Home Fire Sprinkler Coalition Australia

Automatic Fire Sprinkler System for Class 1A Homes

Sprinkler System Efficacy Study

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Arup Australia Pty Ltd | ABN 76 625 912 665

Arup Australia Pty Ltd
Level 5
151 Clarence Street
Sydney
NSW, 2000
Australia
arup.com

ARUP

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Executive Summary

The Home Fire Sprinkler Coalition Australia (HFSCA) is overseeing the development of a safe, reliable, cost-effective and fit-for-purpose automatic home fire sprinkler system for Class 1a buildings (homes) for Australia conditions. This is referred to in the report as the HFS102 home fire sprinkler system (former working title FPAA102).

As part of this system, it is proposed that the minimum design performance of the HFS102 home fire sprinkler system is for the operation of the most hydraulically disadvantaged single (one) sprinkler head, operating at a flow rate and residual pressure necessary to achieve the desired sprinkler coverage in accordance with the sprinkler head's listing.

Typically, Australian and international standards for residential fire sprinkler systems, for example FPAA101D, FPAA101H, AS2118.5-2008, BS 9251:2021, and NFPA13D, have a basis of design that requires pressures and flows to operate the most hydraulically disadvantaged two (2) heads. Herein referred to as 'conventional' domestic sprinkler systems.

The scope of this study is to study the efficacy of the proposed HFS102 system. CFD modelling was undertaken to:

- Demonstrate the HFS102 system performance in simulations of 'real fire' events, and
- Compare the HFS102 system performance against the Class 1a status quo, i.e. no sprinkler protection. Fire sprinkler protection is not required in Class 1a buildings under the National Construction Code - Building Code of Australia (NCC BCA) requirements.
- Compare the HFS102 system performance against a 'conventional' domestic sprinkler systems, with respect to water supply and the resulting pressures and flows. The basis of the 'conventional' domestic sprinkler systems was a series of full scale fire tests undertaken by FRNSW in 2017 [1].

From statistical data the majority of domestic fires are controlled by a single sprinkler head activation. Where fire sprinklers are installed and the fire event is large enough to activate a sprinkler head, the fire sprinkler system is effective 97% of the time. In almost 90% of home fires with operating sprinklers, only one fire sprinkler head operated [2].

Based on the typical coverage of a residential sprinkler head is 24m² and that typical room sizes in a residential dwelling in Australia are less than 24m², except for larger houses where large or open living spaces can exceed 24m², with respect to the efficacy of the fire sprinkler system, the majority of rooms/spaces in a residential dwelling will achieve sprinkler coverage with one head; in these cases, the number of sprinkler heads activating is most likely going to be limited to the one sprinkler head in the room. Therefore, compliant pressure and flow will be achieved and it is highly unlikely that the fire sprinkler system will become overwhelmed in a fire event. In these cases the HFS102 system is equivalent to a 'conventional' domestic sprinkler system.

The CFD modelling shows that in situations where there may be multiple sprinklers in a room and more than one sprinkler head can operate in an HFS102 system, despite the reduced performance, the HFS102 system was effective in controlling fire growth, and spread, resulting in conditions better than a non-sprinkler protected simulation. For example, in the high challenge case, where the 'no sprinkler' case fire conditions reached flashover, in the HFS102 system simulation all four sprinkler heads operated. Despite the pressure and flow at each sprinkler head being a fraction of the sprinkler head's listed pressure and flow, 29% and 53% respectively, the fire sprinkler system reduced the temperatures within the room and maintained conditions in the room such that flashover did not occur.

The CFD modelling demonstrated that the HFS102 system would meet the objectives of a 'conventional' domestic sprinkler system, and the fire safety objectives for Class 1a buildings.

The Objective is to—

(a) *safeguard the occupants from illness or injury by alerting them of a fire in the building so that they may safely evacuate; and*

(b) ***avoid the spread of fire.***

Though the simulations did not exactly replicate the full scale fire tests, they provide insight to the expected behaviour of the fire sprinkler system under different conditions. The benefit of utilising fire modelling is that combinations of variables can be modelled relatively quickly and cost-effectively. As such, it can be used to test combinations of a variety of sprinkler designs, room/ dwelling configurations, and fuel package configurations to stress test the sprinkler system and its design criteria.

At this stage CFD modelling of the sprinkler system does not replace the data that is able to be gathered from full scale testing. However, it can be used as a precursor to full scale testing by identifying critical combinations of parameters, to maximise the benefit of full scale testing and reducing the number of expensive full scale tests required.

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1. Introduction

1.1 Project Description

The Home Fire Sprinkler Coalition Australia (HFSCA) is overseeing the development of a safe, reliable, cost-effective and fit-for-purpose automatic home fire sprinkler system for Class 1a buildings (homes) for Australia conditions; this is referred to in the report as the HFS102 home fire sprinkler system (former working title FPAA102).

It is proposed that the minimum design performance of the HFS102 home fire sprinkler system is for the operation of the most hydraulically disadvantaged single (one) sprinkler head, operating at a flow rate and residual pressure necessary to achieve the desired sprinkler spacing (coverage) in accordance with the sprinkler head's listing.

Typically, Australian and international standard's residential sprinkler systems, for example FPAA101D, FPAA101H, AS2118.5-2008, BS 9251:2021, and NFPA13D, have a basis of design that requires pressures and flows to operate the most hydraulically disadvantaged two (2) heads. Designing for two (2) heads operating would increase the number of homes requiring additional pumps and therefore increase the initial cost, and ongoing maintenance requirements, among other concerns. This is anticipated to reduce the potential uptake of domestic sprinkler systems.

There are other aspects of the proposed HFS102 system which deviate from the various 'conventional' domestic sprinkler system standards; however these aspects are beyond the scope of this study.

1.2 Scope of this Study

The scope of this study is to:

- To review the benefits of a fire sprinkler system compared to the status quo, i.e. no sprinkler protection in the majority of residential dwellings. Fire sprinkler protection is not required in Class 1a buildings under the National Construction Code - Building Code of Australia (NCC BCA) requirements.
- To study the efficacy of an HFS102 system by:
  - Comparing the system to a 'conventional' domestic sprinkler systems (FPAA101D, FPAA101H, AS2118.5-2008, BS 9251:2021, NFPA13D), with respect to water supply and the resulting pressures and flows.
  - Assessing the HFS102 system with respect to its ability to prevent fire spread from the area of fire origin.

This report does not consider the level of property protection, business interruption, or environmental protection associated with the provision of a home sprinkler system, or insurance issues.

1.3 Assessment Methodology

1.3.1 Benefits of Fire Sprinkler Protection

To review the benefits of an HFS102 system compared to the status quo, an assessment of statistical data and research is undertaken to examine the risks and consequences arising from fires in non sprinklered residential dwellings. This is then compared to the consequences for sprinkler protected residential buildings. This is undertaken in section 3.

This is not intended to be an extensive study, as a literature review is being undertaken by others as part of the HFSCA project. The purpose of this study is to provide context for the efficacy study.

The relevant building classification for this study is Class 1a; however as fire sprinkler systems are not required in Class 1a buildings the study includes data from other types of residential dwellings (Class 2); this is further explained in section 2.

1.3.2 Study of HFS102 Efficacy

With respect to the efficacy of the fire sprinkler system, the majority of rooms/spaces in a residential dwelling will achieve sprinkler coverage with one head; in these cases, the number of sprinkler heads activating is most likely going to be limited to the one sprinkler head in the room. The typical coverage of a residential sprinkler head is $24m^2$ and typical room sizes in a residential dwelling in Australia are less than $24m^2$, except for larger houses where large or open living spaces can exceed $24m^2$, this is detailed further in Appendix A. Therefore, compliant pressure and flow will be achieved and it is highly unlikely that the fire sprinkler system will become overwhelmed in a fire event. In this case the HFS102 system is equivalent to a 'conventional' domestic sprinkler system.

The challenge cases for the HFS102 system is in rooms where there are two or more fire sprinkler heads, where multiple heads could activate in a fire event, reducing the water pressure and flow from the sprinkler head. Should a fire continue to grow despite the activation of the fire sprinkler system, multiple sprinkler heads may then activate and overwhelm the fire sprinkler system.

An engineering study was conducted to explore the cases where more than one head activates. A series of computational fluid dynamics (CFD) models were conducted to study the efficacy of an HFS102 system. The basis for the engineering study is outlined in section 4.

CFD modelling was undertaken as a proxy for full scale fire testing to demonstrate the relative efficacy of the HFS102 system. The objective of the CFD study was first to test for reasonable replication of full scale testing undertaken by FRNSW [1], then model the HFS102 system and compare performance against the full scale testing. The results are summarised in section 4.6.

It is noted that this study does not account for pressure losses through a water meter nor a reduction in water supply to account for any bleed for domestic usage.

2. NCC BCA Context

The NCC is Australia's primary set of technical design and construction provisions for buildings. The technical building requirements for Class 2 to 9 buildings are mostly covered by Volume One of the NCC and those for Class 1 and 10 are mostly covered by Volume Two of the NCC. Volume Three of the NCC covers plumbing and drainage requirements for all building classifications.

Compliance with the NCC is achieved by complying with the Governing Requirements of the NCC; and the Performance Requirements.

Performance Requirements are satisfied by one of the following, as shown in Table 1, Performance Solution, Deemed-to-Satisfy (DtS) Solution or a combination of the two.

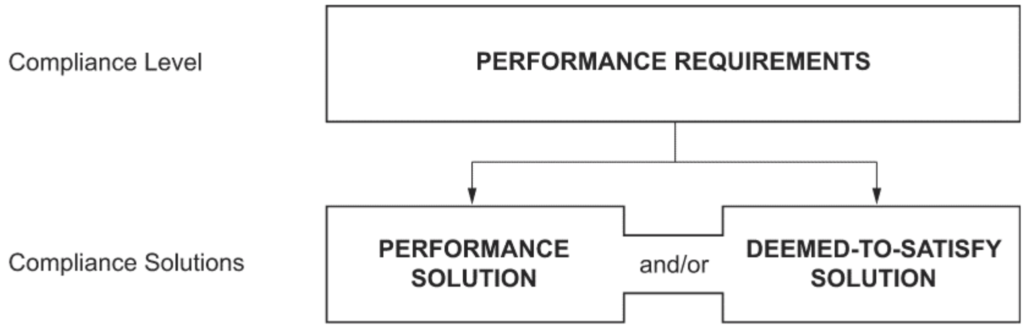

Table 1: NCC Compliance Structure (Figure A2G1) [3]

This section references the NCC BCA Volume One [3] and Volume Two [4].

2.1 Building Classification

The NCC groups buildings and structures by the purpose for which they are designed, constructed or adapted to be used, assigning each type of building or structure with a classification.

The building classifications are labelled "Class 1" through to "Class 10". Some classifications also have sub-classifications, referred to by a letter after the number (e.g. Class 1a).

The building classification for residential dwellings that are considered in this study is:

A **Class 1** building is a dwelling. The Class 1a sub-classifications is one or more buildings, which together form a single dwelling including the following:

- A detached house.
- One of a group of two or more attached dwellings, each being a building, separated by a fire-resisting wall, including a row house, terrace house, town house or villa unit.

Class 1b, Class 2, Class 3 and Class 4 buildings [1] are explicitly excluded from this study.

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[1] Other NCC residential building classifications:

- A Class 1b is one or more buildings which together constitute, a boarding house, guest house, hostel or the like; or four or more single dwellings located on one allotment and used for short-term holiday accommodation.
- A Class 2 building is a building containing two or more sole-occupancy units. Each sole-occupancy unit in a Class 2 building must be a separate dwelling. A Sole-occupancy unit is a room or other part of a building for occupation by one or joint owner, lessee, tenant, or other occupier to the exclusion of any other owner, lessee, tenant, or other occupier.
- A Class 3 building is a residential building providing long-term or transient accommodation for a number of unrelated persons.
- A Class 4 is a dwelling in a Class 5, 6, 7, 8 or 9 building if it is the only dwelling in the building. Class 4 classification applies to some tyes of accommodation located within a Class 5-9 building. The most common include a caretaker's flat within a building; and accommodation over or otherwise connected to a shop.

2.2 Fire Sprinkler Requirements Class 1a Buildings

Fire Safety Objectives

Within Volume Two, Part H addresses fire safety, the introduction states, *this Part is intended to minimise the risk of illness, injury or loss of life occurring due to fire*. The Objectives H3O1 states:

'The Objective is to—

(a) safeguard the occupants from illness or injury by alerting them of a fire in the building so that they may safely evacuate; and

(b) avoid the spread of fire.'

Deemed to Satisfy Provisions

For a Class 1a building, the minimum fire systems required to meet the NCC BCA DtS provisions are smoke alarms, complying with Part 9.5 of the ABCB Housing Provisions.

There are no requirements for a fire sprinkler system to be installed in Class 1a dwellings.

2.3 Discussion

The fire safety objectives for Class 1a dwelling and the minimum required fire safety measures are focused on alerting occupants to a fire so that *may safely* evacuate, and avoiding fire spread to other dwellings. The NCC BCA sets out the minimum building requirements. As there is no regulatory trigger or BCA DtS provision to require fire sprinklers in residential dwellings, the impetus to install sprinklers is on the owner. As such, very few residential dwellings (Class 1a) are fitted with fire sprinkler systems.

3. Study of Residential Dwelling Fire Events

3.1 General

A detailed literature review has been undertaken by others. A short study of statistical data is included here to understand the fire event is in residential dwellings and the effectiveness of sprinkler systems on potential consequences of a fire.

As there is no legislative requirement for Class 1a dwellings to have fire sprinkler systems, there are only a small number of homes where fire sprinkler systems are installed. As such it is not possible to undertake a statistical study of just Class 1a dwellings to understand the effect of fire sprinkler systems in mitigating the consequences of home fires.

Including Class 2 dwellings is considered reasonable, given that once inside the dwellings (SOUs) in a Class 2 building (residential apartment building), the function and use is the same i.e. private residential space. The rooms sizes and fuel loads are expected to be similar, as are the potential ignition sources.

3.2 Fire Incident Statistics Australia

Data from fire events clearly shows that residential dwelling fires account for the majority of fire fatalities, and that a significant portion of residential fires result in injury or fatality. For example, '*Preventable Residential Fire Fatalities in Australia July 2003 to June 2017*' [5] and '*Fire and Rescue NSW Adverse Structure Fire Outcomes 2016 – 2021*' [6] provide the following insights:

- In Australia between July 2003 to June 2017:
  - There were 810 preventable residential fire incidents that resulted in 900 cases of fatality.
  - In almost a quarter of the fatality cases 24.3% (219) the ignition origin of fire was unknown; of the known cases 28.0% (202) originated in the living room / lounge, and 27.0% (195) originated in the bedroom.
  - With respect to fire severity, 36.1% (250) of fatalities were in fires that burnt at least one room, 22.4% (155) in fires that destroyed the entire residence and 19.9% (138) in fires after which major repairs were required. It is noted that a large number of fires resulting in fatality, the fire severity is unknown 23.0% (207).
- From the NSW data from 2016 – 2021, there were 30,891 structure fire[2], the largest proportion of structure fire were in Class 1a dwellings 54.6% (16,866):
  - Resulting in 1,630 injuries and 71 fatalities from the fires in Class 1a dwellings.
  - The fire spread beyond the room of origin in 3,488 of these structure fires.

A study on the causes, characteristics, and consequences of residential fire incidents in Class 1a dwellings in NSW during 2005 to 2014 found that sprinkler systems were present in 0.9% of fire-related incidents, with sprinklers not present in 55.2% and the presences of sprinklers was undetermined in 43.9%.

Table 2: Presence of sprinkler systems in residential fire-related incidents from 2005 to 2014 in NSW Australia [7]

Sprinkler Status	Number	Percentage
Present	396	0.9%
Not Present	24,117	55.2%
Undetermined	19,194	43.9%

[2] 30,891 structure fires led to a total of 109,592 persons evacuated, 2,346 injuries, and 88 fatalities, the fire extended beyond the room of origin in 5,417 cases.

The status quo is that fire sprinkler protection is not required in Class 1a residential dwellings in Australia, therefore it is likely that the majority, if not all, of the cases identified as undetermined did not have fire sprinklers present.

3.3 Merits of Fire Sprinkler Protection

In order to reduce fire fatalities and injuries, the number of and/or severity of residential fires needs to be reduced. Based on data available, refer Appendix A, the presence of fire sprinklers significantly reduces the likelihood:

- A fire will spread beyond the object or room of fire origin, and
- Of injury and fatality in a residential dwelling fire.

