Development of a fuel package for use in the Fire Performance of Houses Project

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Institute for Research in Construction
Fire Research Program

TABLE OF CONTENTS

PREFACE

With the introduction of technological changes and innovations to building materials, design and construction practices in housing, the challenge is to determine the potential impacts of such changes on home fire safety. To help address this challenge, the Canadian Commission on Building and Fire Codes and the Canadian Commission on Construction Materials Evaluation asked the National Research Council Canada (NRC) to undertake research that will provide information to assist in the assessment of possible impacts.

In response, NRC's Institute for Research in Construction (IRC) undertook to conduct research into fires in single-family dwellings with the primary objective of determining the impact of innovative residential construction products and systems on the fire safety of houses occupants. This phase of the research includes two components:

1. Full-scale experiments to address how long egress routes within the house will remain viable from the perspective of tenability for occupants and structural integrity;
2. Literature review of related aspects, including evacuation of occupants, smoke alarm activation times, and statistics related to factors affecting fire-related deaths.

This research has been planned with multiple phases. This report addresses Phase 1 of the study (2004 to 2006) which focuses on basement fires and their impacts on the structural integrity of unprotected floor assemblies above a basement. It also looks at the impact upon egress routes, as well as smoke movement and tenability conditions within a house.

This report documents a series of bench- and medium-scale calorimetric tests to develop a fuel package for use in Phase 1 full-scale experiments to simulate a basement living area fire in a house. A polyurethane foam sofa mock-up combined with wood cribs was developed as the fuel package for full-scale fire scenario tests in the Fire Performance of Houses facility.

NRC gratefully acknowledges the financial and technical support of the Special Interest Group on Fire Performance of Houses. This external advisory committee provided valuable input to the research and included representatives from the following organizations:

- Canadian Automatic Sprinkler Association
- Canada Mortgage and Housing Corporation
- Canadian Wood Council
- Cement Association of Canada
- Forintek Canada Corporation
- North American Insulation Manufacturers Association
- Ontario Ministry of Municipal Affairs and Housing
- Wood I-Joist Manufacturers Association

The authors would like to acknowledge H. Cunningham (deceased), B. Di Lenardo, E. Gardin, J. Haysom (retired), I. Oleszkiewicz, G. Proulx, and M. Sultan who served in the IRC steering committee for the project.

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by

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1 INTRODUCTION

This report documents a series of bench- and medium-scale fire experiments that were conducted in order to develop a fuel package to simulate a fire in a residential basement room. The scenario selected for this phase of the study had the fire initiated with an item of upholstered furniture. Repeatability across tests and simplicity of the material composition were two of the key requirements that the fuel package had to satisfy. To this end, a fuel package consisting of a mock-up sofa constructed with exposed polyurethane foam (PUF), the dominant combustible constituent of upholstered furniture, and wood cribs was selected. The mock-up sofa would be the first item ignited and the wood cribs would provide the remaining fire load to sustain the fully-developed fire for the desired period of time.

The omission of upholstery fabrics in the mock-up sofa was justified in that they largely affect the incipient stage of the fire by either delaying or hastening the involvement of the PUF in the fire. The real danger from an upholstered furniture fire begins when the PUF begins to burn. Therefore, a sofa mock-up constructed with non-fire-retardant PUF, a non-combustible frame and no upholstery was sufficient to simulate the inherent fire hazard. However, as there are many different types of PUF available on the market, initial fire tests were conducted with representative samples of PUF using bench- and medium-scale calorimeters in order to select two types of PUF that were used to construct the mock-up sofa test specimens for more extensive testing. Eventually, one type of PUF was selected after conducting tests with the mock-up sofas.

Used sofas were tested before the mock-up sofas to provide reference data. The used sofas and mock-up sofas, which were tested, were all less than full size since the capacity of the medium-scale calorimeter to measure the heat release rate was limited to about 2 MW and peak heat release rates of sofas were known to exceed this value. Two tests were conducted with two wood cribs of different sizes and a final test was conducted to investigate the effect of wood density on burning behaviour.

2 TEST SPECIMENS

Six samples of non-fire-retardant polyurethane foam (PUF) (Samples 1 to 6 in Table 1) that are commonly used in the manufacture of upholstered furniture were obtained from two different vendors. Three additional samples of PUF (Samples 7 to 9 in Table 1) were taken from used sofas for comparison. The measured density of the samples of PUF is given in Table 1. From Table 1, it can be seen that the density of all but one of the new foams, sample 2, was within the range of the density of the PUF obtained from used sofas.

PUF specimens for the screening tests, which were conducted in the cone calorimeter, were cut into blocks of 100 mm x 100 mm x 50 mm. For the tests in the open calorimeter, the nominal dimensions of the PUF blocks were 610 mm long x 610 mm wide x 100 mm thick. PUF B (Sample 2) was not tested in the open calorimeter and was excluded from further consideration due to its low density.

Table 1. Samples of PUF

Sample #	Assigned code	Vendor	Measured density (kg/m^3)
1	A	1	30.7
2	B	1	14.0
3	C	2	30.0
4	D	2	32.8
5	E	2	32.3
6	F	2	31.8
7	G	NA	30.2
8	H	NA	32.9
9	I	NA	32.1

NA: Not applicable

As full-size sofas could not be tested in the open calorimeter, the used sofas were cut into one-third and two-thirds sections to simulate upholstered chairs and love seats (small sofas), respectively. Photographs of the tested used sofas specimens are given in Appendix A (Figure A - 3, Figure A - 5, Figure A - 7 and Figure A - 9).

The mock-up sofa specimens were comprised of a steel frame and PUF blocks (cushions) measuring 610 mm long x 610 mm wide and having two thickness: 100 mm and 150 mm. The specimens were of two sizes: one-third and two-thirds of full size. Figure 1 illustrates the one-third mock-up and gives the dimensions of the steel frame. The two-thirds mock-up is illustrated in Figure 2.

