Fire research report

Research Tests: Hoarding Fire Behaviour

This fire research report provides an analysis of hoarding fire behaviour from two test burns conducted at the CSIRO fire research laboratory in July 2014

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Executive Summary

Fire & Rescue NSW (FRNSW) responds to more than 4000 residential fires each year and it is noted that a number of fire fatalities occurring each year were victims living in hoarding and squalor conditions. While hoarding and squalor are primarily considered a health and amenity issue for the occupants, hoarding does also present increased fire risks and hazards to the occupants, responding firefighters and surrounding properties.

Quantifying the extent to which hoarding is a fire problem is difficult for FRNSW as hoarding is underreported. The post incident data collection system (a national data base), called the Australian Incident Reporting System (AIRS), has no specific area in which to identify hoarding and/or squalor. For example, a house fire in Marrickville in July 2013, required a third alarm response from FRNSW (ten fire appliances) due to the excessive hoarded materials. Capturing information on these types of incidents is limited yet anecdotal evidence from firefighters identifies that most have responded to fires in these types of homes in their careers.

FRNSW is therefore committed to investigating this fire risk and is trying to improve both the operational response to these incidents, specific risk reduction advice and a system for directing people affected by hoarding to appropriate treatment programs and services. This has also been challenging as there is currently no state-wide standard protocol that is specific for addressing situations of hoarding and referring affected people to services and treatment programs.

The current gap in the research relating to these issues has led FRNSW to conduct this research to qualify and analyse the increased fire risks and hazards that hoarding and abnormally high fuel loads poses to occupants, responding firefighters and surrounding properties.

The goal of this research was to undertake full scale fire testing to determine the fire risks and hazards associated with hoarding and elevated fuel loads, including visual observation of fire behaviour, measuring temperature and rate of heat rise and monitoring atmospheric hazards. The hypothesis of greater fire risks being associated with hoarding was assessed by conducting a comparative analysis between severe and moderate levels of clutter.

FRNSW has also undertaken this research to identify outcomes that can be used in community safety programs aimed specifically towards this risk. Results and tangible findings will directly influence the online 'Hoarding & Squalor Fire Prevention Toolkit' to be implemented for external stakeholders by FRNSW.

Research Method

To achieve the goal of this study, two full-scale scenario burns of a bedroom were conducted, test 1 being measured as a level 8 (severe) on Dr Frost's Clutter Image Rating Scale (CIR) and test 2 being measured as a CIR level 5 (moderate).

The tests were conducted at the Commonwealth Scientific and Industrial Research Organisation's (CSIRO) large burn gallery in North Ryde, which is purposely built for standards based testing for industry. Centrally located within the gallery was a burn room (test cell) constructed using simple timber frame design.

The burn room was enclosed on three sides with walls and the front was open to atmosphere to provide adequate observation of the fire development. Thermocouples were inserted through the walls to measure gas temperatures and pinhole cameras were positioned on the walls to visually record the ignition and fire growth. Multi-gas monitors analysed gases around the burn room in the gallery.

The two separate burns required typical hoarded materials to be placed into the room emulating severe and moderate levels of clutter (CIR level 8 and CIR level 5, respectively). The contents were designed to reflect a spare bedroom and the horded materials were based upon Mogan's (2008) most frequently hoarded items such as clothing, magazines and books.

The comparative analysis consisted of identifying the fire behaviour, temperature, rate of heat rise and atmospheric hazards from each test. We compared the results of both tests against a previous FRNSW test burn of a 'standard' bedroom. We also observed firefighters extinguishing the test burns to confirm that hoarding fires increase fire risk and require more resources to fight than non-hoarding fires.

Findings

The key findings include:

1. Fire growth and flashover time was not determined by the fuel load. Principal factors were the ignition, type of fuel and fuel arrangement.

2. Fire risk dramatically increases with open flame ignition sources such as unconventional cooking and heating practices (as occurs when utilities are disconnected).

3. Depending on fuel, maximum temperatures reached are similar irrespective of fuel load, however, higher fuel loads will burn longer as there are more materials to combust.

4. Hoarded materials can provide good thermal insulation against hot gases. In the second test a maximum temperature of 17°C was recorded under a pile of clothing despite ceiling temperatures being 1020°C.

5. The tests demonstrated that greater effort was required to extinguish and overhaul the fire.

6. Working smoke alarms are critical in hoarding households to provide early warning to occupants. Escape time may be significantly reduced because of the hoarded materials, thus occupants must not delay their escape when an alarm activates.

Conclusions and Recommendations

This research has found that fire growth is not determined by fuel load. Using similar combustible materials in each burn, we found the peak gas temperatures reached were similar despite the differing levels of hoarding. However, the research identified that fire will burn at maximum intensity for longer when the hoarding level is higher. Hoarded materials can increase the intensity of fire depending on their combustibility.

Fuel load did not determine the rate of fire growth nor the time to reach flashover. The level 8 CIR burn reached flashover in 100 seconds, the level 5 CIR burn in 260 seconds, whilst a previous FRNSW test burn of a level 1 CIR bedroom reached flashover in 110 seconds. Both test burns showed that fire growth was principally determined by the ignition and first materials ignited (e.g. Polyurethane).

The higher density of accumulated materials does provide much greater opportunities for ignition and can increase fire spread through materials as they are packed closer.

Working smoke alarms provided early warning to the presence of early fire and offered sufficient time to any occupants to safely evacuate, however immediate action is required by occupants as tenability was rapidly lost by the high smoke production rate.

Background

Fire & Rescue NSW (FRNSW) responds to more than 4000 residential fires each year which result in approximately 20 fire deaths. Since 2009, 12% of all residential fire fatalities in NSW were victims reported as living in hoarding and squalor conditions, and of these over 70% were aged 50 years or older.

Hoarding is primarily considered a health and amenity issue for the occupant, particularly when living in domestic squalor, however, hoarding is also commonly associated with increased fire risks and hazards to the occupants, firefighters and surrounding properties.

What is 'hoarding'?

Hoarding is a behaviour involving the collection and inability to dispose of large quantities of possessions that interfere with ability to perform normal functions (Frost & Hartl, 1996). Hoarding is a progressive and chronic psychological disorder typically in the form of an anxiety disorder such as Obsessive-Compulsive Disorder (OCD), where the perceived importance of materialistic items exceed their true value, thus the person is reluctant to discard unneeded items.

Note: In May 2013, 'Hoarding Disorder' was newly defined and included in a new chapter of the DSM-5 on Obsessive-Compulsive and Related Disorders (AMA).

Hoarding is typified by:

- large accumulation of possessions having little use or no apparent value
- areas (rooms) no longer being able to be used for the purpose they were intended
- being conducted by a person most likely to be aged 50 years and over and also likely to be living alone, and
- occurring within a household that is occupied by the owner.

People will hoard materials because of a feeling of attachment to these items and as such, the type of materials hoarded will vary depending on that attachment value set by each individual (e.g. a person may hoard newspapers and magazines for historical relevance). The materials hoarded can range from media items, food, clothing and fabrics, equipment and machines, storage and containers, general household items and in some cases, other people's waste material. This often means that the environment, in which they are being kept, becomes so cluttered that it can no longer be used for the purpose for which it was designed. Consequently, this impairs basic living activities (such as cooking, cleaning, sleeping, showering, access and moving) for the occupant.

The degree of hoarding typified by an individual can vary from very mild to very extreme. This is determined by the severity of clutter from the hoarded materials as defined by the Clutter Image Rating (CIR) scale determined by Professor Randy O. Frost. The CIR scale rates the severity of clutter within a room on a scale of 1 (minimal) to 9 (most severe).

Note: If hoarding has been identified as CIR level 5 or higher, an alert notification will be placed on that address within the FRNSW fire station response system.

Hoarding is a complex social issue which requires intervention and long term support from appropriate agencies. Currently there is no state-wide protocol for addressing cases of hoarding and referring affected people to services and treatment programs. Even when action is taken and hoarded materials are removed, the underlying psychological disorder may not be treated and hoarding behaviour will be replicated within days or weeks.

Research by Macquarie University's Emotional Health Clinic found 4% of the NSW population are affected by this psychological disorder and live in squalor conditions (Gaston, 2010). Hoarding that comes to the attention of public authorities may be an issue related to mental health, environmental, public health, medical, public safety, legal and housing issues; as well as having financial implications.

Identifying hoarding fire risks

The accumulation of items in hoarding households results in a higher fuel load and blocked means of egress. This leads to fires that are more serious than other residential fires as they are tougher to fight and more likely to be fatal (Schorow, 2012). In addition, a fire spreading to or being ignited from a hoarding household poses severe hazards to firefighters and the surrounding properties and occupants (Colpas et al, 2012).

