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Fire Properties of Floor Coverings: New Fire Test Methods and Acceptable Solutions

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The work reported here was jointly funded by Building Research Levy whose logo is shown above.

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Preface

This is the second of a series of reports prepared during research into fire properties of lining/surface products.

Acknowledgments

This work was funded by the Building Research Levy.

Note

This report is intended for:

- the Department of Building and Housing (DBH) as a technical basis for reviewing and/or updating provisions contained within the New Zealand Building Code (NZBC) Approved Documents
- manufacturers of flooring products as a basis to evaluate test parameters and real fire performance
- designers to enable a greater understanding between the reaction-to-fire performance of flooring materials in laboratory tests and real fire performance
- other researchers involved in reaction-to-fire of flooring materials.

FIRE PROPERTIES OF FLOOR COVERINGS: NEW FIRE TEST METHODS AND ACCEPTABLE SOLUTIONS

BRANZ Study Report SR 181 (2007) PCR Collier

Reference

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Abstract

This project trialled the current reaction-to-fire test requirements for flooring and compared this with two alternative test methods on a range of flooring products. The findings indicated that the current test method of the Hot Metal Nut (HMN) required by the NZBC Compliance Documents does not adequately identify the flooring products that present a hazard. Alternative test methods – the Flooring Radiant Panel Test (FRPT) and the cone calorimeter (CC) – were shown to identify flooring products that do present a hazard when the HMN had indicated the same products to be in the low hazard category.

Recommendations are made for changes to the current requirements for the reaction-to-fire testing of flooring products in the NZBC based mainly on CC data. However, it is acknowledged that the FRPT results also indicate properties not necessarily highlighted in the CC.

Keywords

Floor coverings, cone calorimeter, flooring radiant panel, hot metal nut, radiant flux, heat release rate, ignition, smoke production.

Contents

Page

Figures

Page

Tables Page

1. INTRODUCTION

The motivation for this project was to ensure that regulatory requirements in the New Zealand Building Code (NZBC) Compliance Documents reflected state-of-the-art research and benefited from the new knowledge generated by this. One of the key features of the research that has been done into the reaction-to-fire area is the strong move towards fire test methods that are either more representative of realistic full-scale scenarios, or small-scale tests that generate engineering data able to be interpreted or utilised in theoretical models for simulating fire spread for full-scale configurations.

The current NZBC Compliance Documents require that the flammability of floor coverings is classified to BS 5287 when tested to: BS 4790 *Method for determination of the effects of small source ignition on textile floor coverings (hot metal nut method)* (BS 1976 and 1987).

The Hot Metal Nut (HMN) test has been rejected from a review of the Building Code of Australia (BCA) because it is only intended to test a material's response to a small point source ignition and is thus unsuited to testing responses to a larger heat source. The shortcomings of this test method are further highlighted in the Fire Code Reform Centre (FCRC) report on the *Fire Performance of Floors and Floor Coverings* (FCRC 1999).

2. BACKGROUND

Fire properties of floor coverings are controlled to make sure that the fire involvement of floor covering materials does not lead to rapid fire growth and smoke spread such that occupants are prevented from safely evacuating the building.

This project follows previous BRANZ research– BRANZ *Study Report 160* (Collier, Whiting and Wade 2006) – where the reaction-to-fire of walls and ceiling linings was studied in the ISO 9705 room corner test and the cone calorimeter (CC). The findings from that study supported recommendations for the adoption of the above two test methods and classifications in accordance with that adopted in Australia by the BCA but suitably modified to conform to the purpose groups in the NZBC. It is intended that this study will lead to recommendations to the DBH for updated performance and test requirements for flooring.

2.1 Current requirements in New Zealand

The requirements for flooring in the NZBC Compliance Document (DBH 2005) are as follows:

> **Flooring**
> **6.20.8** Flooring shall be either *noncombustible*, or have a low radius of effects of ignition (assessed according to BS 5287) when tested to the BS 4790 standard test for flammability of floor coverings; whenever that floor covering serves:
> a) *Exitways* for all *purpose groups*, or
> b) Any space occupied by *purpose groups* SC or SD.
> **6.20.9** Paragraph 6.20.8 applies to flexible finishes such as carpets, vinyl sheet or tiles, and to finished or unfinished floor surfaces.
> **6.20.10** In *firecells* equipped with sprinklers

the flooring need not comply with the requirements in Paragraph 6.20.8.

A scenario to consider is that fire may spread from one room to another by means of the flooring. Having effectively regulated walls and ceiling linings to limit fire spread the next possible route could be along the flooring.

A review of the New Zealand Fire Service (NZFS) database of fire incidents was carried out for the period 1 January 2000 to 4 December 2005 to gain an understanding of the scale of fires in which floor coverings were reported to have contributed to fire spread. For 162 (4.6%) incidents out of a total of 3448 the flooring was the first or second item ignited causing 20 injuries and three deaths. In 137 (4%) of incidents the floor covering was recorded as the avenue of flame travel.

The FCRC Technical Report *Building Fire Scenarios – An Analysis of Incident Statistics* (FCRC 1996) provides a summary analysis of the Australian, US and UK fire statistics and found that:

"Of the 48,802 building fires studied floor coverings were cited as being involved in 6048 fires, or 12.4% of the total". Italicised and put quote marks on this – is it a quote?

In a Swedish study (Hertzberg, Blomqvist and Tuovinen 2007) including a laboratory reconstruction of a double fatality and multiple casualty hospital fire started by the occupant on a bed, melting and dropping material from the mattress ignited the PVC carpet and a pool fire developed beneath the bed. The fire developed quickly, involving all of the floor carpet. The PVC carpet then became the main source of fire and smoke and a full flashover occurred soon after that resulting in the spread of fire and smoke beyond the room of origin.

2.2 Reasons for controlling floor coverings

To summarise the FCRC report (FCRC 1998), in many buildings the contents play a dominant role in the initiation and growth of a fire, but the linings only provide a path for fire spread. It is a combination of the contents, linings (including flooring) and building geometry that dictate the outcome of a fire.

The underlying performance objectives of the FCRC study were to:

- safeguard occupants from injury or illness due to fire in a building or whilst evacuating a building during a fire
- facilitate the activities of emergency services
- avoid the spread of fire between buildings
- protect other property by avoiding fire-related structural failure.

Within this general context, the FCRC has suggested that an appropriate performance objective for fire hazard property provisions as they relate to floor materials and floor coverings is "to ensure that, in the event of a fire, floor materials do not significantly decrease the safety of occupants".

Fire spread along the floor coverings is a possibility in instances where the wall and ceiling linings have been adequately controlled and the next easiest avenue is via the floor.

New Zealand's continued reliance on the HMN test (BS 4790) could also be seen as representing a trade barrier and is counter to an expressed desire to utilise international standards whenever possible. This is an incentive to consider the test methods being adopted by Australia in the first instance and internationally in general.

2.2.1 Flamespread mechanisms

Flamespread on floor coverings can occur by two different mechanisms: 'wind-aided flow' and 'opposed flow'.

Wind-aided flow is when the convective flow (generated by the heat) is in the direction of the flamespread, such as on a vertical surface where cooler air is drawn into the plume on the lower side and exits on the upper side pre-heating a significant region in advance of the flamespread.

Opposed flow is when the flamespread is against the direction of the convective flow, such as on a horizontal (floor) surface where the vertical flames draw cooler air into the plume resulting in minimal pre-heating of unburnt material and a much slower spread outwards compared with wind-aided flow.

Wind-aided flamespread is much more rapid and potentially dangerous compared to opposed flow, and for this reason fire spread via floor coverings is often perceived as a less hazardous scenario compared with walls/ceilings.

However, flamespread on floor coverings on stairs (where the scenario could more closely be described as wind-aided rather than opposed flow) is probably the worse case when considering floor coverings. For this reason, it may be justifiable to subject floor coverings on stairs to the same fire test requirements as walls.

2.3 Literature search

A selection of international research projects has reached various conclusions.

In a previous BRANZ study (Cowles 1999) a selection of 13 commercial flooring products (including wool, polypropylene, nylon, PVC, linoleum and timber veneer) were tested in the CC and subjected to the HMN test. It was found that the floor coverings showed a wide range of fire performance, including a factor of four in the peak heat release rate (HRR) and the time to ignition. It was not possible to correlate the results obtained from the CC with the HMN test, the FRPT or the AS 1530.3 (EFHT).

The findings are summarised as follows:

- the HMN method is unsuitable for assessment of fire hazard for full-scale fire involvement in compartment fires
- the CC provided a small-scale rate of heat release test that gives good correlations with full-scale fire test methods for assessing fire hazards of floor coverings
- a rate of heat release classification method for floor coverings is able to eliminate floor coverings, which are of high fire hazard.

It has also been established (Babrauskas and Peacock 1990) that the single most important parameter in determining fire hazard from burning materials is rate of heat release and the CC provides a small-scale economical test method that is well established. The CC provides data that can be used to predict the full-scale performance of many but not all floor coverings and building materials in general.

Hirschler (1992) also concluded that the CC was most suitable for fire testing carpet tiles and to be more indicative of fire performance than the NBS smoke density chamber or the Flooring Radiant Panel (FRP). In the CC the optimum incident radiant flux for carpet tile floor coverings was shown to be 25 kW/m^2. A classification scheme based on the ratio of the time to ignition (in seconds) and the peak HRR (in kW/m^2) was proposed as follows:

$0.40 <= TTI / RHR_{pk}$	I
$0.20 <= TTI / RHR_{pk} < 0.40$	II
$0.10 <= TTI / RHR_{pk} < 0.20$	III
$TTI / RHR_{pk} < 0.10$	IV

Attempts to find a correlation between the Critical Radiant Flux (CRF), FRP) and the CC results with combinations of peak RHR and inverse of time to ignition (1/TTI) or products of the two were unsuccessful with the limited number of carpet tiles tested (6). Explanations suggested included:

- only 6 values of CRF were considered and they were close together
- CRF values are not really intended as a measure of fire hazard but as cut-off points to indicate whether the carpet will spread along a corridor on its own and in so doing eliminates carpets that perform poorly.

Blackmore and Delichatsios (2002) in a study that included testing wool, polypropylene and nylon carpets and vinyl flooring conclude that:

- CC data cannot be used to predict CRF as measured in the FRP
- to characterise the flammability of any material, measurements are needed from both the CC and the FRP
- maximum $HRR^2/t_{ignition}$ is a suitable parameter to classify the hazard of floor coverings used on stairs large-scale corridor tests provide insufficient data to predict the performance of floor coverings under severe fire exposure and the HRR in the CC is needed to predict this performance
- it is necessary to consider smoke to predict the toxicity hazard from floor coverings and a suitable means is CC data such as: HRR x SEA
- the proposed test methods provide data that is suitable for sophisticated fire engineering calculations as well as for the development of regulatory controls.

Commenting on the adoption of the FRP by the ABCB for floor coverings, the authors express concern that the analysis of the exhaust products is used for smoke controls and that only the CC can give an appropriate measurement for smoke control.

A similar method for evaluation of the flamespread is proposed by Tomann (1993) (Cowles 1999) that uses CC data and the flamespread parameter from Nordtest 007 (NT 1985).

Nordtest 007 is a Nordic test method for floor coverings that has been developed from a test used for roof coverings. The 1000 mm x 400 mm specimen is mounted at an angle of 30^o to the horizontal plane. Forced air flow of 2 m/s is passed over the exposed surface. A burning wooden crib is placed on the surface of the specimen. The burning crib exposes the underlying surface to a heat flux of 20-75 kW/m^2, and ignites it. There is not external heat radiation. Wind forces the flames along the surface. Damage inflicted to the specimen and the light absorbed by the smoke are observed. Conditioning and preparation of specimens is the same as the CC.

A correlation between the flamespread parameter from Nordtest 007 and the CC for 11 products was determined as follows:

$$Flamespread(mm) = x_f = 44\dot{Q}''^{\,0.38}_{\max}.t_{ig}^{\,-0.19}.t_b^{0.12}$$ **.....Equation 1**

Where $\dot{Q}''_{\max}$ is the maximum rate of heat release, t_{ig} is the time to ignition and t_b is the duration of burning from CC data.

The flamespread parameter is used to classify the test products as follows:

$x_f \leq 200$ Class 1

$200 < x_f < 300$ Class 2

$300 < x_f < 400$ Class 3

$400 \leq x_f$ Class 4.

A similar analysis of wind-aided flamespread on floor coverings by Van Hees and Vandevelde (1997) uses CC data to predict the likelihood of flashover.

The proposed method considers the following CC data:

$\dot{E}'' =$ heat release of the material, taken as the average of the burn time

$k_f = 0.01\,\mathrm{kW/m^2}$ constant relating the flame length to heat release

$t_{ig} =$ time to ignition

$t_{bo} =$ time to extinguishment

and determines the parameters C_i and C_b.

$$\mathrm{C_i} = k_f.\dot{E}'' - 1$$ **Equation 2**

$$\mathrm{C_b} = k_f.\dot{E}'' - \frac{t_{ig}}{t_{bo}} - 1$$ **Equation 3**

If Ci >1, then the material is likely to cause flashover

or 0 > Ci >1, then the material is likely to support steady flamespread

or Ci < 0, then there is unlikely to be any flamespread.

C_b represents the inclusion of a parameter accounting for the period that the floor covering is burning, the t_{ig}/t_{bo} factor increases in magnitude for delayed ignition and/or a short duration of burning thus reducing the overall value of C_b, while an early ignition and/or sustained burning results in a small t_{ig}/t_{bo} factor and does not reduce C_b as much. This provides a measure of the length of the period of burning by comparing C_i and C_b.

2.4 Test methods considered by FCRC

The test methods for floor coverings considered in the review by the FCRC (FCRC 1999) were as follows:

- Early Fire Hazard Test (EFHT)
- Flooring Radiant Panel Test
- Cone Calorimeter
- Hot Metal Nut Test
- Methenamine Pill Test
- 10 m Corridor Test
- Room Fire Tests
- Danish Floorings Test for fire and smoke generation, and
- LIFT Apparatus.

From these tests, the following sub-sets were chosen for comparison:

- Early Fire Hazard Test
- Cone Calorimeter
- Flooring Radiant Panel Test, and
- 10 m Corridor Test.

The remaining tests were excluded from consideration because of their inability to assess the three parameters identified as essential to assess materials' contribution to the potential for rapid flamespread and time to reach untenable conditions. These three parameters are: potential to spread fire (horizontally and on stairs), contribution to fire growth (i.e. heat release), and smoke generated.

The HMN Test and Methenamine Pill were rejected because they are designed only to test a material's response to a small point ignition source and are thus unsuited to testing responses to a larger heat source. The LIFT test was rejected because its vertical orientation (of the sample) means its use is limited to those materials that do not melt copiously. All materials that melt are regarded as failing the test. This is regarded as too strict a control for the circumstances in question. The Danish floorings test was regarded as comprehensive and otherwise appropriate, but was rejected because of its lack of international availability and acceptance.

2.4.1 Early Fire Hazard Test

The EFHT (SA 1999) has previously been used by Australian regulators to determine the performance of floor coverings, with the Spread of Flame Index being the critical parameter employed. FCRC PR 99-02 (1996) tested the EFHT for a range of parameters. It concluded that the test could not be used to characterise the horizontal flamespread in floor coverings, particularly because the test unnecessarily penalises certain floor coverings. FCRC notes that "this is substantiated by comparison with a full-scale corridor test … which shows that EFHT cannot always differentiate between the performance of two floor coverings, while FRP can".

Consequently, FCRC concluded that the EFHT is not suitable for use in a regulatory context.

2.4.2 Cone calorimeter

Comparison of results given by the CC and the FRPT leads FCRC to conclude that "… the Cone cannot be used to determine the critical heat flux as measured in the FRP … It follows that the Cone alone cannot replace the FRP apparatus".

However:

> *"There are situations (for example floor coverings on stairs) where the FRP critical heat flux is not sufficient to assess fire growth because fire spread also involves spread on vertical surfaces. Measurement of heat release such as in the cone calorimeter is necessary to address this situation".*

The FCRC's conclusion is that neither the CC nor the FRPT can be used as a single test capable of assessing the fire hazard characteristics of floor coverings in all circumstances. For this reason, the adoption of the two tests in tandem was proposed.

A Technical Working Group subsequently reviewed the FCRC recommendations. In respect of flooring materials, the TWG recommended that the FRPT, as standardised in ISO 9239.1, should be adopted as the regulatory test for DTS fire performance of flooring materials. The TWG recommendations were considered by the Building Codes Committee (BCC), which is the ABCB's peak technical advisory body. The BCC accepted the bulk of these recommendations, including the recommendation to use the FRPT for DTS fire performance for flooring materials.

2.4.3 Flooring Radiant Panel Test

In the FRPT EN ISO 9239-1, a test specimen of size 1050 mm × 230 mm is placed horizontally below a gas-fired radiant panel inclined at 30°. The specimen is exposed to a defined field of total heat flux, 11 kW/m^2 at the hotter end close to the radiant panel, and decreasing to 1 kW/m^2 at the other end farther away from the radiant panel. A pilot flame front from a line burner is applied to the hotter end in order to ignite the specimen. The test apparatus is presented in Figure 1.

The progress of the flame front along the length of the specimen is recorded in terms of the time it takes to travel various distances. The smoke development during the test is measured on the basis of light obscuration by smoke in the exhaust duct. The duration of the test is 30 minutes.

As noted above, FCRC's testing involved assessing the results of the FRPT (as well as the other small-scale tests discussed above) against the results from the 10 m Corridor Test, which is a large-scale test. It was found that the FRP was, in all cases, able to differentiate between the performance of two floor coverings and hence "it follows that the FRP is appropriate for assessing flamespread from floor coverings".

Consequently this test, as standardised in ISO 9239-1, has been specified as the accepted test for measuring the Critical Radiant Flux (CRF) of floor covering materials in the Building Code of Australia Specification C1.10a. (ABCB 2006) The CRF can be defined as the minimum radiant energy a fire needs to sustain flame propagation on the material. The lower the number, the greater is the tendency of the material to spread flame.

2.4.4 10 m Corridor Test

The 10 m Corridor Test is a large-scale test that gives an indication of the comparative performance of floor coverings in one particular building enclosure. According to FCRC "the data it provides is not suitable for fire engineering calculations, or in assessing the performance of floor coverings in enclosures with different geometries".

2.4.5 Recommended test method from FCRC study

The FCRC (1999) study recommended that for floor materials and floor coverings, the new test requirements will be based on the materials' CRF, as measured by the internationally standardised test ISO 9239-1.

The following specification sets out requirements in relation to the *fire hazard properties* of floor materials and coverings as recommended and adopted in the BCA.

A floor material or floor covering must have a CRF not less than that listed in Table 1 and, in a building not protected by a sprinkler system complying with Specification E1.5, a maximum s*moke development rate* of 750 percent-minutes.

Table 1: CRF in kw/m² of floor materials and floor coverings

BCA Building Class	General		Fire-Isolated Exits
	Building not fitted with a sprinkler system complying with Specification E1.5	Building fitted with a sprinkler system complying with Specification E1.5	
Class 2, 3, 5, 6, 7, 8 or 9b Excluding accommodation for the aged	2.2	1.2	2.2
Class 3 Accommodation for the aged	4.5	2.2	4.5
Class 9a			
Patient care areas	4.5	2.2	4.5
Areas other than patient care areas	2.2	1.2	4.5

2.5 Euroclass system

Many of the member countries of the European Union (EU) have adopted the harmonised Euroclass system of reaction-to-fire performance of building products. The background of the harmonisation process lies on the Commission Decision 94/611/EC implementing Article 20 of Directive 89/106/EEC on construction products in the field of fire safety (EC 1994). The Euroclass decision includes a classification system for building products based on their reaction-to-fire performance. It additionally defines the test methods according to which construction products shall be categorised. In the Euroclass system, floor coverings and other surface linings are considered separately.

The purpose of harmonisation is to facilitate the trade of building products between the member countries of the EU by removing trade barriers due to differences in test methods and classification systems. Previously, products had to be tested and classified according to national standards in each country in which they were launched to the market. In the new system, the Euroclass classification of a product is acknowledged in all member countries based on its performance in the harmonised fire tests.

