flash over and did not spread beyond a single foam pad.
- With a significantly shielded fire to prevent the water from the sprinkler from impacting immediately on the fire and with only one head operating, the sprinkler system effectively delivered enough water to prevent the fire from spreading, preventing flashover and providing temperature tenability conditions.
- The temperatures throughout the Bedroom dropped significantly upon the activation of the sprinkler head.
- Also, according to the data, it would have been possible for an occupant to safely egress from the Bedroom after the sprinkler activation, as the access path throughout the apartment would have been safe for evacuation.
- It would also have been possible for the occupant to seek refuge in another part of the apartment, as the sprinkler prevented spread of the fire from the Bedroom.

- At a height of 1.6 metres all temperatures in any part of the unit were below the tenability criteria of 65°C, including in the closed Bedroom.
- FED_{asp} at 1 metre height (G2) remained under 0.3 for 2 min 39 s into the test.
- FED_{asp} at 1.6 m (G1) remained under 0.3 for 3 min 59s minutes.
- The small, enclosed space contributed to the rapid elevation of toxicity levels within the Bedroom. While the sprinkler activation prevented fire spread and temperature rise, toxicity levels quickly became untenable within the Bedroom.
- The early activation of the smoke alarm and sprinkler would have adequately alerted an able occupant for escape. It is assumed that opening the door to escape would have vented the space quickly.

Table 18 Summary of Test 8 event timings

TIME AFTER IGNITION	EVENT
27 s	First smoke alarm activation
56 s	Impaired escape FEC_{esc} >0.3 at G1 (1.6 m)
	Impaired escape FEC_{esc} >0.3 at G2 (1 m)
	Irritant incapacitation FEC_{inc} >0.3 at G1 (1.6 m)
58 s	First sprinkler activation (D8)
1 min 4 s	Impaired escape FEC_{esc} >1 at G1 (1.6 m)
	Impaired escape FEC_{esc} >1 at G2 (1 m)
1 min 12 s	Irritant incapacitation FEC_{inc} >1 at G1 (1.6 m)
1 min 19 s	Irritant incapacitation FEC_{inc} >1 at G2 (1 m)
2 min 39 s	Asphyxiant incapacitation FED_{asp} >0.3 at G2 (1 m)
3 min 59 s	Asphyxiant incapacitation FED_{asp} >0.3 at G1 (1.6 m)
5 min 26 s	Asphyxiant incapacitation FED_{asp} >1 at G2 (1 m)
7 min 33 s	Asphyxiant incapacitation FED_{asp} >1 at G1 (1.6 m)
50 min	Test end – fire extinguished

3.9 Test 9: Kitchen oil fire, Domestic system, Non-ventilated, Bedroom door open

3.9.1 Test Description

Test 9 was conducted on 21 April 2017. The conditions during testing are summarised in Table 19 below.

Table 19 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 9.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.04 (0.02)	0.03 (0.02)
Air temp (ºC)	20.29 (0.10)	19.99 (0.03)
Relative humidity (%)	63.8 (0.60)	66.9 (0.97)
Air pressure (mBar)	1021.59 (0.08)	1020.67 (0.31)

In Test 9, a pan containing 500 ml of preheated vegetable oil was placed on the live electric stove in the Kitchen at the start of the test. A flame from a butane blow torch was introduced to the oil surface as the temperature reached the ignition range. The arrangement is pictured in Figure 53 and detailed in Figure 54. In this test, both the external and internal doors were closed.

There were seven sprinkler heads in operation in this test: D2, D3, D4, D5, D6, D7 and D8. The pressure at the meter was set at 250 kPa. All other sprinkler heads were made inoperable. To further challenge the Domestic sprinkler system in this test, 12 L/min was bled from the domestic water supply from the start of the test.

The test duration was approximately 50 minutes, ending at 20 minutes after oil ignition.

Figure 53 Photo showing the test arrangement in Test 9

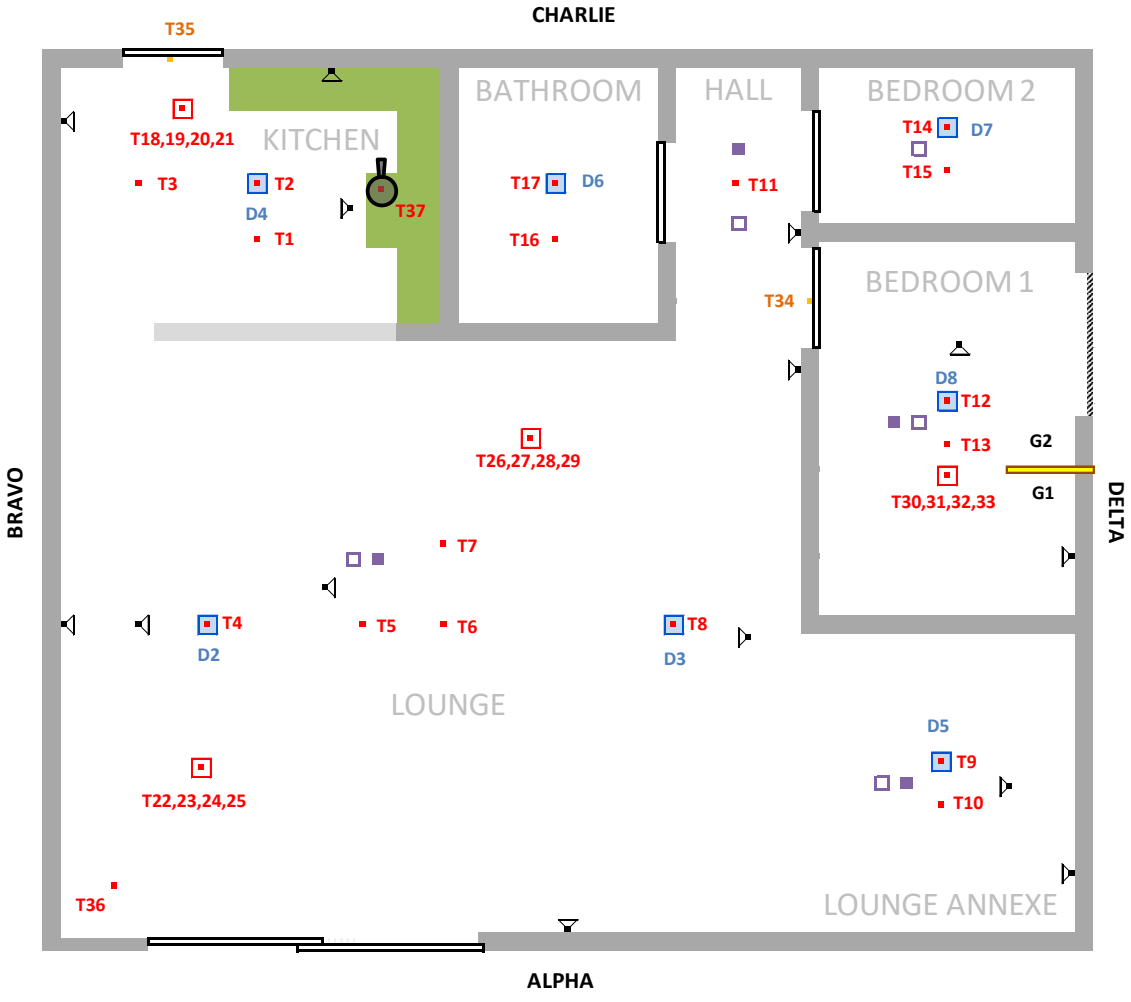

Figure 54 Map showing the Test 9 arrangement

3.9.2 Results

Fire size and fuel consumption

In Test 9, visible smoke begins to issue from the pan at 9 min 30 s from the start of the test. After a further 20 min 18 s, the oil ignited at a pan temperature of 376.2°C (T37). The elevated flames impinged on the overhead cupboards (Figure 55). The fire consumed a number of items in the vicinity of the flames, but did not spread laterally (Figure 56). The last flames were extinguished at approximately 4 min 27 s after ignition.

Figure 55 View of the test fire before sprinkler activation

Figure 56 View of the test furnishings at the end of Test 9

Activations

The smoke alarm at the Lounge centre sounded at 21 min 16 s into the test, which was 11 min 46 s after the smoke became visible in the Kitchen, and 8 min 32 s before ignition.

The Kitchen sprinkler head (D4) activated at 1 min 43 s after ignition, 10 min 15 s after the smoke alarm sounded. The peak temperature at the sprinkler head was 144.6°C. The (north) Lounge sprinkler head (D2) activated at 1 min 59 s after ignition, 10 min 31 s after the smoke alarm sounded. The peak temperature at that sprinkler head was 77.9°C.

Water pressure at the meter was 250kPa at the start of the test and 220-230kPa at the sprinkler pipe. During activation, pressure was maintained at 250kPa at the meter and 50kPa at the sprinkler pipe. After both sprinklers activated, the 12L/min that was bled from the system from the start of the test reduced to 4.8 L/min.

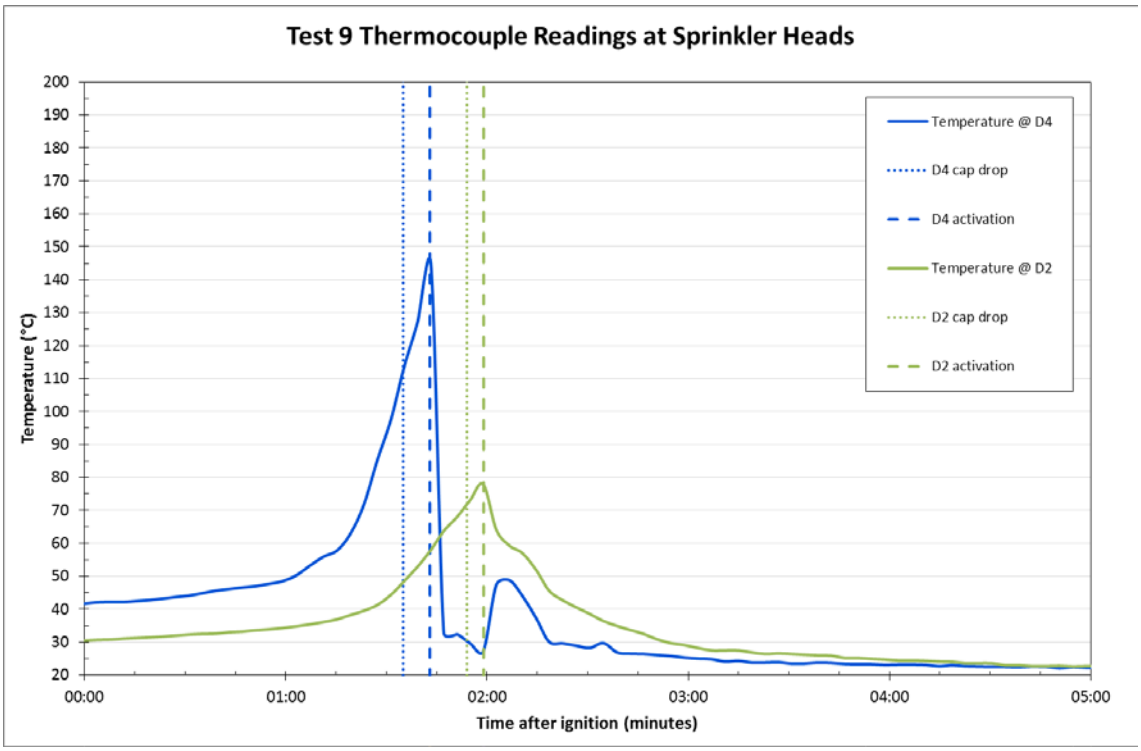

Figure 57 Sprinkler head activation times and temperatures for Test 9

Temperatures

The maximum temperature reached in the unit was 144.6°C at T2, the thermocouple positioned below the sprinkler D4. This peak occurred at 1 min 43 s after ignition and fell to below 100°C immediately after sprinkler activation.

Temperatures measured at 1.6 metres remained below 65°C throughout the test, peaking at 29.2°C in Bedroom 1 (T32), 31.8°C (T28) and 38.2°C (T24) in the Lounge room, and 38°C (T20) in the Kitchen. The cumulative heat tenability limit (FED_{heat} > 0.3) was not reached at any location.

Smoke Toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to FEC_{esc} > 0.3 at 1 min 52 s after ignition. Irritant incapacitation FEC_{inc} 0.3 was reached at 3 min 19 s. FED_{asp} 0.3 was not reached.

In Bedroom 1, FEC_{esc} > 0.3 was reached at 2 min 39 s after ignition. FEC_{inc} > 0.3 was reached at 3 min 2 s. The cumulative asphyxiant gas concentrations did not reach FED_{asp} > 0.3.

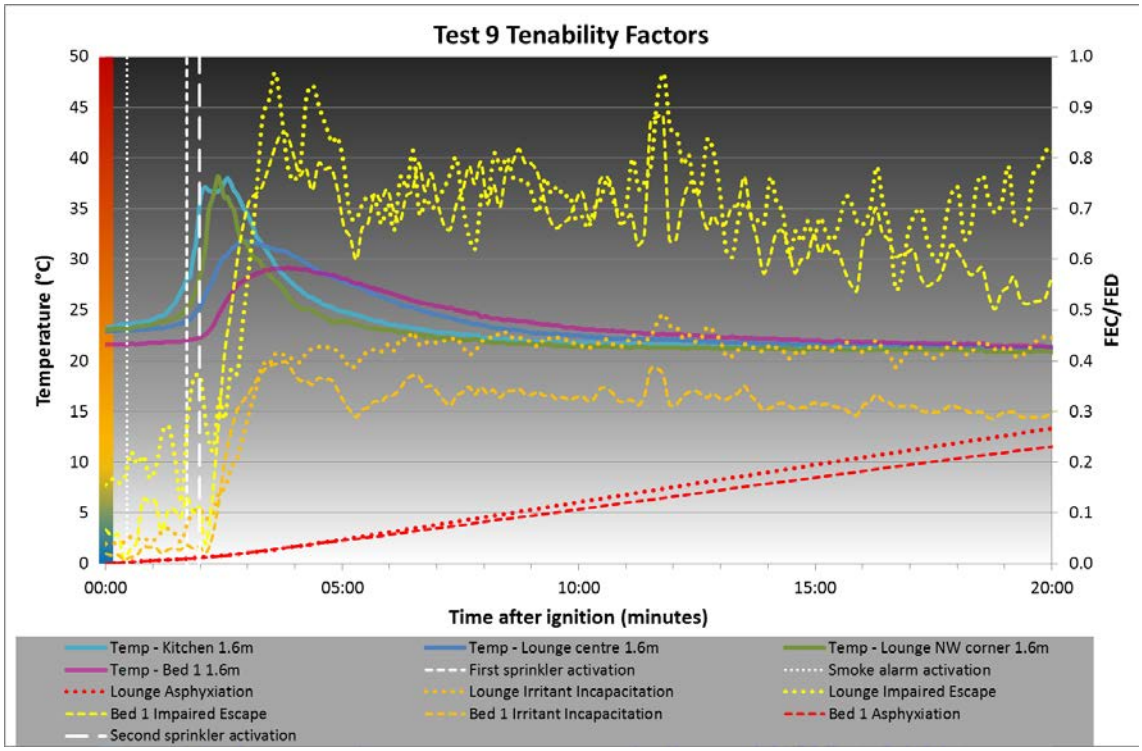

Figure 58 Chart showing timing of activations and tenability factors for Test 9

Table 20 Summary of Test 9 event timings

TIME AFTER IGNITION	EVENT
-29 min 48 s	Test initiated – pan of hot vegetable oil (500ml) placed on stove
-20 min 18 s	Smoke becomes visible
-8 min 32 s	First smoke alarm activation (Lounge centre)
0 min	Ignition of oil pan
1 min 43 s	First sprinkler activation (D4)
1 min 52 s	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
1 min 59 s	Second sprinkler activation (D2)
2 min 39 s	Impaired escape FEC_{esc} >0.3 at G1 (Bedroom 1)
3 min 02 s	Irritant incapacitation FEC_{inc} >0.3 at G1 (Bedroom 1)
3 min 19 s	Irritant incapacitation FEC_{inc} >0.3 at G2 (Lounge)
20 min	Test end – fire extinguished

3.9.3 Observations

The following was observed from the data:

- With the one head operating in the Kitchen and one in the Lounge room, the oil fire was controlled, did not flash over and did not spread laterally along the kitchen benches. It was noted that the fire did reach and ignite the overhead cupboards; however, the last flames died out approximately 4 ½ minutes after ignition.
- At a height of 1.6 metres, all temperatures in any part of the apartment were below the tenability threshold.
- Asphyxiant incapacitation limits were not reached in the Lounge room or the closed Bedroom; however, the threshold for irritant incapacitation FEC_{inc} 0.3 was reached in the Lounge at 3 min 19 s and at 3 min 2 s in Bedroom 1.

3.10 Test 10: Corner test, Hydrant system, Non-ventilated, Real furniture

3.10.1 Test Description

Test 10 was conducted on 27 April 2017. The conditions during testing are summarised in Table 21 below.

Table 21 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 10.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.05 (0.03)	0.09 (0.07)
Air temp (ºC)	15.6 (0.00)	16.01 (0.27)
Relative humidity (%)	46.23 (0.64)	47.25 (1.69)
Air pressure (mBar)	1009.67 (0.04)	1009.51 (0.05)

In this test, the ignition crib was located in the NW corner of the Lounge room under a stylised plywood side table, which was placed in the corner between two 'real' two-seater sofas. The arrangement is pictured in Figure 59 and detailed in Figure 60. In this test, the external doors were closed and the Bedroom 1 door was open. The fuel under the crib was a 1:2 mixture of heptane and water.