Since 2009, 12% of all residential fire fatalities in NSW were victims reported as living in hoarding and squalor conditions, and of these over 70% were aged 50 years or older. Anecdotal evidence suggests FRNSW regularly respond to fires in homes where hoarding is a factor. As a result, people who engage in moderate to severe hoarding behaviour (i.e. CIR level 5 or higher) are considered an 'at-risk' group and specifically targeted by FRNSW prevention campaigns.

Properties which involve hoarding can present specific and complex challenges to fire services including:

- Accumulated material results in an abnormally high fuel load which can increase the intensity of the fire, dependant on the combustibility of the material (i.e. calorific output of fuel determining Heat Release Rate (HRR)). Properties with high fuel loads require more firefighting resources to extinguish.
- The higher density of accumulated materials provides much greater opportunities for ignition and generally increases rate of fire spread through materials. Rapid fire spread minimises time margins to make safe egress with most hoarding fires reaching flashover well within typical fire service's response and intervention times.
- Egress routes are generally blocked or impeded (i.e. narrowed paths of travel) directly hindering safe escape by the occupant/s. Similarly, access by firefighters to undertake rescue and extinguishment will be blocked or impeded.
- Unorthodox items may be hoarded presenting dangerous and unexpected hazards during a fire, including higher smoke toxicity, explosive conditions (e.g. from pressure vessels), injuries from sharp objects, collapse hazards from piled debris or overloaded structures etc.
- Utilities such as electricity are often disconnected or misused, which can result in the occupant conducting unsafe practices when cooking, and heating. According to an

MFB study (2012), the majority of hoarding fires start from either cooking or heating where accumulated materials are within close proximity or make contact with an open flame or heat source.

- Most occupants who engage in hoarding behaviour do not have a working smoke alarm present in the household. The 2009 MFB hoarding study found 60% of hoarding households involved in a fire did not have a working smoke alarm.

Purpose of research

FRNSW has undertaken this research to determine the fire risks and hazards associated with hoarding and elevated fuel loads, and to test the hypothesis of greater fire risks being associated with hoarding. Identified outcomes and tangible findings will enhance FRNSW's current risk reduction advice and directly influence the 'Hoarding & Squalor Fire Prevention Toolkit' to be implemented for external stakeholders by FRNSW.

Full scale fire testing was conducted to determine the fire risks and hazards associated with hoarding and elevated fuel loads, including visual observation of fire behaviour, measuring temperature and rate of heat rise and monitoring atmospheric hazards.

Objectives

The scope of testing was defined to satisfy the following objectives:

1. Test the following:
   - establish the fire risk associated with medium levels of hoarding
   - establish the fire risk associated with high levels of hoarding
   - determine whether higher levels of hoarding requires more firefighting resources, and
   - compare the fire risks between higher and lower level hoarding.
2. Gather data and evidence to support fire prevention strategies and hoarding risk reduction advice.
3. Contribute to the body of research knowledge in relation to fire behaviour involving a high level of contents and furnishings in domestic dwellings[1], while testing the efficacy of smoke alarms.
4. Strengthen existing research partnerships with universities, industry peak bodies and other stakeholders.
5. Provide high definition imagery for community engagement campaigns.
6. Provide situational awareness into changes within the built environment that impact on the safety of operational firefighters.

[1] As defined in *National Construction Code Volume One*, *Building Code of Australia Class 2 to Class 9 Buildings*, Part A3.2 Classifications.

Hypothesis

The hypothesis of greater fire risks being associated with hoarding was assessed by conducting comparative analysis between two CIR levels, a severe level of clutter (CIR level 8) and moderate level of clutter (CIR level 5).

Two full-scale scenario recreation burns of a bedroom were conducted for this analysis, test 1 being CIR level 8 (severe) and test 2 being CIR level 5 (moderate).

Figure 1: CIR level 8 (left) and level 5 (right) as used in test 1 an 2 respectively

Methodology

Burn room (test cell)

The tests were conducted at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Materials Science and Engineering division located in Julius Avenue, North Ryde. The tests were carried out within the Fire Science and Technology Laboratory's large burn gallery, which is purposely designed for standards based testing for industry.

Note: The large burn gallery is an approved testing facility registered by the National Association of Testing Authorities (NATA).

Centrally located within the gallery was a burn room constructed using simple timber frame design (i.e. bearers, joists and 450 centre stud walls). The room was enclosed on three sides with walls and the front was open to atmosphere to provide adequate observation of the fire development by various stakeholders present during both burns.

The burn room was fabricated to resemble a bedroom with dimensions measuring 3.6m (W) x 3.6m (L) and 2.4m (H). This resulted in the burn room having a floor area of 13.0m² and a volume of 31.1m³.

Note: The room is larger than a 'standard' bedroom size which measures 3m x 3m, but is smaller than the average master bedroom which is typically 16m² (i.e. 4m x 4m).

The walls and ceilings were lined with standard 10mm thick plasterboard sheeting and painted with a single coat of matt paint. Owing to the high Heat Release Rate (HRR) in test 1 which caused burn-through of the linings and damage to the timber structure, 16mm *Gyprock Fyrchek*® plasterboard was used to line the entire room for test 2.

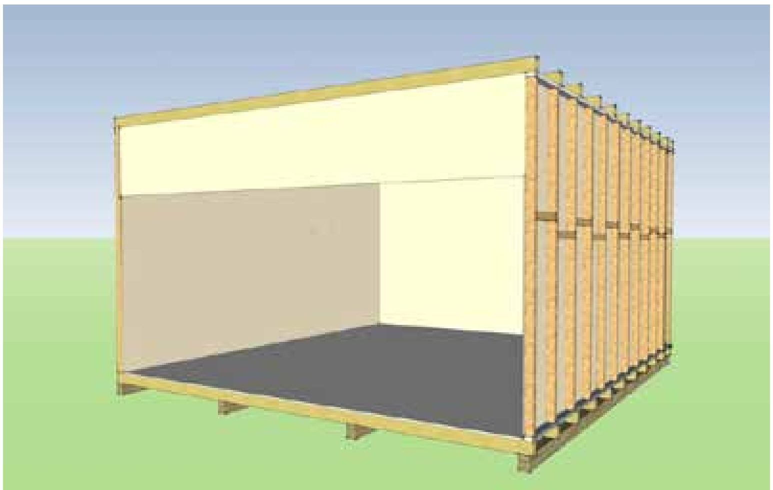

Figure 2: Three dimensional overview of test room showing open front with baffle

A bulkhead was fitted across the front of the room creating a baffle 600mm deep below the height of the ceiling. This baffle restrained the flow of heated gases from the fire gas plume (i.e. smoke) creating a dense hot gas layer across the ceiling.

Note: The ceiling hot gas layer provides thermal feedback, mostly in the form of radiant heat energy, which enables flash-over to occur despite open ventilation.

The floor was fitted with standard yellow-tongue chipboard flooring and was lined with carpet (no underlay).

Thermocouples were inserted through the plasterboard linings of the walls to measure gas temperatures at the bounding surfaces, and were placed at increments of 700mm from floor level i.e. 0.7m, 1.4m and 2.1m above floor level. Thermocouples were installed:

- front and rear of left side wall
- front and rear of right side wall
- down the centreline of rear facing wall
- in the centre of the front bulkhead (baffle)
- in the centre of the ceiling, and
- in the centre of the floor (test 2 only).

Note: In test 2, a thermocouple was not placed at the front along the left sided wall at the topmost location (i.e. 2.1m from floor) as it was relocated to the centre of the floor.