In the context of the reaction-to-fire of flooring products, the four tests adopted for Euroclass classifications are described below.

2.5.1 Flooring Radiant Panel Test EN ISO 9239-1

The classification criterion is the Critical Heat Flux (CHF) defined as the radiant flux at which the flame extinguishes or the radiant flux after a test period of 30 minutes, whichever is lower. In other words, CHF is the flux corresponding to the furthest extent of spread of flame

For comparison purposes, the Euroclass System combines several other ISO test methods with ISO 9239-1 for determining the classes of reaction-to-fire performance for floorings**.** Table 2 lists the test requirements for the various Euroclasses where from

A2 to D the critical flux in kW/m^2 is only one test parameter to be satisfied. Other test parameters are non-combustibility (ISO 1182), gross calorific potential (PCS) (ISO1716, bomb calorimeter) and ignitability (ISO 11925-1), depending on the class to be met.

Test methods ISO 1182 and ISO 1716 are only applicable for non-combustible materials that apply to classes A1 and A2.

For further information visit:

http://virtual.vtt.fi/virtual/innofirewood/stateoftheart/database/euroclass/euroclass.html#Radiantpaneltest

Table 2: Classes of reaction-to-fire performance for floorings

Class	Test method(s)	Classification criteria	Additional classification
A1$_{FL}$	EN ISO 1182 (1); *and*	$\Delta T \leq 30°C$; *and* $\Delta m \leq 50\%$; *and* $t_f = 0$ (i.e. no sustained flaming)	-
	EN ISO 1716	PCS ≤ 2.0 $MJ.kg^{-1}$ (1); *and* PCS ≤ 2.0 $MJ.kg^{-1}$ (2); *and* PCS ≤ 1.4 $MJ.m^{-2}$ (3); *and* PCS ≤ 2.0 $MJ.kg^{-1}$ (4)	
A2$_{FL}$	EN ISO 1182 (1); *or*	$\Delta T \leq 50°C$; *and* $\Delta m \leq 50\%$; *and* $t_f \leq 20s$	
	EN ISO 1716; *and*	PCS ≤ 3.0 $MJ.kg^{-1}$ (1); *and* PCS ≤ 4.0 $MJ.m^{-2}$ (2); *and* PCS ≤ 4.0 $MJ.m^{-2}$ (3); *and* PCS ≤ 3.0 $MJ.kg^{-1}$ (4)	
	EN ISO 9239-1 (5)	Critical flux (6) ≥ 8.0 $kW.m^{-2}$	Smoke production (7)
B$_{FL}$	EN ISO 9239-1 (5) *and*	Critical flux (6) ≥ 8.0 $kW.m^{-2}$	Smoke production (7)
	EN ISO 11925-2(8): *Exposure = 15s*	Fs ≤ 150mm within 20s	
C$_{FL}$	EN ISO 9239-1 (5) *and*	Critical flux (6) ≥ 4.5 $kW.m^{-2}$	Smoke production (7)
	EN ISO 11925-2(8): *Exposure = 15s*	Fs ≤ 150mm within 20s	
D$_{FL}$	EN ISO 9239-1 (5) *and*	Critical flux (6) ≥ 3.0 $kW.m^{-2}$	Smoke production (7)
	EN ISO 11925-2(8): *Exposure = 15s*	Fs ≤ 150mm within 20s	
E$_{FL}$	EN ISO 11925-2(8): *Exposure = 15s*	Fs ≤ 150mm within 20s	-
F$_{FL}$	No performance determined		

(1) For homogeneous products and substantial components of non-homogeneous products.
(2) For any external non-substantial component of non-homogeneous products.
(3) For any internal non-substantial component of non-homogeneous products.
(4) For the product as a whole.
(5) Test duration = 30 minutes.
(6) Critical flux is defined as the radiant flux at which the flame extinguishes or the radiant flux after a test period of 30 minutes, whichever is the lower (i.e. the flux corresponding with the furthest extent of spread of flame).
(7) **s1** = Smoke ≤ 750%.min; **s2** = not s1.
(8) Under conditions of surface flame attack and, if appropriate to the end–use application of the product, edge flame attack.

2.5.2 Non-combustibility test EN ISO 1182

The purpose of the non-combustibility test EN ISO 1182 is to identify the products that will not, or significantly not, contribute to a fire. The test apparatus is shown in Figure 1. A test specimen of cylindrical shape is inserted into a vertical tube furnace with a temperature of about 750°C. Temperature changes due to the possible burning of the specimen are monitored with thermocouples. The flaming time of the specimen is visually observed. After the test, the mass loss of the specimen is determined.

The quantities used in the European classification are the temperature rise of the furnace (ΔT), the mass loss of the specimen (Δm), and the time of sustained flaming of the specimen (t_f).

2.5.3 Gross calorific potential test EN ISO 1716

The PCS test EN ISO 1716 determines the potential maximum total heat release of a product when burned completely. The test apparatus is shown in Figure 1. A powdery test specimen is ignited in pressurised oxygen atmosphere inside a closed steel cylinder (calorimetric bomb) surrounded by a water jacket. The temperature rise of water during burning is measured. The PCS is calculated on the basis of the temperature rise, specimen mass and correction factors related to the specific test arrangement used.

The classification parameter of the method is the PCS measured in MJ/kg or MJ/m^2, depending on the features of the product and its components.

2.5.4 Ignitability test EN ISO 11925-2

In the ignitability test EN ISO 11925-2, the specimen is subjected to direct impingement of a small flame. The test specimen of size 250 mm × 90 mm is attached vertically on a U-shaped specimen holder. A propane gas flame with a height of 20 mm is brought into contact with the specimen at an angle of 45°. The application point is either 40 mm above the bottom edge of the surface centreline (surface exposure) or at the centre of the width of the bottom edge (edge exposure). Filter paper is placed beneath the specimen holder to monitor the falling of flaming debris. The test apparatus is shown in Figure 1.

Two different flame application times and test durations are used depending on the class of the product. For Class E, the flame application time is 15 seconds, and the test is terminated 20 seconds after the removal of the flame. With a flame application time of 30 seconds for Classes B, C and D, the maximum duration of the test is 60 seconds after the removal of the flame. The test is terminated earlier if no ignition is observed after the removal of the flame source, or the specimen ceases to burn (or glow), or the flame tip reaches the upper edge of the specimen.

The classification criteria are based on observations about whether the flamespread (Fs) reaches 150 mm within a given time and whether the filter paper below the specimen ignites due to flaming debris. In addition, the occurrence and duration of flaming and glowing are observed.

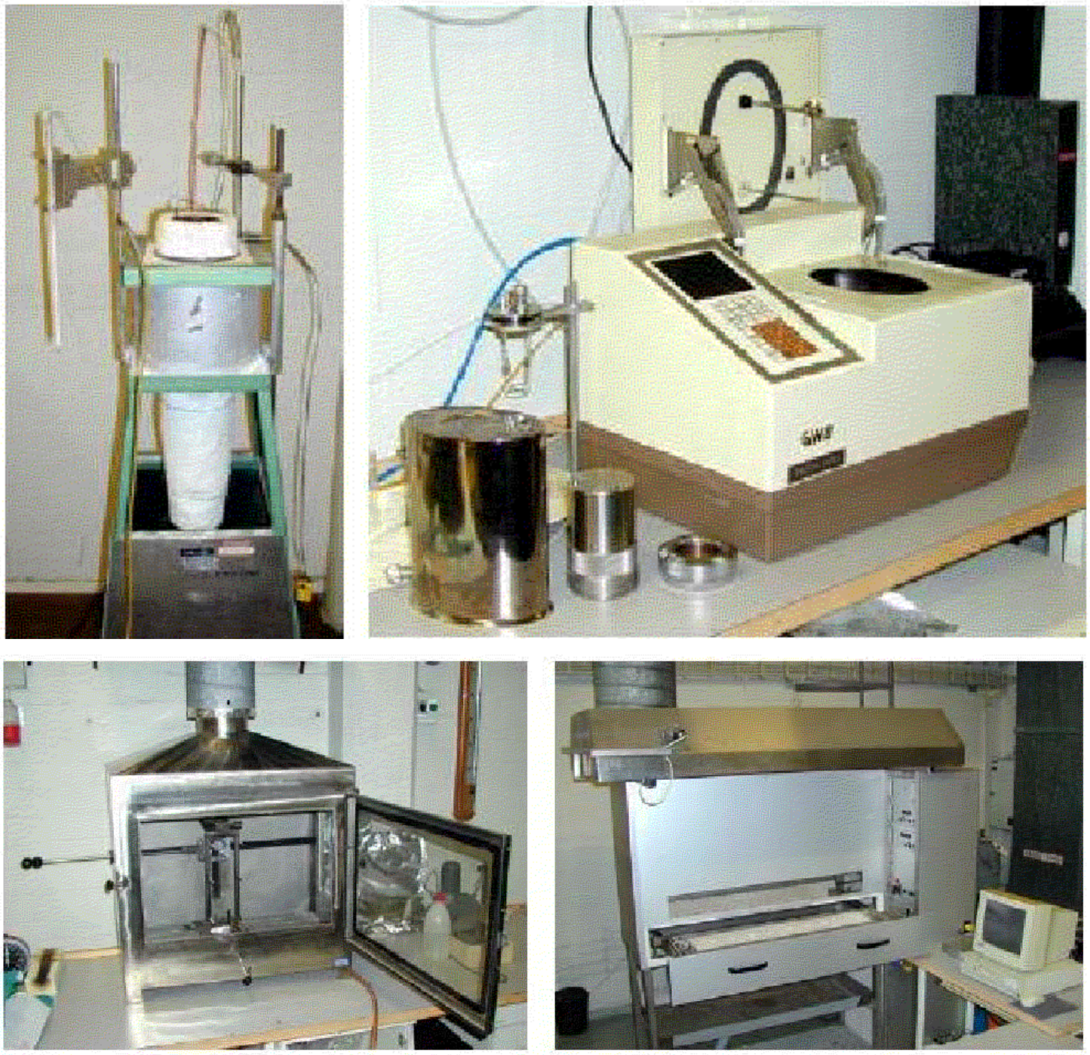

Figure 1: The test apparatus for the European classification. From top left clockwise: test for non-combustibility (ISO 1182); test for gross calorific potential (ISO 1716); test for ignitability of building products subjected to direct impingement of flame (ISO 11925-1); and test for floorings (ISO9239-1).

3. EXPERIMENTAL TRIALS AND ANALYSIS

The approach of this study is to compare the results obtained in the CC, FRPT and HMN test apparatus of a selection of typical New Zealand available flooring products. Table 3 lists the physical properties of the tested flooring products and Figure 23 and Figure 24 (in the Appendices) show photographs of the samples. The materials were selected based on covering the range from low to high hazard. Materials obviously at the extreme low hazard end of the scale were omitted, as it was considered that the evidence gathered would be of limited use in demonstrating that the test methods are capable of discriminating levels of performance when there is obviously no hazard. The types of materials omitted were ceramic and stone flooring tiles as they are essentially non-combustible.

Table 3: Selection of flooring types and testing

#	Flooring product type	Thickness, mm (nominal including backing)	Density, kg/m^2	Cone	FRP	HMN
A	Flooring laminate (0.25 mm) on MDF	7 mm	879	x	x	x
B	Carpet tile (polyester)	4 mm	347	x	x	x
C	Cork tile	6 mm	460	x	x	x
D	Flooring laminate (0.25 mm) (formica) on HDF	12 mm	978	x	x	x
E	Flooring laminate 0.25 mm (formica) on HDF	8 mm	896	x	-	-
F	Vinyl tiles	1.5 mm	898	x	x	x
G	Polyester, overlay	12 mm	148	x	x	x
H	Plywood flooring	20 mm	511	x	x	x
I	Rubber floor covering	2.4 mm	2073	x	x	x
J	Polypropylene carpet with latex backing	6 mm	142	x	*	*
K	Polypropylene carpet bonded to polyolefin backing	6.2 mm	337	x	*	*

x tested for this project

*Data supplied by manufacturer

3.1 Test results

3.1.1 Flooring Radiant Panel Test

The results from the FRPT ISO 9239-1:2002 (2002) for the CRF and smoke measurements are shown in Table 4. The results are derived from the average of three samples.

Table 4: Summary of FRP results (heat and smoke)

#	Flooring product type	CRF, kW/m^2	Smoke, %.min
A	Flooring laminate on MDF, 7 mm	7.5	131
B	Carpet tile (Autex)	4.6	542
C	Cork tile, 6 mm	5.3	106
D	Flooring laminate (formica), 12 mm	11.8	234
E	Flooring laminate (formica), 8 mm	11.8*	234*
F	Vinyl tiles, 1.5 mm	11.7	158
G	Polyester, overlay	<1.1	629
H	Plywood flooring	5.8	185
I	Rubber floor covering	5.9	813
J	Polypropylene on latex	7.0	124
K	Polypropylene on polyolefin backing	4.24	660

*Not tested – estimated from material D

The materials A to K are ranked in order of reducing CRF and plotted in Figure 2. Subsequent analysis using bar charts has retained the same order to determine whether the trend of increasing hazard is maintained for the different assessment parameters of the other test methods.

While the measurement of CRF may not be truly representative of the actual hazard, which is the ability of floor coverings to aid transport of fire/flame from one area/compartment to another, it is the test method adopted in Australia, Europe and USA in conjunction with the smoke measurement in Figure 3 from the same test.

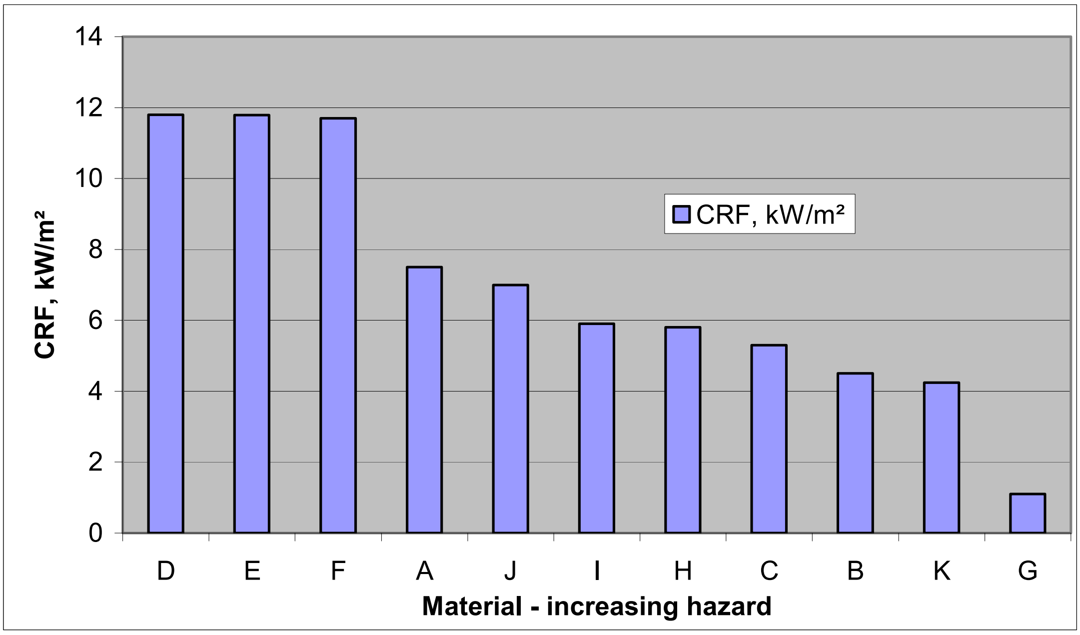

Figure 2: FRP – CRF, kW/m^2 results to ISO 9239-1:2002(E)

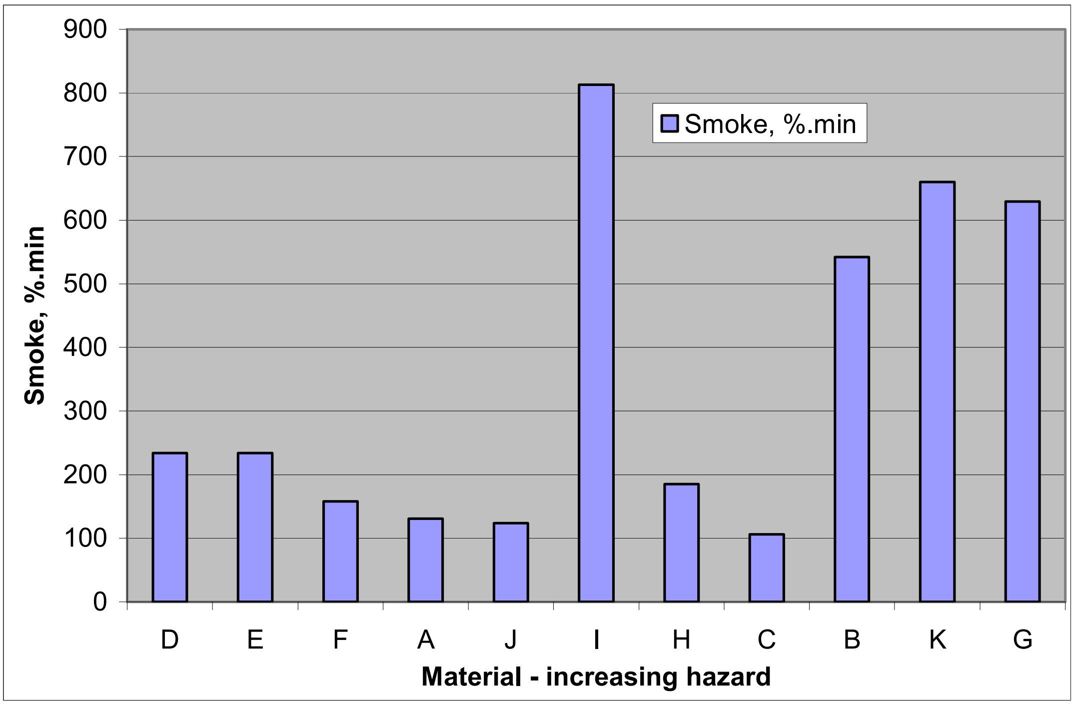

Figure 3: FRP – smoke measurement, %.min

3.1.2 Hot Metal Nut

The test results for HMN are listed in Table 5 and then sorted in order of increasing hazard and presented on a bar chart in Figure 4.

In New Zealand the currently accepted test method is the HMN BS 4790:1987 (BS 1987). It is evident that there is only a minor variation in the radius of the affected area in all products with the exception of G, which had the lowest CRF of 1.1 kW/m^2. The results are assessed to BS 5287 (BS 1976) as follows according to the radius of the affected area:

(a) up to 35 mm, indicates that if material is ignited it will not spread flame under normal conditions in the absence of supporting thermal radiation

(b) 40 to 75 mm, indicates that if the material is ignited it will spread flame to a limited extent only

(c) 80 mm and over, indicates material will ignite and may continue to spread flame.