A comprehensive study of fires, between 2015 and 2019, where there was sprinkler protection was undertaken by NFPA [2] found that:

- Of the fire events in fire sprinkler protected homes, 95% of the fires were large enough to activate the sprinklers and they were effective at controlling the fire in 97% of the fires in which they operated.
- In 99.5% of one to five sprinkler heads activated. In 89.3% of home fires where operating sprinklers were present, only a single head activated.

4. Engineering Study

4.1 Objective of Engineering Study

The objective of this study is to quantitatively demonstrate HFS102 system's effectiveness in controlling a fire event in a residential dwelling environment.

4.2 Approach

The engineering study considered:

- The performance of the proposed HFS102 systems compared with performance of a home sprinkler system designed to the criteria of the existing home sprinkler standards.
- Reviewing the performance of the proposed HFS102 system and its ability to control the spread of fire.

The approach was to develop CFD models, using the modelling software Fire Dynamics Simulator (FDS), to simulate fire events within a full-scale residential dwelling and model the response of the fire sprinkler system. The modelling validation and the scenarios in this study are based on a series of fire tests conducted by FRNSW [1] (FRNSW Test), as detailed in Appendix B.

The CFD modelling is a proxy for full scale testing of the HFS102 system for the purposes of determining the potential performance of the HFS102 system in real fire scenarios.

4.3 Basis of Home Fire Sprinkler System Design

4.3.1 Design Criteria

Conventional Domestic Sprinkler Systems

The design criteria for the current standards for home sprinkler systems, for example, FPAA101D, AS2118.5, NFPA13D etc. are summarised in Appendix A, the design criteria of each of the systems is fairly similar.

For AS2118.5 the design criteria is:

Home sprinkler systems shall be hydraulically designed to provide a flow of at least 50 L/min from each sprinkler. The sprinkler coverage, minimum pressure and flow requirements for approved home sprinklers (see Clause 4.3.1) shall be in accordance with the sprinkler approval listing details specified in the manufacturer's data sheets. The number of sprinklers assumed to be in simultaneous operation shall be ***two****.* The design flow for the sprinkler system shall be not less than 100 L/min plus an additional 12 L/min for possible simultaneous domestic demand from such appliances as washing machines and dishwashers...

Proposed HFS102 System

The design criteria for the proposed HFS102 system is:

*The minimum design performance of the HFS102 home fire sprinkler system is for the operation of the most hydraulically disadvantaged single (****one****) sprinkler head, operating at a flow rate and residual pressure necessary to achieve the desired sprinkler spacing (coverage) in accordance with the sprinkler head's listing.*

4.3.2 Residential fire sprinkler head

The assessment is based on the fire sprinkler head that was used in the FRNSW tests, Tyco Rapid Response Series LFII Residential 4.9 K-factor Pendent Sprinkler [14] [15]. The minimum pressure and flow for 3.7m spacing, 4.3m spacing, and 4.9m spacing is 49.2L/min and 48kPa, resulting in a sprinkler coverage area of 24m^2, refer Appendix A.

4.4 Assessment Criteria

It is noted that the objective for AS 2118.5 is:

The objective of this Standard is to provide a sprinkler system that, together with smoke alarms, will detect and control fires in a home, thus providing a level of protection against injury or loss of life, together with reduction of property damage. A sprinkler system designed and installed in accordance with this standard is ***expected to delay and possibly prevent flashover (total room involvement) in the room of fire origin*** *and to improve the likelihood of occupants escaping or evacuating.* ***(emphasis added)***

The assessment of the HFS102 system is against the same criteria; as such, the fire sprinkler system meets the objective of the home fire sprinkler system and can be deemed effective when it is demonstrated the system can delay and possibly prevent flashover (total room involvement) in the room of fire origin. The assessment criteria focus on radiant heat and temperature.

- Fire sprinkler activation.
- Fire spread or ignition of other combustible objects in the room is considered to occur:
  - The radiant heat at a combustible object exceeds 10kW/m² which corresponds to the radiant heat flux of curtain material in the presence of a spark [13].
- Flashover is considered to occur: [16].
  - The direct radiation at floor level reached 20kW/m².
  - The temperature in the upper layer reaches approximately 600°C.

4.5 Assessment Methodology

CFD modelling can simulate the effects of sprinkler activation (sprinkler spray pattern, control of fire size, reduction of smoke temperature etc.); however, the input parameters need to be determined for the specific fire sprinkler system's design.

The methodology developed to study the HFS102 system is:

1. Develop a CFD model and associated inputs to reasonably replicate the FRNSW tests.
2. Model the HFS102 system in the CFD model with the same inputs as established in step 1, except with reduced pressure and flow due to the difference in the basis of design.
3. Create a high challenge 'no sprinkler' multiple fuel package model and compare the performance of the FRNSW system and the HFS102 system.[3]

Refer Appendix B for CFD modelling inputs and detailed results from the simulations.

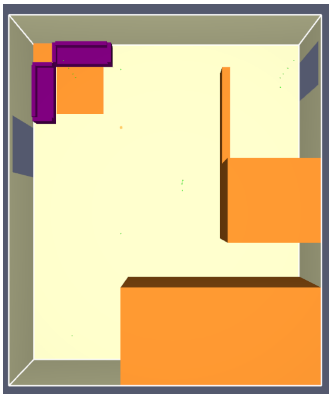
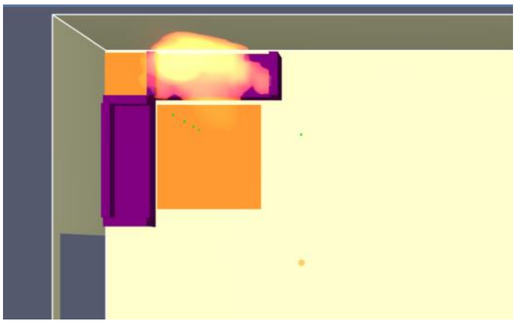
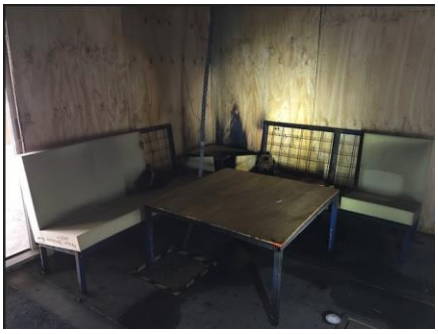
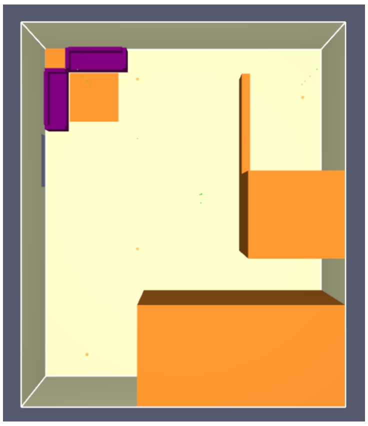
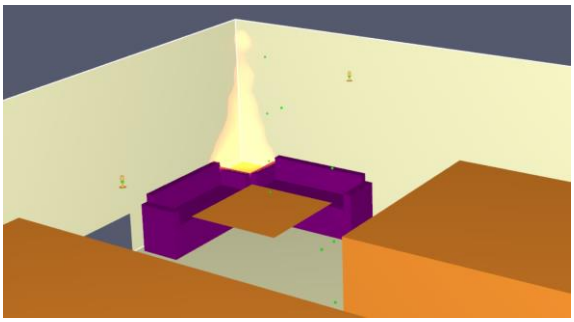
[3] Higher fuel load then any of the FRNSW tests.

4.6 Modelling Results

4.6.1 Validation using FRNSW Test Models

Validation of the models with the FRNSW tests (Test 4 and Test 6) assessed the sprinkler activation times.

Table 3: FRNSW Full Scale Test compared to FDS Models

FRNSW Test 4	FDS Model
Before Test  After Test 	 
FRNSW Test 6	**FDS Model**
Before Test  After Test 	 

The results below in Table 4 compare the sprinkler activation times in the simulations with the FRNSW tests.

Table 4: Fire Sprinkler Activation Time - FRNSW Fire Tests compared to FDS Simulations

Test	Origin	Scenario and Conditions	FRNSW Fire Test Sprinkler Activation times	Simulation Sprinkler Activation time Note 1
4	Lounge NW corner. Burner under coffee table.	UL-based corner test, external doors open, Internal doors closed, single sprinkler (UL location) only.	D1: 1 min 51 sec (111s)	D1: 60s (90s)
6	Lounge NW corner. Burner under side table.	Corner fire, stylised furniture, all doors closed.	D2: 1 min 13 sec (73s) D3: 2 min 37 sec (157s) D4: DNA D5: DNA	D2: 41s (71s) D3: 139s (169s) D4: DNA D5: DNA

Note 1: Modelled time (+ 30s time shift of the modelling results was utilised to align the models to the FRNSW Test results, as the CFD models do not include the initial incipient or growth phase of the burner).

DNA: Sprinkler heads were 'charged'/ modelled but Did Not Activate (DNA)

The modelling results demonstrate that, with a time shift in results to account for the growth rate of the burner in the real life tests which is not replicated in the models, the FDS results replicated sprinkler activation time, with an acceptable degree of accuracy, in Test 6 (the scenario with multiple heads active) with the time shift ±2s for the first head and ±12s for the second head. The simulations also depicted the degree of fire/ fire spread containment due to the fire sprinkler activation with a reasonable degree of accurately.

Based on the modelling results, FDS can reasonably predict fire sprinkler activation time and fire spread/ containment due to fire sprinkler activation.

4.6.2 HFS102 Design Comparison against FRNSW Tests System Design

To compare the fire sprinkler system designs, the FRNSW Test System and the HFS102 systems the following simulations were undertaken, using the validated Test 4 and Test 6 models:

- No sprinkler system,
- FRNSW test sprinkler system,
- HFS102 sprinkler system.

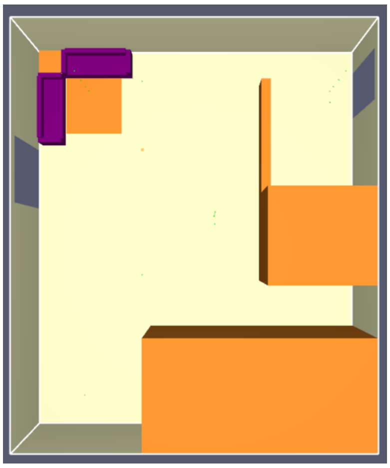
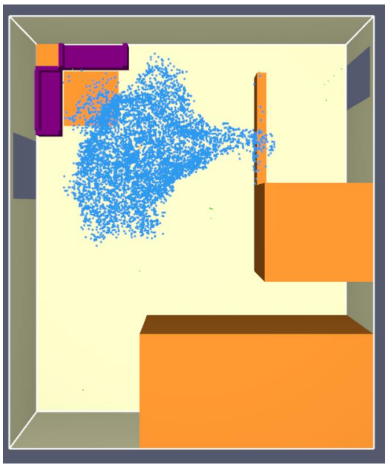
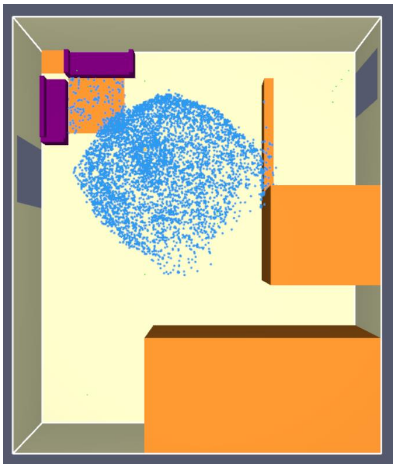
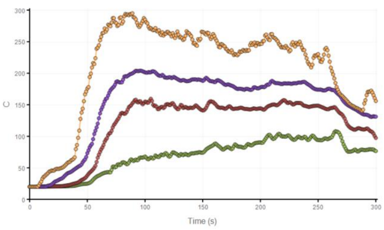
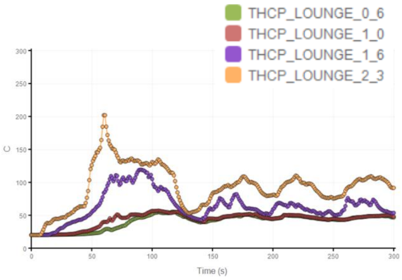
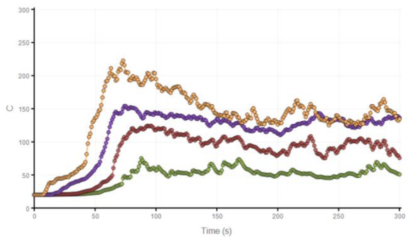
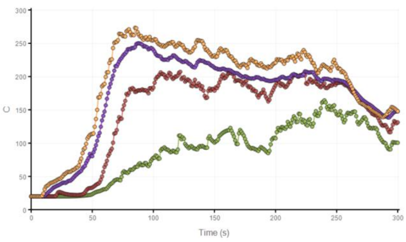
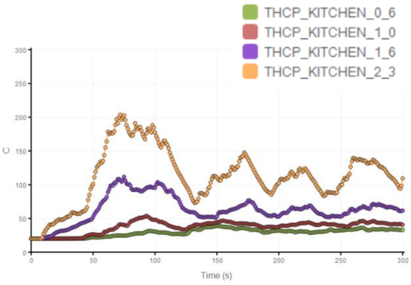
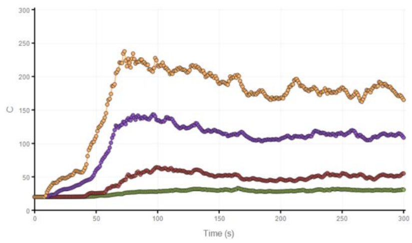
The 'no sprinkler' case provides a baseline to quantify the benefit of HFS102 system against the status quo.

Table 5: Fire Sprinkler Activation Time

Test	Origin	Scenario and Conditions	FRNSW Test System	HFS102 System
4	Lounge NW corner. Burner under coffee table.	UL-based corner test, external doors open, Internal doors closed, single sprinkler (UL location) only.	D1: 60s	D1: 58s
6	Lounge NW corner. Burner under side table.	Corner fire, stylised furniture, all doors closed.	D2: 41s D3: 139s D4: DNA D5: DNA	D2: 39s D3: 81s D4: 120s D5: DNA

DNA: Sprinkler heads were modelled but Did Not Activate (DNA) during the simulation.