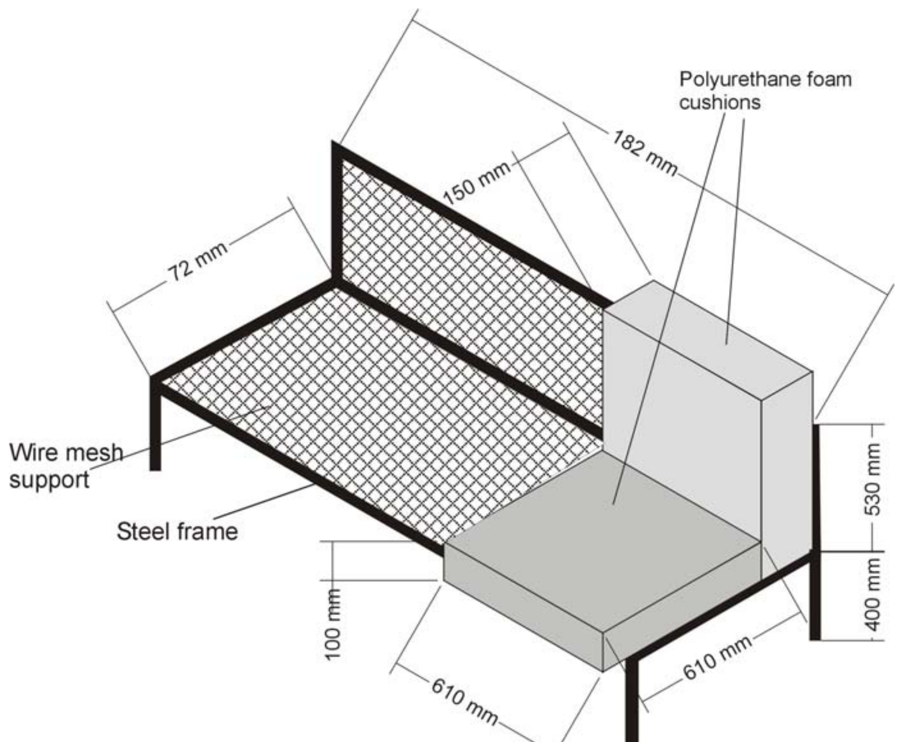

Figure 1. One-third mock-up sofa

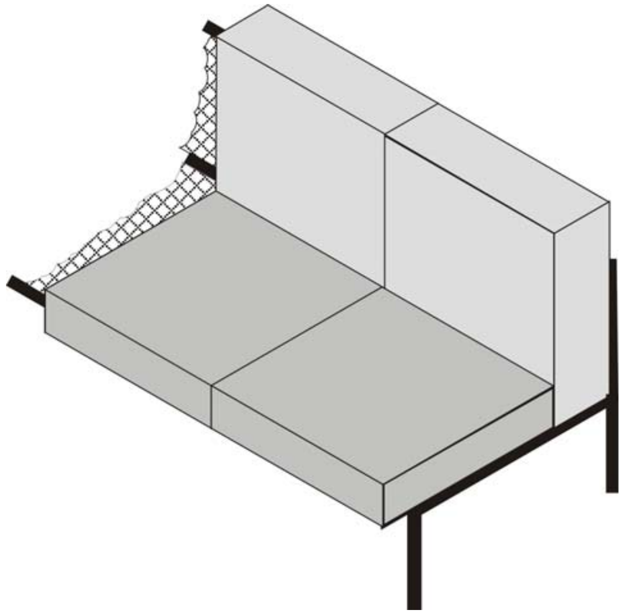

Figure 2. Two-thirds mock-up sofa

The wood cribs were made with kiln-dried (KD-HT), spruce-pine-fir (S-P-F) lumber pieces, each measuring 38 mm x 89 mm x 800 mm. The pieces were evenly spaced in rows of six and stacked (with upright 38 mm x 89 mm rectangular cross sections) in parallel pairs at right angles to the parallel pair immediately below to heights of 356 mm (4 rows high) and 712 mm (8 rows high) for the small and large wood cribs, respectively. Photographs of the wood cribs are shown in Figure A - 15 (small wood crib) and Figure A - 17 (large wood crib), in Appendix A.

3 TEST FACILITIES

The small-scale tests were conducted using a cone calorimeter with four heat flux levels in accordance with the ASTM E 1354 method [1]. The cone calorimeter is instrumented to measure all the quantities (O_2, CO, CO_2, temperature and volumetric flow rate) in the exhaust stream that are needed to calculate the heat release rate using the oxygen-consumption technique [2]. In addition, measurements of mass loss, smoke production and ignition times were also taken.

The medium-scale fire experiments were conducted using an open calorimeter designed for measuring the rate of heat release and the production of light-obscuring smoke under well-ventilated conditions. The basic elements of the calorimeter are a 558-mm-diameter duct, an exhaust fan assembly, and a rectangular hood of 3900 mm x 3640 mm, which is 2350 mm above the ground. Measurements of the volumetric flow rate and temperature of the exhaust gases, and concentrations of oxygen, carbon dioxide and carbon monoxide were taken in the hood exhaust duct to facilitate calculation of the heat release rate by using the oxygen consumption method [2]. Additional measurements taken were: mass loss (using a weighing scale), and smoke optical density in the exhaust duct (using a pulsed white light smoke meter).

4 EXPERIMENTS AND RESULTS

4.1 Cone Calorimeter Tests

The cone calorimeter tests were conducted at heat flux levels of 15, 20, 25 and 35 kW/m^2, in single runs, to determine the critical ignition heat flux and the effect of the heat flux level on burning behaviour. The test results at a heat flux level of 35 kW/m^2 are summarized in Table 2 and Figure 3. Test results for the other heat flux levels are given in Appendix B.

Table 2. Cone calorimeter test results at 35 kW/m^2 heat flux level.

PUF	Initial mass (g)	Ignition time (s)	Peak MLR (g/s)	Peak HRR (kW/m^2)	Total HR (MJ/m^2)	Peak SPR (m^2/s)	Total smoke (m^2)
A	16.3	11	0.22	183.1	39.1	0.032	2.376
B	7.7	11	0.38	235.4	18.1	0.030	1.249
C	14.6	11	0.35	168.8	40.0	0.023	1.610
D	16.5	11	0.29	191.0	41.7	0.043	4.183
E	17.2	11	0.20	195.4	42.1	0.033	3.401
F	15.9	13	0.24	185.0	41.7	0.026	2.163

HRR – Heat Release Rate   Total HR – Total Heat Release   MLR – Mass Loss Rate
SPR – Smoke Production Rate   NA – Data not available

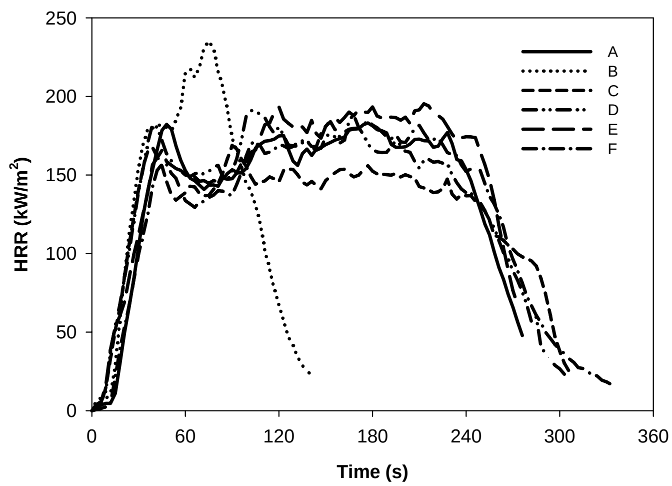

Figure 3. Heat release rate of PUF specimens at 35 kW/m^2 heat flux level.

These results show that all of the PUF specimens with comparable density exhibit similar burning characteristics. PUF B had a higher peak HRR likely due to its low density. It is generally known that low-density materials burn faster and have higher heat release rates than higher density materials of similar make-up.

4.2 Open Calorimeter Tests

In the open calorimeter tests, the PUF and sofa specimens were placed on a weighing scale directly under the hood and ignited with a 250 mm by 250 mm square burner with a propane flow rate of 13 L/min (HRR of about 19 kW) for 80 s, in accordance with the ASTM 1537 test protocol [3].

The wood cribs were ignited from underneath with 1000 mL of methanol (density 796 kg/m^3; heat of combustion 20 MJ/kg) [4] that was distributed equally among five shallow metal pans (200 mL per pan) having a mean diameter of 18.5 mm. The total heat output of this ignition source was at least 40 kW and the free-burning time was about 360 s. The clearance to facilitate the placement of the pans was achieved by resting the four bottom corners of a wood crib on concrete blocks 102 mm high.

For all of the tests, the results of the gas analysis showed that the concentrations of CO in the exhaust duct were negligible as combustion occurred under well-ventilated conditions. Therefore, these results have been omitted.

Analysis of the exhaust gases using a Fourier Transform Infra Red Spectroscopy (FTIR) technique was conducted on three of the tests with used sofas (tests 2, 3 and 4) and two of the tests with PUF blocks (PUFs A and F). Hydrogen cyanide (HCN) was the only toxic gas identified from the FTIR analysis, in addition to CO and CO_2.

Heat flux measurements were taken in two tests only: a test with a mock-up sofa and a test with a wood crib. The radiometers were setup at two positions behind the test specimens: 1) 1000 mm height above the base of the specimen, 200 mm away; and 2) 1100 mm height above the base of the specimen, 400 mm away.

4.2.1 Single PUF Blocks

The initial series of tests on single PUF blocks that were conducted in the open calorimeter served to complement the cone calorimeter screening tests. The first test was conducted with PUF block C, which was placed on a porous support. In this configuration, much of the molten PUF that collected underneath the support did not burn as there was insufficient radiation feedback from the flames above to ignite the molten PUF. Therefore, in subsequent tests, PUF blocks A, D, E and F were placed on shallow aluminium foil pans in order to promote a pool fire and to achieve greater heat release rates for better measurement accuracy. Table 3 summarizes the results of the tests with PUF blocks.