Table 5: Hot Metal Nut test

Material	Radius (ave) mm	time to ext, sec	BS 5287 assessment	Afterglow	Time to reach clamping ring 250 mm dia
A	15	30	No flamespread	nil	
B	26.7	93	No flamespread	nil	
C	19.3	30	No flamespread	nil	
D	15	31	No flamespread	nil	
E	15*	–	No flamespread	nil	
F	15	0	No flamespread	nil	
G	125	1300	Ignition and flamespread	nil	139
H	15	30	No flamespread	nil	
I	15	39.3	No flamespread	nil	
J	22.5*	–	No flamespread	nil	
K	22.5*	–	No flamespread	nil	

*Estimated result

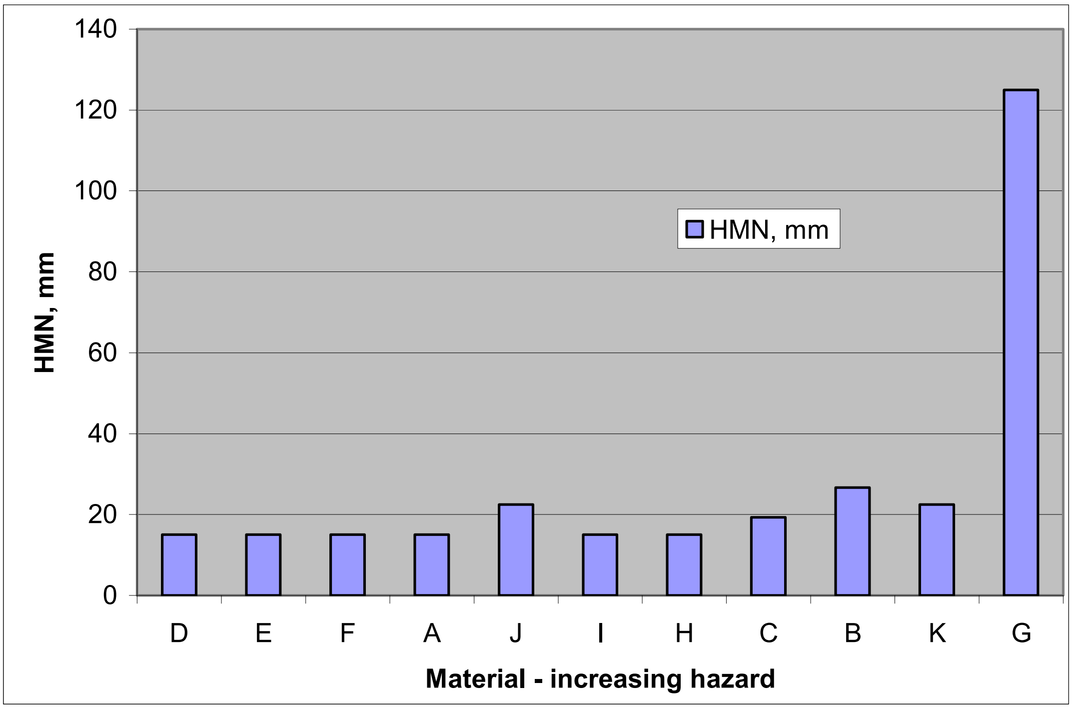

Figure 4: Hot Metal Nut test results to BS 4790:1987

The order of increasing hazard in Figure 4, the same as for the CRF, indicates a general upward trend of the radius of affected area with two exceptions on material J and B. The low radius for the materials before G leads to a conclusion that the method does not resolve the increasing hazard to a useful extent.

3.1.3 Cone calorimeter results

The flooring samples were exposed to a range of radiation levels in the CC ranging from a maximum of 50 kW/m^2, with subsequent exposure levels approximately 70% of the previous level, following a sequence 50, 35, 25, 17 … until ignition did not occur.

Comprehensive results of the CC testing to ISO5660-1 are included in the Appendices in Table 13 to Table 23**.**

Based on the findings of previous research (Hirschler 1992, Cowles 1999, Blackmore and Delichatsios 2002, Tomann 1993, and Van Hees and Vandevelde 1997) radiation levels of 25 and 35 kW/m^2 were selected for in-depth analysis as being representative of exposures where variations in the fire performance floor coverings can be discriminated.

Figure 5 shows a graphical representation where HRR is plotted against time. The materials that occupy the greatest hazard end of the scale in Figure 2 are indicated in Figure 5 by the higher peak HRRs that generally occur in a relatively early time. Materials with lower peak HRRs and where the peak occurs at a later time are generally considered less hazardous, and another factor to consider is the area under the HRR curves which equates to the total heat released per unit area. For the HRR over a greater time interval refer to Figure 25 to Figure 35 for each material.

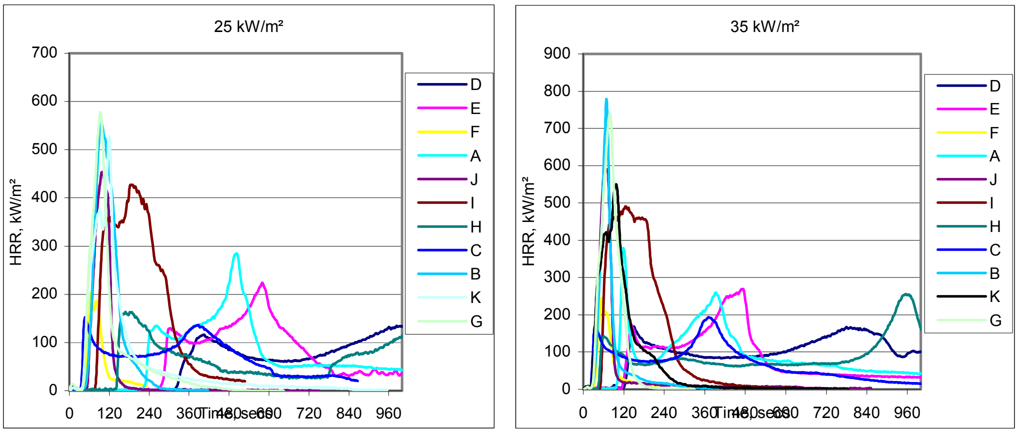

Figure 5: HRR vs time at 25 and 35 kW/m² exposure

Further comparison of the various single parameters measured in the cone testing are plotted in Figure 6, Figure 7 and Figure 8 in the same order as the CRF.

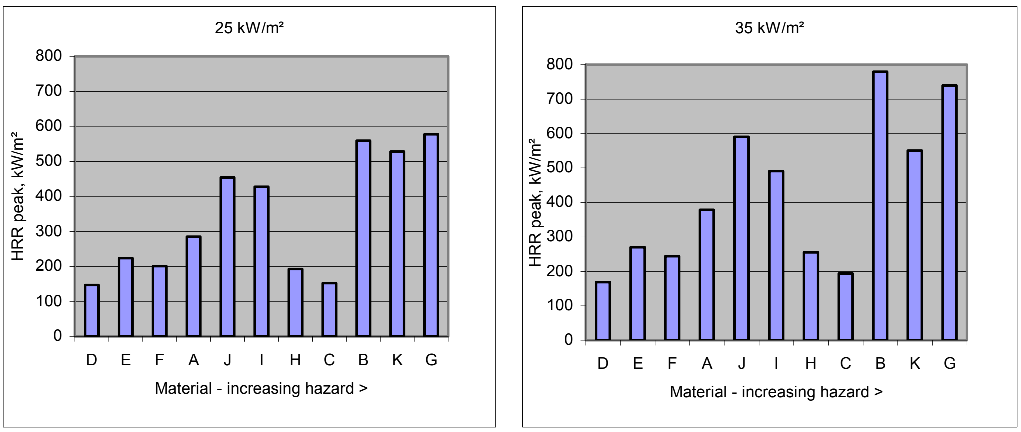

Figure 6: Peak HRR ranked in order of FRP testing results

For the peak HRR the trend is generally increasing with the notable exceptions of the 20 mm plywood flooring (H) and the 6 mm cork tiles (C); these indicated characteristically low peaks and the observed behaviour supports this. Each ignited relatively easily but the HRR only reached a modest peak and then further development was impeded by charred material covering and protecting the remaining material underneath.

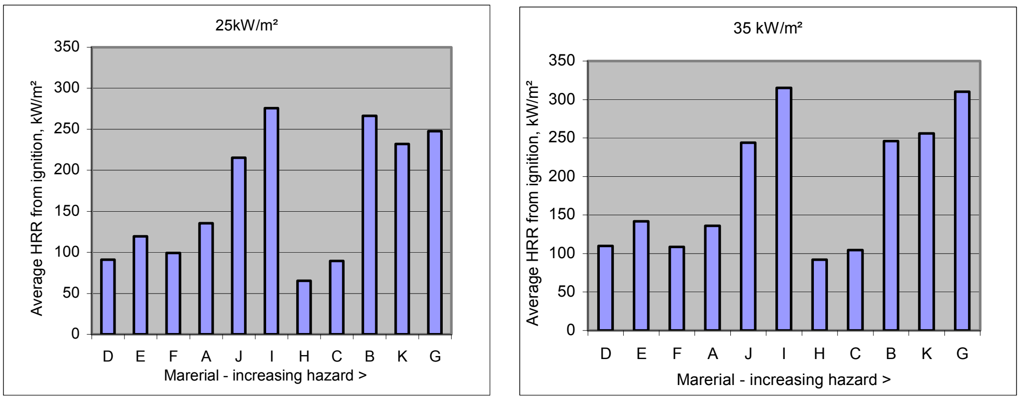

Figure 7: Average HRR ranked in order of FRP testing results

Similarly, the average HRR in Figure 7 follows the same general trend indicating a loose relationship between the peak and the average HRR.

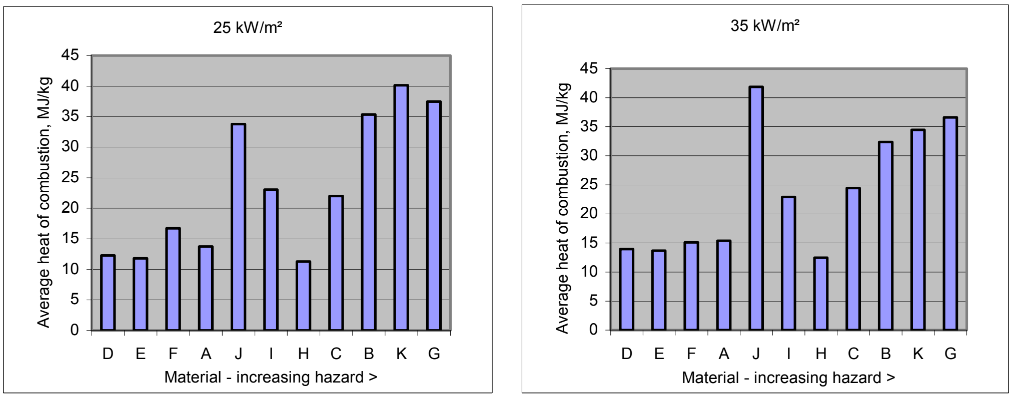

Figure 8: Average heat of combustion ranked in order of FRP testing results

The same general trend is followed with the average heat of combustion in Figure 8. even though it is compared with the mass in kg instead of area in m^2.

The total heat release shown in Figure 9 indicates a quite different trend to the parameters above. The results are skewed by the varying thicknesses/mass below the surface area exposed and they are only loosely related to the peak or average HRR, being the integral of the HRR over the burning time.

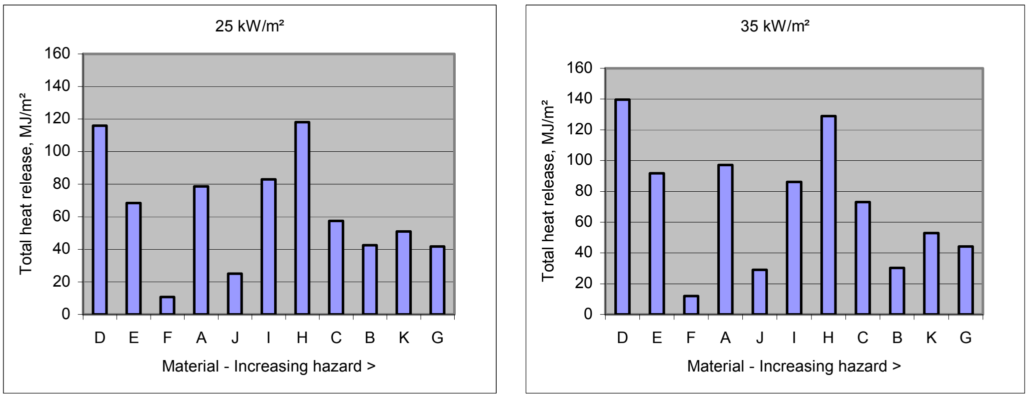

Figure 9: Total heat release ranked in order of FRP testing results

In the case of the plywood (material H) the radiant flux of 25 kW/m^2 was not sufficient to initiate and maintain the full potential of heat release compared with the heat release obtained with the 35 kW/m^2 radiant flux (see Table 20).

3.1.4 Class analysis based on cone calorimeter

3.1.4.1 Hirschler classification

For more precise analysis it is necessary to compare combinations of parameters. Hirschler (1992 – see section 2.3) uses the ratio of the time to ignition to peak HRR.

$$Fire\ hazard = \frac{t_{ig}}{\dot{Q}''_{\max}}$$ **…Equation 4**

Where $\dot{Q}''_{\max}$ is the maximum rate of heat release and t_{ig} is the time to ignition from CC data. The results from $Fire\ hazard = \frac{t_{ig}}{\dot{Q}''_{\max}}$ …Equation 4 are plotted in Figure 10 and indicate a general decreasing trend, which equates to an increasing hazard.

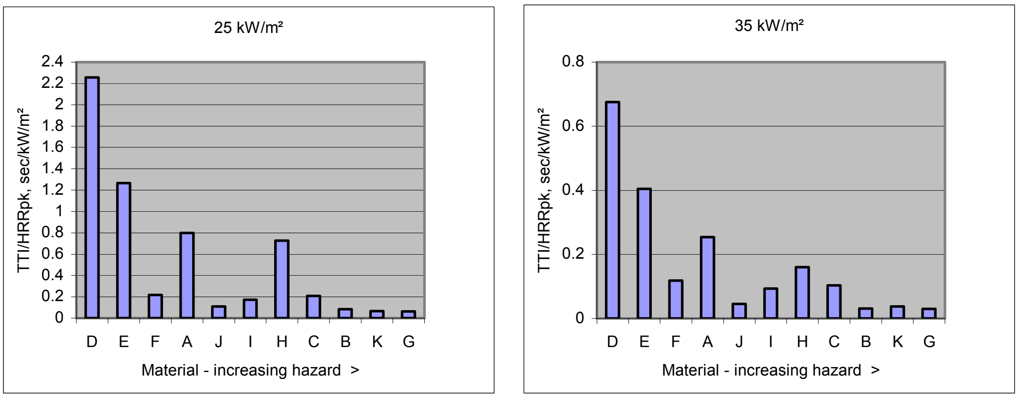

Figure 10: Time to ignition over peak HRR

A classification proposed by Hirschler (1992) is based on the TTI/HRR_{pk} at a recommended radiant flux of 25 kW/m^2 as follows:

$0.40 < TTI/HRR_{pk}$	Class 1 (best)
$0.20 < TTI/HRR_{pk} < 0.40$	Class 2
$0.10 < TTI/HRR_{pk} < 0.20$	Class 3
$< TTI/HRR_{pk} < 0.1$	Class 4 (worst)

and these are plotted in Figure 11.

For 25 kW/m^2 radiant flux exposure the wood-based materials D, E and A fit into Class 1 even if they are protected by a thin laminate on the surface. Class 2 captures F and C, the thin vinyl and cork tile samples. Falling into Class 3 were samples H, I and J – the plywood, studded rubber floor covering and a polypropylene carpet with the latex backing. Finally Class 4 are the products with the most hazardous performance – they were all carpets or overlay made of polypropylene (or polyester) with various backings B, K and G, where the backing also contributed to the burning behaviour.

For 35 kW/m^2 radiant flux exposure all of the materials record a lower TTI/HRR_{pk} and some of the materials (ACFIJ) would be classified in a worse class due to the earlier ignition and increased heat release. However the classification system is only intended to apply to a 25 kW/m^2 radiant flux and the results in Figure 11 demonstrate why the lower radiant flux would be preferred.

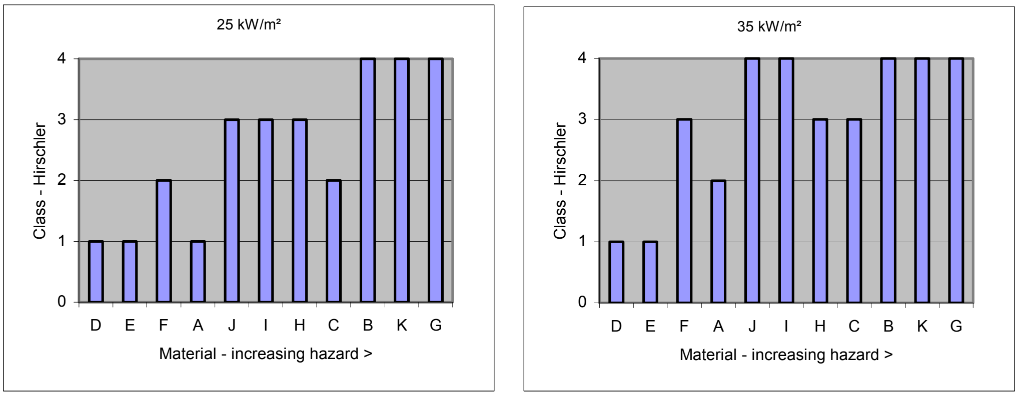

Figure 11: Class according to Hirschler

3.1.4.2 Tomann classification

A similar analysis using the Tomann correlation (section 2.3) for flamespread using the CC results:

$$Flamespread(mm) = x_f = 44.\dot{Q}''^{\,0.38}_{max}.t_{ig}^{-0.19}.t_b^{0.12}$$

is plotted in Figure 12 indicating a similar increasing trend of increasing hazard.

The flamespread parameter is used to classify the test products as follows:

$x_f \leq 200$ Class 1

$200 < x_f < 300$ Class 2

$300 < x_f < 400$ Class 3

$400 \leq x_f$ Class 4.

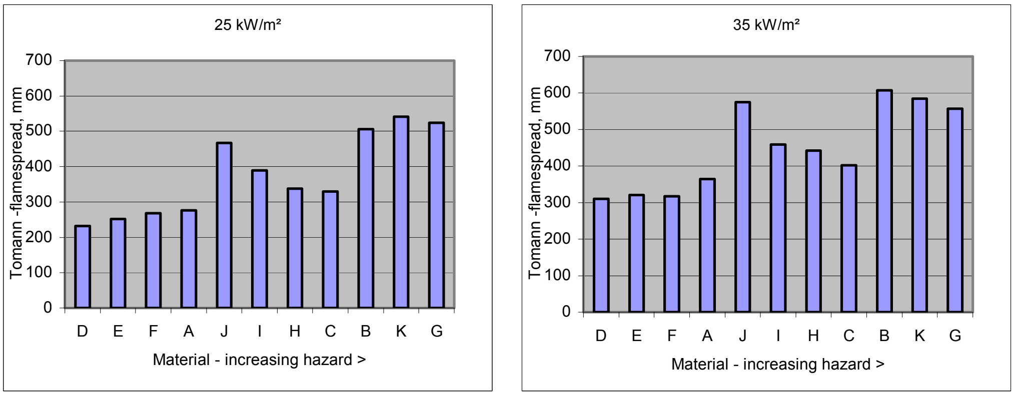

Figure 12: Flamespread – Tomann correlation

The classifications are shown in Figure 13 and range between Class 2 and 4. None of the materials fall into Class 1 and for a material to do so it would need to be essentially non-combustible.

For the 25 kW/m^2 radiant exposure the wood-based materials (D, E, A and H) are grouped in one class (Class 2) along with the thin vinyl (F). Class 3 materials are rubber flooring (I) and the cork tiles (C). The most hazardous class (Class 4) is synthetic carpets (B, G, J and K).

For the 35 kW/m^2 radiant exposure a similar upward movement of classes (Hischler) occurs for the wood-based materials and the rubber and cork tiles.