There were seven sprinkler heads in operation in this test: H1, H3, H4, H5, H6, H7 and H8. Note that H1 was used in this test instead of H2, the position of which is in accordance with the sprinkler distance in the UL test. The pressure at the meter was set at 700 kPa. All other sprinkler heads were made inoperable.

The test duration was approximately 40 minutes.

Figure 59 Photo showing the test arrangement for Test 10

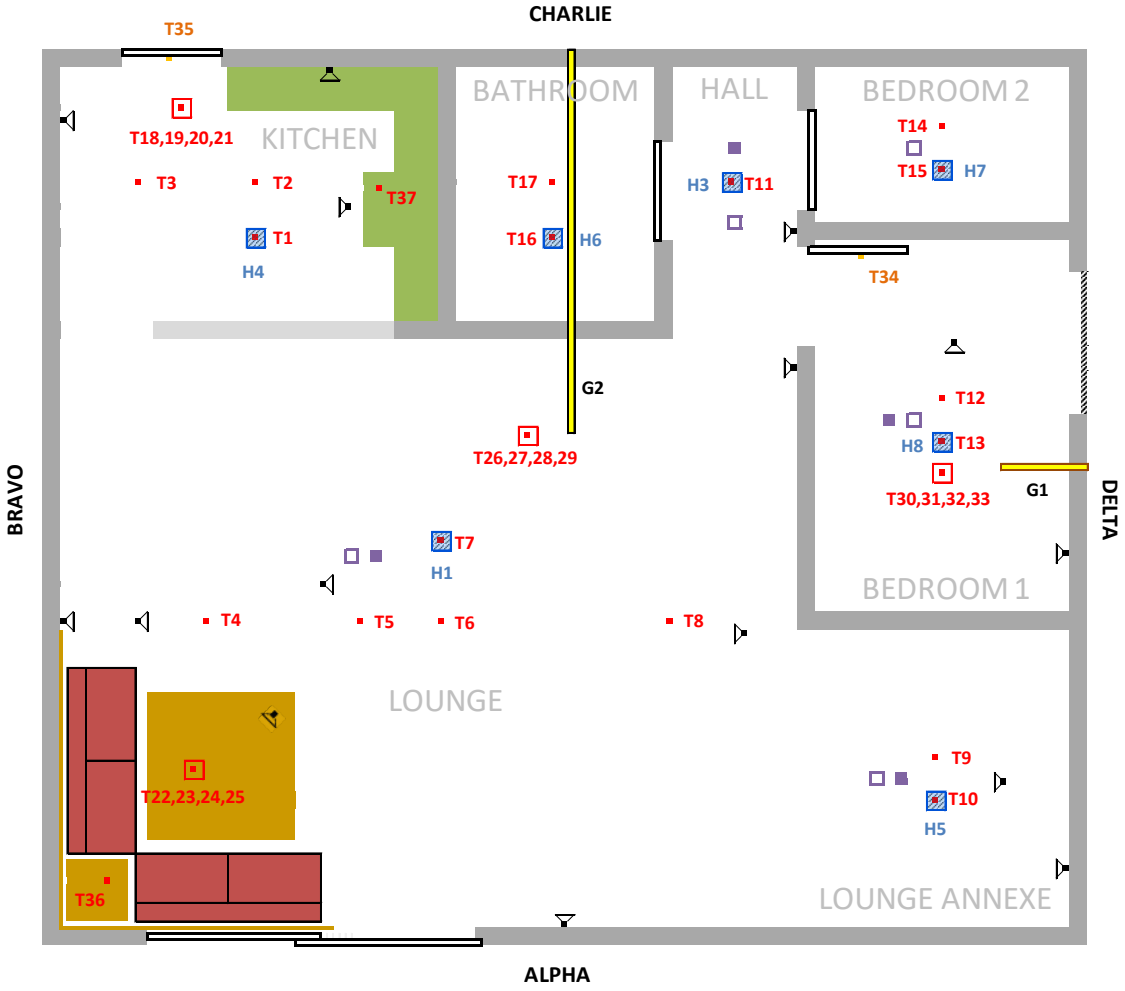

Figure 60 Map showing the Test 10 arrangement

3.10.2 Results

Fire size and fuel consumption

In Test 10, the peak flame height was approximately 2.4 metres or ceiling height (Figure 61). The fire spread to both sofas. The two arm rests were consumed as well as the seat cushion of the northern sofa (Figure 62).

Figure 61 View of the test fire before sprinkler activation

Figure 62 View of the test furnishings at the end of Test 10

Figure 63 View of the ignition crib at the end of Test 10

Activations

Two sprinkler heads activated during the test. H1 activated at 2 min 20 s and H4 in the Kitchen at 2 min 28 s, 46 seconds and 54 seconds after the first smoke alarm activation, respectively. The peak temperatures at the sprinkler heads were 95.1°C at H1, and 86°C at H4.

Temperatures

The maximum temperature reached in the unit was 344.8°C at T36, the thermocouple positioned above the ignition point. This peak occurred at 2 min 29 s after ignition. The temperature fell to below 100°C at 5 min 24 s after ignition.

Temperatures along the paths of egress and in Bedroom 1 at 1.6 metres remained below 65°C throughout the test, peaking at 28°C in Bedroom 1 (T32), 35.8°C at the Lounge centre (T28), and 59.8°C in the Kitchen (T20). The cumulative heat tenability limit (FED_{heat} > 0.3) was not reached for any of the three locations.

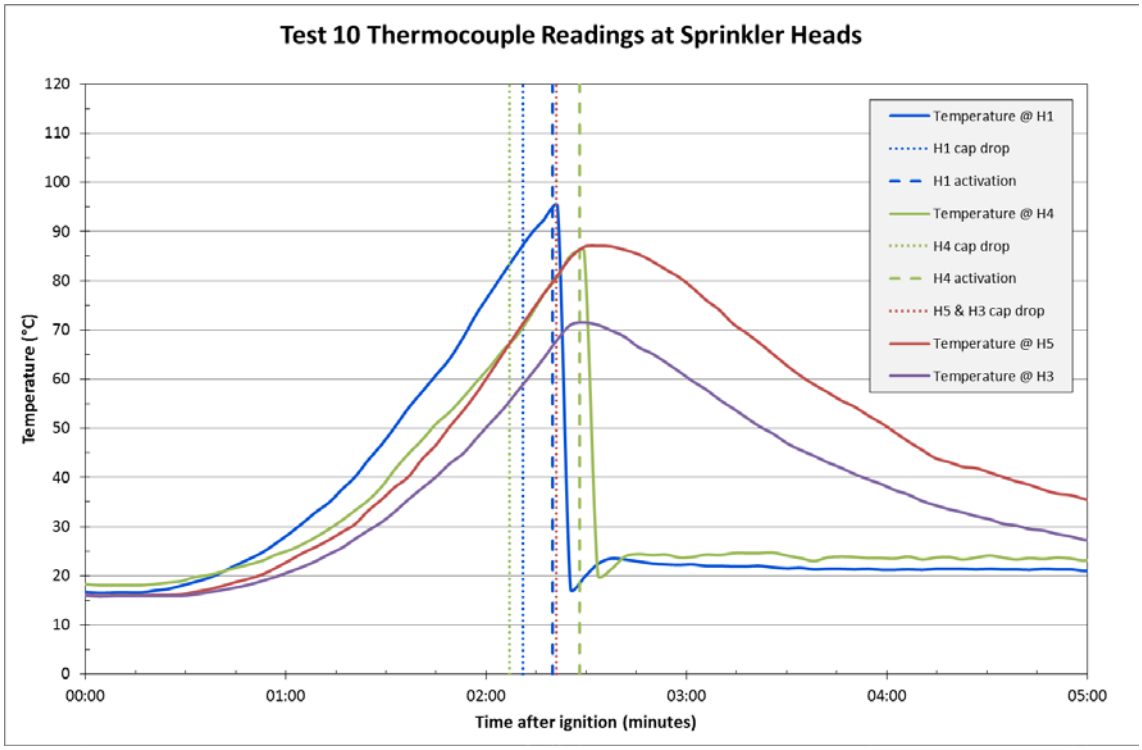

Figure 64 Sprinkler head activation times and temperatures for Test 10

Smoke Toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to FEC_{esc} > 0.3 at 2 min 23 s and FEC_{esc} > 1 at 4 min 46 s after ignition. Irritant incapacitation FEC_{inc} 0.3 was reached at 3 min 18 s and rose above FEC_{inc} = 1 at 7 min 48 s. FED_{asp} 0.3 was reached at 10 min 59 s, and FED_{asp} 1 at 19 min 20 s.

In Bedroom 1, FEC_{esc} > 0.3 was reached at 2 min 46 s and FEC_{esc} > 1 was reached at 8 min 52 s. FEC_{inc} > 0.3 was reached at 5 min 41 s, with FEC_{inc} 1 exceeded after 12 min 3 s. The cumulative asphyxiant gas concentrations rose to FED_{asp} > 0.3 in 14 min 42 s, and exceeded FED_{asp} 1 after 28 min 44 s.

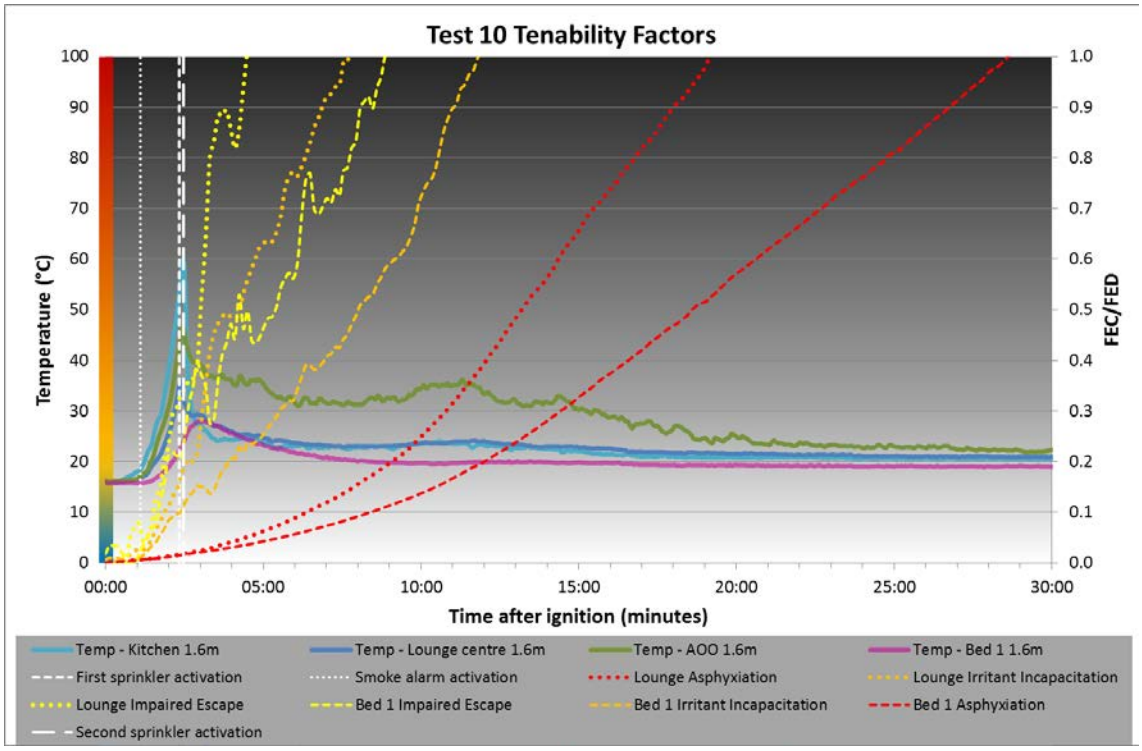

Figure 65 Chart showing timing of activations and tenability factors for Test 10

3.10.3 Observations

The following was observed from the data:

- With only the two heads operating, a shielded fire, and disadvantaged sprinkler head in the H1 position, the fire was controlled, did not flash over and did not spread further along the sofas.
- The temperatures throughout the apartment dropped significantly upon the activation of the sprinkler heads.
- At a height of 1.6 metres, all temperatures in any part of the apartment were below the tenability criteria of 65°C.
- The data indicates that an occupant remaining in the Bedroom with the door open would be safe for at least 5 min 41 s before possibly becoming incapacitated from irritant smoke inhalation. Escape via the most direct egress path would have been possible prior to this.
- FED_{asp} in the Lounge room remained under 0.3 until 11 minutes into the test.
- FED_{asp} in Bedroom 1 remained under 0.3 for 14 min 42 s.
- An aspect of this test noted by the research team was that the test had to be terminated at 40 mins due to the amount of water generated and possible water damage to the test

rig. This is obviously due to the additional water flow and pressure that is available from the Hydrant system.

Table 22 Summary of Test 10 event timings

TIME AFTER IGNITION	EVENT
1 min 6 s	First smoke alarm activation
2 min 20 s	First sprinkler activation (H1)
2 min 23 s	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
2 min 28 s	Second sprinkler activation (H4)
2 min 46 s	Impaired escape FEC_{esc} >0.3 at G1 (Bedroom 1)
3 min 18 s	Irritant incapacitation FEC_{inc} >0.3 at G2 (Lounge)
4 min 46 s	Impaired escape FEC_{esc} >1 at G2 (Lounge)
5 min 41 s	Irritant incapacitation FEC_{inc} >0.3 at G1 (Bedroom 1)
7 min 48 s	Irritant incapacitation FEC_{inc} >1 at G2 (Lounge)
8 min 52 s	Impaired escape FEC_{esc} >1 at G1 (Bedroom 1)
10 min 59 s	Asphyxiant incapacitation FED_{asp} >0.3 at G2 (Lounge)
12 min 3 s	Irritant incapacitation FEC_{inc} >1 at G1 (Bedroom 1)
14 min 42 s	Asphyxiant incapacitation FED_{asp} >0.3 at G1 (Bedroom 1)
19 min 20 s	Asphyxiant incapacitation FED_{asp} >1 at G2 (Lounge)
28 min 44 s	Asphyxiant incapacitation FED_{asp} >1 at G1 (Bedroom 1)
40 min	Test end – fire extinguished

3.11 Test 11: Corner test, Domestic system, Non-ventilated, Real furniture

3.11.1 Test Description

Test 11 was conducted on 2 May 2017. The conditions during testing are summarised in Table 23 below.

Table 23 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 11.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.04 (0.02)	0.06 (0.04)
Air temp (ºC)	20.22 (0.04)	207 (0.27)
Relative humidity (%)	49.85 (1.47)	48.41 (2.18)
Air pressure (mBar)	1009.56 (0.05)	1009.88 (0.06)

The arrangement for this test was identical to that of Test 10, except for the ventilation characteristics. The ignition crib was located in the NW corner of the Lounge room under a stylised plywood side table, which was placed in the corner between two ‘real’ two-seater sofas. The arrangement is pictured in Figure 66 and detailed in Figure 67. In this test, the SOU door at the Kitchen was closed, and the sliding door to the Lounge room was open, but with a baffle installed to expose a 500 mm gap from the floor. The Bedroom 1 door was closed. The fuel under the crib was a 1:2 mixture of heptane and water.

There were seven sprinkler heads in operation in this test: D1, D3, D4, D5, D6, D7 and D8. The pressure at the meter was set at 250 kPa. All other sprinkler heads were made inoperable. To further challenge the Domestic sprinkler system in this test, 12 L/min was bled from the domestic water supply from the start of the test.

The test duration was approximately 50 minutes.

Figure 66 Photo showing the test arrangement for Test 11

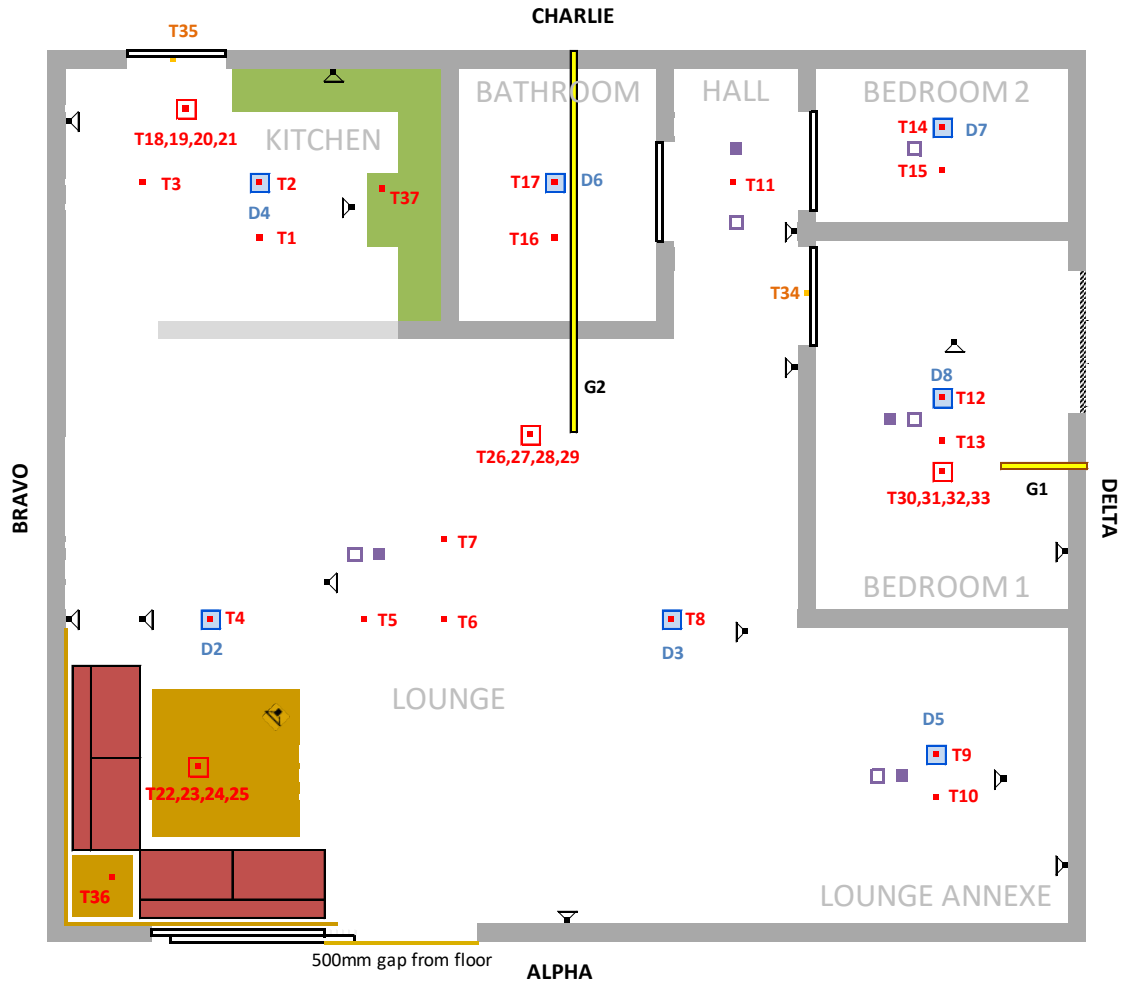

Figure 67 Map showing the Test 11 arrangement

3.11.2 Results

Fire size and fuel consumption

In Test 11, the peak flame height was approximately 1.5 metres (Figure 68). The fire spread to both sofas. The two arm rests were consumed as well as one seat cushion from each sofa (Figure 69).