Table 3. Open calorimeter test results for single PUF blocks for a 360 s duration of burning.

PUF	Measured density	Mass	Peak HRR	Time to peak	HR	Total smoke	Mass loss
	(kg/m^3)	(kg)	kW/m^2)	(s)	(MJ)	(m^2)	(kg)
A	30.7	1.178	272	170	35.17	229	1.055
C*	30.0	1.139	122	105	8.94	123	0.320
D	32.8	1.245	298	175	38.78	342	1.165
E	32.3	1.243	313	175	34.54	231	NA
F	31.8	1.220	238	165	27.30	221	1.025
G	30.2	1.172	198	140	27.80	184	0.935

HRR – Heat Release Rate; Total HR – Total Heat Release; NA – Data not available due to Instrument malfunction

* The test specimen was placed on a porous support. The fire duration was only 200 s due to the unburned pool of melted PUF that remained underneath the support.

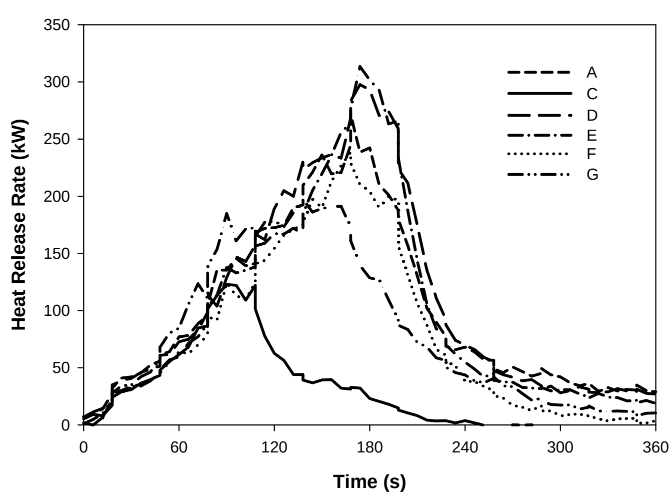

Figure 4. Heat release rate of PUF blocks.

The graphs of heat release rate versus time are shown in Figure 4. All the PUFs burned in a similar fashion except for PUF C, for which a porous support was used. This is in good agreement with test results from the cone calorimeter. PUFs D and E had the highest peak HRRs and total smoke production in both the cone and open calorimeter tests. On this basis, they were selected for subsequent tests of mock-up sofas.

The differences in the total amount of smoke produced among the different PUF samples is likely due to variations in their molecular composition since bond structure can affect smoke production [5].

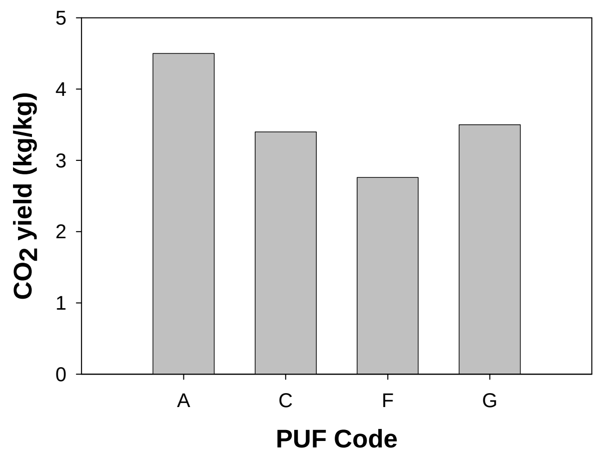

Figure 5. Mean CO_2 yields for PUFs A, C, F and G (not calculated for PUFs D and E due to a malfunction of mass loss instrumentation).

Figure 5 shows the estimated mean yield (kg/kg) of CO_2 for PUFs A, C, F and G. The yield of CO_2 was obtained by dividing the mass flow rate of CO_2 in the exhaust duct by the rate of mass loss. In all of the tests, the CO_2 yield remained fairly constant for a large part of the burning period since the rate of change with time of the CO_2 concentration and heat release rate are essentially the same, as can be seen in Figure 6 for PUF D, as an example.

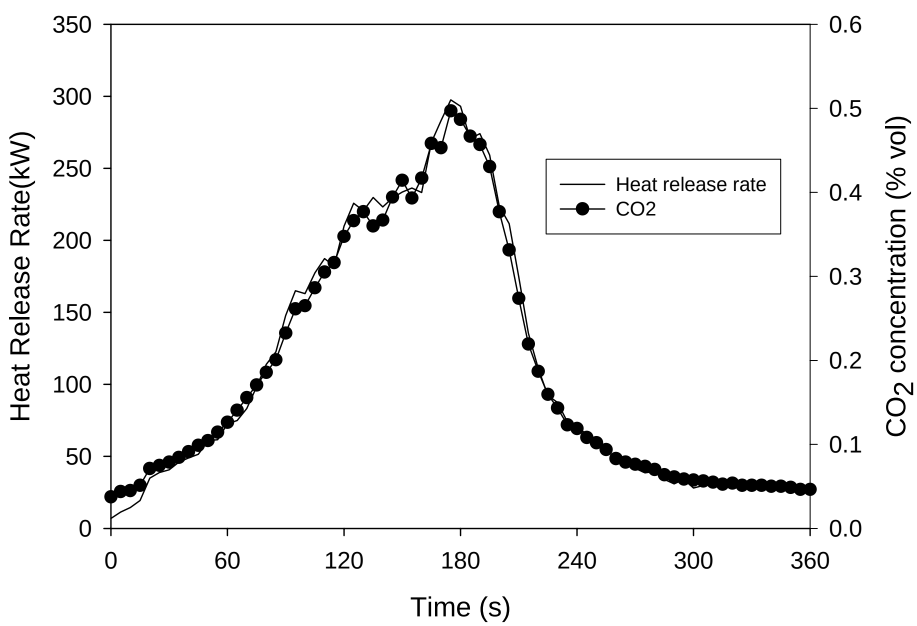

Figure 6. Rate of change with time of the heat release rate and CO_2 concentration for PUF D (typical example).

4.2.1.1 FTIR Results

The concentration of HCN during the Tests with PUFs A and F was too low to be detected as it was of the same order of magnitude as the instrument's noise level.

4.2.2 Used Sofas

Table 4 summarizes the results of the test with used sofas. The estimated mean yields (kg/kg) of CO_2 for the used sofas are given in Appendix C.

Table 4. Open calorimeter test results for used sofas for a 600 s duration of burning.

Test	Specimen	Mass (kg)	Peak HRR (kW/m^2)	Time to peak (s)	HR (MJ)	Total smoke (m^2)	Mass loss (kg)
1	US1-GI	16.53	838	375	132.70	649	6.447
2	US2-H	24.54	1169	205	254.94	1847	18.200
3	US1-G	13.37	354	410	100.22	635	5.265
4	US1-G*	12.40	314	85	78.39	372	2.775

HRR – Heat Release Rate   Total HR – Total Heat Release
Naming convention: size-PUF code
Size: US1: one-third section; US2: two-thirds section;
US1-GI: seat cushion made of PUF I (see Table 1)
US1-G*: No upholstery fabric