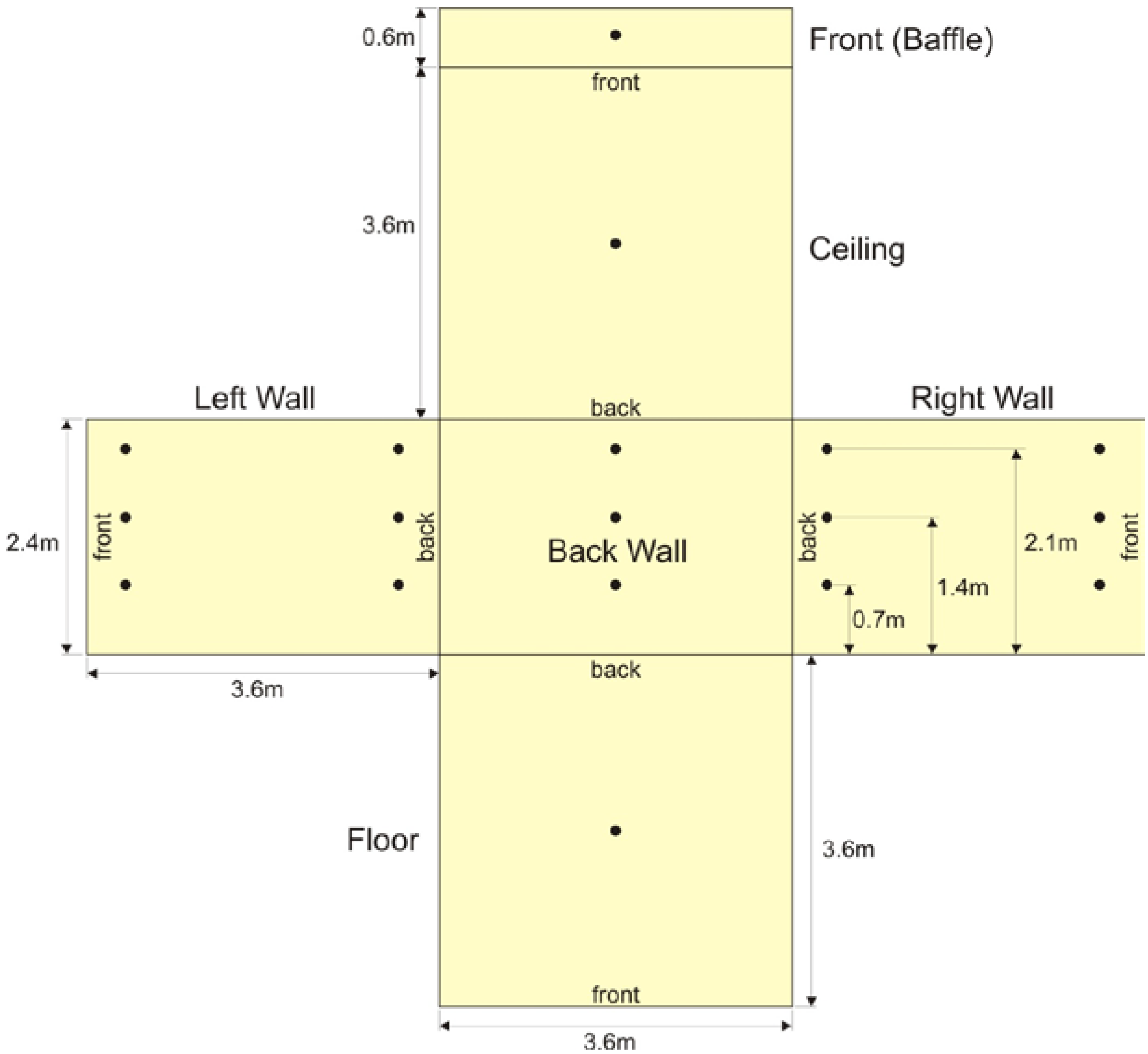

Figure 3: Exploded view of test room showing thermocouple positions

Four sacrificial pinhole cameras were positioned on the walls in set locations to visually record the ignition and fire growth. These cameras were positioned on the right side wall at the back and below the top-most thermocouple, near the centre of the front bulkhead (baffle), and on the front edge of both the left and right walls near the baffle.

Note: In test 1 the two cameras positioned at the front sides were above the baffle line thus were quickly obscured by smoke; these were positioned below the baffle line in test 2.

Room contents (combustibles)

The room was configured to resemble a typical spare bedroom commonly used to store hoarded materials. Such rooms typically include furniture as well as other items but are generally uninhabited spaces. The two separate burns required typical hoarded materials (Mogan, 2008) to be placed into the room emulating severe and moderate levels of clutter (CIR level 8 and CIR level 5, respectively).

The following combustible materials were used to clutter the rooms:

Materials used in Test 1 – CIR level 8	Materials used in Test 2 – CIR level 5
Wooden cot	Wooden cot
Cardboard boxes (under cot)	Cushions (wool fibre based in cot)
Lounge cushions (x8 in cot)	Piled clothing (under cot)
Bed linen	Sleeping bags (nylon) over cot
Baby car seat (plastic)	Cardboard boxes
Cane bookshelf	Toys (synthetic)
Suitcases (x2) packed with linen/clothing	Wooden wardrobe
Books/clothing (in bookshelf)	Piled clothes (in wardrobe)
Books (in boxes)	Boxed games and toys (on wardrobe)
Single-seat lounge chair	Wooden framed mirror (on rear wall)
Books (piled on floor)	Suitcase (x1) packed with clothing
Large 2-seat sofa chair (polyurethane fill)	Single-seat lounge chair
Wooden shelf	Sheep-skin rug
Books (in wooden shelf)	Wooden cabinet
Doona and bed sheets	Books (piled in wooden cabinet)
Wooden pallets	Cane chair
Curtains (hanging on walls)	Medium 2-seat sofa bed
Boxes (in floor)	Piled clothing (on furniture and floor items)
Plush toys (foam based)	Clothing (in bags)
Pictures (hanging on right wall)	Books/puzzles (piled on floor)
Leather coats	Curtains (hanging on right wall)
Piled clothing (on furniture and floor items)	Clothing (hanging on right wall)
Hats (hanging on right wall)	Heater (ignition source)
Carpet (on floor)	Carpet (on floor)

Table 1: Inventory of combustible materials used in test burns

Ignition source

The source of ignition was located in the rear left corner of the room for both burns, and material were arranged accordingly either within or suspended from (i.e. draping to allow vertical fire run) a cot placed in this corner.

The method of ignition was as follows:

(a) For test 1, a piece of paper was scrunched and ignited by a lighter which was placed at the bottom of materials piled into the cot.

Figure 4: Ignition from lit paper placed at the bottom of material pile in cot (Test 1)

(b) For test 2, clothing was draped over the side of the cot and placed in contact with a standard electric radiant bar heater, which was switched ON to commence the test.

Figure 5: Ignition from radiant bar heater showing first material ignited (Test 2)

A standard domestic photo-electric smoke alarm was fitted on the ceiling to identify the alarm's activation time in response to the smoke being produced between ignition and growth stages. This reaction time will be compared with the time taken to reach flashover so that the relative risks can be determined and an assessment made on the probable time to safely egress the room of fire origin at the two clutter levels.

Atmospheric monitoring

Atmospheric monitoring was conducted by FRNSW's Hazardous Materials Response Unit. Four wireless multi-gas monitors were positioned around the burn cell to analyse gases being released from each burn into the cavity of CSIRO's large burn gallery.

Note: The burn gallery is a large enclosed test cell designed to capture large volumes of released smoke and pass it through filters and a thermal oxidizer to burn off combustible particles within the gases.

The multi-gas monitors continuously analyse sampled air to measure levels of Carbon Monoxide (CO), Volatile Organic Compounds (VOC), Chlorine gas (Cl_2), Lower Explosive Limit (LEL) and Oxygen (O_2). The units provide alarm at the following hazardous concentrations:

Gas ppm	Cal Gas/ Balance	Unit	TWA[2]	STEL[3]	Low	High
CO	50 / Air	ppm	35	100	35	200
VOC	100 / Air	ppm	10.0	25.0	50.0	100
Cl2	10 / N_2	ppm	0.5	1	0.5	5
0_2	20.9 / N_2	%	-	-	19.5	23.5

Table 2: Default alarm concentration levels of multi-gas monitors

The four (4) multi-gas monitors were positioned both in front and behind the burn room, and both at ground level and at head height, as follows:

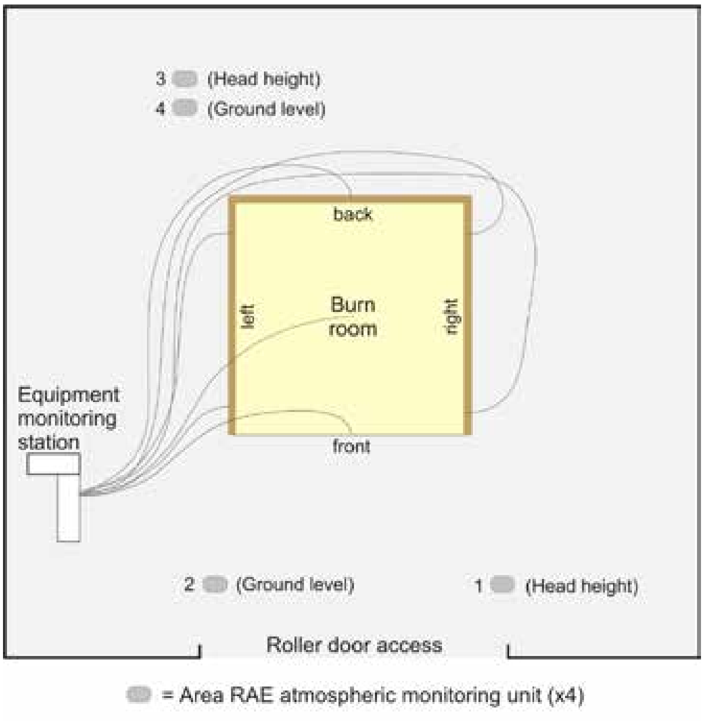

Figure 6: Plan of test facility showing burn room and monitoring equipment location

[2] TWA = Time Weighted Average.
[3] STEL = Short Term Exposure Limit.

Test equipment

The following equipment and materials are as follows:

Figure 7: Thermocouple installation

(a) Unsheathed wire thermocouple assemblies from *TC Measurement & Control Pty. Ltd.* Type 12 (12-N-10,000-1143.0-2I-3P4CL-10 MTRS A30NX-F11NX/F40-IEC) were used to measure gas temperatures.