Figure 68 View of the test fire before sprinkler activation

Figure 69 View of the test furnishings at the end of Test 11

Activations

Two sprinkler heads activated during the test. D2 activated at 1 min 39 s and D3 at 2 min 3 s, 5 seconds before and 19 seconds after the first smoke alarm activation, respectively. The peak temperatures at the sprinkler heads were 93.1°C at D2, and 86.8°C at D3.

The mains water pressure of 240k Pa at the meter reduced to 150 kPa after the first sprinkler activation, then 90 kPa after the second sprinkler activation. After both sprinklers activated, the 12 L/min that was bled from the system from the start of the test reduced to 7.5 L/min.

Temperatures

The maximum temperature reached in the unit was 250.7°C at T36, the thermocouple positioned above the ignition point. This peak occurred at 1 min 45 s after ignition. The temperature fell to below 100°C at 12 min 6 s after ignition.

Temperatures along the paths of egress and in Bedroom 1 at 1.6 metres remained below 65°C throughout the test, peaking at 21.4°C in Bedroom 1 (T32), 40.6°C at the Lounge centre (T28), and 50°C in the Kitchen (T20). The cumulative heat tenability limit (FED_{heat} > 0.3) was not reached for any of the three locations.

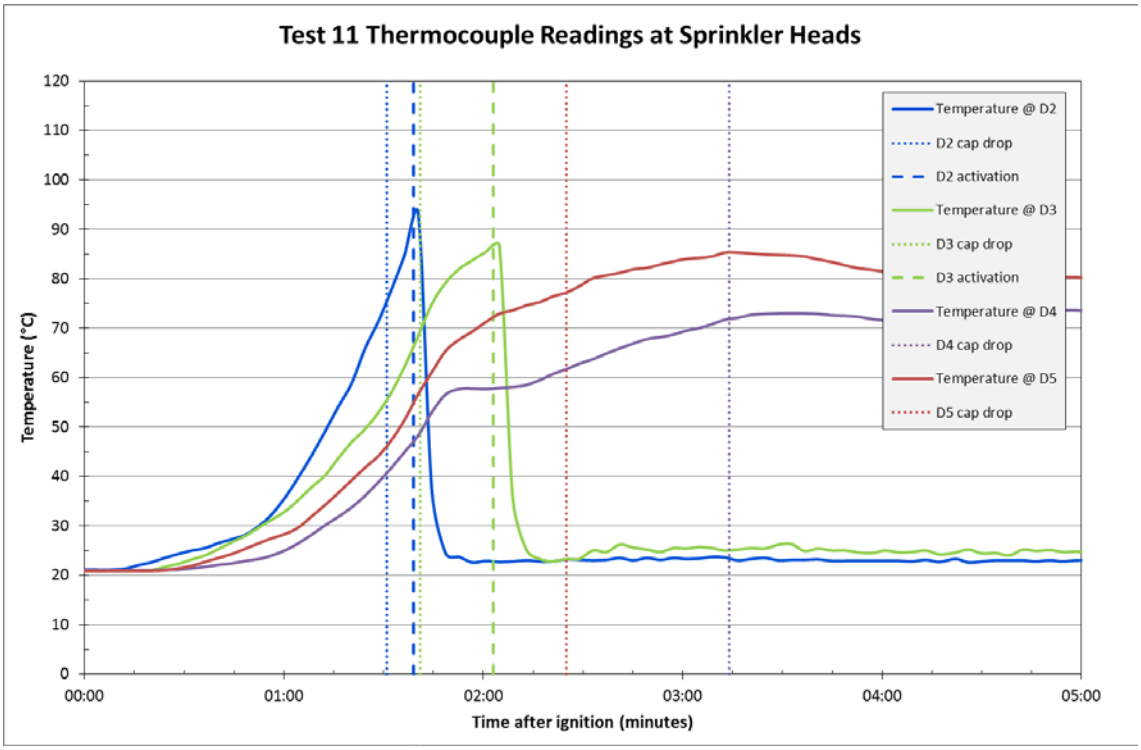

Figure 70 Sprinkler head activation times and temperatures for Test 11

Smoke Toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to FEC_{esc} > 0.3 at 1 min 44 s and FEC_{esc} > 1 at 3 min 27 s after ignition. Irritant incapacitation

FEC_{inc} 0.3 was reached at 2 min 39 s and rose above FEC_{inc} = 1 at 5 min 2 s. FED_{asp} 0.3 was reached at 8 min 29 s, and FED_{asp} 1 at 14 min 50 s.

In Bedroom 1, FEC_{esc} > 0.3 was reached at 6 min 38 s and FEC_{esc} > 1 was reached at 12 min 27 s. FEC_{inc} > 0.3 was reached at 10 min 36 s, with FEC_{inc} 1 exceeded after 22 min 31 s. The cumulative asphyxiant gas concentrations rose to FED_{asp} > 0.3 in 20 min 32 s, and exceeded FED_{asp} 1 after 39 min 52 s.

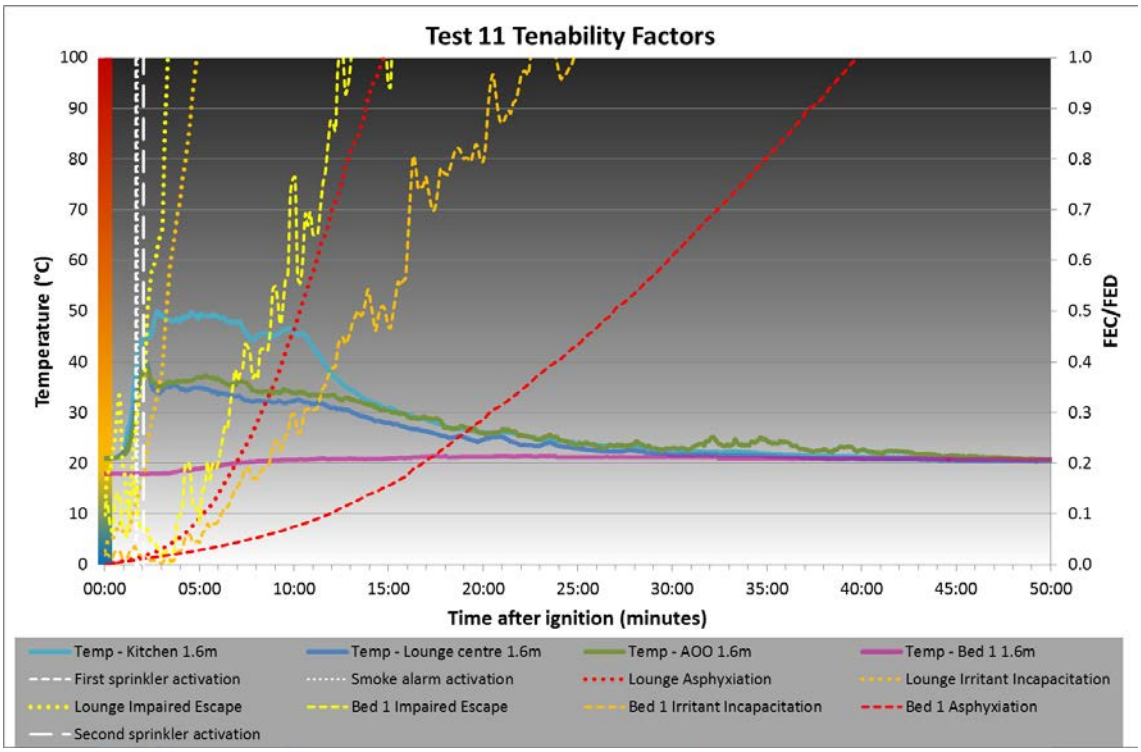

Figure 71 Chart showing timing of activations and tenability factors for Test 11

3.11.3 Observations

The following was observed from the data:

- With only the two heads operating, the fire was controlled, did not flash over and did not spread further along the sofas.
- With the 'real' furniture fire load, a significantly shielded fire and with only two heads operating, the sprinkler system effectively delivered enough water to prevent the fire from spreading, preventing flashover and providing tenable temperature conditions at a height of 1.6 metres.
- At a height of 1.6 metres, all temperatures in any part of the unit were below the tenability criteria of 65°C.

- The data indicates that an occupant remaining in the Bedroom with the door open would be safe for at least 10 ½ minutes before possibly becoming incapacitated from irritant smoke inhalation. Escape via the most direct egress path would have been possible prior to this.
- FED_{asp} in the Lounge room remained under 0.3 for 8 ½ minutes into the test.
- FED_{asp} for Bedroom 1 remained under 0.3 for 20 ½ minutes.

Table 24 Summary of Test 11 event timings

TIME AFTER IGNITION	EVENT
1 min 39 s	First sprinkler activation (D2)
1 min 44 s	First smoke alarm activation
	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
2 min 3 s	Second sprinkler activation (D3)
2 min 39 s	Irritant incapacitation FEC_{inc} >0.3 at G2 (Lounge)
3 min 27 s	Impaired escape FEC_{esc} >1 at G2 (Lounge)
5 min 2 s	Irritant incapacitation FEC_{inc} >1 at G2 (Lounge)
6 min 38 s	Impaired escape FEC_{esc} >0.3 at G1 (Bedroom 1)
8 min 29 s	Asphyxiant incapacitation FED_{asp} >0.3 at G2 (Lounge)
10 min 36 s	Irritant incapacitation FEC_{inc} >0.3 at G1 (Bedroom 1)
12 min 27 s	Impaired escape FEC_{esc} >1 at G1 (Bedroom 1)
14 min 50 s	Asphyxiant incapacitation FED_{asp} >1 at G2 (Lounge)
20 min 32 s	Asphyxiant incapacitation FED_{asp} >0.3 at G1 (Bedroom 1)
22 min 31 s	Irritant incapacitation FEC_{inc} >1 at G1 (Bedroom 1)
39 min 52 s	Asphyxiant incapacitation FED_{asp} >1 at G1 (Bedroom 1)
50 min	Test end – fire extinguished

3.12 Test 12: Corner test, Domestic system, Ventilated, Stylised furniture, Bedroom door open

3.12.1 Test Description

Test 12 was conducted on 12 May 2017. The conditions during testing are summarised in Table 25 below.

In this test, the ignition crib was located in the NW corner of the Lounge room under a stylised plywood side table, which was placed in the corner between two stylised sofas. The arrangement is pictured in Figure 72 and detailed in Figure 73. In this test, the external doors were open and the Bedroom 1 door was open. The fuel under the crib was a 1:2 mixture of heptane and water.

Table 25 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 12.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.05 (0.04)	0.09 (0.07)
Air temp (ºC)	16.30 (0.00)	17.88 (0.16)
Relative humidity (%)	66.25 (0.25)	69.51 (1.25)
Air pressure (mBar)	1020.7 (0.00)	1020.04 (0.12)

There were seven sprinkler heads in operation in this test: L2, L3, L4, L5, L6, L7 and L8. The pressure at the meter was set at 150 kPa, 40kPa at the sprinkler head. All other sprinkler heads were made inoperable. To further challenge the Domestic sprinkler system in this test, 12 L/min was bled from the domestic water supply from the start of the test.

The test duration was approximately 50 minutes.

Figure 72 Photo showing the test arrangement for Test 12

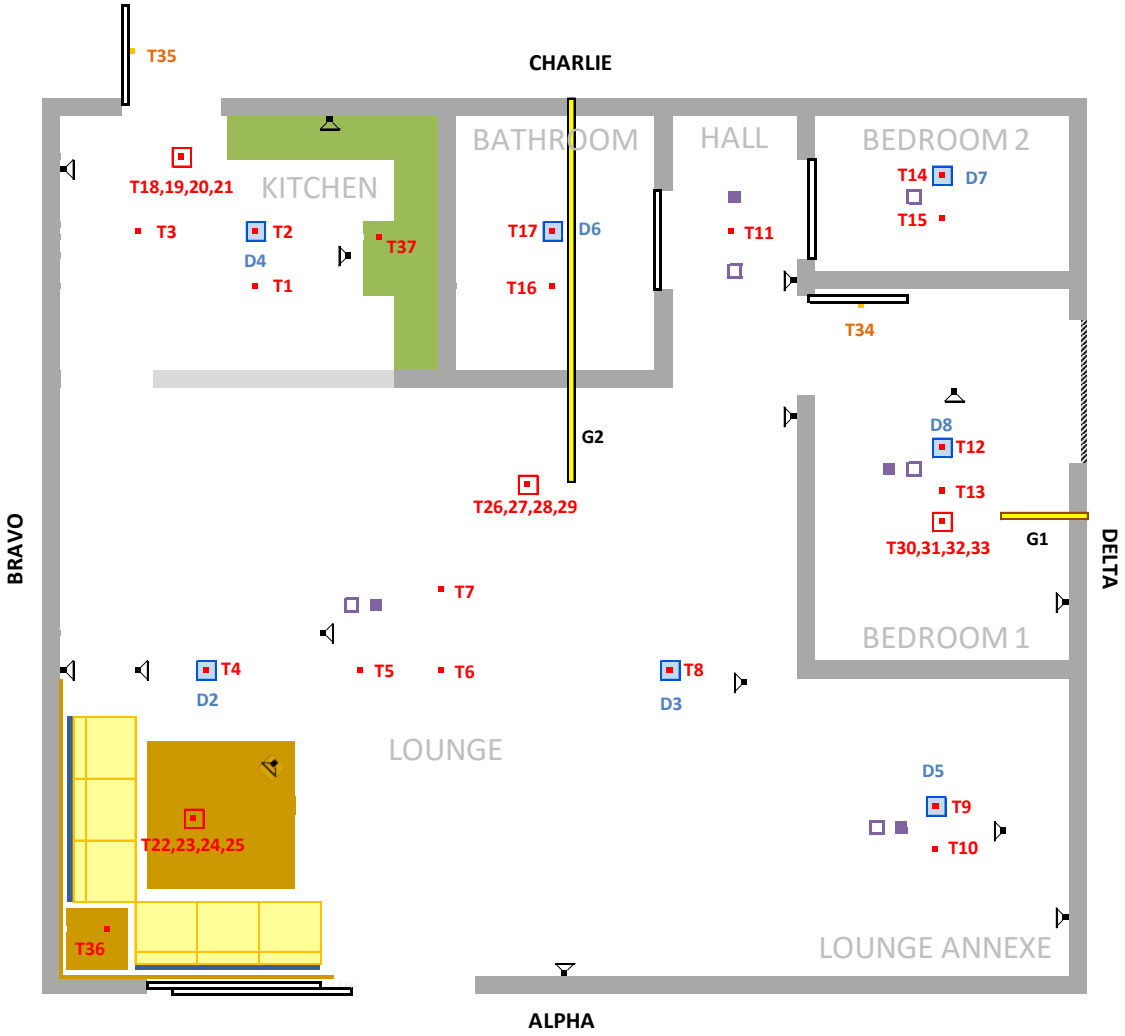

Figure 73 Map showing the Test 12 arrangement

3.12.2 Results

Fire size and fuel consumption

In Test 12, the peak flame height was approximately 1.5 metres (Figure 74). The fire spread to both sofas, consuming most of the foam cushions by test end (Figure 75).

Figure 74 View of the test fire before sprinkler activation

Figure 75 View of the test furnishings at the end of Test 12

Activations

Three sprinkler heads activated during the test. D2 activated at 1 min 37 s, D4 at 2 min 10 s, and D3 at 2 min 18 s, 16, 49 and 57 seconds after the first smoke alarm activation, respectively. The peak temperatures at the sprinkler heads were 101.1°C at D2, 85.5°C at D4, and 97.6°C at D3.

After the sprinklers activated, the 12 L/min that was bled from the system from the start of the test reduced to 5.4 L/min.