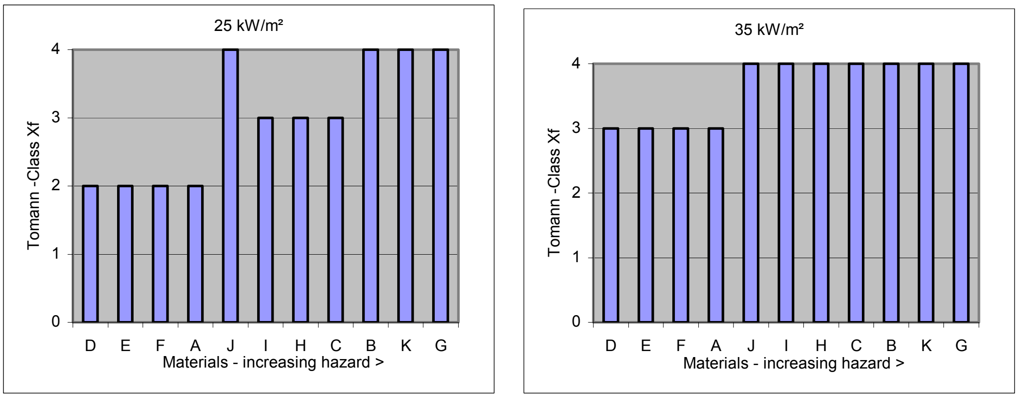

Figure 13: Classification by Tomann

3.1.4.3 Van Hees classification

The method proposed by Van Hees and Vandevelde (1997) in section 2.3 is used to evaluate the likelihood of flashover in wind-aided flamespread scenarios.

$$C_i = k_f.\dot{E}'' - 1$$

$$C_b = k_f.\dot{E}'' - \frac{t_{ig}}{t_{bo}} - 1$$

If C_i >1, then the material is likely to cause flashover,

or 0 > C_i >1, then the material is likely to support steady flamespread

or C_i < 0, then there is unlikely to be any flamespread.

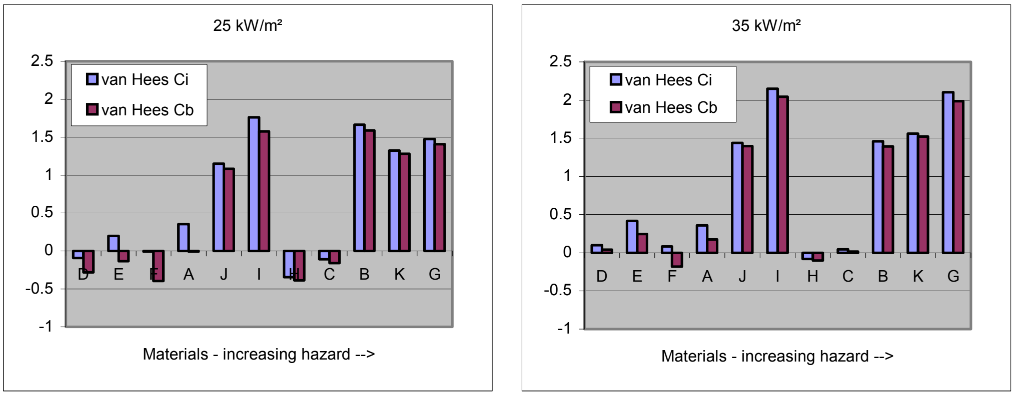

Figure 14: Flame acceleration and flashover at 25 kW/m^2 and 35 kW/m^2 exposure

The parameters C_i and C_b are plotted in Figure 14, where values above 1 indicate flashover and sustained burning for materials (rubber and synthetic carpets) B, G, I, J and K likely. The remaining materials (wood-based, vinyl and cork) A, C, D, E, F and H indicated minor less severe contributions and self-extinguishment.

The three classification methods proposed by Hirschler, Tomann and Van Hees are all capable of ranking flooring materials in order of hazard and are included in further analysis.

3.1.5 Smoke production

The smoke parameters measured in the CC and the FRP are compared in Figure 15. Some significant differences between the two test methods (FRP and CC) are noted, combined with only a loose correlation with the CRF order chosen as the basis for ranking the results in order of best to worst.

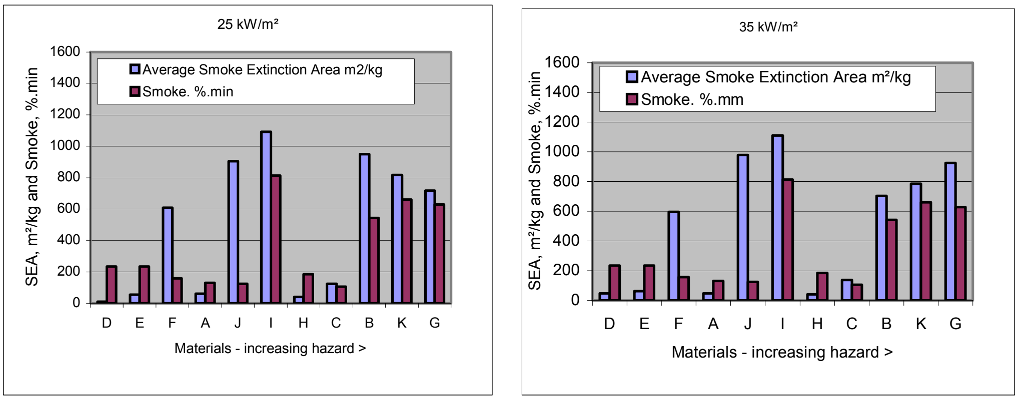

Figure 15: Comparison of SEA and FRP (smoke %.min)

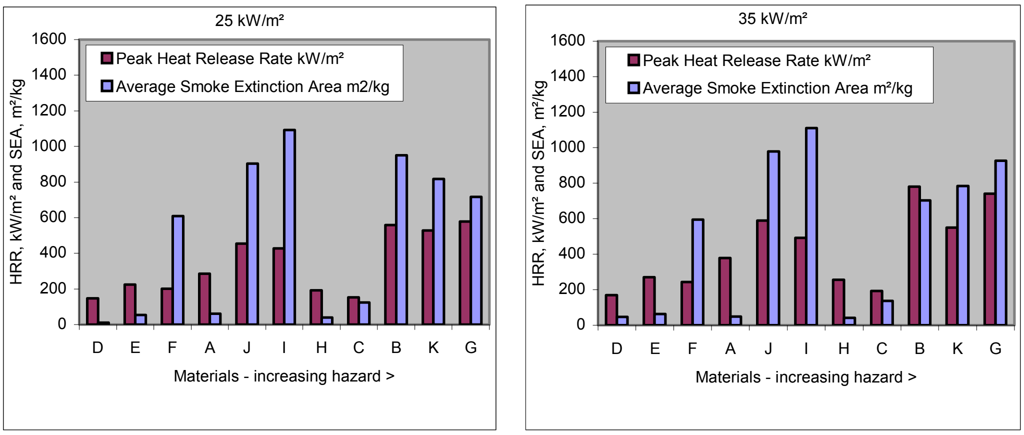

Figure 16: Comparison of peak HRR and SEA

The peak HRR and average smoke extinction area (SEA) are compared in Figure 16 and for the materials at the upper end of the peak HRR scale there is a significant increase in the SEA.

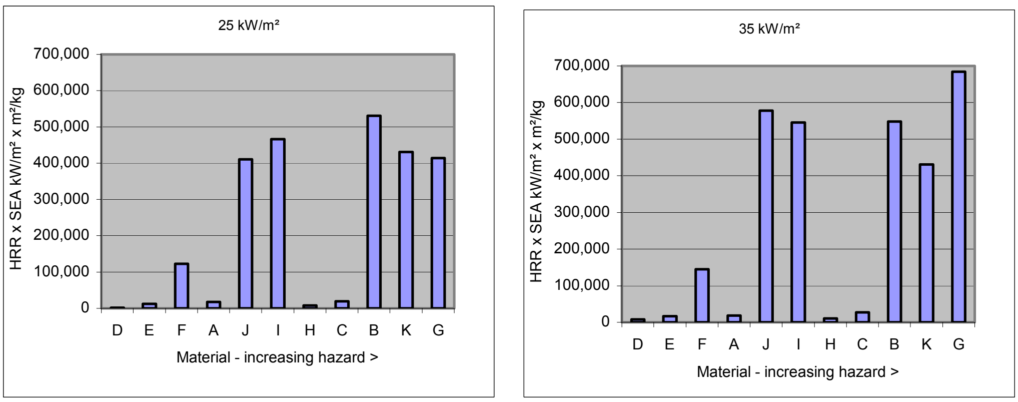

Figure 17: Product of HRR and SEA

The product HRR x SEA (from the CC) that is graphed in Figure 17 shows marked increases for products that having a high peak HRR also produce a lot of smoke (SEA) when burning. Blackmore and Delichatsios (2002) propose HRR x SEA as a measure of the toxicity hazard posed by floor coverings and the results show a clear difference between the two ends of the spectrum.

3.1.6 Summary of analysis of cone calorimeter trends

Figure 6 to Figure 17 compare various raw and derived parameters of the CC for exposures of 25 kW/m^2 and 35 kW/m^2. In general the increasing hazard ranking determined by the FRP is continued, but there are several exceptions that appear to be out of order. The most obvious exceptions are materials H and C (the plywood and cork tiles) and some other materials also show much smaller variations resulting in minor shifts in hazard order.

Of the CC parameters examined the total heat release (in Figure 9) appeared to be inconsistent with the general trend and was eliminated from further comparison with the FRP rankings. The two stepwise classification systems of Hirschler (Figure 11) and Tomann (Figure 13) were put to one side, as far as this analysis was concerned, and just the raw data was used to decide those classes to determine whether the assessment method was relevant or not.

Included for further consideration of hazard were the following derived data:

- HRR peak, kW/m^2 in Figure 6
- Average HRR from ignition, kW/m^2 in Figure 7
- Average heat of combustion, MJ/kg in Figure 8
- TTI/HRR peak, $sec/kW/m^2$ (Hirschler raw data) in Figure 10
- Tomann – flamespread, mm (Tomann raw data) in Figure 12
- Van Hees – flame acceleration and flashover in Figure 14
- SEA, m^2/kg in Figure 15
- Product of HRR x SEA in Figure 17.

The trends are analysed separately for radiant fluxes of 25 and 35 kW/m^2 in the graphs in Figure 18 and Figure 19. The parameters have been normalised by the peak values so that the maximum value is 1 and the term TTI/HRR has been inverted to align in the direction of the others parameters. In addition, an average value has been included to combine all the parameters, and then the order of increasing hazard has been changed on the basis of the average.

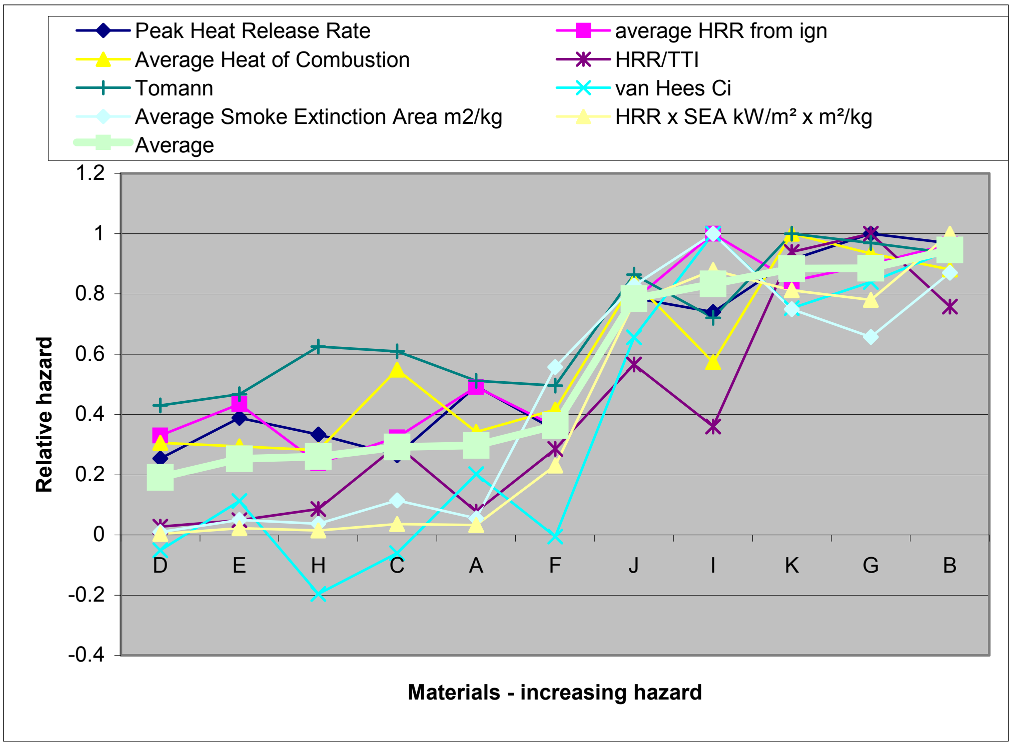

Figure 18: Normalised relative hazard at 25 kW/m^2 exposure

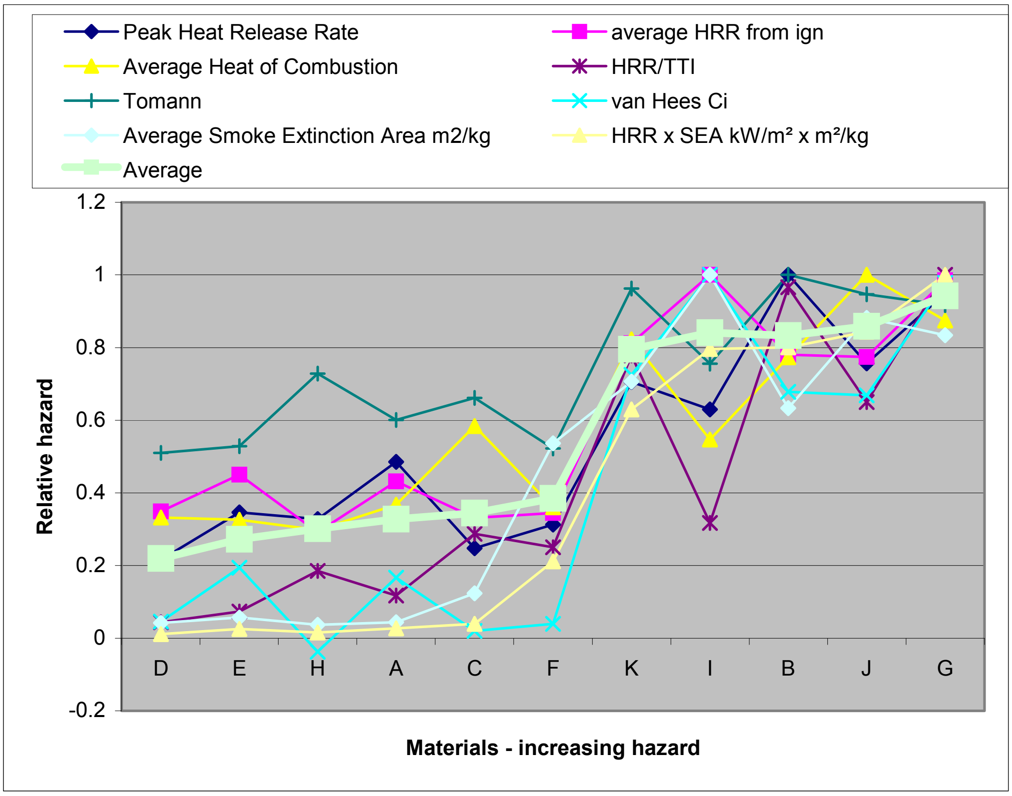

Figure 19: Normalised relative hazard at 35 kW/m² exposure

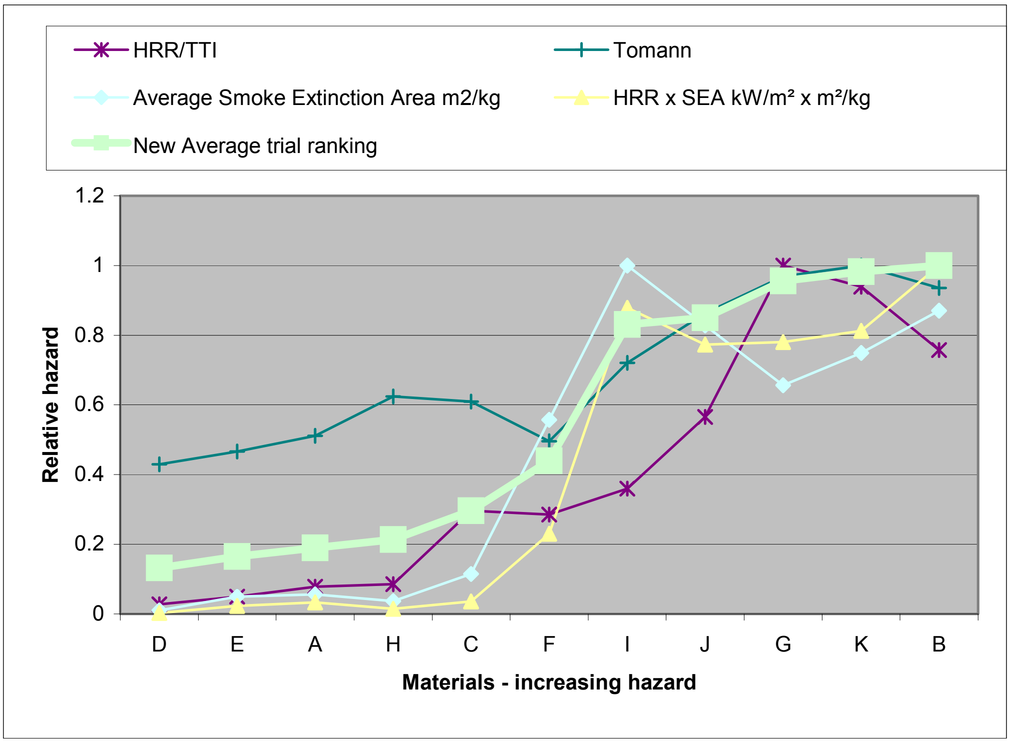

Figure 20: Relative hazards at 25 kW/m²

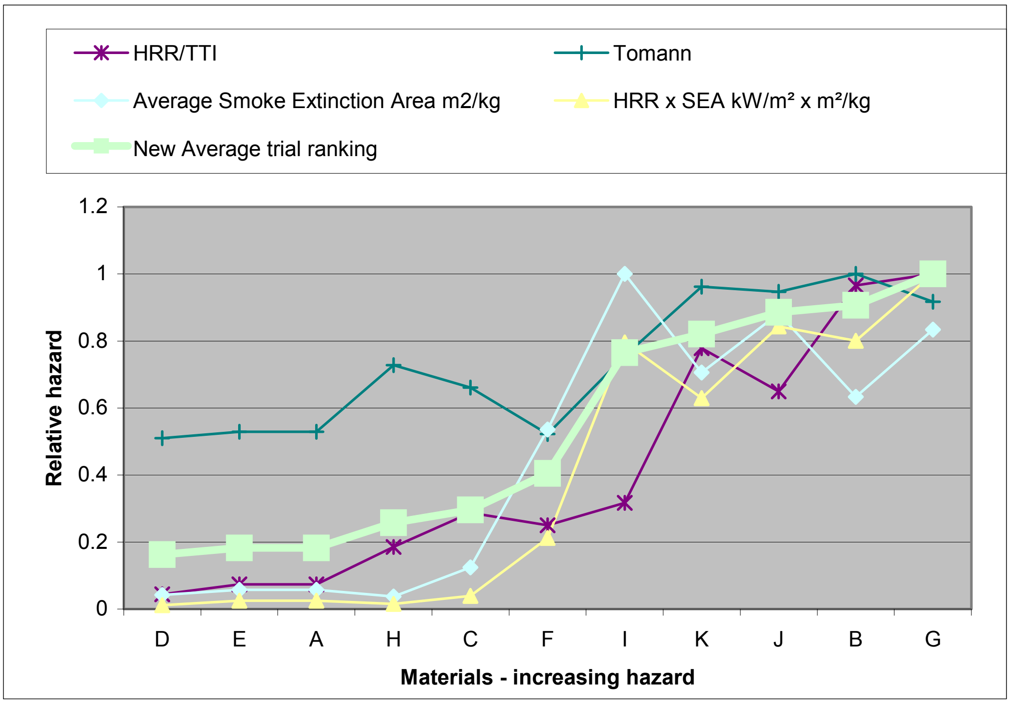

Figure 21: Relative hazards at 35 kW/m^2

The following parameters:

- HRR peak, kW/m^2
- Average HRR from ignition, kW/m^2
- Average heat of combustion, MJ/kg

were removed from the data in Figure 18 and Figure 19 and re-plotted in Figure 20 and Figure 21. The three parameters were removed to simplify the analysis. Based on the new average relative hazards of the materials the order was modified slightly and for the lower hazard end of the range (materials D to I) the order was the same for both 25 and 35 kW/m^2 exposure. For materials J, G, K and B the hazard order changes slightly between the 25 and 35 kW/m^2 exposure. Given that there does not appear to be much difference between the results for 25 and 35 kW/m^2 radiant exposures, with the possible exception of the high hazard end of the spectrum, a single radiant exposure of 25 kW/m^2 consistent with the recommendations of Hirschler (1992) has been selected for the ongoing analysis and proposal of a rating system for flooring.