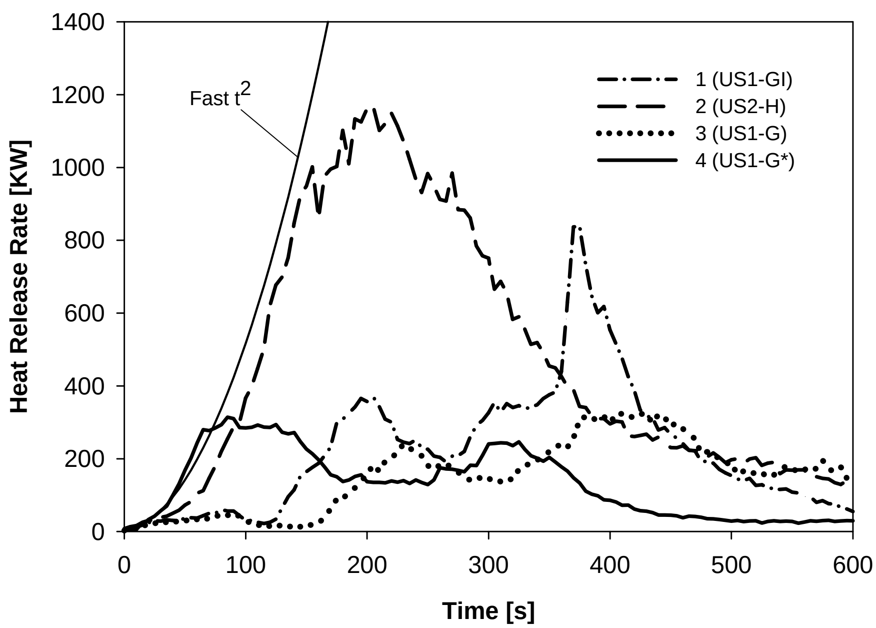

Figure 7. Heat release rate of used sofas

Figure 7 shows the heat release rate of the used sofas. The fire growth of specimen US2-H (Test 2), which was observed to burn readily, aligns well with a fast t-squared fire [6]. This is a reasonable representation of the inherent fire hazard associated with upholstered furniture given that upholstered furniture is usually classified as having ultra-fast t-squared fire growth rates [6]. The differences in the heat release rate profiles of Tests 1, 2 and 3 are mostly due to the influence of the upholstery fabrics on the ignition of the PUF and surface flame spread. The fabrics in tests 1 and 3 appeared to contribute to the delay of flame spread and consequently the time at which the peak heat release rate was attained. In the cases where there were two distinct peaks (Tests 1, 3 and 4), the first peak was caused by a backrest-predominant fire that resulted from the rapid upward flame spread. The second peak was due to burning confined to the seat section.

In test 4, the PUF components were quickly consumed by faster fire growth, which failed to ignite the wooden framing components and hence resulted in the lower total heat release value given in Table 4.

4.2.2.1 FTIR Results

Hydrogen cyanide (HCN) was only found in appreciable quantities in Test 2 as can be seen in Figure 8.

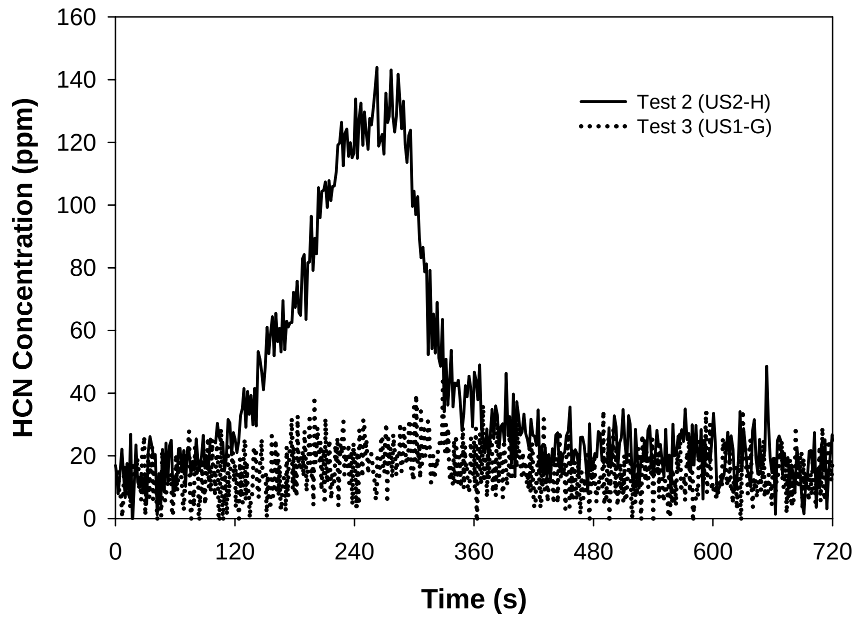

Figure 8. HCN concentrations for Tests 2 and 3 obtained using an FTIR technique (mass flow rate of gases in exhaust duct: 5 kg/s). HCN concentration profile for Test 4 (not shown) is comparable to that of Test 3.

Note that in a room environment, a HCN concentration of 140 ppm would cause human subjects to lose consciousness after 10 minutes of exposure [7].

4.2.3 Mock-up Sofas

Table 5 summarizes the results of the tests with mock-up sofas. The estimated mean yields (kg/kg) of CO_2 are given in Appendix C. Tests 5 to 9 investigated the effect of the seat and backrest thickness on the peak heat release. It was found that a thicker (150 mm versus 100 mm) backrest resulted in a higher peak heat release rate. Therefore, this configuration was selected for the tests with the two-thirds mock-up sofas.

Table 5. Open calorimeter test results for mock-up sofas for a 600 s duration of burning.

Test	Specimen	Mass (kg)	Peak HRR (kW/m²)	Time to peak (s)	HR (MJ)	Total smoke (m²)	Mass loss (kg)
5	MS1-D-1	3.052	433	90	64.87	NA	2.325
6	MS1-D-1*	2.933	403	95	76.74	765	2.635
7	MS1-D-2	2.973	690	145	78.07	783	2.902
8	MS1-E-1	2.999	429	190	78.94	443	NA
9	MS1-E-2	3.005	780	135	90.58	446	2.720
10	MS2-D-2	5.840	1376	155	142.16	1019	5.510
11	MS2-E-2	6.035	NA	NA	NA	NA	5.88

HRR – Heat Release Rate; Total HR – Total Heat Release; NA – Data not available due to Instrument malfunction

* Placed on an aluminium foil pan to promote the formation of a pool fire

Naming convention: Specimen size-PUF code-PUF thicknesses

Specimen size: MS1: one-third mock-up; MS2: two-thirds mock-up

PUF thicknesses: 1 - 150 mm seat thickness and 100 mm backrest thickness;
2 - 100 mm seat thickness and 150 mm backrest thickness

During the tests, it was observed that mock-up specimens constructed with PUF E melted readily and a pool fire formed beneath the sofa frame earlier than with PUF D specimens. This melting characteristic is undesirable as it promotes variability in burning behaviour since it occurs in a random manner. Figure 9 shows that the two-thirds mock-up MS2-D-2 achieved a rate of fire growth that lies between the ultra-fast and fast t-squared fire curves [6].

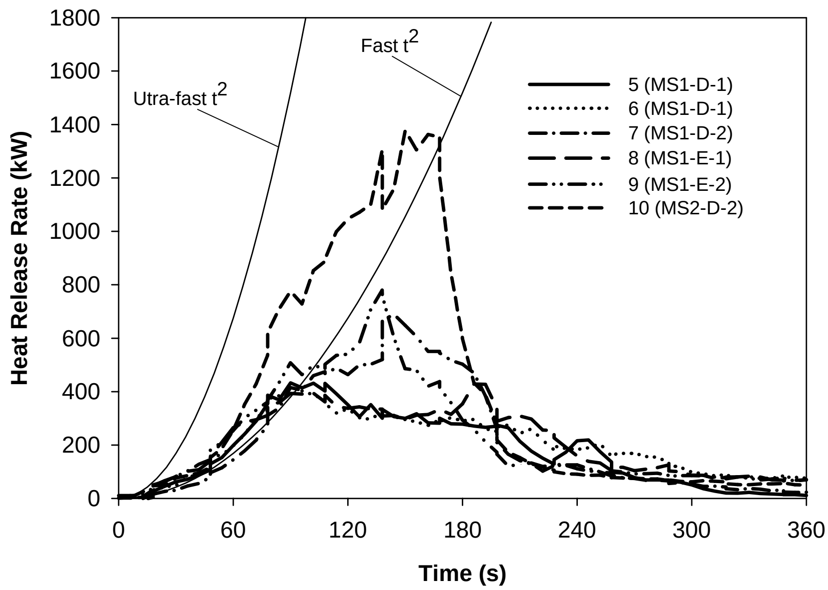

Figure 9. Heat release rate of mock-up sofas.