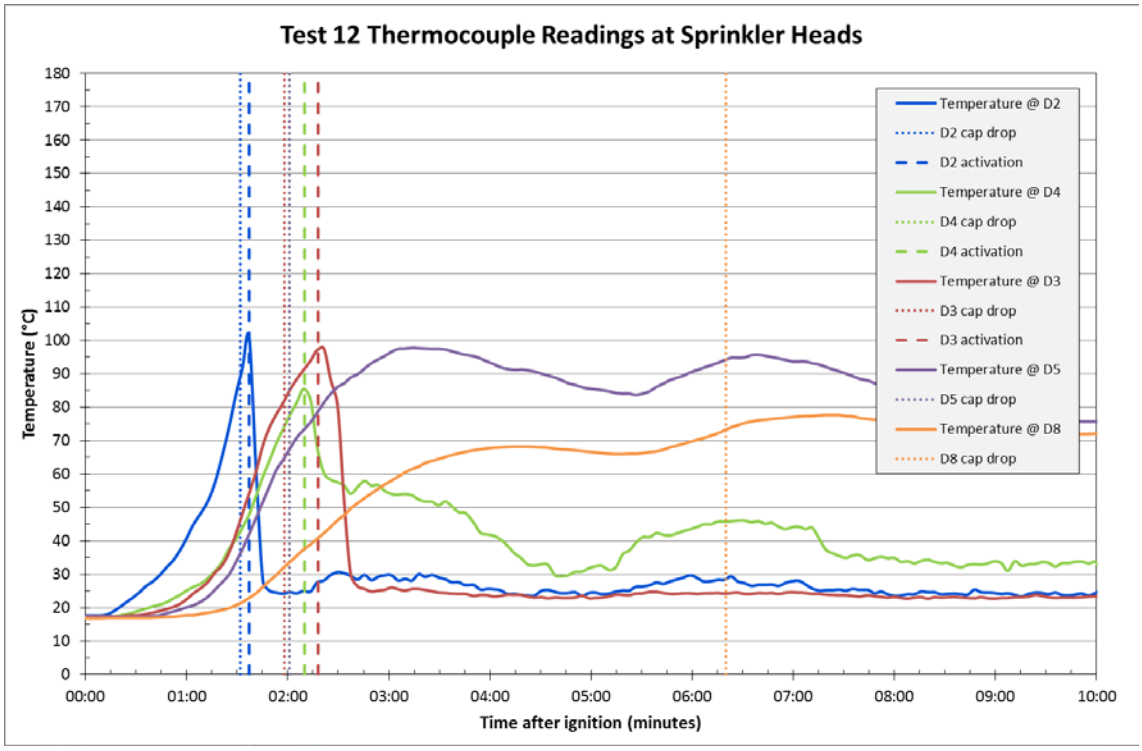

Figure 76 Sprinkler head activation times and temperatures for Test 12

Temperatures

The maximum temperature reached in the unit was 328.1°C at T36, the thermocouple positioned above the ignition point. This peak occurred at 2 min 53 s after ignition. The temperature fell to below 100°C at 14 minutes after ignition.

Temperatures along the paths of egress and in Bedroom 1 at 1.6 metres remained below 65°C throughout the test, peaking at 56.2°C in Bedroom 1 (T32), 45.2°C at the Lounge centre (T28), and 45.7°C in the Kitchen (T20). The cumulative heat tenability limit (FED_{heat} > 0.3) was not reached for any of the three locations.

Smoke Toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to FEC_{esc} > 0.3 at 2 min 15 s and FEC_{esc} > 1 at 6 min 13 s after ignition. Irritant incapacitation FEC_{inc} 0.3 was reached at 2 min 46 s and rose above FEC_{inc} = 1 at 19 min 28 s. FED_{asp} 0.3 was reached at 13 min 06 s, peaking at 0.88 by test end.

In Bedroom 1, FEC_{esc} > 0.3 was reached at 2 min 39 s and FEC_{esc} > 1 was reached at 5 min 26 s. FEC_{inc} > 0.3 was reached at 4 min 7 s, peaking at 0.96 at 25 min 10 s. The cumulative

asphyxiant gas concentrations rose to FED_{asp} > 0.3 in 27 min 49 s, peaking at 0.43 by test end.

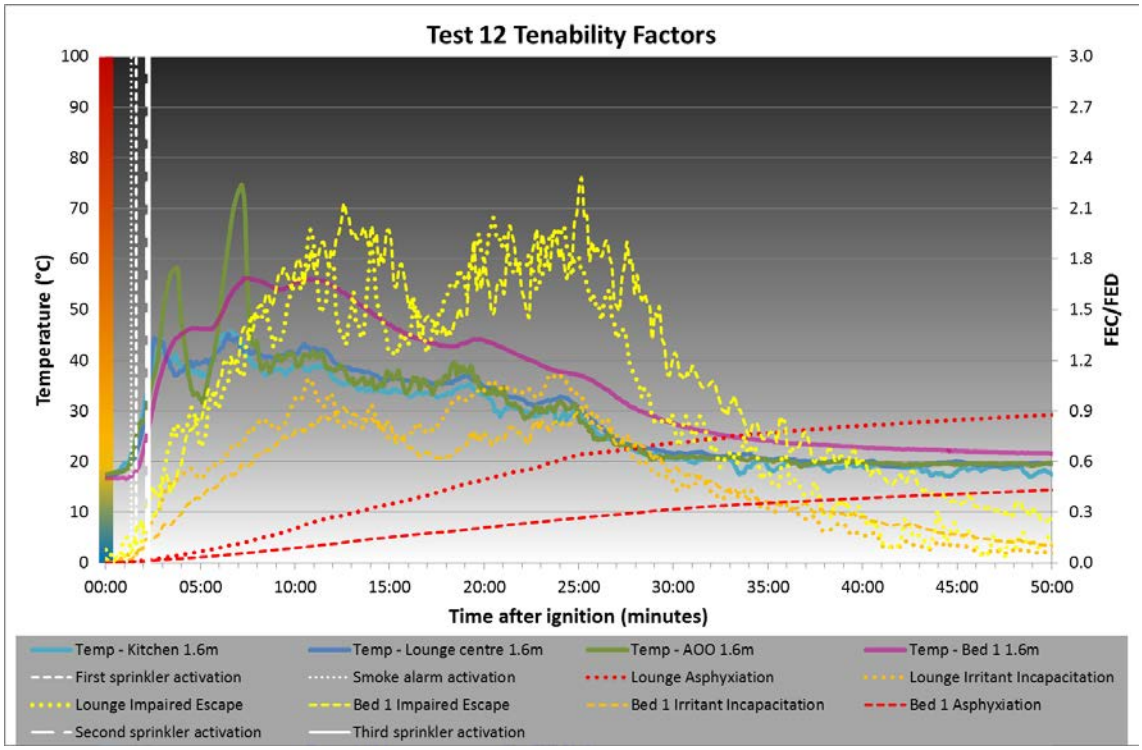

Figure 77 Chart showing timing of activations and tenability factors for Test 12

3.12.3 Observations

The following was observed from the data:

- With three heads operating and a significantly reduced pressure, the ventilated fire was controlled and did not flash over. The two sofas were, however, fully consumed.
- At a height of 1.6 metres, all temperatures in any part of the apartment remained below the tenability criteria of 65°C, except in the NW corner adjacent to the fire where the temperature peaked at 74.7°C.
- The data indicates that an occupant remaining in the Bedroom with the door open would be safe for at least 4 minutes before possibly becoming incapacitated from irritant smoke inhalation. Escape via the most direct egress path would have been possible prior to this.
- FED_{asp} in the Lounge room remained under 0.3 for 13 minutes.
- FED_{asp} in Bedroom 1 remained under 0.3 for 27 min 49 s.

Table 26 Summary of Test 12 event timings

TIME AFTER IGNITION	EVENT
1 min 21 s	First smoke alarm activation
1 min 37 s	First sprinkler activation (D2)
2 min 10 s	Second sprinkler activation (D4)
2 min 15 s	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
2 min 18 s	Third sprinkler activation (D3)
2 min 39 s	Impaired escape FEC_{esc} >0.3 at G1 (Bedroom 1)
2 min 46 s	Irritant incapacitation FEC_{inc} >0.3 at G2 (Lounge)
4 min 7 s	Irritant incapacitation FEC_{inc} >0.3 at G1 (Bedroom 1)
5 min 26 s – 32 min 19 s	Impaired escape FEC_{esc} >1 at G1 (Bedroom 1)
6 min 13 s – 28 min 36 s	Impaired escape FEC_{esc} >1 at G2 (Lounge)
13 min 6 s	Asphyxiant incapacitation FED_{asp} >0.3 at G2 (Lounge)
19 min 28 s – 25 min 1 s	Irritant incapacitation FEC_{inc} >1 at G2 (Lounge)
27 min 49 s	Asphyxiant incapacitation FED_{asp} >0.3 at G1 (Bedroom 1)
50 min	Test end – fire extinguished

3.13 Test 13: Corner test, Domestic system, Non-ventilated, Real furniture, Bedroom door open

3.13.1 Test Description

Test 13 was conducted on 16 May 2017. The conditions during testing are summarised in Table 27 below.

Table 27 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 13.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.02 (0.04)	0.05 (0.05)
Air temp (ºC)	15.43 (0.05)	16.45 (0.49)
Relative humidity (%)	69.81 (0.23)	55.13 (1.99)
Air pressure (mBar)	1011.94 (0.05)	1011.49 (0.20)

In this test, the ignition crib was located in the NW corner of the Lounge room under a stylised plywood side table, which was placed in the corner between two ‘real’ two-seater sofas. The

arrangement is pictured in Figure 78 and detailed in Figure 79. In this test, the external doors were closed and the Bedroom 1 door was open. The fuel under the crib was a 1:2 mixture of heptane and water.

There were seven sprinkler heads in operation in this test: D1, D3, D4, D5, D6, D7 and D8. The pressure at the meter was set at 200 kPa. All other sprinkler heads were made inoperable. To further challenge the Domestic sprinkler system in this test, 12 L/min was bled from the domestic water supply from the start of the test.

The test duration was approximately 50 minutes.

Figure 78 Photo showing the test arrangement for Test 13

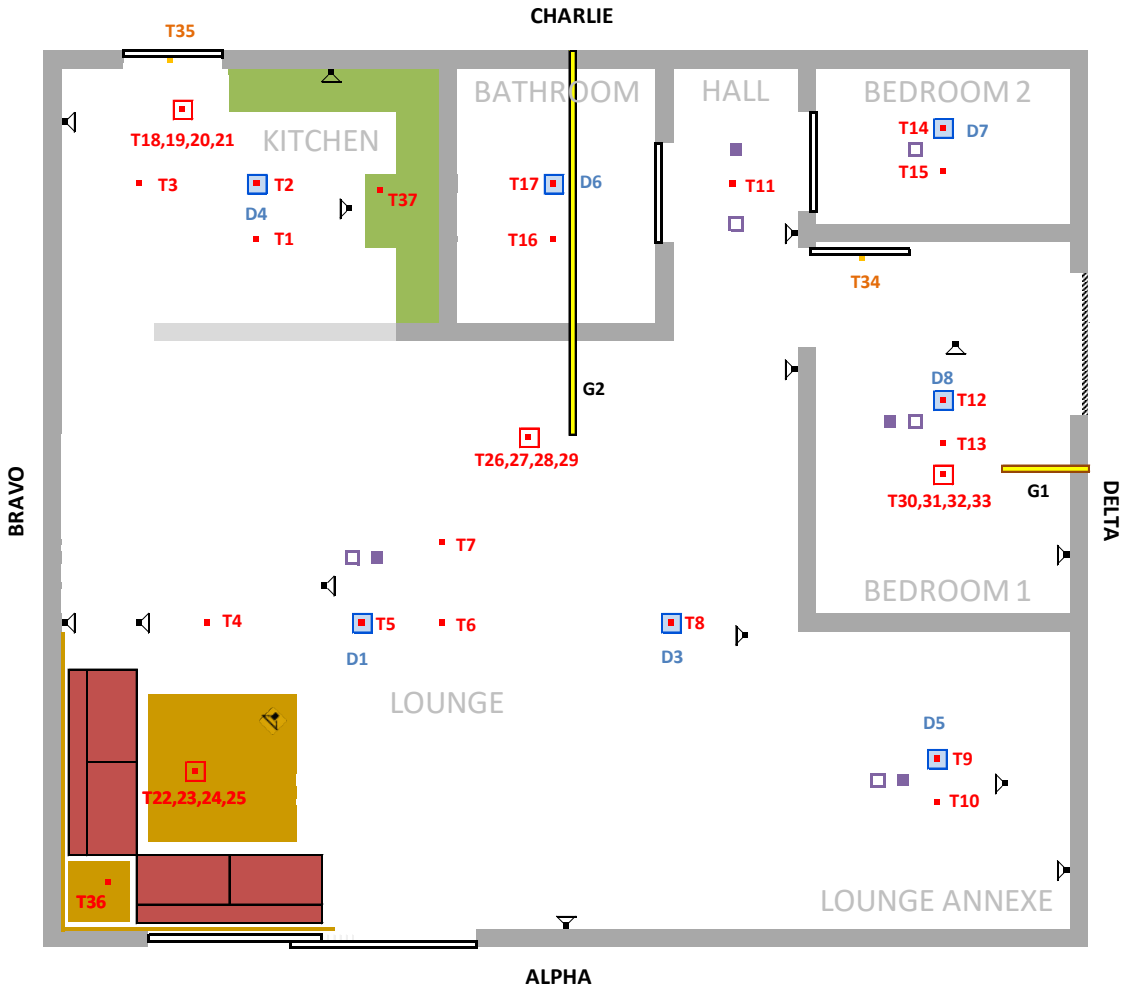

Figure 79 Map showing the Test 13 arrangement

3.13.2 Results

Fire size and fuel consumption

In Test 13, the peak flame height was approximately 1.5 metres (Figure 80). The fire spread mainly to the western sofa, consuming the side of the arm rest and most of one seat cushion (Figure 81).

Figure 80 View of the test fire before sprinkler activation

Figure 81 View of the test furnishings at the end of Test 13

Activations

One sprinkler head activated during this test, D1 at 1 min 50 s, which was 9 seconds after the first smoke alarm activation. The peak temperature at the sprinkler heads was 101.4°C.

After sprinkler activation, the 12 L/min that was bled from the system from the start of the test reduced to 10.6 L/min, while the water pressure at the meter fell to 120 kPa.

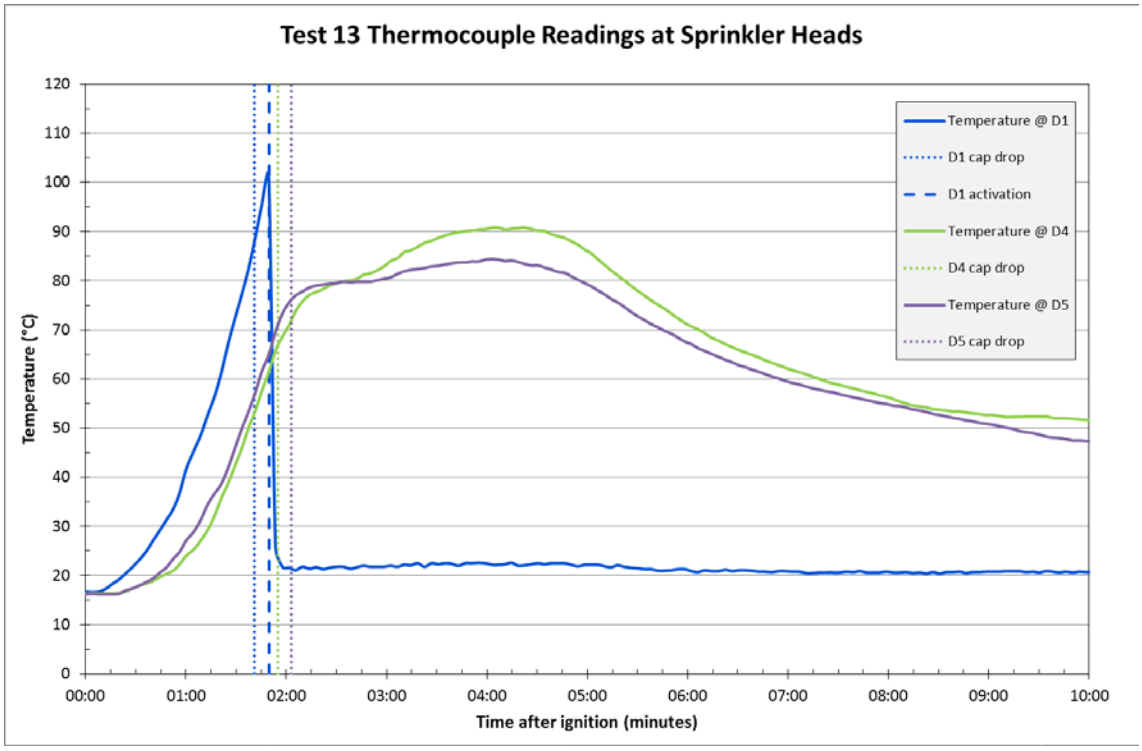

Figure 82 Sprinkler head activation times and temperatures for Test 13

Temperatures

The maximum temperature reached in the unit was 249.2°C at T36, the thermocouple positioned above the ignition point. This peak occurred at 2 min 2 s after ignition. The temperature fell to below 100°C at 6 min 35 s after ignition.

The temperature in Bedroom 1 at 1.6 metres (T32) remained below 65°C throughout the test, peaking at 43.9°C. At the Lounge centre (T28), the temperature peaked at 36.3°C; however, at the Kitchen (T20) the temperature was elevated above 65°C between 3 min 2 s and 5 min 6 s, peaking at 70.6°C. The cumulative heat tenability limit (FED_{heat} > 0.3) was not reached for any of the three locations.

