STUDY REPORT

SR 301 (2014)

Simplified Reaction to Fire for Interior Wall, Ceiling and Floor Linings

– Literature Review

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MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
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Preface

This is the first of a series of reports prepared during research into interior wall, ceiling and floor lining reactions to fire in the New Zealand regulatory context.

The second report in this series is titled "Simplified Reaction to Fire for Interior Wall and Ceiling Linings – Paint Coatings – Testing Results and Analysis" BRANZ Study Report 302.

Acknowledgments

This work was jointly funded by the Ministry of Business, Innovation and Employment and BRANZ from the Building Research Levy.

Note

This report is intended for regulatory authorities, fire researchers, scientists, engineers and manufacturers of materials and systems used for internal linings.

Disclaimer

No product is identified by manufacturer or brand in this report or elsewhere, as there is no endorsement or other comment by BRANZ on the performance or appropriateness of any specific product included in the range of commercially available products included in this report or in the context of the wider project that report forms one part.

Simplified Reaction to Fire of Interior Wall, Ceiling and Floor Linings – Literature Review

BRANZ Study Report SR 301

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Reference

Robbins, A.P. 2013. *Simplified Reaction to Fire of Interior Wall, Ceiling and Floor Linings – Literature Review. Study Report 301*. BRANZ Ltd. Judgeford, New Zealand.

Abstract

The focus for the overall project was to investigate the possibility of providing simplified 'deemed to comply' solutions to demonstrate code compliance for fire properties of surface coatings and other interior finishes in the New Zealand regulatory context.

The approach used for this literature review has been to collect together published test results that may be (directly or indirectly) relevant to the fire testing procedures required for compliance with the New Zealand Building Code, and to provide guidance for designing a test program. However the ability for the collation of data is limited because of the wide range of different types of substrates and specific test conditions that were used for the various data sets. Data sets pertaining to the specific samples tested are not to be applied generically, unless further analysis has been undertaken and the limitations of the applicability defined.

Highlights discovered during the literature review include:

- Estimating fire performance based on the substrate alone (i.e. without the intended coating systems applied) was not recommended.
- Extensive research efforts have been spent investigating substrate reactions to fire, resulting in the European Classification without Further Testing (CWFT) scheme describing generic groups of substrate classifications; however coatings are not included in this scheme.
- Thickness of paint coatings influence test results:
    - Less than the manufacturer's recommended application rate of a paint coating may decrease the fire protection performance of the sample compared with a full application of the coating.
    - More than the manufacturer's recommended application rate of a paint coating may be initially associated with a comparable or a small increase in fire protection performance for increasing numbers of layers (application rate), followed by a decrease in fire performance for continued increasing numbers of layers.
- Combinations of different types of coatings have been suggested to have too much variation in test results to be treated using a generic grouping scheme. Care must be taken when defining groups of types of coatings.

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Nomenclature

SBI	Single Burning Item test, EN 13823 (2002)
FCRC	Fire Code Reform Centre
FIGRA	FIre Growth RAte (a parameter for the main fire class according to the EN 13823 test that is the maximum value of heat release per time during the test)
SMOGRA	SMOke Growth Rate
CHF	Critical Heat Flux
ISO	International Standardization Organization
CWFT	(Euroclass) Classification without Further Testing
EUREFIC	EUropean REaction to FIre Classification
OSB	Oriented StrandBoard
SPR	Smoke Production Rate
SPR60	60 s moving average of the Smoke Production Rate
BCA	Building Code of Australia
NZBC	New Zealand Building Code
VM2	(New Zealand Building Code) Verification Method 2
NZ Group Number	New Zealand (Building Code), (Material) Group Numbers abbreviation used in tables in this document. NOTE: NZ Group Numbers values appearing in this document have been calculated from the available data set and therefore apply only to the specific specimen tested and are not to be applied generically.

1. INTRODUCTION

The recently introduced Protection from Fire Building Code requirements included controls on the performance of internal surface finishes (walls, ceiling and floor coverings). These requirements require testing to internationally recognised standards to establish where in a building a particular combination of substrate and finish will be permitted.

This project aims to provide simplified solutions to demonstrate code compliance for fire properties of surface coatings and other interior finishes. The simplified (prescriptive) solutions would ultimately be included in the Acceptable Solutions, C/AS1 to C/AS7, and Verification Method 2 (C/VM2) of the New Zealand Building Code (NZBC) supporting documents and would remove the need for ongoing product testing for some specific combinations of substrate and surface coating where performance can be predetermined to fall within relevant Group Number categories required by the NZBC.

Whilst simplified solutions would clearly be of some benefit to manufacturers of both substrate and interior finishes, it will more importantly benefit all parties involved with the building inspections and compliance processes, for example:

- Specifiers and designers can propose generic combinations of products or specific products without the need to source fire test data for them
- Building Consent processors can accept a proposal without needing large quantities of product data
- Monitoring during construction will be more straightforward and it will be easier to establish that the construction as built does comply
- Final inspections won't always require evidence that products used are those specified in consent documentation
- Building warrant of fitness inspections, are similarly easier as redecoration occurs during the life of a building
- Alterations to the building will be more readily accepted by councils since assessment of means of escape from fire can be conducted by comparisons of generic descriptions rather than specific products.

All of the above would result in a considerably more straightforward compliance regime for buildings and therefore significant cost savings across the board when applied to every non-residential building consent throughout the country.

The approach used for this literature review has been to collect together published test results that may be (directly or indirectly) relevant to the fire testing procedures required for compliance with the New Zealand Building Code, and to provide guidance for designing a test program. However the ability for the collation of data is limited because of the wide range of different types of substrates and specific test conditions that were used for the various data sets. Data sets pertaining to the specific samples tested are not to be applied generically, unless further analysis has been undertaken and the limitations of the applicability defined.

1.1 Objectives

The overall objective of this project is to provide simplified solutions to demonstrate code compliance for fire properties of surface coatings and other interior finishes for some specific combinations of substrate and surface coating for buildings where the fire properties of interior surface linings are regulated.

The specific objective of this piece of work is to collate and review published investigations and available data related to reaction to fire of various coatings on various substrates of interior building surfaces.

1.1.1 Scope

Interior surface finish, in relation to the scope of this work, refers to exposed surfaces of walls (fixed or movable), ceilings and floors within buildings, where walls and ceilings are the major focus. The scope does not include concealed or inaccessible spaces, building contents, nor furnishings that may be fixed in place within a building.

Foamed plastics are outside of the scope of this report.

2. NEW ZEALAND BUILDING REGULATIONS

The following summaries of the New Zealand regulations for the fire performance of interior surface linings is included to provide the context for the classifications of materials. This also provides a basis to enable discussion of developments that are related to international test standards and classification systems and are not necessarily directly comparable to the New Zealand material classification system, which is the focus here.

A discussion of the implications of fire safety of wall, ceiling and floor linings in the Australian context, including a comparison of standard test methods and the potential implications of using them in a regulatory context was summarised for the Fire Code Reform Centre (FCRC, 1998). Although the contents of this document is not directly applicable to the focus of this literature review, it provides useful background information.

2.1.1 Building Code

The performance requirements from the New Zealand Building Code, Performance C3.4.a (NZBR, 1992):

Materials used as internal surface linings in the following areas of buildings must meet the performance criteria specified below:

Table 1 Performance determined under conditions described in ISO 9705: 1993 (NZBR, 1992)

Area of *building*	**Material Group Number for**	
	***Buildings* not protected with an automatic *fire* sprinkler system**	***Buildings* protected with an automatic *fire* sprinkler system**
Wall/ceiling materials in sleeping areas where care or detention is provided	1-S	1 or 2
Wall/ceiling materials in exitways	1-S	1 or 2
Wall/ceiling materials in all *occupied spaces* in importance level 4 *buildings*	1-S	1 or 2
Internal surfaces of ducts for *HVAC systems*	1-S	1 or 2
Ceiling materials in crowd and sleeping uses except *household units* and where care or detention is provided	1-S or 2-S	1 or 2
Wall materials in crowd and sleeping uses except *household units* and where care or detention is provided	1-S or 2-S	1, 2, or 3
Wall/ceiling materials in occupied spaces in all other locations in *buildings*, including *household units*	1, 2, or 3	1, 2, or 3
External surfaces of ducts for HVAC systems	1, 2, or 3	1, 2, or 3
Acoustic treatment and pipe insulation within airhandling plenums in sleeping uses	1, 2, or 3	1, 2, or 3

C3.4.a (b) floor surface materials in the following areas of *buildings* must meet the performance criteria specified below:

Table 2 Building Code floor surface material minimum critical radiant flux when tested to ISO 9239-1: 2010 (NZBR, 1992)

Area of *building*	*Buildings* not protected with an automatic *fire* sprinkler system	*Buildings* protected with an automatic *fire* sprinkler system
Sleeping areas and exitways in *buildings* where care or detention is provided	4.5 kW/m^2	2.2 kW/m^2
Exitways in all other *buildings*	2.2 kW/m^2	2.2 kW/m^2
Firecells accommodating more than 50 persons	2.2 kW/m^2	1.2 kW/m^2
All other occupied spaces except *household units*	1.2 kW/m^2	1.2 kW/m^2

Clause C3.4 does not apply to *detached dwellings*, within *household units* in *multi-unit dwellings*, or *outbuildings* and *ancillary buildings*.

2.1.2 Acceptable Solution

From the New Zealand Acceptable Solutions, Appendix C (MBIE 2013a, 2013b):

"C4.1.2 Material for internal surface linings shall be given a Group Number in accordance with Appendix A of C/VM2 and tested to either:

ISO 5660 Reaction-to-fire tests Part 1 Heat release rate (cone calorimeter method), and Part 2 Smoke production rate (dynamic method), or

ISO 9705 Fire tests – Full scale room test for surface products"

2.1.3 Verification Method 2

From the New Zealand Building Code (NZBC) Verification Method 2 (C/VM2) for fire safety, Appendix A (MBIE 2013c, 2013d) prescribes the Group Numbers for various occupancies and building locations and how a material Group Number is assigned, as follows:

> ***A1.1 Tests for material Group Numbers***
>
> *Materials shall be assigned a material Group Number when tested to either:*
>
> *a) ISO 9705 Fire tests – full scale room test for surface products, or*
>
> *b) ISO 5660 Reaction to fire tests (Heat release, smoke production and mass loss rate) Part 1: Heat release rate (cone calorimeter method); and ISO 5660 Reaction to fire tests (Heat release, smoke production and mass loss rate) Part 2: Smoke production rate (dynamic measurement).*
>
> *This is except in the following cases:*
>
> *a) Metal-skin panel assemblies with combustible core materials, which shall only be assessed using either the ISO 9705 or ISO 13784 Part 1 test method, or*
>
> *b) Foil-faced combustible materials, which shall only be assessed using the ISO 9705 test method, or*

c) Other products that an accredited test laboratory believes are not appropriate to be evaluated using the ISO 5660 test method due to the configuration or other characteristics of the product. Such products shall be assessed using either the ISO 9705 test or another large scale test if deemed to be appropriate.

Comment:

ISO 5660 is unsuitable in cases where the fire performance of the assembly is dominated by the construction details rather than the flammability characteristics of the surface material or in cases where, due to the configuration of the material in the test, significant mechanical damage occurs at full scale which does not occur with small, horizontal samples.

A1. 2 Determining a material's Group Number when tested to ISO 9705

For a material tested to ISO 9705, the material's Group Number shall be determined as follows:

Group Number 1 material has total heat release not greater than 1 MW following exposure to 100 kW for 10 minutes then 300 kW for 10 minutes

Group Number 1–S material has total heat release not greater than 1 MW following exposure to 100 kW for 10 minutes then 300 kW for 10 minutes and the average smoke production rate over the period 0–20 min is not greater than 5.0 m²/s

Group Number 2 material has total heat release not greater than 1 MW following exposure to 100 kW for 10 minutes

Group Number 2–S material has total heat release not greater than 1 MW following exposure to 100 kW for 10 minutes and the average smoke production rate over the period 0–10 min is not greater than 5.0 m²/s

Group Number 3 material has total heat release not greater than 1 MW following exposure to 100 kW for 2 minutes, and Group Number 4 material has total heat release greater than 1 MW following exposure to 100 kW for 2 minutes.

The rate of total heat release determined in ISO 9705 includes contribution from both the internal lining and the exposure source (100 kW or 300 kW).

The Group Number of a material predicted in accordance with Paragraph A1.3 using data obtained by testing the material at 50 kW/m² irradiance in the horizontal orientation with edge frame in accordance with ISO 5660 is given by:

Group Number 1 material: as predicted in accordance with Paragraph A1.3

Group Number 1-S material: as predicted in accordance with Paragraph A1.3 and an average specific extinction area less than 250 m²/kg

Group Number 2 material: as predicted in accordance with Paragraph A1.3

Group Number 2-S material: as predicted in accordance with Paragraph A1.3 and an average specific extinction area less than 250 m²/kg

Group Number 3 material: as predicted in accordance with Paragraph A1.3, and Group Number 4 material: as predicted in accordance with Paragraph A1.3.

A1. 3 Determining a material's Group Number when tested to ISO 5660

For a material tested to ISO 5660, the material's Group Number must be determined in accordance with the following:

a) Data must be in the form of time and HRR pairs for the duration of the test. The time interval between pairs should not be more than 5 seconds. The end of the test (t_f) is determined as defined in ISO 5660, and

b) At least three replicate specimens must be tested.

The following five steps must be applied separately to each specimen:

Step 1: Determine time to ignition (t_{ig}). This is defined as the time (in seconds) when the HRR reaches or first exceeds a value of 50 kW/m².

Step 2: Calculate the Ignitability Index (I_{ig}) expressed in reciprocal minutes.

$$I_{ig} = \frac{60}{t_{ig}}$$

Step 3: Calculate the following two HRR indices:

$$I_{Q1} = \int_{t_{ig}}^{t_f} \left[\frac{q''(t)}{(t - t_{ig})^{0.34}} \right] . dt$$

$$I_{Q2} = \int_{t_{ig}}^{t_f} \left[\frac{q''(t)}{(t - t_{ig})^{0.93}} \right] . dt$$

Comment:

These definite integral expressions represent the area under a curve from the ignition time until the end of the test, where the parameter is plotted on the vertical axis and time (t) is plotted on the horizontal axis.

Step 4: Calculate the following three integral limits:

$$I_{Q,10min} = 6800 - 540 I_{ig}$$

$$I_{Q,2min} = 2475 - 165 I_{ig}$$

$$I_{Q,12min} = 1650 - 165 I_{ig}$$

Step 5: Classify the material in accordance with the following:

i. If $I_{Q1} > I_{Q,10min}$ and $I_{Q2} > I_{Q,2min}$, the material is a Group Number 4 material *ii. If $I_{Q1} > I_{Q,10min}$ and $I_{Q2} \leq I_{Q,2min}$, the material is a Group Number 3 material*

iii. If $I_{Q1} \leq I_{Q,10min}$ and $I_{Q2} > I_{Q,12min}$, the material is a Group Number 2 material

iv. If $I_{Q1} \leq I_{Q,10min}$ and $I_{Q2} \leq I_{Q,12min}$, the material is a Group Number 1 material, or

v. If the ignition criterion in Step 1 above is not reached, the material is a Group Number 1 material.

Repeat steps 1 to 5 above for each replicate specimen tested. If a different classification group is obtained for different specimens tested, then the highest (worst) classification for any specimen must be taken as the final classification for that material.

Comment:

It is expected that the fire testing laboratory will determine the material Group Number as described in this section when reporting the fire test results.

2.1.3.1 Thresholds for these indices

Considering these three limits ($I_{Q,10min}$, $I_{Q,2min}$ and $I_{Q,12min}$) for the indices (I_{Q1} and I_{Q2}), the three limits versus time to ignition is shown in Figure 1. The two indices have positive values for all times to ignition, therefore there are minimum values for time to ignition below which a Group Number 1, 2 and 3 cannot be achieved, depending specifically on the instantaneous heat release rate versus time curve.

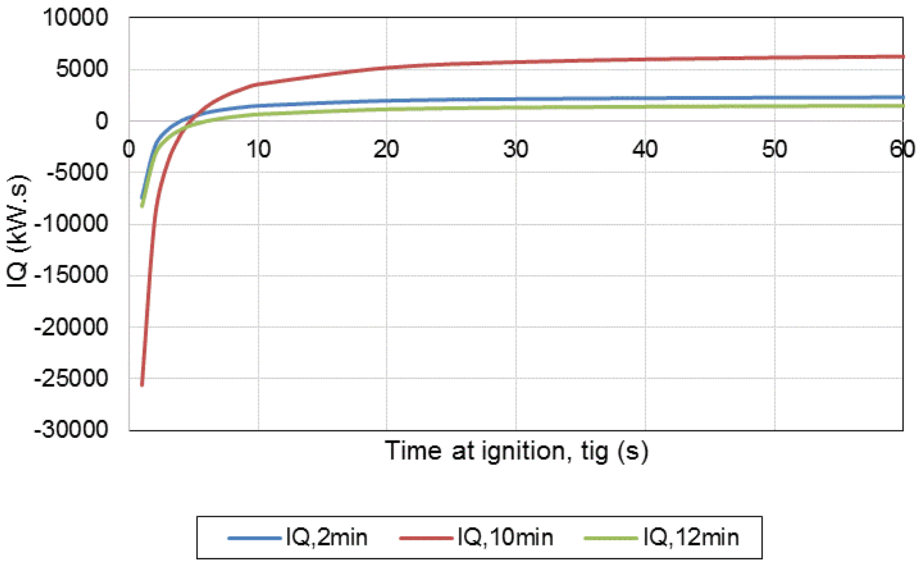


Figure 1 Schematic of the three limits versus time to ignition.

Another way of considering the limits for the range of potential values in relation to each of the thresholds for each Group Number is to consider the ratio of the difference between the rate of heat release indices (I_{Q1} and I_{Q2}) and related limit ($I_{Q,10min}$, and $I_{Q,2min}$ or $I_{Q,12min}$). That is, the ratios:

$$\frac{(I_{Q1}-I_{Q,10min})}{I_{Q1}}, \text{ and } \frac{(I_{Q2}-I_{Q,2min})}{I_{Q2}} \text{ or } \frac{(I_{Q2}-I_{Q,12min})}{I_{Q2}}$$

Then, if $\frac{(I_{Q1}-I_{Q,10min})}{I_{Q1}} \leq 0$, then the limit $I_{Q,12min}$ must be used to assess the value of I_{Q2}; if $\frac{(I_{Q2}- I_{Q,12min})}{I_{Q2}} \leq 0$ then the Group Number is 1, else the Group Number is 2.

If $\frac{(I_{Q1}-I_{Q,10min})}{I_{Q1}} > 0$, then the limit $I_{Q,2min}$ must be used to assess the value of I_{Q2}; if $\frac{(I_{Q2}- I_{Q,2min})}{I_{Q2}} \leq 0$ then the Group Number is 3, else the Group Number is 4.

The quadrants relating to each of the four group numbers using these ratios are visually represented as shown in the schematic of Figure 2. As data approaches the horizontal axis between 1 and 2 (highlighted in blue), the group number approaches the transition threshold between these two groups. As data approaches the vertical axis between 2 and 4 or between 3 and 1 (highlighted in green), the data approaches the transition threshold between group numbers 2 and 3. Similarly, as data approaches the horizontal axis between 3 and 4 (highlighted in red), the group number approaches the transition threshold between groups 3 and 4.

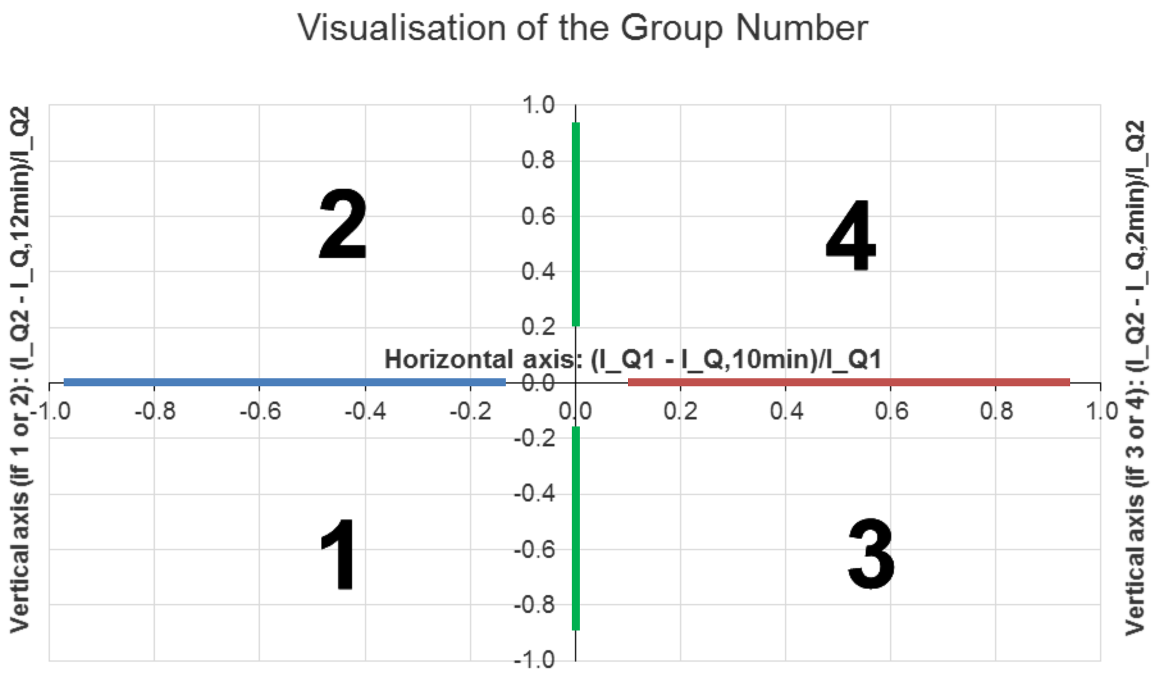


Figure 2 Schematic of the visualisation of a specimen group number used in the sensitivity analysis where axes relate to the ratios of how close the indices are to the limit thresholds

2.1.4 ISO 9705, Full-Scale Room Test

The test method described in ISO 9705 (ISO 1993) is a full-scale room test for surface products. Test parameters are summarised in Table 3 and test variables are summarised in Table 4.

Table 3 Summary of ISO 9705 (ISO 1993) test parameters

<table>
<tr><th>Test Method Parameters</th><th>Value</th></tr>
<tr><td>Room size</td><td>3.6 m long x 2.4 m wide x 2.4 m high</td></tr>
<tr><td>Room vent size</td><td>0.8 m wide x 2.0 m high</td></tr>
<tr><td>Ignition source
– square propane gas burner
– location

– heat output</td><td>
0.17 x 0.17 m
On the floor in a corner opposite to the vent, in contact with the specimen<table><tr><th>Time from Test Start (min)</th><th>Heat Output (kW)</th></tr><tr><td>0 to 10</td><td>100</td></tr><tr><td>10 to 20</td><td>300</td></tr></table></td></tr>
<tr><td>Exhaust capacity</td><td>3.5 m³/s minimum</td></tr>
<tr><td>Duct volume flow rate</td><td>± 5% accuracy</td></tr>
<tr><td>Initial conditions
– Temperature
– Horizontal wind speed</td><td>
20°C ± 10°C
≤ 0.5 m/s</td></tr>
</table>

Table 4 Summary of ISO 9705 (ISO 1993) test variables

Test Method Variable	Expected Range/Required Accuracy
Gas analysis – Oxygen – Carbon Dioxide – Carbon Monoxide	 ± 0.05% (V/V) accuracy, < 3s time constant ± 0.1% (V/V) accuracy, < 3s time constant ± 0.02% (V/V) accuracy, < 3s time constant
Optical density	Detector output within ± 5% over a range of ≥ 3.5 decades
Heat flux measurements – Type – Design range – Location	 Gardon or Schmidt-Boelter Up to 50 kW/m² Geometric centre of the floor, 5 to 30 mm above the floor, facing upward
Visual observations	Product photographed or filmed before test Test filmed
Time of events	 a) Ignition of ceiling b) Flame spread on wall and ceiling surfaces c) Change of the heat output from the burner d) Flames emerging through the doorway
End of test	Flashover or after 20 min (source A.1) or 15 min (source A.2) Observations continue for 2 h, or until visual signs of combustion have ceased
Post-test observations	Extent of damage of the product Any unusual behaviour

2.1.4.1 Thin Surface Materials

Thin surface materials, thermoplastic products that melt, paints and varnishes, are either tested using one of the substrates described in Table 5 or (if it significantly differs from the thermal properties of the substrates listed in Table 5, e.g. metal, mineral wool, etc.) the intended substrate. The application rate of paints and varnishes are as specified by the manufacturer.