If the revised order of hazard is re-plotted in an updated version of the CRF graph (Figure 2) into Figure 22, then compared with the order established by the FRP it is entirely different and not altogether unexpected since the two test methods measure different parameters confirming the findings of other research where a lack of correlation was evident.

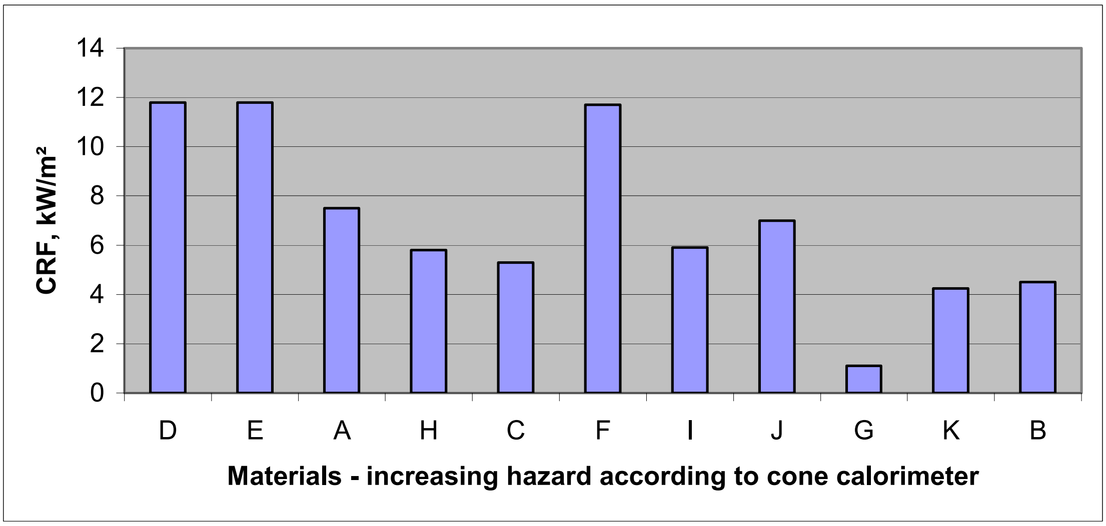

Figure 22: CRF values from the FRP re-ordered on the basis of hazard measured by the cone calorimeter

Referring to the BCA building classes and the various levels of CRF in Table 1, considering the lower limits of CRFs of 1.2/2.2/4.5 kW/m^2 it is apparent that some products (materials I and J in Figure 22) recorded CRFs greater than 4.5 kW/m^2 (the least hazardous level) but were at the upper end of the (hazardous) scale in the CC assessment. The materials of concern were the rubber-based flooring (I) and one of the polypropylene carpets (J).

3.1.7 Correlation of test results

The lack of a correlation between the CRF measured in the FRP and CC derived parameters analysed above concurs with the findings of Hirschler (1992) and Blackmore and Delichatsios (2002). It is recognised that the two test methods are intended to measure different fire performance parameters, and CRF values are not really considered as measures of fire hazard but as cut-off points to indicate whether the carpet or flooring material will spread horizontally along a corridor on its own. The lower CC radiant fluxes recorded in Table 13 to Table 20 (18 kW/m^2 and below) show that for some of the materials tested ignition does not occur after a considerable exposure time, an indication that the maximum CRF of 11.1 kW/m^2 in the FRP test may be too low and it is predominantly the pilot flame that initiates burning.

The explanation above supports the FCRC (1999) finding in section 2.4.2, considering that the CC and FRP do not agree but that they each give a measure of the hazard of the flooring material.

In Table 6 the HRR with respect to time of the CC for single samples at the various radiant fluxes has been analysed using the method of Kokkala, Thomas and Karlsson (1993). This was used to determine the BCA Group Number that was similarly applied in the assessment of wall and ceiling materials in a previous BRANZ project (Collier, Whiting and Wade 2006). The method primarily requires the radiant flux exposure to be 50 kW/m^2 but the data at other exposures was used as well and, as is shown, the significant reductions in the radiant flux do not necessarily result in an immediate improvement in the BCA Group Number. Moreover, it is apparent that the Group Number prediction is relatively insensitive to the radiant flux and in the cases of materials I, J and K it is unlikely if they were tested at 50 kW/m^2 that a higher Group Number would have been assessed. It is very apparent that the Group Numbers that would be applied to wall/ceiling applications would be too stringent for flooring.

Table 6: BCA Group Number for wall/ceilings at various radiant flux exposures

Material	50 kW/m^2	35 kW/m^2	25 kW/m^2	18 kW/m^2	14 kW/m^2	12 kW/m^2	8 kW/m^2
A	3	3	3	3	3	NI	-
B	4	3	3	3	-	3	3
C	3	3	3	3	-	1	1
D	3	3	3	3	NI	NI	-
E	3	3	3	3	3	NI	-
F	2	2	1	1	-	NI	NI
G	4	4	3	3	-	3	3
H	3	3	3	3	-	3	-
I	-	4	4	-	-	-	-
J	-	3	3	-	-	-	-
K	-	4	3	-	-	-	-

(-) Not tested at this radiant flux

3.2 Proposing a classification system (protocol)

The Euroclass classification for flooring in Table 2 relates to the same classes for wall and ceiling linings A1, A2 through to F. The Australian system BCA uses a coarser set of divisions of Groups 1 to 4 for walls and ceiling linings based on the ISO 9705 test and the CC (Collier 2006). In considering the Euroclass classes A1$_{FL}$ and A2$_{FL}$ for floorings materials to qualify for either of these two classes they are essentially required to be non-combustible with limits on PCS which approximately equate to the total heat release (in MJ/m^2) or average heat of combustion (in MJ/kg) as measured by the CC. None of the materials tested in this project recorded (see Table 13 to Table 23) levels below 3 MJ/kg or 4 MJ/m^2 required for Euroclass A2. Non-combustible products were not selected when selecting materials for testing as it was considered they would not provide any useful data in determining the effectiveness of the test methods.

The derived values of the 25 kW/m^2 radiant flux CC results are presented in Table 7.

Table 7: Derived parameters from 25 kW/m^2 radiant flux cone calorimeter tests

	D	E	A	H	C	F	I	J	G	K	B
Peak Heat Release Rate, kW/m²	146.68	224.16	285.14	192.37	152.31	201.29	427.27	454.00	577.59	527.50	558.96
HRR from ign, kW/m²	91.00	119.70	135.39	65.43	89.37	99.09	275.76	215.15	247.48	232.23	266.18
Heat of Combustion, kW/m²	12.28	11.80	13.74	11.28	22.01	16.71	23.03	33.79	37.48	40.16	35.35
Total Heat Release, kW/m²	115.92	68.48	78.55	118.12	57.52	10.83	82.98	25.02	41.81	50.94	42.46
TTI/HRR, sec/kW/m²	2.257	1.267	0.800	0.728	0.210	0.219	0.173	0.110	0.062	0.066	0.082
Hirschler Class	1	1	1	1	2	2	3	3	4	4	4
Tomann flamespread, mm	232	252	276	338	330	268	389	467	524	541	506
Tomann Class	2	2	2	3	3	2	3	4	4	4	4
Van Hees Ci	-0.1	0.2	0.4	-0.3	-0.1	0.0	1.8	1.2	1.5	1.3	1.7
SEA, m²/kg	10.9	54.0	60.7	40.2	124.8	607.9	1091.5	903.7	716.8	817.3	949.7
HRR x SEA, kW/m² x m²/kg	1,597	12,099	17,315	7,726	19,005	122,354	466,348	410,279	414,042	431,133	530,821

Table 8 is a proposal to allocate appropriate hazard levels for flooring at loosely comparative levels of performance as recommended for the wall/ceiling linings in

BRANZ *Study Report 160* (Collier, Wade and Whiting 2006). Non-combustible products such as stone/masonry would by definition alone be included in Level 1 and some other materials of low HRR and SEA may also qualify; it is just a matter of determining a suitable cut-off level.

Table 8: Possible hazard level schedule for floor coverings

Hazard Level	Measure CRF, kW/m^2	Hirschler Class	Tomann Class	Van Hees Ci	SEA, m^2/kg	HRR x SEA
Level 1	>8	1	1&2	Ci<0	SEA<100	HRRxSEA<100k
Materials	DEF	ADEH	DEF	CH	DEAH	ACDEH
Level 2	>4.5	2 & 3	3	0<Ci<1	100<SEA <400	100k<HRRxSEA<200k
Materials	ACHJI	CFIJ	ACH	ADEF	C	F
Level 3	>3	4	4	Ci>1	400<SEA	200k<HRRxSEA
Materials	BK	BKG	BGIJK	BGIJK	BFGIJK	BGIJK
Level 4	<3					
Materials	G					

3.2.1 Comments on hazard levels in Table 8

Considering the CRF, the levels of 8/4.5/3 kW/m^2 conveniently match the levels required for the Euroclasses B, C and D in Table 2 and for E and F there is no CRF requirement.

The Hirschler proposed class distributes the lower risk materials into Class 1 or Level 1. These were all wood-based products and although they did burn in the CC the HRR was relatively low and times to ignition were longer. None of the materials qualifies for Class 2/Level 2 but if the Class 3 is included in Level 2 then the vinyl and cork tiles are elevated. Although they burned relatively easily, the vinyl had only a small amount of combustible material to contribute because it was thinner than the other materials at 1.5 mm. The cork on the other hand swelled under the radiation and produced a thick layer of char that protected the cork layer underneath leading to slow combustion. Also in Class 3 were the rubber-based flooring and one polypropylene carpet. In Class 4/Level 3 were the remaining synthetic materials with short ignition times and high peak HRR.

Considering the Tomann Class based on a flamespread parameter a similar distribution to the Hirschler Class is recorded with the distribution compressed into three bands Classes (1 and 2 combined) 3 and 4 to fill Levels 1 to 3.

The classifications determined by the Van Hees method separate those materials likely to cause or contribute to flashover (Ci>1) and they have been allocated to Level 3. The other two bands, unlikely to be any flamespread (Ci<0) and likely to support steady flame (0<Ci<1), are less clearly defined and disagree with the Hirschler and Tomann Class distributions with some materials moving up or down to different levels.

Including the smoke parameter (SEA) into the consideration causes only minor changes. Considering SEA in isolation and combined as HRR x SEA separates the materials into two levels, with the possible exception of C and F (cork and vinyl) in the middle, at opposite ends of the scale, low hazard as opposed to high hazard. The same basic order is maintained as for the previous assessments in Table 8 and the main difference is where the breakpoints between levels are placed.

All of the above proposals for classifying the performance of flooring materials are based on CC test data at a 25 kW/m^2 exposure ranking the products in much the same order of hazard. The remaining question is where the boundaries of the various levels of performances should be placed.

3.2.2 Preliminary recommendation

The objective is to restrict flooring materials that will cause spread of fire or have a likelihood of spread of fire greater than the walls and ceiling that have already been subjected to controls.

In the Acceptable Solutions C/AS1 Table 6.2 (DBH 2005) the requirements for floor coverings for all *exitways* and purpose groups SC and SD require the covering to be non-combustible or have low radius of ignition in accordance with paragraph 6.20.8 which refers to BS 4790 (1987) (HMN test) and the method of assessment BS 5287 (1976) where the lowest radius specified is 35 mm. The results of the HMN testing in Table 5 and Figure 4 show that for all materials tested (with the exception of G) the radius of affected area was less than 35 mm, but in the FRP and CC testing all materials were combustible to a greater or lesser extent. On this basis the current test method would permit the use of flooring materials that are combustible and clearly unsuitable.

For flooring materials on horizontal flat surfaces the flamespread criteria is generally opposed flow and better represented by the FRP test. Although there is a case for considering CC data as some degree of consistency would be obtained by combining with the FRP data as indicated in Table 8.

In the case of floor coverings in stairways, for the vertical surface the flamespread mechanism would be predominantly wind-aided as it is for walls/ceilings. So, there is a case for proposing the same acceptance criteria for flooring materials on stairways. The BCA Group Number prediction based on the CC for the materials listed in Table 6 could be applied directly according to the floor covering in stairways.

In summary:

- Level 1 is reserved for essentially non-combustible and low-risk materials
- Level 2 is for those materials that will burn, but not with a HRR that is expected to result in flashover at least on the basis of the contribution of the floor covering alone
- Level 3 materials may contribute to flashover only after a reasonable period of exposure
- Level 4 hazardous materials are likely to be involved in flashover scenarios.

The above principle for ranking flooring materials is satisfactory. although fine-tuning may be required by moving the boundaries between levels.

3.2.3 Alternative recommendations

The above recommendation appears to be very conservative by using the Tomann derived classes, especially when compared with current international practices.

Reliance on CC test data is a significant departure from the test requirements for flooring in current use internationally, although numerous proposals have been made. For this reason, an alternative proposal that combines the currently accepted (BCA and Euroclass) FRP test data with some compatible data from CC testing that takes into account the hazard once the flooring material is burning may be warranted. Table 9 shows a combination of a Euroclass CRF level and the Tomann Class where the Tomann Classes 1 and 2 are combined in Level 1 with the net result that a reasonable agreement across the levels is maintained. However, due to the conservative nature of the Tomann Class some materials drop to a lower combined level.

Table 9: Combining CRF and Tomann Class

	CRF, kW/m²		Tomann Class	Combined
Level 1 Materials	>8 DEF	and	1&2 DEF	DEF
Level 2 Materials	>4.5 ACHIJ	and	3 ACH	ACH
Level 3 Materials	>3 BK	and	4 BGIJK	BIJK
Level 4 Materials	<3 G	and		G

The process is repeated in Table 10 – substituting in the Hirschler Class and the Combined Class shows some of the materials also move down a level.

Table 10: Combining CRF and Hirschler Class

	CRF, kW/m²		Hirschler Class	Combined
Level 1 Materials	>8 DEF	and	1 ADEH	DE
Level 2 Materials	>4.5 ACHIJ	and	2 CFI	ACFHI
Level 3 Materials	>3 BK	and	3 BGJK	BJK
Level 4 Materials	<3 G	and	4	G

A smoke component SEA is added to the analysis with a single break point at 200 m^2/kg between Levels 2 and 3; this is to differentiate between products contributing minor smoke levels and significant smoke levels as shown in Figure 15. Table 11 shows the combined assessment, and the significant observation for the materials tested are that none of them shifted to another level by adding the smoke parameter.

Table 11: Combining CRF, Hirschler Class and SEA

	CRF, kW/m²		Hirschler Class		SEA, m²/kg	Combined
Level 1 Materials	>8 DEF	and	1 ADEH	and	SEA<200 ACDEH	DE
Level 2 Materials	>4.5 ACHIJ	and	2&3 CFI	and		ACH
Level 3 Materials	>3 BK	and	4 BGJK	and	200<SEA BFGIJK	BFIJK
Level 4 Materials	<3 G	and		and		G

For materials that produce a moderate amount of smoke this parameter would not have been identified on the basis of the FRP smoke measurement in %.min (Figure 15) as materials F and J only recorded low levels of smoke in the FRP. However, they were shown to be potentially hazardous in the CC (based on SEA) and as a result are more appropriately allocated to Level 3 or worse.

In considering wind-aided flamespread (such as may occur on the vertical faces of stairs due to convection currents), then the Van Hees classification is suitable for predicting this. Table 12 combines the FRP for opposed flow flamespread with the Van Hees classification for wind-aided scenarios as may occur on stairs.

Table 12: Combining CRF and Van Hees

	CRF, kW/m²		**Van Hees Ci**	**Combined**
Level 1 Materials	>8 DEF	and	Ci<0 CDH	D
Level 2 Materials	>4.5 ACHIJ	and	0<Ci<1 ADEF	ACEFH
Level 3 Materials	>3 BK	and	Ci>1 BGIJK	BIJK
Level 4 Materials	<3 G	and		G

3.3 Testing on substrates

All of the flooring materials tested were not mounted on any substrate. In the case of the CC the samples were placed in the holder on a ceramic fibre wool pad of low thermal conductivity and specific heat. In the FRP the samples were loose laid on fibre-cement board.

In practice the substrate may influence the result. For instance vinyl was tested on its own and it melted and burned away with a relatively low HRR. Vastly different results could have been obtained if it had been attached to timber floor on the one extreme or concrete on the other. Timber would be expected to deliver a worse result due to it also burning and concrete may be a slightly better result due to the dense material conducting heat away.

The purpose of the testing in this project was to show the effectiveness of the test methods in ranking products, rather than the performance of the individual products, which in this instance was of secondary importance.

In practice when flooring materials are tested for classification, it is expected that the test standard standards will specify the mounting requirements and the test results will apply to that particular installation.

4. CONCLUSIONS

The three test methods used to evaluate the products exhibited varying degrees of success in sorting the test materials into an order of increasing hazard:

- The HMN test BS 4790 showed only minimal variation in the radius of affected area with all but one material falling within the minimum range that indicates that flame will not spread under normal circumstances in the absence of thermal radiation. One other product exceeded the maximum allowed where flamespread may continue, and no materials recorded radii in the middle range. This supported a conclusion that the HMN test is not suitable for identifying materials that are hazardous.
- The FRP ISO 9239-1 test measured the CRF and smoke produced, and distributed the performance of the materials tested over the entire range of radiation levels from 1.1 to 11.8 kW/m2.
- The CC ISO 5660-1 test results on the materials were analysed by several methods using the parameters of heat release, ignition time, burn time and smoke production at two different radiant flux levels. The different derived parameters indicated a reasonable agreement to a trend of increasing hazard as determined by the FRP test, but with some obvious discrepancies that would only alter the order by one or two places. In general, the measurements indicated a clear demarcation between the materials at the opposite ends of the hazard spectrum. At the lower hazard end of the scale are the wood-based products and cork, which behaves similarly to wood, while at the high hazard end are the synthetic products plus rubber. An exception was the vinyl: while being a synthetic material, it was rated at the lower end due to it recording a heat of combustion more comparable with the timber-based materials and a very low total heat release due to it being nominally 1.5 mm thick. The CC was effective in identifying products that are likely to ignite when exposed to radiant fluxes and once burning will present a significant hazard contributing to fire spread and production of smoke and toxic gases.

Comparing the three test methods the FRP indicates how easily a floor covering may ignite but not necessarily, the ongoing hazard once burning except perhaps on the basis of the smoke generated. The CC is capable of evaluating the entire hazard from ignition to heat release and smoke hazard although the ease of ignition may not be wholly representative due to the higher radiant fluxes used in the test. The HMN was shown to be of limited value and would permit the use of materials that are shown to be hazardous by the other two tests.

The findings of this study support the adoption of the CC test method (ISO5660-1 and AS/NZS 3837) at a radiant flux of 25 kW/m^2 for ranking flooring materials in terms of the hazard presented. How exactly the parameters are analysed and separated into classes may be subject to some minor adjustment. The FRPT (ISO 9239-1) could be adopted in conjunction with the CC to screen products that ignite easily and provide an overall hazard assessment. There is no justification for retaining the HMN test (BS 4790) because it does not apply where radiation from a developing hot layer enhances fire spread and resultant heat release. The HMN test shows that potentially hazardous products (under conditions of imposed heat flux) would meet the requirements of low radius of ignition and thus be permitted by NZBC C/AS1 for use in *exitways* in all purpose groups and all spaces in purpose groups SC and SD.

5. RECOMMENDATIONS

It is recommended that the reaction-to-fire characteristics of flooring materials presently assessed by the HMN test (BS 4790) as required by NZBC Compliance Document C/AS1 be replaced with a selection of the options below.

