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An Experimental Study of the Effect of Thermal Radiation Feedback on the Room-Burning Behaviour of Horizontal Slabs of Polyurethane Foam

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Abstract

This report presents the results of three fire experiments (one free-burn and two room tests) that were carried out to investigate the influence of thermal radiation feedback on the rate of surface flame spread and heat release rate (HRR) for a horizontal block of furniture-grade non-fire-retarded polyurethane foam measuring 1200 x 600 x 200 mm and weighing approximately 4.8 kg. The room tests were conducted in a small compartment measuring 2400 mm wide x 2800 mm deep x 2400 mm high with a rectangular vent (opening under a calorimeter hood) measuring 740 mm wide x 1500 mm high (a ventilation limit of approximately 2000 kW) located in one of the 2400 mm walls. The room was lined with one of two different non-combustible materials – 12.7 mm thick cement board or 50 mm thick mineral wool insulation – with substantially differential thermal inertias in order to subject the test specimen to one of two thermal environments. Measurements were taken to quantify the temporal variation of heat release rates (HRRs), smoke density, radiant heat flux, temperatures and the concentration of O_2, CO_2 and CO in the test room. The tests were also recorded using an infrared camera in order to determine the surface rate of flame spread.

The free-burn peak HRR was found to be 498 kW at 172 s from ignition, plateauing at this value for approximately 34s before it rapidly declined. The peak HRR for the test conducted with a cement board room lining was 526 kW at 159 s from ignition (with immediate decline), while that for a mineral wool insulation lining was 965 kW at 176 s (with immediate decline). The maximum room temperatures for the tests with cement board and mineral wool linings were 435 ℃ and 850 ℃, respectively. The results indicated that for the test with a cement board lining, there was no significant change in the peak HRR compared to the test conducted under free-burn conditions. Lowering the thermal inertia (with a mineral wool lining) resulted in a considerably greater (~ 90%) increase in peak HRR compared to the other two tests, which confirmed that radiation feedback from hot layer and walls was responsible for the dramatic increase in the peak HRR.

From the analysis of data record with an infrared camera, it was found that surface flame spread rates were higher (~ 12 mm/s) when the PUF was burning in the room than under free-burn conditions (~ 8 mm/s), regardless of the lining material used.

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by

Annemarie Poulsen[1] and Alex Bwalya[2]

1 Introduction

During the last decade many countries adopted performance-based fire regulations for the design of buildings. As part of the documentation of fire safety, the designer may select one or more design fires based on the knowledge of the expected occupancy. One of the key parameters that must be defined is the evolution of the heat release rate (HRR), which defines the temperature conditions in the room or building.

Much data on fire growth and HRR rates for burning items are available in the literature. However, most of the data has limitations as the experiments were conducted in open conditions, and therefore enclosure effects such as radiation feedback from the hot gas layer and surrounding walls are not reflected. During a room fire, radiation feedback is believed to have an impact on fire development. Radiation feedback can affect the rate of surface flame spread, burning rate and, consequently, the rate of fire growth and onset of critical events such as flashover [1]. One group of variables known to have a significant effect on the radiation feedback are the thermal properties of the wall lining materials since different values of thermal inertia will affect the temperature levels in the smoke layer and the room surfaces.

This report presents the results of fire experiments with horizontal blocks of polyurethane foam (PUF) conducted as part of a joint research project between NRC-IRC's Fire Research Program and The Technical University of Denmark, department of civil engineering, DTU Civil Engineering. The experiments were also part of the Thesis work on *Fire Models and Design Fires* for the first author, a PhD candidate at DTU Civil Engineering, who was a visiting worker at NRC-IRC.

2 Objectives

The aim of the experiments was to study the effect of radiation feedback on surface flame spread, rate of fire growth and peak HRR during the pre-flashover phase of a fire. For this reason a test conducted in the open, under the calorimeter hood (also referred to as a "free-burn test"), and two room fire tests were conducted with identical blocks of non fire retarded polyurethane foam (PUF), which is commonly used in the manufacture of upholstered furniture. The room tests had non-combustible linings with vastly different thermal inertia to subject the test specimen to one of two thermal environments. The thermal radiation feedback is in this context understood to occur due to radiation from the smoke layer below the ceiling and heated walls.

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3 Test specimens

The test specimen was required to be sized so that the resulting fire did not exceed a heat release rate of approximately 1000 kW, which was the flashover threshold for the small room used in this study [2]. The type of PUF material used in the study was the same as that used for constructing a mock-up sofa in a previous project [3] conducted at NRC-IRC in order to take advantage of existing experimental data in preliminary estimates of burning behaviour. In that project, a free-burn experiment with a 610 x 610 x 100 mm PUF block placed on shallow aluminum pan resulted in a fire with a peak HRR of 298 kW. Based on these results, it was estimated that a PUF block of approximately twice the size would produce a free-burn HRR of slightly greater than 500 kW, which has been indicated as a minimum value at which the effects of thermal feedback would be expected to occur in a small room [4]. Therefore, the dimensions of the PUF block was chosen to be 1,200 mm long x 600 mm wide x 200 mm thick. The dimensions and mass of each PUF block are given in Table 1. A 100 mm square grid was drawn on the surface of the PUF block (Figure 1) for the purpose of measuring the rate of surface flame spread.

Figure 1. Photograph of the PUF block showing the 100 mm grid marks.

Table 1. Dimensions of test specimens.

Specimen number	Length [mm]	Width [mm]	Thickness [mm]	Mass [kg]	Density [kg/m^3]
1	1213	600	203	4.760	32.2
2	1201	609	204	4.812	32.2
3	1206	601	204	4.702	31.8

4 Experimental Design

The test facility was comparable to the ISO-9705 room calorimeter [5], but the depth of the standard room was reduced from 3600 mm to 2800 mm while the width and height each remained

2400 mm. This was done to lower the flashover threshold since preliminary tests showed that the free-burn HRR was only expected to be slightly greater than 500 kW. A ventilation opening of 740 mm wide x 1500 mm high was provided in one of the 2400 x 2400 mm walls. The opening was directly under a fume hood, which was connected to an exhaust duct having a diameter of 406 mm.

Two preliminary tests (presented in Appendix A) were conducted to refine the test setup (including the position and strength of the burner) and test procedures.

The experimental matrix consisted of three tests: one free-burn test and two room tests. In the room tests the wall and ceiling lining materials were varied in order to alter the radiation feedback. The non-combustible lining materials used were 12.7 mm thick cement board with a density of approximately 1257 kg/m^3 and 50 mm thick mineral wool with a density of approximately 100 kg/m^3. The mineral wool insulation was attached to the cement board lining. The thermal inertias ($k \cdot \rho \cdot c$) for the cement board and mineral wool were approximately 0.6 and 0.004 W^{2}s/K^{2}m^4, respectively

Table 2 lists the three experiments that were conducted with identical pieces of PUF.

Table 2. List of experiments conducted.