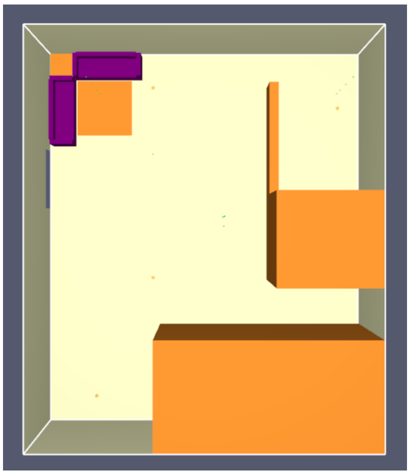
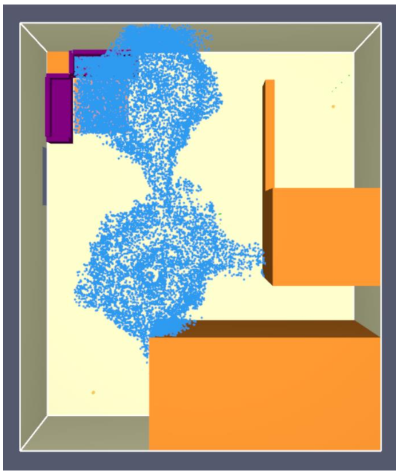
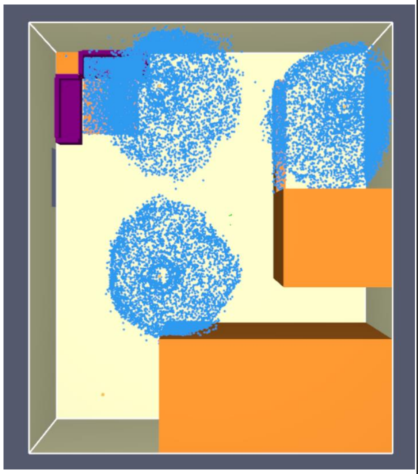
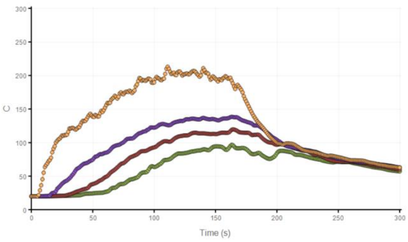
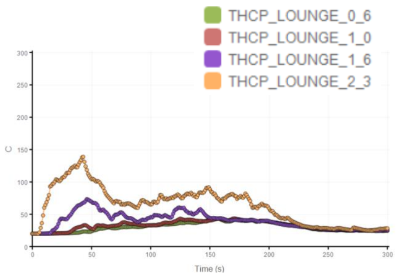
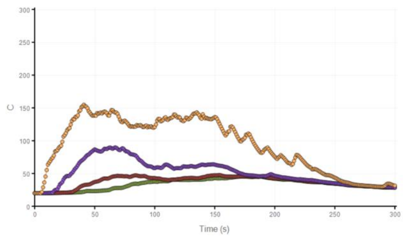
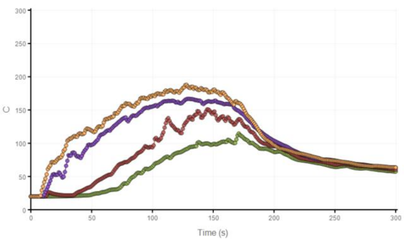
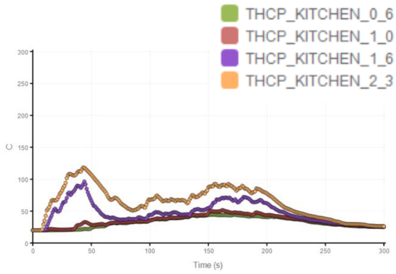
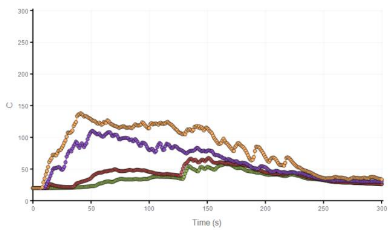
Table 6: Test 4 Configuration Modelling Results

No Sprinklers	FRNSW Test System	HFS102 System
Time = 0s 	Time = 300s 	Time = 300s 
Thermocouples Lounge 		
Thermocouples Kitchen 		

The simulation results show that temperatures in the area of fire origin rapid increase during the growth phase of the fire before sprinkler activation. With the one sprinkler head active in the space, the FRNSW system simulation has water pressure and flow significantly higher than the minimum requirement, once the sprinkler head operates there is a notable drop in temperature at the two different locations within the room (lounge and kitchen), and at different heights.

In this case the HFS102 sprinkler system also represents the minimum pressure and flow in accordance with the manufacturer’s data sheet. The simulation shows that the sprinkler activation effectively controls the fire, by limiting fire spread, and reducing the temperatures within the area of fire origin compared to the same model where there are no sprinklers.

Table 7: Test 6 Configuration Modelling Results

No Sprinklers	FRNSW Test System	HFS102 System
Time = 0s 	Time = 300s 	Time = 300s 
Thermocouples Lounge 		
Thermocouples Kitchen 		

The simulation results illustrate the differences in performance of the FRNSW system compared to the HFS102 system. With the FRNSW system the sprinkler system effectively controls the fire with only two fire sprinkler heads operating, in line with the design criteria. Noting that the FRNSW system simulation has water pressure and flow significantly higher than the minimum requirement.

The HFS102 system with the lower water pressure and flow, the reduction in temperature is more gradual and the as a result an additional fire sprinkler head activates. The HFS102 system, is however, still considered to control the fire and improve conditions, compared to the ‘no sprinkler’ case. With the HFS102 system case the room’s temperatures start decreasing before the temperatures peak in the ‘no sprinkler’ case.

4.6.3 High Challenge Case

To compare the fire sprinkler system designs, the FRNSW Tests systems and the HFS102 systems the following simulations were undertaken, using a model created to challenge both the fire sprinkler system designs. The fuel load density and location of the additional fuel packages in the lounge room and additional ventilation were configured so that, in the 'no sprinkler' case, a fire would spread to adjoining fuel packages and the room would reach flashover conditions.

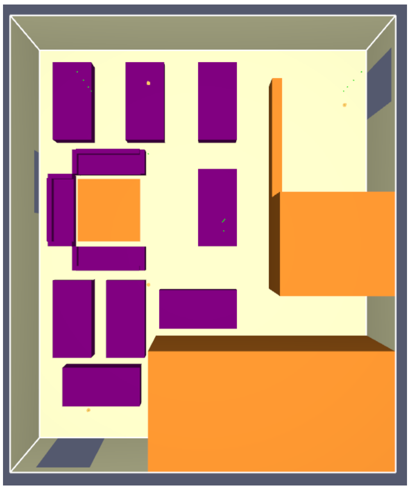
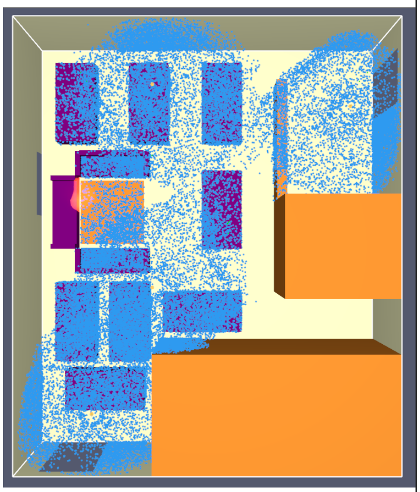
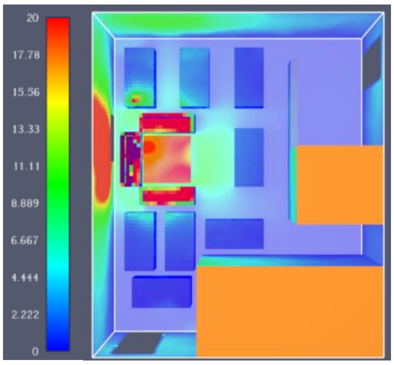
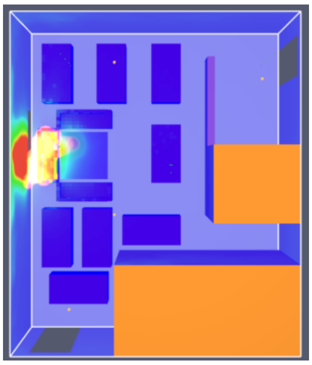
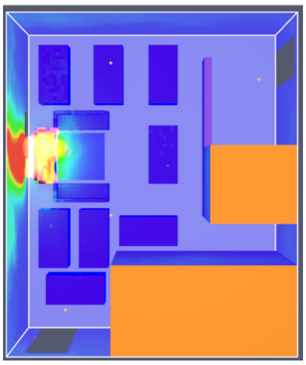
The following simulations were undertaken, using the validated Test 4 and Test 6 models:

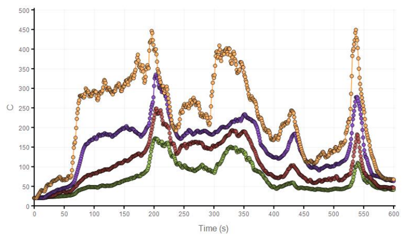
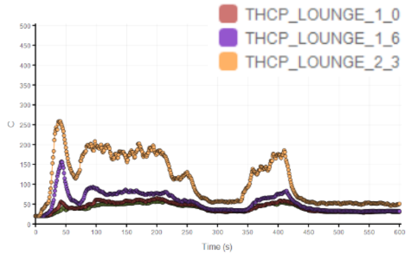
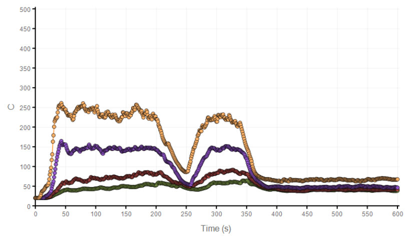
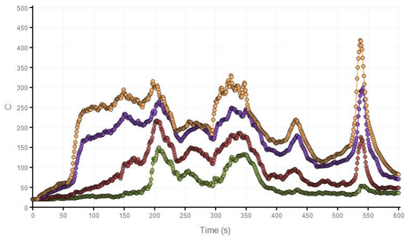
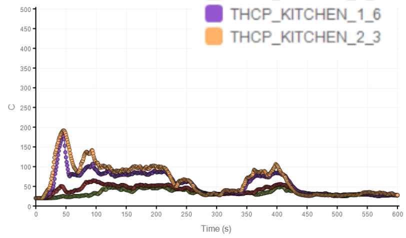
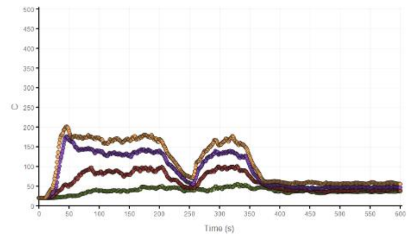
- No sprinkler system,
- FRNSW test sprinkler system,
- HFS102 sprinkler system.

Table 8: Fire Sprinkler Activation Time

Test	Origin	Scenario and Conditions	FRNSW System	HFS102 System
Challenge Case	Lounge centre of room. Burner under coffee table.	Multiple fuel loads and ventilation to maximise HRR in the no sprinkler condition.	D2: 44s D3: 41s D4: 93s D5: 51s	D2: 44s D3: 41s D4: 64s D5: 45s

Table 9: High Challenge Case Modelling Results

No Sprinklers	FRNSW Test System	HFS102 System
Time = 0s 	Time = 600s 	Time = 600s 
Total Heat Flux [kW/m²] Time = 140s 	Time = 140s 	Time = 140s 

No Sprinklers	FRNSW Test System	HFS102 System
Thermocouples Lounge 		
Thermocouples Kitchen 		

In the ‘no sprinkler’ case, at approximately 140s, the heat flux on the surfaces around the area of fire origin increased to over 20kW/m² and there was a rapid temperature spike, indicating the space was reaching flashover, the rapid reduction at 157s indicates the conditions within the space became ventilation controlled and there was insufficient oxygen within the space to sustain the complex combustion. This same phenomenon was repeated at 313s and 406s.

The simulation results illustrate the differences in performance of the FRNSW system compared to the HFS102 system. In both cases more sprinkler heads activated then the basis of design (two sprinkler heads and one sprinkler head, respectively).

Noting that in the FRNSW system simulation the water pressure and flow at all four sprinkler heads still achieved pressure and flow consistent with the manufacturer’s data sheet (49kPa and 49L/min at each sprinkler head) i.e. significantly higher than if the sprinkler system achieved the minimum requirement to comply with the ‘conventional’ domestic sprinkler standards.

The HFS102 system had significantly lower water pressure and flow at each sprinkler head (14kPa and 26L/s) by 65s into the simulation after the fourth sprinkler head activated. Despite the fire sprinkler system only achieving 29% of the design pressure and 53% of the design flow at each sprinkler head, the system effectively reduced the room temperature and sufficiently controls such that the room is prevented from reaching flashover conditions.

5. Findings & Conclusions

From statistical data, the majority of domestic fires are controlled by a single sprinkler head activation. Where fire sprinklers are installed and the fire event is large enough to activate a sprinkler head, the fire sprinkler system is effective 97% of the time. In almost 90% of home fires with operating sprinklers, only one fire sprinkler head operated [2].

Based on the typical coverage of a residential sprinkler head is 24m² and that typical room sizes in a residential dwelling in Australia are less than 24m², except for larger houses where large or open living spaces can exceed 24m², with respect to the efficacy of the fire sprinkler system, the majority of rooms/spaces in a residential dwelling will achieve sprinkler coverage with one head; in these cases, the number of sprinkler heads activating is most likely going to be limited to the one sprinkler head in the room. Therefore, compliant pressure and flow will be achieved and it is highly unlikely that the fire sprinkler system will become overwhelmed in a fire event. In these cases the HFS102 system is equivalent to a 'conventional' domestic sprinkler system.

The CFD modelling study first modelled the sprinkler performance of the system used in the FRNSW tests (the 'conventional' domestic sprinkler system) against the results of those tests, validating the CFD modelling. With a time shift in results to account for the growth rate of the burner in the real life tests which is not replicated in the models, the FDS results replicated sprinkler activation time with an acceptable degree of accuracy, for example, in 'Test 6'simulation the sprinkler head activation compared to the fire test results was ±2s for the first head and ±12s for the second head

Modelling then compared the sprinkler performance of the 'conventional' domestic sprinkler system against an HFS102 design for various fire scenarios. It is important to note that the FRNSW test systems performance exceeded the minimum design criteria [4] for a 'conventional' domestic sprinkler systems (FPAA101D, FPAA101H, AS2118.5-2008, BS 9251:2021, NFPA13D).

Based on the CFD modelling, as expected, activation of the first sprinkler is the same for the two systems. In rooms where only one sprinkler head is required to achieve complaint coverage the HFS102 system will provide equivalent performance/ protection to a 'conventional' domestic sprinkler system.

The modelling shows that in situations where there may be multiple sprinklers in a room the HFS102 system was not as effective at reducing the room temperatures as the FRNSW test system due to the lower water pressure and flows from each sprinkler head. Resulting in either: more heads operating, such as in the Test 6 model configuration where in the HFS102 system design three heads operated compared to the two heads operating in the FRNSW test system; or as in the high challenge case, all the sprinklers in the room activated for both systems (four heads) but the HFS102 system had lower pressure and flows from each sprinkler head.

Despite the reduced performance the modelling demonstrated that the HFS102 system was effective in controlling fire growth, and spread, resulting in conditions better than a non-sprinkler protected simulation. In the high challenge case, where the 'no sprinkler' case fire conditions reached flashover, in the HFS102 system simulation, despite the pressure and flow at each sprinkler head being a fraction of the sprinkler head's listed pressure and flow, 29% and 53% respectively, the fire sprinkler system reduced the temperatures within the room and maintained conditions in the room such that flashover did not occur.

The CFD modelling demonstrated that the HFS102 system would meet the objectives of a 'conventional' domestic sprinkler system, and the fire safety objectives for Class 1a buildings.

The Objective is to—

- *(c) safeguard the occupants from illness or injury by alerting them of a fire in the building so that they may safely evacuate; and*
- ***(d) avoid the spread of fire.***

---

[4] With respect to both pressure and flow.

Though the simulations did not exactly replicate the full scale fire tests, they provide good insight on the expected behaviour of the fire sprinkler system under different conditions.

CFD modelling can be used to test combinations of a variety of sprinkler designs, room/ dwelling configurations and fuel package configurations to stress test the sprinkler system and its's design criteria. Based on the modelling results:

- Modelling results can be used to identify critical combinations of parameters that may benefit from full scale testing.
- Full scale testing can be used to further refine and validate the modelling, if required.

6. References

[1] FRNSW, “Fire Research Report: Residential Sprinkler Research,” NSW State Government (FRNSW), Sydney, 2017.

[2] M. Ahrens, “US Experience with Sprinklers,” National Fire Protection Association, 2021.

[3] Australian Building Codes Board, *National Construction Code Volume One - Building Code of Australia,* vol. Volume One, Canberra, Australia: ABCB, 2022.

[4] Australian Building Codes Board, *National Construction Code Volume Two - Building Code of Australia,* vol. Volume One, Canberra, Australia: ABCB, 2022.

[5] L. Coates, G. Kaandorp, J. Harris, J. V. Leeuwen, A. Avci, J. Evans, S. George, A. Gissing, D. R. V. D. Honert and D. K. Haynes, “Preventable residential fire fatalities in Australia July 2003 to June 2017,” Bushfire and Natural Hazards CRC, Melbourne, 2019.

[6] D. K. Pooley, R. Lam and P. Duong, “FRNSW Adverse Structure Fire Outcomes 2016 -2021,” Fire and Rescue NSW, 2023.

[7] N. Ghassempour, K. Tannous, K. E. Agho, G. Avsar and L. A. Harvey, “Comparison of causes, characteristics and consequences of residential fires in social and non-social housing dwellings in New South Wales, Australia,” *Preventive Medicine Reports,* 2022.

[8] Coroners Court New South Wales, “Inquest into the death of Connie Zhang and inquiry into the fire at Unit 53, 4 West Terrace Bankstown,” 2015. [Online]. Available: https://coroners.nsw.gov.au/documents/findings/2015/Zhang%20findings%2018%2009%2015%20FINAL.pdf. [Accessed April 2024].