Table 5 Summary of substrates for testing thin surface materials to ISO 9705 (1993)

Substrate Description§	Dry Density (kg/m³)	Conditioned Density* (kg/m³)
Non-combustible fibre-reinforced silicate board	680 ± 150	-
Non-combustible board	1,640 ± 150	-
Chipboard (particle board)	-	680 ± 50
Gypsum board	-	750 ± 50

Table Notes:
* Conditioned in an atmosphere of 50% ± 5% relative humidity at a temperature of 23°C ± 2°C. Equilibrium is deemed to have been achieved when the change in mass in any 24 hour period does not change more than greater of 0.1% of the mass of the test piece or 0.1 g.
§ Substrate thickness is 9 to 13 mm.

2.1.5 Cone Calorimeter Tests

ISO 5660 Part 1, BS 476 Part 15 and AS/NZS 3837 are all standard tests using the cone calorimeter apparatus. ISO 5660 Part 1 (ISO, 2002) and BS 476 Part 15 (BSi, 1993) are identical. It is noted that AS/NZS 3837 (1998) has the same apparatus and test methodology, yet different end of test criteria compared to ISO 5660 Part 1 (ISO, 2002) and BS 476 Part 15 (BSi, 1993). AS/NZS 3837 is used by the National Construction Code (NCC) Specification C1.10 for the Classification of Fire Performance of Wall and Ceiling Lining Materials for the Australian regulations. ISO 5660 Part 1 is used in the NZBC.

The test methods are intended for subjecting 100 x 100 mm specimens of homogeneous or composite materials with flat surfaces (i.e. ≤ 1 mm out of plane irregularity) to a uniform incident heat flux, with or without piloted ignition, and in two orientations (one horizontal, one vertical). Vertically orientated specimen testing is rarely done, and is not required for group number classification in NZ or Australia.

The incident heat flux is supplied by a cone-shaped radiant electric heater. The irradiance is controlled by the temperature of three K-type thermocouples (with ± 2°C accuracy) located within the wound element. The irradiance is to be with ± 2% over the 50 x 50 mm centre of the horizontal target area. The element control is to be capable of holding the temperature from 0 to 1,000 °C to within ± 2°C.

The load cell for measuring the specimen mass loss has an accuracy of 0.1 g and a range of up to 500 g.

Exhaust gases are sampled (for oxygen from 0 to 25%, with a response of < 12 s for a range of 10 to 90% oxygen and a drift of < ±50 ppm in 30 min) using a ring sampler, containing 12 holes in the downstream face of the ring. The sampler is located 685 mm downstream of the hood, were a restrictive orifice that is used to promote mixing is located. The exhaust gas temperature is measured 100 mm before the flow measuring orifice plate (a sharp edge orifice plate located > 350 mm downstream after the fan).

An external ignition source is a spark plug with a 3 mm gap and powered by a 10 kV transformer. In the horizontal specimen position, the spark is orientated 13 mm above the centre of the sample. In the vertical specimen position, the spark is located 5 mm above the top of the holder. In the place of the face of the specimen.

Similar test methods include ASTM E1354 (ASTM, 2013) and NFPA 271 (NFPA, 2009).

2.1.5.1 Suitable Product Characteristics for the Test Method

Aspects of a product suitable for testing are (according to ISO 5660-1, 2002):

1. Surface characteristics:
    a. Flat; or
    b. Evenly distributed irregularities:
        i. At least 50% of the surface is < 10 mm deep from the topmost surface height; or
        ii. Where there are cracks, fissures or holes, they are ≤ 30% of the surface area and ≤ 10 mm deep and ≤ 8 mm wide.
2. If a specimen has asymmetrical faces (in terms of composition, surface characteristics or differences in depths of laminated layers), each face that is intended for use as an exposed surface in occupied spaces will be tested.
3. Thin materials may be inappropriate, if the low mass and completion of burning of the available fuel is such that it effects the calculation of the heat release rate. A shorter data collection interval may negate this effect.
4. Materials that change their geometry when exposed to the cone radiation will worsen the precision of the test method, and are not suitable.

2.1.5.2 General Specimen Requirements

Each specimen needs to be prepared such that (according to ISO 5660-1, 2002):

1. Three specimens of each sample are tested at the elected level(s) of irradiance and for each different exposed surface.
2. Specimens are representative of the product.
3. Specimens have 100 mm +0mm/-5mm square sides.
4. For products of nominal thicknesses of 50 mm or less, the specimen is the full thickness of the product.
5. For products of nominal thicknesses of greater than 50 mm, the specimens are reduced to a thickness of 50 mm +0mm/3mm by removal of material from the unexposed side of the specimen.
6. For products with irregular surface characteristics, the highest point on the surface is to be arranged such that it is in the centre of each specimen.
7. Where a material or system would be normally attached to a substrate, then an appropriately representative substrate and fixing technique is to be used in the specimen.
8. Products thinner than 6 mm are to be tested with a representative substrate that would normally be used in practice. The combined product and substrate is to have a combined thickness of at least 6 mm. Where an air gap would be adjacent to the thin product in practice, then the specimen will be mounted such that there is at least a 12 mm gap between the unexposed surface of the specimen and the refractory fibre blanket in the specimen holder.
9. Specimens are to be conditioned according to ISO 554.
10. Excluding the face to be exposed, specimens are to be wrapped in a single layer of aluminium foil, including any substrate or air gap that is representative of intended installation.

2.1.5.3 Correlation of ISO 5660-1 results to ISO 9705 Group Numbers

New Zealand Building Code Verification Method 2 (C/VM2) Appendix 1.3 Group Numbers classifications (MBIE 2013c), based on Cone Calorimeter (ISO 5660-1:2002) heat release test data and ISO 9705 test data, are estimated based on the method presented by Kokkala, Thomas and Karlsson (1993). This estimation method is described in the following section.

The smoke rating (-S) (for the NZBC C/VM/2) is determined from ISO 9705 or ISO 5660 smoke production data, depending on which test method has been used.

2.1.5.3.1 Estimating a Group Number

For a material tested to ISO 5660-1, the NZ Group Number for the material must be determined in accordance with the following:

a) Data must be in the form of time and rate of heat release pairs for the duration of the test. The time interval between pairs should not be more than 5 seconds. The end of the test (t_f) is determined as defined in ISO 5660-1 (ISO 2002):

  a. End of test criteria:

    i. ISO 5660-1 (ISO 2002), whichever occurs first:

      1. 32 min after sustained flaming or other signs of combustion cease;
      2. 30 min after the start of the test, if the specimen has not ignited;
      3. oxygen concentration returns to the preset value within 100 parts per million for 10 min; or
      4. the mass of the specimen becomes zero.

b) At least three replicate specimens must be tested. The following procedure must be applied separately to each specimen:

  i. Determine time to ignition (t_{ig}) is defined as the time (s) when the rate of heat release reaches or first exceeds a value of 50 kW/m².

  ii. Calculate the Ignitability index ($I_Q = {}^{60}/_{t_{ig}}$) expressed in reciprocal minutes.

  iii. Calculate the following two rate of heat release indices:

$$I_{Q1} = \int_{t_{ig}}^{t_f} \left[\frac{q''(t)}{(t - t_{ig})^{0.34}} \right] . dt$$

$$I_{Q2} = \int_{t_{ig}}^{t_f} \left[\frac{q''(t)}{(t - t_{ig})^{0.93}} \right] . dt$$

  where

  t refers time (s), and

  $q''(t)$ refers to rate of heat release (kW/m²) at time t.

  iv. Calculate the following three integral limits:

$$I_{Q,10min} = 6800 - 540I_{ig}$$
$$I_{Q,2min} = 2475 - 165I_{ig}$$
$$I_{Q,12min} = 1650 - 165I_{ig}$$

v. Classify the material by applying the following rules:

If $I_{Q1} > I_{Q,10min}$ and $I_{Q2} > I_{Q,2min}$, then the material is a Group Number 4 material.

If $I_{Q1} > I_{Q,10min}$ and $I_{Q2} \leq I_{Q,2min}$, then the material is a Group Number 3 material.

If $I_{Q1} \leq I_{Q,10min}$ and $I_{Q2} > I_{Q,12min}$, then the material is a Group Number 2 material.

If $I_{Q1} \leq I_{Q,10min}$ and $I_{Q2} \leq I_{Q,12min}$, then the material is a Group Number 1 material.

If the ignition criterion, of 50 kW/m², is not reached, then the material is a Group Number 1 material.

2.1.6 Flooring Radiant Panel Tests

2.1.6.1 ISO 9239 Part 1

ISO 9239-1 Reaction to Fire Tests for Floorings – Part 1: Determination of the burning behaviour using a radiant heat source (ISO, 2010) is intended to assess the burning behaviour and flame spread on horizontally mounted floor linings, when exposed to a radiant flux and ignited with pilot flames.

Test results are reported as flame-spread distance versus time, critical heat flux (CHF) at extinguishment, and smoke density versus time.

The radiant heat source is a panel of porous refractory material (with a radiation surface of 300 ± 10 mm x 450 ± 10 mm) mounted in a metal frame, where the longer axis of the radiant plane is at 30° to the specimen. The propane pilot burner consists of a 6 mm ID and 10 mm OD pipe with 3 lines of 0.7 mm diameter holes. In the ignition position, flames from the lower line of holes impinge on the specimen at 10 ± 2 mm from the zero point. The burner is located 3 mm above the surface of the specimen.

A steel scale is located along at least one side of the specimen. An anemometer (with an accuracy of ± 0.1 m/s) is located on the centreline of the exhaust stack. A radiation pyrometer (with a range of 480 to 530°C, and accuracy of ± 5°C) is used to control the thermal output of the radiant panel. A K-type thermocouple is located within the exhaust duct. A heat flux meter (with a range of 0 to 15 kW/m²) is used to determine the heat flux profile on the specimen.

Specimens are tested in the way in which they are intended to be installed. This may be with adhesives, underlays, with joints, loose laid installations without adhesives, etc. Six 1,050 ± 5 mm by 230 ±5 mm specimens are prepared: three with the major axis in the direction of production and three with the major axis perpendicular to the direction of production. One of each are specimen is initially tested and the remainder of the specimen with the lower CHF and/or HF-30 value(s) are tested.

The heat flux profile distribution required on the dummy specimen board for calibration is presented in Table 6.

Table 6 ISO 9239-1 (ISO, 2010) required heat flux distribution on the dummy specimen board during calibration

Distance from Zero Point of Specimen (mm)	Incident Heat Flux (kW/m²)
110	10.9 ± 0.4
210	9.2 ± 0.4
310	7.1 ± 0.4
410	5.1 ± 0.2
510	3.5 ± 0.2
610	2.5 ± 0.2
710	1.8 ± 0.2
810	1.4 ± 0.2
910	1.1 ± 0.2

Application of the pilot burner is as described in Table 7. Table 8 lists the times at which the distance of the flame front from the zero point on the specimen is to be recorded. In addition, the times are recorded at which the flame front reaches each 50 mm mark (± 10 mm).

Table 7 ISO 9239-1 (ISO, 2010) application of the burner to the specimen.

Time from Insertion of Specimen into Test Chamber (min)	Description of the Location of the Pilot Burner
0	At least 50 mm away from the intended zero point of the test specimen. Pre-heating the specimen.
2	Pilot burner flames brought into contact with the test specimen 10 mm from the edge of the holder.
10	
12	Withdraw burner to at least 50 mm away from the intended zero point of the test specimen. Extinguish the pilot burner flames.
20	
30	
32	End of test, unless sponsor required a longer test duration.

Table 8 ISO 9239-1 (ISO, 2010) times for recording flame front distances.

Time from Insertion of Specimen into Test Chamber at which to Record Distance of Flame Front (min)
10
12
20
30
32 (End of test, unless sponsor required a longer test duration)

2.1.6.1.1 Critical Heat Flux

The ISO 9239-1 (ISO, 2010) critical heat flux (CHF) (kW/m²) is determined from the area under heat flux profile curve (as summarised in Table 6) for the observed distances of flame spread. If specimen is extinguished at 30 min, then there is no CHF. In these cases, a HF-30 value is reported instead that is based on the flame spread distance at the end of test.

Table 9 ISO 9239-1 (ISO, 2010) critical heat flux values for minimum and maximum flame spreads.

Distance of Flame Spread (mm)	Critical Heat Flux (kW/m²)
No specimen ignition	≥ 11
< 110 mm	≥ 11
> 910 mm	≤ 1.1

Other standards, such as NFPA 253 (2011) and ASTM E 648 (2010), are similar to and have been harmonised with ISO 9239-1 (2010).

3. SUMMARY OF EXISTING DATA

Little directly applicable data is available for cone testing of substrates with coatings for the New Zealand regulations. Where applicable data is available it has been collated here; however the analysis of data in terms of the associated regulations for jurisdictions and depending on the current regulations at the time, even where the standard test method is similar to the New Zealand requirements, the results of the analysis are not directly applicable. In these cases, the results are summarised since the methods for grouping and generically describing similar products may provide useful insights. Note that a rough correlation with NZBC group numbers can be made, since performance in the ISO 9705 test is the reference scenario for both the NZ classification system and the SBI (EN13501-1) test in Europe: Euroclass A and B roughly equate to NZ group 1, Euroclass C roughly is NZ group 2, Euroclass D is roughly NZ group 3, and Euroclass E is approximately NZ group 4.

Significant efforts have been associated with the development of a scheme for the European reaction to fire classification system (EN13501-1, a schematic of the classification system is shown in Figure 3) in terms of classification of products without the requirement for testing of some generically described products (Wickström, 1993; Östman and Mikkola, 2006; Sundström, 2007). This scheme is referred to as classification without further testing (CWFT). Examples for an example selection of typical types of products is presented in Table 10. Details of how these generic products are described and summaries of the data collated for this and other data sources are included in the following sections for discussion.

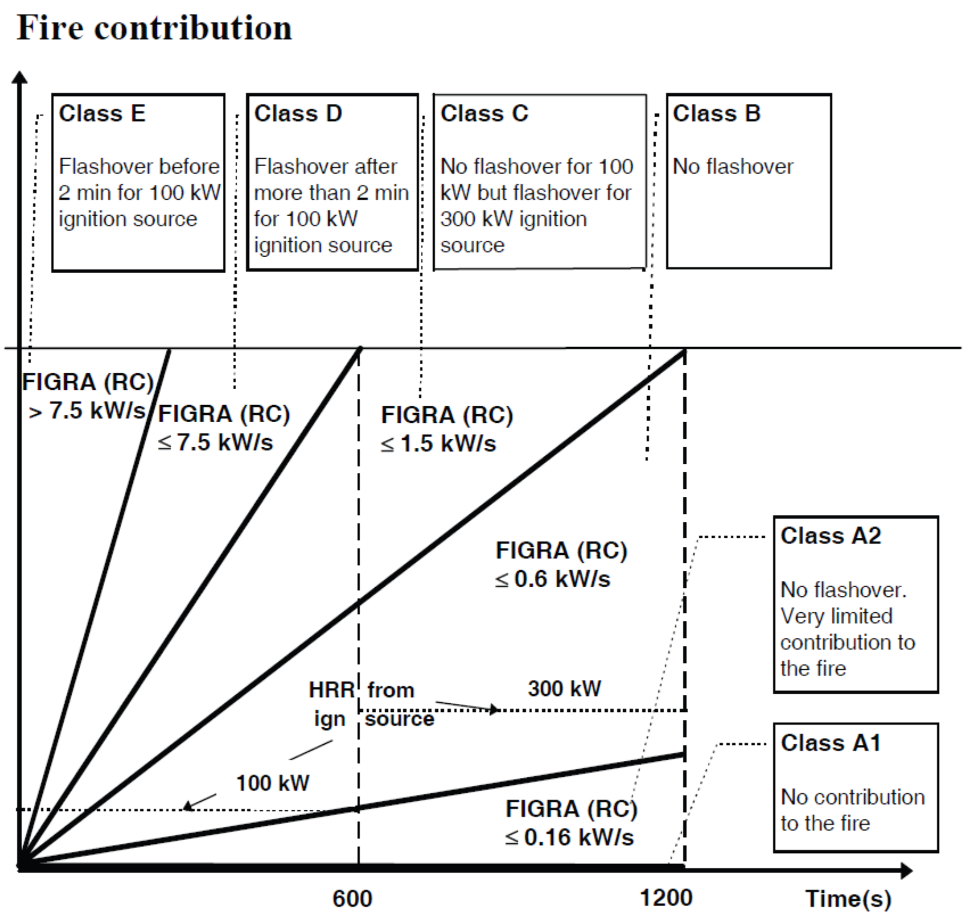


Figure 3 Limiting values for FIGRA$_{RC}$ (FIGRA for the room corner test) and correlations with time to flashover and the European classifications. Extracted from Sundström (2007).

Table 10 Selection of examples of Euroclasses for typical products. Extracted from Östman and Mikkola (2006)

Euroclass	Smoke Class	Burning Droplets Class	Fire Growth Rate (FIGRA) (W/s)	Examples of Typical Products
A1	-	-	-	Stone, concrete
A2	s1, s2 or s3	d0, d1 or d2	≤ 16	Gypsum boards (thin paper), mineral wool
B	s1, s2 or s3	d0, d1 or d2	≤ 60	Gypsum boards (thick paper), fire retardant wood
C	s1, s2 or s3	d0, d1 or d2	≤ 150	Coverings on gypsum boards
D	s1, s2 or s3	d0, d1 or d2	≤ 750	Wood, wood-based panels
E	-	- or d2	-	Some synthetic polymers
F	-	-	-	No performance determined

Another related study associated with the correlation of results from ISO 9705 testing and ISO 5660 testing is also another source of relevant data, however it is also a relatively small collective data set.

Initially, Tsantaridis and Östman (1989) investigated 13 building products in use in the Scandinavian market using the cone calorimeter. (Specimen density and thickness are summarised in Table 11.) Subsequently, Thureson (1991) presented cone calorimeter test results for 11 building products in the European market. (Specimen substrate or total thickness, coating mass per unit area and density are summarised in Table 12.) These two sets of data were later used in the example analysis for the hypothesised correlation between test results from ISO 9705 and ISO 5660 presented by Kokkala, Thomas and Karlsson (1993), that forms the basis for the analysis of ISO 5660 data for estimating Group Numbers, as described in Appendix A.1.3 of C/VM2 of the NZBC supporting documents.

The test results from these two investigations and further analysis are included in the following sections for discussion, along with the results from other sources of data.

Table 11 Summary of the description of the 13 Scandinavian building products investigated by Tsantaridis and Östman (1989) and Östman and Tsantaridis (1993).

Material Description	Thickness (mm)	Density (kg/m³)
Particle board	10	670
Insulating fibre board	13	250
Medium density fibre board	12	655
Wood panel (spruce)	11	450
Melamine-faced particleboard	12 + 1	870
Gypsum board	13	725
Paper wall-covering on gypsum board	13+0.5	725
Plastic wall-covering on gypsum board	13+0.7	725
Textile wall-covering on gypsum board	13+0.5	725
Textile wall-covering on mineral wool	42+0.5	150
Paper wall-covering on particle board	10+0.5	670

Table 12 Summary of the description of the 11 European building products investigated by Tsantaridis and Östman (1989), Tsantaridis (1992) and Östman and Tsantaridis (1993).

Material Description	Substrate Thickness (mm)	Coating (g/m^2)	Density (kg/m^3)
Painted gypsum plaster board	12 (substrate)	100 (paint coating)	800
Birch plywood	12	NC	600
Textile wall-covering on gypsum paper plasterboard	12 + 1	505 (textile surface + base paper)	800
Melamine faced high density non-combustible board	12 + 1.5	NR	1055 (total)
Plastic faced sheet steel on mineral wool	23 + 0.7 + 0.15	NR	640 (total)
Fire retardant particleboard (type German B1)	16	NC	630
Combustible faced mineral wool	30 + 1	NR	87 (total)
Fire retardant particleboard	12	NC	750
Plastic faced steel sheets on polyurethane foam	40 + 1 + 0.1	NR	160 (total)
PVC wall carpet on paper-faced plasterboard (affixed with vinylacetat copolymers)	12 + 0.9	1250 (base paper + surface covering)	800

Table Notes:
NR refers to Not Reported
NC refers to Not Coated

Table 13 Summary of the description of the 11 European building products investigated by Tsantaridis and Östman (1999).

Material Description	Substrate Thickness (mm)	Coating (g/m^2)	Density (kg/m^3)
Pine, varnished	9	NR	450
Spruce, unvarnished	9	NC	439
Plasterboard on polystyrene	37 + 13	197	725 (total)
Intumescent coat on particleboard	13 + 0.4	NR	723 (total)
Melamine-faced medium density fibreboard	12+ 0.1	NR	768
Unfaced mineral wool	50	NC	151
Low-density fibreboard	12	NC	294
Textile covering on calcium silicate board	9 + 0.7	NR	959 (total)
Paper-faced glass wool	100 + 0.3 (50 tested)	NR	28 (total)

Substrate materials and whether there is a cavity behind the substrate or not are known to influence the test outcome for thin coatings and coverings (BRE, 2012;Dyar and Boser, 1996;Östman and Mikkola, 2004, 2006;). For example, tests of wallpaper and decorative lining products on calcium silicate board produced better results than when the same products were tested on a standard plasterboard substrate (BRE, 2012). Therefore identification of the substrate for the intended end-use application is important. Thus the following sub-sections are presented to summarise relevant literature associated with the lining substrates first, then followed by the published literature associated with coated substrates. This layout is intended to facilitate the comparison of the results, where possible.

3.1 Wall and Ceiling Lining Substrates

The following sub-sections provide a summary of available relevant data for wall and ceiling lining substrates. The subsequent section summarises available results for various coatings on these substrates. ISO 9705 test results and ISO 5660 cone calorimeter test results, relating to 50 kW/m² in the horizontal orientation, are the primary focus of the summarised results to enable the highest applicability to the New Zealand context.

The following are summaries of the relevant test results reported, which were predominantly for larger overall research programs, e.g. the European classification without further testing (CWFT) scheme and correlations between standard tests. However these summaries are only intended as indicative for the focus of this report, since there is not automatically a direct correlation between the testing, analysis or international classification systems and the New Zealand context.

3.1.1 Wood and Wood Products

Wood and wood products have been the focus of several investigations For example, Tsantaridis’ (2003b) thesis is based on cone calorimeter results carried out at Trätek, the Swedish Institute for Wood Technology Research, from 1988 to 2000. Also a clear relationship between reaction to fire performance for the European classification system was demonstrated by Östman and Mikkola (2004, 2006) for a selection of wood-products. The key parameters of influence were reported by Östman and Mikkola as product thickness, density and application conditions (e.g. substrates, air gaps, etc.). Wood and wood-products in the building industry has also been an ongoing area supported by the Timber Development Association in Australia (TDA, 2011, 2012) by The Australian Timber Database (ATD, 2013b).