Test No.	Specimen No.	Type	Room Lining
1	2	Free-burn	NA[1]
2	1	Room test (uninsulated)	Cement board
3	3	Room test (insulated)	Mineral wool

[1] Not applicable (free-burn test was conducted under the hood).

Previous experiments [3] showed that the PUF had a tendency to melt and form a pool on the pan after it was ignited. Only a small amount of char residual was left on the pan in those experiments. Therefore, to contain the melt-pool and limit the burning area, the test specimen was placed on a steel pan measuring 1400 mm long x 800 mm wide x 50 mm deep. The pan was supported on a 750 mm high load-cell apparatus that was designed to measure mass loss, see Figure 2.

Based on the results of preliminary experiments (Appendix A), the burner was designed so that it produced two flames of approximately equal strength and having a total HRR of 75 kW: a horizontal flame to ignite the PUF block and a vertical flame to attenuate the horizontal flame and provide the balance of the burner HRR output, see Figure 3. The burner was left on for the entire duration of each test.

Figure 2. Photograph of pan and load cell.

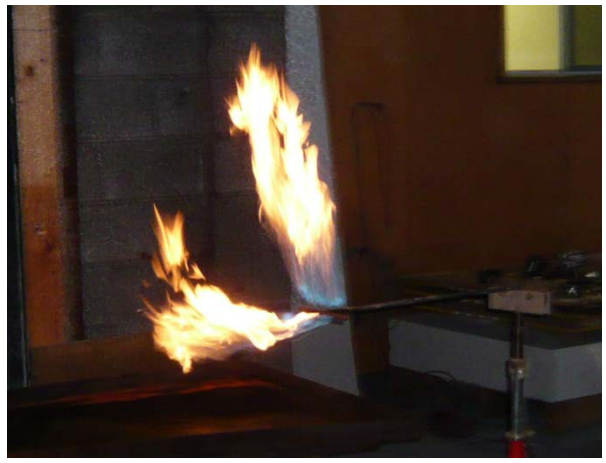

Figure 3. Photograph of dual-flame T-burner.

4.1 Instrumentation

Figure 4 is an illustration of the floor plan and instrumentation of the test setup for the free-burn experiment. The test specimen was located directly under the hood to allow combustion products to be collected. Measurements of mass flow rate, gas temperature and concentrations of oxygen, carbon dioxide and carbon monoxide were taken in the exhaust duct to facilitate calculation of the heat release rate by using an oxygen consumption method [6]. The smoke density was measured in the duct using a pulsed white light meter. In addition, the mass loss rate of the test specimen and heat flux at two different locations was recorded. One heat flux gauge (HF#1) was positioned in a vertical plane at a distance of 600 mm from the pan and height of 1200 mm above the floor facing the flames. The second heat flux gauge (HF#2) was positioned in a horizontal plane at the end of the pan facing upwards towards the hood. The tests were also recorded using an infrared camera to aid the study of flame spread.

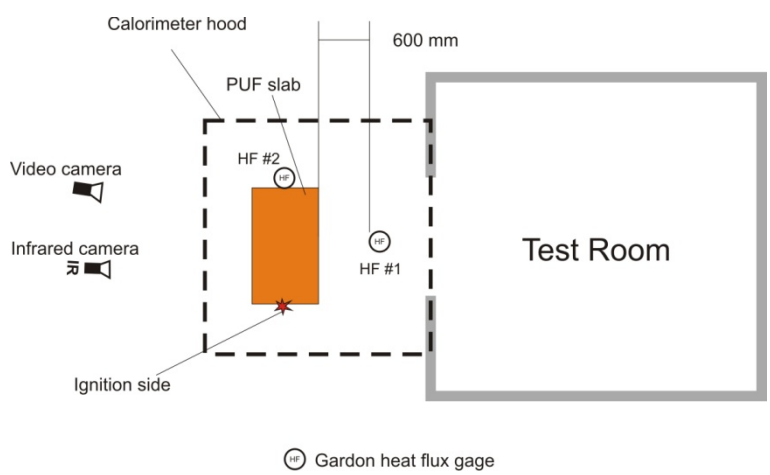

Figure 4. Layout of instrumentation for the free-burn Test 1.

Figure 5 shows the layout of instrumentation for Test 2. The depth of the standard room was reduced to 2800 mm by constructing a light-weight frame partition wall using cement board. The instrumentation was repeated from Test 1 (free-burn). In addition to these measurements, temperatures in the room were recorded at different locations in the room as shown in Figure 5. TCs nos 1, 2 and 3 were positioned at 200 mm below the ceiling whereas TC no. 4 was installed at a height of 200 mm above the floor. TC's 5 to 8 were mounted on the back wall to measure surface temperatures inside the room and on the backside of the lining. Two thermocouple trees were installed in opposite corners.

Figure 6 shows the layout of instrumentation for Test 3. All surfaces in the room, except for the floor, were covered with a layer of 50 mm thick mineral wool insulation. In order to maintain the same volume of the room as in Test 2, the depth of the room was extended by 280 mm before the mineral wool insulation was installed. The instrumentation was the same as that used in Test 2, except that the thermocouple trees were adjusted to give the same relative positions (eg. distance from the pan, walls and ceiling) as those in Test 2.

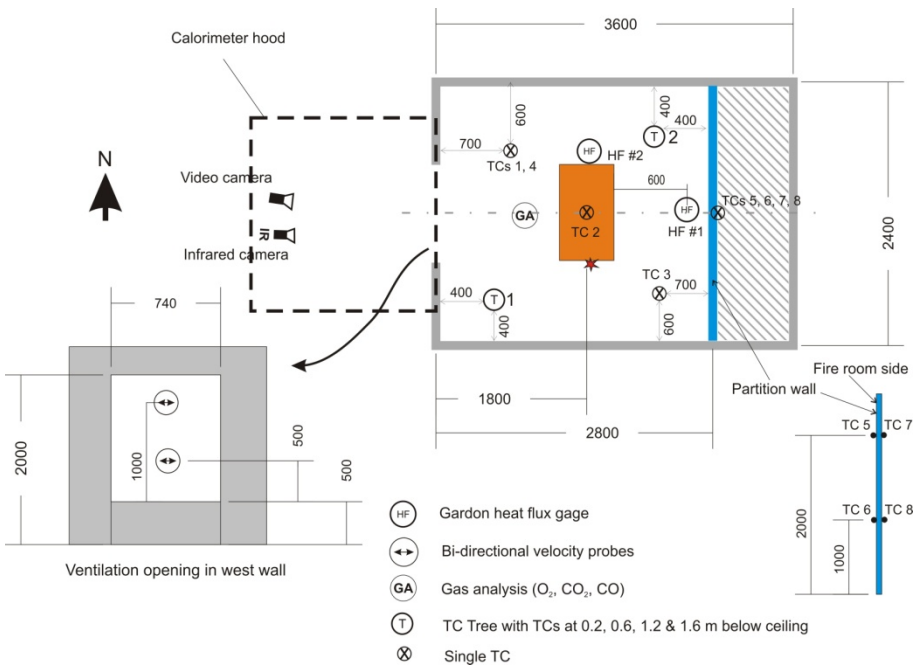

Figure 5. Room burn test setup with cement board lining (Test 2).