Note: The end-probes were inserted through small holes drilled through the linings.

(b) A *dataTaker* DT80 data logger with CEM20 extension module was used to capture measurements from seventeen thermocouple assemblies.

(c) A closed-circuit television (CCTV) installation comprising a *Techview* H264 4-channel digital video recorder and four *Signet* QC3692 mini pinhole cameras were installed.

(d) *RAE Systems* AreaRAE PGM-5020 wireless multi-gas monitors were used to analyse atmospheric gases.

(e) An *MSA* EVOLUTION 6000 X thermal imaging camera was used to capture heat signatures and observe thermodynamic actions (i.e. gas layer fluid dynamics).

(f) Additional video and photos were taken using a *Sony* HD video camera, *Canon* digital SLR cameras and *GoPro* sports action cameras.

Note: The GoPro cameras were fitted to firefighters helmets for point-of-view video of the fire development and firefighting operations.

(g) A *Quell* P3010L sealed Lithium battery photoelectric smoke alarm (test 1) and a *Quell* QPI9010 Dual Sensor (ionisation and photoelectric) smoke alarm (test 2) was used to identify alarm reaction time. Both alarms were Australian Standards compliant.

Figure 7: Set up of equipment monitoring station

Results and observations

Test 1 – Level 8 clutter

Test 1 was conducted on Friday 18th July. Ambient conditions were not recorded at the time of the test however weather records indicate that around the time of the test the outside air temperature would have been around 10°C. Air humidity was around 47% (one of the driest days in July) and a steady wind averaging 30-35km/h was blowing in from the WSW, with occasional stronger gusts.

Note: The wind blew through the open roller door of the gallery and directly into the burn room, thus resulting in the open ventilated fire scenario being slightly wind driven[4].

Ignition commenced at 10:55hrs using a scrunched piece of paper that was ignited by a lighter. This burning paper was placed at the bottom of the pile of materials placed in the cot.

The polyurethane cushions quickly ignited allowing fire to rapidly spread vertically and laterally through the combustibles within the cot. A dense smoke layer formed very quickly from the combusting foam cushions with the ceiling mounted smoke alarm activating only 35 seconds after ignition.

Figure 8: Early fire growth and rapid fire spread (Test 1)

The hot gas layer bounded by the front baffle quickly increased in temperature as fire rapidly spread from the cot to the immediate surrounding contents. Rollover fire quickly began in the unburnt particles of this smoke layer along with evidence of thermal feedback of radiant energy from the gas layer pre-heating the remaining room contents (from 70 seconds).

Fluid dynamic observations gave clear visual indication of strong entrainment of fresh oxygenated air feeding the fire, and resultant pressure surge forming a strong hot gas current spilling over the front baffle and ventilating into the gallery. As the burn room was situated relatively close to the open roller doors it is believed that wind on the day did play a role in exaggerating the ventilation of this fire.

[4] Wind driven fires are high energy fires where oversupply of oxygen directly influences the combustion process causing fuel to burn more quickly and at a higher temperature.

Flashover was reached in approximately 100 seconds, where ceiling gas temperatures were around 800°C.

Figure 9: Fire at flashover stage – flashover was reached in 100 seconds (Test 1)

Fire was allowed to burn post flashover for approximately 4½ minutes before extinguishing commenced as the structure was becoming compromised from fire burn through of the plaster linings. Gas temperatures at ceiling level typically hovered between 1000-1100°C, and gas temperatures near the front of the room being slightly cooler from the inrushing air supply.

Thermocouples at the rear of the room, the location of fire origin, recorded significantly lower temperatures depending on the degree of thermal insulation provided by the hoarded materials located in front of the thermocouple. All these thermocouples did however register increasing temperatures as the materials became heated, hot gases permeated through the materials, or as fire encroached closer from mass loss of combusted materials.

The thermocouples recorded the follow peak gas temperatures during test 1:

Location	Max. temp.	Location	Max. temp.
Left Wall, Front-Top	1042°C	Right Wall, Back-Top	819°C
Left Wall, Front-Middle	964°C	Right Wall, Back-Middle	707°C
Left Wall, Front-Bottom	619°C	Right Wall, Back-Bottom	270°C
Left Wall, Back-Top	1067°C	Right wall, Front-Top	1094°C
Left Wall, Back-Middle	904°C	Right Wall, Front-Middle	604°C
Left Wall, Back-Bottom	399°C	Right Wall, Front-Bottom	1013°C
Back Wall, Top	992°C	Ceiling, Centre	1126°C
Back Wall, Middle	774°C	Front wall (baffle), Top	990°C
Back Wall, Bottom	85°C		

Table 3: Peak gas temperatures measured by thermocouples in test 1

The highest recorded gas temperature of 1126°C was recorded at the ceiling centre and the lowest peak temperature of 85°C was recorded at the bottom of the back wall.

Note: Despite being very close to the ignition source, it is assumed that contents were compactly stacked on the floor along the rear wall creating good thermal insulation and possible air pocket against the hot gasses nearby.

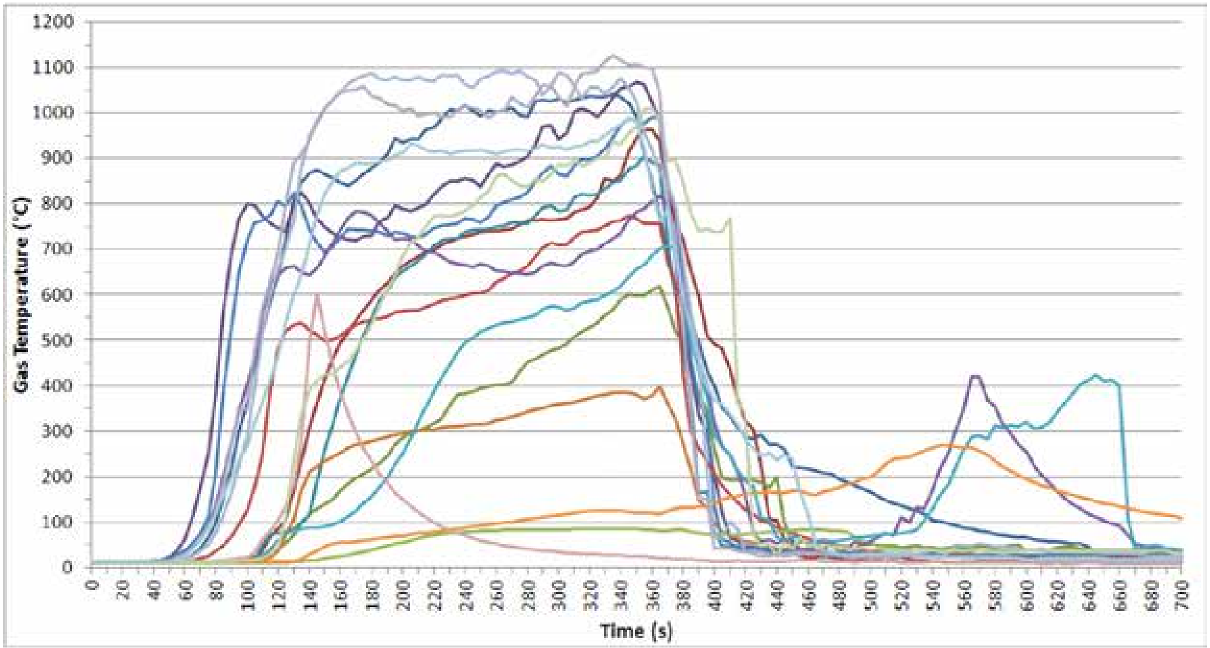

Figure 10: Overview of gas temperature measurements from test 1 – Level 8 CIR

Extinguishment saw immediate cooling of all gas temperatures. A significant degree of overhaul was required by firefighters to extinguish all pockets for fire amongst the hoarded materials, and a Thermal Imaging Camera was required to locate these 'hot spots' during extinguishment.

Figure 11: Post fire damage and debris (Test 1)

The fire burned in test 1 for duration of just over 6 minutes. Even at peak HRR where gas temperatures averaged greater than 1000°C, only a small percentage of the available fuel load was actually consumed through combustion. Notably, mass loss was greatest across the top of material piles where highly combustible fuels were encountered. Burn though of the plaster linings did result in charring of the timber framed structure.

Test 2 – Level 5 clutter

Test 2 was conducted on Friday 25th July. Weather conditions on the day were noticeably different than during test 1. Weather records indicate that the likely ambient conditions around the time of the test were an outside air temperature around 12°C, relative air humidity of 82% (following morning showers) and slight westerly breeze (less than 10kph).

Despite minimal wind being present during test 2, the burn room had in fact been displaced further towards the centre of the gallery for the second burn in order to reduce any wind driven ventilation from the open roller door.