Quintiere et al. (1985, 1986) investigated a range of wall linings, using the apparatus designed by Ahmed and Faeth (1979) to investigate pyrolysis zones in a vertical specimen with the addition of a radiant panel (with incident heat fluxes of 2.5, 3.0 and 3.6 W/cm²), including Douglas Fir particle board, reporting an average heat release rate of 140 to 195 kW/m².

Nagaoka et al. (1988) investigated 8 species of wood using the cone calorimeter. Time to ignition, peak heat release rate and total heat release were reported with respect to density. A trend of an increase in total heat release rate with increasing specimen density was reported. Insignificant variations in the values for peak heat release rate or time to ignition were observed for the range of specimen densities.

In the 1980’s and 1990’s, the Scandinavian’s spearheaded testing (e.g. Östman, 1981;Tsantaridis and Östman, 1989;Tsantaridis and Östman, 1990;Thureson, 1991;Tsantaridis, 1992;Östman and Tsantaridis, 1993;Tsantaridis and Östman, 1999), which is briefly summarised in this section. This work lead onto further analysis toward generic descriptions for groups of similar products and the development of the classification without further testing scheme, as will be discussed in the sub-sections of 3.1.

Östman and Mikkola (2004, 2006) then furthered the investigation by focusing on five wood-product families of building materials in terms of the reaction to fire performance. The test methods used in this study were:

- EN 13823 (2002) Single Burning Item (SBI) test,
- EN ISO 9239-1 (2002) Radiant panel test, and
- EN ISO 11925-2 (2002) Small flame test

The wood-product types were (Östman and Mikkola, 2004, 2006):

1. Wood-based panels (e.g. particle board)
2. Structural timber
3. Glued laminated timber
4. Solid wood panelling and cladding
5. Wood flooring

Relationships between the Euroclass fire performance parameters and product parameters, including density and thickness, were reported where grouping of generic products was based on the Classification without Further Testing (CWFT) procedure. This procedure is summarised in Section 4.1. The discussion on available floorings literature is included in Section 3.3.

A full list of wood-based panels considered in the investigation by (Östman and Mikkola, 2004, 2006) are included in Table 14 and Table 15.

Table 14 List of wood-based panels (subject to EN 13823) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood-based panel	Thick-ness mm	Density kg/m³	Flame spread, Fs, within 60 or 20 s, mm						Ref. No
			Exposure 30 s (Fs within 60 s)			Exposure 15 s (Fs within 20 s)			
			Surface	Edge	Vertical edge	Surface	Edge	Vertical edge	
Particleboards:									
Particleboard	10	675		< 150	-		< 150	-	3.1.1
Particleboard	10	710	0	0	-	0	0	-	3.1.3
Ordinary particleboard	12	710	0	0	-	0	0	-	3.1.2
Particleboard	12	770	0	0	-	0	0	-	3.1.3
Melamine faced particleb.	12	700	0	< 150	0	0	< 150	0	3.1.2
FR chip board	12	780	0	0	-	0	0	-	3.1.2
MDF:									
MDF	3	880	0	< 150	-	0		-	3.1.3
MDF	4	760	0	< 150	-	0		-	3.1.3
MDF	5	800	0	< 150	-	0	0	-	3.1.3
MDF	9	765	0	< 150	-	0	< 150	-	3.1.4
MDF	10	760	< 150	< 150	-	< 150	< 150	-	3.1.1
MDF	10	830	0	< 150	-	0		-	3.1.3
MDF	12	850	0	0	-	0	0	-	3.1.2
MDF	19	565	0	< 150	-	0	< 150	-	3.1.4
MDF	19	820	0	0	-	0		-	3.1.3
MDF	28	800	0	0	-	0		-	3.1.3
MDF	50	700	0	0	-	0		-	3.1.3
Melamine faced MDF	12	770	0	< 150	0	0	< 150	0	3.1.2
Fibreboards, hard:									
Hardboard	2	1010	0	> 150	-	0		-	3.1.3
Hardboard	3	960	0	< 150	-	0	< 150	-	3.1.3
Hardboard	6	1050	0	< 150	-	0	< 150	-	3.1.4
Fibreboards, medium:									
Medium board	9	850	0	< 150	-	0	0	-	3.1.4
Fibreboard	12	450	< 150	< 150	-	< 150	< 150	-	3.1.3
Fibreboards, soft:									
Softboard	9	350	> 150		-	< 150	< 150	-	3.1.3
Low density fibreboard	12	250	< 150	< 150	-	0	< 150	-	3.1.2
Softboard	13	275	> 150		-	< 150	< 150	-	3.1.3
Bitumen board	13	310	> 150	< 150	-	< 150	< 150	-	3.1.3
Plywood:									
Plywood, oak	4	490	< 150	> 150	(0)	< 150	< 150	(0)	3.1.3
Plywood, pine	7	660	0	< 150	(0)	0	-	(0)	3.1.3
Plywood, poplar	9	360	0	< 150	-	0	< 150	-	3.1.4
Plywood, spruce	9	480	0	< 150	-	0	< 150	-	3.1.4
Plywood, birch	9	675	0	0	(0)	0	0	(0)	3.1.3
Plywood, spruce	11	510	0	< 150	0	0	< 150	0	3.1.3
Plywood, poplar	12	410	0	0	< 150	0	0	< 150	3.1.4
Ordinary plywood	12	720	0	0	0	0	0	0	3.1.4
Plywood, birch	12	740	0	0	0	0	0	0	3.1.1
Plywood, spruce	18	465	< 150	< 150	0	< 150	< 150	0	3.1.3
OSB:									
OSB	9	690	< 150	< 150	-	< 150	< 150	-	3.1.5

Note: No ignition of filter paper occurred, i. e. no flaming droplets in the small flame test.

References:

3.1.1 Results of Round Robin on Ignitability test. CEN TC 127 Doc N 1267, January 1998

3.1.2 Tsantaridis L, Östman B: CEN Ignitability test results for the SBI RR products. Trätek Report L 9808059, 1998.

3.1.3 Tsantaridis L: CEN Ignitability test results for wood building products. Trätek Report L 9702010, 1997.

3.1.4 Mollek V and Tsantaridis L: Reaction to fire testing of wood-based panels - Ignitability by single-flame source. Trätek test report No A12164/2001-03-28, 2001.

3.1.5 Small flame test, BRE FRS, SI test reference number RTF/639, Test report number 204886, 2001.

Table 15 Continued list of wood-based panels (subject to EN 13823) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood-based panels	Thickness mm	Density kg/m³	Substrate[1]	Heat		Smoke		Droplets		Class	Ref. No
				FIGRA W/s	THR$_{600s}$ MJ	SMOGRA m²/s²	TSP$_{600s}$ m²	FDP 600s	FDP$_{600s}$ >10s	EN 13501-1	
Particleboards:											
Particleboard	10	670	Ca sil.	495	27.1	3	27	no	no	D-s1, d0	3.1.13
Part. b. with str. vert. joint *	10	660	Ca sil.	515	26.7	4	57	no	no	D-s2, d0	3.1.14
Ordinary particleboard	12	710	Ca sil.	404	26.9	3	29	no	no	D-s1, d0	3.1.10
Particleboard, alcyd tr.	12	710	Ca sil.	496	23.8	7	69	no	no	D-s2, d0	3.1.12
Particleboard V313	12	710	Ca sil.	411	25.1	8	45	no	no	D-s1, d0	3.1.12
Melamine faced particleb.	12	700	Ca sil.	381	20.1	2	39	no	no	D-s1, d0	3.1.10
Paper wall cov. on part. b.	13	700	Ca sil.	479	26.7	2	18	no	no	D-s1, d0	3.1.10
Particleboard	22	690	Ca sil.	327	23.5	7	114	no	no	D-s2, d0	3.1.12
Flaxboard *	32	~400	Ca sil.	708	20.9	5	67	no	no	D-s2, d0	3.1.15
Particleboard, painted	18	550	Ca sil.	27	1.5	-	-	-	-	B	3.1.11
FR chip board	12	780	Ca sil.	25	2.3	12	101	no	no	B-s2, d0	3.1.10
MDF:											
MDF	9	740	Ca sil.	503	32.0	4	35	no	no	D-s1, d0	3.1.13
MDF	10	830	Ca sil.	456	38.8	11	30	no	no	D-s1, d0	3.1.12
MDF (1)	12	850	Ca sil.	436	33.4	1	21	no	no	D-s1, d0	3.1.10
MDF	19	570	Ca sil.	525	24.7	4	56	no	no	D-s2, d0	3.1.13
MDF (2)	19	800	Ca sil.	457	37.5	10	58	no	no	D-s2, d0	3.1.12
MDF	28	800	Ca sil.	410	34.7	11	79	no	no	D-s2, d0	3.1.12
Melamine faced MDF	12	770	Ca sil.	601	24.0	1	24	no	no	D-s1, d0	3.1.10
FR MDF (1)	12	820	Ca sil.	46	2.6	-	-	-	-	B	3.1.11
FR MDF (2)	12	820	Ca sil.	159	5.4	-	-	-	-	C	3.1.11
MDF	9	730	Rw [2,3]	606	45.7	13	113	no	no	D-s2, d0	3.1.13
MDF	9	730	Air [2,4]	>750 [5]	>15 [5]	>30 [5]	>200 [5]	no	no	E	3.1.13
Fibreboards, hard:											
Hardboard	5,5	900	Ca sil.	486	57.9	9	58	no	no	D-s2, d0	3.1.12
Hardboard	6	950	Ca sil.	407	56.8	3	37	no	no	D-s1, d0	3.1.13
Hardboard	6	950	Part.b.	439	68.2	15	156	no	no	D-s2, d0	3.1.13
Hardb., catalytic painted	3,3	970	Ca sil.	921	36.7	5	33			D-s1, d0	3.1.12
FR Hardboard	3,5	920	Ca sil.	137	8.1	-	-	-	-	C	3.1.11
Fibreboards, medium:											
Medium board	9	820	Ca sil.	527	40.0	2	20	no	no	D-s1, d0	3.1.13
Fibreboards, soft:											
Low density fibreboard	12	250	Ca sil.	1103	39.7	9	79	no	no	D-s2, d0	3.1.10
FR-painted LDF	12	350	Ca sil.	235	10.4	-	-	-	-	C	3.1.11
Plywood:											
Plywood, spruce	9	460	Ca sil.	570	23.1	6	61	no	no	D-s2, d0	3.1.13
Plywood, poplar *	9	410	Ca sil.	588	19.5	3	36	no	no	D-s1, d0	3.1.13
Plywood, spruce	12	480	Ca sil.	542	16.8	3	45	no	no	D-s1, d0	3.1.12
Plywood (pine surface)	12	540	Ca sil.	437	16.6	1	21	no	no	D-s1, d0	3.1.12
Plywood, phenol faced	12	660	Ca sil.	451	21.7	3	18	no	no	D-s1, d0	3.1.12
Ordinary plywood (birch)	12	720	Ca sil.	399	21.7	1	19	no	no	D-s1, d0	3.1.10
Plywood, poplar with multiple joints	12	420	Ca sil.	621	20.8	2	30	no	no	D-s1, d0	3.1.13
Plywood (2)	14	350	Ca sil.	682	16.2	-	-	-	-	D	3.1.11
Plywood	18	470	Ca sil.	434	15.8	2	28	no	no	D-s1, d0	3.1.12
Plywood, spruce	9	460	Rw [2,3]	463	30.4	7	71	no	no	D-s2, d0	3.1.13
Plywood, spruce	9	460	Air [2,4]	>750 [5]	>15 [5]	>30 [5]	>200 [5]	no	no	E	3.1.13
OSB:											
OSB	9	690	Ca sil.	374	26.5	2	37	no	no	D-s1, d0	3.1.16
OSB	9	690	Air [6]	647	69.6	12	82	yes	yes	D-s2, d2	3.1.17
OSB with T&G joints *	9	690	Ca sil.	384	29.0	2	26	no	no	D-s1, d0	3.1.18
Cement bonded particleb:											
Cement bonded particleb.	~10	~1000	Ca sil.	4.9	0.9	0	22	no	no	B-s1, d0	3.1.19

FIGRA Fire Growth Rate
THR$_{600s}$ Total Heat Release during first 600 s
LFS Lateral Flame Spread to edge
SMOGRA Smoke Growth Rate
TSP$_{600s}$ Total Smoke Production during first 600 s
FDP$_{600s}$ Flaming Droplets or Particles during first 600 s

1) Panels screwed to standard substrate
2) Panels attached to wood studs (45x145 mm) cc 600 mm and open at the top
3) Gap filled with rockwool, Rw, 30 kg/m³
4) Gap empty
5) Tests terminated after 7-9 minutes due to high heat release
6) Free standing with 80 mm air gap
* Single test only (all others are duplicate tests)

References:

3.1.10 prEN 13823 Reaction to fire test for building products - Building products excluding floorings – exposed to the thermal attack by a single burning item (Table B.2 Statistical results), Final draft, 2000.
3.1.11 van Mierlo R, Janse E: Analysis of THR threshold values in the SBI draft test method. TNO-report 1999-CVB-R0904, 1999.
3.1.12 Hakkarainen T, Mikkola E: SBI test results of wood products, VTT Building Technology Internal report, Jan. 1998.
3.1.13 EPF, FEIC and FEROPA test program, SBI graphs and Summary, VTT Building and Transport, 2001.
3.1.14 SBI test report, BASF Fire Safety Department, Report-Nr.: 21.1-3343/12258, 2001.
3.1.15 SBI test report, BASF Fire Safety Department, Report-Nr.: 21.1-3343/12255, 2001.
3.1.16 SBI test, BRE FRS, SI test reference number RTF/480A-B, Test report number 204528 (a-b), 2001.
3.1.17 SBI test, BRE FRS, SI test reference number RTF/481A-B, Test report number 204530 (a-b), 2001.
3.1.18 SBI test, BRE FRS, SI test reference number RTF/482, Test report number 204532, 2001.
3.1.19 SBI test, Test Report WARRES No. 112089, 2000.

For the wood-based panels tested and then reported by Östman and Mikkola (2004, 2006) a general trend of a reducing FIGRA value for increasing specimen densities was suggested. For densities greater than 500 kg/m³, it was reported that the FIGRA values were relatively independent of the density. The exceptions to these observations were low density products and a thin free-standing product tested with an air gap. Horizontal or vertical joints and different types of substrates did not influence the performance significantly. No correlation between smoke production and density was observed.

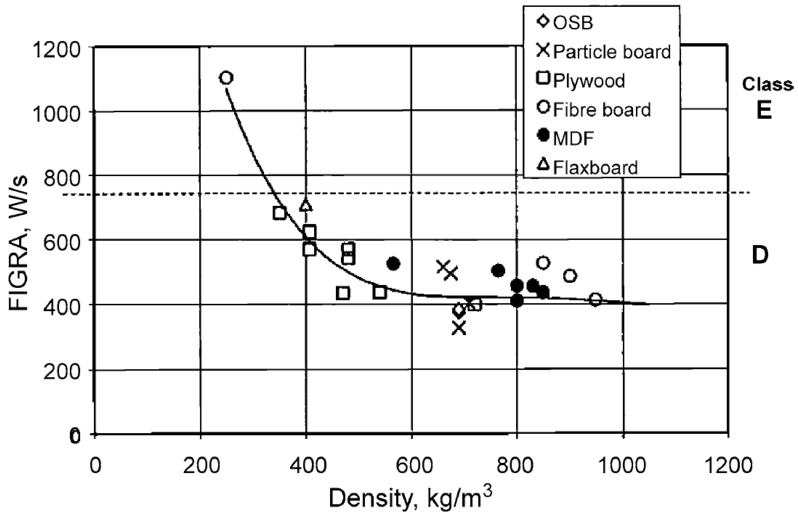


Figure 4 FIGRA values versus density for tested wood-based panels attached to a calcium silicate substrate. (Östman and Mikkola, 2006)

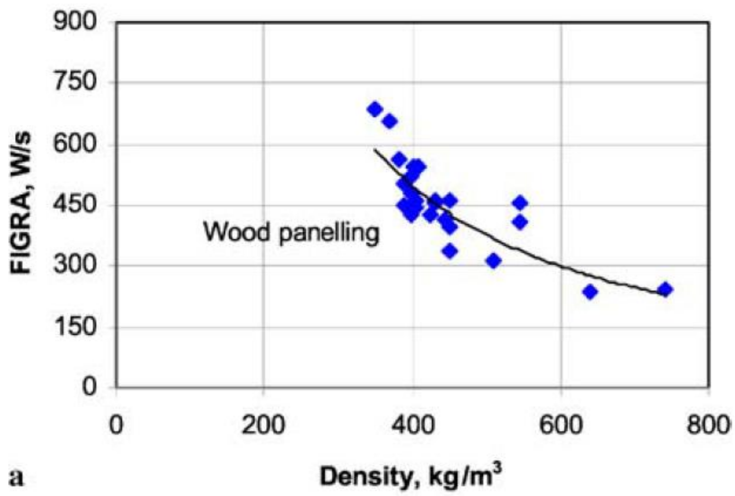


Figure 5 FIGRA values versus density for all tested wood-based panels with and without an air gap behind. (Östman and Mikkola, 2006)

3.1.1.1 Solid Wood

A summary of the average values for some test variables for published solid wood samples (Tsantaridis and Östman, 1989, 1999) investigated in support of the European Classification without Further Testing is presented in Table 16. Examples of the heat release rates and smoke specific extinction area for these samples are shown in Figure 6, Figure 7 and Figure 8.

Table 16 Summary of reported time to ignition and average effective heat of combustion for 50 kW/m² irradiance cone calorimeter tests and time to flashover in room test of substrates and coatings.

Material Description	Time To Flashover in ISO room (min:s) [Ref. E, F]	Time to Ignition in Cone Calorimeter (s)	Average Effective Heat of Combustion (kJ/g)	Total Heat Released (MJ/m²)	Average Rate of Smoke Production/ Rate of Heat Release (ob.m³/MJ)	Ref.
Wood panel (spruce), 11 mm thick	2:11	21	15	NR	22	A
Pine, varnished	1:43	13	125	49.5	-	F
Spruce, unvarnished	1:48	21	123	45.5	-	F

Table Notes:
Ref. refers to Reference for test results.
NR refers to Not Reported.
NI refers to No Ignition
FR refers to material had a Fire Retardant treatment.
- refers to not reported because of irregularities.
Ref. A: Average results from two tests, as reported by Tsantaridis and Östman (1989).
Ref. F: Average results from three test reported by Tsantaridis and Östman (1999).

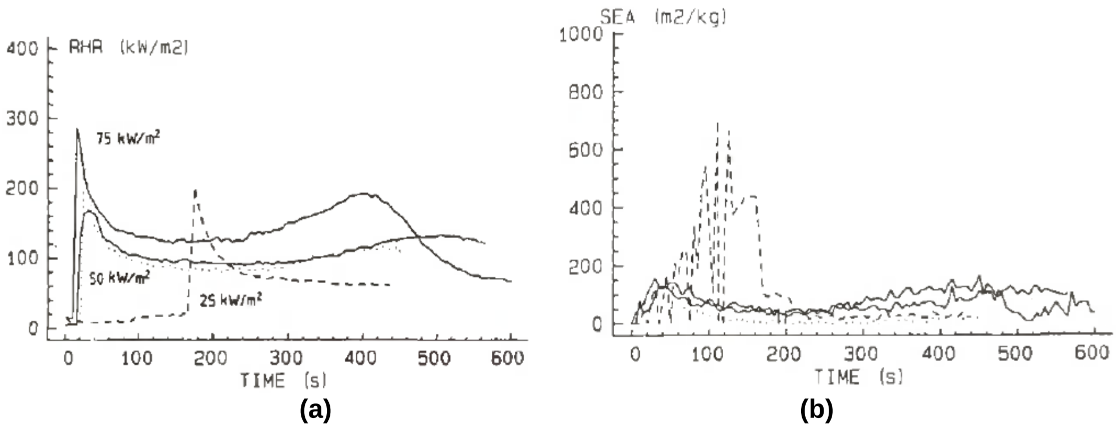
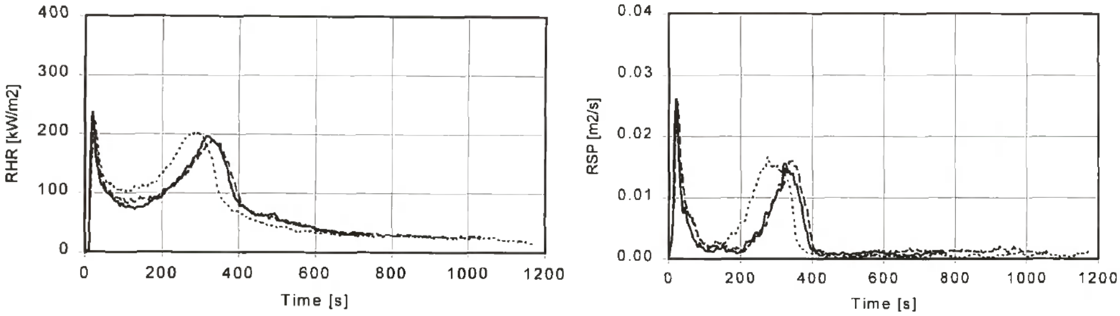
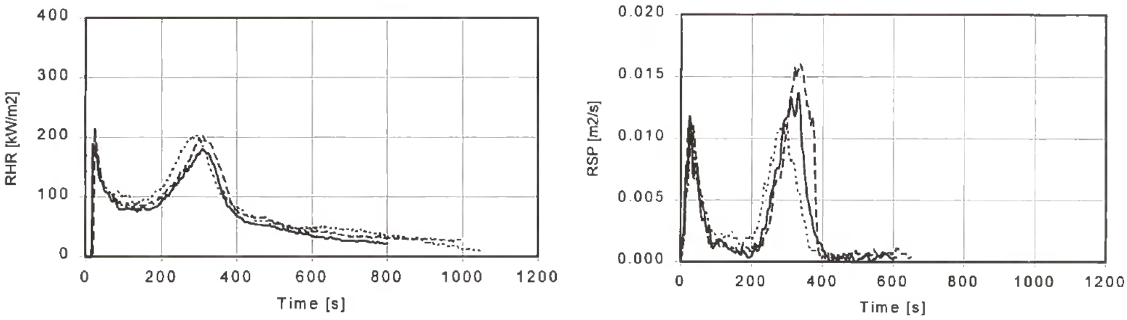


Figure 6 (a) Rate of Heat Release (RHR) for three levels of irradiance (with the average of two tests performed at 50 kW/m²) and (b) Specific Extinction Area (SEA) for 11 mm thick wood panel (spruce). Extracted form Tsantaridis and Östman (1989).



(a) (b)

Figure 7 (a) Heat release rate and (b) rate of smoke production for 3 specimens of varnished pine at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis and Östman (1999).



(a) (b)

Figure 8 (a) Heat release rate and (b) rate of smoke production for 3 specimens of unvarnished spruce at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis and Östman (1999).

To provide a comparison for the current New Zealand regulations, where sufficient published data was available material group numbers were calculated according to the description in the NZBC Verification Method C/VM2 (2013c). A summary of these results in included in each relevant section; Table 17 includes a summary for solid-wood specimens (one also included in Table 16) tested by Tsantaridis and Östman (1989) and Thureson (1991) (and summarised by Kokkala, Thomas and Karlsson (1993)), where indicative NZ material group numbers could be calculated.