Figure 10 shows the results of heat flux measurements taken during Test 7 to investigate the likelihood of wood igniting at the two radiometer positions. For exposure to a constant heat flux, White and Dietenberger [8] found that ignition times for solid wood typically ranged from 3 s for a heat flux of 55 kW/m^2 to 930 s for a heat flux of 18 kW/m^2. A peak heat flux level of about 45 kW/m^2 was recorded at a point 200 mm behind the sofa. This is sufficient to ignite wood.

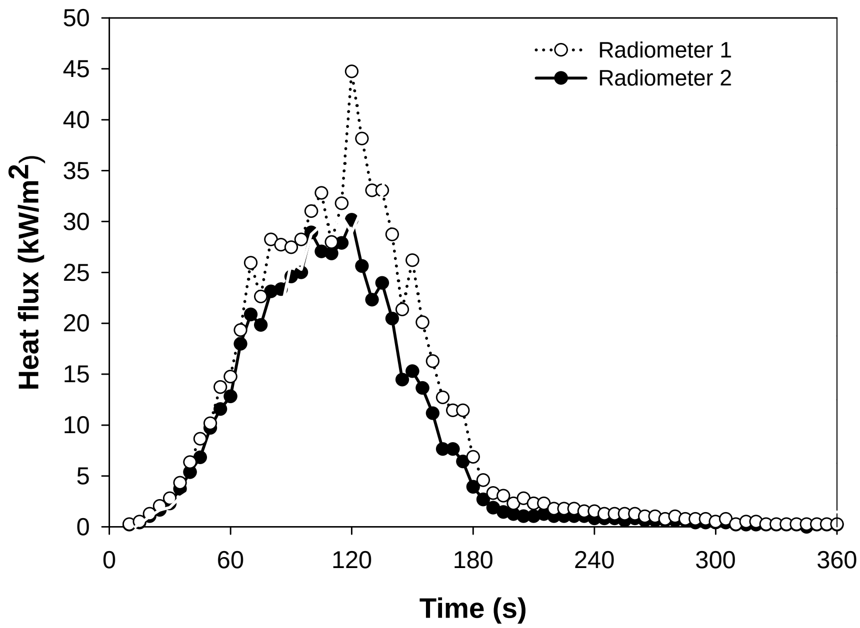

Figure 10. Heat flux measurements during Test 7 (Positions: Radiometer 1 – 1000 mm height, 200 mm behind sofa; Radiometer 2 – 1100 mm height, 400 mm behind sofa).

4.2.4 Wood Cribs

Table 6 summarizes the results of the tests with wood cribs. The heat release rates are shown in Figure 11. The results of heat flux measurements taken during test 12 are given in Figure C-4 in Appendix C.

Table 6. Open calorimeter test results for wood cribs for a 1800 s duration of burning.

Test	Specimen	Density (kg/m^3)	Mass (kg)	Peak HRR (kW/m^2)	Time to peak (s)	HR (MJ)	Total smoke (m^2)	Mass loss (kg)
12	WC1	378	25.9	422	318	408.1	1115	24.7
13	WC2	378	50.9	1383	235	829.7	NA	46.6

WC1: Small wood crib; WC2: Large wood crib
HRR – Heat Release Rate; Total HR – Total Heat Release; NA – Data not available due to instrument malfunction.
The moisture content of the specimens used for measuring the density was 6%.
The tested wood cribs had a moisture content of 6%.

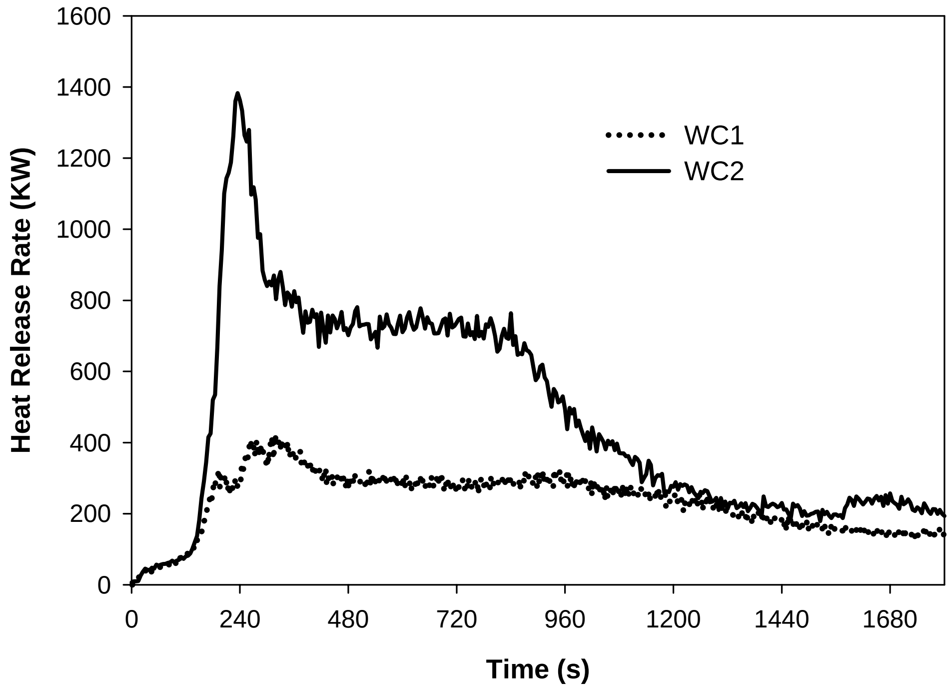

Figure 11. Heat release rate of wood cribs

4.2.4.1 Effect of Wood Density

An additional test (no. 14) was conducted to investigate the effect of variations in wood density that exist in S-P-F lumber bearing the same grade mark. A different batch of lumber obtained from the same source had a higher density than that of the lumber used in Tests 12 and 13. The results of the test are summarized in Table 7 and the heat release rate profiles are compared in Figure 12.

Table 7. Open calorimeter test results for wood cribs with different wood density for a 1800 s duration of burning

Test	Specimen	Density* (kg/m^3)	Mass (kg)	Peak HRR (kW/m^2)	Time to peak (s)	HR (MJ)	Total smoke (m^2)	Mass loss (kg)
13	WC2	378	50.9	1383	235	829.7	NA	46.6
14	WC2**	505	61.5	1498	215	1018.6	NA	59.9

WC2 and WC2**: Large wood crib; NA – Data not available due to instrument malfunction
* The moisture content of the specimens used for measuring the density was 6%.
Moisture content of WC2 was 10%.

The heavier wood crib (WC2**) achieved an increase in the heat release rate of around 10% compared to the lighter wood crib (WC2) over the duration of the test. However, as the overall burning behaviour was similar, the variation in wood density would not be expected to have significant impact on fire development.