Smoke Toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to FEC_{esc} > 0.3 at 1 min 59 s and FEC_{esc} > 1 at 3 min 50 s after ignition. Irritant incapacitation FEC_{inc} 0.3 was reached at 2 min 39 s and rose above FEC_{inc} = 1 at 5 min 33 s. FED_{asp} 0.3 was reached at 9 min 16 s, and FED_{asp} 1 at 16 min 33 s.

In Bedroom 1, FEC_{esc} > 0.3 was reached at 3 min 3 s and FEC_{esc} > 1 was reached at 4 min 54 s. FEC_{inc} > 0.3 was reached at 4 min 14 s and rose above FEC_{inc} = 1 at 9 min 32 s. The cumulative asphyxiant gas concentrations rose to FED_{asp} > 0.3 in 12 min 43 s, and FED_{asp} 1 at 24 min 30 s.

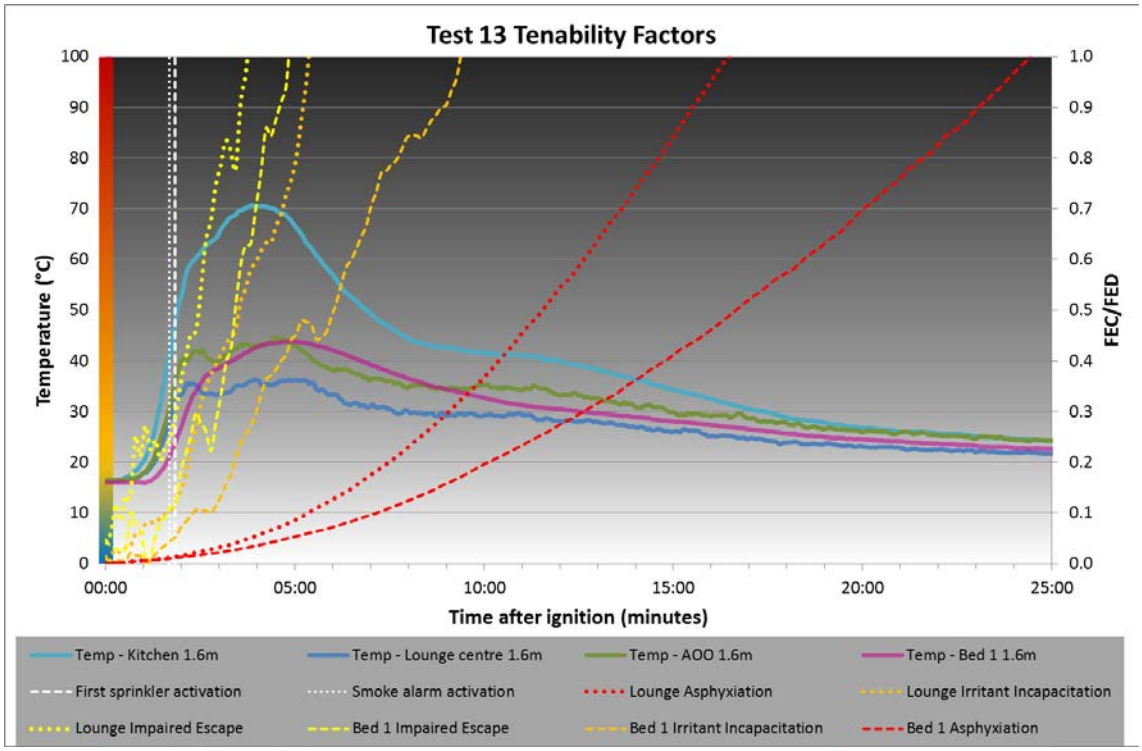

Figure 83 Chart showing timing of activations and tenability factors for Test 13

3.13.3 Observations

The following was observed from the data:

- With one head operating at the maximum spacing and at a reduced pressure, the fire was controlled, did not flash over and did not spread further along the sofas.
- At a height of 1.6 metres, temperatures throughout the unit were below the tenability criteria of 65°C, except in the Kitchen where it peaked at 70.6°C.
- The data indicates that a person in the Bedroom with the door open would remain safe for 4 min 14 s before possibly becoming incapacitated from smoke inhalation. Escape via the most direct egress path would have been possible prior to this.
- FED_{asp} in the Lounge room remained under 0.3 until 9 min 16 s into the test.
- FED_{asp} in Bedroom 1 remained under 0.3 for 12 min 43 s.

Table 28 Summary of Test 13 event timings

TIME AFTER IGNITION	EVENT
1 min 41 s	First smoke alarm activation
1 min 50 s	First sprinkler activation (D1)
1 min 59 s	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
2 min 39 s	Irritant incapacitation FEC >0.3 at G2 (Lounge)
3 min 2 s – 5 min 6 s	Temperature at Kitchen door 1.6m elevated above 65°C
3 min 3 s	Impaired escape FEC_{esc} >0.3 at G1 (Bedroom 1)
3 min 50 s	Impaired escape FEC_{esc} >1 at G2 (Lounge)
4 min 14 s	Irritant incapacitation FEC >0.3 at G1 (Bedroom 1)
4 min 54 s	Impaired escape FEC_{esc} >1 at G1 (Bedroom 1)
5 min 33 s	Irritant incapacitation FEC >1 at G2 (Lounge)
9 min 16 s	Asphyxiant incapacitation FEC >0.3 at G2 (Lounge)
9 min 32 s	Irritant incapacitation FEC >1 at G1 (Bedroom 1)
12 min 43 s	Asphyxiant incapacitation FEC >0.3 at G1 (Bedroom 1)
16 min 33 s	Asphyxiant incapacitation FEC >1 at G2 (Lounge)
24 min 30 s	Asphyxiant incapacitation FEC >1 at G1 (Bedroom 1)
50 min	Test end – fire extinguished

3.14 Test 14: Corner test, No sprinklers, Ventilated, Real furniture and furnishings, Bedroom door closed

3.14.1 Test Description

Test 14 was conducted on 19 May 2017. The conditions during testing are summarised in Table 29 below.

Table 29 Atmospheric conditions (Mean (S.D.)) internal to the unit pre-test, and external to the unit during Test 14.

CONDITION	INTERNAL	EXTERNAL
Wind speed (m/s)	0.05 (0.04)	0.06 (0.05)
Air temp (ºC)	17.9 (0.00)	18.2 (0.06)
Relative humidity (%)	83.91 (0.15)	82.96 (0.32)
Air pressure (mBar)	1017.99 (0.03)	1017.64 (0.07)

In this test, the ignition crib was located in the NW corner of the Lounge room under a stylised plywood side table, which was placed in the corner between two ‘real’ two-seater sofas. The entire living space is furnished with additional furniture and décor. The arrangement is pictured in Figure 84 and detailed in Figure 85. In this test, the external doors were open and the Bedroom 1 door was open. The fuel under the crib was a 1:2 mixture of heptane and water.

There were no sprinkler heads in operation during this test. Firefighters were on hand to extinguish the blaze.

The test duration was approximately 8 min 44 s.

Figure 84 Photo showing the test arrangement for Test 13

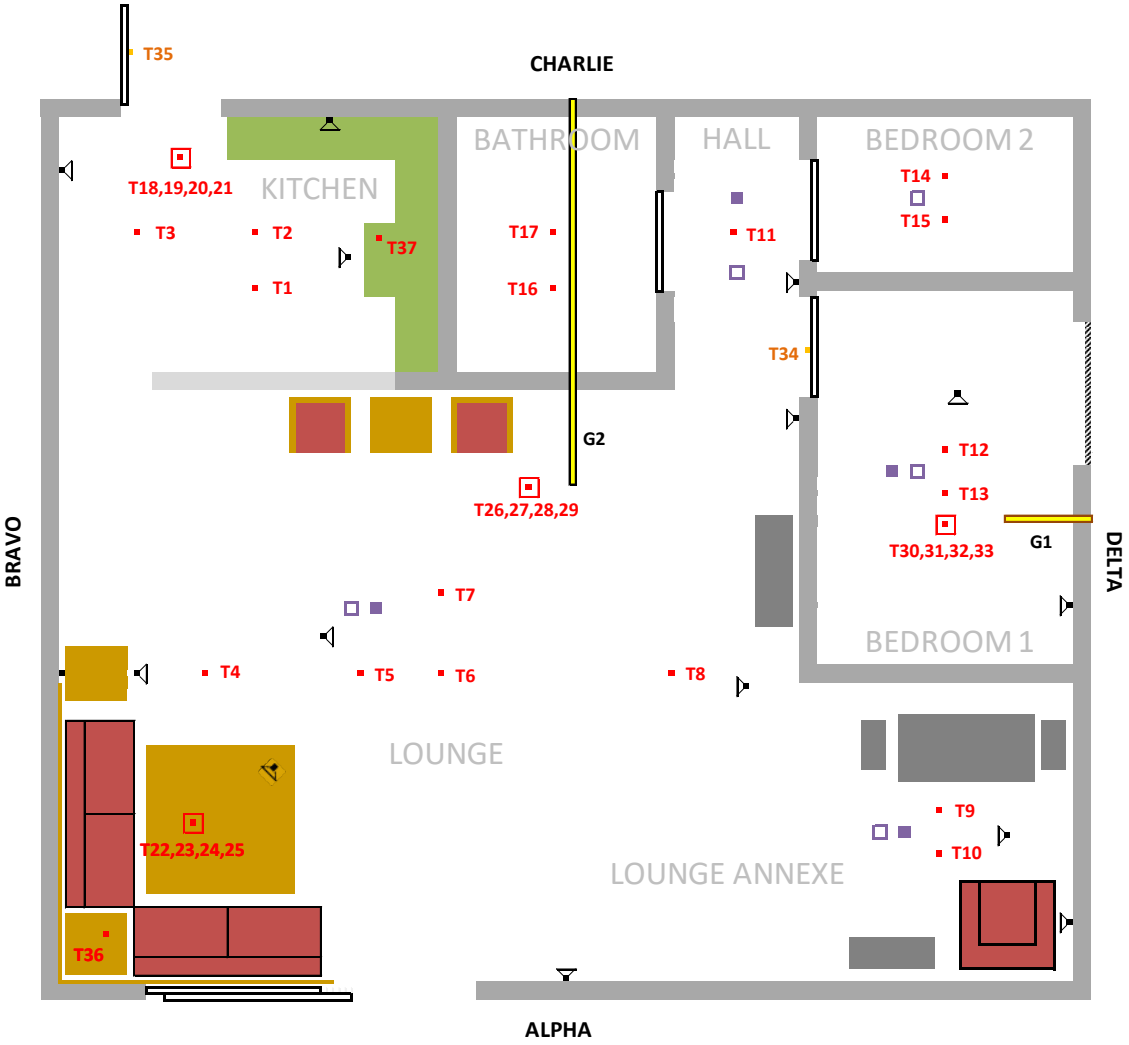

Figure 85 Map showing the Test 14 arrangement

3.14.2 Results

Fire size and fuel consumption

In Test 14, the peak flame height was approximately 2.4 metres or ceiling height (Figure 86). The fire spread to full room involvement (Figure 87).

Activations

The first smoke alarm activated at 57 seconds after ignition. There were no sprinkler activations in this test as all heads were inoperable.

Figure 86 Views of the developing test fire. Note the height of the smoke layer.

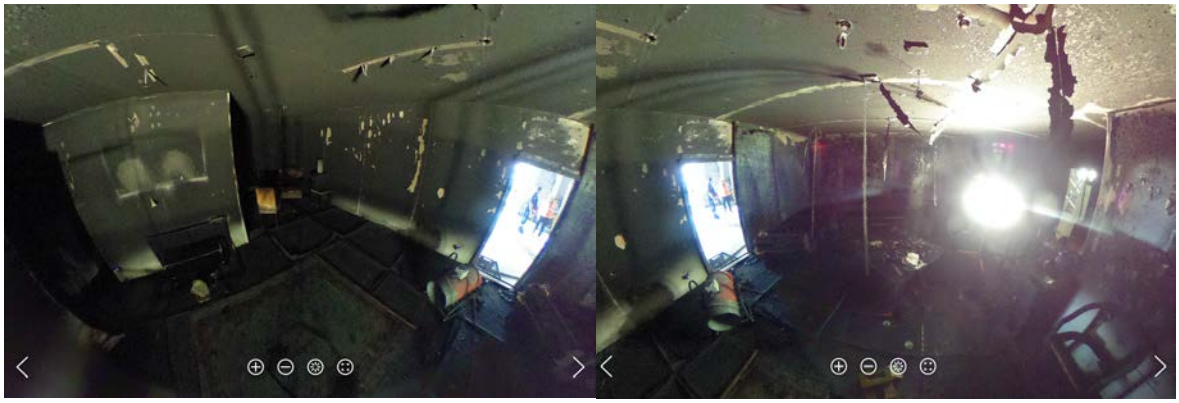

Figure 87 View of the test furnishings at the end of Test 14

Temperatures

The maximum temperature reached in the unit was 918°C at T22, the thermocouple positioned at the ceiling in the NW corner of the Lounge room. This peak occurred at 3 min 42 s after ignition.

The temperatures measured at 1.6 metres rose above 65°C at the Lounge centre (T28) and Kitchen (T20) at 2 min 45 s, peaking at 568.8°C and 507.3°C respectively. In Bedroom 1, the temperature at 1.6 m (T32) reached 65°C at 4 min 22 s, peaking at 149.7°C.

The cumulative heat tenability limit FED_{heat} > 0.3 was reached at 3 min 18 s in the Kitchen, 3 min 22 s in the Lounge room, and 6 min 2 s in Bedroom 1.

Smoke Toxicity

At the Lounge centre, gas sampling at 1.6 m (G2) found that irritant concentrations rose to FEC_{esc} > 0.3 in 16 s and FEC_{esc} > 1 at 1 min 19 s after ignition. Irritant incapacitation FEC_{inc}

0.3 was reached at 1 min 27 s and rose above FEC_{inc} = 1 at 2 min 55 s. FED_{asp} 0.3 was reached at 3 min 19 s, and FED_{asp} 1 at 3 min 27 s.

In Bedroom 1, FEC_{esc} > 0.3 was reached at 3 min 19 s and FEC_{esc} > 1 was reached at 3 min 26 s. FEC_{inc} > 0.3 was reached at 3 min 26 s and rose above FEC_{inc} = 1 at 3 min 34 s. The cumulative asphyxiant gas concentrations rose to FED_{asp} > 0.3 in 3 min 50 s, and FED_{asp} 1 at 3 min 58 s.

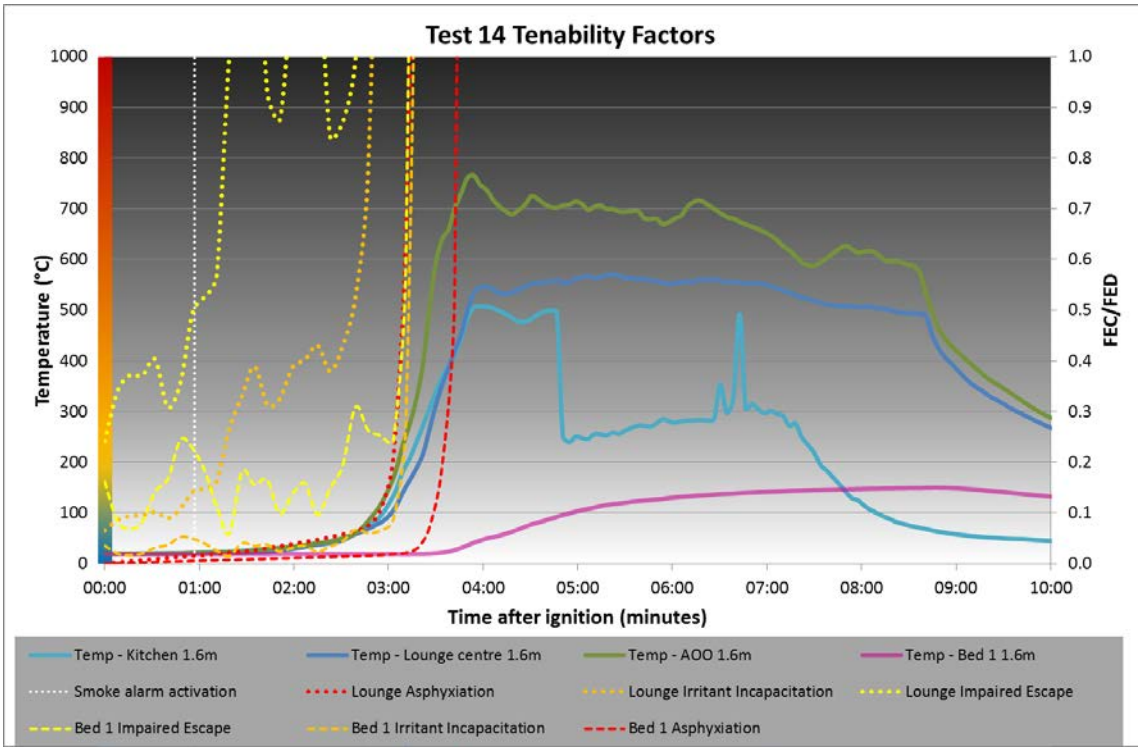

Figure 88 Chart showing timing of activations and tenability factors for Test 14

Table 30 Summary of Test 14 event timings

TIME AFTER IGNITION	EVENT
16 s	Impaired escape FEC_{esc} >0.3 at G2 (Lounge)
57 s	First smoke alarm activation
1 min 19 s	Impaired escape FEC_{esc} >1 at G2 (Lounge)
1 min 27 s	Irritant incapacitation FEC_{inc} >0.3 at G2 (Lounge)
2 min 55 s	Irritant incapacitation FEC_{inc} >1 at G2 (Lounge)
3 min 19 s	Asphyxiant incapacitation FED_{asp} >0.3 at G2 (Lounge)
	Impaired escape FEC_{esc} >0.3 at G1 (Bedroom 1)
3 min 26 s	Impaired escape FEC_{esc} >1 at G1 (Bedroom 1)
	Irritant incapacitation FEC_{inc} >0.3 at G1 (Bedroom 1)
3 min 27 s	Asphyxiant incapacitation FED_{asp} >1 at G2 (Lounge)
3 min 34 s	Irritant incapacitation FEC_{inc} >1 at G1 (Bedroom 1)
3 min 50 s	Asphyxiant incapacitation FED_{asp} >0.3 at G1 (Bedroom 1)
3 min 58 s	Asphyxiant incapacitation FED_{asp} >1 at G1 (Bedroom 1)
4 min 22 s	Temperature in Bedroom 1 at 1.6m (T32) elevated above 65°C
6 min 02 s	FED_{Heat} > 0.3 in Bedroom 1 at 1.6m
7 min 46 s	FED_{Heat} > 1 in Bedroom 1 at 1.6m
8 min 44 s	Test end – fire extinguished

3.14.3 Observations

The following was observed from the data:

- In this non-sprinklered test, the available safe egress time after smoke alarm activation was approximately 30 seconds before irritant gas levels became incapacitating in the Lounge area.
- Flashover occurred in the main area of the unit in 3 ½ minutes from ignition.
- Heat tenability was lost in approximately 3 ½ minutes in the Lounge and Kitchen, and 6 minutes in the closed Bedroom.
- The smoke concentrations throughout the unit rendered it untenable within 4 minutes.