[9] Standards Australia, “AS 2118.5 Automatic fire sprinkler system - Part 5: Home fire sprinkler systems,” SAI Global Limited, 2008.

[10] Standards Australia, “AS 2118.4 Automatic fire sprinkler systems - Part 4: Sprinkler protection for accommodation buildings not exceeding four storeys in height,” SAI Global Limited, 2012.

[11] FPA Australia, “FPAA101D Automatic fire sprinkler system design and installation - drinking water supply,” 2021.

[12] FPA Australia, “FPAA101H Automatic fire sprinkler system design and installation - hydrant watwer supply,” 2018.

[13] Australian Building Codes Board, National Construction Code: Volume One - Building Code of Australia 2019 Amendment 1, Canberra, 2020.

[14] Tyco, *TFP400 - RAPID RESPONSE Series LFII Residential 4.9 K-factor Pendent Sprinkler Wet Pipe and Dry Pipe Systems,* 2016.

[15] Tyco, *TFP710 - SPRINKLER SPRAY PATTERNS Refer to the General Description section before applying the spray pattern data,* 2018.

[16] M. Spearpoint, Fire Engineering Design Guide, Christchurch: New Zealand Centre for Advanced Engineering, 2008, 2008.

[17] M. Ahrens and R. Maheshwari, “Home Structure Fires,” National Fire Protection Association , 2021.

[18] M. Runefors, N. Johansson and P. V. Hees, "How could the fire fatalities have been prevented? An analysis of 144 cases during 2011–2014 in Sweden: An analysis," *Journal of Fire Sciences,* 2016.

[19] NIST, "NIST Special Publication 1018-3 Sixith Edition Fire Dynamics Simulator Technical Reference Guide Volume 3: Validation," NIST, Gaithersburg, 2020.

Appendix A

Literature Review

A.1 Average Room Sizes

A selection of room sizes by room type as provided in an Australian guide to residential room sizes (https://buildsearch.com.au/average-room-size).

Room Type	Small			Large			Average
	Width [m]	Length [m]	Area [m²]	Width [m]	Length [m]	Area [m²]	Area [m²]
Master Bedroom	3.0	3.1	9.3	5.0	4.2	21.0	15.2
Minor Bedroom	2.8	2.5	7.0	4.0	3.3	13.2	10.1
Living	4.2	3.4	14.3	5.5	5.0	27.5	20.9
Kitchen	3.0	2.4	7.2	4.8	3.6	17.3	12.2
Dining	3.0	2.3	6.9	4.5	5.0	22.5	14.7
Lounge	4.0	3.4	13.6	5.5	5.0	27.5	20.6
Other living spaces (e.g. games room)	3.3	4.0	13.2	5.8	5.8	33.6	23.4
Bath	1.5	2.0	3.0	3.2	3.0	9.6	6.3
Toilet	0.9	1.3	1.1	1.3	1.8	2.3	1.7
Laundry	1.6	2.0	3.2	2.4	3.4	8.2	5.7
Garage	5.4	5.4	29.2	6.2	6.2	38.4	33.8

A.2 Summary of ‘Conventional’ Domestic Sprinkler System Standards

Sprinkler Standard	Design Criteria	Sprinkler Coverage
FPAA101D-2021	Home sprinkler systems shall be hydraulically designed to provide a flow of at least 50 L/min from each sprinkler. The sprinkler coverage, minimum pressure and flow requirements for approved home sprinklers (see Clause 4.3.1) shall be in accordance with the sprinkler approval listing details specified in the manufacturer’s data sheets. The number of sprinklers assumed to be in simultaneous operation shall be **two**. The design flow for the sprinkler system shall be not less than 100 L/min plus an additional 12 L/min for possible simultaneous domestic demand from such appliances as washing machines and dishwashers.	In accordance with the sprinkler approval listing details specified in the manufacturer’s data sheets.
FPAA101H-2018	N/A - Not included as homes do not have fire hydrant systems.	N/A
AS2118.5-2008 Automatic fire sprinkler systems, Part 5: Domestic sprinkler systems	Home sprinkler systems shall be hydraulically designed to provide a flow of at least 50 L/min from each sprinkler. The sprinkler coverage, minimum pressure and flow requirements for approved home sprinklers (see Clause 4.3.1) shall be in accordance with the sprinkler approval listing details specified in the manufacturer’s data sheets. The design flow for the sprinkler system shall be not less than 100 L/min (determined by multiplying the unit sprinkler flow (see Clause 4.2.1) by two)— (a) plus an additional 12 L/min for possible simultaneous domestic demand from such appliances as washing machines and dishwashers; or (b) alternatively, for independent systems only, a priority valve may be installed to shut off the domestic demand at the time of sprinkler operation.	Maximum coverage area per sprinklers 24.0m²
BS9251:2021 Sprinkler systems for residential and domestic occupancies. Code of Practice	The minimum design discharge densities, number of design sprinklers capable of operating simultaneously in a compartment (sprinkler) and duration of supply should be in accordance with Table 2. For all categories, the number of design sprinklers should be determined by the maximum number of sprinklers in any compartment (sprinkler) (see 3.10), up to the maximum in accordance with Table 2. The density of water delivered by each sprinkler should be calculated by the physical area of coverage, as opposed to the maximum area of the data sheet. In all cases, the manufacturer’s minimum head pressure for the corresponding coverage area should be met or exceeded (see Annex B, B.7). Table 2 for Category 1 system (Single family dwellings): • Minimum discharge density: 2.1 mm/min* • Number of sprinklers: 1 or 2 • Minimum duration of supply: 10 min *footnote relating to increased requirements for ‘higher ‘than normal risk profiles’	The manufacturer’s minimum head pressure for the corresponding coverage area should be met or exceeded
NFPA13D-2025 Standard for Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes	The system shall be provided at least the flow required to produce a minimum discharge density of 2.0mm/min or the sprinkler listing, whichever is greater, to the design sprinklers. For each of the situations, the number of sprinklers in the design shall be all of the sprinklers within the compartment.	Sprinklers shall be installed in accordance with their listing where the type of ceiling configuration is referenced in the listing.

Sprinkler Standard	Design Criteria	Sprinkler Coverage
	Up to a maximum of two sprinklers, that require the greatest hydraulic demand.	
NZS4517-2010 Fire sprinkler systems for domestic occupancies	Sprinklers other than residential type shall be installed only when allowed by 4.4.1. Areas where residential sprinklers are used: • No. sprinklers in the room – 1: 1 sprinkler operating at the listed pressure. • No. sprinklers in the room – more than 1: 2 sprinklers operating at the listed pressure.	Maximum area of coverage 21m² - depending on sprinkler type and orifice pressure.
HFS102 Design	*The minimum design performance of the HFS102 home fire sprinkler system is for the operation of the most hydraulically disadvantaged single (**one**) sprinkler head, operating at a flow rate and residual pressure necessary to achieve the desired sprinkler spacing (coverage) in accordance with the sprinkler head's listing.*	*Sprinkler spacing (coverage) in accordance with the sprinkler head's listing*

A.3 Example Residential Sprinkler Head Design Criteria

Tyco Series LFII Residential Sprinklers 4.9 K-factor Domed-Plate Concealed Pendent Wet Pipe Systems (Tyco® TFP450, 2022 Johnson Controls)

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 in. to 3/4 in. Beamed Ceilings per NFPA 13D or 13R Installed in Beam 1/4 in. to 3/4 in. 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

A.4 Sprinkler Studies

A.4.1 National Fire Protection Association , 2021

An NFPA study [17] investigated fire events in 'home structure fires' in the United States (US) between 2015-2019, it noted that, *'In a 2020 article, Nilson and Bonander describe five possible points of intervention to prevent fire deaths: "reduce heat; stop ignition of first object; hinder fire growth; initiate evacuation; and complete evacuation." The first two prevent the fire while the last three come into play after the fire starts. Smoke detection or another method of discovery can alert occupants to act — to evacuate or hinder the fire. Fire growth can be limited by depriving the fire of oxygen, by operating sprinklers, or by other means of fire control. The ability to complete evacuation depends on occupant characteristics, the location and size of the fire, and the availability of an exit.'*

The data demonstrates the effectiveness of automated extinguishing systems (AES) such as fire sprinkler protection to control a fire until help arrives, even when the occupants are unable to act.

Table 10: In part replication of Table A - Sprinkler Systems in Reported Home Structure Fires: 2015–2019 Annual Averages [17]

Item	Value
Percentage of reported home fires with sprinklers present	7.0%
When sprinklers were present and the fire was large enough to activate them, the percent that operated	95.0%
Percentage of fires with operating sprinklers in which sprinklers were effective in controlling the fire	97.0%
Percentage of fires in which sprinklers operated and were effective when sprinklers were present and the fire was large enough to activate them	92.0%
Civilian deaths per 1,000 reported fires	
• Without automatic extinguishing system (AES)	8.1
• When sprinklers were present regardless of operation	1.0
• Percent reduction when sprinklers were present	88%
Civilian injuries per 1,000 reported fires	
• Without automatic extinguishing system (AES)	33
• When sprinklers were present regardless of operation	24
• Percent reduction when sprinklers were present	28%
Firefighter injuries per 1,000 reported fires	
• Without automatic extinguishing system (AES)	51
• When sprinklers were present regardless of operation	11
• Percent reduction when sprinklers were present	78%

Using the same data, a companion study further explored the fire incidents where AES were present in home fires [2]. The percentage of reported home fires with sprinklers present was 7.0% which equates to 23,600 home structure fires. Of these 10% represented what is considered Class 1a residential dwellings in an Australian context.

It was found that a combination of sprinkler systems and hardwired smoke alarms resulted in the lowest home fire death rate, noting that the following rates are based only on presence and not operation [2].

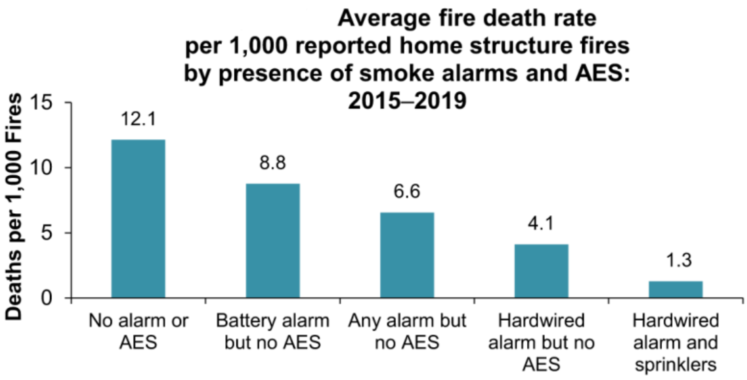


Figure 1: Average fire death rate per 1,000 reported home structure fires by presence of smoke alarms and AES: 2015-2019 [2].

With respect to efficacy of fire sprinkler installations, of the fire events in fire sprinkler protected homes, 95% of the fires were large enough to activate the sprinklers. They were effective at controlling the fire in 97% of the fires in which they operated. Taken together, fire sprinkler activated and were effective in 92% of cases. This is illustrated in Figure 2.

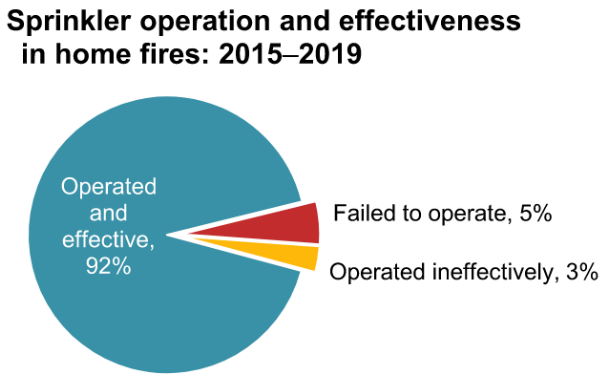


Figure 2: Sprinkler operation and effectiveness in home fires: 2015-2019 [2].

In 99.5% of home fires where operating sprinklers were present, one to five sprinkler heads activated, while 89.3% occurred with a single head activation, as shown in Figure 3.

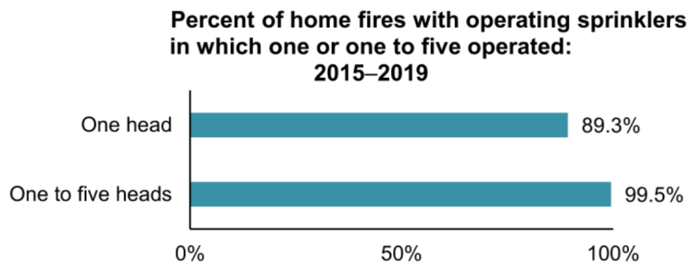


Figure 3: Percent of home fires with operating sprinklers in which one or one to five operated: 2015-2019 [2].

The data illustrated the benefits of fire sprinkler protection; in 97% of home fires where sprinklers were present, the fire was contained to the object or room of fire origin. Figure 4 also illustrates that there was an 88% reduction in fatality and a 28% reduction in injury rates in homes with sprinklers. Note the injury rate includes injuries that occurred in fire events that were too small to activate the automatic extinguishing systems (AES), or where people attempted to fight the fire before sprinklers could activate [2].

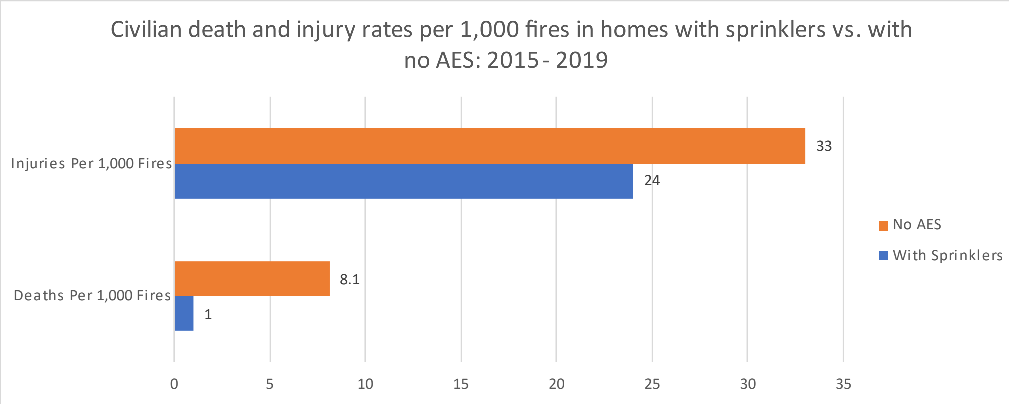


Figure 4: Civilian death and injury rates per 1,000 fires in homes with sprinklers vs. with no AES: 2015 – 2019 [2].

Most importantly, it was found that a combination of sprinkler systems and hardwired smoke alarms resulted in the lowest home fire death rate [2].

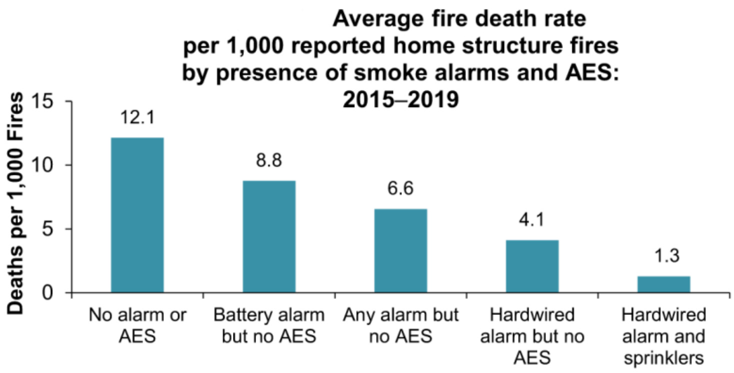


Figure 5: Average fire death rate per 1,000 reported home structure fires by presence of smoke alarms and AES: 2015-2019 [2].

A.4.2 Swedish Study, 2016

A Swedish study was undertaken to systematically study potential mitigation measures that could stop the negative progression of a fire event. [18]. The source data was unintentional lethal fires in residential buildings between 2011 and 2014 in Sweden and that were investigated by either the police or the fire department. A lethal fire was defined as all fatalities directly related to the fire that occurs within 30 days of the fire event. Based on the 144 cases, 23 mitigation measures were identified that could have prevented the fatalities in one or more cases were identified. Of these measures, a thermally activated suppression system was found to have the highest potential effectiveness (68%). Other mitigation measures included a detector-activated suppression system in bedroom and living room, smoke alarms, well maintained electrical systems, flame resistant clothing/ bedding/ furniture. In the study, thermal activated suppression systems such as sprinklers were differentiated from detector-activated suppression systems, as the study recognised that sprinkler activation may not be effective at preventing fatalities on the object of fire origin, such as a bed or sofa.