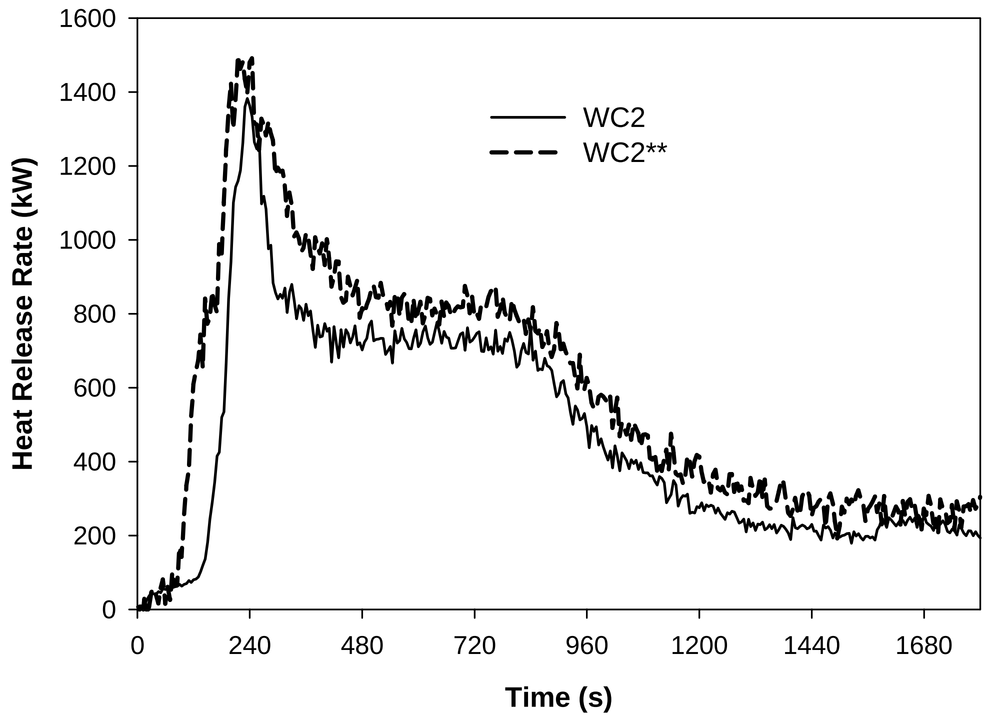

Figure 12. Comparison of the heat release rate of WC2 cribs made with wood of different densities and moisture content.

5 PROPOSED CONFIGURATION OF THE FUEL PACKAGE

In order to determine the configuration of the fuel package to be used in full-scale fire tests in the Fire Performance of Houses test facility (a detailed description of the test facility is provided in a separate report [9]), the results from the bench- and medium-scale calorimeter experiments were further analyzed. On account of its better melting characteristics, PUF D was selected for constructing the full size mock-up sofa for use in the full-scale fire tests.

Figure 13 summarizes the heat release rates of the MS2-D-2 two-thirds mock-up sofa and the two different-sized wood cribs during the open calorimeter tests. These results indicate that, as the first item to be ignited, a full-size mock-up sofa would be expected to quickly achieve a peak heat release rate greater than 2 MW since a proportional increase in the peak heat release rate would be expected with the increase in size from two-thirds to full-size. Thereafter, the wood cribs would be expected to provide sufficient fuel to sustain the fire provided there is sufficient ventilation. Considering that the large wood cribs would have to be ignited by radiation in order to simulate a natural fire progression in the house test facility, and that their initial rate of fire growth would be slow, it was decided to integrate the mock-up sofa with two of the small wood cribs located underneath the sofa. In this scenario, the small wood cribs would be progressively ignited by the PUF pool fire as it forms beneath the sofa and they would have ignited completely by the time sofa reaches its peak heat release rate. This would counteract the rapid decay of the sofa fire that would otherwise be expected to occur after attainment of the peak heat release rate and help to ignite the large wood cribs.

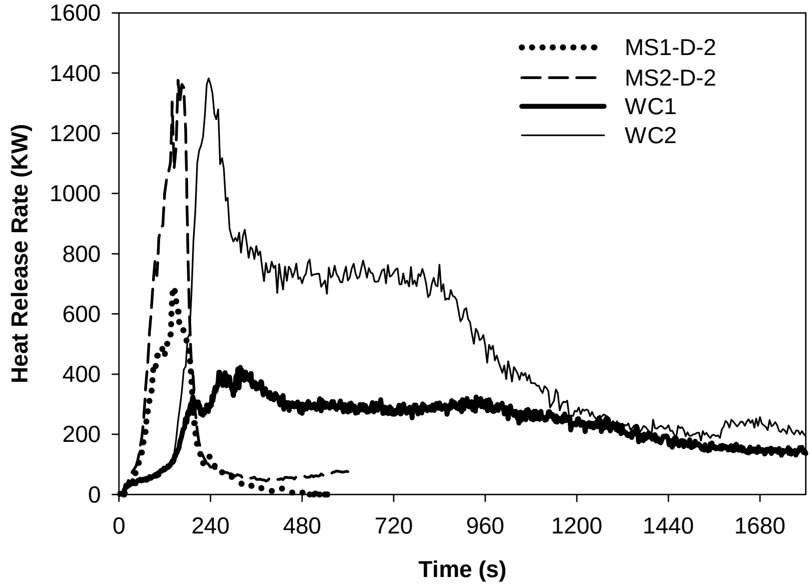

Figure 13. Summary of the heat release rates of the wood cribs and the selected mock-up sofa.

Based on survey results for residential living areas [10], a fire load density of 350 MJ/m^2 and floor area of 27.6 m^2 was selected for the simulated basement room in the full-scale fire scenario experiments for the Fire Performance of Houses project. The dimensions of the basement room and location of openings are shown in Figure 14. The number of large wood cribs (in addition to the sofa and two small wood cribs) required to represent a fire load density of 350 MJ/m^2 in such a room is ten. However, given the expected limited ventilation opening to the outside of 1 m^2 provided by the single opening to the outside, placing the full fire load in the room during an actual test with a combustible floor assembly above the fire room would merely extend the duration of the fire beyond the time when a substantial portion of the floor assembly would have failed. Therefore, only two large cribs (representing a fire load density of 350 MJ/m^2 in the area shown in Figure 14) were included in the fuel package so as to limit the potential duration of the fire to about 30 minutes.

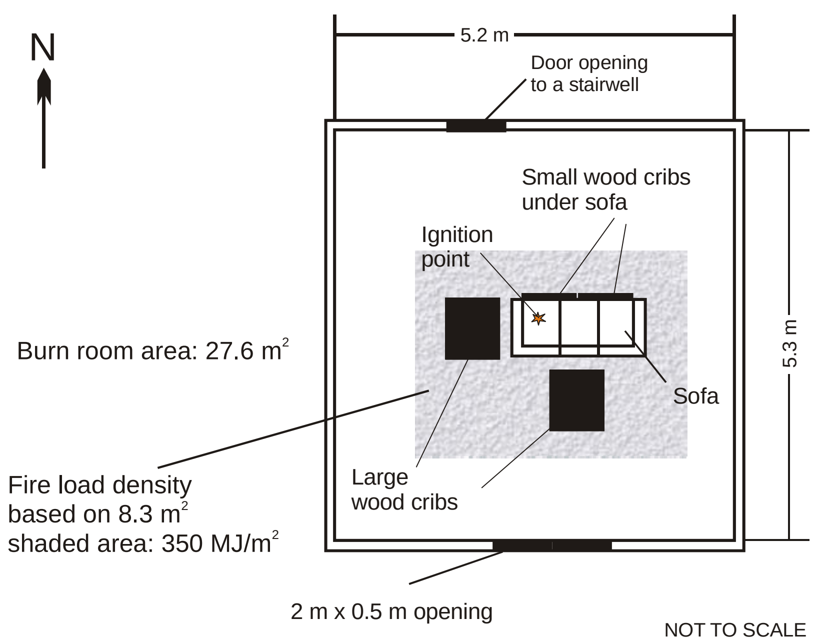

Figure 14. Proposed arrangement of the fuel package in the fire compartment.

NRC·CNRC

The total fuel package recommended for use in the full-scale fire scenario experiments for the Fire Performance of Houses project (shown in Figure 14) consists of:

1. A full-size mock-up sofa constructed in a similar fashion to the one-third and two-thirds specimens described in Section 2;
2. Two small wood cribs, as described in Section 2, and;
3. Two large wood cribs, as described in Section 2.

This results in a fire load density of 350 MJ/m^2 for a 8.3 m^2 floor area, as shown in Figure 14.

6 CONCLUSION

A fuel package to simulate a fire initiated by an item of upholstered furniture was designed using a series of calorimetric experiments. The experimental results show that the initial fire growth from the package would lie between the fast- and ultra-fast t-squared fire curves. The use of this fuel package in full-scale fire scenario tests conducted in the Fire Performance of Houses test facility will be reported elsewhere [9].

7 REFERENCES

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Appendix A: Test Specimens and Fire Pictures

Figure A - 1. Typical PUF block specimen and test setup with centrally located propane burner.