4 SUMMARY

4.1 Overall results

4.1.1 Non-sprinklered test benchmark

As a comparison benchmark, the last test was undertaken without sprinklers and was free to burn. The fire scenario was similar to the other tests, with the fire source in the corner of the main lounge area. The data from this test showed that:

Toxicity

The FED_{asp} in the bedroom reached 0.3 at 3 min 50 s ***with bedroom doors closed***.

Temperatures

The peak temperature of 918°C was reached in 3 min 42 s. It is assumed that after this time there was no tenability.

4.1.2 Sprinklered tests

Toxicity

In all tests, regardless of ventilated or non-ventilated, bedroom doors open or closed, or the fire scenario, the shortest time taken to reach FED_{asp} 0.3 was 3 min 59 s in the Bedroom in Test 8. This test was with the Domestic sprinkler system with all heads charged, non-ventilated fire in the bedroom, bedroom door closed, the fire source in the NW corner of the bedroom under the stylised bed.

The longest time taken to reach FED_{asp} 0.3 was 37 min 53 s with a non-ventilated fire and the bedroom door closed. This was testing the Hydrant system.

It should be noted that in Tests 1, 2, and 3, the tests only ran for 8–12 minutes. The FED_{asp} was very low and the reasonable expectation is that the time to reach 0.3 would be a significantly longer time.

Of the tests than ran longer than 13 minutes, the ***average time*** to reach FED_{asp} 0.3, with the bedroom doors closed was 26 min 34 s, and the average time with the bedroom doors open was 19 min 26 s.

Temperatures

The peak temperature measured reached in all the sprinkler tests was 372°C in Test 4, being the Domestic system. No flashover occurred in any sprinklered test. The peak temperatures measured were generally at ceiling height, directly above the fire.

As such, FRNSW's testing demonstrated that both sprinkler design concepts achieve the tenability criteria targets. FRNSW's tests provide evidence that an occupant would have at least four times as long to escape from the fire or seek refuge in the Sole Occupancy Unit (SOU) than in the same apartment without sprinkler protection.

4.1.3 Domestic sprinkler system results

Temperatures

- In all tests, the sprinkler heads successfully operated.
- Number of heads activated was between one and four, with the most common being two heads.
- The average peak temperature measured was 267°C (*SD* = 90°C).
- Sprinkler heads activated at most 55 seconds after the activation of the smoke alarms.
- Flashover temperatures were not reached, and were significantly below this temperature.
- Except for the bedroom fire, all temperatures measured were well within both tenability criteria in the bedrooms for all tests.
- Emergency evacuation was possible at all times, at 1 metre in all areas, even in peak temperatures.
- The egress path from the bedroom to the SOU door at peak temperatures at 1.6 metres was tenable except in Test 3, with the fire in the Lounge Centre, (therefore impacting on egress route) at 1.6 metres reached 94°C. At 1 metre height, the peak temperature was 33°C. Evacuation may have been possible, depending upon exposure time.
- The egress path from the bedroom to the SOU door at peak temperatures at 1.6 metres was tenable or was not exceeded significantly in all but two tests. In Test 1 the temperature at 1.6 metres in the Kitchen peaked at 105°C and in Test 3 the temperature in the Lounge Centre peaked at 94°C. Evacuation still may have been possible, depending upon exposure time.
- In all tests 65°C was not exceeded at the 1 metre height.

Toxicity

- The worst toxicity level measured in the bedroom was at 12 min 43 s in Test 13 with two heads activated, ventilated fire, real furniture, fire in the Lounge NW corner with the bedroom doors open.

- The longest time to activation was in Test 3, which was a ventilated fire in the centre of the Lounge and the bedroom door closed. There were four sprinkler activations within 14 seconds, and FED_{asp} remained under 0.3 for the entire test.

4.1.4 Hydrant sprinkler system results

Temperatures

- The average peak temperature was 314°C (*SD* = 52°C).
- The egress path from the bedroom to the SOU door was, in all tests, was below the temperature tenability criteria of 65°C.
- In all tests, the heads activated successfully.
- In two tests, two heads activated and in one test, only one head activated.
- Sprinkler heads activated between 29 seconds and 1 min 14 s after the activation of the smoke alarm.
- Flashover temperatures were not reached.
- Emergency evacuation was possible from all parts of the apartment at peak temperatures.

Toxicity

- Note that only three tests were undertaken as the system is compliant with the Standard and therefore considered reliable and effective.
- Test 1 ran for 13 minutes and did not reach FED_{asp} of 0.3 in that time in both the lounge room and the bedroom. It would be a reasonable assumption that the time would in fact be significantly longer to reach 0.3.
- In Test 5, with the bedroom door closed, the time to FED_{asp} of 0.3 was 37 min 53 s.
- In Test 10 with the bedroom door open, the time to FED_{asp} of 0.3 was 14 min 42 s.
- From these tests, the time to reach the FED_{asp} 0.3 was significantly higher than the benchmark non-sprinklered fire:
  - With bedroom door open, tenability times improved four-fold
  - With bedroom door closed, tenability times improved ten-fold.

4.2 General comments

The effectiveness of sprinklers has been known for some time and supported by numerous test programs and research case studies. While the tests in this study were conducted only on one particular sprinkler head specification, the results when compared with the non-sprinklered fire well supported the use of sprinklers in residential fires.

4.2.1 Activation times

Sprinkler activation times are summarised in Table C 2 in Appendix C. First sprinkler activation times in the 13 sprinklered tests ranged from 58 to 140 seconds after ignition (*M* = 95.5, *SD* = 32.8). For the Domestic system, sprinkler activation time ranged from 58 to 115 seconds (*M* = 92.7, *SD* = 18.9), and the Hydrant system ranged from 80 to 140 seconds (*M* = 105, *SD* = 31.2).

Sprinkler activation temperatures ranged between 77.9°C to 144.6°C (*M* = 95.8, *SD* = 14.6).

In Test 14, temperatures measured at the sprinkler heads closest to the fire origin (T4, T5, T6,T7) show that they would have activated between 1 min 37 s and 2 min 41 s. The activation of at least one of these sprinklers would most likely have controlled the fire and prevented the flashover temperatures being reached at 3 min 42 s.

4.2.2 Effects on heat tenability

Sprinkler activations had the effect of cooling conditions within the unit, and preventing fire growth. It was found that the additional water flow and pressure from the Hydrant system dropped the temperatures quicker and less heads operated than in the Domestic system. Heat tenability thresholds were reached in five of the 13 sprinklered tests (Table C 5). To be considered is the potential for water damage from flooding.

At the Lounge centre, the temperature at a height of 1.6 metres was elevated above 65°C in Tests 3 and 4, involving the Domestic sprinkler system. The cumulative fractional effective dose for convective heat ($FED_{heat)}$ reached 0.3 in Test 3. The heat levels in these tests would not have affected an escaping occupant, but rather an occupant either impaired or incapacitated in the vicinity of the Lounge centre during the fire.

At the Kitchen, the temperature at a height of 1.6 metres was elevated above 65°C in Tests 1, 4, 6 and 13, again all involving the Domestic sprinkler system. The cumulative fractional effective dose for convective heat FED_{heat} reached 0.3 in Tests 1 and 6. The heat levels in these tests would not have affected an escaping occupant, but rather an occupant either impaired or incapacitated in the vicinity of the Kitchen during the fire.

In Bedroom 1, heat tenability thresholds were not exceeded in any of the sprinklered tests.

In the non-sprinklered test (Test 14), the heat tenability thresholds were all exceeded within 6 minutes of ignition.

4.2.3 Effects on toxic tenability

Times to reach smoke tenability thresholds are summarised in Table C 3 and Table C 4 in Appendix C.

Times to reach irritant-induced escape impairment, incapacitation and asphyxiant-induced incapacitation were significantly increased in most tests in comparison with those in the non-sprinklered test.

While sprinkler activations did not necessarily cease the growth in irritant and asphyxiant concentrations during the fires, as they did not completely extinguish the fires, they aided in controlling fire growth and in most cases the amount of polyurethane consumed. Water sprays also had the effect of 'scrubbing', or acting as a physical barrier to smoke travel within the unit. With the varied toxicity levels within the unit, coupled with a relatively controlled fire and tenable temperatures, there is a possibility that occupants may misjudge the risk of remaining in place or returning into the environment to retrieve their belongings. These results reveal a need to reinforce the public safety messaging to "Get out, stay out, call Triple Zero (000)" even in a sprinklered fire, and the importance of educating the public on closing doors to compartmentalise the fire.

5 RECOMMENDATIONS

Based on the results of tests undertaken in this fire research program and within the limitations of the number and type of scenarios tested, it is clear the activation of automatic fire sprinklers significantly improves the tenability of occupants in the event of a fire. The improvement in temperatures and atmospheric toxicity also significantly improves conditions for firefighters, resulting in a safer operating environment at the time of fire brigade intervention. It is therefore recommended that:

1. The two tested concept designs be finalised and used to support a Proposal for Change to the 2019 National Construction Code that mandates sprinklers in new Class 2 and Class 3 shared residential accommodation buildings up to 25 metres in effective height.

2. Further fire research be undertaken by FRNSW and its research partners to develop and test cost-effective and reliable sprinkler systems for application in other residential structures, particularly Class 1 buildings.

3. Develop and implement a public education program to reinforce the “Get out, stay out, call Triple Zero (000)” message as pertaining to sprinklered homes.

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APPENDIX A Tenability Criteria

A.1 Smoke/gas toxicity

The formulae used to calculate Fractional Effective Dose (FED) for asphyxiant gases, and Fractional Effective Concentrations (FEC) for irritant gases are detailed in the *SPFE Handbook of Fire Protection Engineering* by Purser (2008) and in ISO 13571 *Life-threatening components of fire — Guidelines for the estimation of time to compromised tenability in fires* (International Standards Organization, 2012). FED or FEC values of 1 correspond to a median value of human responses to the toxicological insult (International Standards Organization, 2012), i.e. the value at which 50% of the population is susceptible to the insult. A more conservative threshold of 0.3 represents a value that statistically affects 11.4% of the population, which can be considered to be the most vulnerable.

Table A1 details the gases monitored during the tests and the reference concentration values used where available in the calculations.

Table A1. Tenability limits used in gas calculations

	Effective concentration for Escape Impairment (ppm) [REF]		Effective concentration for Incapacitation (ppm) [REF]		Lethal Effective Dose (ppm.min) [REF]	
1,3 Butanediol	-		-		-	
1,3-Butadiene C4H6	6700	[AEGL]	27000	[AEGL]	810000	[AEGL]
Acetaldehyde C2H4O	340	[AEGL]	1100	[AEGL]	33000	[AEGL]
Acetone C3H6O	9300	[AEGL]	8600	[AEGL]	258000	[AEGL]
Acrolein C3H4O	4	[SFPE]	20	[SFPE]	4500	[SFPE]
Ammonia NH3	220	[AEGL]	1600	[AEGL]	48000	[AEGL]
Benzene C5H6	2000	[AEGL]	5600	[AEGL]	168000	[AEGL]
Carbon dioxide CO2	-		-		-	
Carbon monoxide CO	420	[AEGL]	600	[AEGL]	18000	[AEGL]
Carbonyl sulfide COS	69	[AEGL]	190	[AEGL]	5700	[AEGL]
Chlorobenzene C6H5Cl	430	[AEGL]	800	[AEGL]	24000	[AEGL]
Ethane C2H6	-		-		-	
Ethanol C2H6O	-		-		-	
Ethyl benzene C8H10	2900	[AEGL]	2600	[AEGL]	78000	[AEGL]
Ethylene C2H4	-		-		-	
Formaldehyde CH2O	6	[SFPE]	30	[SFPE]	22500	[SFPE]
Formic acid CH2O	-		-		-	
Hydrogen bromide HBr	200	[SFPE]	900	[SFPE]	114000	[SFPE]

SFPE (National Fire Protection Association. & Society of Fire Protection Engineers, 2002)

AEGL (US Environmental Protection Agency, 2016)

Table A1. Tenability limits used in gas calculations – cont.

	Effective concentration for Escape Impairment (ppm) [REF]		Effective concentration for Incapacitation (ppm) [REF]		Lethal Effective Dose (ppm.min) [REF]	
Hexane C6H14	4000	[AEGL]	8600	[AEGL]	258000	[AEGL]
Hydrogen bromide HBr	200	[SFPE]	900	[SFPE]	114000	[SFPE]
Hydrogen chloride HCl	200	[SFPE]	900	[SFPE]	114000	[SFPE]
Hydrogen cyanide HCN	-		-		-	
Hydrogen fluoride HF	200	[SFPE]	900	[SFPE]	87000	[SFPE]
Methane CH4	-		-		-	
Methanol CH4O	11000	[AEGL]	14000	[AEGL]	420000	[AEGL]
Methyl ethyl ketone (2-Butanone)	4900	[AEGL]	10000	[AEGL]	300000	[AEGL]
m-Xylene C8H10	2500	[AEGL]	3600	[AEGL]	108000	[AEGL]
Nitrogen dioxide NO2	70	[SFPE]	350	[SFPE]	1900	[SFPE]
Nitrogen monoxide NO	-		1000	[SFPE]	-	
Nitrous oxide N2O	-		-		-	
Octane C8H18	-		-		-	
o-Xylene C8H10	2500	[AEGL]	3600	[AEGL]	108000	[AEGL]
Phenol C6H5OH	29	[AEGL]	-		-	
Propane C3H8	17000	[AEGL]	33000	[AEGL]	990000	[AEGL]
Propene C3H6	-		-		-	
p-Xylene C8H10	2500	[AEGL]	3600	[AEGL]	108000	[AEGL]
Styrene C8H8	230	[AEGL]	1900	[AEGL]	57000	[AEGL]
Sulfur dioxide SO2	24	[SFPE]	120	[SFPE]	12000	[SFPE]
Toluene C7H8	1400	[AEGL]	5200	[AEGL]	156000	[AEGL]

SFPE (National Fire Protection Association. & Society of Fire Protection Engineers., 2002)

AEGL (US Environmental Protection Agency, 2016)

A.2 Heat tenability

Purser (2008) calculated a Fractional Effective Dose for convective heat using recorded temperature measurements T(°C). The threshold value of 1 represents extreme pain resulting in incapacitation in 50% of the population.

$$FED_{conv\ heat} = \sum_{t1}^{t2} \left(\frac{1}{5 \times 10^{7} T^{-3.4}} \right) \Delta t$$

In addition, a temperature threshold value of 65°C is used for a saturated atmosphere in which the occupant is not able to breathe properly.

APPENDIX B Sprinkler head specifications

tyco Fire Protection Products

Worldwide Contacts | www.tyco-fire.com

RAPID RESPONSE Series LFII Residential Sprinklers 4.9 K-factor Domed-Plate Concealed Pendent Wet Pipe and Dry Pipe Systems

General Description

The TYCO RAPID RESPONSE Series LFII Residential Domed-Plate Concealed Pendent 4.9 K-factor Sprinklers (TY2234) are decorative, fast response, frangible bulb sprinklers designed for use in residential occupancies such as homes, apartments, dormitories, and hotels.

The Cover Plate/Retainer Assembly conceals the sprinkler operating components above the ceiling. The domed profile of the cover plate provides aesthetically appealing sprinkler design with lower flow rates than can be achieved by lower profile cover plates. The separable two-piece design of the Cover Plate and Support Cup Assemblies allows installation of the sprinklers and pressure testing of the fire protection system prior to the installation of the ceiling or application of a finish coating.

Also, the separable "push-on and thread-off" two-piece design of the Sprinkler provides for 1/2 inch (12,7 mm) of vertical adjustment.