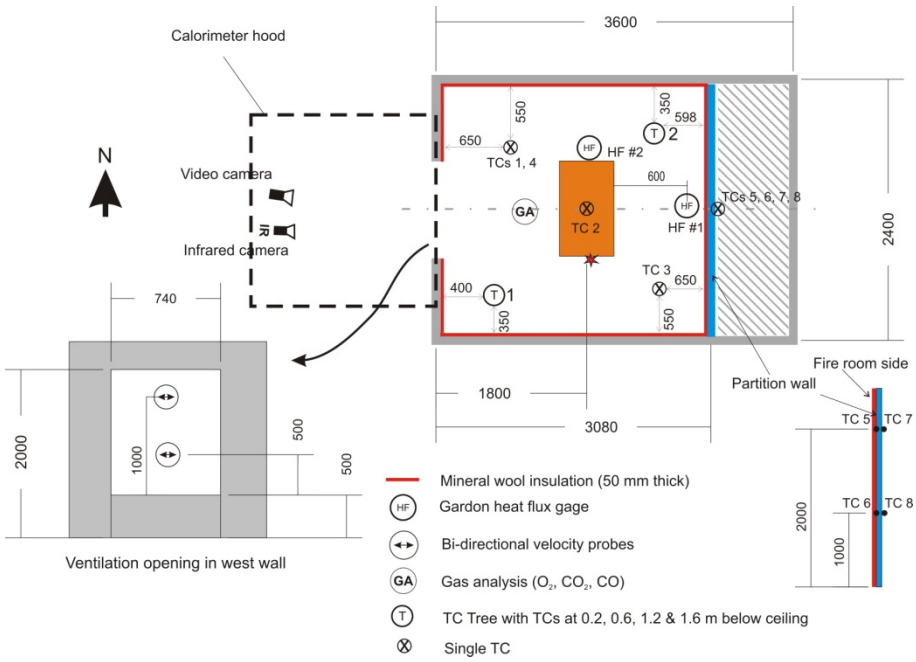

Figure 6. Room burn test setup with mineral wool insulation (Test 3).

The Infrared camera used was a JENOPTIK VarioCAM HiRes infrared (IR) camera incorporating a 16 bit micro bolometer (an uncooled thermal detector) with 384 x 288 pixels. Additional technical data for the IR camera are given in Table 3.

Table 3. Technical data for the VarioCAM® IR camera.

Spectral sensitivity	Temperature range	Measurement accuracy	Thermal resolution (at 30°C)
7.5 – 14 μm	-40°C - 2,000°C	0°C - 120°C: ± 1.5 K >120°C: ±2%	<60 - 80 mK

4.2 Data Acquisition System

A 16 bit Solartron (Schlumberger) Instruments distributed data acquisition system with 3595 series isolated measurement pods (each having 20 channels) and a personal computer interface was used to record all measurements directly to a hard disk drive at specified intervals. All temperature data were instantly processed by the data acquisition system and recorded as temperature values with an accuracy of better than 1°C. Outputs from heat flux gauges, load cells, pressure transducers, gas analyzers and the smoke meter were recorded as either direct current (DC) voltage or current values and were converted by applying the appropriate calibration constants after each experiment. The sensitivity of the data acquisition system for voltage and current measurements is 1 μV and 10 nA, respectively.

4.3 Test procedure

The dual-flame propane T-burner was positioned at 75 mm from the edge of the PUF block and 33 mm above the surface of the block. The test procedure is given in Table 4; it was designed to measure pre- and post-test conditions (including burner output) for each test.

Table 4. Planned test procedure (sequence and timing of events).

Time (sec)	Event	Comment
0	Start data logger	Record pre-ignition conditions
60	Light burner (without specimen)	Measures of burner output
120	Switch-off burner	
180	Place specimen in pan	Measures initial specimen mass
240	Re-light burner (to ignite PUF block)	This is where the actual test starts
	Wait until complete burnout	
+ 60	Stop burner	
+ 60	Stop measurements	Measures end conditions and allows for correction of any drift in measurements

5 Results and Discussion

5.1 Measurements

The measured HRR profiles are presented in Figure 7 and the measurements of smoke density are presented in Figure 8. The HRR results show that Test 1 (free-burn) and Test 2 (cement board lining) had two peaks, whereas Test 3 (mineral wool lining) only had one significantly greater peak. The second HRR peak was likely caused by a combination of two factors: a) burning of unconsumed PUF material around the edges of the block after the material in the central area was initially consumed; and b) deflection of the pan (observed to occur around the time that the peak HRR was reached), which caused the molten PUF to collect at the opposite ends of the pan.

Tests 1 and 2 had comparable fire growth rates and HRR profiles, but there was no considerable increase in HRR in Test 2 due to room effects – Test 2 was only slightly quicker in reaching the peak (498 kW at 172s in Test 1 versus 526 kW at 159 s in Test 2). Test 1 exhibited a plateaued peak lasting 34s before the HRR begun to decline. A second peak of 499 kW occurred at 206 s (towards the end of the plateau). However, considering that the accuracy of HRR measurements using the oxygen consumption method [6] is not better than 5%, the first peak HRR value of 498 kW is here considered to be more important in describing the rate of fire growth in Test 1, i.e. within the stated margin of error, there is a negligible difference between 498 kW and 499 kW, but selecting the second peak HRR value would give an inaccurate impression of the rate of fire growth leading up to the peak.

The measurements of smoke density show similarities with the HRRs except that the first peak for the test with mineral wool lining is not significantly larger than the other two tests, which may suggest that smoke production may be a function of combustion stoichiometry and material properties given that the same material was used in all of the tests. Further research and analysis is needed to determine if the trend of HRR magnitudes should have been repeated. Detailed information about peak values is given in Section 5.5.

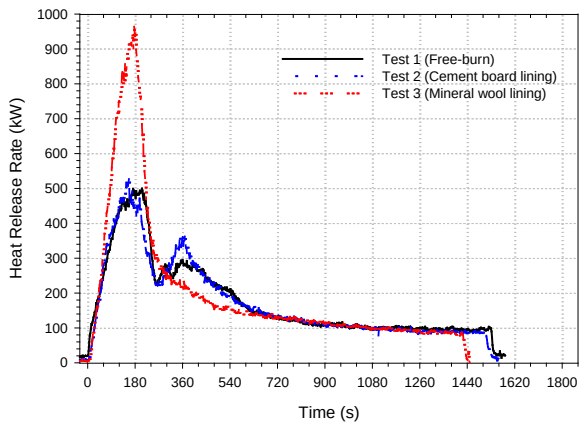

Figure 7. Graph of HRR vs. time.