Table 17 Summary of various reported tested specimens with a solid wood substrate. Data extracted from Tsantaridis and Östman (1989) and Thureson (1991), initial analysis extracted from Kokkala, Thomas and Karlsson (1993) and Group Number calculated from NZBC C/VM2 (2013c) application.

Description of Material	I_{ig} (1/min)	$I_{Q,m=34}$	$I_{Q,m=0.93}$	$I_{Q,10min}$	$I_{Q.2min}$	$I_{Q,12min}$	NZ Group Number
Ordinary 12 mm birch plywood	2.31	15271	2088	5552	2093	1268	3
	2.31	14778	2099	5552	2093	1268	4
Wood panel (spruce), 11 mm thick	2.86	10907	1703	5255	2003	1178	3

Structural timber (21 to 22 mm thick) were reported to show a decrease in FIGRA values for increasing density. Various densities and wood species were tested (as summarised in Table 18, Table 20, Table 21 and Table 22). Specimens were tested with and without an open air gap. Summaries of the EN 13823 fire growth rate (FIGRA) versus density for structural timber samples are shown in Figure 9, for solid wood panels and cladding samples are shown in Figure 10 and for timber ribbon samples are shown in Figure 11. (Östman and Mikkola, 2006)

Table 18 List of structural timber (subject to EN 11925-2) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Timber product	Thickness mm	Density kg/m³	Flame spread within 60 s, mm		Ignition of filter paper	Class EN 13501-1	Ref. no
			Surface	Edge			
Spruce, planed	12	463	< 150	< 150	No	*	3.2.1
Spruce, planed, knot	12	430	< 150	< 150	No	*	3.2.1
Spruce, planed, joint	12	482	< 150	< 150	No	*	3.2.1
Spruce, planed, joint, knot	12	423	< 150	< 150	No	*	3.2.1
Spruce, unplaned	12	500	< 150	< 150	No	*	3.2.1
Spruce, unplaned, knot	12	488	< 150	< 150	No	*	3.2.1
Spruce, unplaned, joint	12	474	< 150	< 150	No	*	3.2.1
Spruce, unplaned, joint, knot	12	471	< 150	< 150	No	*	3.2.1
Spruce, planed	32	526	< 150	< 150	No	*	3.2.1
Spruce, planed, joint	32	477	< 150	< 150	No	*	3.2.1
Spruce, planed, joint, knot	32	482	< 150	< 150	No	*	3.2.1
Spruce, unplaned	38	494	< 150	< 150	No	*	3.2.1
Spruce, unplaned, knot	38	480	< 150	< 150	No	*	3.2.1
Spruce, unplaned, joint	38	495	< 150	< 150	No	*	3.2.1
Spruce, unplaned, joint, knot	38	482	< 150	< 150	No	*	3.2.1
Pine	20	515	< 150	< 150	No	*	3.2.1
Oak	22	700	< 150	< 150	No	*	3.2.2
Poplar	22	400	< 150	< 150	No	*	3.2.2
Sitka spruce	22	300	< 150	< 150	No	*	3.2.3

* Satisfies the small flame requirements for class D.

References

3.2.1 Tsantaridis L: CEN Ignitability test results for wood building products, Trätek report L 9702010, 1997.
3.2.2 Gaillard J-M: Reaction to fire test EN ISO 11925-2, CTBA Test Report N° 02/PC/PHY/277/3, 2002.
3.2.3 Tsantaridis L and Mollek V: Fire testing of Sitka spruce according to EN ISO 11925-2, Trätek Test Report A12323/2002-12-17, 2003.

Table 19 List of structural timber (subject to EN 11823) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Timber product	Thick-ness mm	Density kg/m^3	Sub-strate	FIGRA (W/s)	THR 600 (MJ)	SMOGRA (m^2/s^2)	TSP (m^2)	Burning Particles	Class EN 13501-1	Ref. no
Spruce (M12)	10	410	Ca sil.	440	16	3	47	None	D-s1, d0	3.2.4
Spruce (P191)	18	490	Ca sil.	438	18	4	36	None	D-s1, d0	3.2.5
Norway spruce t&g vertical	15	490	Ca sil.	452	17	3	34	None	D-s1, d0	3.2.6
Norway spruce t&g horisontal	15	490	Ca sil.	494	18	4	50	None	D-s1, d0	3.2.6
Norway spruce	20	500	Ca sil.	545	19	2	38	None	D-s1, d0	3.2.7
Pine	45	550	Ca sil.	587	24	12	54	None	D-s2, d0	3.2.6
Pine	21	550	Ca sil.	321	23	3	15	None	D-s1, d0	3.2.6
Pine	21	550	Air gap 1)	329	22	4	36	None	D-s1, d0	3.2.6
Oak horisontal orientation	22	700	Air gap 2)	250	14,5	9	36	None	D-s1, d0	3.2.8
Poplar horisontal orientation	22	400	Air gap 2)	449	18,0	16	52	None	D-s2, d0	3.2.8
Sitka spruce horisontal orientation	22	390	Air gap 3)	551	42	19	122	None	D-s2, d0	3.2.9
Sitka spruce vertical orientation	22	390	Air gap 3)	501	16	16	127	None	D-s2, d0	3.2.9
Sitka spruce vertical orientation	22	350	Air gap 3)	586	14	11	105	None	D-s2, d0	3.2.10
Sitka spruce vertical orientation	22	390	Glass wool 4)	553	13	3	46	None	D-s1, d0	3.2.9
Sitka spruce vertical orientation	2x22	390	Glass wool 4)	524	15	1	27	None	D-s1, d0	3.2.9

1) 45 mm air gap, battens 45 x 45 mm at 600 mm center, perpendicular to the orientation of the timber pieces.
2) 40 mm air gap, battens 40 x 40 mm at 500 mm center, perpendicular to the orientation of the timber pieces.
3) 44 mm air gap, battens 44 x 44 mm at 500 mm center, perpendicular to the orientation of the timber pieces.
4) 44 mm gap, filled with glass wool, 50 mm and 19 kg/m^3, battens 44 x 44 mm at 500 mm center, perpendicular to the orientation of the timber pieces

References

3.2.4 prEN 13823 Reaction to fire test for building products - Building products excluding floorings – exposed to the thermal attack by a single burning item (Table B.2 Statistical results), Final draft, 2000.

3.2.5 van Mierlo R, Janse E: Analysis of THR threshold values in the SBI draft test method. TNO-report 1999-CVB-R0904, 1999.

3.2.6 Hakkarainen T, Mikkola E: SBI test results of wood products, VTT Building and transport, Int. report, 1998.

3.2.7 Östman B: Wooden facades in multi-storey buildings, Proc. Fire and Materials Conf, San Francisco, Jan 2001.

3.2.8 Gaillard J-M: Reaction to fire test EN 13823, CTBA Test Report N° 02/PC/PHY/277/1-2, 2002.

3.2.9 Hakkarainen T: Fire test of Sitka spruce according to EN 13823:2002 (SBI) test procedure, VTT Research Report No RTE 136/03, 2003.

3.2.10 Paloposki T: Fire test of Sitka spruce according to EN 13823:2002 (SBI) test procedure, VTT Research Report No RTE 432/03, 2003.

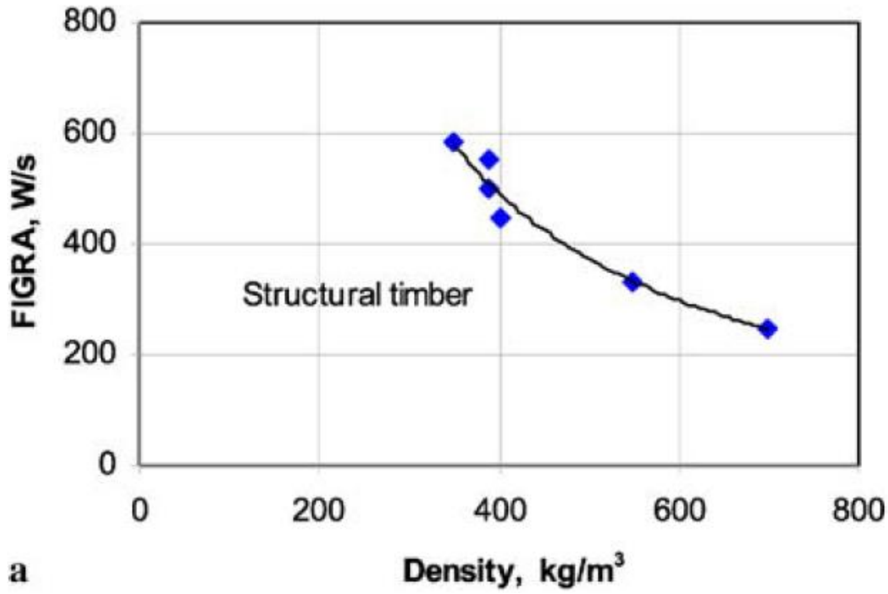


Figure 9 FIGRA values versus density for tested 21 to 22 mm thick structural timber samples. (Östman and Mikkola, 2006)

Table 20 List of solid wood panelling and cladding (subject to EN 11925-2) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood product	Thick-ness mm	Density kg/m^3	Flame spread within 60 s, mm		Ignition of filter paper	Class EN 13501-1	Ref. no
			Surface	Edge			
Spruce, planed	12	463	< 150	< 150	No	*	3.4.1
Spruce, planed, knot	12	430	< 150	< 150	No	*	3.4.1
Spruce, planed, joint	12	482	< 150	< 150	No	*	3.4.1
Spruce, planed, joint, knot	12	423	< 150	< 150	No	*	3.4.1
Spruce, unplaned	12	500	< 150	< 150	No	*	3.4.1
Spruce, unplaned, knot	12	488	< 150	< 150	No	*	3.4.1
Spruce, unplaned, joint	12	474	< 150	< 150	No	*	3.4.1
Spruce, unplaned, joint, knot	12	471	< 150	< 150	No	*	3.4.1
Spruce, planed	32	526	< 150	< 150	No	*	3.4.1
Spruce, planed, joint	32	477	< 150	< 150	No	*	3.4.1
Spruce, planed, joint, knot	32	482	< 150	< 150	No	*	3.4.1
Spruce, unplaned	38	494	< 150	< 150	No	*	3.4.1
Spruce, unplaned, knot	38	480	< 150	< 150	No	*	3.4.1
Spruce, unplaned, joint	38	495	< 150	< 150	No	*	3.4.1
Spruce, unplaned, joint, knot	38	482	< 150	< 150	No	*	3.4.1
Pine	20	515	< 150	< 150	No	*	3.4.1
Oak	22	700	< 150	< 150	No	*	3.4.2
Poplar	22	400	< 150	< 150	No	*	3.4.2
Sitka spruce	22	300	< 150	< 150	No	*	3.4.3
Red ceder	18	350	< 150	< 150	No	*	3.4.4

* Satisfies the small flame requirements for class D.

References

3.4.1 Tsantaridis L: CEN Ignitability test results for wood building products, Trätek report L 9702010, 1997.
3.4.2 Gaillard J-M: Reaction to fire test EN ISO 11925-2, CTBA Test Report N° 02/PC/PHY/277/3, 2002.
3.4.3 Tsantaridis L and Mollek V: Fire testing of Sitka spruce according to EN ISO 11925-2, Trätek Test Report A12323/2002-12-17, 2003.
3.4.4 DANAK Prøvningsrapport, Dansk Brand- og sikringsteknisk Institut, Sag nr PF11326, Løbe nr 8775, Ref MPA/DB, 2002-11-13.

Table 21 List of solid wood panelling and cladding (subject to EN 13823) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood product		Wood specie	Thick-ness mm	Profile min thickn mm	Density kg/m³	Orien-tation	Vapour barrier	Substrate	No of tests	FIGRA W/s	THR 600 MJ	SMOGRA m²/s²	TSP m²	Burning Particles	Class EN 13501-1	Ref. no
1	Panelling	Spruce	9	6	430	Vert	-	Closed air gap 40 mm	3	463±55	20±3	2	37±6	no	D-s1, d0	3.4.10
2	-"-	-"-	9	6	408	Vert	PE-Paper class F 3)	Min wool 5) class A2-s1,d0	3	547±63	32±2	2	33±9	yes/no	D-s1, d2	3.4.10
3	-"-	-"-	9	6	370	Vert	PE-LD class E/F 4)	-"-	1	657	36	3	37	yes	D-s1, d1	3.4.10
4	-"-	-"-	12	8	423	Vert	-	-"-	2	428±80	20±1	1	25±5	no	D-s1, d0	3.4.10
5	-"-	-"-	9	6	382	Vert	-	Insulation 7) class E/F	3	560±105	27±3	2	29±11	no	D-s1, d0	3.4.10
6	Cladding	-"-	21	12,5	399	Vert	-	Open air gap 21 mm	2	520±94	16±1	2	44±25	no	D-s1, d0	3.4.10
7	-"-	Sitka spruce	21	21 1)	400	Vert	-	-"-	1	543	12	4	40	no	D-s1, d0	3.4.10
8	-"-	Spruce	21	12,5	430	Hor	-	-"-	3	454±57	15±1	8	49±10	no	D-s1, d0	3.4.10
9	-"-	Sitka spruce	21	21 1)	397	Hor.	-	-"-	3	426±36	13±1	7	39±8	no	D-s1, d0	3.4.10
9a	Panelling	Spruce	9	6	399	Vert	-	Closed air gap 40 mm	1	481	18	3	45	no	D-s1, d0	3.4.10
9b	-"-	-"-	9	6	388	Vert	-	Min wool 5) class A2-s1,d0	3	503±18	27±2	0	24±10	no/yes	D-s1, d1	3.4.10
10a	-"-	-"-	10	10 1)	404	Vert	-	Closed air gap 40 mm	3	460±37	15±1	2	39±8	no	D-s1, d0	3.4.10
10b	-"-	-"-	10	10	388	Vert	-	Min wool 5) class A2-s1,d0	2	452 ± 44	23±0,9	0	25±1	no	D-s1, d0	3.4.10
12	-"-	-"-	12	8	405	Vert	PE-Paper class F 3)	-"-	2	447±85	19±2	2	34±8	no	D-s1, d0	3.4.10
30	-"-	Pinus pinaster	10	5 2)	545	Hor./Vert.	-	Min wool 6) class A2-s1,d0	4	458±98	46±9	2	47±14	no	D-s1, d0	3.4.5
31	-"-	-"-	10	5 2)	545	Hor./Vert.	-	Closed air gap 20 mm	4	406±54	43±10	8	89±34	no	D-s2, d0	3.4.5
32	-"-	Oak	11	11	740	Hor.	-	-"-	3	240±18	25±2	0	17±2	no	D-s1, d0	3.4.6
33	Cladding	Larch	19,5	12	640	Vert	-	-"-	3	239±7	12±0	8	49±10	no	C-s1, d0	3.4.7
34	-"-	Oregon pine	19,5	9	510	Vert	-	Closed air gap 35 mm	3	315±33	17±6	10	87±11	no	D-s2, d0	3.4.8
35	-"-	Red cedar	17,6	12	350	Hor	-	Open air gap 25 mm	3	689±57	15±1	12	98±17	no	D-s2, d0	3.4.9

1) No tougue and groove; 2) two profiles of type 'Grain d'Orge' and two profiles of type 'Mouchette';
3) PE-Paper (paper with plastic facing), 160 g/m², F class fire performance; 4) Rani PE-LD (plastic foil), 185 g/m², F/E class fire performance.
5) Thickness 100 mm, density about 11 kg/m³; 6) Thickness 20 mm; 7) Cellulose insulation, thickness 45 mm, density about 60 kg/m², F/E class fire performance.

Table 22 List of solid wood ribbons and panelling (subject to EN 13823) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood product		Wood specie	Thick -ness mm	Profile min thickn mm	Width mm	Spac-ing mm	Density kg/m³	Orien-tation	Vap. Barr.	Substrate	No of tests	FIGRA W/s	THR 600 MJ	SMOGRA m²/s²	TSP m²	Burn. Part.	Class EN 13501-1	Ref. no
10	Ribbons	Spruce	21	21 [1]	70	70	430	Hor. [4]	-	Open air gap [2] 46 mm	2	810±93	55±4	4	49±11	no	E	3.4.11
11	-"-	-"-	21	21 [1]	70	70	380	Hor. [5]	-	-"-	1 [9]	≈130	> 45	≈29	> 87	no	E	3.4.11
13	-"-	-"-	21	21 [1]	70	100	430	Hor. [4]	-	-"-	1	679	36	2	27	no	D-s1, d0	3.4.11
14	-"-	-"-	10	10 [1]	75	120	440	Vert [3]	-	-"-	1	895	62	8	85	no	E	3.4.12
15	-"-	-"-	21	21 [1]	70	140	450	-"-	-	-"-	1	553	46	4	51	no	D-s1, d0	3.4.12
16	-"-	-"-	21	21 [1]	70	100	450	Hor. [4]	-	-"-	1	664	41	2	34	no	D-s1, d0	3.4.12
17	-"-	-"-	10	10 [1]	75	100	440	-"-	-	-"-	2	600±21	33±3	1	36±0	no	D-s1, d0	3.4.12
18	-"-	-"-	21	21 [1]	70	150	450	Hor. [5]	-	-"-	5	670±37	74±3	7	67±12	no/yes	D-s1, d1	3.4.12
19	Panelling	-"-	9	6	87	-	445	Hor.	Al foil	Open air gap [7] + min wool [6]	3	413±20	39±6	17	77±26	no	D-s2, d0	3.4.13
20	-"-	-"-	10	10 [1]	92	-	450	Vert	-	Closed air gap [7] + particleboard	1	462	17	2	21	no	D-s1, d0	3.4.13
21	-"-	-"-	10	10 [1]	92	-	450	-"-	-	-"- [8]	1	340	14	2	34	no	D-s1, d0	3.4.13
22	-"-	-"-	10	10 [1]	92	-	450	Hor.	-	-"- [7]	1	398	18	7	33	no	D-s1, d0	3.4.13
22b	-"-	-"-	9	6	89	-	440	-"-	-	-"- [7]	2 [9]	(460)	21±2	(6)	32±1	no	Undef.	3.4.13
23	-"-	-"-	10	10 [1]	92	-	450	-"-	-	-"- [8]	1 [9]	(371)	19	(9)	42	no	Undef.	3.4.13

[1] No tougue and groove; [2] Calcium silicate substrate behind the air gap; [3] with flat side at 45°; [4] with flat side vertical; [5] with flat side horizontal; [6] thickness 50 mm; [7] air gap 20-21 mm; [8] air gap 40 mm; [9] early termination of one test.

References

3.4.11 Paloposki T: Fire tests of wooden grating structures according to EN 13823:2002 (SBI) test procedure, VTT Research Report No RTE 3259 /03, 2003.
3.4.12 Hakkarainen T: Additional fire tests of wood grating structures according to EN 13823:2002 (SBI) test procedure, VTT Research Report No RTE 4148 /03, 2003.
3.4.13 Hakkarainen T: Additional fire tests of wood panelling and cladding according to EN 13823:2002 (SBI) test procedure, VTT Research Report No RTE 4212 /03, 2003.

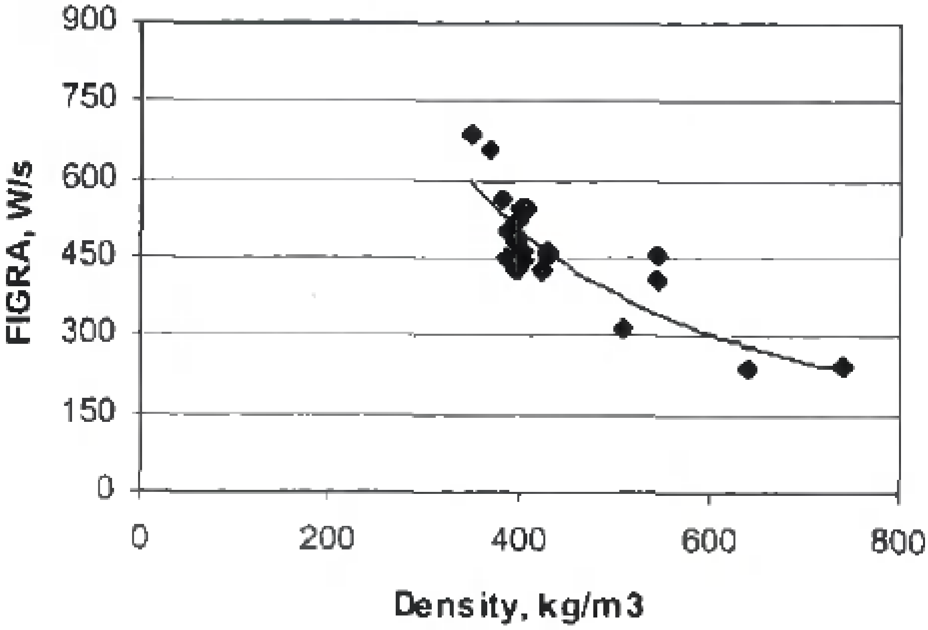


Figure 10 FIGRA values versus density for tested solid-wood panels and cladding (9-21 mm thick) samples. (Östman and Mikkola, 2004)

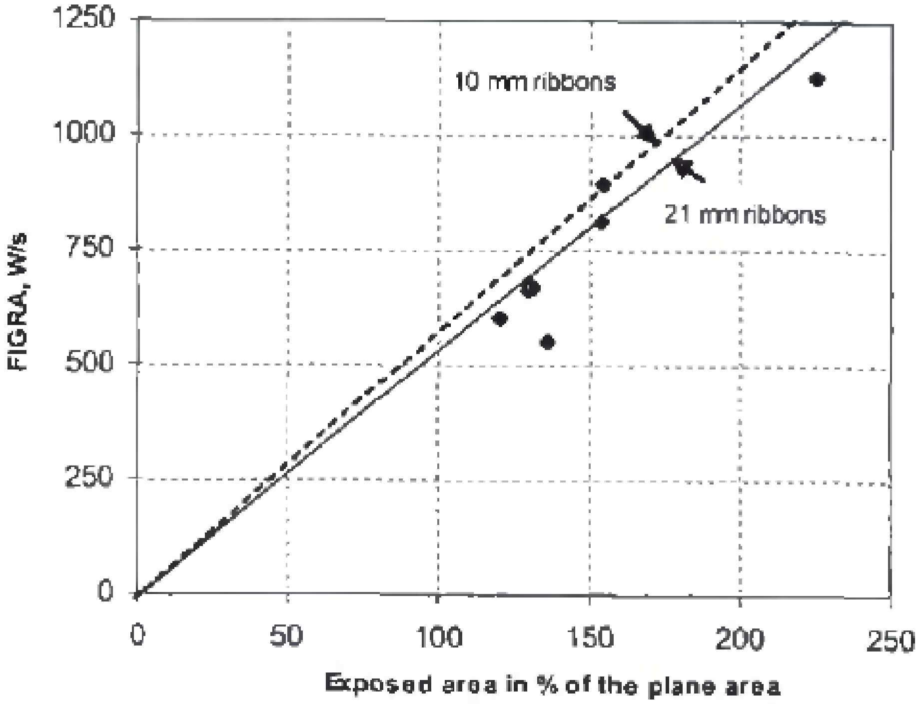


Figure 11 FIGRA values versus exposed surface area of the plane area for tested wood ribbons (10 – 21 mm wide) samples. (Östman and Mikkola, 2004)

The Australian Timber Database (ATD, 2013b) lists a range of solid timber species (Table 23) that all had a Building Code of Australia Classification of Group Number 3 and an average extinction area of less than 250 m^2/kg, all at least 9 mm thick. This summary was based on an assessment (EWFA, 2010;Paroz, 2002) of various timber species and various thicknesses and a smooth milled surface finish were tested in accordance with AS/NZS 3837:1998 at 50 kW/m^2 irradiance. Allowable joint profiles included v-joint, shiplap profile, regency, or any other profile with a nominal thickness of 9 mm and a minimum of 5 mm thickness at any discrete point.