The Series LFII Residential Sprinklers (TY2234) are intended for use in the following scenarios:

- wet and dry pipe residential sprinkler systems for one- and two-family dwellings and mobile homes per NFPA 13D
- wet and dry pipe residential sprinkler systems for residential occupancies up to and including four stories in height per NFPA 13R
- wet and dry pipe sprinkler systems for the residential portions of any occupancy per NFPA 13

IMPORTANT

Always refer to Technical Data Sheet TFP700 for the "INSTALLER WARNING" that provides cautions with respect to handling and installation of sprinkler systems and components. Improper handling and installation can permanently damage a sprinkler system or its components and cause the sprinkler to fail to operate in a fire situation or cause it to operate prematurely.

The Series LFII Residential Sprinklers have been designed with heat sensitivity and water distribution characteristics proven to help in the control of residential fires and to improve the chance for occupants to escape or be evacuated.

The Series LFII Residential Domed-Plate Concealed Pendent Sprinklers (TY2234) are shipped with a Disposable Protective Cap. The Protective Cap is temporarily removed for installation, and it must be replaced to protect the sprinkler while the ceiling is being installed or finished. The tip of the Protective Cap can also be used to mark the center of the ceiling hole into plaster board or ceiling tiles by gently pushing the ceiling product against the Protective Cap. When ceiling installation is complete, the Protective Cap must be removed and the Cover Plate Assembly installed. The Protective Cap must be removed to ensure proper performance of the sprinklers.

Dry Pipe System Application

The Series LFII Residential Domed-Plate Concealed Pendent Sprinklers (TY2234) Listing offers a laboratory approved option for designing dry pipe residential sprinkler systems, whereas, most residential sprinklers are laboratory approved for wet systems only.

Through extensive testing, it has been determined that the number of design sprinklers (hydraulic design area) for the Series LFII Residential Domed-Plate Concealed Pendent Sprinklers (TY2234) need not be increased over the number of design sprinklers (hydraulic design area) as specified for wet pipe sprinkler systems, as is customary for density/area sprinkler systems designed per NFPA 13.

Consequently, the Series LFII Residential Domed-Plate Concealed Pendent Sprinklers offer the features of non-water filled pipe in addition to not having to increase the number of design sprinklers (hydraulic design area) for systems designed to NFPA 13, 13D, or 13R. Non-water filled pipe will permit options for areas sensitive to freezing.

NOTICE

The Series LFII Residential Domed-Plate Concealed Pendent Sprinklers (TY2234) described herein must be installed and maintained in compliance with this document and the applicable standards of the National Fire Protection Association, in addition to the standards of any authorities having jurisdiction. Failure to do so may impair the performance of these devices.

The owner is responsible for maintaining their fire protection system and devices in proper operating condition. Contact the installing contractor or sprinkler manufacturer with any questions.

Sprinkler Identification Number (SIN)

TY2234

Technical Data

Approvals

UL Listed for use with wet pipe and dry pipe systems

C-UL Listed for use only with wet pipe systems

NYC Approved under MEA 44-03-E

The Series LFII Residential Domed-Plate Concealed Pendent Sprinklers are only listed with the Series LFII Residential Domed-Plate Concealed Pendent Cover Plates having a factory applied finish.

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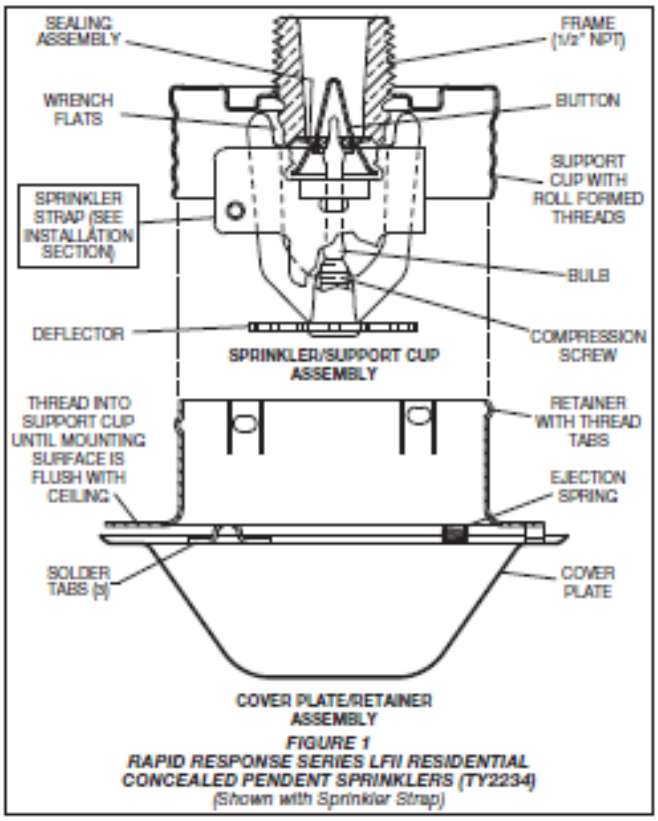

FIGURE 1
RAPID RESPONSE SERIES LFII RESIDENTIAL CONCEALED PENDENT SPRINKLERS (TY2234)
(Shown with Sprinkler Strap)

For details on these approvals, refer to the Design Criteria section.

All listed cover plates and corresponding part numbers having factory applied finishes can be found in the Ordering Procedure section of this data sheet.

Maximum Working Pressure
175 psi (12,1 bar)

Discharge Coefficient
K = 4.9 GPM/psi1/2 (70,6 LPM/bar1/2)

Temperature Rating
155°F (68°C) Sprinkler with
139°F (59°C) Cover Plate

Vertical Adjustment
1/2 inch (12,7 mm)

Finishes
Refer to Ordering Procedure section.

Physical Characteristics

Frame	Brass
Button	Bronze
Sealing Assembly	Beryllium Nickel w/ TEFLON
Bulb (3 mm)	Glass
Compression Screw	Brass
Deflector	Copper
Button Ejection Spring	Stainless Steel
Support Cup	Steel
Cover Plate	Brass
Retainer	Brass
Cover Plate Ejection Spring	Stainless Steel

Operation

When exposed to heat from a fire, the Cover Plate, which is normally soldered to the Support Cup at three points, falls away to expose the Sprinkler Assembly. The glass bulb contains a fluid that expands when exposed to heat. When the rated temperature is reached, the fluid expands sufficiently to shatter the glass bulb allowing the sprinkler to activate and flow water.

Design Criteria

The TYCO RAPID RESPONSE Series LFII Residential Domed-Plate Concealed Pendent 4.9 K-factor Sprinklers (TY2234) are UL and C-UL Listed for installation in accordance with this section.

Residential Sprinkler Design Guide
When conditions exist that are outside the scope of the provided criteria, refer to the Residential Sprinkler Design Guide TFP490 for the manufacturer's recommendations that may be acceptable to the authority having jurisdiction.

System Types
Per the UL Listing, wet pipe and dry pipe systems may be utilized. Per the C-UL Listing, only wet pipe systems may be utilized.

Refer to Technical Data Sheet TFP485 about the use of Residential Sprinklers in residential dry pipe systems.

Ceiling Types
Smooth flat horizontal, or beamed, or sloped, in accordance with the 2013 Edition of NFPA 13D, 13R, or 13 as applicable.

Hydraulic Design (NFPA 13D and 13R)
For systems designed to NFPA 13D or NFPA 13R, the minimum required sprinkler flow rate are given in Tables A and B as a function of temperature rating and the maximum allowable coverage areas. The sprinkler flow rate is the minimum required discharge from each of the total number of "design sprinklers" as specified in NFPA 13D or NFPA 13R. The number of "design sprinklers" specified in NFPA 13D and 13R for wet pipe systems is to be applied when designing dry pipe systems.

Hydraulic Design (NFPA 13)
For systems designed to NFPA 13, the number of design sprinklers is to be the four most hydraulically demanding sprinklers. The minimum required discharge from each of the four sprinklers is to be the greater of the following:

- The flow rates given in Tables A and B as a function of temperature rating and the maximum allowable coverage area.
- A minimum discharge of 0.1 gpm/ft². over the "design area" comprised of the four most hydraulically demanding sprinklers for the actual coverage areas being protected by the four sprinklers.

Maximum Coverage Area[a] Ft. x Ft. (m x m)	Maximum Spacing Ft. (m)	WET PIPE SYSTEM Minimum Flow and Residual Pressure[b,c]				
		Ordinary Temp. Rating 155°F (68°C)		Deflector to Ceiling	Installation Type	Minimum Spacing Ft. (m)
		Flow GPM (L/min)	Pressure PSI (bar)			
12 X 12 (3,7 X 3,7)	12 (3,7)	13 (49,2)	7.0 (0,48)	Smooth Ceilings 1/4 to 3/4 Inches Beamed Ceilings per NFPA 13D or 13R Installed in Beam 1/4 to 3/4 Inches below bottom of beam	Concealed	8 (2,4)
14 X 14 (4,3 X 4,3)	14 (4,3)	13 (49,2)	7.0 (0,48)			
16 X 16 (4,9 X 4,9)	16 (4,9)	13 (49,2)	7.0 (0,48)			
18 X 18 (5,5 X 5,5)	18 (5,5)	17 (64,3)	12.0 (0,83)			
20 X 20 (6,1 X 6,1)	20 (6,1)	20 (75,7)	16.7 (1,15)			

a. For coverage area dimensions less than or between those indicated, use the minimum required flow for the next highest coverage area for which hydraulic design criteria are stated.

b. Requirement is based on minimum flow in GPM (LPM) from each sprinkler. The associated residual pressures are calculated using the nominal K-factor. Refer to Hydraulic Design under the Design Criteria section.

c. For NFPA 13 residential applications, the greater of 0.1 gpm/ft.² over the design area or the flow in accordance with the criteria in this table must be used.

TABLE A
WET PIPE SYSTEMS
SERIES LFII RESIDENTIAL DOMED-PLATE CONCEALED PENDENT SPRINKLERS (TY2234)
NFPA 13D, 13R, AND 13 HYDRAULIC DESIGN CRITERIA

Maximum Coverage Area[a] Ft. x Ft. (m x m)	Maximum Spacing Ft. (m)	DRY PIPE SYSTEM Minimum Flow and Residual Pressure[b,c]				
		Ordinary Temp Rating 155°F (71°C)		Deflector to Ceiling	Installation Type	Minimum Spacing Ft. (m)
		Flow GPM (L/min)	Pressure PSI (bar)			
12 X 12 (3,7 X 3,7)	12 (3,7)	13 (49,2)	7.0 (0,48)	Smooth Ceilings 1/4 to 3/4 Inches Beamed Ceilings per NFPA 13D or 13R Installed in Beam 1/4 to 3/4 Inches below bottom of beam	Concealed	8 (2,4)
14 X 14 (4,3 X 4,3)	14 (4,3)	14 (53,0)	8.2 (0,57)			
16 X 16 (4,9 X 4,9)	16 (4,9)	15 (56,8)	9.4 (0,65)			
18 X 18 (5,5 X 5,5)	18 (5,5)	20 (75,7)	16.7 (1,15)			
20 X 20 (6,1 X 6,1)	20 (6,1)	22 (83,3)	20.2 (1,39)			

a. For coverage area dimensions less than or between those indicated, use the minimum required flow for the next highest coverage area for which hydraulic design criteria are stated.

b. Requirement is based on minimum flow in GPM (LPM) from each sprinkler. The associated residual pressures are calculated using the nominal K-factor. Refer to Hydraulic Design under the Design Criteria section.

c. For NFPA 13 residential applications, the greater of 0.1 gpm/ft.² over the design area or the flow in accordance with the criteria in this table must be used.

TABLE B
DRY PIPE SYSTEM
SERIES LFII RESIDENTIAL DOMED-PLATE CONCEALED PENDENT SPRINKLERS (TY2234)
NFPA 13D, 13R, AND 13 HYDRAULIC DESIGN CRITERIA

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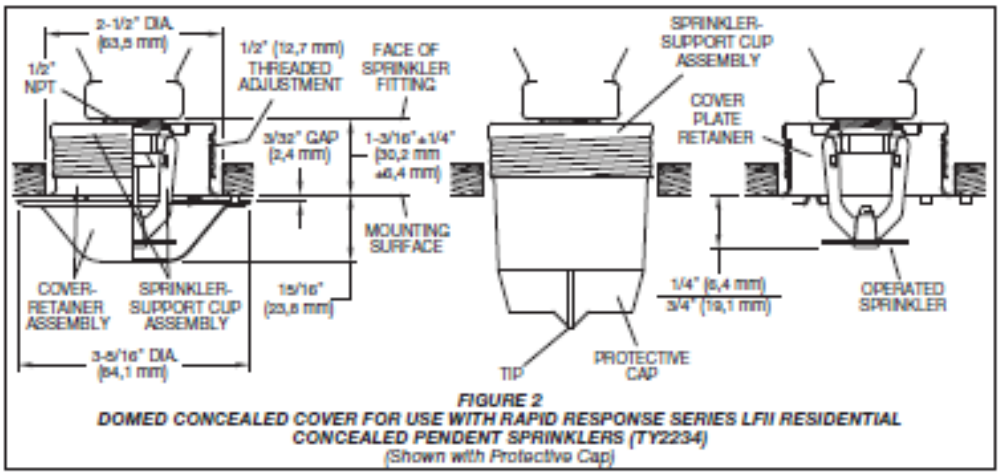

FIGURE 2
DOMED CONCEALED COVER FOR USE WITH RAPID RESPONSE SERIES LFII RESIDENTIAL CONCEALED PENDENT SPRINKLERS (TY2234)
(Shown with Protective Cap)

The number of "design sprinklers" specified in NFPA 13D and 13R for wet pipe systems is to be applied when designing dry pipe systems.

Dry Pipe System Water Delivery
When using the Series LFII Residential Pendent Sprinklers (TY2234) in dry pipe sprinkler systems, the time for water delivery must not exceed 15 seconds for the most remote operating sprinkler.

Obstruction to Water Distribution
Sprinklers are to be located in accordance with the obstruction rules of NFPA 13D, 13R, and 13 as applicable for residential sprinklers as well as with the obstruction criteria described within the Technical Data Sheet TFP490.

Operational Sensitivity
The sprinklers are to be installed relative to the ceiling mounting surface as shown in Figure 2.

The Series LFII Residential Domed-Plate Concealed Pendent Sprinklers must not be used in applications where the air pressure above the ceiling is greater than that below. Down drafts through the Support Cup could delay sprinkler operation in a fire situation.

Sprinkler Spacing
The minimum spacing between sprinklers is 8 feet (2,4 m). The maximum spacing between sprinklers cannot exceed the length of the coverage area (Table A or B) being hydraulically calculated (e.g., maximum 12 feet for a 12 ft. x 12 ft. coverage area, or 20 feet for a 20 ft. x 20 ft. coverage area).

Installation

The TYCO RAPID RESPONSE Series LFII Residential Domed-Plate Concealed Pendent 4.9 K-factor Sprinklers (TY2234) must be installed in accordance with this section.

General Instructions
Do not install any bulb type sprinkler if the bulb is cracked or there is a loss of liquid from the bulb. With the sprinkler held horizontally, a small air bubble should be present. The diameter of the air bubble is approximately 1/16 inch (1,6 mm).

A leak-tight 1/2 inch NPT sprinkler joint should be obtained by applying a minimum-to-maximum torque of 7 to 14 ft.-lbs. (9,5 to 19,0 Nm). Higher levels of torque can distort the sprinkler inlet with consequent leakage or impairment of the sprinkler.

Do not attempt to compensate for insufficient adjustment in an Escutcheon Plate by under- or over-tightening the Sprinkler. Re-adjust the position of the sprinkler fitting to suit.

Step 1. Install the sprinkler in the pendent position and with the centerline of the sprinkler perpendicular to the mounting surface.

Step 2. Remove the Protective Cap. Refer to NFPA 13 for guidance regarding removal of protective straps and caps

Step 3. With pipe thread sealant applied to the pipe threads, and using the W-Type 7 Wrench shown in Figure 3, install and tighten the Sprinkler/Support Cup Assembly into the fitting. The W-Type 7 Wrench will accept a 1/2 inch ratchet drive.

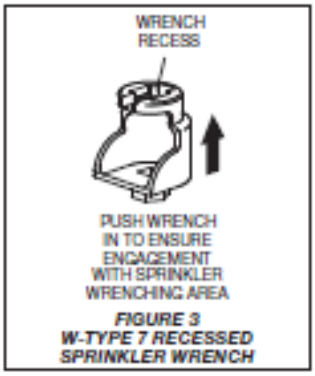

FIGURE 3
W-TYPE 7 RECESSED SPRINKLER WRENCH

Step 4. Replace the Protective Cap by pushing it upwards until it bottoms out against the Support Cup. The Protective Cap helps prevent damage to the Deflector and Arms during ceiling installation and/or during application of the finish coating of the ceiling. It may also be used to locate the center of the clearance hole by gently pushing the ceiling material against the center point of the Cap.

As long as the Sprinkler Strap (Figure 1) or the Protective Cap (Figure 2) remains in place, the system is considered to be "Out Of Service."

Step 5. After the ceiling has been completed with the 2-1/2 inch (63 mm) diameter clearance hole and in preparation for installing the Cover Plate/Retainer Assembly, remove and discard the Protective Cap and the Sprinkler Strap.

NOTE: *Refer to Technical Data Sheet TFP700 regarding instructions for the removal of the Sprinkler Strap.*

Step 6. Push the Cover Plate/Retainer Assembly into the Support Cup, and as necessary, make the final adjustment of the Cover Plate with respect to the ceiling by turning the Cover Plate/Retainer Assembly clockwise until its flange just comes in contact with the ceiling.

If it becomes necessary to remove the Cover Plate, it can be removed by unscrewing in a counter-clockwise direction.