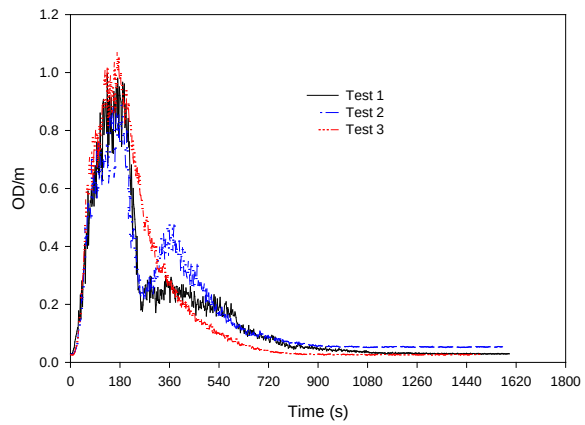

Figure 8. Measurements of smoke optical density in the exhaust duct.

Figures 9 to 14 show the results of temperature measurements at corresponding measurement locations in Tests 2 and 3 (presented side-by-side). Figures 9 and 11 show that peak temperature in the room during Test 2 was generally below 435 °C, although TC2 recorded a peak temperature of 659 °C, which was a localized effect since it was located directly above the burning specimen. In contrast, in Test 3, all peak temperatures in the upper smoke layer (up to 1.2 m below the ceiling) exceeded 600 °C (Figures 10 and 12), which is indicative of the attainment of flashover conditions. In Test 2 temperatures in the lower level (at 1.6 m below the ceiling) were less than 100 °C, which indicated that a two zone division of the room existed. In Test 3, the temperature at the same position had peak value of more than 300 °C, indicating that the smoke layer had likely descended to that level.

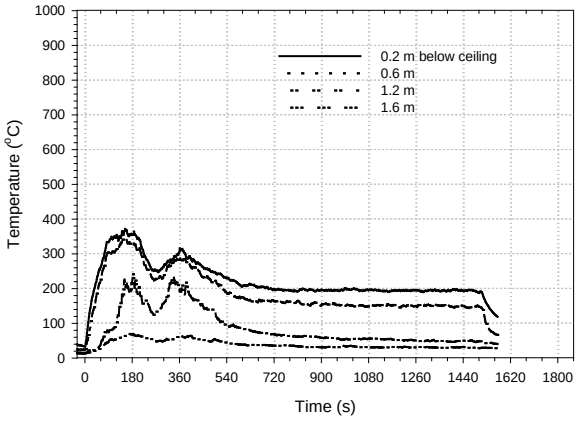

Figure 9. Test 2: Temperatures profiles from TC tree #1.

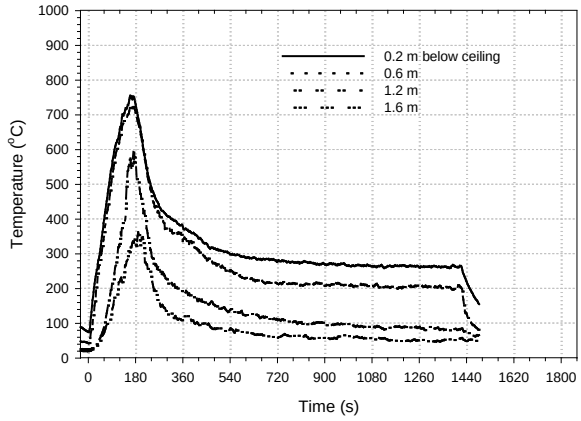

Figure 10. Test 3: Temperatures profiles from TC tree #1.

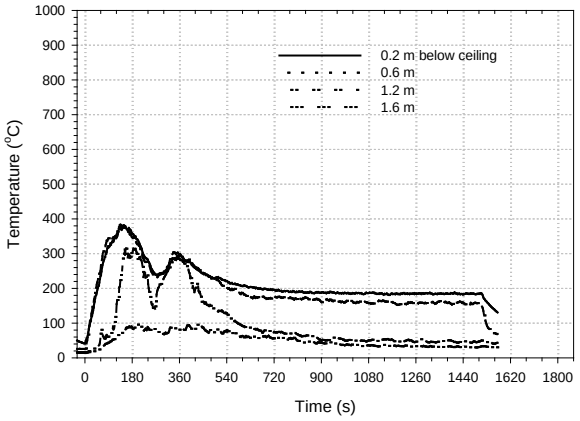

Figure 11. Test 2: Temperatures profiles from TC tree #2.

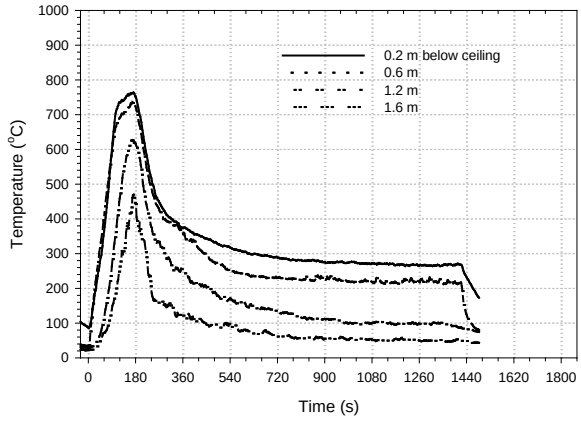

Figure 12. Test 3: Temperatures profiles from TC tree #2.

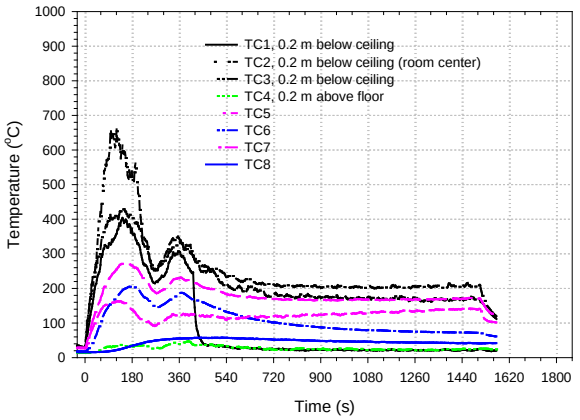

Figure 13. Test 2: Temperatures profiles from TCs 1 to 8.

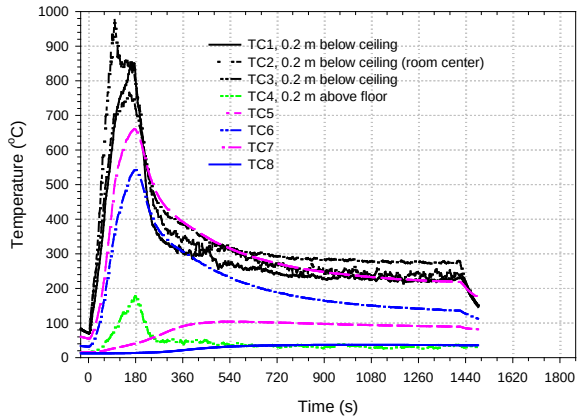

Figure 14. Test 3: Temperatures profiles from TCs 1 to 8.