Note: The roller door remained open to allow easy access/egress for attending observers, firefighters and media personnel.

Ignition commenced at 10:54hrs by connecting power to switch ON the electric radiant bar heater. After a few seconds the flannelette pyjamas in contact with the heater ignited and power to the heater was disconnected. Initial fire growth was limited by the flammability and spread of flame index of the pyjamas. Fire spread up the clothing was quick, however lateral fire spread to fuels within the cot was quite slow, especially compared to test 1.

Figure 12: Early fire growth and fire spread (Test 2)

The wool fibre cushions in the cot were slow to ignite compared to the polyurethane cushions and the heat released much lower. Initial fire growth was slow but steady. The initial smoke generated was 'clean' indicating pyrolysis was more complete, however as the smoke stratified across the ceiling the ceiling mounted smoke alarm was activated only 60 seconds after ignition.

Fire continued steadily developing to involve fuels within the cot, and as temperatures increased, fire began to spread laterally to involve other fuels around the cot. The hot gas layer across the ceiling began to thicken and radiant heat began to thermally feedback increasing the rate of fire growth.

Various items with low auto-ignition temperatures began to ignite from the radiant heat and the heat released cumulatively added to the fire load causing flashover to occur after 260 seconds (4min and 20sec).

When flashover occurred, gas temperature at the ceiling was 977.8°C and temperature at the floor was 692.6°C. Temperatures were steadily increasing post flashover, however the test was terminated within 30 seconds of reaching flashover due to a minor explosion which resulted in a projectile causing concern for safety.

Note: The cause of this explosion is unknown however it is strongly suspected that it was a battery, possibly from the ceiling mounted smoke alarm.

Figure 13: Fire at flashover stage – flashover was reached in 260 seconds (Test 2)

The thermocouples recorded the follow peak gas temperatures during test 2:

Location	Max. temp.	Location	Max. temp.
Left Wall, Front-Middle	906°C	Right Wall, Back-Top	820°C
Left Wall, Front-Bottom	371°C	Right Wall, Back-Middle	96°C
Left Wall, Back-Top	877°C	Right Wall, Back-Bottom	17°C
Left Wall, Back-Middle	769°C	Right wall, Front-Top	806°C
Left Wall, Back-Bottom	140°C	Right Wall, Front-Middle	731°C
Back Wall, Top	980°C	Right Wall, Front-Bottom	765°C
Back Wall, Middle	913°C	Ceiling, Centre	1020°C
Back Wall, Bottom	456°C	Front wall (baffle), Top	888°C
		Floor, Centre	931°C

Table 4: Peak gas temperatures measured by thermocouples in test 2

The highest recorded gas temperature of 1020°C was recorded at the ceiling centre, and the lowest peak temperature of 17°C was recorded at the bottom of the right wall near the back.

Note: Clothing piled in the right rear room corner was so compactly stacked that it created near perfect thermal insulation against the hot gasses nearby. Above the top of the pile gas temperatures reached 820°C, in the middle just 96°C and at the bottom of the pile, a near ambient 17°C.

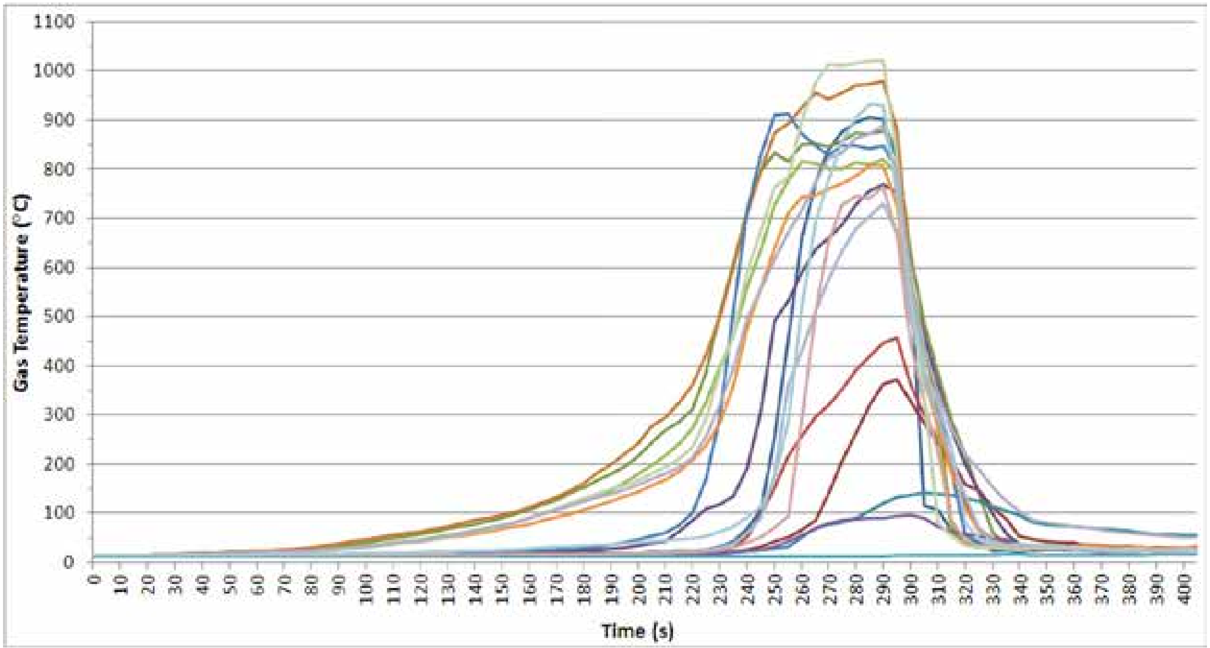

Figure 14: Overview of gas Temperature measurements from test 2 – Level 5 CIR

The fire was extinguished quickly with immediate impact. The Thermal Imaging Camera was again used to locate 'hot spots' during overhaul, however as extinguishment occurred soon after flashover the depth of fire penetration into the piled materials was less than for test 1.

Figure 15: Post fire damage and debris (Test 2)

Fire burned in test 2 for duration of just over 5 minutes, however there was slow initial fire growth resulting in some time being elapsed before reaching flashover. The short duration at peak HRR meant that mass loss across the fuels in the room was minimal and significant damage only occurring at the point of origin (the cot). There was no burn though of the plaster linings other than at penetration points.

Atmospheric monitoring

Multi-gas monitors analysed gases around the burn room in the gallery. This gallery was designed to positively extract smoke through the thermal oxidizer at the top of the chamber, thus most gases vented away from the monitors. Readings only became detectable when the rate of smoke generation exceeded the extraction rate to fill much of the gallery chamber with smoke, some of which also descended as it cooled.

For both tests, there were negligible VOC, Cl_2 and LEL readings. There was also minimal O_2 deviation in either test, however both tests did indicate elevated CO levels, particularly with test 1 where extended peak combustion filled the entire gallery with smoke. The two monitors behind the burn room registered CO levels above the alarm level of 30ppm during test 1, where wind forced smoke toward the rear of the gallery.

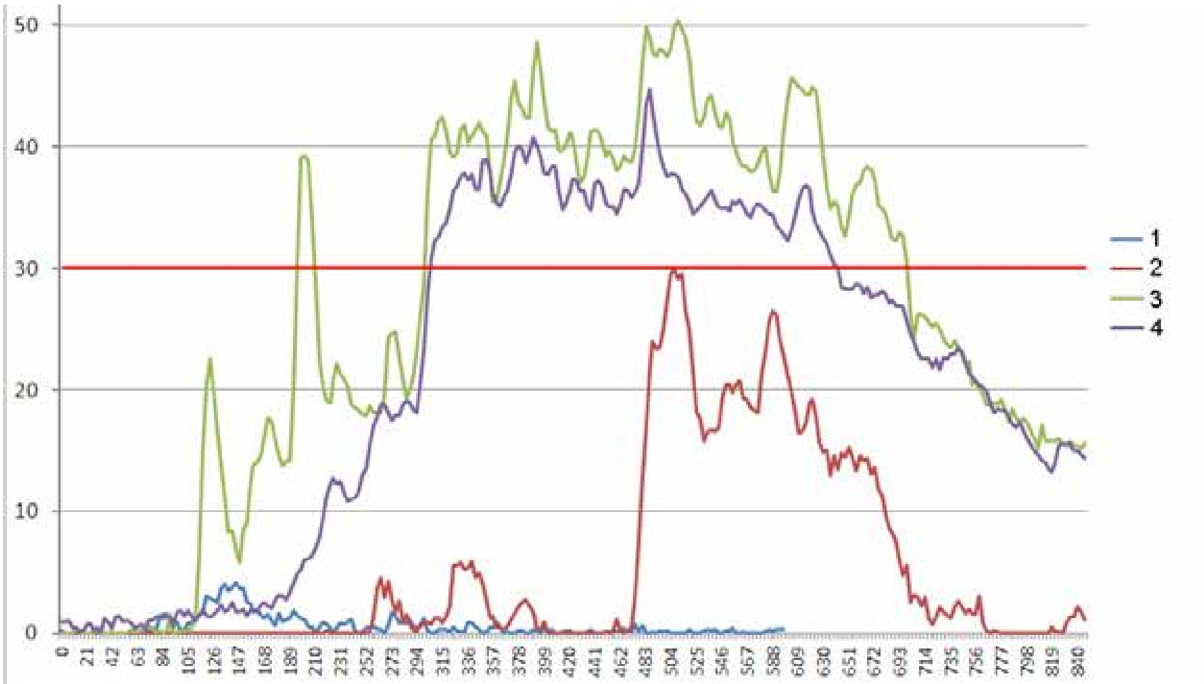

Figure 16: CO level readings from each multi-gas monitor used in test 1

Readings captured from the gas monitors for test 2 were not synchronous indicating that they were possibly not calibrated with the datalogger. Only one of the monitors in test 2 detected elevated CO levels, being no 2 in front of the burn room at ground level. The CO level did not exceed 13ppm in test 2 which is well below the alarm level of 30ppm.