Appendix B

CFD Modelling

B.1 Modelling Validation

B.1.1 FRNSW Tests

In 2017 FRNSW published a Fire Research Report, *Residential Sprinkler Research* [1]. The report summarised the research undertaken to develop a fire sprinkler system that is cost effective (ideally cost neutral) and is suitable for installation in 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 NCC BCA. The research was in response to recommendations from the NSW Coroner's Court [8] from the inquest of a catastrophic unit fire in Bankstown, NSW in September 2012.

Central to the research was the development of a re-burnable test structure to be used to test the proposed sprinkler systems at the fire testing facility at CSIRO in North Ryde, NSW. The re-burnable unit replicated a 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.

Two sprinkler systems were used during the testing: one was a modified domestic system based on AS 2118.5 [9] and the other was a modified residential system, serviced by a fire hydrant system based on AS 2118.4 [10]. These tests became the basis of FPAA101D [11] and FPAA101H [12] Technical Specifications, which became reference standards in the NCC BCA 2019 Amendment 1 [13]. Within the test rig the research team conducted 14 tests over a 15-week period between February and May 2017. The tests replicated different fire locations, fuel packages, ventilation and sprinkler systems.

Given the controlled environment and the variety of test conditions the FRNSW tests provide an ideal basis for this engineering study. This study focusses on the tests associated with the design basis for the domestic sprinkler system (modified AS2118.5) and the resulting FPAA101D standard, as they are applicable to the Class 1a case.

B.2 Assessment Methodology

1. Develop a CFD model and associated inputs to reasonably replicate the FRNSW tests.
2. Model the HFS102 system in the CFD model with the same inputs as established in step 1, except with reduced pressure and flow due to the difference in the basis of design.
3. Create a high challenge 'no sprinkler' multiple fuel package model and compare the performance of the FRNSW system and the HFS102 system.[5]

B.2.1 Develop a validated CFD model.

The FRNSW tests were used to validate the CFD models, due to the amount of information available, and the variety of tests conditions undertaken in the same test rig. Modelling parameters and validation of the results was undertaken using information from product specifications, the FRNSW summary report, raw output data, and videos.

The FRNSW tests modelled during this stage were Test 4 and Test 6.

Table 11: FRNSW Sprinkler Test Configurations [1]

Test	Sprinkler System	Origin	Scenario and Conditions	Sprinkler Setup (charged sprinklers) Note 1
4	Domestic	Lounge NW corner	UL-based corner test, external doors open, Internal doors closed, single sprinkler (UL location) only	One head: D1. The pressure at the meter was set at 250 kPa.
6	Domestic	Lounge NW corner	Corner fire, stylised furniture, all doors closed	Seven heads: D2, D3, D4, D5, D6, D7 and D8. The pressure at the meter was set at 250 kPa.

Note 1: All other sprinkler heads in the test rig were made inoperable.

The inputs for the sprinkler parameters pressure and flow from each sprinkler head was not measured in the fire tests, so the pressure and flow at each sprinkler head was approximated by undertaking hydraulic calculations using the documented fire sprinkler layout drawings and the reported static pressure at the source (meter) i.e. 250 kPa.

B.2.2 Compare the HFS102 System performance against the FRNSW Test System

The FRNSW Test 4 and Test 6 models were modelled with the HFS102 design criteria. The inputs for the sprinkler parameters pressure and flow from each sprinkler head was determined by the following hydraulic calculations:

- To establish the minimum pressure necessary, the most disadvantaged sprinkler was set to operate at the designated minimum pressure and flow, and the corresponding source pressure that was calculated was the minimum requirement for the remaining hydraulic calculations. A static pressure of 110 kPa as calculated as required.
- Based on this static pressure, the pressure and flow at each sprinkler head was calculated depending on the number of fire sprinkler heads activated simultaneously.

[5] Higher fuel load then any of the FRNSW tests.

B.2.3 High Challenge Scenario

A model was created using the FRNSW test geometry but with additional fuel packages in the lounge room and additional ventilation, to create a non-sprinkler protected case where the fire continued to spread to adjoining fuel packages and reach flashover conditions.

The model was re-run with both sprinkler systems to determine if both fire sprinkler systems were effective at controlling the high challenge fire.

B.3 Modelling Input

B.3.1 Modelling Software

FDS Version 6 software (6.8.0) was used in this study to simulate three-dimensional air velocity, temperature, and smoke distribution within the flow domain of the model. FDS is a CFD analysis program developed specifically for fire and smoke spread modelling. FDS is CFD software developed by the Building and Fire Research Laboratory at the National Institute of Standards and Technology (NIST), Maryland, USA and the VTT Technical Research Centre of Finland.

The software solves a form of the Navier-Stokes equations appropriate for low-speed, thermally driven flow with an emphasis on smoke and heat transport from fires.

The verification and validation undertaken by NIST for FDS is well documented and publicly available to download from NIST [19].

The FDS models were developed using PyroSim developed by Thunderhead Engineering Consultants, Inc, and the results of the FDS simulations such as temperature and visibility are visualised and extracted using the companion visualising software within Pyrosim.

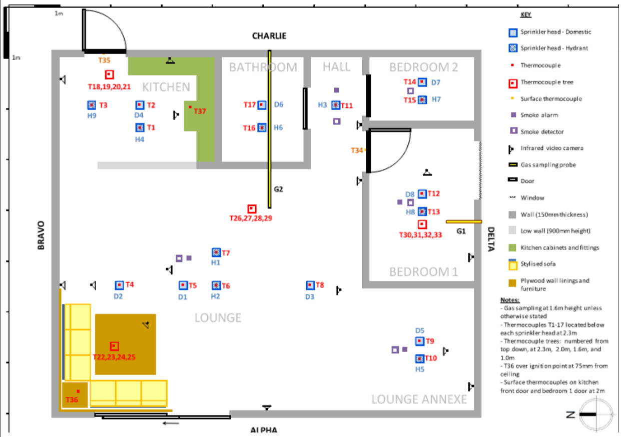
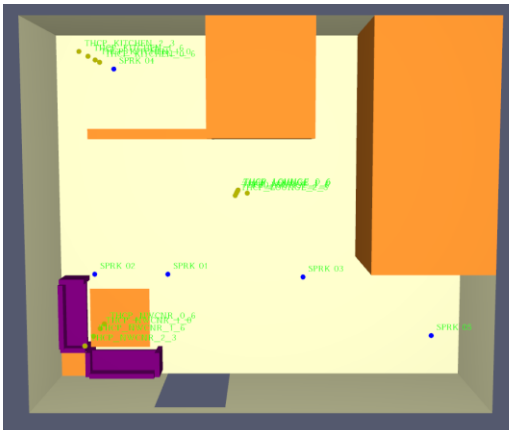
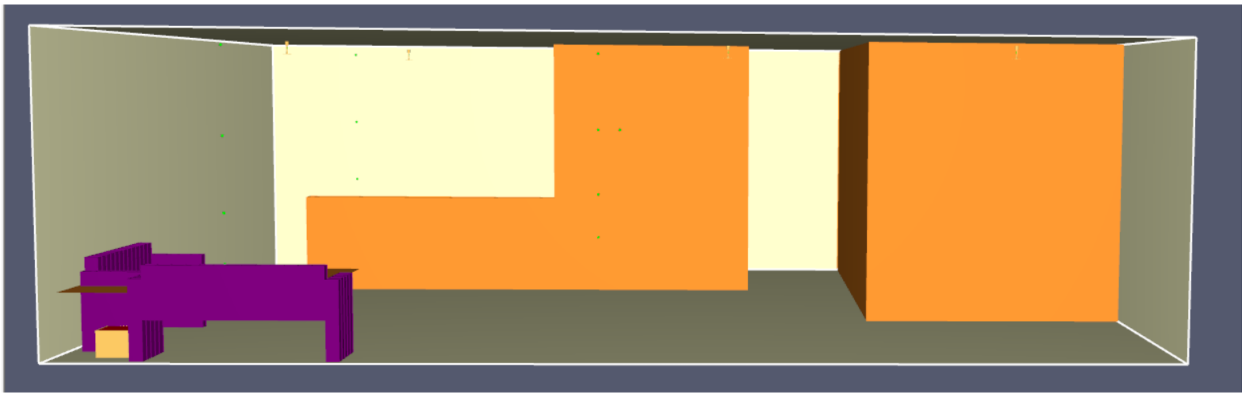
B.3.2 Model Geometry and Parameters

The CFD model used the same geometry as the FRNSW test rig as described above.

For the purpose of this study the bedrooms and bathrooms were modelled as solid blocks.

Table 12: Model Geometry

Parameter	Value
Mesh size	0.1m x 0.1m x 0.1m
Model Bounds	7.0m x 8.3m x 2.4m
Ventilation	External door open: 1.3m x 2.1m External door closed: 1.3m x 0.5m
Sprinkler Layout	As per test layout of domestic sprinklers (D1, D2, D3, D4, D5)

Parameter	Value
	
	

B.3.3 Fuel Packages and Test Materials

The fuel packages mirrored the stylised furniture pieces used in the tests, and included:

Table 13: Fuel Packages and Test Materials

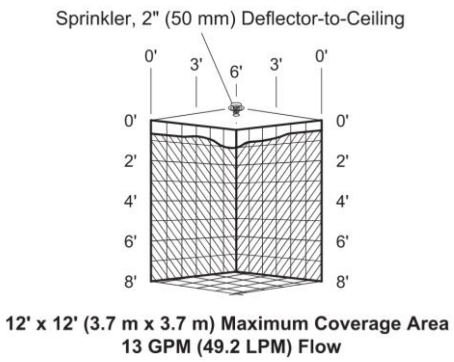
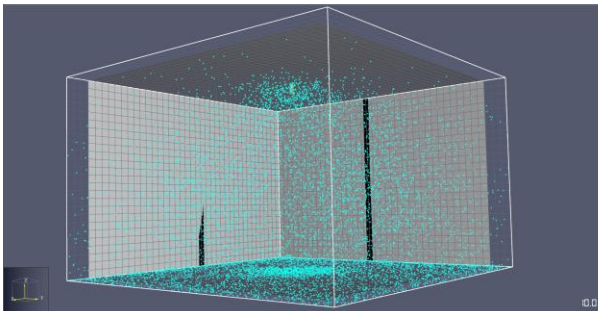
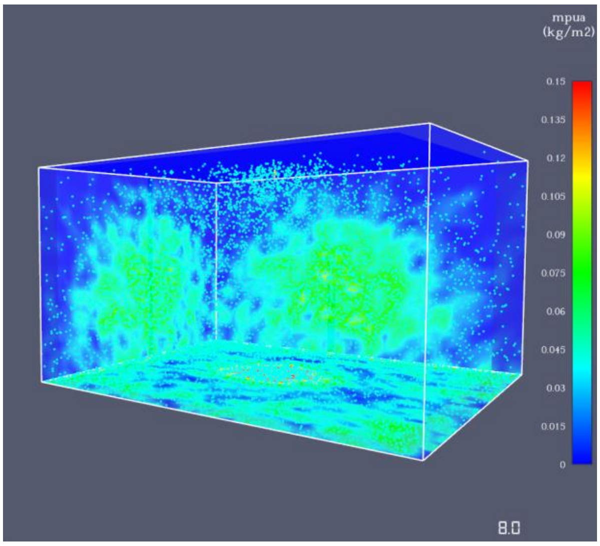
Used in Test	Modelled
Ignition source: 300 mm x 300 mm square stack crib constructed from 38 mm x 38 mm x 300 mm Douglas fir timber batons. The crib was placed above a steel tray containing 250 ml of heptane or kerosene, and 500 ml of water.	0.3m x 0.3m x 0.2m with the top surface as a square burner with a HRR of 100kW (simple pyrolysis model).
Steel-framed plywood coffee table (1.2 m x 1.2 m square)	1.2m x 1.2m surface (no thickness) Material properties of yellow pine (not involved in the pyrolysis model)
Steel-framed plywood side table (500 mm x 500 mm square)	0.5m x 0.5m surface (no thickness) Material properties of yellow pine (not involved in the pyrolysis model)
Two steel-framed polyurethane padded sofas (1.5 m long), general-purpose medium-density (26–27 kg/m3), polyurethane foam, 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.	1.5m long with 0.1m thick section, seat back and arm rests. Material properties of upholstery consisting of foam and fabric cover (complex pyrolysis model)
Walls – 16mm fire resistant gypsum board panels	16mm thick gypsum

As the focus of this study was the activation and performance of the fire sprinkler systems the material properties of the fuel packages were not validated, with default properties available within Pyrosim being used for the material properties.

B.3.4 Sprinkler Parameters

The principal input was the definition of the fire sprinklers. A separate validation study was undertaken to determine the various parameters used to define the fire sprinkler heads and sprinkler spray pattern. The parameters used in this study are outline below in Table 14.

Table 14: Fire Sprinkler Parameters

Fire Sprinkler Parameters	
Temperature Link: • Activation temperature: 68°C • RTI: 120 $(m.s)^{1/2}$ • C Factor: 0.5 **Spray Model:** • Flow rate (minimum design): – Operating pressure: 0.48 bar – K factor: 70.6 • Jet streams: – Offset: 0.05 – Type: conical – Velocity: 8.0 m/s – Angle: 30,120 **Water** • Duration: 10.0 s **Simulation parameters** • Particles disappear at floor: False **Outputs** • Boundary Water MPUA **Mesh** • 0.1m x 0.1m x 0.1m **Model Bounds** • 4.0m x 4.0m x 2.5m	 Ref: [15]  

In the full scale models, the pressure and flow was dependant on the number of sprinkler heads operating simultaneously, based on hydraulic calculations. As a simplification, the pressure was the same at each sprinkler head when multiple heads operated simultaneously. The flow was calculated in FDS based on the operating pressure and the K factor, refer Table 15.

For the FRNSW tests, the inputs for the sprinkler parameters pressure and flow from each sprinkler head was not measured in the fire tests, so the pressure and flow at each sprinkler head was approximated (back calculated) by undertaking hydraulic calculations using the documented static pressure at the source (meter) i.e. 250 kPa. For the FRNSW test cases this meant the pressure and flow exceeded the minimum design pressure and flow.

For the HFS102 system the inputs are as outlined in section B.2.2 .

Table 15: Scenario Based Pressure & Flow at the Fire Sprinkler Head

Scenario	Pressure [kPa]	Approximate Flow [L/min]	% Listed Pressure	% Listed Flow
Tyco Series LFII Residential Sprinklers listed pressure and flow				
4.9m x 4.9m coverage	**48**	**49.2**	-	-
FRNSW Tests static pressure at the source (meter) i.e. 250kPa				
1 head operating	168	90	350%	183%
2 heads operating	112	74 at each head	233%	150%
3 heads operating	73	60 at each head	152%	122%
4 heads operating	49	49 at each head	102%	100%
HFS102 minimum static pressure at the source (meter) to achieve 1 head operating at 49.2L/min and 48kPa i.e. 110kPa				
1 head operating	51	50	106%	102%
2 heads operating	33	40 at each head	69%	81%
3 heads operating	21	32 at each head	44%	65%
4 heads operating	14	26 at each head	29%	53%

B.3.5 Modelling Outputs

The following thermocouples from the test rig were replicated in the model:

- Temperature thermocouples were installed 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.
- Temperature thermocouples were installed at the sprinkler locations.
- At a height of 1.6 metres in the Lounge room along the path of egress a thermocouple measuring FED.