If the Cover Plate/Retainer Assembly cannot be engaged with the Support Cup or the Cover Plate/Retainer Assembly cannot be engaged sufficiently to contact the ceiling, the Sprinkler Fitting must be repositioned.

Care and Maintenance

The TYCO RAPID RESPONSE Series LFII Residential Domed-Plate Concealed Pendent 4.9 K-factor Sprinklers (TY2234) must be maintained and serviced in accordance with this section.

Before closing a fire protection system main control valve for maintenance work on the fire protection system that it controls, obtain permission to shut down the affected fire protection systems from the proper authorities and notify all personnel who may be affected by this action.

Absence of a Cover Plate may delay sprinkler operation in a fire situation.

The owner must assure that the sprinklers are not used for hanging any objects and that the sprinklers are only cleaned by means of gently dusting with a feather duster; otherwise, non-operation in the event of a fire or inadvertent operation may result.

When properly installed, there is a nominal 3/32 inch (2,4 mm) air gap between the lip of the Cover Plate and the ceiling, as shown in Figure 2. This air gap is necessary for proper operation of the sprinkler by allowing heat flow from a fire to pass below and above the Cover Plate to help assure appropriate release of the Cover Plate in a fire situation. If the ceiling needs repainting after sprinkler installation, exercise care to ensure that the new paint does not seal off any of the air gap. Failure to do so may impair sprinkler operation.

Factory painted Cover Plates must not be repainted. They should be replaced, if necessary, by factory painted units. Non-factory applied paint may adversely delay or prevent sprinkler operation in the event of a fire.

Do not pull the Cover Plate relative to the Retainer. Separation may result.

Sprinklers which are found to be leaking or exhibiting visible signs of corrosion must be replaced.

Automatic sprinklers must never be painted, plated, coated, or otherwise altered after leaving the factory. Modified or overheated sprinklers must be replaced.

Care must be exercised to avoid damage to the sprinklers - before, during, and after installation. Sprinklers damaged by dropping, striking, wrench twist/slippage, or the like, must be replaced. Also, replace any sprinkler that has a cracked bulb or that has lost liquid from its bulb. (Ref. Installation Section.)

The owner is responsible for the inspection, testing, and maintenance of their fire protection system and devices in compliance with this document, as well as with the applicable standards of the National Fire Protection Association (e.g., NFPA 25), in addition to the standards of any authorities having jurisdiction. Contact the installing contractor or sprinkler manufacturer regarding any questions.

Automatic sprinkler systems are recommended to be inspected, tested, and maintained by a qualified Inspection Service in accordance with local requirements and/or national codes.

Limited Warranty

For warranty terms and conditions, visit www.tyco-fire.com.

Ordering Procedure

Contact your local distributor for availability. When placing an order, indicate the full product name and Part Number (P/N).

Sprinkler Assembly
Specify: Series LFII (TY2234), K = 4.9, Residential Domed-Plate Concealed Pendent Sprinkler without Cover Plate Assembly, P/N 51-873-1-155

Cover Plate Assembly
Specify: Series LFII (TY2234), K = 4.9, Residential Domed-Plate Concealed Pendent Sprinkler Cover Plate Assembly with (specify) finish, P/N (specify):

Pure White* (RAL9010) ..... P/N 56-873-3-135
Signal White (RAL9003) ..... P/N 56-873-4-135
Chrome ..... P/N 56-873-9-135
Custom ..... P/N 56-873-X-135

* Eastern Hemisphere sales only.

Sprinkler Wrench
Specify: W-Type 7 Sprinkler Wrench, P/N 56-850-4-001

APPENDIX C Data Tables

Table C 1 Test scenarios

	SPRINKLER SYSTEM	ORIGIN	SCENARIO AND CONDITIONS	DURATION
Test 1	Domestic	Lounge NW corner	UL-based corner test, external doors open, internal closed, corner located crib shielded by plywood-backed foam	12 min 13 s
Test 2	Hydrant	Lounge NW corner	UL-based corner test, external doors open, internal closed, corner located crib shielded by plywood-backed foam	8 min 20 s
Test 3	Domestic	Lounge centre	Centre Lounge, stylised furniture (2x 2-seater sofas + coffee table), external doors open, internal closed	10 min 19 s
Test 4	Domestic	Lounge NW corner	UL-based corner test, external doors open, Internal doors closed, single sprinkler (UL location) only	50 min
Test 5	Hydrant	Lounge NW corner	Corner fire, stylised furniture, all doors closed	45 min
Test 6	Domestic	Lounge NW corner	Corner fire, stylised furniture, all doors closed	45 min
Test 7	Domestic	Lounge NW corner	Corner fire, external doors closed, internal doors open	30 min
Test 8	Domestic	Bedroom 1 NW corner	Bedroom fire, door closed, Gas sampling at 1m & 1.6m	50 min
Test 9	Domestic	Kitchen stove	Kitchen oil fire, external doors closed, internal doors open	20 min
Test 10	Hydrant	Lounge NW corner	Corner fire, real furnishings, doors closed	40 min
Test 11	Domestic	Lounge NW corner	Corner fire, real furnishings, doors closed	50 min
Test 12	Domestic	Lounge NW corner	Corner fire, stylised furniture, external doors open, Bedroom door open	50 min
Test 13	Domestic	Lounge NW corner	Corner fire, real furniture, external doors closed, Bedroom door open	50 min
Test 14	None	Lounge NW corner	Real furnishings, external doors open, Bedroom door closed	8 min 44 s

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Table C 2 Smoke alarm and sprinkler activations times

	SPRINKLER SYSTEM	First smoke alarm activation	First sprinkler activation	Second sprinkler activation	Third sprinkler activation	Fourth sprinkler activation
Test 1	Domestic	50 s	1 min 23 s	1 min 33 s		
Test 2	Hydrant	18 s	1 min 20 s	1 min 21 s		
Test 3	Domestic	1 min	1 min 55 s	1 min 58 s	2 min 5 s	2 min 9 s
Test 4	Domestic	1 min 1 s	1 min 51 s			
Test 5	Hydrant	1 min 6 s	1 min 35 s			
Test 6	Domestic	1 min 4 s	1 min 13 s	2 min 57 s		
Test 7	Domestic	1 min 7 s	1 min 18 s	1 min 42 s		
Test 8	Domestic	27 s	58 s			
Test 9	Domestic	-8 min 32 s	1 min 43 s	1 min 59 s		
Test 10	Hydrant	1 min 6 s	2 min 20 s	2 min 28 s		
Test 11	Domestic	1 min 44 s	1 min 39 s	2 min 3 s		
Test 12	Domestic	1 min 21 s	1 min 37 s	2 min 10 s	2 min 18 s	
Test 13	Domestic	1 min 41 s	1 min 50 s			
Test 14	None	57 s				

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Table C 3 Lounge room (G2) smoke tenability threshold times

	SPRINKLER SYSTEM	FEC_{esc} >0.3 at G2 (Lounge)	FEC_{esc} >1 at G2 (Lounge)	FEC_{inc} >0.3 at G2 (Lounge)	FEC_{inc} >1 at G2 (Lounge)	FED_{asp} >0.3 at G2 (Lounge)	FED_{asp} >1 at G2 (Lounge)
Test 1	Domestic	1 min 42 s		2 min 16 s – 4 min 44 s			
Test 2	Hydrant	2 min 35 s					
Test 3	Domestic	2 min	3 min 19 s	2 min 23 s			
Test 4	Domestic	1 min 27 s	2 min 31 s	2 min 7 s	10 min 51 s	12 min 58 s	
Test 5	Hydrant	1 min 43 s	3 min 43 s	2 min 39 s	6 min 29 s	9 min 48 s	19 min 44 s
Test 6	Domestic	1 min 43 s	3 min 3 s	2 min 15 s	3 min 50 s	7 min 25 s	13 min 38 s
Test 7	Domestic	1 min 20 s	3 min 35 s	1 min 59 s	4 min 46 s	7 min 41 s	12 min 19 s
Test 8*	Domestic	56 s	1 min 4 s		1 min 19 s	2 min 39 s	5 min 26 s
Test 9	Domestic	1 min 52 s		3 min 19 s			
Test 10	Hydrant	2 min 23 s	4 min 46 s	3 min 18 s	7 min 48 s	10 min 59 s	19 min 20 s
Test 11	Domestic	1 min 44 s	3 min 27 s	2 min 39 s	5 min 2 s	8 min 29 s	14 min 50 s
Test 12	Domestic	2 min 15 s	6 min 13 s – 28 min 36 s	2 min 46 s	19 min 28 s – 25 min 1 s	13 min 6 s	
Test 13	Domestic	1 min 59 s	3 min 50 s	2 min 39 s	5 min 33 s	9 min 16 s	16 min 33 s
Test 14	None	16 s	1 min 19 s	1 min 27 s	2 min 55 s	3 min 19 s	3 min 27 s

*G2 located in Bedroom 1 at 1 metre in this test

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Table C 4 Bedroom 1 (G1) smoke tenability threshold times

	SPRINKLER SYSTEM	FECesc >0.3 at G1 (Bed1)	FECesc >1 at G1 (Bed1)	FECinc >0.3 at G1 (Bed1)	FECinc >1 at G1 (Bed1)	FEDasp >0.3 at G1 (Bed1)	FEDasp >1 at G1 (Bed1)
Test 1	Domestic						
Test 2	Hydrant						
Test 3	Domestic	6 min 5 s					
Test 4	Domestic	10 min 44 s				31 min 39 s	
Test 5	Hydrant	26 min 53 s		34 min 50 s		37 min 53 s	
Test 6	Domestic	7 min 25 s	27 min 1 s	21 min 11 s	40 min 56 s	28 min 5 s	
Test 7	Domestic	1 min 20 s	2 min 55 s	4 min 6 s	7 min 33 s	17 min 45 s	
Test 8	Domestic	56 s	1 min 4 s	56 s	1 min 12 s	3 min 59 s	7 min 33 s
Test 9	Domestic	2 min 39 s		3 min 02 s			
Test 10	Hydrant	2 min 46 s	8 min 52 s	5 min 41 s	12 min 3 s	14 min 42 s	28 min 44 s
Test 11	Domestic	6 min 38 s	12 min 27 s	10 min 36 s	22 min 31 s	20 min 32 s	39 min 52 s
Test 12	Domestic	2 min 39 s	5 min 26 s – 32 min 19 s	4 min 7 s		27 min 49 s	
Test 13	Domestic	3 min 3 s	4 min 54 s	4 min 14 s	9 min 32 s	12 min 43 s	24 min 30 s
Test 14	None	3 min 19 s	3 min 26 s	3 min 26 s	3 min 34 s	3 min 50 s	3 min 58 s

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Table C 5 Heat tenability threshold times

	SPRINKLER SYSTEM	Kitchen (T20) > 65°C	Kitchen FED_{heat} 0.3	Lounge centre (T28) >65°C	Lounge centre FED_{heat} 0.3	Bedroom 1 (T32) > 65°C	Bedroom 1 FED_{heat} 0.3
Test 1	Domestic	2 min 5 s – 4 min 50 s	8 min 25 s				
Test 2	Hydrant						
Test 3	Domestic			3 min 5 s – 7 min 25 s	6 min 50 s		
Test 4	Domestic	2 min 11 s – 4 min 16 s		2 min 3 s – 2 min 14 s			
Test 5	Hydrant						
Test 6	Domestic	2 min 46 s – 8 min 25 s	11 min 34 s				
Test 7	Domestic						
Test 8	Domestic						
Test 9	Domestic						
Test 10	Hydrant						
Test 11	Domestic						
Test 12	Domestic						
Test 13	Domestic	3 min 2 s – 5 min 6 s					
Test 14	None	2 min 45s	3 min 18 s	2 min 45 s	3 min 22 s	4 min 22 s	6 min 2 s

Table C 6 Peak temperatures measured at the sprinkler heads (degrees Celsius).

	T1 (H4)	T2 (D4)	T3 (H9)	T4 (D2)	T5 (D1)	T6 (H2)	T7 (H1)	T8 (D3)	T9 (D5)	T10 (H5)	T11 (H3)	T12 (D8)	T13 (H8)	T14 (D7)	T15 (H7)	T16 (H6)	T17 (D6)
Test 1	167.4	158.6	164.3	218.9	100.3	92.0	125.2	**96.4**	142.1	152.0	117.2	27.9	27.5	31.1	31.4	32.6	34.4
Test 2	**98.2**	90.3	95.9	158.4	109.7	106.6	93.3	92.8	88.2	94.0	62.6	24.7	24.6	24.1	24.2	24.7	25.3
Test 3	122.0	**80.9**	119.8	**91.8**	183.4	223.1	248.1	**86.7**	**85.9**	91.3	126.7	27.1	26.3	28.2	28.7	32.2	34.6
Test 4	112.3	105.1	107.1	152.9	**95.0**	142.4	132.7	130.8	118.9	121.7	90.9	27.0	26.8	27.3	27.2	29.2	30.5
Test 5	80.2	70.7	74.4	129.5	96.8	**85.9**	83.2	77.0	70.6	70.9	55.7	23.7	24.0	23.3	23.5	23.9	24.0
Test 6	94.4	91.7	96.2	**89.0**	127.2	132.8	122.3	**117.5**	97.2	102.6	86.8	24.0	23.4	28.0	28.3	29.7	31.0
Test 7	105.5	101.2	108.0	**89.4**	159.0	153.3	143.8	**89.5**	94.0	99.9	97.1	61.4	59.0	68.4	71.0	27.4	28.3
Test 8	27.3	26.1	20.2	21.8	24.4	27.9	23.7	22.6	20.4	20.5	23.6	125.8	141.7	20.6	20.7	25.0	26.7
Test 9	133.3	**144.6**	106.5	**77.9**	80.9	73.4	82.1	71.4	63.6	66.1	54.5	36.1	35.2	39.9	41.7	21.2	21.6
Test 10	**86.0**	79.6	83.0	158.0	125.4	118.4	**95.1**	96.5	86.3	87.1	71.5	45.1	43.0	50.0	52.6	17.9	18.6
Test 11	73.4	73.6	79.9	**93.1**	92.4	116.9	94.7	**86.8**	85.3	90.6	65.8	27.2	22.9	41.1	42.8	25.9	26.0
Test 12	133.1	**85.5**	127.7	**101.1**	158.1	152.9	142.3	**97.6**	97.8	97.3	106.1	77.7	74.0	77.9	78.3	28.3	29.9
Test 13	94.3	90.8	91.4	126.0	**101.4**	98.1	86.9	103.6	84.4	88.3	73.3	53.3	51.4	59.4	59.4	23.2	24.2
Test 14	669.80	600.20	717.00	884.30	785.10	718.20	732.90	620.00	499.70	492.60	437.00	226.90	222.30	160.60	167.40	75.20	80.60

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Table C 7 Peak temperatures measured at the thermocouple trees (degrees Celsius) – note T36 is a single thermocouple located above the NW corner

	T18	T19	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30	T31	T32	T33	T34	T35	T36
Test 1	150.1	149.1	105.2	33.5	333.4	229.3	236.3	58.9	140.1	65.5	53.9	36.6	27.5	26.9	26.6	26.4	85.6	147.2	303.5
Test 2	81.6	79.0	55.9	35.3	252.7	131.0	254.2	88.3	68.7	60.1	49.8	36.0	24.4	24.6	24.5	24.5	32.3	79.1	193.1
Test 3	114.2	65.2	59.6	33.0	130.3	117.2	94.0	33.3	155.3	121.9	92.9	40.6	26.2	24.2	23.0	21.6	64.9	110.8	118.3
Test 4	99.0	97.0	76.4	33.8	210.6	106.1	87.0	97.3	111.4	95.9	71.5	39.3	26.4	25.8	25.3	25.0	45.5	97.9	372.2
Test 5	62.2	62.8	48.0	39.6	103.0	56.6	47.1	46.3	58.2	50.5	34.6	36.9	23.6	23.8	23.7	23.7	31.9	38.8	343.6
Test 6	89.7	89.1	72.2	42.4	132.7	47.4	45.9	42.0	108.3	93.2	46.2	41.3	23.1	21.9	20.8	20.8	54.6	53.8	304.2
Test 7	98.8	97.6	60.0	37.3	151.8	45.0	39.4	36.7	117.9	69.3	43.4	36.0	58.2	52.6	48.3	40.0	43.9	53.9	348.2
Test 8	26.4	24.5	20.1	21.1	20.3	20.2	20.2	39.4	32.8	31.3	20.3	20.3	243.4	70.6	63.1	57.1	25.7	27.4	22.3
Test 9	59.4	53.6	38.0	28.7	81.3	43.4	38.2	25.0	58.1	49.3	31.8	25.8	34.2	33.7	29.2	21.3	25.4	35.3	89.8
Test 10	65.6	73.4	59.8	28.6	212.1	72.9	46.7	38.7	80.3	66.6	35.8	29.4	36.1	35.5	28.0	20.8	24.3	38.8	344.8
Test 11	71.3	71.7	50.0	32.9	87.6	44.0	39.7	34.6	83.6	65.2	40.6	35.6	22.0	22.0	21.4	21.1	41.9	35.5	250.7
Test 12	113.6	69.7	45.7	32.3	165.3	118.6	74.7	33.5	127.7	114.7	45.2	29.2	68.1	64.4	56.2	25.7	44.5	38.5	328.1
Test 13	82.0	82.6	70.6	30.4	123.2	50.3	44.6	34.9	80.1	62.8	36.3	35.6	47.9	46.1	43.9	25.3	32.9	40.7	249.2
Test 14	507.2	550.1	507.3	316.9	918.0	910.6	765.5	581.3	710.6	657.7	569.8	487.3	192.3	169.0	149.7	74.3	397.8	576.9	853.3

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