Figure 17: CO level reading from no. 2 multi-gas monitor used in test 2

Review and analysis

On face value one might assume that the first burn was much more rapid and intense than the second, however there are many contributing factors behind the varying results causing this distorted perception. When comparing the results of both tests against a previous FRNSW test burn of a 'standard' bedroom on 22nd September 2013, where flashover was reached in 110 seconds and peak ceiling temperature was 1124°C, it is clear that factors other than fuel load had greater influence over the results.

Note: The 'standard' bedroom was configured with a clutter image rating of 1. The bed did include a polyurethane based mattress.

Principal to the fire's development and time to flashover is the method of ignition; the first, second and third materials ignited; and the arrangement of those materials relative to the ignition. The use of piloted ignition and readily combustible materials in the level 8 CIR burn exaggerated the initial fire growth leading to rapid flashover (100s), where as the use of contact ignition and less flammable natural fibre materials which required some run before igniting other materials, resulted in lagged initial fire growth and more time to reach flashover (260s).

Note: Rapid fire growth should not automatically be associated with high levels of hoarding. A level 1 CIR bedroom can readily reach flashover in a similar amount of time to level 8 CIR (100 seconds versus 110 seconds).

The level of hoarded material does not seem to directly influence maximum temperatures. The level 8 CIR burn did not necessarily yield much greater temperatures than the level 5 CIR burn (1126°C vs 1020°C). While the thermocouple readings for test 2 were slightly lower, gas were still steadily increasing when extinguishment occurred shortly after flashover was reached. Gas temperatures in test 1 would have been slightly elevated due to the higher ventilation by the wind on the day.

The peak HRR for both burns was not measured, but it appears that they are not dependant on fuel load. Other factors are more critical in determining the HRR such as the fire properties of the material of combustion. While fuel load may not determine HRR, it does increase the burn duration at maximum HRR as there is greater mass of material to combust.

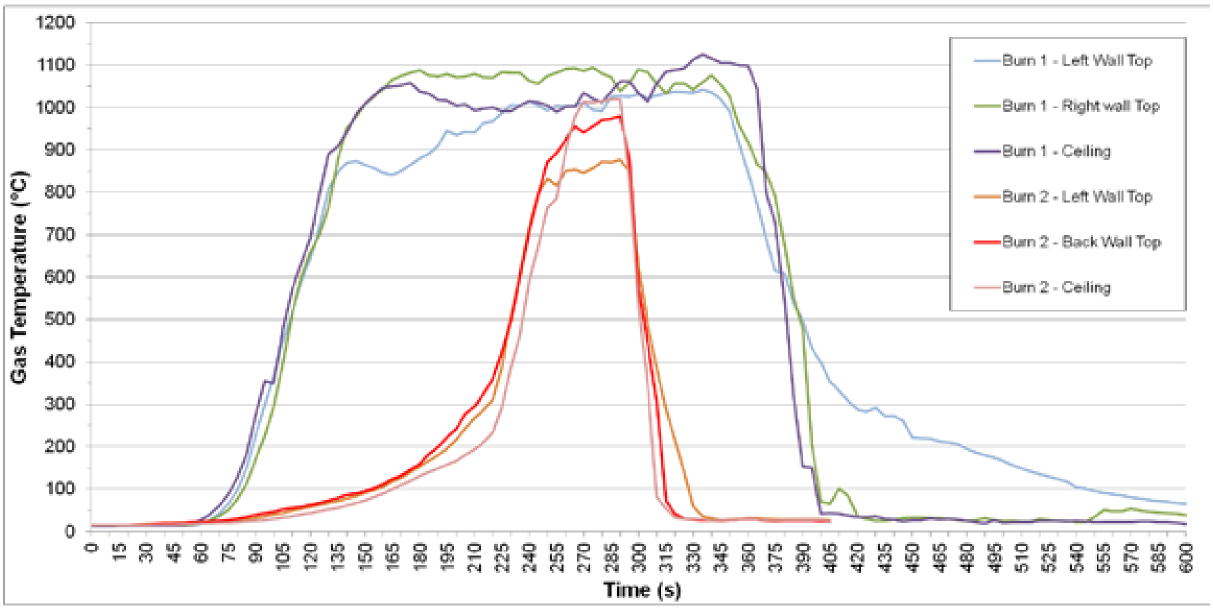

Figure 18: Gas temperature comparison between both burns

There were no measurements taken of the Smoke Produced Rate (SPR), however visual observations indicate that test 1 had greater SPR than for test 2, particularly during early fire growth. This most likely was a result of the materials involved in combustion such as polyurethane cushions. The much longer duration of post flashover burn for test 1 also meant that the gallery chamber became smoke logged hence the CO alarms being registered by atmospheric monitoring.

While there was no measurement of extinguishment such as amount of water required or time taken to extinguish, both fires did require considerable effort to extinguish all hot spots within the pile fire debris.

Note: Separate research could be conducted into minimum requirements necessary to extinguish hoarding fires of various CIR levels, including assessing types of extinguishing mediums.

Review of methodology

Discrepancies in methodology made direct comparison between the burns difficult. Uncontrolled variables resulted in two significantly different fires rather than the expected level 8 CIR burn being either more accelerated or intense than the level 5 CIR burn. The arrangement of fuels is a critical factor in determining initial fire growth and time to flashover.

Direct comparison flashover times cannot be undertaken with any validity. It would be beneficial to conduct further testing with tighter control of known variables so that comparative analysis can be undertaken.

Note: The scenario for the second burn (level 5 CIR) was more realistic with better control of variables, and could form the basis from which further retesting of level 8 clutter conditions could be used for direct comparison.

Primarily, different materials used for each test resulted in fuels with significant differences in combustibility, hence different calorific output from fuels amplified any expected variations in HRR and rate of fire spread. The level 8 CIR burn included significantly greater amounts of furnishings including polyurethane foam (PUF), which has a high HHR for its given density[5].

Note: To directly compare different clutter levels the materials chosen as the fuel source for both burns should be consistently uniform with known fire properties. The level 8 CIR burn would simply have more of the same fuel used for the level 5 CIR burn.

Concepts from ISO standard *ISO 9705:1993: Fire tests - Full-scale room test for surface products* should be adopted in future tests to allow capture of relevant metrics, including using a cone calorimeter to capture HRR data.

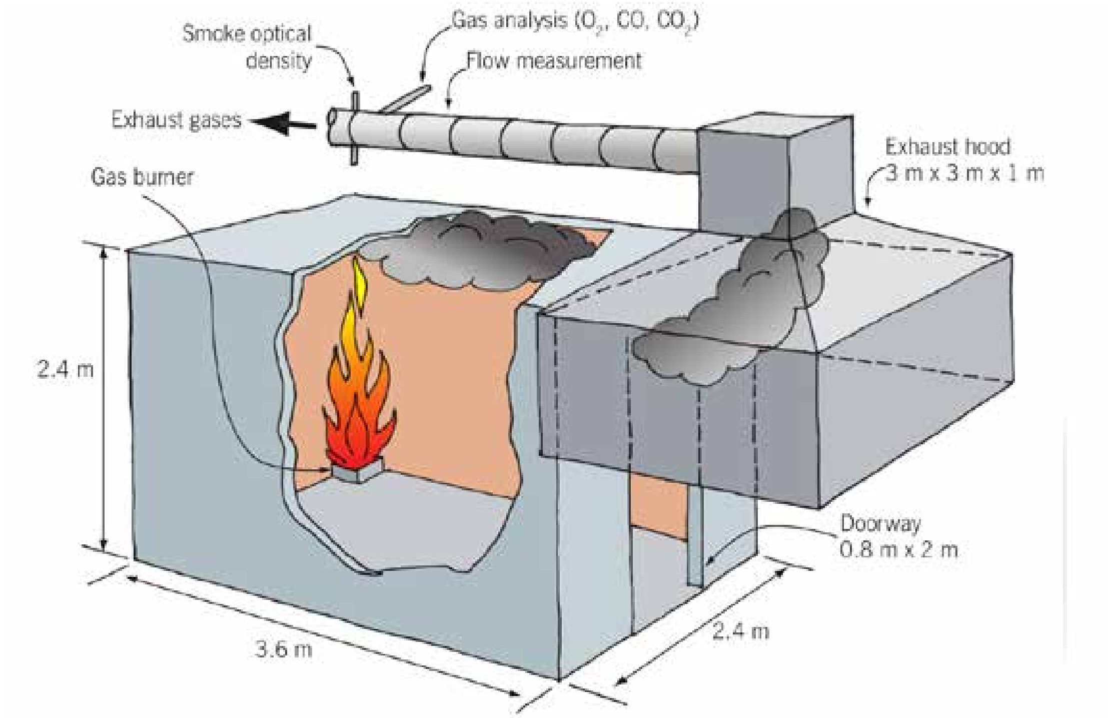

Figure 19: ISO 9705:1993 Full scale room test facility

Principal benefits from adopting ISO room concepts include:

- standardised room size (3.6m x 2.4m) and compartment volume (20.7m³) from which comparisons with other tests can be made
- conventional room configuration of four walls with single access door provides realistic fire dynamics with limited ventilation
- exhaust hood would allow capture of gases from which relevant measurements can be taken including HRR and smoke produced.

[5] Polyurethane foam has a Heat of Combustion commensurate with other solid fuels, however it has a much lower density thus releases more heat energy for a given volume.

Limitations of test procedure

Different ignition methods used for both tests resulted in significant variations in initial fire growth and times taken to reach flashover. Piloted ignition in test 1 had an instantaneous effect on fire growth, where as contact ignition for test 2 required materials to heat to auto-ignition temperature before flaming occurred.

The fuel type and arrangement at the ignition points were also different, thus further affecting the rates of fire growth. Test 1 involved ignition directly at the base of a substantial fuel load (polyurethane), where as test 2 required fire to run up draping clothes before spreading laterally to contents within the cot.

The lack of ventilation control resulted in fire that was heavily influenced by external conditions including strong wind blowing into the gallery during test 1. This necessitated the room being moved further inwards for test 2. The ISO room configuration of four walls with a single door would reduce ventilation substantially altering fire dynamics as fire becomes ventilation controlled.

Existing test equipment was not conducive to measuring metrics relevant to the objectives of the tests. Limited information is gained from use of thermocouples alone, and other equipment such as cone calorimeter, flux meter and load cells (mass loss) would have yielded more valuable information. The atmospheric monitoring only served to monitor safe conditions within the gallery and did not provide any practical data on smoke production.

Testing of smoke alarm activation times was based under the premise that the smoke alarm is installed within the bedroom. For most dwellings, the *Environmental Planning and Assessment Amendment (Smoke Alarms) Regulation 2006* only requires a single smoke alarm on each level within the corridor leading to bedrooms.

Findings

The following findings are made in respect to the test results:

1. Regardless of the level of fuel load, this research identified that the type of fuel and arrangement determined the level of fire risk. While test 1 achieved flashover in a significant shorter time than test 2, the role of the method of ignition and fuel arrangement of both burns were principal in the outcomes.

2. Both the level 5 CIR and level 8 CIR burns resulted in peak temperatures that were similar. It is assumed that peak HRR would also be similar, however, fire will burn at peak intensity much longer as there is greater mass of combustibles to be consumed.

3. Hoarded materials can provide good thermal insulation from combusting materials and the hot gas layer. The thermocouple reading of 17°C in test 2 at the right wall, back-bottom, while the ceiling gas temperature was 1020°C, indicate that a potential survivable environment may exist as the base of such insulating material

Note: Firefighters need to be aware that victims trapped under fallen materials may be alive when conducting their search operations.

4. Hoarded materials did not present any unexpected hazards during the burns other than observing excessive smoke production and a minor explosion during test 2, believed to be battery from the melted smoke alarm. The materials chosen for these burns were typical domestic products found in a bedroom and do not represent a case where unorthodox materials are being hoarded such as electrical items, mechanical parts, building materials/offcuts and other disposed rubbish.

5. The burn room was not intended to test factors relating to egress being impeded or obstructed nor access by firefighters being hindered by any hoarded materials, however it is known that these are major issues for hoarding fires. The tests did however demonstrate that greater effort is required for salvage/overhaul operations.

6. Ignition from an open flame accelerated initial fire growth in test 1. Occupants who engage in unconventional cooking and heating processes that involve open flame will be at much greater risk when accumulated materials are in close proximity to the flame. Unconventional cooking/heating practices occur when utility services are disconnected.

7. Working smoke alarms are critical in households involving hoarding due to greater ignition risks. A photoelectric alarm, designed to activate from smoke particles thus is able to detect smouldering fires, is strongly recommended. Most occupants who engage in hoarding behaviour do not have a working smoke alarm present in the household.

Note: The time to safely evacuate may be significantly reduced depending on the hoarded materials. Occupants must not delay their escape when an alarm activates.

Recommendations for future build it-burn it research

This research identified that further testing could be conducted to validate assumptions deriving from the results of these tests. Methodology should be refined to capture better metrics for scientific scrutiny. The following should be considered in successive testing:

1. Adopt a standardised room size and configuration such as the ISO room. The room should have a single standard door to ensure fire dynamics is ventilation controlled.

2. The burn room should be built onto load cells so that masses can be determined such as room mass, mass of room contents (i.e. fuel load), mass loss from combustion.

3. An exhaust hood should capture vented gases and equipment used to measure HRR (cone calorimeter), Smoke Produced Rate (SPR) in m^2, and optical density of smoke.

4. Gas sampling ports should be included at various heights from the floor (e.g. ceiling, head high, floor level) and gas samples taken to measure tenability (e.g. identify smoke constituency and toxicity levels).

5. Ambient conditions of the test environment should be monitored and recorded (e.g. temperature, relative humidity, wind). As much as possible these should be controlled (e.g. test conducted on suitable day, close gallery doors as far as practicable, orientate burn room perpendicular to any wind).

6. A heat flux sensor should be positioned a nominated distance from the opening to measure radiant heat output.

7. Where ignition methods are not subject to testing, a standardised method of ignition should be adopted, including using specific material for first/second materials ignited (with known spread of flame index (SFI) and smoke developed index (SDI)). Fuels should be arranged consistently with ignition being uniform (e.g. low energy pilot flame).

Note: Corner room fire tests often use stacked wooden pallets to standardise the material of combustion and its arrangement.

8. A digital clock should be used to synchronously reference events so that accurate time-lines can be established (e.g. start of logging, start of ignition, activation of alarm, time to flashover, time to extinguish).

9. Measure the extinguishing effort such as connect flow meters to outlet of pumping appliance to measure water volume required to extinguish and measure time required to extinguish fire.

10. Measure smoke alarm activation times using standard alarms both within and outside the room of fire origin (e.g. within a corridor space a set distance from the door). Testing could also involve different types of smoke alarms (e.g. photoelectric and ionisation) to determine effectiveness of each type in the test conditions.

Conclusion

FRNSW has identified hoarding as an emerging risk due to the serious safety, health and well-being risks it poses to affected people and the community. The current research on hoarding is limited especially from an emergency response perspective yet hoarding is commonly associated with increased fire risk.

To quantify the extent to which hoarding is a fire problem, we recommend 'hoarding' is included as a data field in the Australian Incident Reporting System (AIRS), ideally with the inclusion of the Clutter Image Rating (CIR) tool in the report itself. This would provide a more complete set of identified hoarding fires and to develop methods for approaching these risks.

Studies into the social science of hoarding are necessary when identifying fire safety needs of hoarding. This study does not identify any argument for domestic sprinklers because fire growth was not determined by fuel load, thus hoarding scenarios are little different from normal residential situations. Any domestic fire, whether hoarding or not, is likely to reach flashover well within fire service's response and intervention times.

Further research could explore the response of people living in hoarding conditions and how their attachment behaviour may directly influence their response in situations of fire (e.g. they may make futile attempts to extinguish a rapidly developing fire in order to save their treasured possessions or not attempt to self-evacuate when a smoke alarm operates).

This research has found that fire growth is not determined by fuel load. Using similar combustible materials in each burn, we found the peak gas temperatures reached were similar despite the differing levels of hoarding. However, the research identified that fire will burn at maximum intensity for longer when the hoarding level is higher. Hoarded materials can increase the intensity of fire depending on their combustibility.

Fuel load does not determine the rate of fire growth nor the time to reach flashover. The level 8 CIR burn reached flashover in 100 seconds, the level 5 CIR burn in 260 seconds, whilst a previous FRNSW test burn of a level 1 CIR bedroom reached flashover in 110 seconds. Both test burns showed that fire growth was principally determined by the ignition and first materials ignited (e.g. Polyurethane).