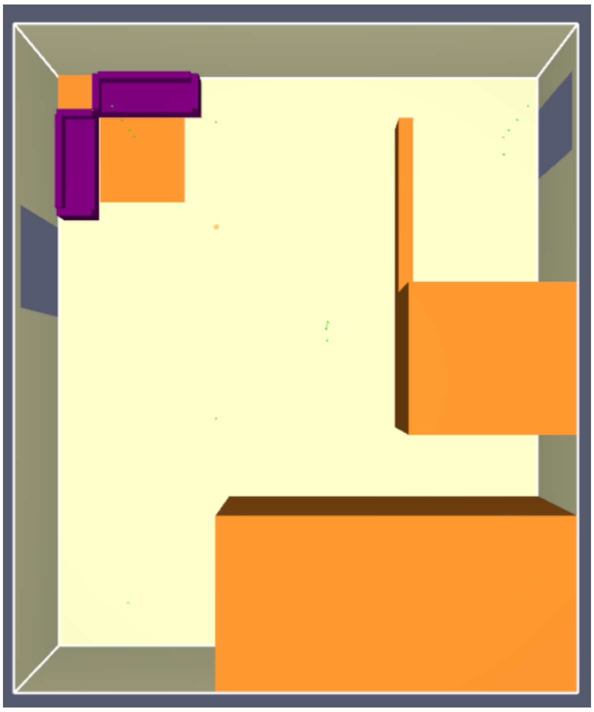
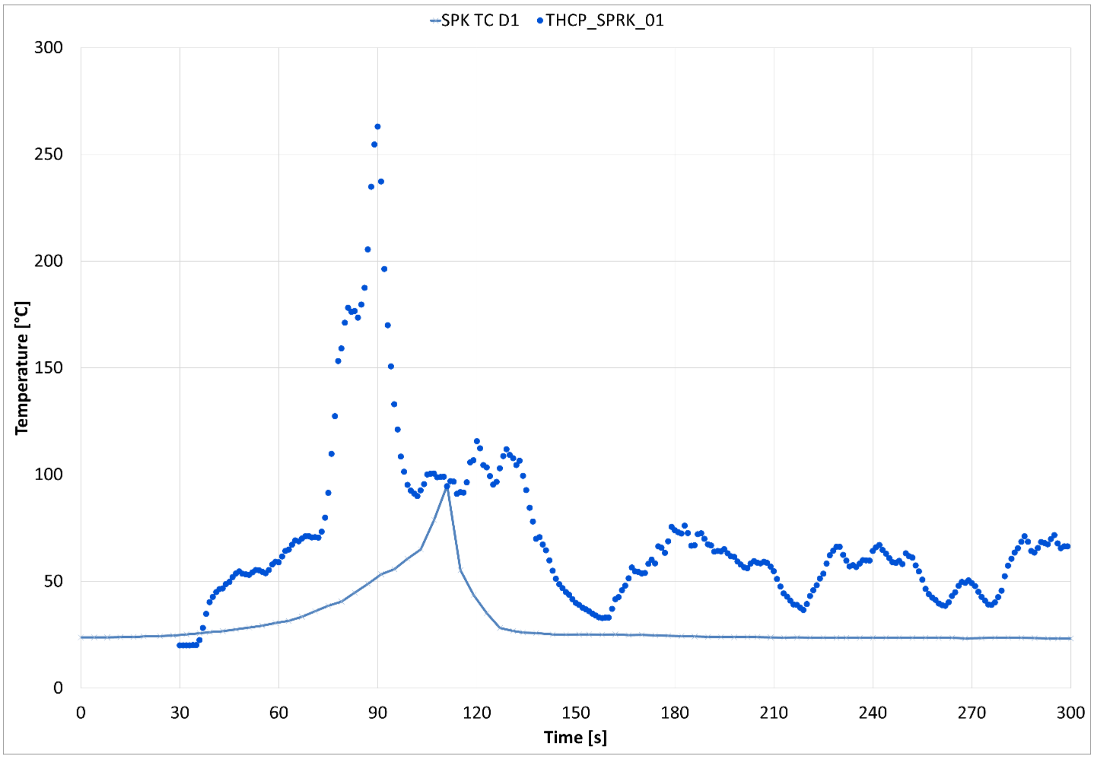
In addition the following modelling outputs were recorded:

- Temperature of the sprinkler devices.
- Heat release rate (within the modelled domain).
- Slice files at 1.6m above floor level – temperature, volume fraction of CO and CO_2.
- Plot3Ds – temperature, velocity and visibility.
- Boundary files – Net heat flux, radiative heat flux and wall temperature.

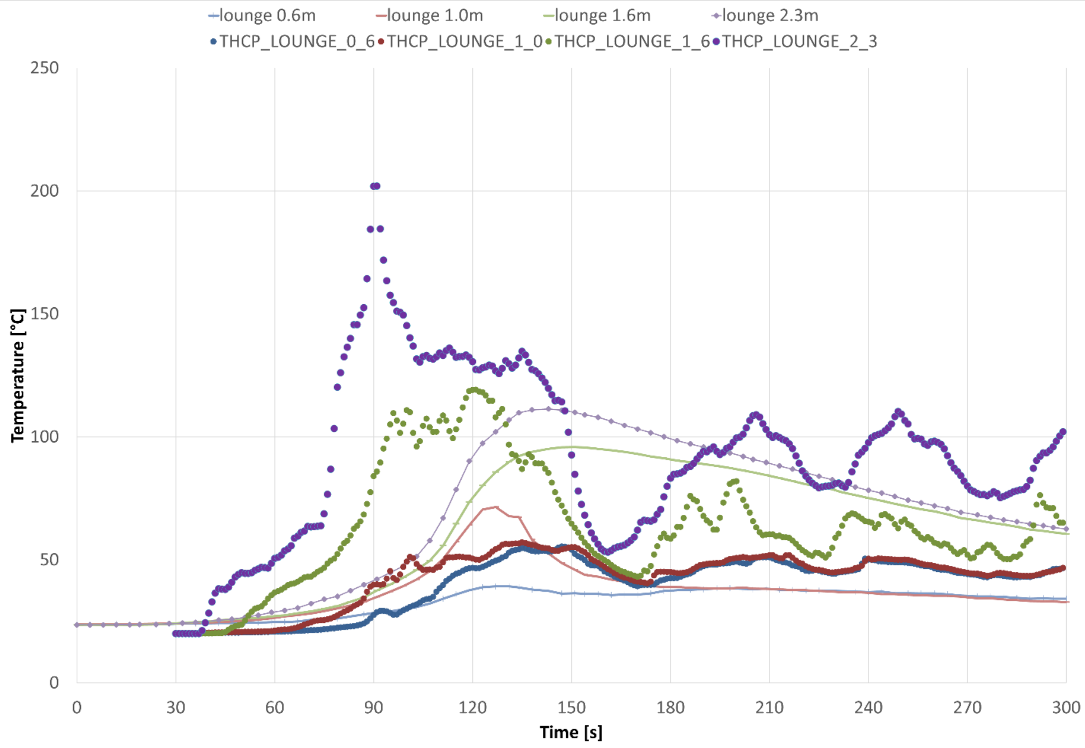
B.4 Modelling Results

B.4.1 Validation using FRNSW Test Models

Table 16: Test 4 FRNSW Full Scale Test compared to Modelling Results

FRNSW Test 4	**FDS Model**
Before Test  After Test 	
Sprinkler Thermocouples	
SPK TC D1	THCP_SPRK_01
	

FRNSW Test 4	FDS Model
Thermocouples Lounge	
lounge 0.6m | lounge 1.0m | lounge 1.6m | lounge 2.3m	THCP_LOUNGE_0_6 | THCP_LOUNGE_1_0 | THCP_LOUNGE_1_6 | THCP_LOUNGE_2_3 |



Thermocouples Kitchen	
kitchen 0.6m | kitchen 1.0m | kitchen 1.6m | kitchen 2.3m	THCP_KITCHEN_0_6 | KITCHEN _1_0 | THCP_ KITCHEN _1_6 | THCP_ KITCHEN _2_3 |

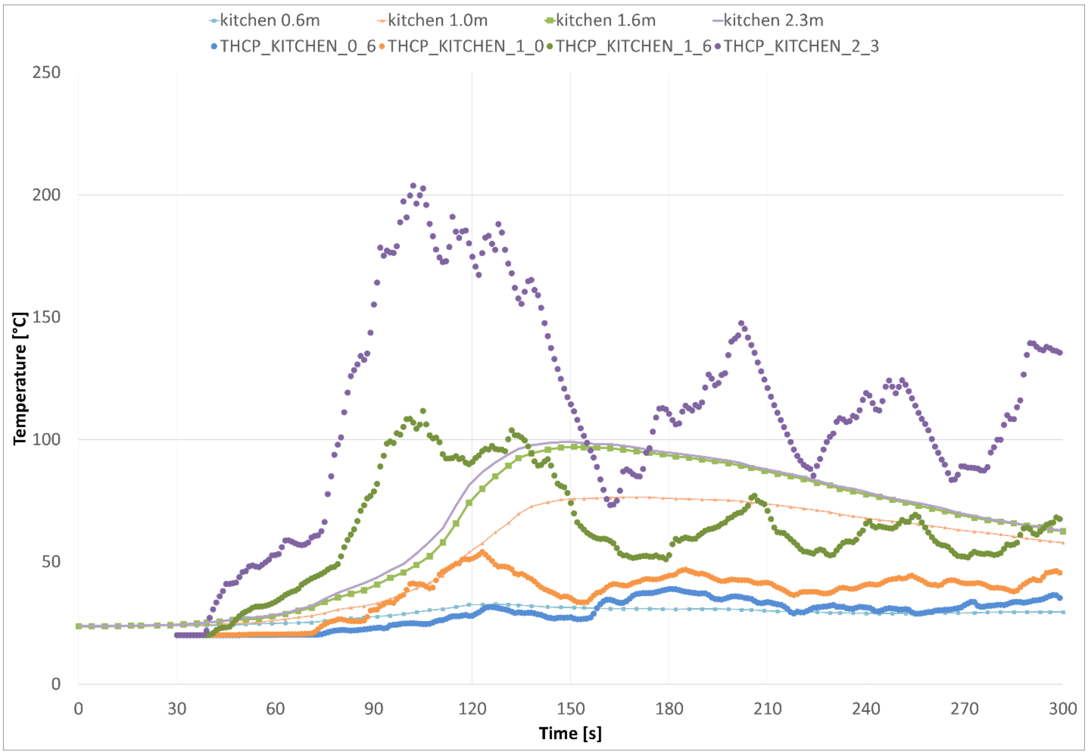
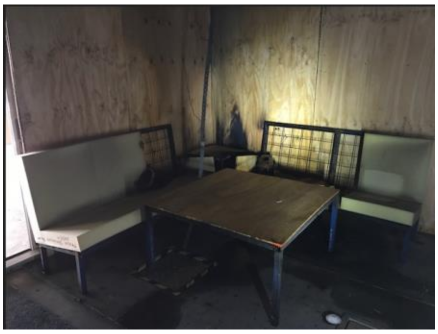
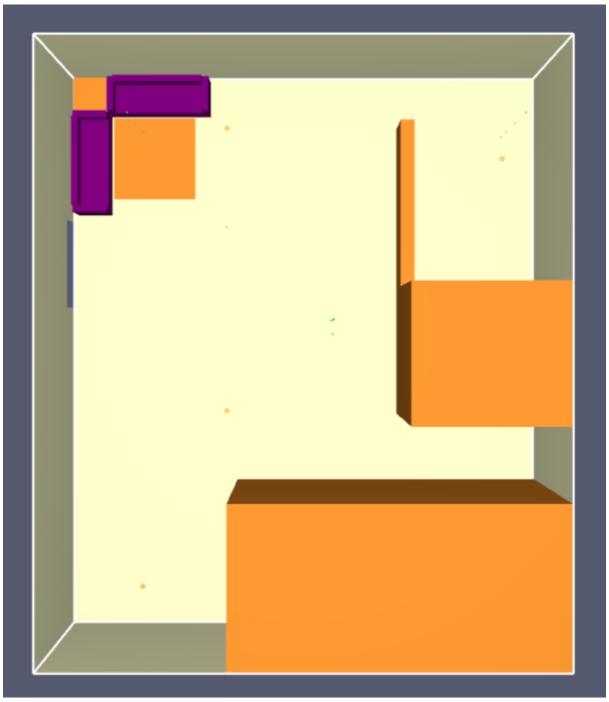
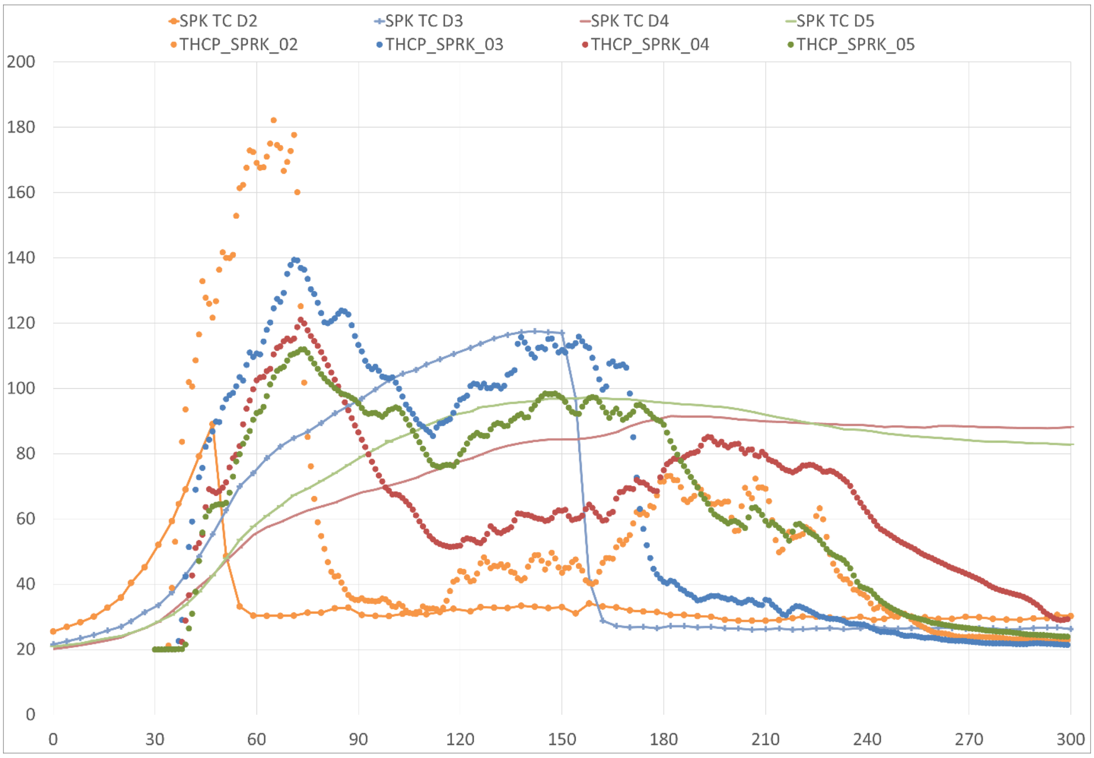
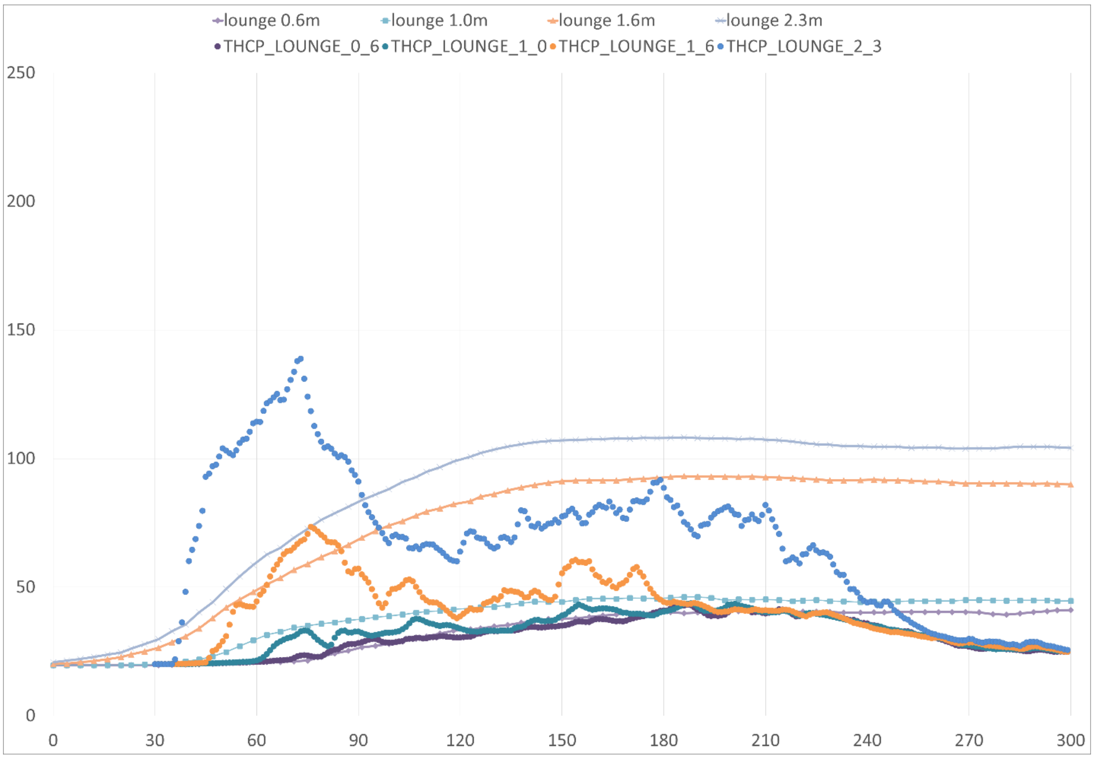
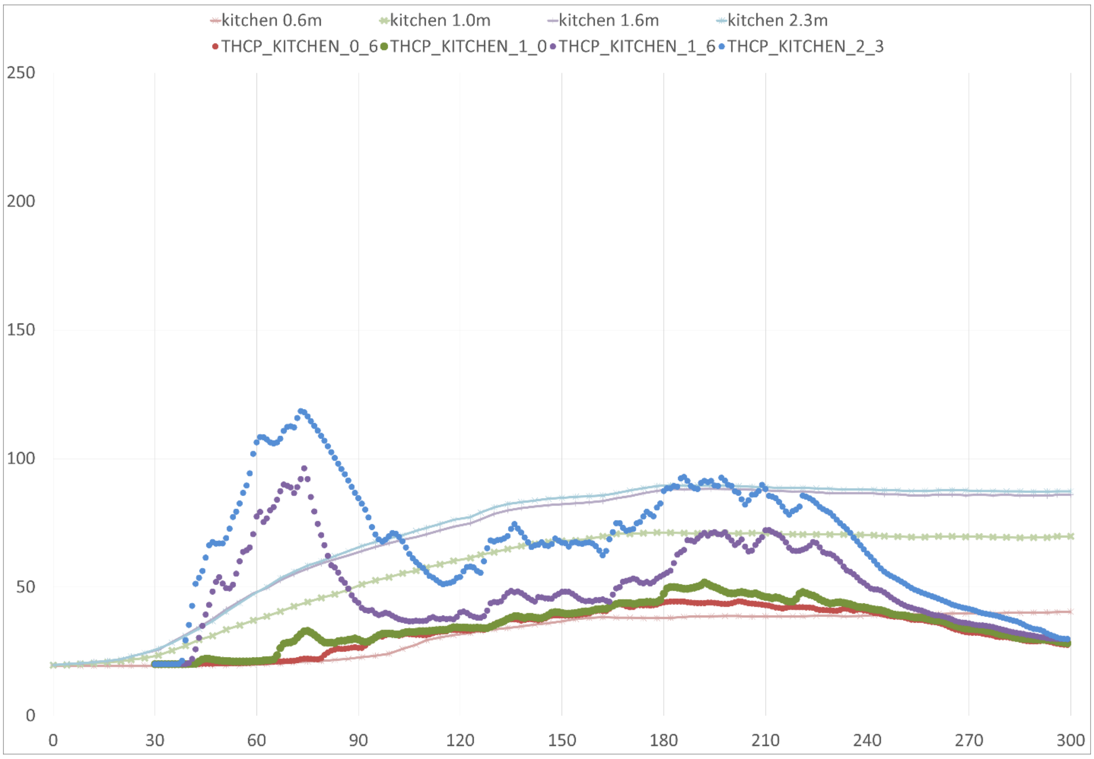