Option A

1. The CRF of flooring materials be assessed in the FRP test ISO9239-1 and classified either along with the BCA or Euroclass systems as described in Table 1 and Table 2 for the various building classes. The most significant difference is the break points in the CRF levels where the BCA uses 4.5 / 3 / 1.2 kW/m^2 and the Euroclass system uses 8 / 4.5 / 3 kW/m^2. A decision would be needed regarding the upper level CRF and that would be the requirement for floor coverings in protected or safe paths, SC, SD purpose groups and assembly spaces with large numbers of people. For all other areas, a lower CRF (for example 1.2 kW/m^2) would be suitable to exclude the worst performing products.
2. In the case of stairs where the surfaces are both horizontal and vertical, the vertical surfaces present a different scenario. The vertical surface could be treated as a wall and be required to meet the same requirement as wall coverings as determined in BRANZ *Study Report 160* (Collier, Whiting and Wade 2006) where a CC result can be used to determine a BCA Group Number and applied accordingly.

Option B

1. Adopt the Van Hees correlation using CC data at 25 kw/m^2 radiant flux. This will address the wind-aided scenario and it has been correlated to room corridor tests. Using the C_i < 1 (or 0) flamespread criteria for stairs in protected or safe paths, SC, SD purpose groups and assembly spaces with large numbers of people. No controls are required in other areas.
2. Having no controls in other areas may lead to some dangerous products being permitted such as material G, so a minimum level of performance may still be necessary for all indoor spaces.

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7. APPENDICIES

7.1 Tested flooring material

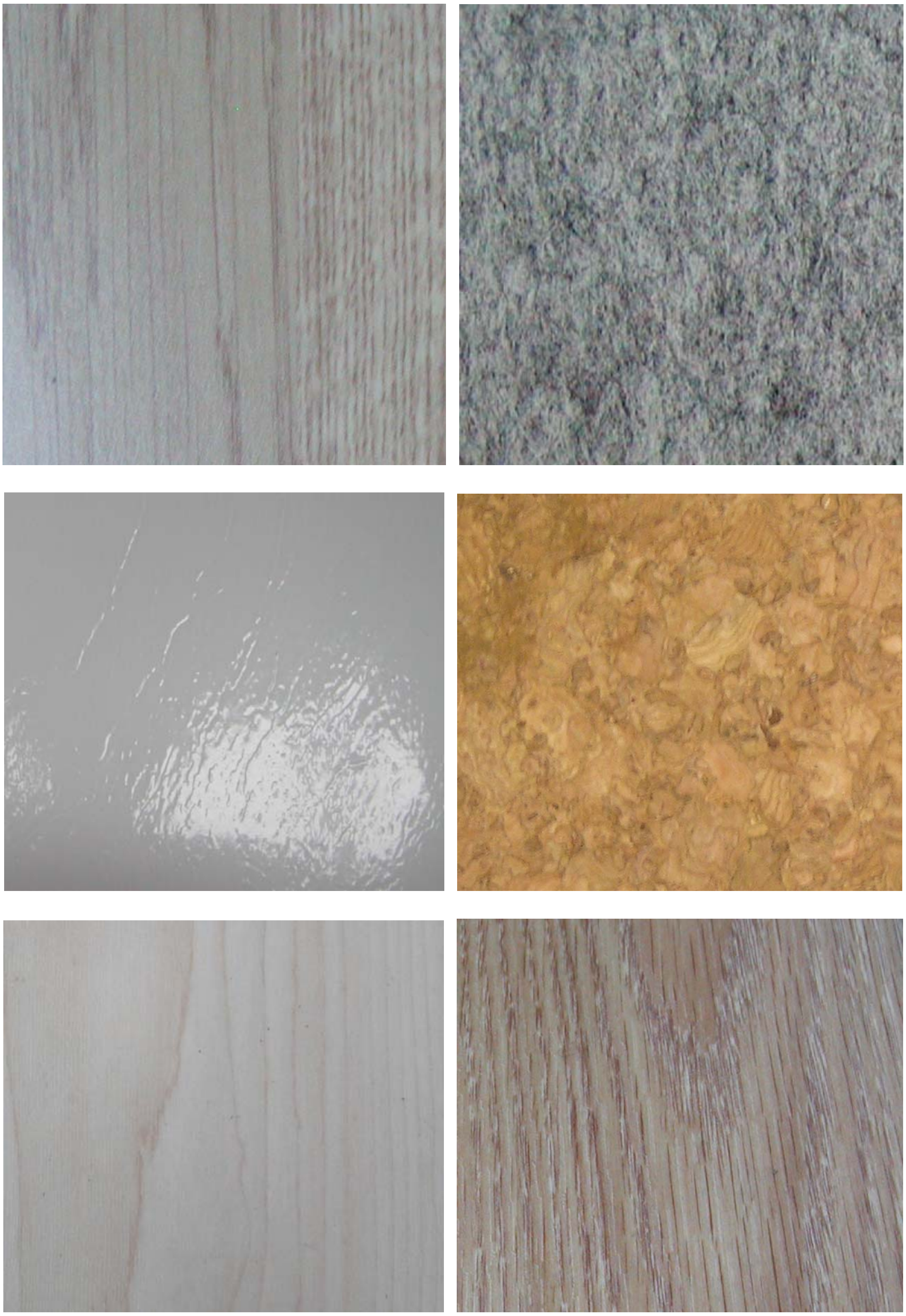

Figure 23: Flooring samples A to F clockwise from top left

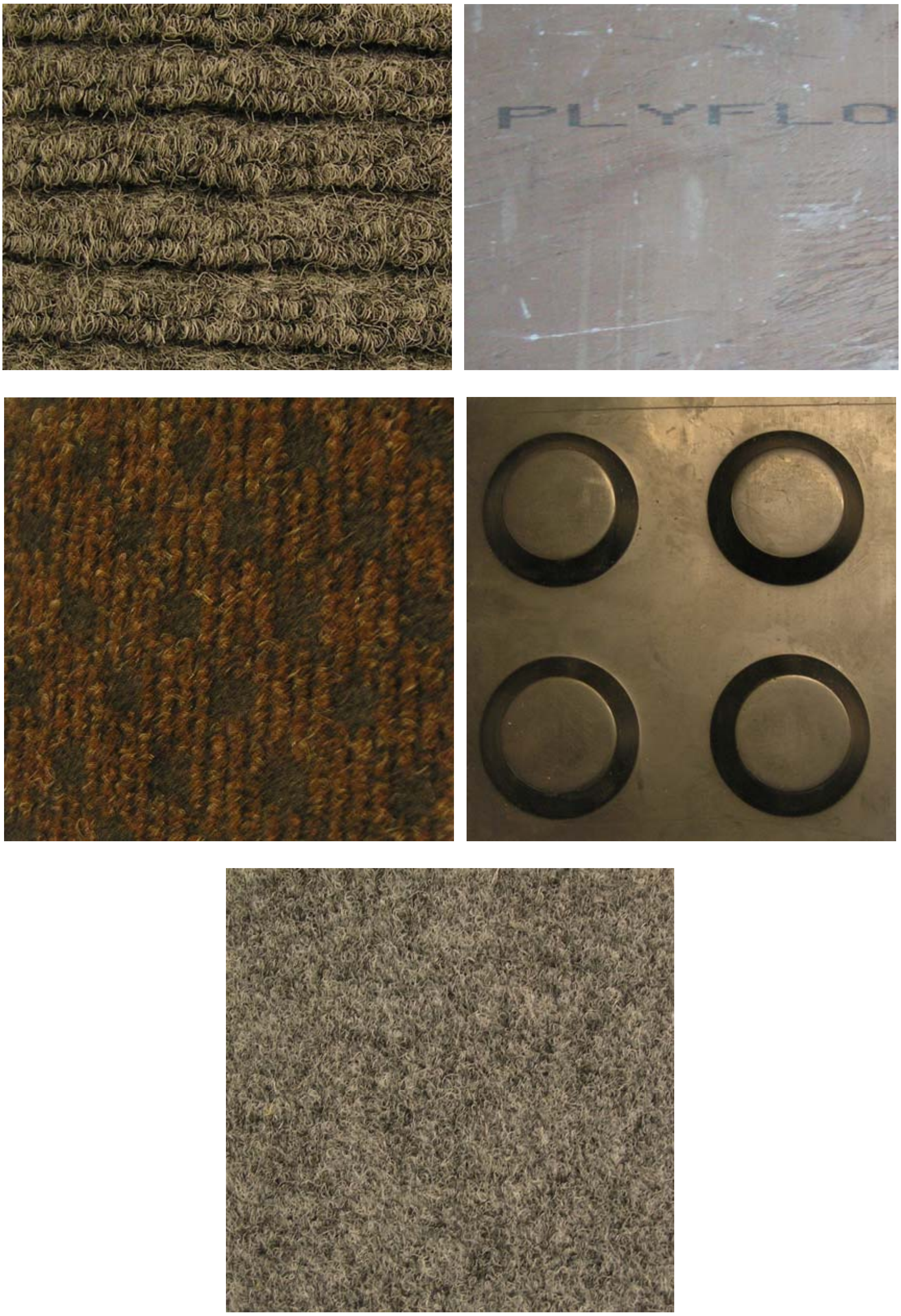

Figure 24: Flooring Samples G to K clockwise from top left

7.2 Cone calorimeter results of single tests at each radiant flux

Table 13: Material A flooring laminate on 7 mm MDF

SPECIMEN DETAILS						
Specimen Thickness	mm	6.8	6.8	6.8	6.8	6.8
Specimen Initial Mass	g	58.5	59.2	59.8	59.6	60.0
Exposed Sample Area	m²	0.0088	0.0088	0.0088	0.0088	0.0088
Overall Apparent Density	kg/m³	860.3	870.6	879.4	879.1	882.4
Nominal Heat Flux	kW/m²	50.0	35.0	25.0	18.0	14.4
Nominal Duct Flow Rate	m³/sec	0.024	0.024	0.024	0.024	0.024
Orientation		H	H	H	H	H
Retainer frame		Y	Y	Y	Y	Y
Wire grid		N	N	N	N	N
TEST RESULTS						
Time to Sustained Flaming	sec	53.0	96.0	228.0	659.0	989.0
Test Duration	sec	1853.0	1896.0	2028.0	2459.0	2789.0
Specimen Final Mass	g	4.0	3.4	9.2	18.1	18.6
Percentage of Total Mass Pyrolyzed		93.2%	94.2%	84.5%	69.6%	69.0%
Sample Mass Loss (from ignition)	kg/m²	5.96	5.95	5.13	3.32	3.06
Average Mass Loss Rate (from ignition)	g/m².s	3.3	3.3	2.9	1.8	1.7
Over the entire test duration						
Peak Heat Release Rate	kW/m²	446.8	378.4	285.1	253.8	258.2
average heat release rate - ignition to end of test						
from ignition plus 60 seconds	kW/m²	175.7	181.4	112.0	149.7	176.1
from ignition plus 180 seconds	kW/m²	145.5	118.6	118.0	181.4	185.7
from ignition plus 300 seconds	kW/m²	182.4	147.4	150.6	135.1	129.8
Total Heat Release	MJ/m²	100.3	97.1	78.5	48.1	44.9
Average Smoke Extinction Area	m²/kg	66	48	61	106	60
Average Heat of Combustion	MJ/kg	16.3	15.4	13.7	10.3	9.6
average HRR from ign	kW/m² x m²/kg	55.7	53.8	43.4	26.3	24.8

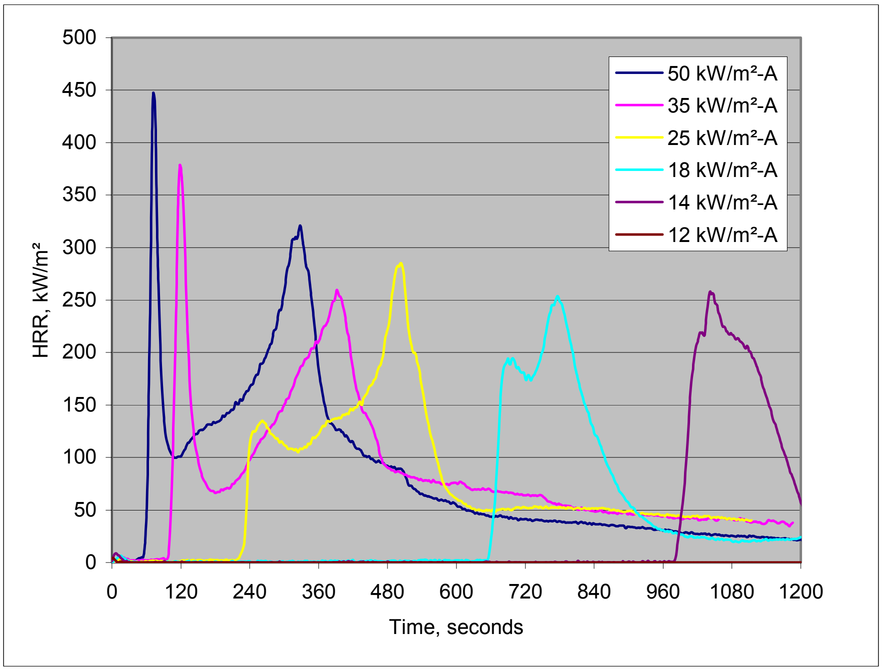

Figure 25: HRR for material A

Table 14: Material B carpet tiles

SPECIMEN DETAILS and TEST REGIME							
Specimen Thickness	mm	4.2	3.5	4.2	4.3	4.3	4.3
Specimen Initial Mass	g	15.2	14.8	14.5	14.8	14.8	14.9
Exposed Sample Area	m²	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088
Overall Apparent Density	kg/m³	361.9	422.9	345.2	344.2	344.2	346.5
Nominal Heat Flux	kW/m²	50.0	35.0	25.0	18.0	12.0	8.0
Nominal Duct Flow Rate	m³/sec	0.024	0.024	0.024	0.024	0.024	0.024
Orientation		H	H	H	H	H	H
Retainer frame		Y	Y	Y	Y	Y	Y
Wire grid		N	N	N	N	N	N
TEST RESULTS							
Time to Sustained Flaming	sec	11.0	24.0	46.0	79.0	101.0	113.0
Test Duration	sec	1811.0	1824.0	1846.0	1879.0	1901.0	746.0
Specimen Final Mass	g	6.5	6.5	3.9	7.8	6.5	9.0
Percentage of Total Mass Pyrolyzed		57.5%	55.9%	73.2%	47.2%	56.2%	39.4%
Sample Mass Loss (from ignition)	kg/m²	1.22	0.86	1.17	0.80	0.96	1.47
Average Mass Loss Rate (from ignition)	g/m².s	0.7	0.5	0.7	0.4	0.5	2.3
Over the entire test duration							
Peak Heat Release Rate	kW/m²	950.4	779.4	559.0	533.6	188.5	248.6
average heat release rate - ignition to end of test							
from ignition plus 60 seconds	kW/m²	461.1	365.6	311.2	245.8	101.9	98.5
from ignition plus 180 seconds	kW/m²	211.4	157.3	229.0	156.3	136.4	96.1
from ignition plus 300 seconds	kW/m²	128.9	99.4	140.7	97.5	103.4	100.4
Total Heat Release	MJ/m²	39.1	30.3	42.5	30.7	33.0	35.6
Average Smoke Extinction Area	m²/kg	1044	703	950	735	920	1109
Average Heat of Combustion	MJ/kg	39.6	32.4	35.3	38.9	35.1	53.7
average HRR from ign	kW/m² x m²/kg	21.7	16.8	23.5	16.9	18.2	56.1

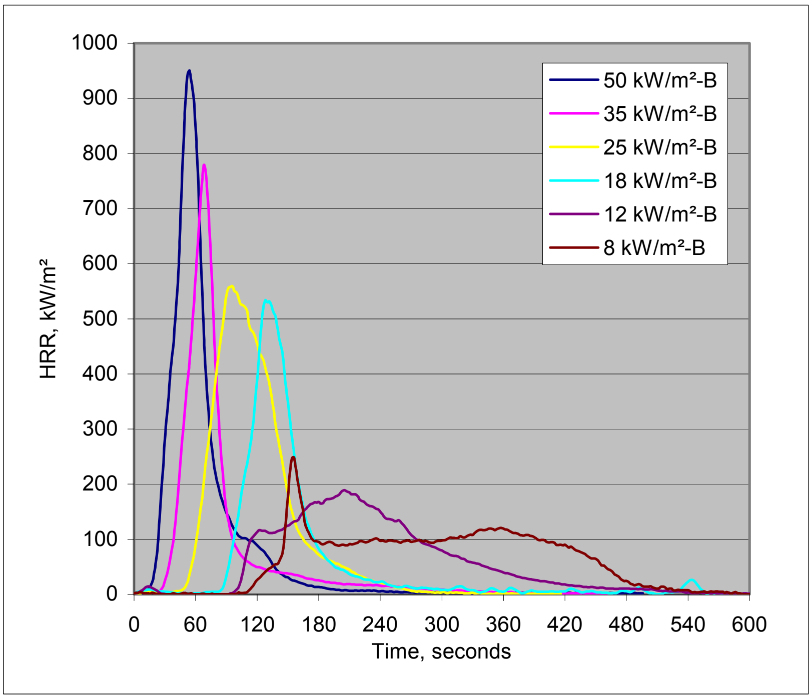

Figure 26: HRR for material B

Table 15: Material C cork tiles

SPECIMEN DETAILS and TEST REGIME							
Specimen Thickness	mm	6.2	6.2	6.2	6.1	6.2	6.2
Specimen Initial Mass	g	28.8	29.4	28.1	28.1	27.6	28.5
Exposed Sample Area	m²	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088
Overall Apparent Density	kg/m³	464.5	474.2	453.2	460.7	445.2	459.7
Nominal Heat Flux	kW/m²	50.0	35.0	25.0	18.0	12.0	8.0
Nominal Duct Flow Rate	m³/sec	0.024	0.024	0.024	0.024	0.024	0.024
Orientation		H	H	H	H	H	H
Retainer frame		Y	Y	Y	Y	Y	Y
Wire grid		N	N	N	N	N	N
TEST RESULTS							
Time to Sustained Flaming	sec	8.0	20.0	32.0	79.0	261.0	822.0
Test Duration	sec	1808.0	1820.0	1832.0	1879.0	2061.0	2622.0
Specimen Final Mass	g	2.0	3.0	5.0	7.6	11.8	18.9
Percentage of Total Mass Pyrolyzed		93.2%	89.7%	82.2%	72.8%	57.1%	33.7%
Sample Mass Loss (from ignition)	kg/m²	2.97	3.01	2.57	2.24	1.68	0.89
Average Mass Loss Rate (from ignition)	g/m².s	1.6	1.7	1.4	1.2	0.9	0.5
Over the entire test duration							
Peak Heat Release Rate	kW/m²	205.8	193.5	152.3	155.5	155.6	132.7
average heat release rate - ignition to end of test							
from ignition plus 60 seconds	kW/m²	138.4	117.3	101.4	93.2	94.2	98.1
from ignition plus 180 seconds	kW/m²	113.2	94.5	83.0	73.5	63.3	69.4
from ignition plus 300 seconds	kW/m²	120.7	90.9	82.0	70.6	52.7	55.1
Total Heat Release	MJ/m²	70.0	73.0	57.5	52.4	36.6	21.1
Average Smoke Extinction Area	m²/kg	218	138	125	49	64	69
Average Heat of Combustion	MJ/kg	23.1	24.4	22.0	22.6	20.5	19.4
average HRR from ign	kW/m² x m²/kg	38.9	40.5	31.9	29.0	20.2	11.4