Figure A - 2. Typical fire for PUF block specimens.

Figure A - 3. Figure 15. Specimen US1-GI (nominal dimensions: 730 mm x 900 mm x 700 mm).

Figure A - 4. Fire picture (specimen US1-G).

Figure A - 5. Specimen US2-H (nominal dimensions: 1280 mm x 800 mm x 650 mm).

Figure A - 6. Fire picture (Specimen US2-H).

Figure A - 7. Specimen US1-G (nominal dimensions: 600 x 900 x 700 mm).

Figure A - 8. Fire picture: specimen US1 G.

Figure A - 9. Specimen US1-G without fabric (nominal dimensions: 660 x 900 x 700 mm).

Figure A - 10. Fire picture: Specimen US1 without fabric.

Figure A - 11. Typical test setup for MS1 mock-up sofa specimens (MS1-E-1 shown).

Figure A - 12. Typical fire stage with MS1 mock-up sofa specimens (MS1-E-1 shown).

Figure A - 13. Typical test setup for MS2 mock-up sofa specimens (MS2-D-2 shown).

Figure A - 14. Typical fire for MS2 mock-up sofa specimens (MS2-D-2 shown).

Figure A - 15. WC1 specimen.

Figure A - 16. Fire picture (WC1).

Figure A - 17. WC2 specimen.

Figure A - 18. Fire picture (WC2).

Appendix B: Results of Cone Calorimeter Tests at Exposures of 15, 20 and 25 kW/m^2

Table B- 1. 15 kW/m^2 exposure

Sample	Initial Mass (g)	Ignition Time (s)	Peak MLR (g/s)	Peak HRR (kW/m^2)	Total HR (MJ/m^2)	Peak SPR (m^2/s)	Total Smoke (m^2)
A	156.0	73	0.26	157.6	33.5	0.016	1.075
B	7.6	69	0.15	155.8	14.7	0.014	0.877
C	154.0	52	0.19	162.6	42.3	0.010	NA
D	171.0	57	0.18	168.5	40.7	0.023	1.276
E	159.0	70	0.17	191.5	42.9	0.016	0.700
F	162.0	67	0.19	173.0	45.2	0.013	0.265

HRR – Heat Release Rate Total HR – Total Heat Release MLR – Mass Loss Rate
SPR – Smoke Production Rate NA – Data not available

Table B- 2. 20 kW/m^2 exposure

Sample	Initial Mass (g)	Ignition Time (s)	Peak MLR (g/s)	Peak HRR (kW/m^2)	Total HR (MJ/m^2)	Peak SPR (m^2/s)	Total Smoke (m^2)
A	16.3	18	0.19	184.3	45.5	0.017	1.106
B	7.5	25	0.18	169.2	17.1	0.020	0.888
C	16.4	19	0.17	181.9	48.7	0.018	1.471
D	16.4	17	0.19	183.3	46.2	0.021	1.909
E	17.1	11	0.19	191.9	47.7	0.016	1.203
F	NA	NA	NA	NA	NA	NA	NA

HRR – Heat Release Rate Total HR – Total Heat Release MLR – Mass Loss Rate
SPR – Smoke Production Rate NA – Data not available

Table B- 3. 25 kW/m^2 exposure

Sample	Initial Mass (g)	Ignition Time (s)	Peak MLR (g/s)	Peak HRR (kW/m^2)	Total HR (MJ/m^2)	Peak SPR (m^2/s)	Total Smoke (m^2)
A	16.4	17	0.24	176.8	42.3	0.022	1.086
B	7.8	17	0.19	164.1	17.9	0.023	0.590
C	15.8	11	NA	164.6	46.9	0.015	NA
D	16.9	10	0.21	187.0	44.2	0.027	2.512
E	16.0	10	0.18	176.6	42.2	0.019	1.210
F	16.5	10	0.21	208.0	49.1	0.015	0.541

HRR – Heat Release Rate Total HR – Total Heat Release MLR – Mass Loss Rate

SPR – Smoke Production Rate NA – Data not available

Table B- 4. Time (s) to ignition for each sample

	Heat Flux (kW/m^2)			
	15	**20**	**25**	**35**
A	73	18	17	11
B	69	25	17	11
C	52	19	11	11
D	57	17	10	11
E	70	11	10	11
F	67	NA	10	13

NA – Data not available

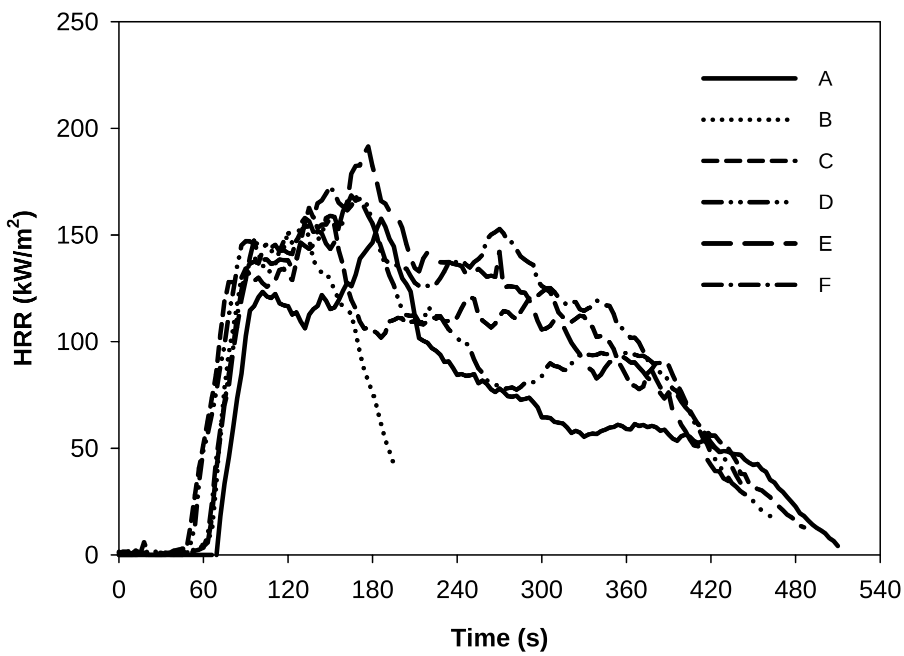

Figure B- 1. Heat release rate versus time at 15 kW/m^2 exposure.

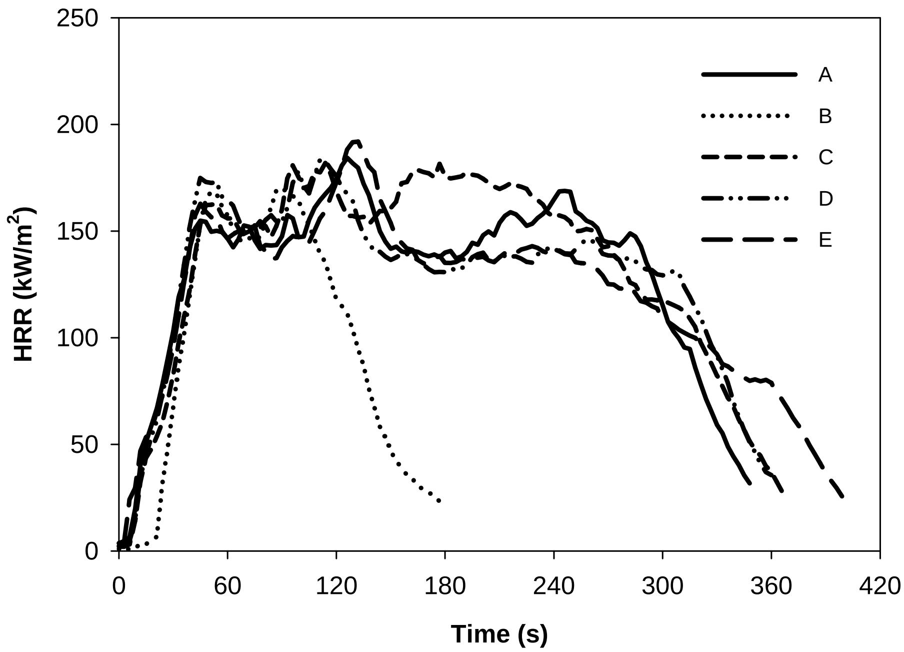

Figure B- 2. Heat release rate versus time at 20 kW/m^2 exposure.