Table 23 Summary of Building Code of Australian Group Numbers for a various solid timber species with a thickness of at least 9 mm. Extracted from ATD (2013b).

	Group Number	Average Extinction Area
Ash, Alpine	3	Less than 250m^2/kg
Ash, Mountain	3	Less than 250m^2/kg
Ash, mountain (Tasmanian oak)	3	Less than 250m^2/kg
Ash, Silvertop	3	Less than 250m^2/kg
Beech, Myrtle	3	Less than 250m^2/kg
Blackbutt	3	Less than 250m^2/kg
Blackbutt, New England	3	Less than 250m^2/kg
Blackbutt, WA *	3	Less than 250m^2/kg
Blackwood	3	Less than 250m^2/kg
Bloodwood, Red	3	Less than 250m^2/kg
Box, Brush	3	Less than 250m^2/kg
Box, Grey	3	Less than 250m^2/kg
Brownbarrel	3	Less than 250m^2/kg
Cedar, western red	3	Less than 250m^2/kg
Cypress pine, northern (white cypress pine)	3	Less than 250m^2/kg
Gum, Blue, Southern	3	Less than 250m^2/kg
Gum, Blue, Sydney	3	Less than 250m^2/kg
Gum, Manna	3	Less than 250m^2/kg
Gum, River Red	3	Less than 250m^2/kg
Gum, Rose	3	Less than 250m^2/kg
Gum, Shining	3	Less than 250m^2/kg
Gum, Spotted	3	Less than 250m^2/kg
Gum, Sugar	3	Less than 250m^2/kg
Gum, Yellow	3	Less than 250m^2/kg
Ironbark, Grey	3	Less than 250m^2/kg
Ironbark, Red	3	Less than 250m^2/kg
Jarrah	3	Less than 250m^2/kg
Karri	3	Less than 250m^2/kg
Kwila (merbau)	3	Less than 250m^2/kg
Mahogany, Red	3	Less than 250m^2/kg
Messmate	3	Less than 250m^2/kg
Oak, red, American	3	Less than 250m^2/kg
Pine, Celery-top	3	Less than 250m^2/kg
Pine, Radiata	3	Less than 250m^2/kg
Rosewood, Papua New Guinea	3	Less than 250m^2/kg
Stringybark, Yellow	3	Less than 250m^2/kg
Tallowwood	3	Less than 250m^2/kg
Turpentine	3	Less than 250m^2/kg
Walnut, black (American walnut)	3	Less than 250m^2/kg
Wattle, Silver	3	Less than 250m^2/kg

Wade et al. (2001) investigated the impact on time to ignition of fire-retardant coating systems on wood products and the effects of varying application rates and (three different procedures for) simulated weathering/ageing using small-scale tests (AS/NZS 3837 and AS 1530 Part 3), as summarised in Table 24. Coating-substrate combinations, intended for interior use, investigated included:

- A clear intumescent coating system, C1, on 10 mm thick radiata pine plywood (455 kg/m³),
- An opaque intumescent coating system, C2, on 10 mm thick radiata pine plywood (455 kg/m³), and
- An ablative fire retardant coating, C3, on a 12 mm thick cellulose fibre insulation board (339 kg/m³).

The coating systems used were, more specifically (Wade et al., 2001):

- C1 – an opaque intumescent basecoating designed to protect specific substrates from the effects of heat and fire and an acrylic pain with low flammability characteristics for the topseal.
    - Application rates tested:
        - Rate 1: 200 g/m² basecoat and 85 g/m² topseal
        - Rate 2: 130 g/m² basecoat and 85 g/m² topseal
- C2 – a clear intumescent coating for internal used, designed to protect timber and timber-based products from the effects of fire, consisting of a base coat and top seal.
    - Application rates tested:
        - Rate 1: 200 g/m² basecoat and 85 g/m² topseal
        - Rate 2: 130 g/m² basecoat and 85 g/m² topseal
- C3 – was a factory applied fire-retardant paint coating.

The durability aspects are included in the discussion in Section 3.5.

A summary of average cone calorimeter test results for the plywood-substrate samples is included in Table 25 (Wade et al, 2001). Heat release rates versus time results for the unweathered samples are shown in Figure 12 to Figure 16. A summary of the test variables for the various substrates and weathering processes are shown in Figure 17 and Figure 18, for the two types of manually applied paints. A visual summary of the influence of the different coating rates/thicknesses is included in Figure 19.

The plywood samples with the two coating systems and two application rates did not show a general trend between average heat release rate and time to ignition for three different coatings and two coating thicknesses (Figure 19).

The acrylic topcoat was reported to provide sufficient fuel for ignition and sustained flaming (Wade et al, 2001), which was consistent with previous findings (Alexious and Garner, 1986;Saxena and Gupta, 1990).

In summary, for the investigated interior lining samples (Wade et al., 2001), various methods for classifying fire performance based on cone calorimeter results (50 kW/m²) were considered, and conclusions included that estimating fire performance based on the substrate alone (i.e. without intended coating systems applied) was not recommended.

The flame spread results reported by the manufacturers for C1 and C2, when tested to AS 1530 Part 3, generally increased with the decreased application rates.

Table 24 Summary of test matrix performed on 3 interior wall linings with fire-retardant coating systems and with or without simulated weathering processes. Extracted from Wade et al. (2001).

ID	Substrate	Coatings	Weathering	Fire Tests
Interior Applications				
A	radiata pine ply 10 mm thick density 455 kg/m^3	none	none	EFH & cone @ 50 kW/m^2
B	radiata pine ply 10 mm thick density 455 kg/m^3	opaque intumescent system (½ recommended application rate)	none	cone @ 50 kW/m^2
C	radiata pine ply 10 mm thick density 455 kg/m^3	opaque intumescent system (½ recommended application rate)	yes (W1)	cone @ 50 kW/m^2
D	radiata pine ply 10 mm thick density 455 kg/m^3	opaque intumescent system (recommended application rate)	none	cone @ 50 kW/m^2
E	radiata pine ply 10 mm thick density 455 kg/m^3	opaque intumescent system (recommended application rate)	yes (W1)	cone @ 50 kW/m^2
F	radiata pine ply 10 mm thick density 455 kg/m^3	clear varnish intumescent system (recommended application rate)	none	EFH & cone @ 50 kW/m^2
G	radiata pine ply 10 mm thick density 455 kg/m^3	clear varnish intumescent system (recommended application rate)	yes (W1)	cone @ 50 kW/m^2
H	radiata pine ply 10 mm thick density 455 kg/m^3	clear varnish intumescent system (½ recommended application rate)	none	EFH & cone @ 50 kW/m^2
I	radiata pine ply 10 mm thick density 455 kg/m^3	clear varnish intumescent system (½ recommended application rate)	yes (W1)	cone @ 50 kW/m^2
J	radiata pine ply 10 mm thick density 455 kg/m^3	clear varnish intumescent system (recommended application rate)	yes (W2)	EFH & cone @ 50 kW/m^2
K	radiata pine ply 10 mm thick density 455 kg/m^3	clear varnish intumescent system (½ recommended application rate)	yes (W2)	EFH & cone @ 50 kW/m^2
L	cellulose fibre insulation board 12 mm thick density 339 kg/m^3	factory-applied fire-retardant coating	none	cone @ 50 kW/m^2
M	cellulose fibre insulation board 12 mm thick density 339 kg/m^3	factory-applied fire-retardant coating	yes (W1)	cone @ 50 kW/m^2
S	cellulose fibre insulation board 12 mm thick density 339 kg/m^3	none	none	cone @ 50 kW/m^2

Table 25 Summary of mean cone calorimeter results for 10 mm thick plywood substrate with various fire-retardant coating systems and with and without simulated weathering. Extracted from Wade et al. (2001).

System ID	*Ignition time (s)*	*End of test[a] (s)*	*Total heat evolved[a] (MJ/kg)*	*Peak RHR (kW/m²)*	*60 s average RHR[b] (kW/m²)*	*180 s average RHR[b] (kW/m²)*	*300 s average RHR[b] (kW/m²)*	*Average RHR[c] (kW/m²)*	*Average EHC[a] (MJ/kg)*	*Average SEA[a] (m²/kg)*
A – UW	20 ± 5	447 ± 81	46.3 ± 3.5	216 ± 25	148 ± 10	115 ± 8	131 ± 13	109 ± 20	11.4 ± 0.6	86 ± 13
B – UW ½ app rate	20 ± 10	450 ± 99	51.3 ± 8.0	236 ± 29	152 ± 4	119 ± 31	141 ± 23	121 ± 32	11.8 ± 1.4	93 ± 41
C – W ½ app rate	37 ± 1	498 ± 108	44.8 ± 4.2	196 ± 63	125 ± 11	104 ± 9	123 ± 24	101 ± 32	10.2 ± 0.8	73 ± 41
D – UW full app rate	24 ± 4	598 ± 185	45.7 ± 5.9	216 ± 34	26 ± 6	59 ± 11	82 ± 26	82 ± 20	10.4 ± 0.1	97 ± 35
E – W full app rate	61 ± 55	478 ± 35	41.7 ± 1.7	242 ± 27	37 ± 58	70 ± 35	96 ± 37	100 ± 10	10.0 ± 0.6	NA
H – UW ½ app rate	52 ± 7	525 ± 148	43.2 ± 5.4	187 ± 49	110 ± 18	103 ± 5	119 ± 23	95 ± 26	9.9 ± 0.8	NA
I – W1 ½ app rate	34 ± 4	390 ± 17	40.0 ± 1.7	224 ± 60	103 ± 16	102 ± 32	122 ± 9	109 ± 6	9.7 ± 0.5	112 ± 25
K – W2 ½ app rate	51 ± 12	450 ± 46	43.2 ± 3.8	220 ± 76	119 ± 8	105 ± 4	129 ± 17	109 ± 19	9.9 ± 0.5	NA
F – UW full app rate	86 ± 10	490 ± 33	39.2 ± 0.8	178 ± 55	84 ± 12	97 ± 11	115 ± 8	97 ± 9	9.7 ± 0.3	NA
G – W1 full app rate	80 ± 21`	556 ± 118	39.9 ± 2.3	158 ± 53	99 ± 23	102 ± 8	109 ± 13	87 ± 19	9.8 ± 0.6	NA
J – W2 full app rate	84 ± 12	460 ± 26	36.4 ± 1.9	198 ± 42	80 ± 14	91 ± 19	113 ± 10	97 ± 11	8.6 ± 0.5	NA

Table Notes:

* All results are mean ± 95% confidence interval for three replicates

[a] From start of test; [b] From ignition; [c] From ignition to end of test

EHC = Effective heat of combustion
RHR = Rate of heat release
SEA = Specific extinction area (a measure of smoke)
UW = Unweathered
W1 = Weathered: For interior application – humidity chamber, humidity – temperature cycles
W2 = Weathered: For interior application – manual washing procedure
NA = Data not available

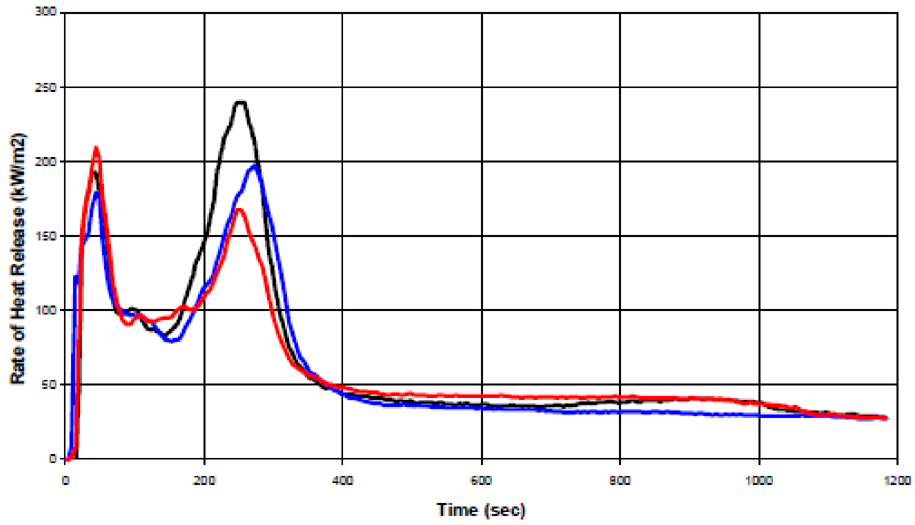


Figure 12 Heat release rate versus time for three specimens of uncoated unweathered plywood (A). Extracted from Wade et al. (2001).

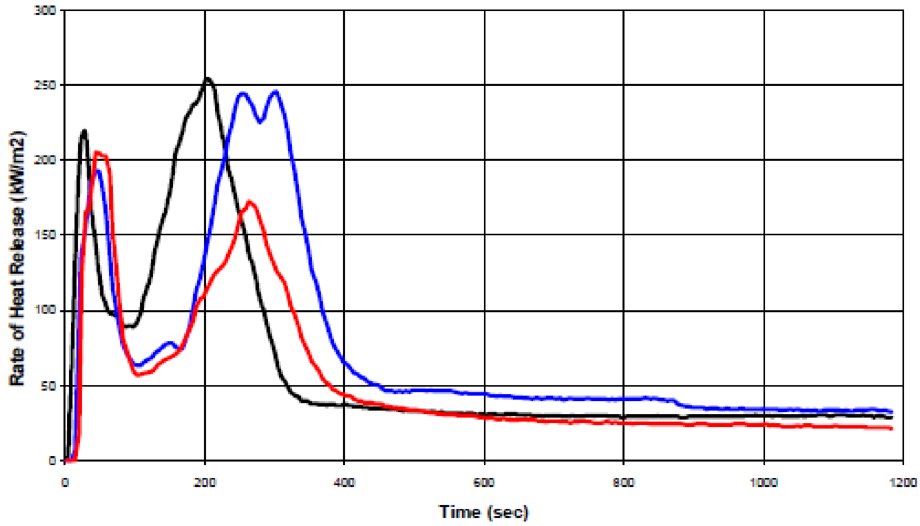


Figure 13 Heat release rate versus time for three specimens of R2 application of C1 unweathered plywood (B). Extracted from Wade et al. (2001).

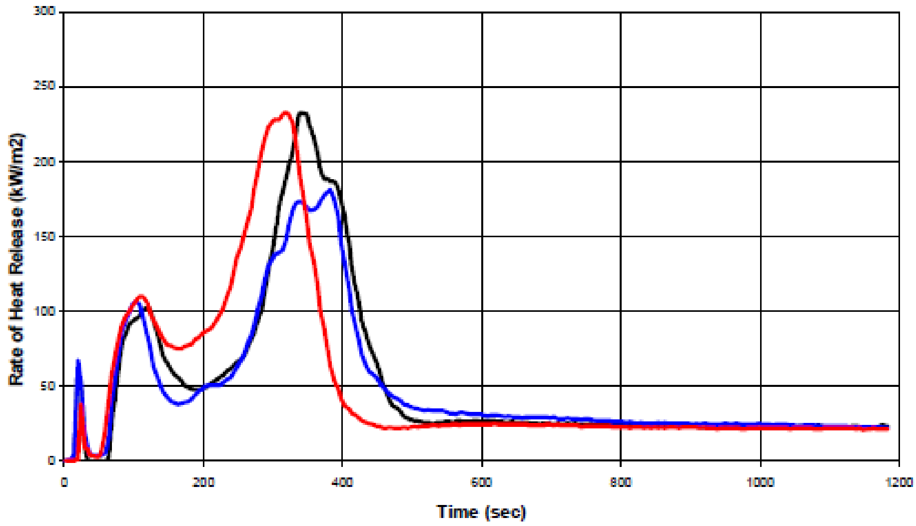


Figure 14 Heat release rate versus time for three specimens of R1 application of C1 unweathered plywood (D). Extracted from Wade et al. (2001).

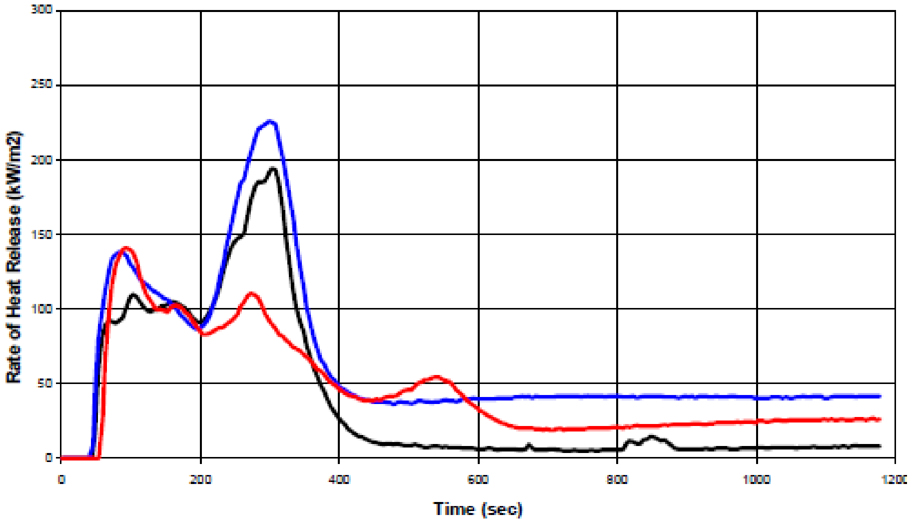


Figure 15 Heat release rate versus time for three specimens of R2 application of C2 unweathered plywood (F). Extracted from Wade et al. (2001).

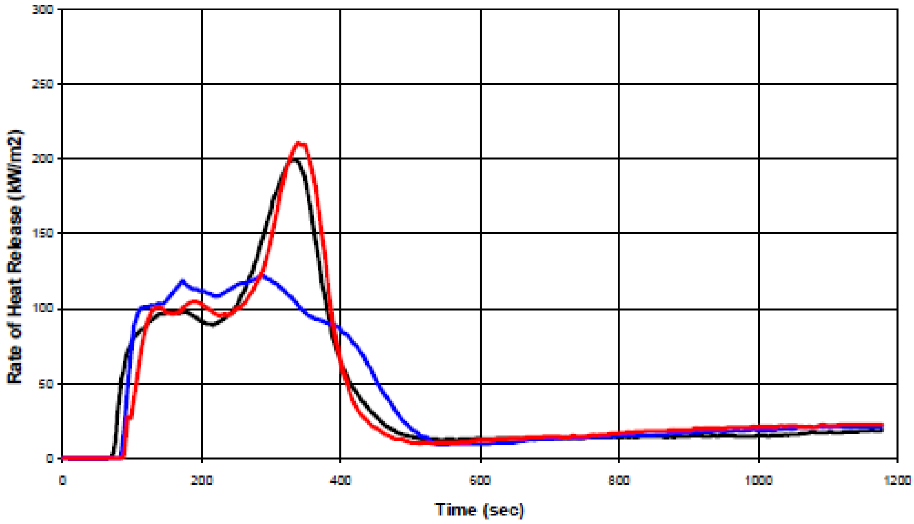


Figure 16 Heat release rate versus time for three specimens of R1 application of C2 unweathered plywood (H). Extracted from Wade et al. (2001).

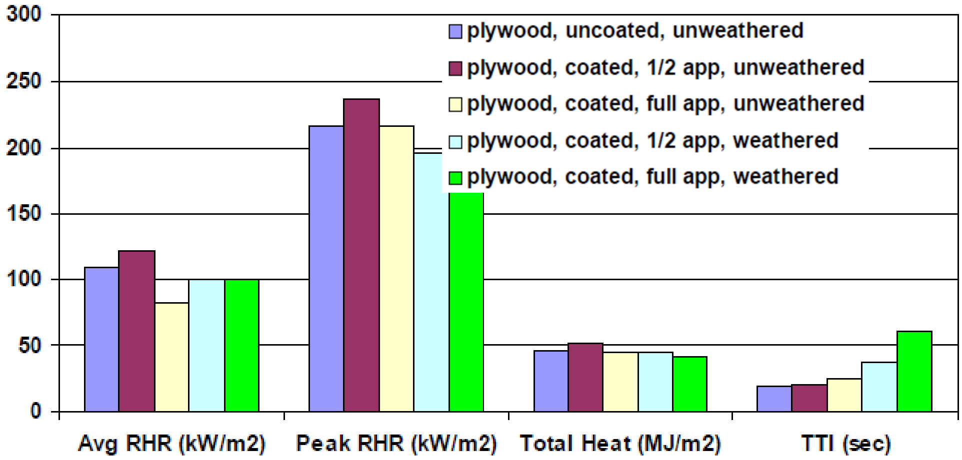


Figure 17 Summary of mean cone calorimeter results (TTI = time to ignition) for C1 on plywood. Extracted from Wade et al. (2001).

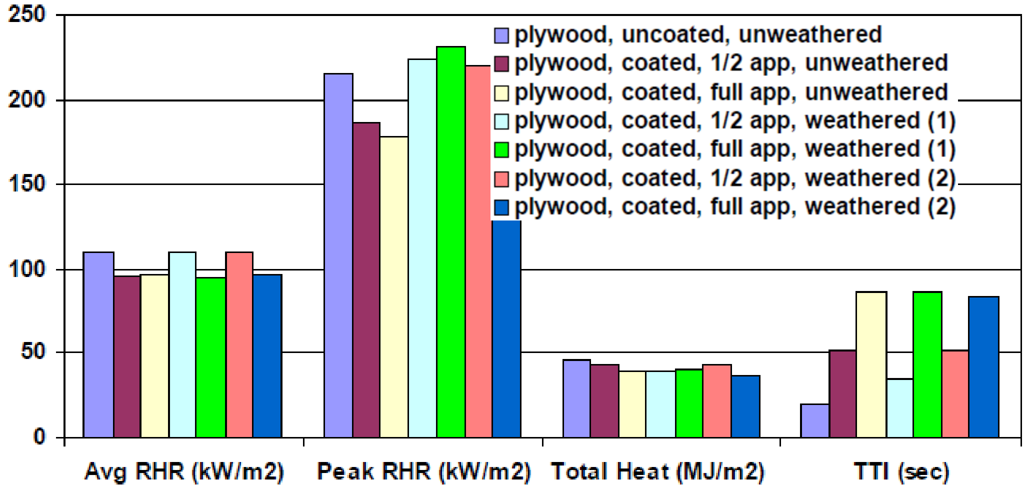


Figure 18 Summary of mean cone calorimeter results (TTI = time to ignition) for C2 on plywood. Extracted from Wade et al. (2001).

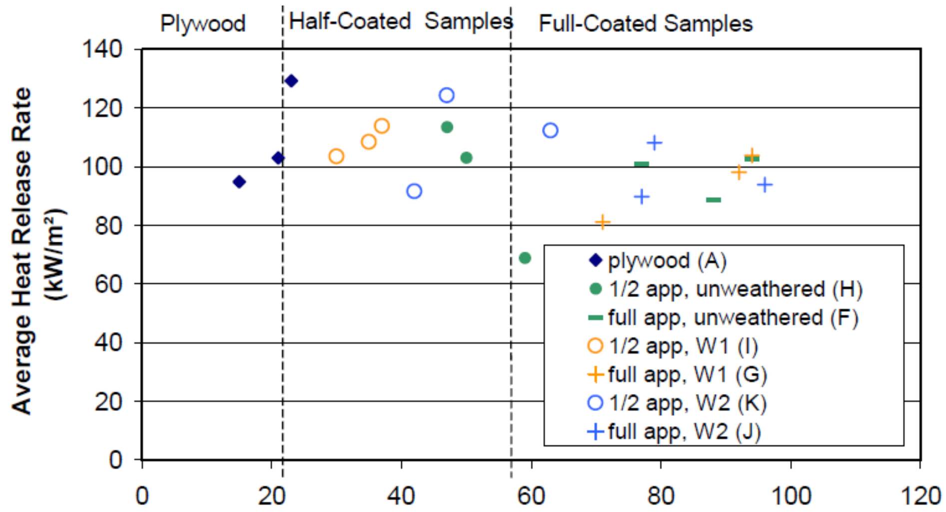


Figure 19 Summary mean average heat release rate versus time to ignition for the plywood specimens with various coatings. Extracted from Wade et al. (2001).