The higher density of accumulated materials does provide much greater opportunities for ignition and can increase fire spread through materials as they are packed closer.

Working smoke alarms provided early warning to the presence of early fire and offered sufficient time to any occupants to safely evacuate, however immediate action is required by occupants as tenability was rapidly lost by the high smoke production rate. We identified in this study that rapid tenability loss minimises any time margin for safe escape.

Capturing data on smoke production will assist with determining tenability loss on adjoining interconnected rooms of a dwelling and for the occupant. Smoke from hoarded materials is likely to rapidly spread through the dwelling so interconnected smoke alarms will maximise the alarm given to occupants.

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Appendix A – Detailed gas temperature graphs

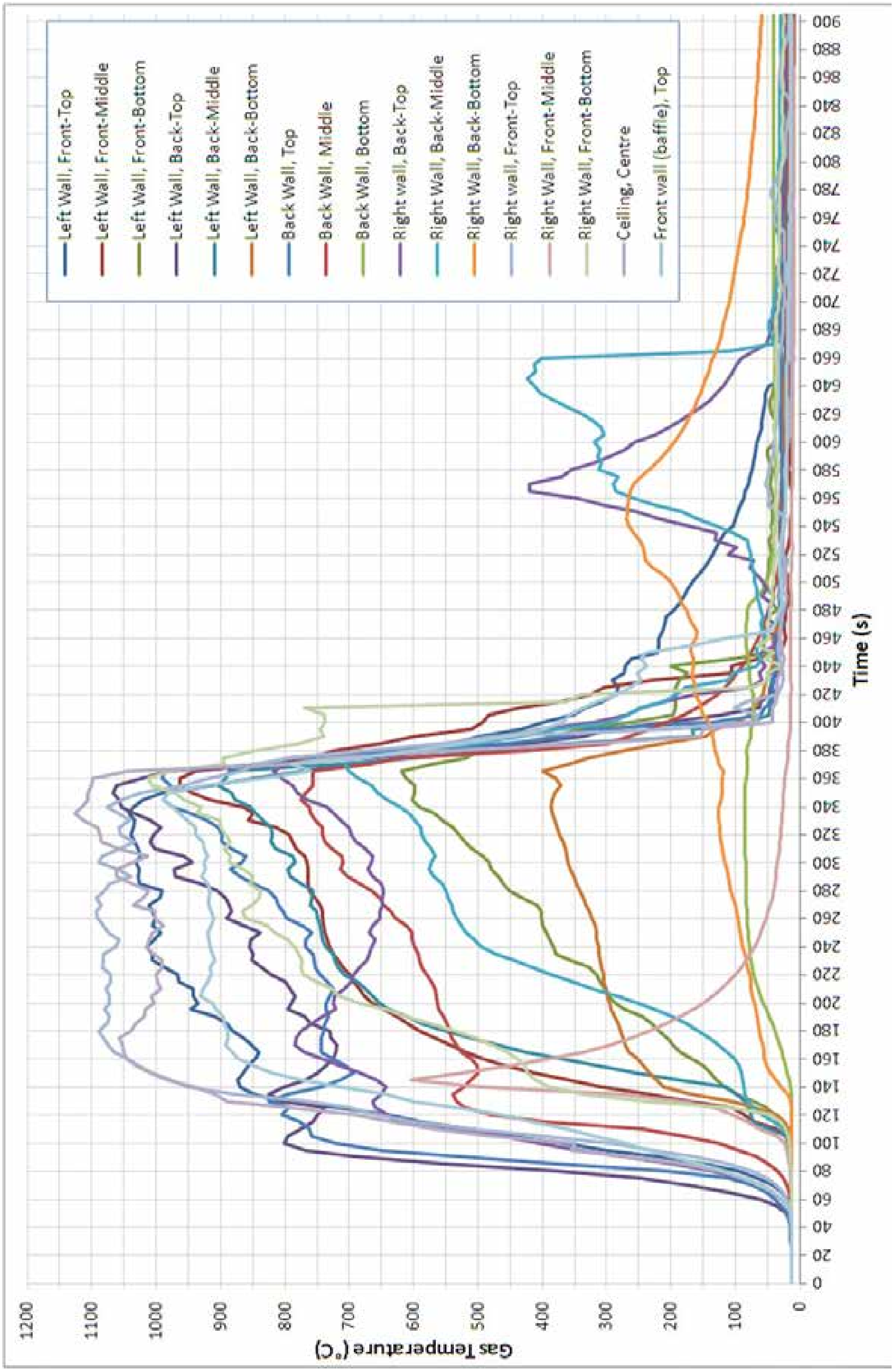

Figure 20: Graph of test 1 gas temperature results (CIR level 8)

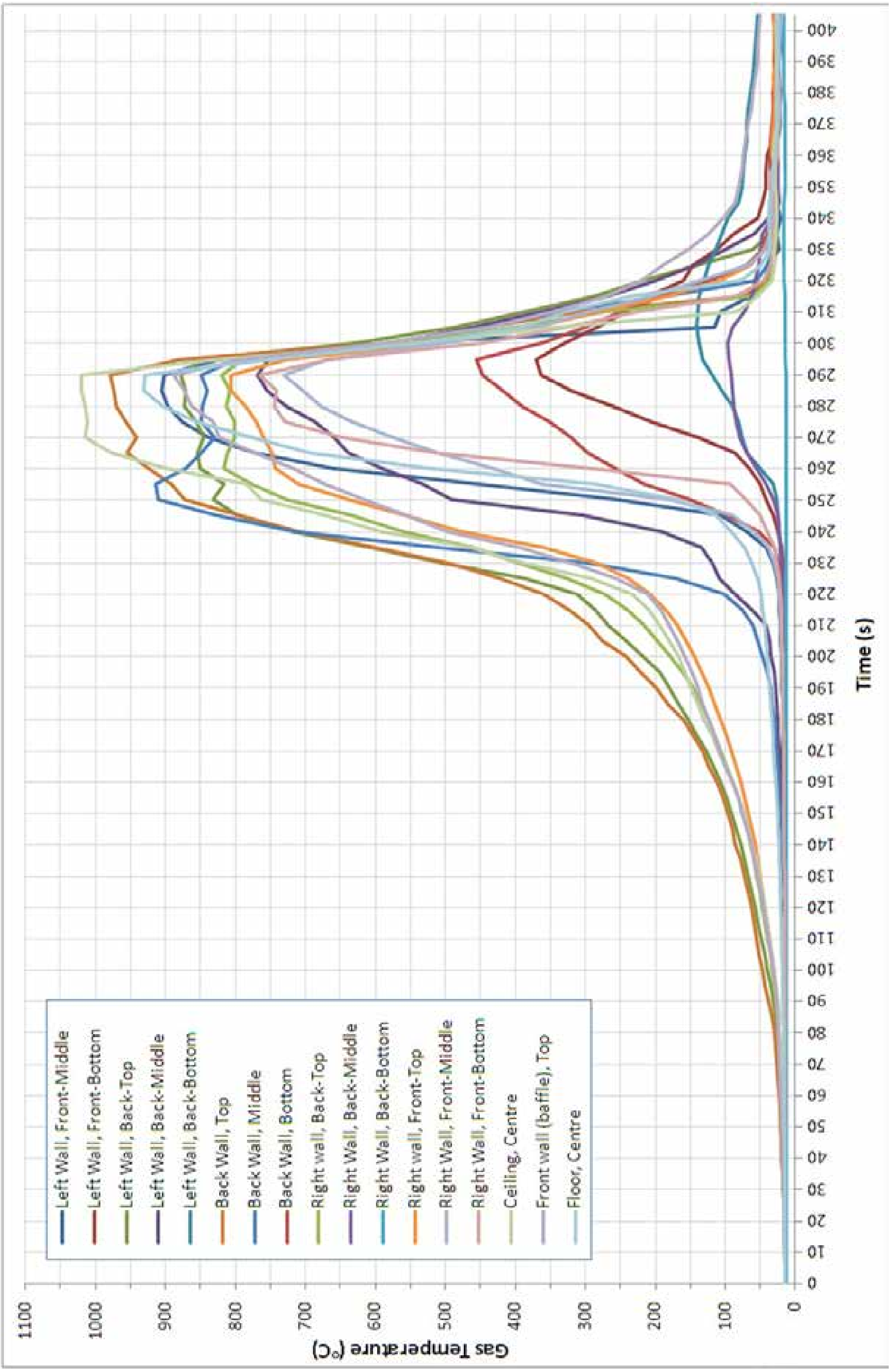

Figure 21: Graph of test 2 gas temperature results (CIR level 5)

Example of CIR level 8 fuel loading and arrangement

Pre-fire fuel loading and arrangement of Test 1 (CIR 8)

Example of CIR level 5 fuel loading and arrangement

Pre-fire fuel loading and arrangement of test 2 (CIR 5)

Figure 22: Comparison between example CIR levels and actual CIR levels used in tests