Measurements of heat flux by gage HF#1 (located at 600 mm from the center of the pan) are given in Figure 15. Since the heat flux meter was facing the flame, the measurements followed the trend of the HRR. The difference between Tests 1 and 2 is more distinct than indicated by HRR measurements; the higher peak heat flux record in Test 2 is consistent with the peak HRR and temperature trends. Figure 16 shows the heat flux measured by gauge HF#2 located at the end of the pan (in a horizontal plane). The measurements give an indication of the background radiation from the room, although when flames were approaching the rear of the pan they likely influenced the measurements. Figure 16 also shows that the background radiation levels were comparable for Test 1 and Test 2 whereas Test 3 (mineral wool lining with low thermal inertia) had significantly higher background radiation due to higher room temperatures (and hotter smoke layer).

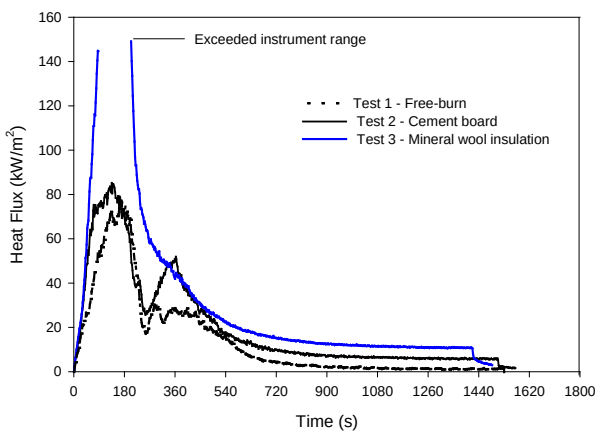

Figure 15. Graph of HF#1 vs. time.

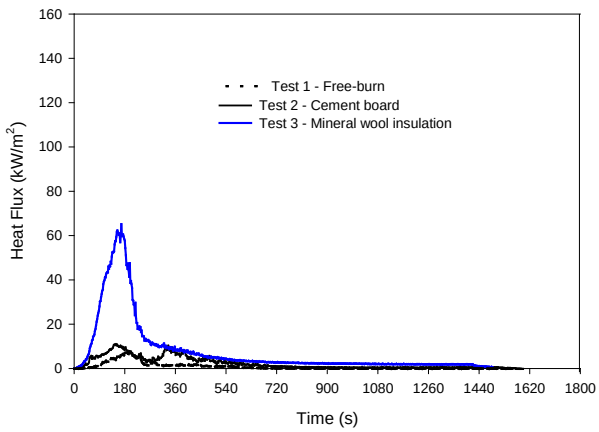

Figure 16. Graph of HF#2 vs. time.

The results of velocity measurements in the room opening are given in Figures 17 and 18 for Tests 2 and 3, respectively. The velocity profiles followed the HRR trend, as can be expected.

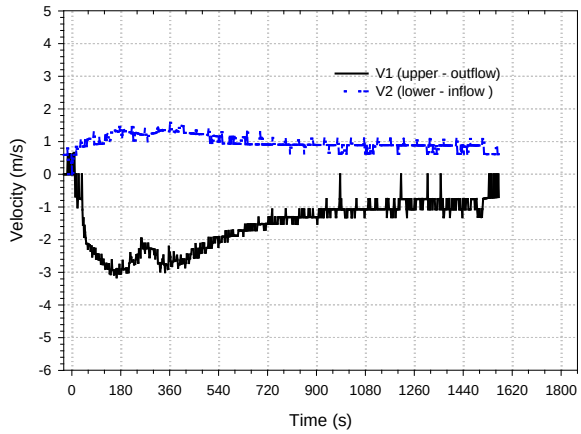

Figure 17. Test 2: Velocity profiles in the ventilation opening.

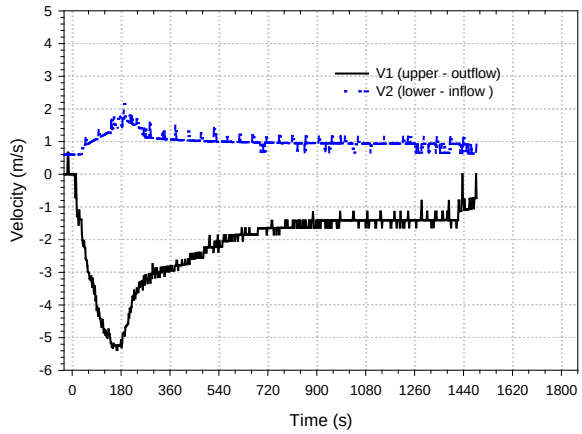

Figure 18. Test 3: Velocity profiles in the ventilation opening.

Figures 19 and 20 show the O_2, CO_2 and CO measured in the room for Tests 2 and 3, respectively. The results are consistent with the respective magnitudes of HRRs for the two Tests – lower O_2 (high depletion due to increased HRR) and consequently higher CO_2 and CO concentrations in Test 3.

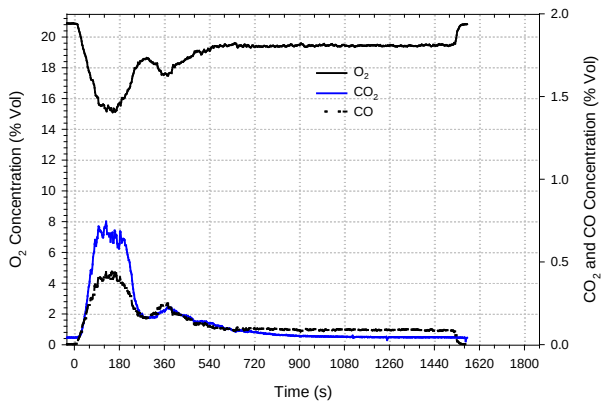

Figure 19. Test 2: O_2, CO_2 and CO measured in the room.

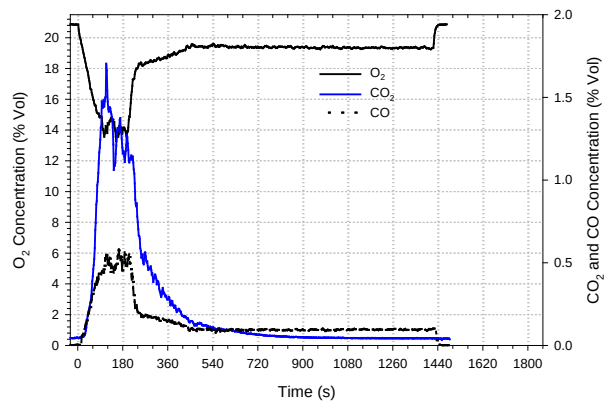

Figure 20. Test 3: O_2, CO_2 and CO measured in the room.