3.1.1.1.1 Laminated Timber

Similarly to structural timber (21 to 22 mm thick) results reported by Östman and Mikkola (2006), glued laminated timber (40 mm thick) products also were reported to show a decrease in FIGRA values for increasing density (Figure 20). Various densities and wood species were tested (as summarised in Table 26 and Table 27). Specimens were tested with and without an open air gap. Specimens with various glues were also tested. (Östman and Mikkola, 2006)

Table 26 List of glue laminated structural timber (subject to EN 11925-2) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood specie	Glue 3)	Thick-ness mm	Density kg/m^3	Lamella thickness mm	Flame spread within 60 s, mm		Ignition of filter paper	Class EN 13501-1	Ref. no
					Surface	Edge			
Spruce	Res.	40	384	18	< 150	< 150	No	*	3.3.1
-"-	PU	40	366	18	< 150	< 150	No	*	3.3.1
-"-	MUF	40	365	18	< 150	< 150	No	*	3.3.1
Douglas fir	MUF	40	482	18	< 150	< 150	No	*	3.3.1
Spruce, hor.	MUF	40	414	18	< 150	< 150	No	*	3.3.2
Spruce, vert. 1)	MUF	40	414	18	< 150	< 150	No	*	3.3.2
Spruce, vert. 2)	MUF	40	414	18	-	< 150	No	*	3.3.2
Larch, hor.	Res.	40	642	18	< 150	< 150	No	*	3.3.2
Larch, vert. 1)	Res.	40	642	18	< 150	< 150	No	*	3.3.2
Larch, vert. 2)	Res.	40	642	18	-	< 150	No	*	3.3.2

1) flame impingement on wood; 3) Res.= Resorcinol; PU= Polyurethane; MUF=Melamine Urea formaldehyde glue;
*2) flame impingement on glue line; * Satisfies the small flame requirements for class D.*

References

3.3.1 Prüfbericht Nr. PB III/B-03-227 vom 06/08/2003 1. Ausfertigung, MFPA Leipzig GmbH
3.3.2 Fire test according to EN 13823, 2002 (SBI method), Report P300091A, 2003-03-18, SP Fire technology.

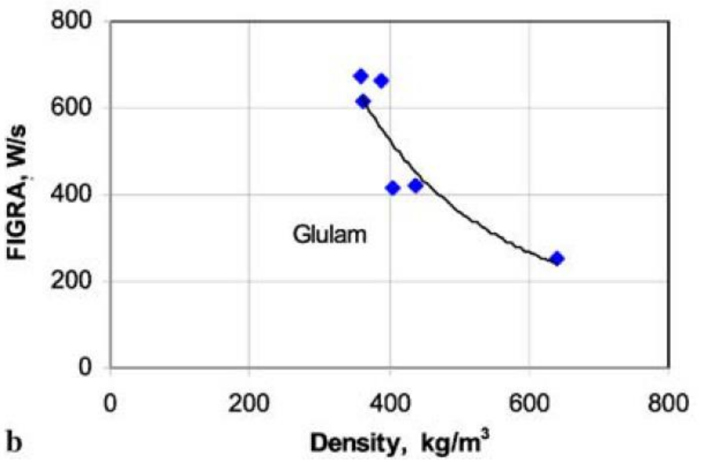
Table 27 List of glue laminated structural timber (subject to EN 11823) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood specie	Glue 1)	Thick ness mm	Density kg/m^3	Lam thick ness mm	Air gap mm	FIGRA (W/s)	THR 600 (MJ)	SMOGRA (m^2/s^2)	TSP (m^2)	Burn. Part.	Class EN 13501-1	Ref. no
Spruce	Res.	40	388	18	40	661	15,8	6	78	No	D-s2, d0	3.3.3
-"-	PU	40	362	18	40	616	15,5	4	71	No	D-s2, d0	3.3.3
-"-	MUF	40	360	18	40	674	18,2	7	67	No	D-s2, d0	3.3.3
Douglas fir	MUF	40	438	18	40	422	13,5	6	64	No	D-s2, d0	3.3.3
Spruce	MUF	40	405	18	60	414 ± 28	13,2 ± 1,0	2 ± 0,4	45 ± 6,5	No	D-s1, d0	3.3.4
Larch	Res.	40	640	18	60	251 ± 16	13,5 ± 0,4	2 ± 0,1	36 ± 3,1	No	D-s1, d0	3.3.4

1) Res. = Resorcinol; PU= Polyurethane; MUF=Melamine Urea formaldehyde glue.

References

3.3.3 Prüfbericht Nr. PB III/B-03-226 vom 06/08/2003 1. Ausfertigung, MFPA Leipzig GmbH
3.3.4 Fire test according to EN 13823, 2002 (SBI method), Report P300091, 2003-03-18, SP Fire Technology.



b

Figure 20 FIGRA values versus density for tested 40 mm thick glue laminated (Glulam) timber samples. (Östman and Mikkola, 2006)

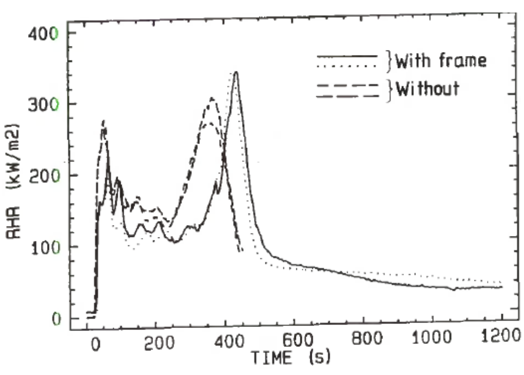
3.1.1.2 Plywood

A summary of average results for various plywood samples tested in a cone calorimeter at an irradiance of 50 kW/m² and ISO 9705 room testing by Tsantaridis and Östman (1990), Thureson (1991) and Tsantaridis (1992) that has been used in support of the development of the basis for the European Classification without Further Testing scheme is presented in Table 28. Heat release rates and smoke specific extinction areas are shown in Figure 21 for the 12 mm thick birch plywood sample.

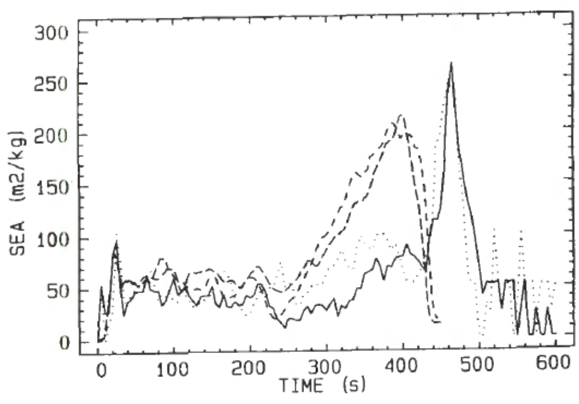
Table 28 Summary of reported time to ignition and average effective heat of combustion for 50 kW/m² irradiance cone calorimeter tests and time to flashover in room test of substrates and coatings.

Material Description	Time To Flashover in ISO room (min:s) [Ref. E, F]	Time to Ignition in Cone Calorimeter (s)	Average Effective Heat of Combustion (kJ/g)	Total Heat Released (MJ/m²)	Average Rate of Smoke Production/ Rate of Heat Release (ob.m³/MJ)	Ref.
Plywood, birch, 12 mm thick	2:30	26 30	NR	78.4	NR	B C
Plywood B, FR	-	NI	NR	NR	NR	D
Plywood K, FR	-	30	NR	NR	NR	D
Plywood A	-	26	NR	NR	NR	D
Plywood L	-	21	NR	NR	NR	D

Table Notes:
Ref. refers to Reference for test results.
NR refers to Not Reported.
NI refers to No Ignition
FR refers to material had a Fire Retardant treatment.
- refers to not investigated
Ref. B: Average results from two tests reported by Thureson (1991).
Ref. C: Average results from two tests reported by Tsantaridis (1992) for cone calorimeter testing at 50 kW/m² using a retainer frame. Comparison of test results performed with and without a retainer frame by two different laboratories was reported by Tsantaridis (1992) to have good repeatability for the products tested.
Ref. D: Results reported by Tsantaridis and Östman (1990).



(a)



(b)

Figure 21 (a) Heat release rate and (b) specific extinction area for 2 specimens of Birch plywood at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis (1992), including data from Thureson (1991).

As part of a project considering the fire performance of 10 various wall linings in a Building Code of Australia (BCA) context, Collier et al. (2006) compared AS 3837 and ISO 9705 test results. A summary of the results for plywood substrates included in this project is presented in Table 29. In this case the smoke production for the plywood samples didn't exceed either the AS 3837 SEA limit (of 250 m²/kg) or the ISO 9705 SMOGRA limit (of 100 m²/s² x 1000) for the BCA context.

Table 29 Summary of the smoke production results for a vinyl wallpaper for AS 3837 and ISO 9705 tests for a BCA context. Extracted from Collier et al (2006).

Material	AS 3837 average SEA (m²/kg)	AS 3837 Total Heat Released (MJ/m²)	AS 3837 prediction of BCA Group number **	ISO 9705 SPR60 (peak) (m²/s)	ISO 9705 SMOGRA (m²/s² x 1000)	ISO 9705 BCA Group number
Plywood	110.4	-	3	5	27.4	3
Ply+intumescent x 2	165	-	1(3†)	8.5	10.8	2
Ply+intumescent x 3	105.9	-	1(3†)	-	-	-

Table Notes:
* 250 m²/kg limit was exceeded, and BCA only permits use in sprinklered premises.
** Estimated according to BCA 2006 Volume One Spec A2.4-3. See APPENDIX 2 – Classification of data, Section 10.1.1 Predicting a material's BCA Group number.
† Prediction of BCA Group number using ISO 5660-1 end of test criteria.

Similar to the assessment carried out for The Australian Timber Database (ATD, 2013b) for solid wood samples, various medium density fibreboards, particle boards, and plywood of various species and thicknesses, also with a smooth milled finish, were also considered (EWFA, 2010;Paroz, 2002). Plywood made from Lauan, Radiata Pine or any of the species listed in Table 23 of a minimum thickness of 6 mm, without a limitation of substrate, and with the use of PVA, resorcinol or PU adhesives was considered. A Building Code of Australia Classification of Group Number 3 and an average extinction area of less than 250 m²/kg was recommended.

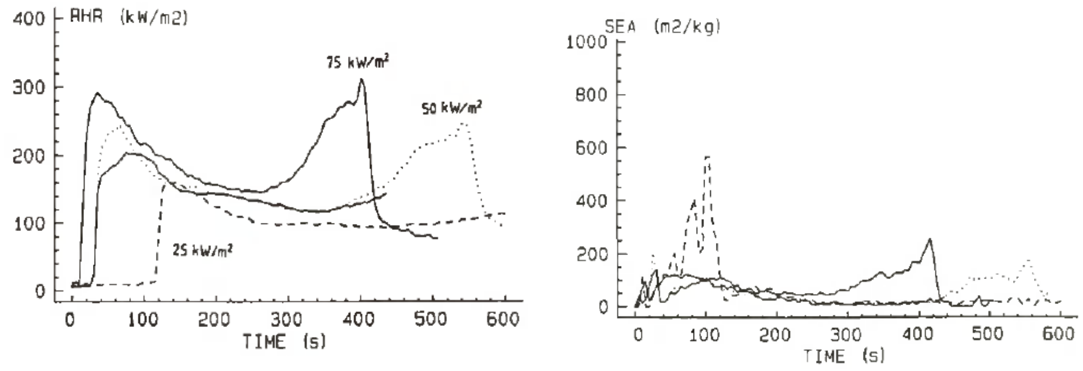
3.1.1.3 Particleboard

As part of the research supporting the European Classification without Further Testing, particleboard samples tested at 50 kW/m² irradiance in the cone calorimeter and ISO 9705 room testing have been reported on by Tsantaridis and Östman (1989, 1990, 1999), Tsantaridis (1992) and Thureson (1991, 1992). A summary of average test results is included in Table 30. Heat release rates and smoke specific extinction areas are included for some of the samples listed in Table 30 in Figure 22 to Figure 28.

Table 30 Summary of reported time to ignition and average effective heat of combustion for 50 kW/m² irradiance cone calorimeter tests and time to flashover in room test of substrates and coatings.

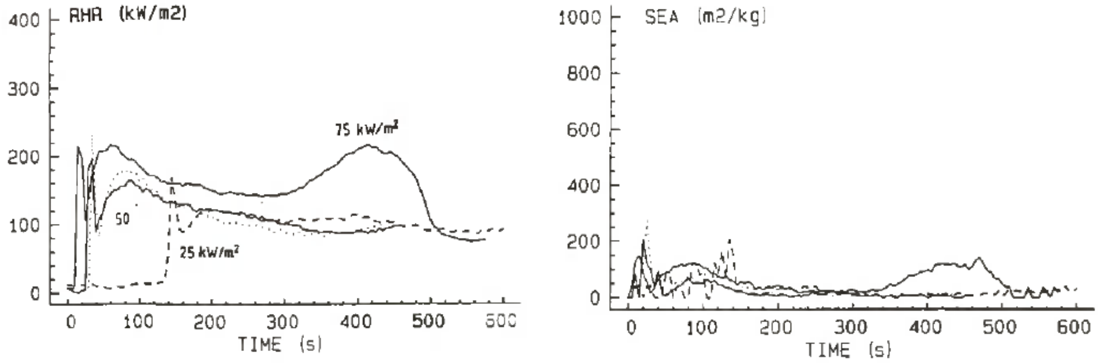
Material Description	Time To Flashover in ISO room (min:s) [Ref. E, F]	Time to Ignition in Cone Calorimeter (s)	Average Effective Heat of Combustion (kJ/g)	Total Heat Released (MJ/m²)	Average Rate of Smoke Production/ Rate of Heat Release (ob.m³/MJ)	Ref.
Particleboard, 10 mm thick	2:37	34	14	NR	21	A
Particleboard C, FR	-	48	NR	NR	NR	D
Particleboard H, FR	-	NI	NR	NR	NR	D
Particleboard D	-	33	NR	NR	NR	D
Particleboard F	-	33	NR	NR	NR	D
Melamine-faced particleboard, 13 mm thick	7:45	42	11	NR	201	A
Paper wall-covering on particleboard, 10 + 0.5 mm thick	2:23	27	12	NR	16	A
Fire retardant particle board (type German B1), 16 mm thick	10:30	19.5 21	NR	7.5	NR	B C
Fire retarded particle board, 12 mm thick	> 20 :00	196 700	NR	8.2	NR	B C
Intumescent coat on particleboard	11:44	411	60	97.6		F

Table Notes:
Ref. refers to Reference for test results.
NR refers to Not Reported.
NI refers to No Ignition
FR refers to material had a Fire Retardant treatment.
- refers to not reported because of irregularities.
Ref. A: Average results from two tests, as reported by Tsantaridis and Östman (1989).
Ref. B: Average results from two tests reported by Thureson (1991).
Ref. C: Average results from two tests reported by Tsantaridis (1992) for cone calorimeter testing at 50 kW/m² using a retainer frame. Comparison of test results performed with and without a retainer frame by two different laboratories was reported by Tsantaridis (1992) to have good repeatability for the products tested.
Ref. D: Results reported by Tsantaridis and Östman (1990).
Ref. F: Average results from three test reported by Tsantaridis and Östman (1999).



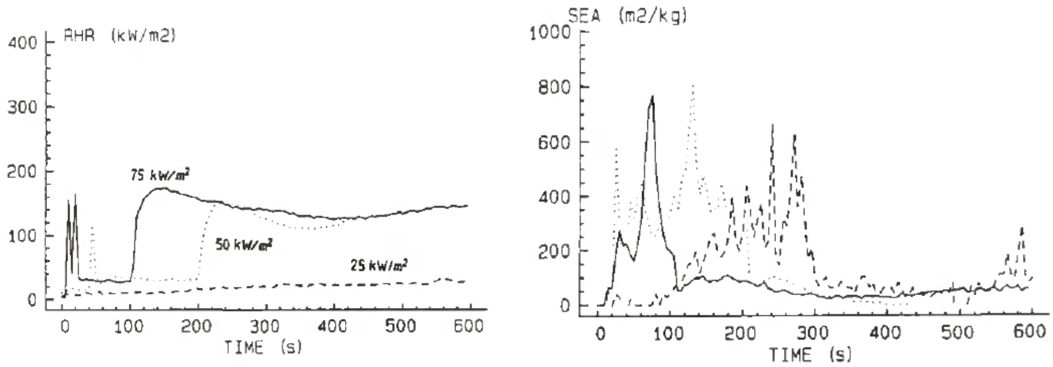
(a) **(b)**

Figure 22 (a) Rate of Heat Release (RHR) and (b) Specific Extinction Area (SEA) for 10 mm thick particle board. Two tests performed at 50 kW/m². Extracted from Tsantaridis and Östman (1989).



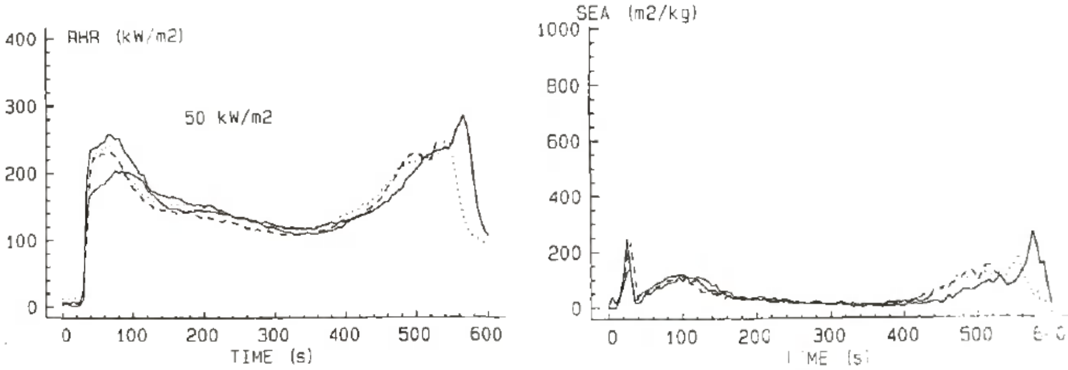
(a) **(b)**

Figure 23 (a) Rate of Heat Release (RHR) and (b) Specific Extinction Area (SEA) for 0.5 mm thick wallpaper covering on 13 mm thick particle board. Two tests performed at 50 kW/m². Extracted form Tsantaridis and Östman (1989).



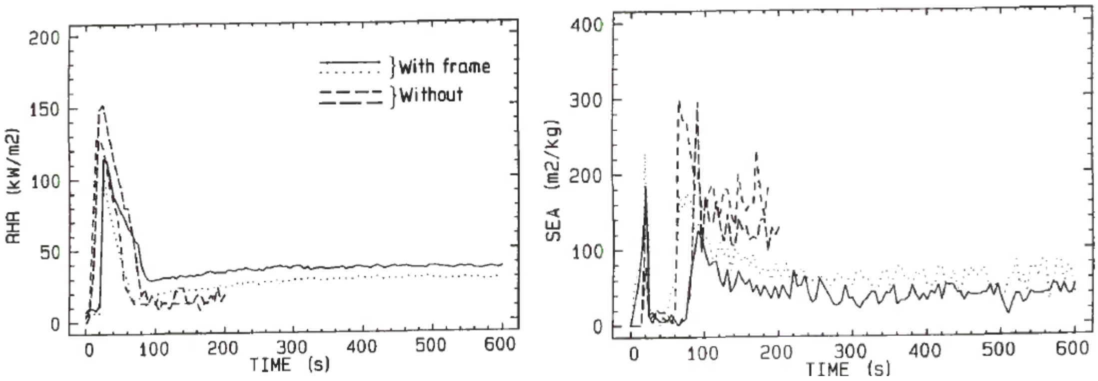
(a) **(b)**

Figure 24 (a) Rate of Heat Release (RHR) and (b) Specific Extinction Area (SEA) for melamine facing on particle board at 13 mm total thickness. Extracted form Tsantaridis and Östman (1989).



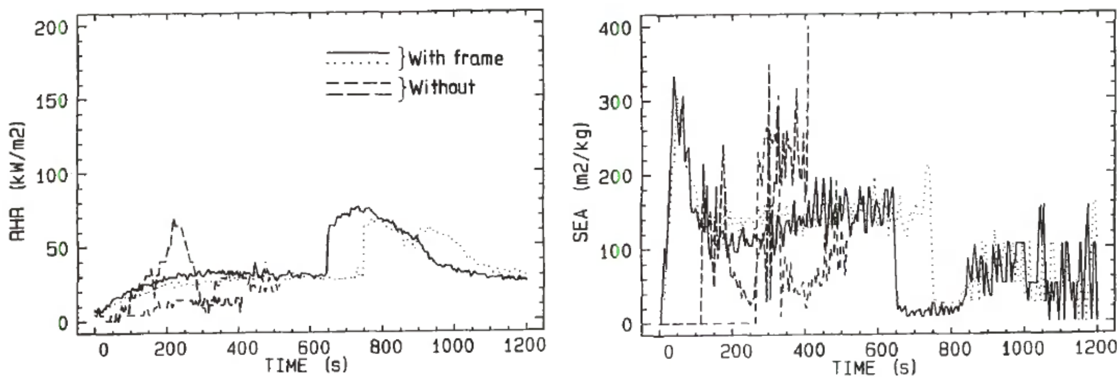
(a) **(b)**

Figure 25 (a) Rate of Heat Release (RHR) and (b) Specific Extinction Area (SEA) for 10 mm thick particle board. Four tests performed at 50 kW/m². Extracted form Tsantaridis and Östman (1989).



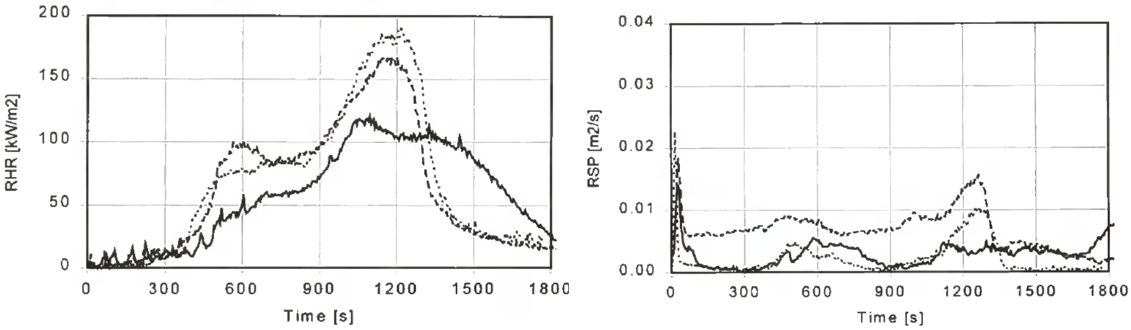
(a) **(b)**

Figure 26 (a) Heat release rate and (b) specific extinction area for 2 specimens of fire retardant particle board (type German B1) at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis (1992), including data from Thureson (1991).