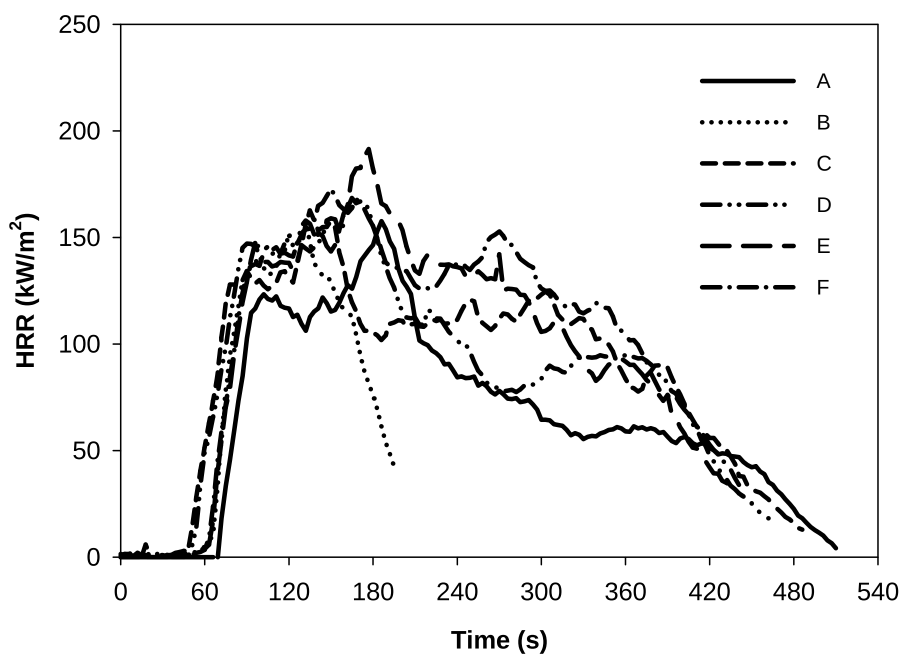

Figure B- 3. Heat release rate versus time at 25 kW/m^2 exposure.

Appendix C: Additional Open Calorimeter Test Results

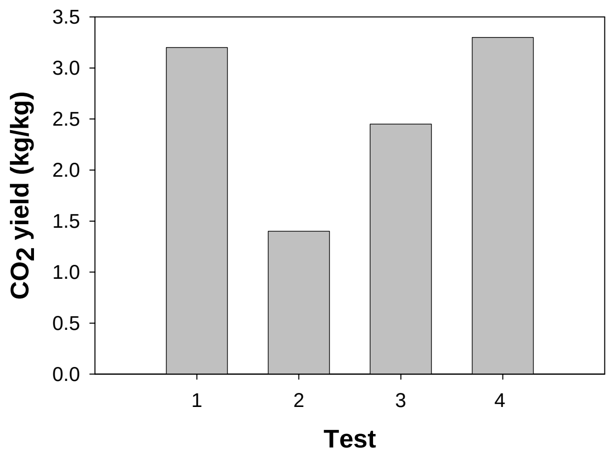

Figure C- 1. Mean CO_2 yields for used sofas

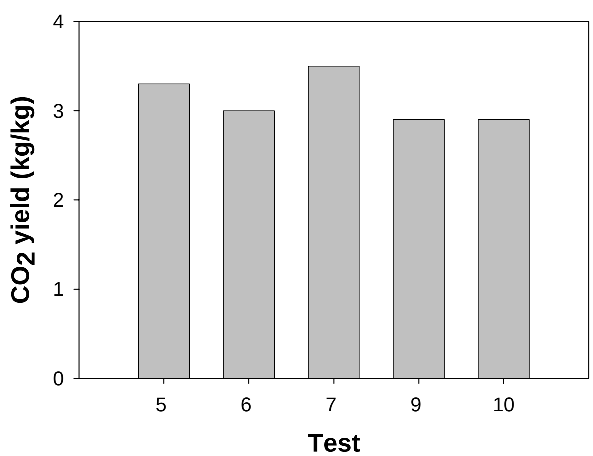

Figure C- 2. Mean CO_2 yields for mock-up sofas (not calculated for tests 8 and 11 due to a malfunction of mass loss instrumentation)

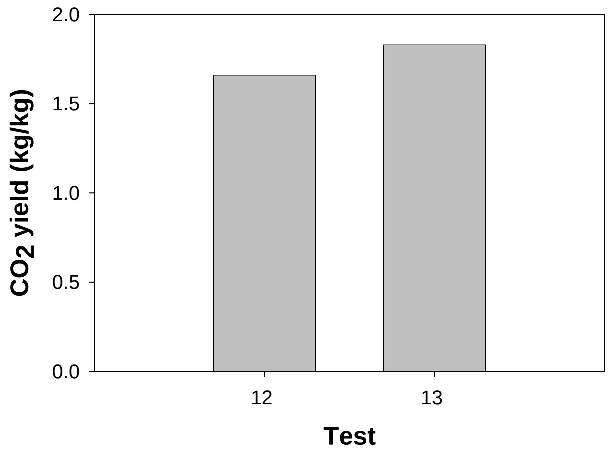

Figure C- 3. Mean CO_2 yields for wood cribs

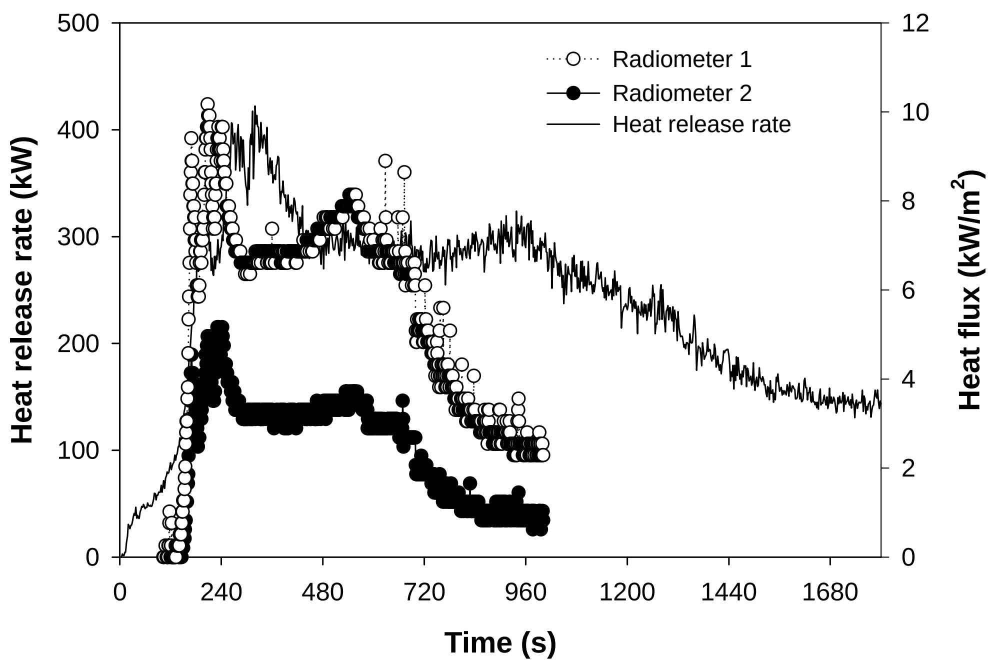

Figure C- 4. Heat release rate and heat flux measurements during Test 12 (Positions: Radiometer 1 – 1000 mm height, 200 mm behind crib; Radiometer 2 – 1100 mm height, 400 mm behind the crib)