5.2 Mass Loss Measurements

Analysis of the results of mass loss measurements did not show meaningful trends after the peak HRR was reached. Contrary to expectations, there was an inexplicable period of significantly negative readings followed by a rebound to positive readings. Therefore, these measurements have been omitted from this report.

5.3 Observations from Thermal Images

All three experiments were recorded using an infrared camera. Figures 21 to 24 show examples of thermal images taken during Test 3.

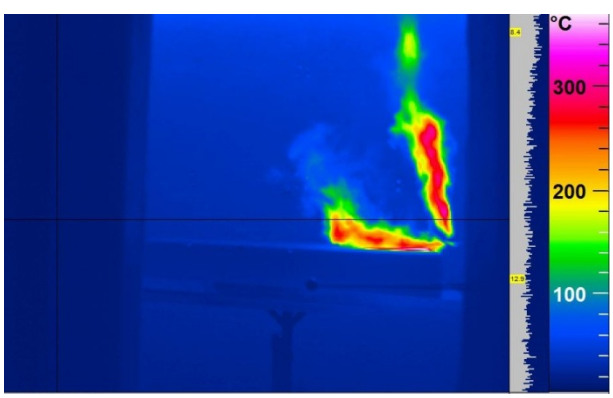

Figure 21. Thermograph at ignition.

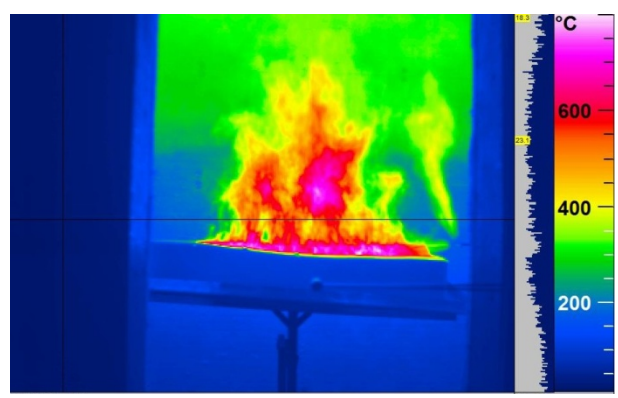

Figure 22. Thermograph showing flame spread at about 44 s after ignition.

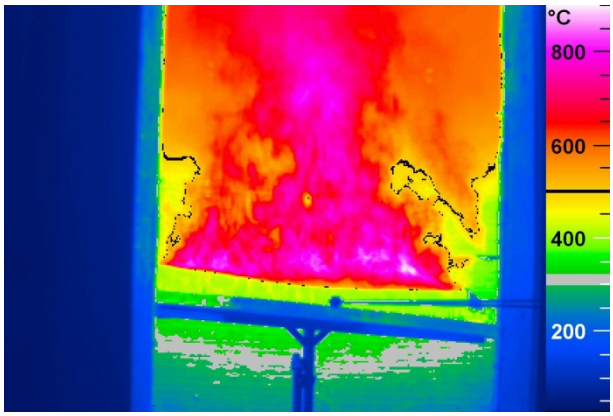

Figure 23. Thermograph at 100 s after ignition during Test 3,

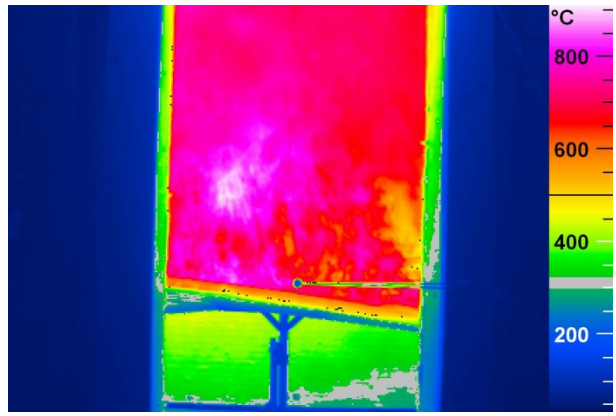

Figure 24. Thermograph at time for peak HRR during Test 3,

Table 5**Error! Not a valid bookmark self-reference.** lists the flame spread rate versus time as recorded by the infrared camera. To avoid influence of the burner, the flame spread rate was measured from the time the flame front reached the longitudinal center of the slab until the flames reached the end of the slab. The observations show that the two room burn tests had comparable flame spread rates, which were faster than the free-burn test. The average velocity of flame spread was found to be 8 mm/s for the free-burn test and 12 mm/s for both room tests.

Table 5. Flame spread rate recorded by infrared camera.

Distance[a] [mm]	**Time[a] [s]**		
	Test 1 (Free-burn)	Test 2 (Cement Board)	Test 3 (Mineral wool)
0	0	0	0
200	32	22	20
400	58	46	40
600	78	52	48

[a] Measurements of distance and time starts when the flames reaches the middle of the slab.

Table 6 summarizes the observations that were made by reviewing the thermal images. An interesting observation was that the pan was deflecting, in all three tests, by which two opposite corners bent down leaving the middle of the pan and the other two corners to form a ridge. This caused molten PUF to separate and flow towards opposite ends of the pan, see Figure 25. After flaming had ceased, it was observed that there was some char on the ridge which may also have contributed to the separation of the molten PUF.

Table 6. Observations from the recordings from the infrared camera.

Event	Test 1 [s]	Test 2 [s]	Test 3 [s]
Ignition	0	0	0
Flame spread to the center of the specimen	14	6	4
Flame spread to the end of the specimen	92	58	52
Full surface involvement,	96	58	54
Center of the specimen melt down	186	158[a]	120[a]
Burn out at the middle of the specimen	232	212[a]	228[a]
The pan starts to deflect	154	96[a]	70[a]
Max pan deflection	222	264[a]	122[a]

[a] Events occurring in the room were very difficult to see from the infrared recordings, which means that an even greater uncertainty is associated with these observations.

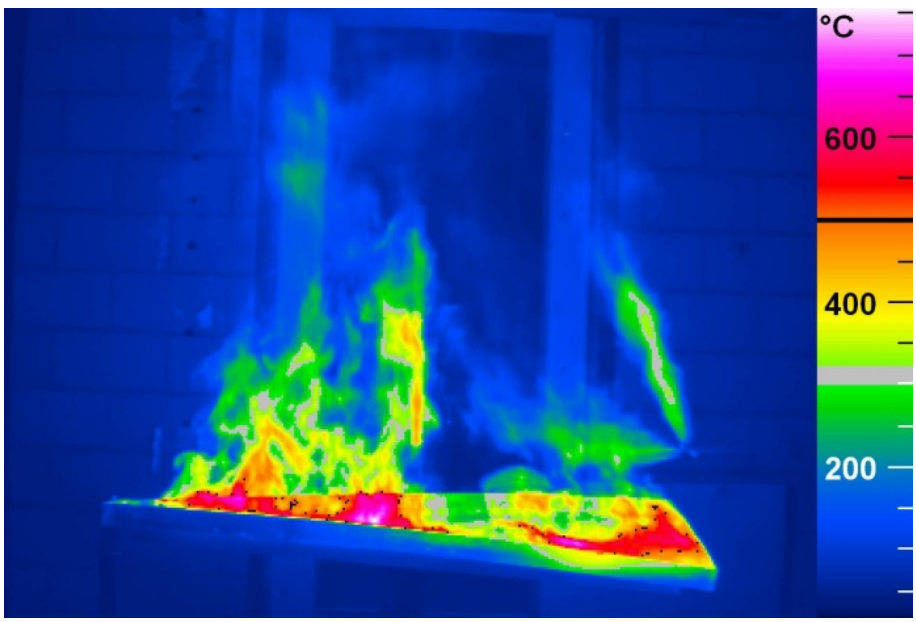

Figure 25. Test 1: Deflection of the pan and separation of molten PUF.