(a) **(b)**

Figure 27 (a) Heat release rate and (b) specific extinction area for 2 specimens of fire retardant particle board at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis (1992), including data from Thureson (1991).



(a) **(b)**

Figure 28 (a) Heat release rate and (b) rate of smoke production for 3 specimens of an intumescent coat on particleboard at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis and Östman (1999).

Similar to the solid wood summary section, to provide a comparison for the current New Zealand regulations, where sufficient published data was available material group numbers were calculated according to the description in the NZBC Verification Method C/VM2 (2013c). A summary of these results in included in each relevant section; Table 31 includes a summary for particleboard specimens (some also listed in Table 30) tested by Tsantaridis and Östman (1989) and Thureson (1991) (and summarised by Kokkala, Thomas and Karlsson (1993)), where indicative NZ material group numbers could be calculated.

Table 31 Summary of various reported tested specimens with a plasterboard substrate. Data extracted from Tsantaridis and Östman (1989) and Thureson (1991), initial analysis extracted from Kokkala, Thomas and Karlsson (1993) and Group Number from NZBC C/VM2 (2013c) application.

Description of Material	I_{ig} (1/min)	$I_{Q,m=34}$	$I_{Q,m=0.93}$	$I_{Q,10min}$	$I_{Q.2min}$	$I_{Q,12min}$	NZ Group Number
Particle board, 10 mm thick	1.76	11927	1873	5849	2184	1359	3
Paper wall covering on particle board, 10 + 0.5 mm thick	2.22	10042	1766	5601	2108	1283	3
Melamine-faced particle board, 13 mm (total) thick	1.43	6059	1219	6027	2239	1414	3
Fire retarded particleboard (German B1), 16 mm thick	2.88	2798	1262	5244	1999	1174	2
	3.31	2155	1179	5012	1928	1103	2
Fire retarded particleboard, 12 mm thick	5	1758	1010	4100	1650	825	2
	0.22	0	0	6681	2438	1613	1

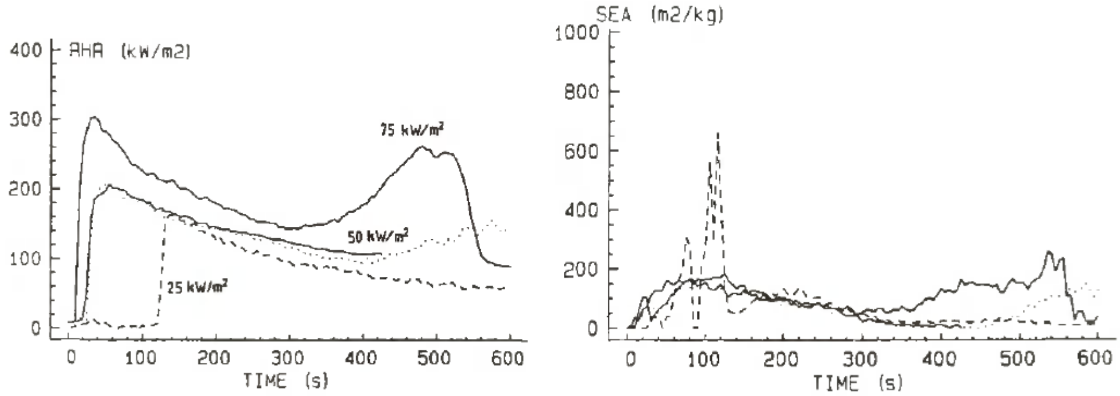
3.1.1.4 Fibreboard

As part of the research supporting the European Classification without Further Testing, particleboard samples tested at 50 kW/m² irradiance in the cone calorimeter and ISO 9705 room testing have been reported on by Tsantaridis and Östman (1989, 1990, 1999), Tsantaridis (1992) and Thureson (1991). A summary of average test results is included in Table 32. Heat release rates and smoke specific extinction areas are included for some of the samples listed in Table 30 in Figure 29 to Figure 31, and Figure 32.

Table 32 Summary of reported time to ignition and average effective heat of combustion for 50 kW/m² irradiance cone calorimeter tests and time to flashover in room test of substrates and coatings.

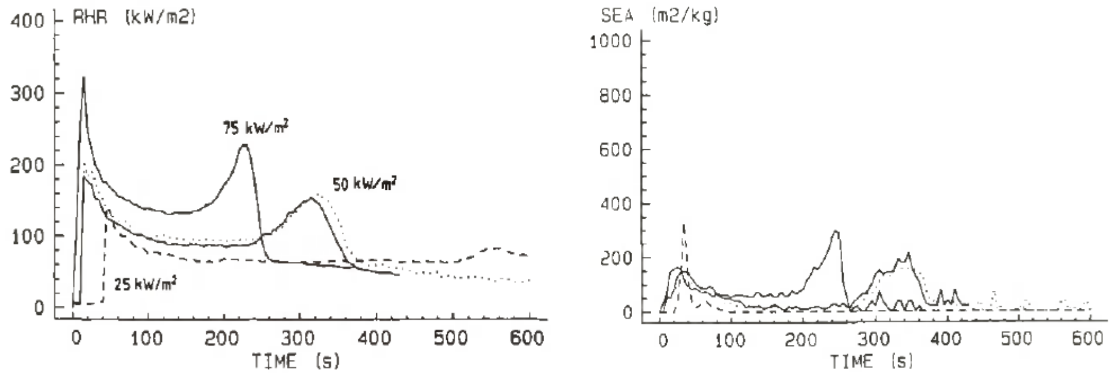
Material Description	Time To Flashover in ISO room (min:s) [Ref. E, F]	Time to Ignition in Cone Calorimeter (s)	Average Effective Heat of Combustion (kJ/g)	Total Heat Released (MJ/m²)	Average Rate of Smoke Production/ Rate of Heat Release (ob.m³/MJ)	Ref.
Insulating fibre board, 13 mm thick	0:59	12	14	NR	26	A
Insulating board P3, FR	-	21	NR	NR	NR	D
Insulating board P0	-	11	NR	NR	NR	D
Melamine-faced high-density non-combustible board, 12.5 mm thick	> 20 :00	110 29	NR	7.4	NR	B C
Textile covering on calcium silicate board	> 20:00	31	28	5.7	-	
Low-density fibreboard	1:20	10	116	43.2	-	F
Medium density fibre board, 12 mm thick	2:11	28	14	NR	34	A
Melamine-faced medium density fibreboard	3:04	45	142	107	-	F
Fibreboard T5, FR	-	515	NR	NR	NR	D
Fibreboard FH, FR	-	37	NR	NR	NR	D
Fibreboard KH	-	22	NR	NR	NR	D
Hardboard RF, FR	-	30	NR	NR	NR	D
Hardboard AS	-	38	NR	NR	NR	D

Table Notes:
Ref. refers to Reference for test results.
NR refers to Not Reported.
NI refers to No Ignition
FR refers to material had a Fire Retardant treatment.
- refers to not reported because of irregularities.
Ref. A: Average results from two tests, as reported by Tsantaridis and Östman (1989).
Ref. B: Average results from two tests reported by Thureson (1991).
Ref. C: Average results from two tests reported by Tsantaridis (1992) for cone calorimeter testing at 50 kW/m² using a retainer frame. Comparison of test results performed with and without a retainer frame by two different laboratories was reported by Tsantaridis (1992) to have good repeatability for the products tested.
Ref. D: Results reported by Tsantaridis and Östman (1990).



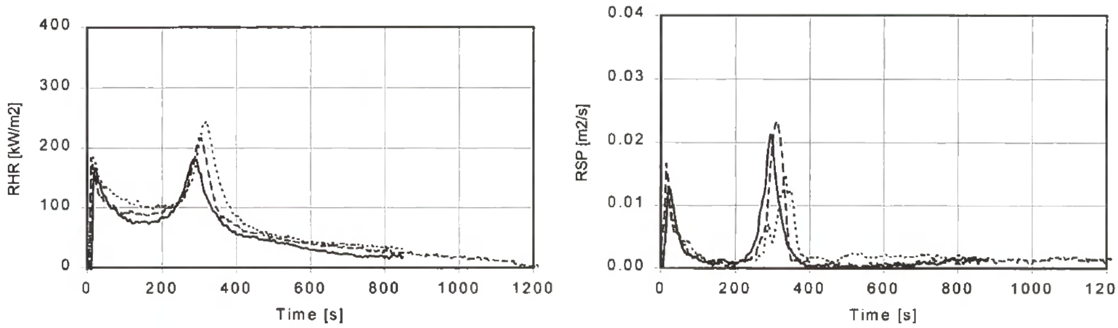
(a) **(b)**

Figure 29 (a) Rate of Heat Release (RHR) and (b) Specific Extinction Area (SEA) for 12 mm thick medium density fibre board. Two tests performed at 50 kW/m². Extracted form Tsantaridis and Östman (1989).



(a) **(b)**

Figure 30 (a) Rate of Heat Release (RHR) and (b) Specific Extinction Area (SEA) for 13 mm thick insulating fibre board. Two tests performed at 50 kW/m². Extracted form Tsantaridis and Östman (1989).



(a) **(b)**

Figure 31 (a) Heat release rate and (b) rate of smoke production for 3 specimens of low-density fibreboard at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis and Östman (1999).

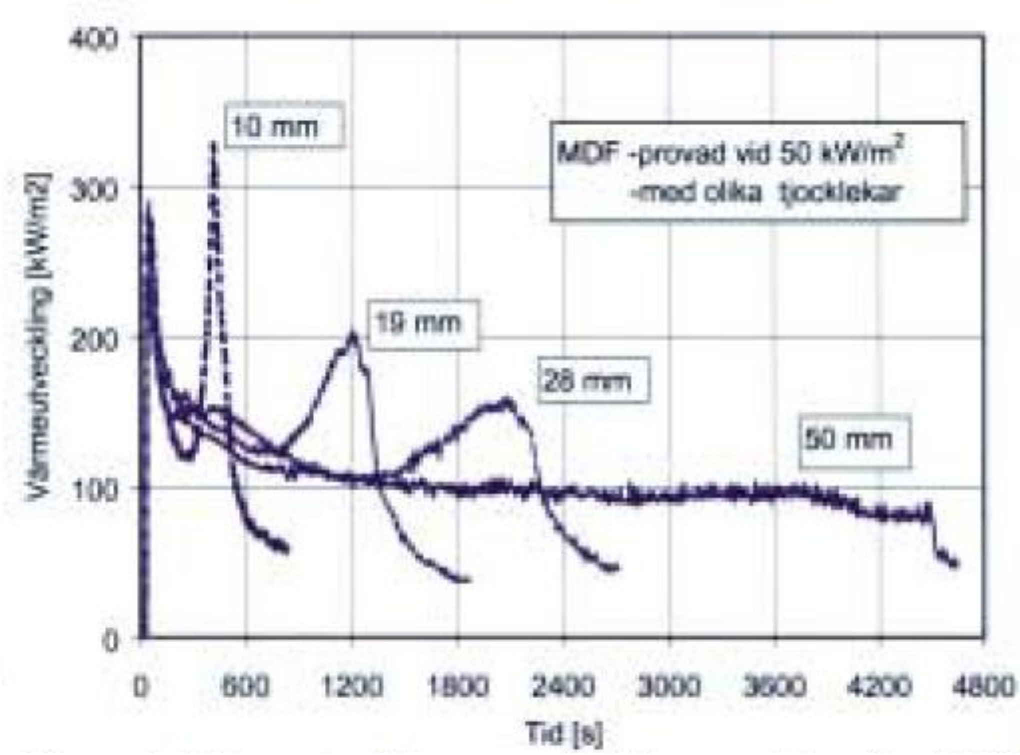


Figure 32 Rate of heat release rate versus time for various thicknesses of medium density fibreboard tested at 50 kW/m². Extracted from Tsantaridis (2003a)

Similar to the previous sections, to provide a comparison for the current New Zealand regulations, where sufficient published data was available material group numbers were calculated according to the description in the NZBC Verification Method C/VM2 (2013c). A summary of these results in included in each relevant section; Table 33 includes a summary for fibreboard specimens (also included in Table 32) tested by Tsantaridis and Östman (1989) and Thureson (1991) (and summarised by Kokkala, Thomas and Karlsson (1993)), where indicative NZ material group numbers could be calculated.

Table 33 Summary of various reported tested specimens with a plasterboard substrate. Data extracted from Tsantaridis and Östman (1989) and Thureson (1991), initial analysis extracted from Kokkala, Thomas and Karlsson (1993) and Group Number from NZBC C/VM2 (2013c) application.

Description of Material	I_{ig} (1/min)	$I_{Q,m=34}$	$I_{Q,m=0.93}$	$I_{Q,10min}$	$I_{Q.2min}$	$I_{Q,12min}$	NZ Group Number
Insulating fibre board, 13 mm thick	5	8677	1711	4100	1650	825	4
Medium-density fibre board, 12 mm thick	2.14	11874	1864	5644	2121	1296	3

As part of the project considering the fire performance of 10 various wall linings in a Building Code of Australia (BCA) context, comparing AS 3837 and ISO 9705 test results, fibreboard samples were investigated (Collier et al., 2006). A summary of the results for softwood fibreboard substrates included in this project is presented in Table 34. In this case the smoke production for the fibreboard samples didn't exceed the AS 3837 SEA limit (of 250 m²/kg).

Table 34 Summary of the smoke production results for a vinyl wallpaper for AS 3837 and ISO 9705 tests for a BCA context. Extracted from Collier et al (2006).

Material	AS 3837 average SEA (m^2/kg)	AS 3837 Total Heat Released (MJ/m^2)	AS 3837 prediction of BCA Group number **	ISO 9705 SPR60 (peak) (m^2/s)	ISO 9705 SMOGRA (m^2/s^2 x 1000)	ISO 9705 BCA Group number
Wood fibre softboard+paint	57.7	-	3	-	-	-
Wood fibre softboard	64.1	-	3	-	-	-

Table Notes:
* 250 m^2/kg limit was exceeded, and BCA only permits use in sprinklered premises.
** Estimated according to BCA 2006 Volume One Spec A2.4-3. See APPENDIX 2 – Classification of data, Section 10.1.1 Predicting a material's BCA Group number.
† Prediction of BCA Group number using ISO 5660-1 end of test criteria.

Wade et al. (2001) investigated the impact on time to ignition of fire-retardant coating systems on wood products and the effects of varying application rates and (three different procedures for) simulated weathering/ageing using small-scale tests (AS/NZS 3837 and AS 1530 Part 3), as summarised in Table 24. One of the substrates was a 12 mm thick cellulose fibre insulation board (339 kg/m^3) with an ablative factory-applied fire retardant coating, C3. A summary of average cone calorimeter test results for the unweathered fibreboard samples are presented in Table 35 and Figure 33. Heat release rates versus time for the samples are included in Figure 34 and Figure 35.

Table 35 Summary of mean cone calorimeter results for 12 mm thick cellulose insulating board substrate with and without a factory applied fire-retardant paint coating, and with and without simulated weathering. Extracted from Wade et al. (2001).

System ID	Ignition time (s)	End of test[a] (s)	Total heat evolved[a] (MJ/m^2)	Peak RHR (kW/m^2)	60 s average RHR[b] (kW/m^2)	180 s average RHR[b] (kW/m^2)	300 s average RHR[b] (kW/m^2)	Average RHR[c] (kW/m^2)	Average EHC[a] (MJ/kg)	Average SEA[a] (m^2/kg)
L – UW	22 ± 10	520 ± 61	39.1 ± 2.7	115 ± 26	73 ± 8	81 ± 5	82 ± 16	79 ± 12	11.6 ± 0.9	32 ± 34
M – W	25 ± 2	650 ± 124	35.9 ± 1.6	85 ± 3	76 ± 6	78 ± 5	73 ± 5	58 ± 9	10.1 ± 1.3	52 ± 8
S – UW no coating	12 ± 3	513 ± 79	42.8 ± 1.2	133 ± 19	113 ± 8	105 ± 15	100 ± 23	97 ± 11	12.0 ± 0.2	NA

Table Notes:
* All results are mean ± 95% confidence interval for three replicates
[a] From start of test; [b] From ignition; [c] From ignition to end of test
EHC = Effective heat of combustion
RHR = Rate of heat release
SEA = Specific extinction area (a measure of smoke)
UW = Unweathered
W = Weathered: For interior application – humidity chamber, humidity – temperature cycles

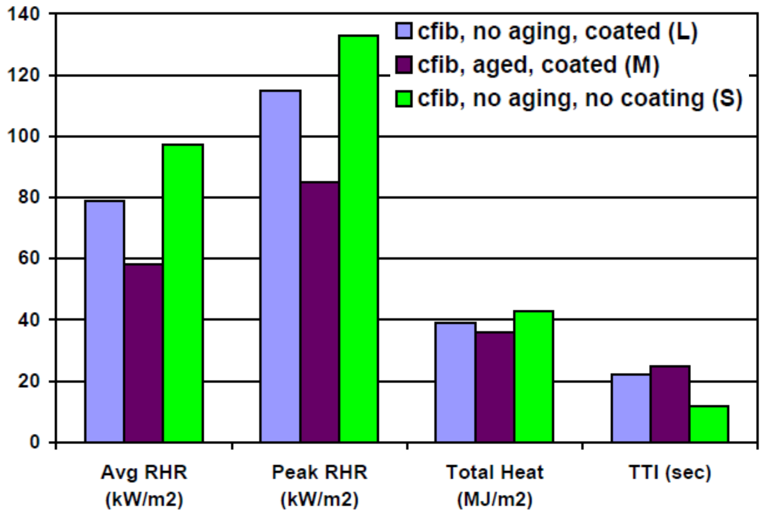


Figure 33 Summary of mean cone calorimeter results for C3 on factory-applied-coated insulating board. Extracted from Wade et al. (2001).

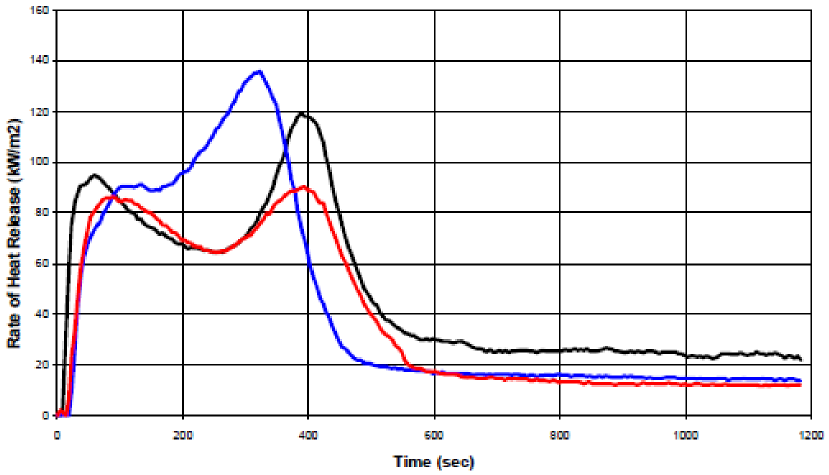


Figure 34 Heat release rate versus time for three specimens of unweathered factory-applied-coated insulating board (L). Extracted from Wade et al. (2001).

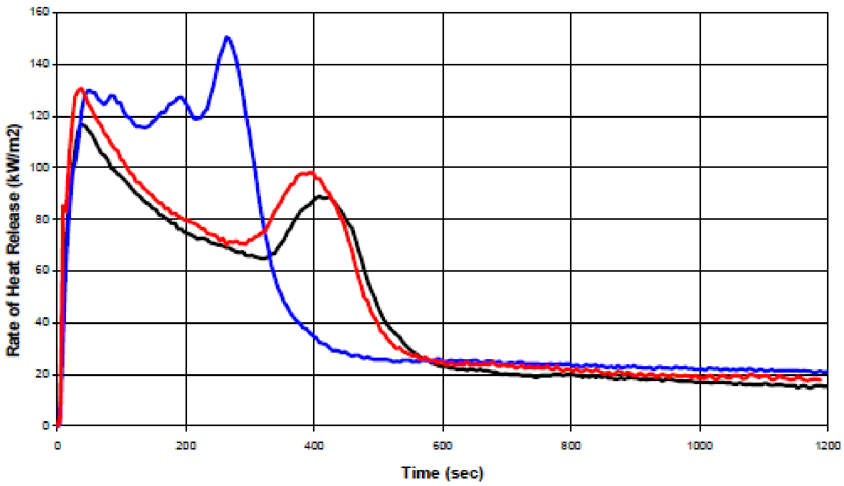


Figure 35 Heat release rate versus time for three specimens of unweathered factory-applied-coated insulating board (N). Extracted from Wade et al. (2001).

3.1.1.5 Generic Descriptions for Wood-based Products

Generic Euroclass (EN 13501-1) values for wood-based panels, according to BS/EN 13986 (2004), are based on three product parameters:

1. An EN product grade reference,
2. Minimum density, and
3. Minimum thickness.

Example of the EN13501-1 classes using classification without further testing (CWFT) for generic products are presented in Table 36 (BS/EN 13986, 2004). Classifications are as described in Commission Decision 2000/147/EC Annex Table 1 (for ceiling and wall linings).

Table 36 Examples of Euroclass classification without further testing (CWFT) generically grouped wood-based products

Wood-based panel product	EN product grade reference	Minimum density (kg/m^3)	Minimum thickness (mm)	Class (excluding floorings)
Oriented Strand Board (OSB) *	EN 300	600	9	D-s2, d0
Particleboards *	EN 312	600	9	D-s2, d0
Fibreboards, Hard *	DN 622-2	900	6	D-s2, d0
Fibreboards, Medium *	DN 622-3	600	9	D-s2, d0
		400	9	E, pass
Fibreboards, Soft *	DN 622-4	250	9	E, pass
Fibreboards, Medium Density Fibre (MDF) (Dry process fibreboard) *	prEN 622-5	600	9	D-s2, d0
Cement-bonded particleboard (at least 75% cement) *	EN 634-2	1,000	10	B-s1, d0
Plywood *	EN 636	400	9	D-s2, d0
Solid wood panels *	EN 13353	400	12	D-s2, d0
Glued laminated timber §	EN 14080	300	40	D-s2, d0
Structural timber †	EN 14081-1+A1	350	22	D-s2, d0
Wood panelling and cladding pieces with or without tongue and groove and with or without a profiled surface ∞	EN 14915	390	9 total & 6 min. Without an air gap [a3] or with a closed air gap [a4]	D-s2, d2
			12 total & 8 min. Without an air gap [a3] or with a closed air gap [a4]	
Wood panelling and cladding pieces with or without tongue and groove and with or without a profiled surface ∞	EN 14915	390	9 total & 6 min. With an open air gap ≤ 20 mm [a5]	D-s2, d0
			18 total & 12 min. Without an air gap [a5] or with a closed air gap [a4]	
Wood ribbon pieces ∞	EN 14915	390	18 Surrounded by open air [a6]	D-s2, d0

Table References (see following page):

Table References for Table 38:

* BS/EN 13986 (2004). Samples were mounted without an air gap, directly against a Class A1 or A2-s1, d0 substrate with a minimum density of 10 kg/m³, or at least a Class D-s2, d0 substrate with a minimum density of 400 kg/m³.

§ BS/EN 14080 (2005). Samples were mounted with an air gap.

† BS/EN 14081-1:2005+A1:2011 and BS/EN 14250 (2010), where the product detail is visual and machine graded structural timber with rectangular cross-sections shaped by sawing, planning or other methods or with round cross-sections; and the minimum overall thickness is 22 mm. Samples were mounted with an air gap.