Table 17: Test 6 FRNSW Full Scale Test compared to Modelling Results

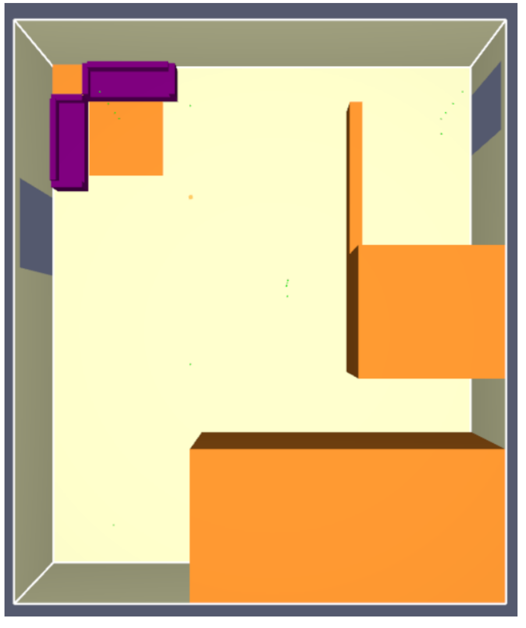
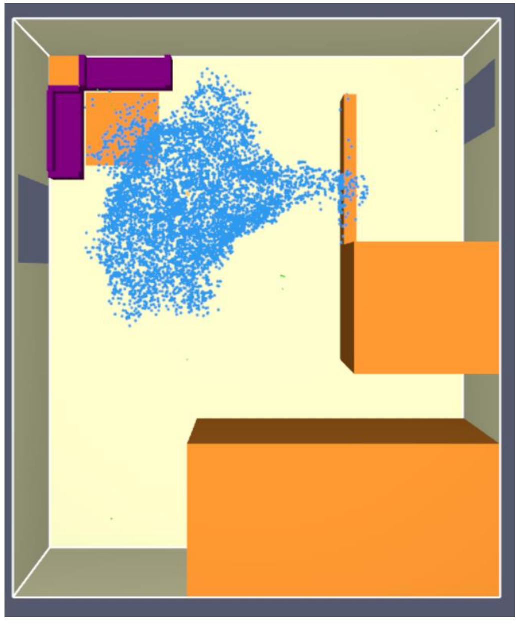
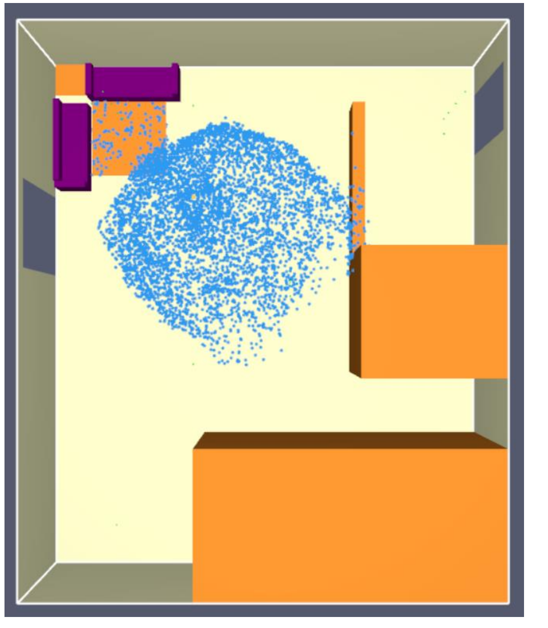
<table>
<tr><th>FRNSW Test 6</th><th>FDS Model</th></tr>
<tr><td>Before Test

After Test
</td><td></td></tr>
<tr><td colspan="2">Sprinkler Thermocouples</td></tr>
<tr><td>SPK TC D2 | SPK TC D3 | SPK TC D4 | SPK TC D5|</td><td>THCP_SPRK_02 | THCP_SPRK_03 | THCP_SPRK_04 | THCP_SPRK_05</td></tr>
<tr><td colspan="2">
</td></tr>
</table>

FRNSW Test 6	FDS Model
Thermocouples Lounge	
lounge 0.6m | lounge 1.0m | lounge 1.6m | lounge 2.3m	THCP_LOUNGE_0_6 | THCP_LOUNGE_1_0 | THCP_LOUNGE_1_6 | THCP_LOUNGE_2_3 |
	
Thermocouples Kitchen	
kitchen 0.6m | kitchen 1.0m | kitchen 1.6m | kitchen 2.3m	THCP_KITCHEN_0_6 | KITCHEN _1_0 | THCP_ KITCHEN _1_6 | THCP_ KITCHEN _2_3 |
	

B.4.2 HFS102 System Design Comparison against FRNSW Test System Design

Table 18: Test 4 Configuration Modelling Results

Test 4: No Sprinklers	FRNSW Test System	HFS102 System
Time = 0s 	Time = 300s 	Time = 300s 

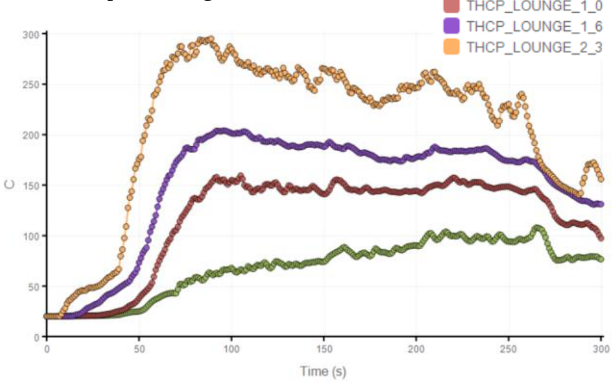
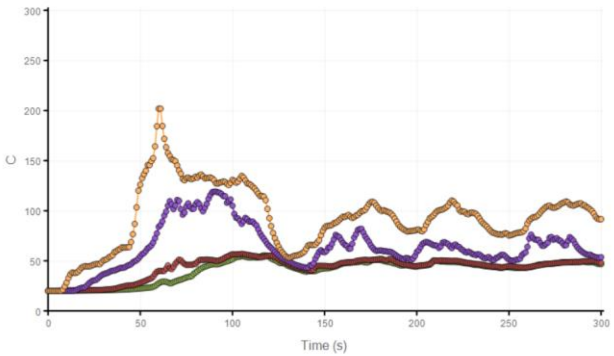
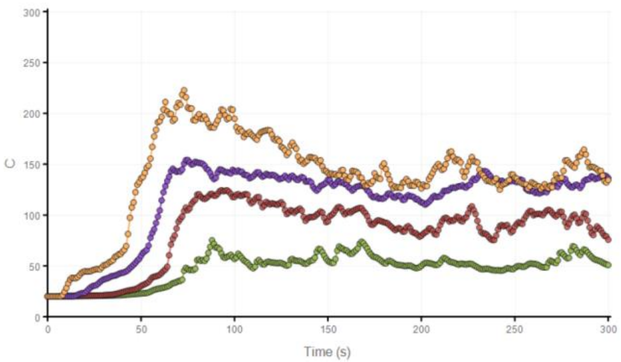
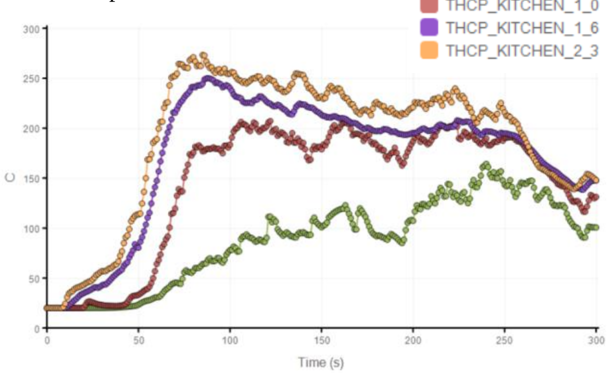
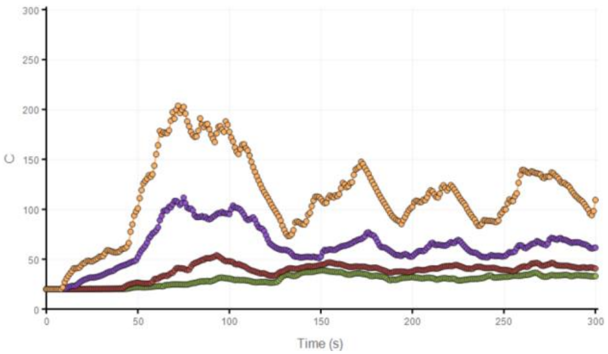
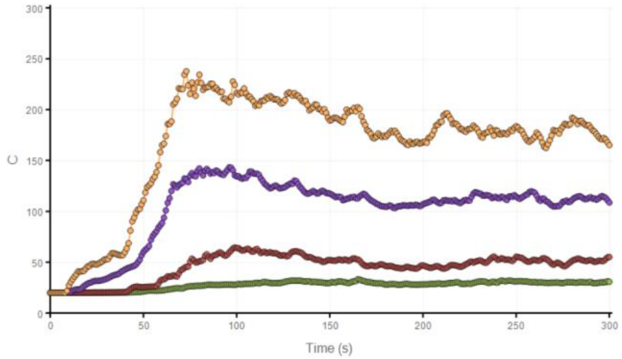
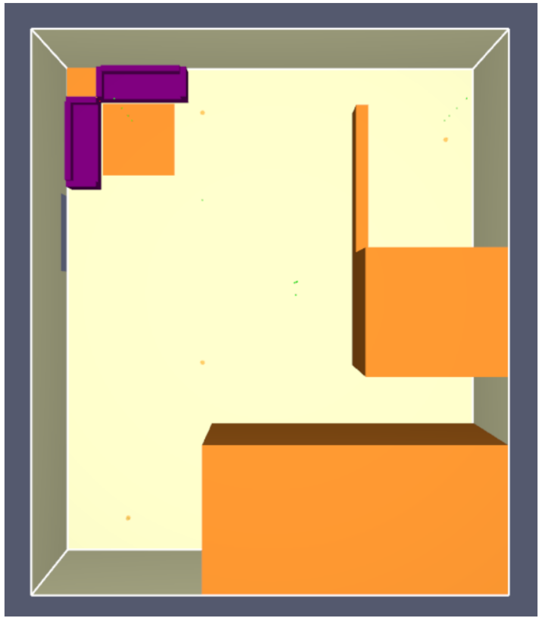
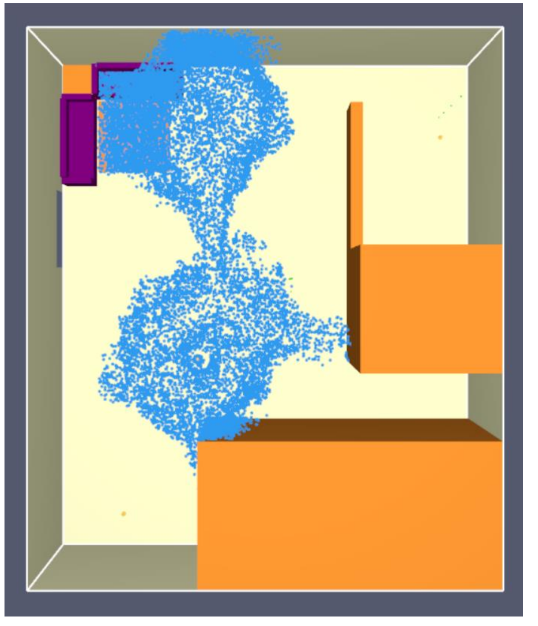
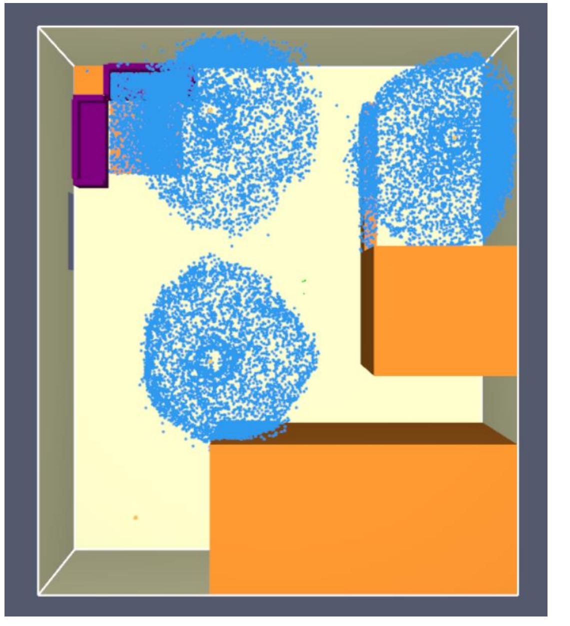
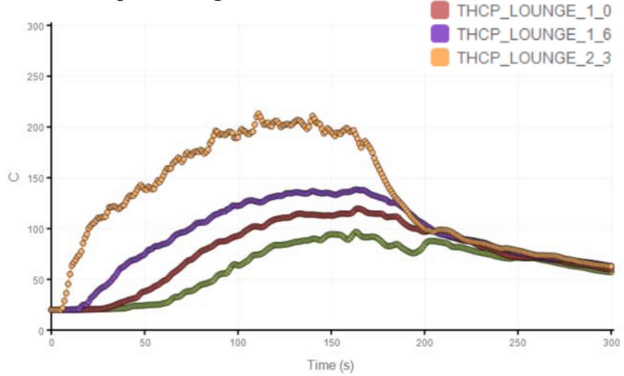
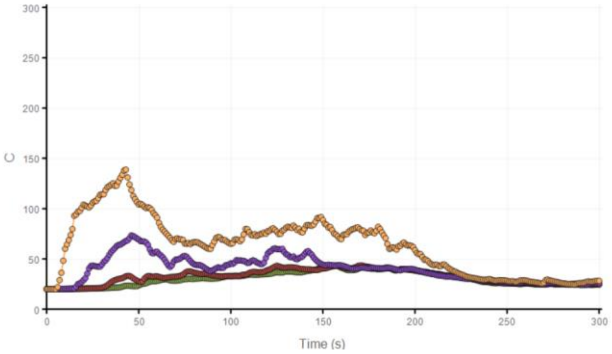
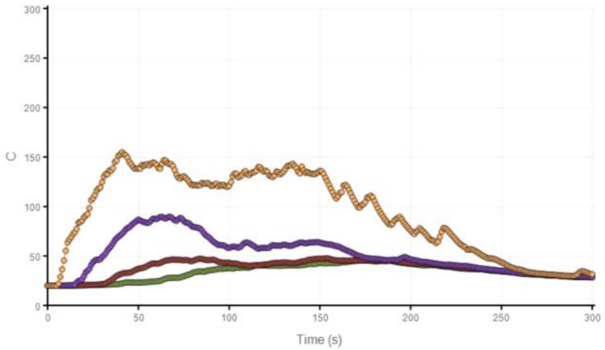
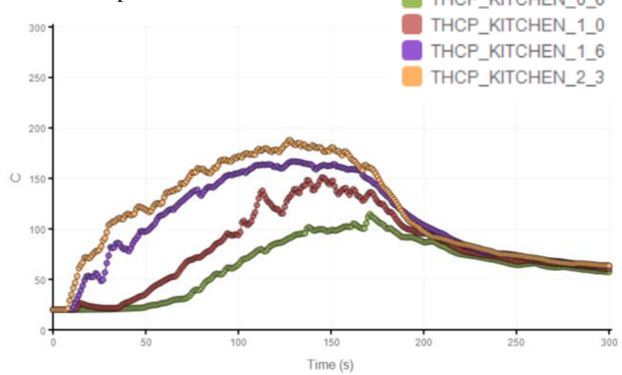
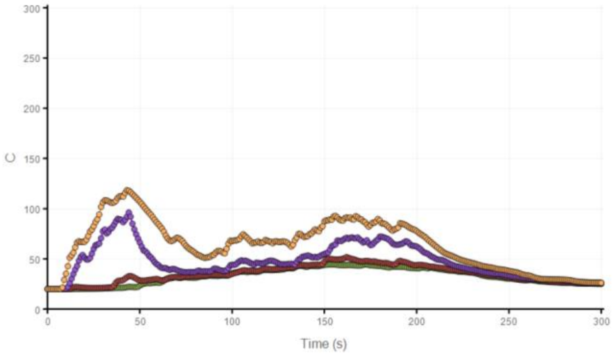
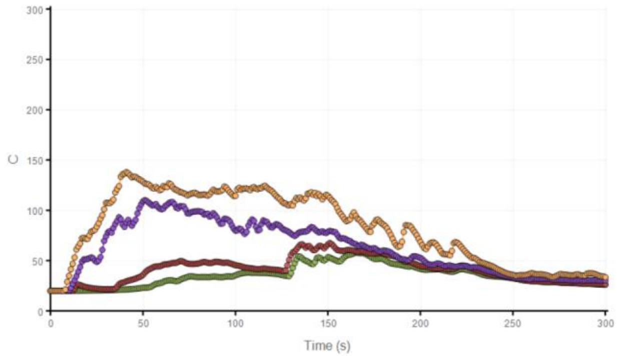
<table>
<tr><th>Test 4: No Sprinklers</th><th>FRNSW Test System</th><th>HFS102 System</th></tr>
<tr>
<td>Thermocouples Lounge
</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermocouples Kitchen
</td>
<td></td>
<td></td>
</tr>
</table>