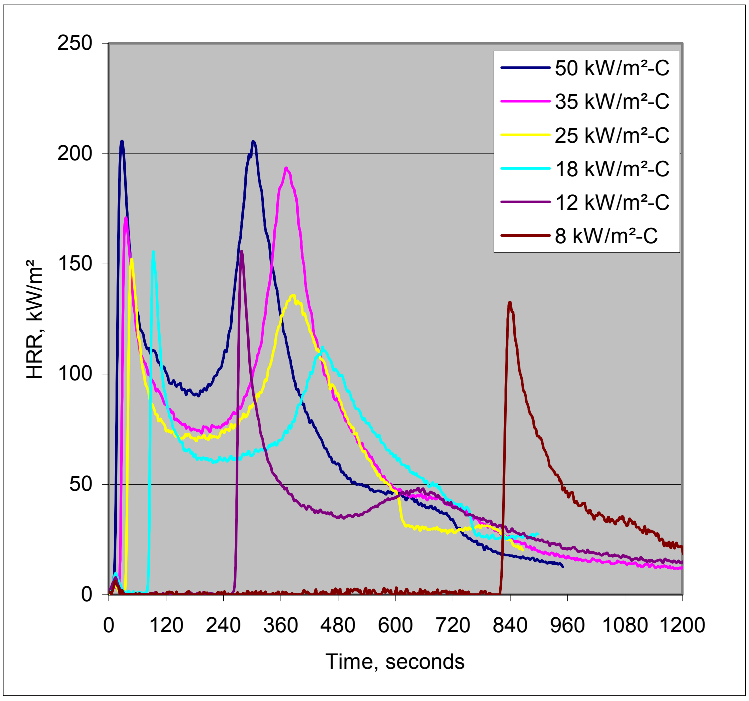

Figure 27: HRR for material C

Table 16: Material D flooring laminate 12 mm

SPECIMEN DETAILS and TEST REGIME							
Specimen Thickness	mm	11.9	12.0	12.0	12.0	12.0	12.0
Specimen Initial Mass	g	116.0	117.6	117.0	116.1	116.9	116.9
Exposed Sample Area	m²	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088
Overall Apparent Density	kg/m³	974.8	980.0	979.1	967.5	978.2	978.2
Nominal Heat Flux	kW/m²	50.0	35.0	25.0	18.0	14.4	12.0
Nominal Duct Flow Rate	m³/sec	0.024	0.024	0.024	0.024	0.024	0.024
Orientation		H	H	H	H	H	H
Retainer frame		Y	Y	Y	Y	Y	Y
Wire grid		N	N	N	N	N	N
TEST RESULTS							
Time to Sustained Flaming	sec	45.0	114.0	331.0	1309.0	2351.0	0.0
Test Duration	sec	1845.0	1914.0	2131.0	3109.0	1800.0	1800.0
Specimen Final Mass	g	20.6	29.0	33.6	34.8	94.9	106.7
Percentage of Total Mass Pyrolyzed		82.2%	75.3%	71.3%	70.0%	18.8%	8.8%
Sample Mass Loss (from ignition)	kg/m²	10.64	9.69	9.01	6.67	-1.62	1.16
Average Mass Loss Rate (from ignition)	g/m².s	5.9	5.4	5.0	3.7	2.9	0.6
Over the entire test duration							
Peak Heat Release Rate	kW/m²	229.9	168.8	146.7	170.2	13.8	30.9
average heat release rate - ignition to end of test							
from ignition plus 60 seconds	kW/m²	142.1	107.4	75.0	70.6	111.1	1.3
from ignition plus 180 seconds	kW/m²	134.3	109.6	89.9	119.2	162.0	0.6
from ignition plus 300 seconds	kW/m²	122.0	101.1	80.5	128.1	154.5	0.9
Total Heat Release	MJ/m²	162.0	139.7	115.9	101.3	4.0	4.2
Average Smoke Extinction Area	m²/kg	54	47	11	67	99	76
Average Heat of Combustion	MJ/kg	15.0	13.9	12.3	11.0	1.6	3.6
average HRR from ign	kW/m² x m²/kg	89.9	77.3	64.2	55.9	2.6	2.3

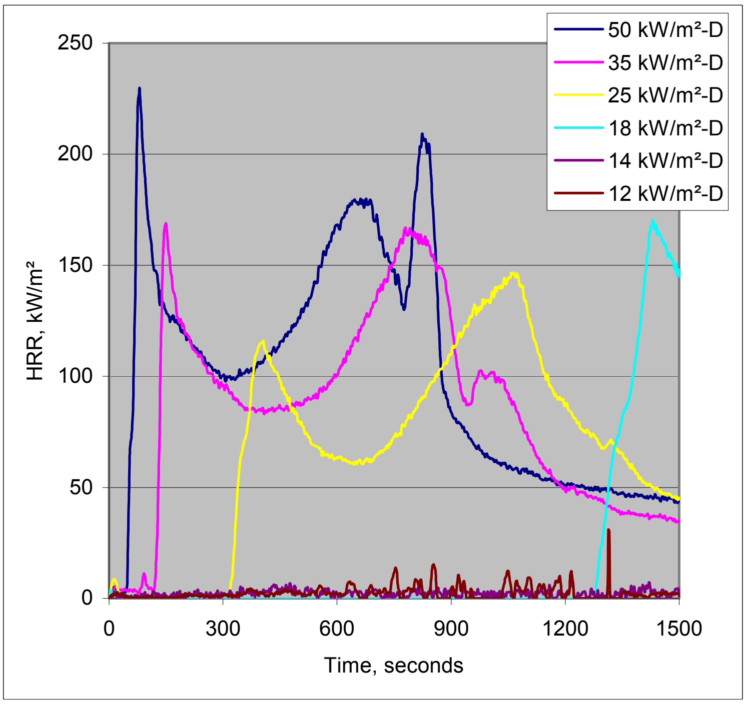

Figure 28: HRR for material D

Table 17: Material E flooring laminate 8 mm

SPECIMEN DETAILS and TEST REGIME							
Specimen Thickness	mm	7.7	7.7	7.8	7.7	7.7	7.7
Specimen Initial Mass	g	68.0	69.0	69.8	70.6	69.8	69.1
Exposed Sample Area	m²	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088
Overall Apparent Density	kg/m³	883.1	896.1	898.3	916.9	912.4	897.4
Nominal Heat Flux	kW/m²	50.0	35.0	25.0	18.0	14.4	12.0
Nominal Duct Flow Rate	m³/sec	0.024	0.024	0.024	0.024	0.024	0.024
Orientation		H	H	H	H	H	H
Retainer frame		Y	Y	Y	Y	Y	Y
Wire grid		N	N	N	N	N	N
TEST RESULTS							
Time to Sustained Flaming	sec	37.0	109.0	284.0	762.0	1191.0	0.0
Test Duration	sec	1837.0	1909.0	2084.0	2562.0	1864.0	1800.0
Specimen Final Mass	g	5.7	9.7	18.5	22.3	-419.7	52.7
Percentage of Total Mass Pyrolyzed		91.6%	85.9%	73.5%	68.4%	701.2%	23.8%
Sample Mass Loss (from ignition)	kg/m²	6.94	6.43	4.94	4.02	53.17	1.86
Average Mass Loss Rate (from ignition)	g/m².s	3.9	3.6	2.7	2.2	79.0	1.0
Over the entire test duration							
Peak Heat Release Rate	kW/m²	283.3	269.7	224.2	214.8	277.3	2.9
average heat release rate - ignition to end of test							
from ignition plus 60 seconds	kW/m²	130.3	101.0	111.3	150.0	201.6	0.9
from ignition plus 180 seconds	kW/m²	133.2	108.8	108.8	171.3	189.9	0.4
from ignition plus 300 seconds	kW/m²	149.7	126.0	131.5	142.9	125.6	0.2
Total Heat Release	MJ/m²	106.4	91.7	68.5	55.2	39.7	1.0
Average Smoke Extinction Area	m²/kg	55	63	54	62	9	129
Average Heat of Combustion	MJ/kg	15.1	13.7	11.8	10.1	0.7	0.5
average HRR from ign	kW/m² x m²/kg	59.0	50.8	37.8	29.9	58.7	0.5

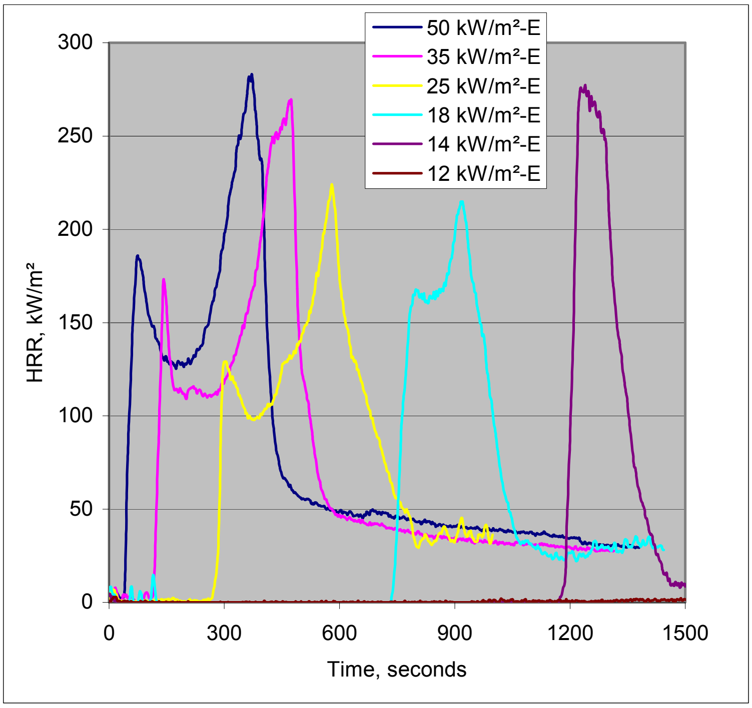

Figure 29: HRR for material E

Table 18: Material F vinyl tiles 1.5 mm

SPECIMEN DETAILS and TEST REGIME							
Specimen Thickness	mm	1.1	1.4	1.4	1.3	1.3	1.3
Specimen Initial Mass	g	23.9	24.0	23.5	24.4	24.4	24.1
Exposed Sample Area	m²	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088
Overall Apparent Density	kg/m³	2172.7	1714.3	1678.6	1891.5	1891.5	1853.8
Nominal Heat Flux	kW/m²	50.0	35.0	25.0	18.0	18.0	12.0
Nominal Duct Flow Rate	m³/sec	0.024	0.024	0.024	0.024	0.024	0.024
Orientation		H	H	H	H	H	H
Retainer frame		Y	Y	Y	Y	Y	Y
Wire grid		N	N	N	N	N	N
TEST RESULTS							
Time to Sustained Flaming	sec	17.0	29.0	44.0	76.0	76.0	0.0
Test Duration	sec	1817.0	1829.0	1844.0	1876.0	1876.0	1800.0
Specimen Final Mass	g	18.0	16.9	17.8	19.0	19.0	7.7
Percentage of Total Mass Pyrolyzed		24.7%	29.4%	24.4%	22.0%	22.0%	68.1%
Sample Mass Loss (from ignition)	kg/m²	0.67	0.69	1.11	0.55	0.55	6.95
Average Mass Loss Rate (from ignition)	g/m².s	0.4	0.4	0.6	0.3	0.3	3.9
Over the entire test duration							
Peak Heat Release Rate	kW/m²	272.2	244.1	201.3	175.4	175.4	2.9
average heat release rate - ignition to end of test							
from ignition plus 60 seconds	kW/m²	150.4	149.9	133.2	104.9	104.9	0.9
from ignition plus 180 seconds	kW/m²	61.1	66.0	59.3	47.4	47.4	0.4
from ignition plus 300 seconds	kW/m²	36.6	40.0	35.9	30.3	30.3	0.2
Total Heat Release	MJ/m²	11.0	12.1	10.8	9.4	9.4	1.0
Average Smoke Extinction Area	m²/kg	719	595	608	498	498	129
Average Heat of Combustion	MJ/kg	16.5	15.1	16.7	15.4	15.4	0.5
average HRR from ign	kW/m² x m²/kg	6.1	6.7	6.0	5.1	5.1	0.5

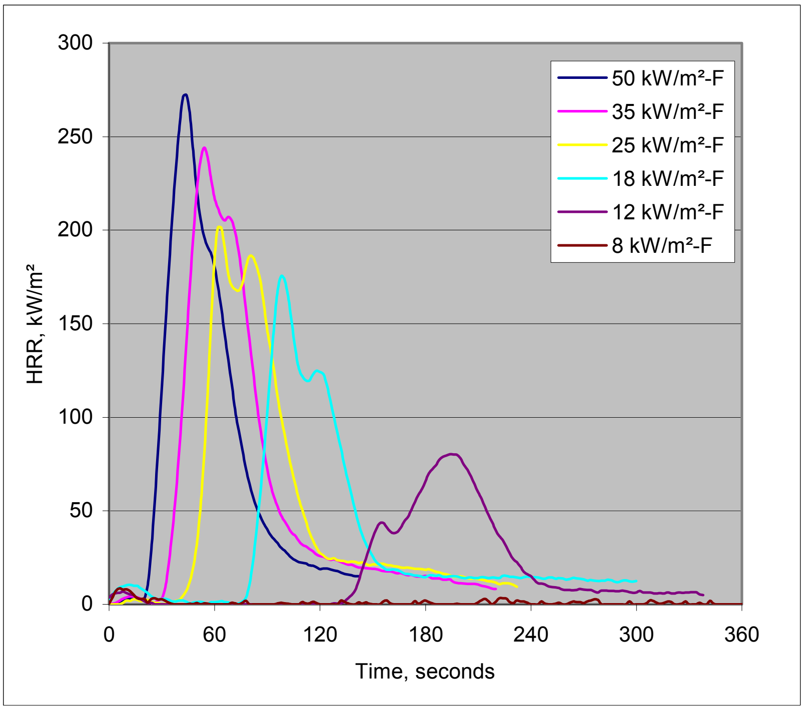

Figure 30: HRR for material F

Table 19: Material G polyester overlay

SPECIMEN DETAILS and TEST REGIME							
Specimen Thickness	mm	8.3	8.5	9.2	8.5	8.5	8.5
Specimen Initial Mass	g	12.8	12.6	12.4	12.6	12.5	12.5
Exposed Sample Area	m²	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088
Overall Apparent Density	kg/m³	154.2	148.2	134.3	148.2	147.1	147.1
Nominal Heat Flux	kW/m²	50.0	35.0	25.0	18.0	12.0	12.0
Nominal Duct Flow Rate	m³/sec	0.024	0.024	0.024	0.024	0.024	0.024
Orientation		H	H	H	H	H	H
Retainer frame		Y	Y	Y	Y	Y	Y
Wire grid		N	N	N	N	N	N
TEST RESULTS							
Time to Sustained Flaming	sec	13.0	22.0	36.0	66.0	107.0	107.0
Test Duration	sec	1813.0	1822.0	1836.0	1866.0	1907.0	1907.0
Specimen Final Mass	g	1.2	1.9	2.5	3.1	3.7	3.7
Percentage of Total Mass Pyrolyzed		90.8%	84.6%	79.5%	75.6%	70.0%	70.0%
Sample Mass Loss (from ignition)	kg/m²	1.24	1.20	1.17	0.96	0.97	0.97
Average Mass Loss Rate (from ignition)	g/m².s	0.7	0.7	0.7	0.5	0.5	0.5
Over the entire test duration							
Peak Heat Release Rate	kW/m²	963.1	739.7	577.6	445.1	340.1	340.1
average heat release rate - ignition to end of test							
from ignition plus 60 seconds	kW/m²	489.2	393.3	306.7	257.9	202.5	202.5
from ignition plus 180 seconds	kW/m²	248.5	243.6	198.7	169.2	175.8	175.8
from ignition plus 300 seconds	kW/m²	149.8	146.9	133.4	109.3	109.8	109.8
Total Heat Release	MJ/m²	45.0	44.2	41.8	38.7	33.4	33.4
Average Smoke Extinction Area	m²/kg	891	925	717	732	828	828
Average Heat of Combustion	MJ/kg	34.2	36.6	37.5	35.9	33.7	33.7
average HRR from ign	kW/m² x m²/kg	25.0	24.5	23.1	21.4	18.5	18.5

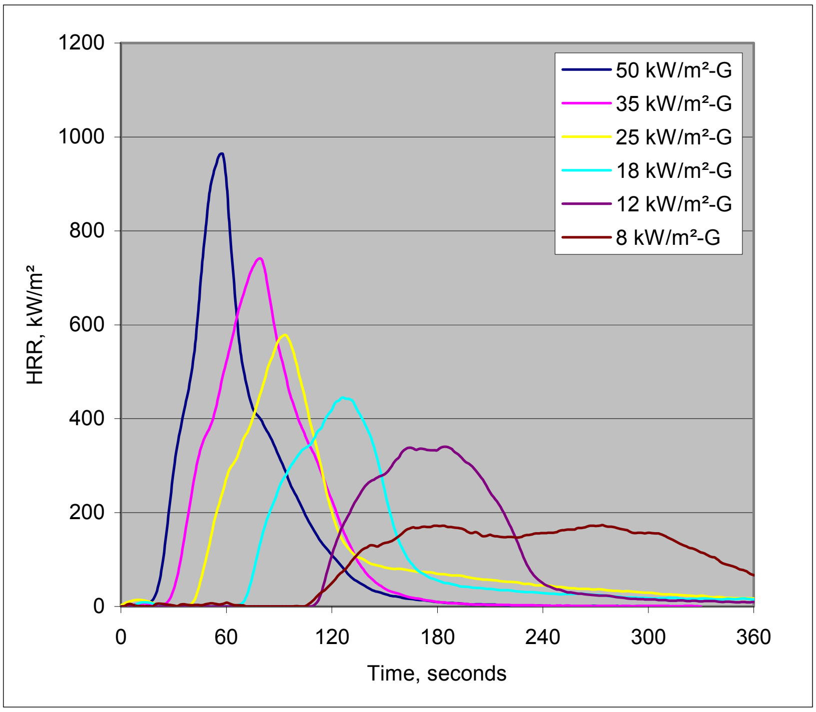

Figure 31: HRR for material G

Table 20: Material H plywood 20 mm

SPECIMEN DETAILS and TEST REGIME						
Specimen Thickness	mm	21.6	21.6	21.5	21.5	21.5
Specimen Initial Mass	g	112.0	109.2	112.5	106.4	110.1
Exposed Sample Area	m²	0.0088	0.0088	0.0088	0.0088	0.0088
Overall Apparent Density	kg/m³	518.5	505.6	523.3	494.8	512.1
Nominal Heat Flux	kW/m²	50.0	35.0	25.0	18	12.0
Nominal Duct Flow Rate	m³/sec	0.024	0.024	0.024	0.024	0.024
Orientation		H	H	H	H	H
Retainer frame		Y	Y	Y	Y	Y
Wire grid		N	N	N	N	N
TEST RESULTS						
Time to Sustained Flaming	sec	21	41	140	220	1611
Test Duration	sec	1821	1841	1940	2020	3411
Specimen Final Mass	g	19.5	18.0	19.9	24.1	31.1
Percentage of Total Mass Pyrolyzed		82.6%	83.5%	82.30%	77.35%	71.8%
Sample Mass Loss (from ignition)	kg/m²	10.45	10.24	10.2	9.1	7.03
Average Mass Loss Rate (from ignition)	g/m².s	5.8	5.7	5.6	5.1	3.9
Over the entire test duration						
Peak Heat Release Rate	kW/m²	265.2	255.6	192.4	137.4	121.5
average heat release rate - ignition to end of test						
from ignition plus 60 seconds	kW/m²	137.3	105.2	139.5	106.4	55.6
from ignition plus 180 seconds	kW/m²	108.0	84.6	117.4	65.7	65.1
from ignition plus 300 seconds	kW/m²	99.4	82.2	96.7	51.9	55.5
Total Heat Release	MJ/m²	137.9	128.9	118.1	95.8	81.8
Average Smoke Extinction Area	m²/kg	50	41	40	25.7	34
Average Heat of Combustion	MJ/kg	13.2	12.5	11.3	10.3	9.1
average HRR from ign	kW/m² x m²/kg	76.6	71.6	65.4	53.2	43.7