5.4 Test sequence

Table 7 lists the actual sequence and timing of the tests, including the duration of the test. All test durations were comparable.

Table 7. Actual sequence and timing of events.

Event	Test 1 (Free-burn)	Test 2 (Cement board)	Test 3 (Mineral wool)
Start data logger	0:00	0:00	0:00
Horizontal flame lit	2:00	0:32	1:08
Vertical flame lit (burner fully lit)	2:00	1:02	2:02
Switch-off burner	3:30	2:00	3:12
PUF block placed on load cell			
Burner re-lit (to ignite PUF)	6:00	4:23	5:30
PUF ceases to burn	30:30	28:30	28:00
Switch-off burner	31:30	29:30	29:10
Stop data logger	32:30	30:30	30:10
Test duration (from PUF ignition)	23:30	24:30	22:30

5.5 Summary of Test Results

Table 8 summarizes selected test results. The results show that flame spread rates are faster in the room than for free-burn conditions, regardless of the lining material used. The flames spread to the end of the block before the peak HRR occurred. When flames had covered the entire PUF surface, there were no significant differences in the magnitude of the HRRs. This indicates that the HRR may not be the only dominant factor in estimating the flame spread rate, as other phenomena such as air flow patterns (likely induced by the exhaust suction) and the specific different boundary conditions may influence the flame spread rate. Since peak HRRs occurred at more than double the time it took for the flames covered the entire surface, it suggests that peak HRRs may be dependent on other parameters than the ignited surface area alone. Since peak HRR appeared to occur after the center of the specimen had completely melted, pool formation and build up of room temperatures are likely to influence the time for peak HRRs as well.

It is noted that Test 3 had almost twice the peak HRR of Test 2, and the room temperatures were considerably higher in Test 3. This indicates that radiation feedback, due to higher room temperatures, was mainly responsible for the enhancement of burning rate (and consequently higher peak HRR) in Test 3.

Table 8. Summary of selected test results.

Test	Flame travel time [a] [s]	Peak HRR [kW]	Peak OD/m	Peak Heat Flux [kW/m^2]	Peak Room Temp[b] [°C]	Peak Lining Temp [°C]
Test 1 (Free-burn)	78	498 (172 s)	1.0	78(HF#1) 8 (HF#2)	-	-
Test 2 (Cement board)	52	526 (159 s)	0.9	85 (HF#1) 11 (HF#2)	435 (TC#1)	270
Test 3 (Mineral wool)	48	965 (176 s)	1.1	NA[c] (HF#1) 65 (HF#2)	850 (TC#1)	660

[a] Measured time it took for the flame front to travel from the center of the block to the end.
[b] As TC#2 is influenced by flame/plume this TC is not included in the finding the peak temperature.
[c] NR - Not recorded, instrument limit exceeded (maximum reading was 150 kW/m^2)

6 Conclusion

This report presented the results of three fire experiments (one free-burn and two room tests) that were carried out to investigate the influence of thermal radiation feedback on the rate of surface flame spread and heat release rate (HRR) of a horizontal block of furniture-grade non fire retarded polyurethane foam measuring 1200 x 600 x 200 mm and weighing approximately 4.8 kg.

The free-burn peak HRR was found to be 498 kW at 172 s from ignition, plateauing at this value for approximately 34s before it rapidly declined. The peak HRR for the test conducted with a cement board room lining was 526 kW at 159 s from ignition (with immediate decline), while that for a mineral wool insulation lining was 965 kW at 176 s (with immediate decline). The maximum room temperatures for the tests with cement board and mineral wool linings were 435 ℃ and 850 ℃, respectively. The results indicated that for the test with a cement board lining, there was no significant change in the rate of fire growth and peak HRR compared to the test conducted under free-burn conditions. Lowering the thermal inertia (with a mineral wool lining) resulted in a considerably greater (~ 90%) increase in peak HRR compared to the other two tests, which confirmed that radiation feedback from hot layer and walls was responsible for the dramatic increase in the peak HRR.

From the analysis of data record with an infrared camera, it was found that surface flame spread rates were higher (~ 12 mm/s) when the PUF was burning in the room than under free-burn conditions (~ 8 mm/s), regardless of the lining material used.

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Appendix A. Preliminary Experiments

Two preliminary free-burn tests were conducted to refine the test setup and procedures.

A1. Test 1P

The PUF was ignited with a 19 kW propane T-burner positioned at 10 mm from the short edge of the PUF, as shown in Figure A1. The burner was turned off after 80 seconds.

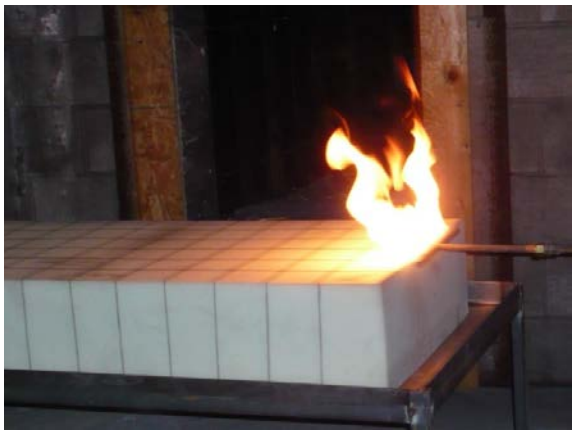

Figure A1. Ignition of PUF block with a 19 kW propane T-burner.

Figure A2. Fire progression at 40 s from ignition.

Test 1P had a peak HRR of 625 kW at 352 s from ignition, as shown in Figure A3. The results of heat flux measurements are shown in Figure A4. It was observed that this configuration resulted in the formation of a backward slope (Figure A2) and PUF material melted and flowed directly onto the pan (towards the burner end) and burnt in that position.

In Test 1P, the PUF block was placed on pan that was in turn placed directly onto a weighing scale for mass loss measurements. The weighing scale failed to measure mass loss and was replaced with a load cell apparatus in Test 2P.