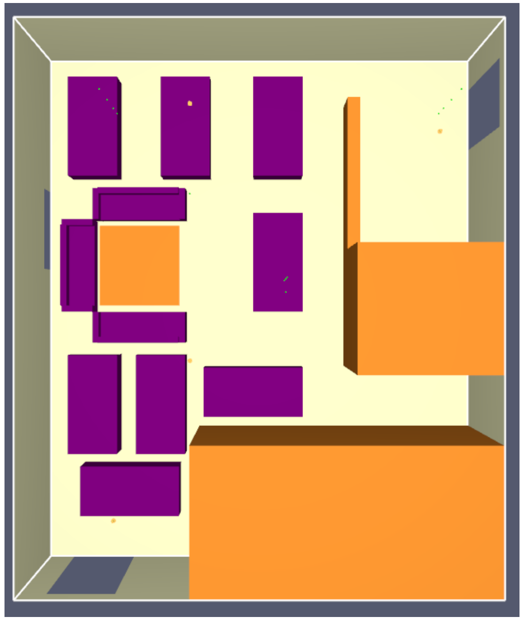
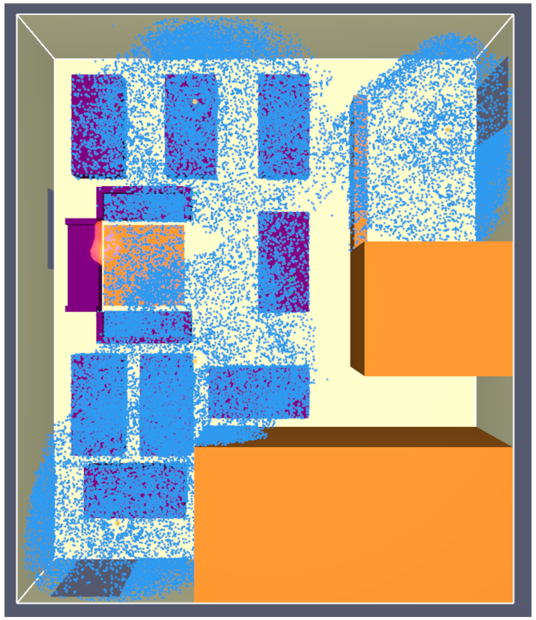
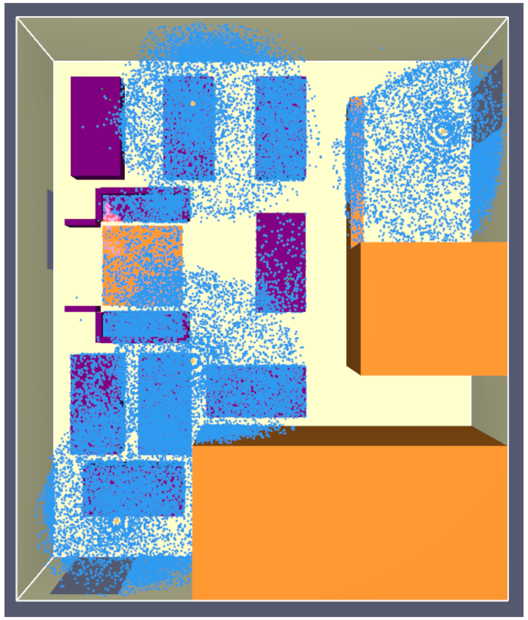
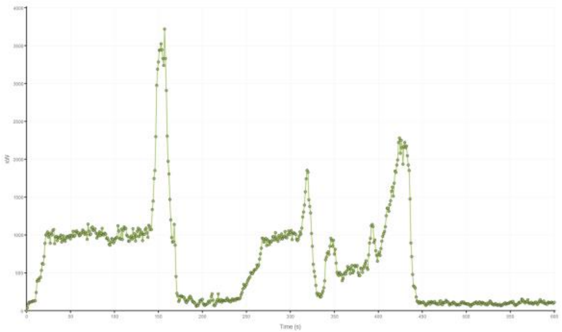
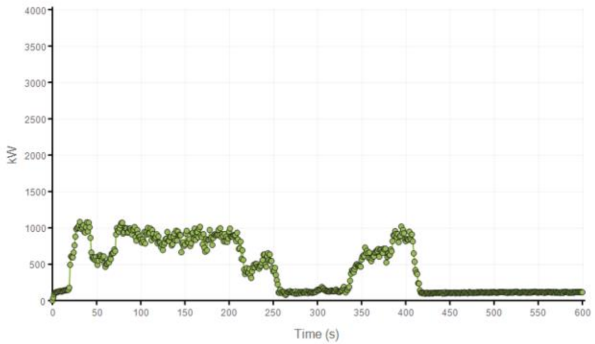
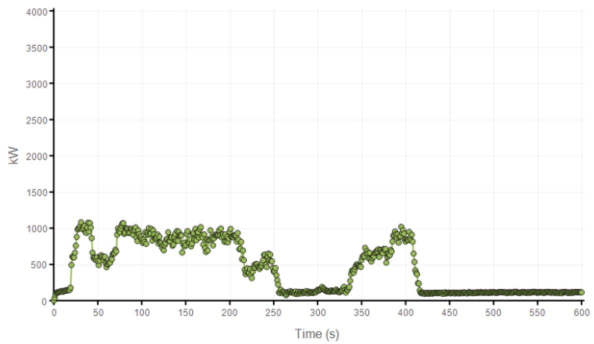
Table 19: Test 6 Configuration Modelling Results

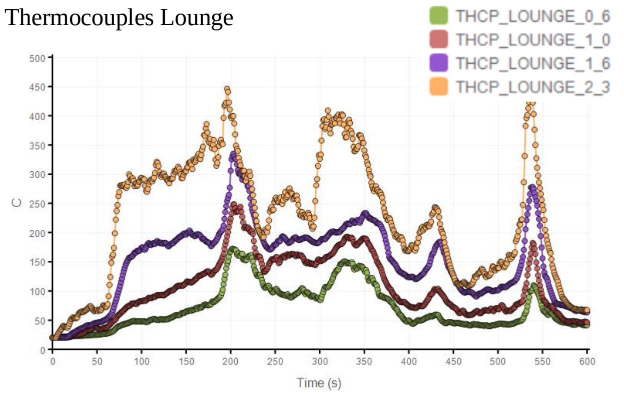
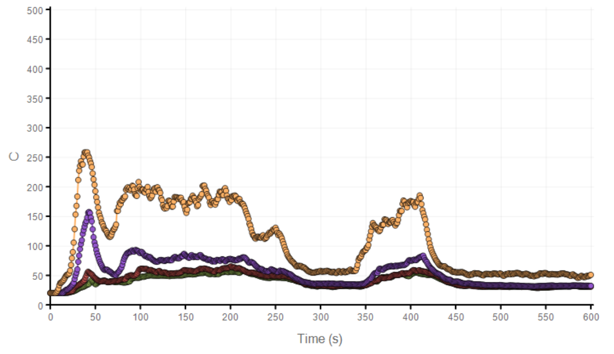
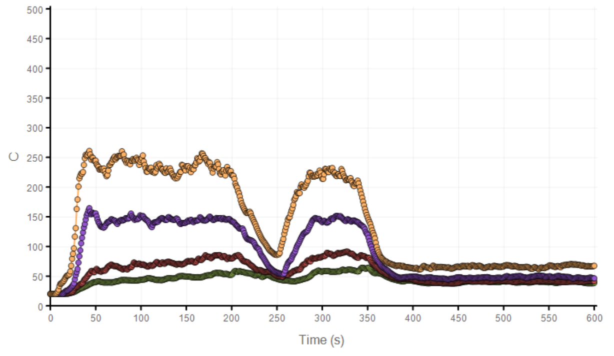
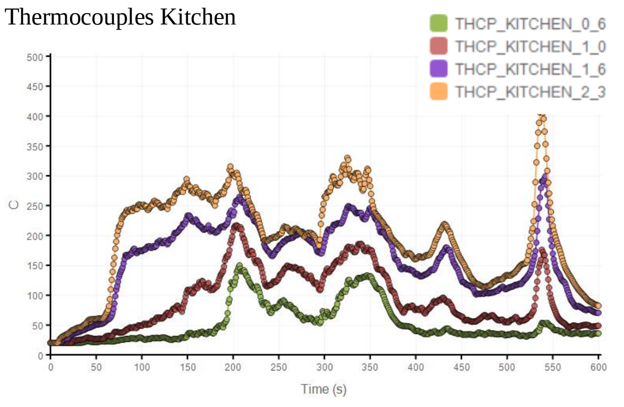
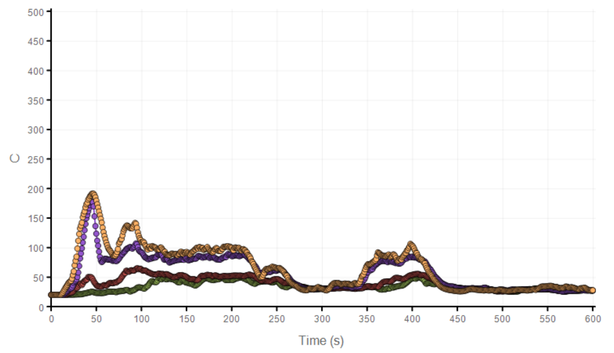
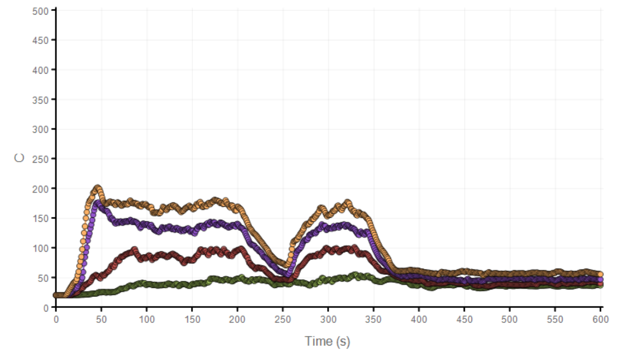
Test 6: No Sprinklers	FRNSW Test System	HFS102 System
Time = 0s 	Time = 300s 	Time = 300s 

Test 6: No Sprinklers	FRNSW Test System	HFS102 System
Thermocouples Lounge 		
Thermocouples Kitchen 		

B.4.3 High Challenge Case

Table 20: High Challenge Case Modelling Results

<table>
<tr><th>High Challenge Case: No Sprinklers</th><th>FRNSW Test System</th><th>HFS102 System</th></tr>
<tr><td>Time = 0s
</td><td>Time = 600s
</td><td>Time = 600s
</td></tr>
<tr><td>HRR: Time = 600s
</td><td>
</td><td>
</td></tr>
</table>

High Challenge Case: No Sprinklers	FRNSW Test System	HFS102 System
		
		

B.4.4 Modelling Limitations

The fire models did not exactly replicate the fire test outcomes. There are a number of limitations to CFD models, and the modelling assumptions and simplifications that may have contributed to the discrepancy. These were identified as:

- Simplified fuel packages and un-validated combustion chemistry.
- Models have been time shifted to match the temperature growth phase which corresponds to fire spread from the ignition source to the furniture item.
- FDS modelling of complex pyrolysis model does not sustain combustion once the fire spreads away from the ignition source and the fuel has burned away.
- FDS overpredicted compartment temperatures prior to sprinkler activation.
- The ‘conventional’ domestic sprinkler system pressure and flow were based on the hydraulic calculations based on the recorded static pressure FRNSW test sprinklers.

There are a number of studies that could be undertaken on various modelling parameters to refine the model so it can more closely replicate a ‘real fire scenario’. These include, but are not limited to:

- Refining the reaction and material combustion parameters, and validating against small scale and furniture item scale fire tests.
- Utilising a mixture of control, complex pyrolysis and burners to simulate uncontrolled fire spread within a compartment.
- Additional sprinkler flow testing to refine the sprinkler spray model in FDS (bucket tests where the water density over the floor are can be measured).