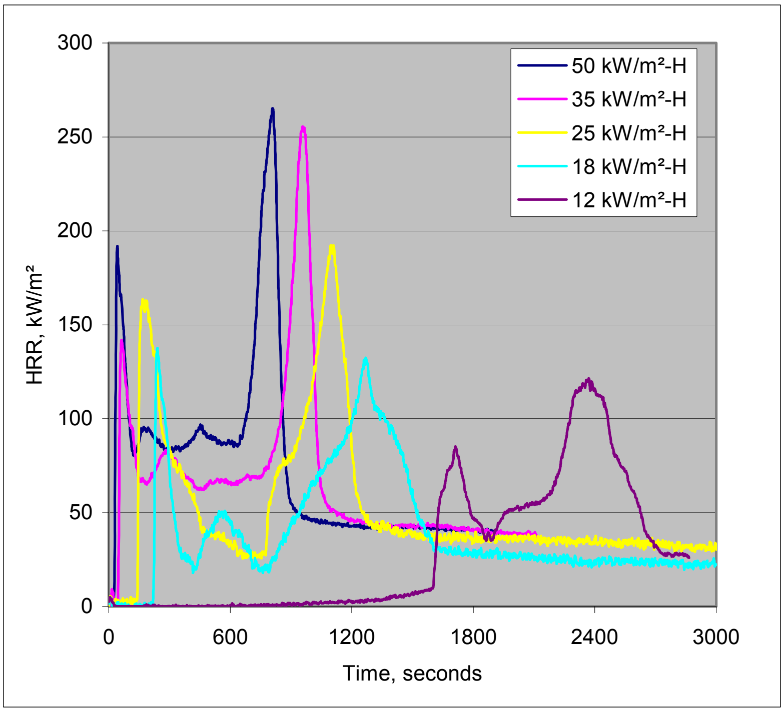

Figure 32: HRR for material H

Table 21: Material I rubber floor covering

SPECIMEN DETAILS and TEST REGIME			
Specimen Thickness	mm	2.4	2.4
Specimen Initial Mass	g	49.0	50.5
Exposed Sample Area	m²	0.0088	0.0088
Overall Apparent Density	kg/m³	2041.7	2104.2
Nominal Heat Flux	kW/m²	35.0	25.0
Nominal Duct Flow Rate	m³/sec	0.024	0.024
Orientation		H	H
Retainer frame		Y	Y
Wire grid		N	N
TEST RESULTS			
Time to Sustained Flaming	sec	46.0	74.0
Test Duration	sec	588.0	1874.0
Specimen Final Mass	g	15.8	18.7
Percentage of Total Mass Pyrolyzed		67.8%	63.1%
Sample Mass Loss (from ignition)	kg/m²	10.48	3.57
Average Mass Loss Rate (from ignition)	g/m².s	19.3	2.0
Over the entire test duration			
Peak Heat Release Rate	kW/m²	491.0	427.3
average heat release rate - ignition to end of test			
from ignition plus 60 seconds	kW/m²	341.2	258.2
from ignition plus 180 seconds	kW/m²	395.8	337.2
from ignition plus 300 seconds	kW/m²	277.9	262.3
Total Heat Release	MJ/m²	86.1	83.0
Average Smoke Extinction Area	m²/kg	1110	1091
Average Heat of Combustion	MJ/kg	22.9	23.0
average HRR from ign	kW/m² x m²/kg	46.0	46.1

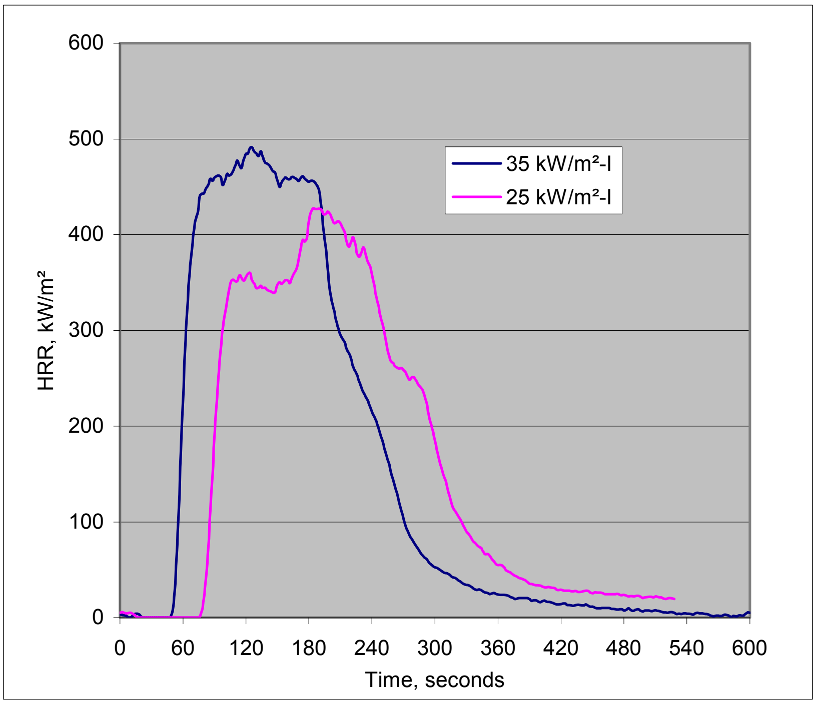

Figure 33: HRR for material I

Table 22: Material J polypropylene on latex

SPECIMEN DETAILS and TEST REGIME			
Specimen Thickness	mm	6.0	6.0
Specimen Initial Mass	g	8.5	8.2
Exposed Sample Area	m²	0.0088	0.0088
Overall Apparent Density	kg/m³	141.7	136.7
Nominal Heat Flux	kW/m²	35.0	25.0
Nominal Duct Flow Rate	m³/sec	0.024	0.024
Orientation		H	H
Retainer frame		Y	Y
Wire grid		N	N
TEST RESULTS			
Time to Sustained Flaming	sec	27.0	50.0
Test Duration	sec	1827.0	1850.0
Specimen Final Mass	g	2.4	1.7
Percentage of Total Mass Pyrolyzed		72.3%	79.8%
Sample Mass Loss (from ignition)	kg/m²	0.70	0.75
Average Mass Loss Rate (from ignition)	g/m².s	0.4	0.4
Over the entire test duration			
Peak Heat Release Rate	kW/m²	590.0	454.0
average heat release rate - ignition to end of test			
from ignition plus 60 seconds	kW/m²	365.6	286.7
from ignition plus 180 seconds	kW/m²	138.7	135.7
from ignition plus 300 seconds	kW/m²	87.5	82.3
Total Heat Release	MJ/m²	29.1	25.0
Average Smoke Extinction Area	m²/kg	979	904
Average Heat of Combustion	MJ/kg	41.9	33.8
average HRR from ign	kW/m² x m²/kg	16.1	13.9

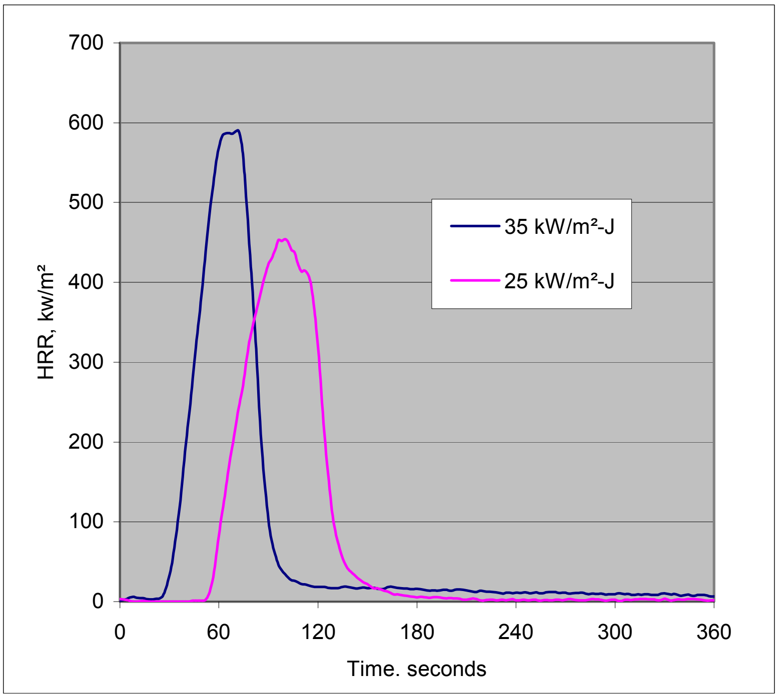

Figure 34: HRR for material J

Table 23: Material K polypropylene on polyolefin backing

SPECIMEN DETAILS and TEST REGIME			
Specimen Thickness	mm	6.2	6.2
Specimen Initial Mass	g	20.8	21.0
Exposed Sample Area	m²	0.0088	0.0088
Overall Apparent Density	kg/m³	335.5	338.7
Nominal Heat Flux	kW/m²	35.0	25.0
Nominal Duct Flow Rate	m³/sec	0.024	0.024
Orientation		H	H
Retainer frame		Y	Y
Wire grid		N	N
TEST RESULTS			
Time to Sustained Flaming	sec	21.0	35.0
Test Duration	sec	1821.0	1835.0
Specimen Final Mass	g	7.2	9.8
Percentage of Total Mass Pyrolyzed		65.4%	53.4%
Sample Mass Loss (from ignition)	kg/m²	1.51	1.32
Average Mass Loss Rate (from ignition)	g/m².s	0.8	0.7
Over the entire test duration			
Peak Heat Release Rate	kW/m²	549.9	527.5
average heat release rate - ignition to end of test			
from ignition plus 60 seconds	kW/m²	282.5	223.6
from ignition plus 180 seconds	kW/m²	259.8	219.6
from ignition plus 300 seconds	kW/m²	171.1	148.0
Total Heat Release	MJ/m²	53.0	50.9
Average Smoke Extinction Area	m²/kg	784	817
Average Heat of Combustion	MJ/kg	34.4	40.2
average HRR from ign	kW/m² x m²/kg	29.4	28.2

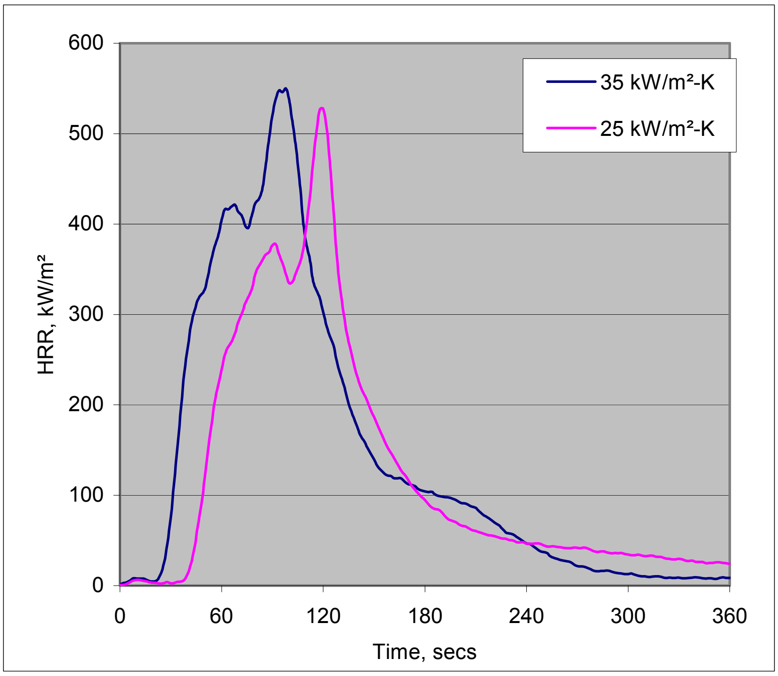

Figure 35: HRR for material K

7.3 Flooring Radiant Panel Tests

Figure 36: Material A

Figure 37: Material B

Figure 38: Material C

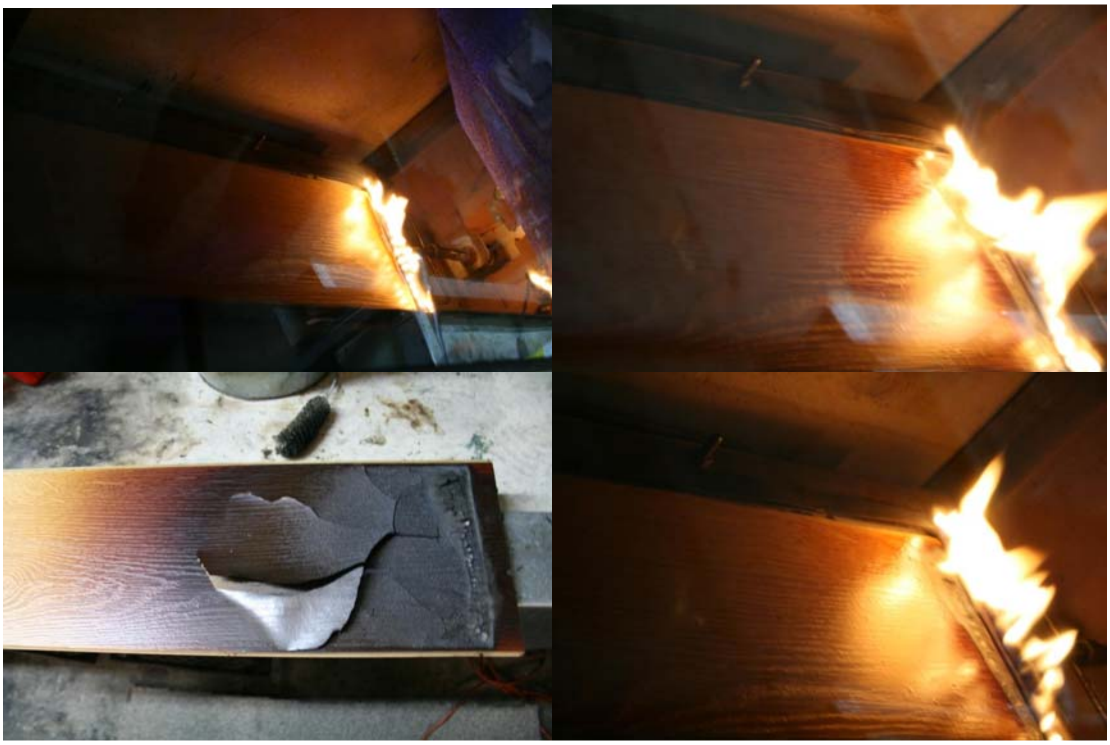

Figure 39: Material D

Figure 40: Material F

Figure 41: Material G

Figure 42: Material H

Figure 43: Material I

7.4 NZBA C/AS1 – Flooring requirements

Sprinklers and foamed plastics

6.20.5 In *firecells constructed* without *foamed plastics*, and equipped with sprinklers, only the ceilings need comply with the *SFI* and *SDI* requirements of Table 6.2. Where *foamed plastics building* materials are used in wall, ceiling or roof systems, the *surface finish* requirements of Paragraphs 6.20.11 to 6.20.13 and Table 6.2 shall apply to the *foamed plastics* materials whether or not sprinklers are installed.

Trampers' huts

6.20.6 In trampers' huts used for overnight accommodation in remote locations, wall and ceiling linings complying with Table 6.2 row 4 are acceptable provided that:

a) The *occupant load* is no greater than 20, and

b) All sleeping spaces have no fewer than two *escape routes*. One *escape route* may be an outward opening window complying with Paragraph 3.18.

COMMENT:
Trampers' huts are backcountry accommodation where access is by tramping. The hut occupants are self-reliant and using the hut for convenience. They recognise that this form of activity involves a measure of risk.

CS and CL purpose groups

6.20.7 *Firecells* with a *FHC* of 1 in *purpose groups* CS or CL, or any classrooms, passageways and corridors of educational *buildings* need not comply with Table 6.2 (rows 2 and 3) provided all the following conditions are satisfied:

a) The *occupant load* is less than 250, and

b) The *firecells* are at ground floor level and are served by at least two *exitways* or *final exits*, and

c) The *SFI* is not greater than 7 and the *SDI* not greater than 5 for surfaces 1.2 m or more above floor level, and

d) The *SFI* is not greater than 8 and the *SDI* not greater than 6 for surfaces less than 1.2 m above floor level.

COMMENT:
This provision allows for materials such as painted particleboard to be used from floor level to a height of 1.2 m where rapid escape is possible.

Flooring requirements

Flooring

6.20.8 Flooring shall be either *non-combustible*, or have a low radius of effects of ignition (assessed according to BS 5287) when tested to the BS 4790 *standard test* for flammability of floor coverings; whenever that floor covering serves:

a) *Exitways* for all *purpose groups*, or

b) Any space occupied by *purpose groups* SC or SD.

6.20.9 Paragraph 6.20.8 applies to flexible finishes such as carpets, vinyl sheet or tiles, and to finished or unfinished floor surfaces.

6.20.10 In *firecells* equipped with sprinklers the flooring need not comply with the requirements in Paragraph 6.20.8.

Foamed plastics building materials

6.20.11 *Foamed plastics* forming part of a wall, ceiling or roof system shall be protected from ignition. This requirement does not apply to *building elements* listed in Paragraph 6.20.4.

6.20.12 Protection from ignition shall be appropriate to the *building* occupancy and be achieved by using one or more of the following methods as required by Table 6.3:

a) Installing *flame barriers*.

b) Providing *fire*-resistant *surface finishes*.

c) Restricting the flame propagation properties of the *foamed plastics* to the permitted levels.

Amend 5 Oct 2005

Table 6.2: Requirements for Interior Surface Finishes and Suspended Flexible Fabrics to Inhibit Fire Spread
Paragraphs 6.18.2 d), 6.20.2, 6.20.5, 6.20.7, 6.20.16, 6.20.20 and 6.20.21

Building elements	Purpose group or location (Note 1)	Maximum permitted index SFI	SDI	FI	Row
Walls, ceilings (Note 2)	*Exitways* in all *purpose groups*. Sleeping areas in *purpose groups* SC and SD.	0	3	-	1
	All *occupied spaces* in *purpose groups* CS and CL excluding *exitways* (see also Paragraph 6.20.7). All *occupied spaces* in *purpose group* CM where the *occupant load* is greater than 50. Sleeping areas in *purpose group* SA (see also Paragraph 6.20.6 for trampers' huts).	2	5	-	2
	Passageways, corridors and *stairways* not being part of an *exitway* in all *purpose groups* except SH and SR.	7	5	-	3
	Minimum requirement for all *occupied spaces* in all *purpose groups* except within *household units* in *purpose groups* SR and SH.	5 or 9	10 / 8	- / -	4
	Within individual *household units* in *purpose groups* SR and SH.	Nil requirement			5
Flooring (coverings)	*Exitways*. Any *occupied space* in *purpose groups* SC and SD.	*Non-combustible*, or have low radius of effects of ignition (see Paragraph 6.20.8).			6
Ducts for *HVAC* systems	Internal surfaces.	0	3	-	7
	External surfaces.	7	5	-	8
Acoustic treatment and pipe insulation	Within air-handling plenum in *purpose groups* SC, SD, SA and SR.	7	5	-	9
Suspended flexible fabrics	*Exitways* serving *purpose groups* SC, SD, SA, SR and CO. All *occupied spaces* in *purpose groups* CS and CL including *exitways*. All *occupied spaces* including *exitways* in *purpose group* CM where *occupant load* is greater than 50. Underlay to exterior cladding or roofing when exposed to view in *occupied spaces* in *purpose groups* SC, SD, SA, WL, WM, WH, WF, CO, CM, CS, CL and IE.	-	-	12	10
Membrane structures	*Purpose groups* CM, CS and CL.	Pass the *standard test* for flammability of membrane structures.			11
Column 1	2	3			

Key:
SFI = spread of flame index
SDI = smoke developed index
FI = flammability index
(The smaller the index number the more stringent the requirement)

Notes:
1. For the purposes of this table, the term *"occupied spaces"* means a space that can be expected to be occupied during normal use of the *building* by its intended occupants. It does not include *concealed spaces* or ceiling cavities which may be accessed only through a hatch, or plant rooms and the like occupied only for maintenance purposes.
2. **Sprinklered firecells:** see Paragraph 6.20.5 for reduced requirements in sprinklered *firecells*.

Flooring requirements