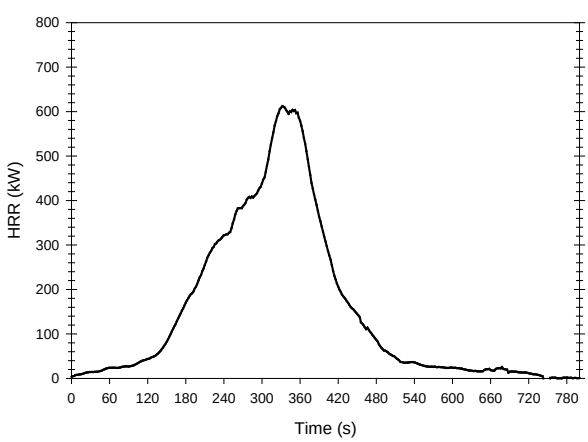

Figure A3. HRR vs. Time for Test 1P.

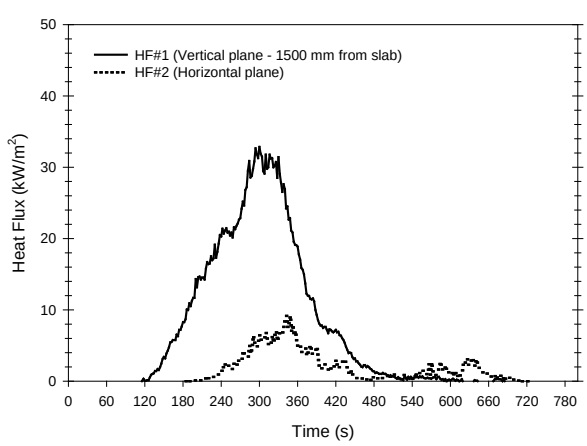

Figure A4. Heat flux measured by vs. Time for Test 1P.

Conclusion: The melt-flow behaviour during the test was undesirable for the purpose of the study. Therefore, in the interest of preventing early formation a PUF melt pool on the pan, a second test (Test 2P) was conducted with the burner moved forward so that it was positioned at 100 mm along the length of the PUF block (i.e. 100 mm from the edge). As well, the HRR of the propane T-burner was increased to 75 kW in order to augment the HRR and ensure that the total HRR in a room test exceeded the threshold value 500 kW required for room feedback effects to be significant. The 75 kW burner HRR was used in previous studies [7] to simulate an ignition source provided by a large waste paper basket.

A2. Test 2P

Figure A5 shows the position of the T-burner in Test 2P. The HRR of the T-burner ignition source was set to 75kW and was left on for the duration of the test. The fire had a peak HRR of 573 kW at 176 s after ignition (Figure A7). The graph was plotted without subtracting the HRR of the burner. The second HRR peak is due to the burning of unconsumed PUF material around the edges of the block after the material in the central area was consumed. In addition, it was observed that the pan began deflecting around the time that the peak HRR was reached, which caused the molten PUF to collect at the opposite ends of the pan. This likely contributed to the occurrence of the second peak. The results of heat flux measurements are shown in Figure A8. Due to the higher burner HRR, a larger area around the center of the PUF was ignited and the file plume was more centralized (Figure A6). This also resulted in a more rapid surface flame spread and rate of fire growth compared to Test 1P, as shown in Figure A9. One disadvantage of the burner arrangement used in Test 2P is that the initial ignition area was very large, which made it difficult to investigate flame spread.

Figure A5. Ignition of PUF block with a 75 kW propane T-burner in Test 2P.

Figure A6. Fire progression at 40 s from ignition.

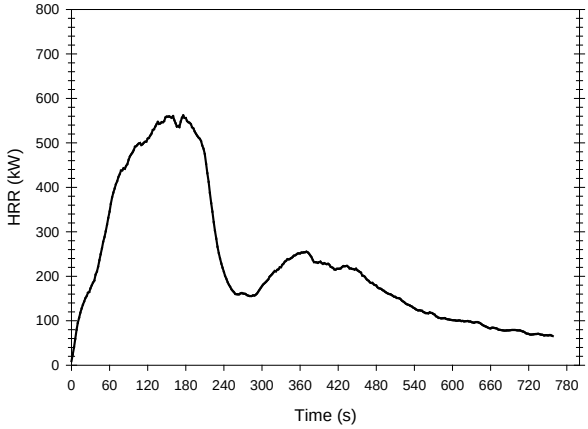

Figure A7. HRR vs. Time for Test 2P.

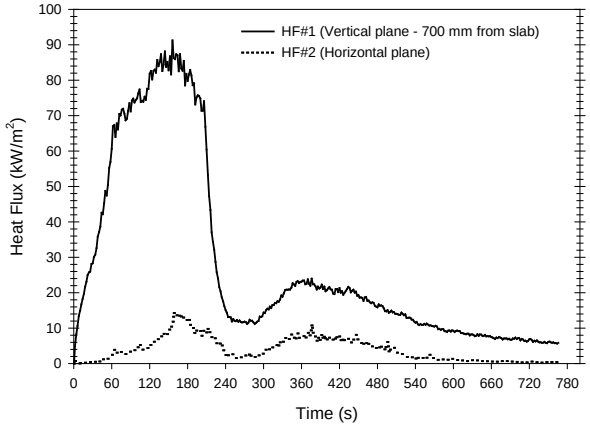

Figure A8. Heat flux measured by vs. Time for Test 2P.

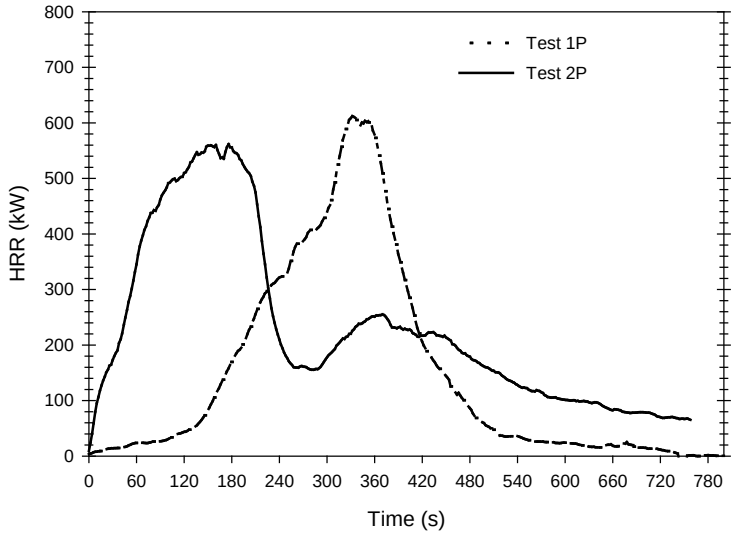

Figure A9. Comparison of HRR vs. time for Tests 1P and 2P.

Conclusion:

The burner configuration was not ideal as too large an area was ignited by the burner leaving an area too small for the investigation of flame spread rate. It was also observed that the gas flow, due to the relative high line pressure, may have influenced the flame spread. Therefore, the single-flame burner was replaced with a dual-flame burner and it was moved further away from the edge of the foam in the final experiments.