∞ EN 14915 (2006). Joints include all types of joints, e.g. butt joints and tongue and groove joints. The product shall be designed to be mounted without open joints. Profiled area of the panel to not exceed 20 % of the panel area, or 25% if measured on both the exposed and unexposed sides.

Table Notes:

[a1] Substrate materials are to be of at least Class D-s2, d0 with a minimum density of 400 kg/m³ (BS/EN 14342, 2013).

[a2] Substrate materials are to be of at least Class A2-s1, d0 (BS/EN 14342, 2013).

[a3] To be mounted mechanically on a wood batten support frame, with the gap closed or filled with a substrate of at least Class A2-s1, d0 with a minimum density of 10 kg/m³ or filled with a substrate of cellulose insulation material of at least Class E and with or without a vapour barrier behind.

[a4] An open air gap may include possibility for ventilation behind the product, while a closed air gap will exclude such ventilation. The substrate behind the air gap is of at least a Class A2-s1, d0 with a minimum density of 10 kg/m³. Behind a closed air gap of a maximum 20 mm and with vertical wood pieces, the substrate may be of at least a Class D-s2, d0.

[a5] Mounded mechanically on a wood batten support frame, with or without an open air gap behind. The wood product shall be designed to be mounted without open joints.

[a6] Rectangular wood pieces, with or without rounded corners, mounted horizontally or vertically on a support frame and surrounded by air on all sides, mainly used close to other building elements, both in interior and exterior applications. Maximum exposed areas (all sides of wood pieces and wood support frame) shall be not more than 110 % of the total plane area. Other building elements at distances from the ribbon:

- closer than 100 mm from the wood ribbon element (excluding its support frame) are required to be at least a Class A2-s1, d0,
- 100 mm to 300 mm are required to be of at least a Class B-s1, d0 and
- more than 300 mm are required to be of at least Class D-s2, d0.

[b] Surface coatings included are acrylic, polyurethane or soap, 50 – 100 g/m², and oil 20 – 60 g/m² (BS/EN 14342, 2013).

[c1] For parquet of 14 mm or more thickness, an interlayer of at least Class E and with maximum thickness 3 mm may be used (BS/EN 14342, 2013).

[c2] For parquet of 14 mm or more thickness, an interlayer of at least Class E, with maximum thickness 3 mm and a minimum density of 280 kg/m³ may be used (BS/EN 14342, 2013).

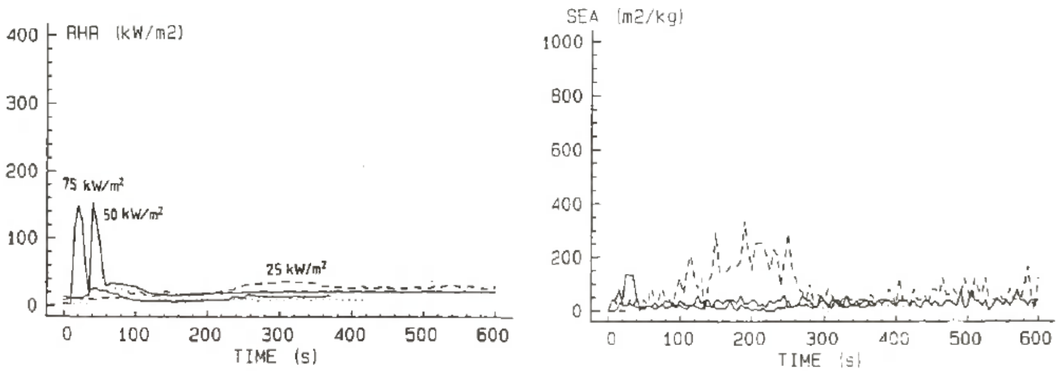
3.1.2 Plasterboards

As part of the research supporting the European Classification without Further Testing, plasterboard samples were also included in testing at 50 kW/m² irradiance in the cone calorimeter and ISO 9705 room testing and have been reported on by Tsantaridis and Östman (1989, 1990, 1999), Tsantaridis (1992) and Thureson (1991, 1992). A summary of average test results is included in Table 37. Heat release rates and smoke specific extinction areas are included for some of the samples listed in Table 37 in Figure 36 to Figure 42.

Table 37 Summary of reported time to ignition and average effective heat of combustion for 50 kW/m² irradiance cone calorimeter tests and time to flashover in room test of substrates and coatings.

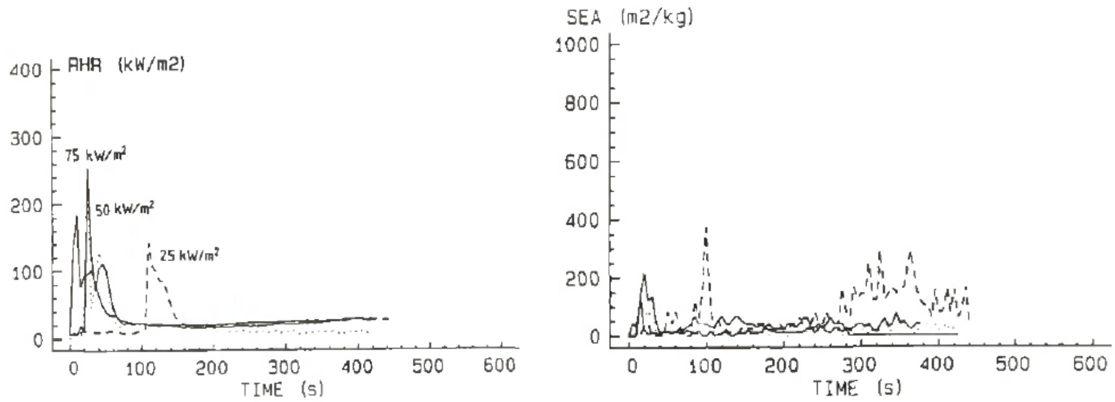
Material Description	Time To Flashover in ISO room (min:s) [Ref. E, F]	Time to Ignition in Cone Calorimeter (s)	Average Effective Heat of Combustion (kJ/g)	Total Heat Released (MJ/m²)	Average Rate of Smoke Production/ Rate of Heat Release (ob.m³/MJ)	Ref.
Plasterboard, 13 mm thick	> 20:00	34	-	NR	16	A
Paper wall-covering on plasterboard, 13 + 0.5 mm thick	10:40	21	-	NR	26	A
Plastic wall-covering on plasterboard, 13 + 0.7 mm thick	10:11	10	13	NR	29	A
Textile wall-covering on plasterboard, 13 + 0.5 mm thick	10:29	20	12	NR	26	A
Painted paper-faced plasterboard, 12 mm thick	> 20 :00	44 47 39	NR	3.9	NR	B C F
Textile wall-covering on paper-faced plasterboard, 12 mm (total) thick	11:00	21.5 25	NR	10.6	NR	B C
PVC wall carpet on gypsum paper plasterboard (affixed with vinylacetate copolymers), 13 mm (total) thick	> 20 :00	14.5 15	NR	16.1	NR	B C

Table Notes:
Ref. refers to Reference for test results.
NR refers to Not Reported.
NI refers to No Ignition
FR refers to material had a Fire Retardant treatment.
- refers to not reported because of irregularities.
Ref. A: Average results from two tests, as reported by Tsantaridis and Östman (1989).
Ref. B: Average results from two tests reported by Thureson (1991).
Ref. C: Average results from two tests reported by Tsantaridis (1992) for cone calorimeter testing at 50 kW/m² using a retainer frame. Comparison of test results performed with and without a retainer frame by two different laboratories was reported by Tsantaridis (1992) to have good repeatability for the products tested.
Ref. E: Results reported by Östman and Tsantaridis (1993).
Ref. F: Average results from three test reported by Tsantaridis and Östman (1999).



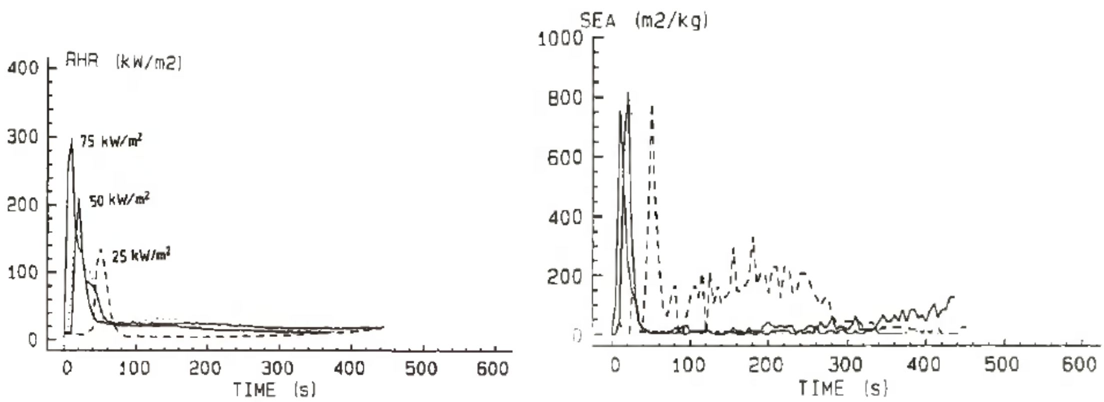
(a) (b)

Figure 36 (a) Rate of Heat Release (RHR) and (b) Specific Extinction Area (SEA) for 13 mm thick gypsum plasterboard. Two tests performed at 50 kW/m². Extracted form Tsantaridis and Östman (1989).



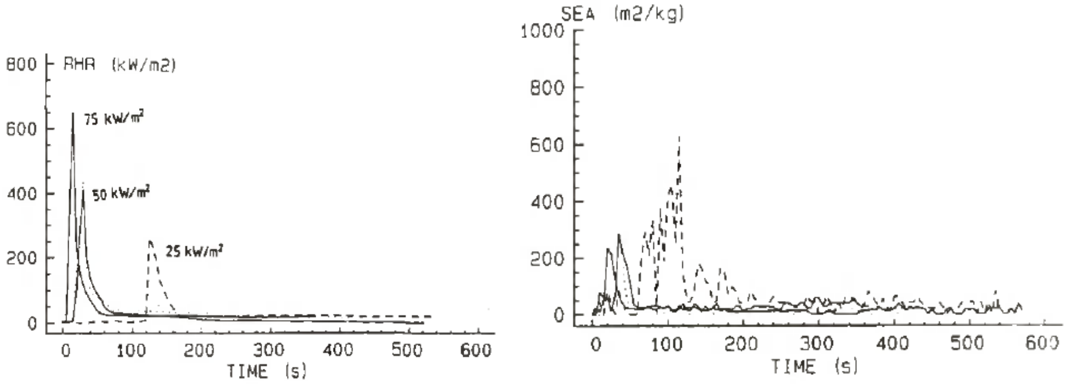
(a) (b)

Figure 37 (a) Rate of Heat Release (RHR) and (b) Specific Extinction Area (SEA) for 0.5 mm thick paper wall covering on 13 mm thick gypsum plasterboard. Two tests performed at 50 kW/m². Extracted form Tsantaridis and Östman (1989).



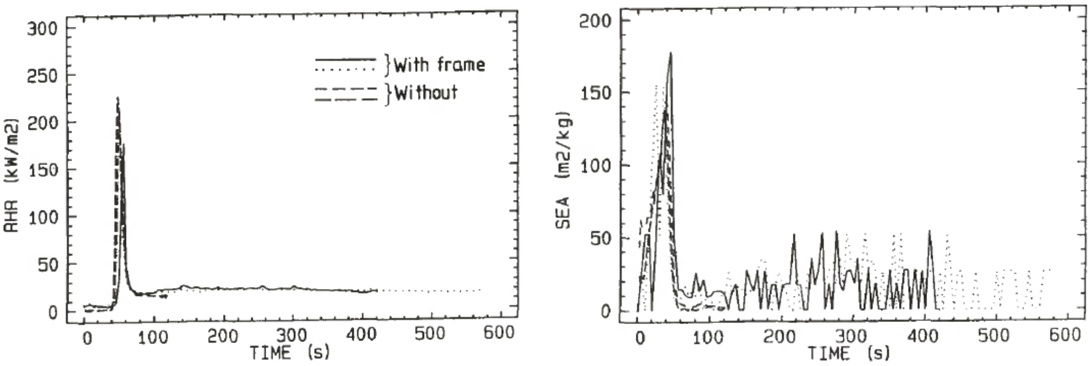
(a) (b)

Figure 38 (a) Rate of Heat Release (RHR) and (b) Specific Extinction Area (SEA) for 0.7 mm thick plastic wall covering on 13 mm thick gypsum plasterboard. Two tests performed at 50 kW/m². Extracted form Tsantaridis and Östman (1989).



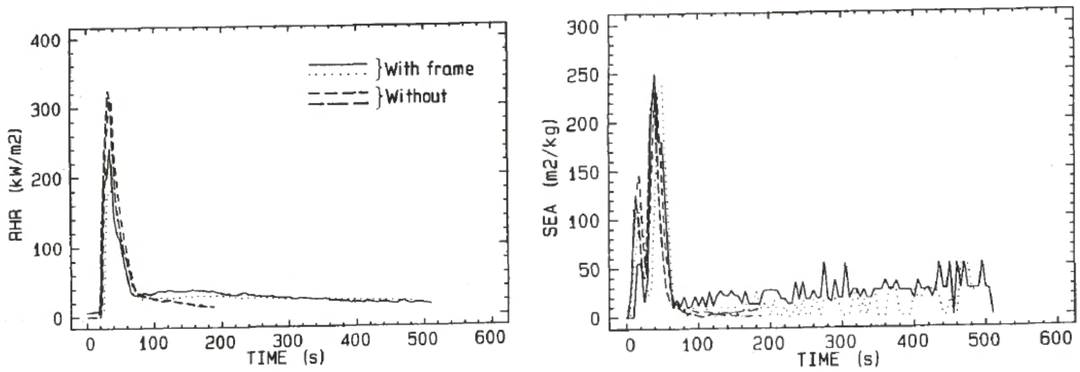
(a) (b)

Figure 39 (a) Rate of Heat Release (RHR) and (b) Specific Extinction Area (SEA) for 0.5 mm thick textile wall covering on 13 mm thick gypsum plasterboard. Two tests performed at 50 kW/m². Extracted form Tsantaridis and Östman (1989).



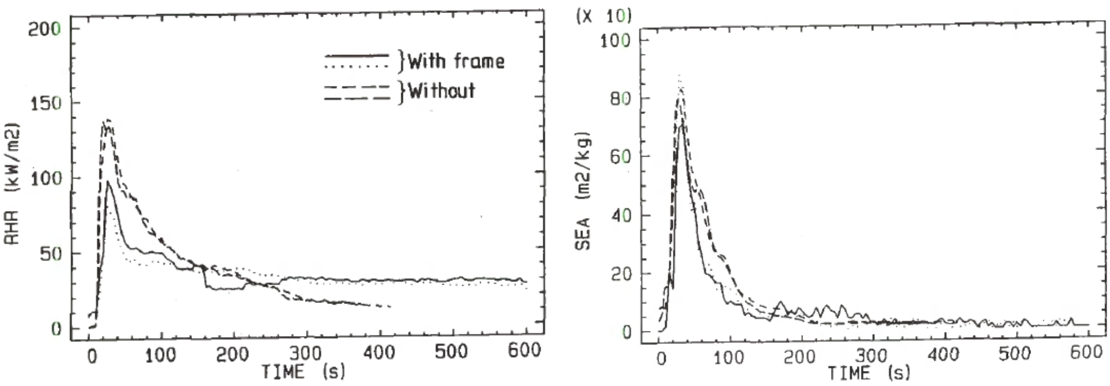
(a) (b)

Figure 40 (a) Heat release rate and (b) specific extinction area for 2 specimens of painted gypsum paper plasterboard at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis (1992), including data from Thureson (1991).



(a) (b)

Figure 41 (a) Heat release rate and (b) specific extinction area for 2 specimens of textile wall-covering on paper-faced gypsum plasterboard at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis (1992), including data from Thureson (1991).



(a) **(b)**

Figure 42 (a) Heat release rate and (b) specific extinction area for 2 specimens of PVC wall carpet on paper-faced gypsum plasterboard at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis (1992), including data from Thureson (1991).

Similar to the previous summary sections, to provide a comparison for the current New Zealand regulations, where sufficient published data was available material group numbers were calculated according to the description in the NZBC Verification Method C/VM2 (2013c). A summary of these results in included in each relevant section; Table 38 includes a summary for plasterboard specimens (some also listed in Table 37) tested by Tsantaridis and Östman (1989) and Thureson (1991) (and summarised by Kokkala, Thomas and Karlsson (1993)), where indicative NZ material group numbers could be calculated.

Table 38 Summary of various reported tested specimens with a plasterboard substrate. Extracted from Kokkala, Thomas and Karlsson (1993). With a calculation of the current NZ Group Number that would be achieved for the presented data.

Description of Material	I_{ig} **(1/min)**	$I_{Q,m=34}$	$I_{Q,m=0.93}$	$I_{Q,10min}$	$I_{Q.2min}$	$I_{Q,12min}$	**NZ Group Number**
Gypsum board	1.76	3299	1231	5849	2184	1359	1
Painted gypsum paper plaster board	1.4	1618	1256	6044	2244	1419	1
	1.33	1452	1199	6081	2255	1430	1
Textile wall covering on gypsum paper plaster board	3	3838	1618	5180	1980	1155	2
	2.61	3817	1595	5390	2044	1219	2
Plastic wall covering on gypsum board	6	3323	1338	3560	1485	660	2
Textile wall covering on gypsum board	3	4174	1537	5180	1980	1155	2
Paper wall covering on gypsum board	2.86	3408	1419	5255	2003	1178	2
PVC wall covering on gypsum paper plaster board	4.29	4077	1355	4483	1767	942	2
	4	4187	1355	4640	1815	990	2

Fisher, MacCracken and Williamson (1986) reported that the exposed paper facing and paint coating of plasterboard burns out locally in the vicinity of fire exposure while investigating room-fire-test-method ignition sources. The coated plasterboard was observed to propagate a fire under some conditions, with a distinct short-lived spike in the heat release rate as the thin surface ignited and quickly burnt out.

Flammability of painted plasterboard was considered by McGraw and Mowrer (McGraw and Mowrer, 1999;Mowrer and McGraw, 1999;Mowrer 2001, 2004), however the focus of the investigation was generally more on dehydration depths of the substrate as a potential indicator of fire incident information. The paper-faced gypsum plasterboard was 15.9 mm thick Type X. The paint coatings consisted of a single latex primer and 0, 2, 4, 6 or 8 coats of latex interior paint. The flammability was relatively tested using the cone calorimeter at incident heat fluxes form 25 to 75 kW/m² for periods from 5 to 15 minutes. Upward fire spread was the focus of the investigation. Results for the time to ignition, peak heat release rate and total heat release is summarised in Table 39. Examples of the heat release rate versus time curves for the specimens subjected to an incident heat flux of 50 kW/m² are included in Figure 43. Note that the uncoated (0 coats of paint) substrate at an incident heat flux of 50 kW/m² had a peak heat release rate of 111 kW/m² that was approximately half the value for the painted specimens.

McGraw and Mowrer (1999) concluded that, based on the experiment results, the ignition of painted plasterboard specimens was delayed slightly with increasing number of coats of paint. Also average peak heat release rates and total heat release rates for different numbers of paint coatings had relatively small difference. However there was considerable scatter in the data for each specimen.

In addition, it is noted that only one specimen of each combination of number of coatings of paint and incident heat flux level was tested.

Table 39 Cone calorimeter results for various numbers of latex interior paint coatings on a paper-faced plasterboard substrate, for various incident fluxes and times of exposure. Extracted from McGraw and Mowrer (1999).

Incident Heat Flux (kW/m²)	Coats of Paint	t_{ig} (sec)	$\dot{Q}''_{peak}$ (kW/m²)	Q'' (kJ/m²)
25	0	NI	N/A	N/A
25	2	NI	N/A	N/A
25	4	NI	N/A	N/A
25	6	NI	N/A	N/A
25	8	NI	N/A	N/A
50	0	37	111	1561
50	2	41	211	2284
50	4	42	224	2359
50	6	44	240	2651
50	8	43	215	2366
75	0	14	134	1527
75	2	15	206	2773
75	4	16	210	2949
75	6	17	215	3318
75	8	9	214	3378

NI = No Ignition

0 coats of paint refer to the unpainted paper-faced plasterboard substrate.

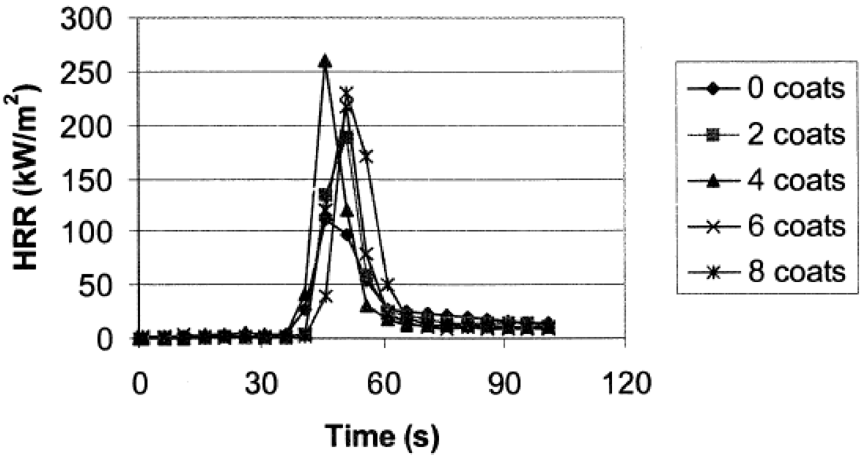


Figure 43 Examples of the heat release rate versus time curves for specimen subjected to an incident heat flux of 50 kW/m². (Note that duration of exposure was not reported.) Extracted from McGraw and Mowrer (1999).

Mowrer and Williamson (1991) investigated flammability of two textile wall covering materials adhered to gypsum plasterboard. One with a distinct growth and decay curve, as shown in Figure 44 for an incident heat flux level of 50 kW/m². One with longer burn durations, as shown in Figure 45 for an incident heat flux level of 30 kW/m². However details of the textiles tested were not reported.

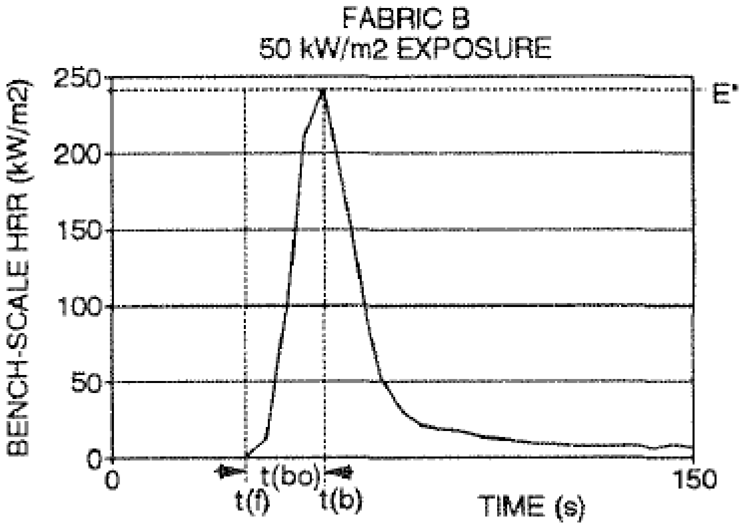


Figure 44 Cone calorimeter results for a textile wall covering (Fabric B) adhered to a plasterboard substrate for an incident heat flux level of 50 kW/m². Extracted from Mowrer and Williamson (1991).

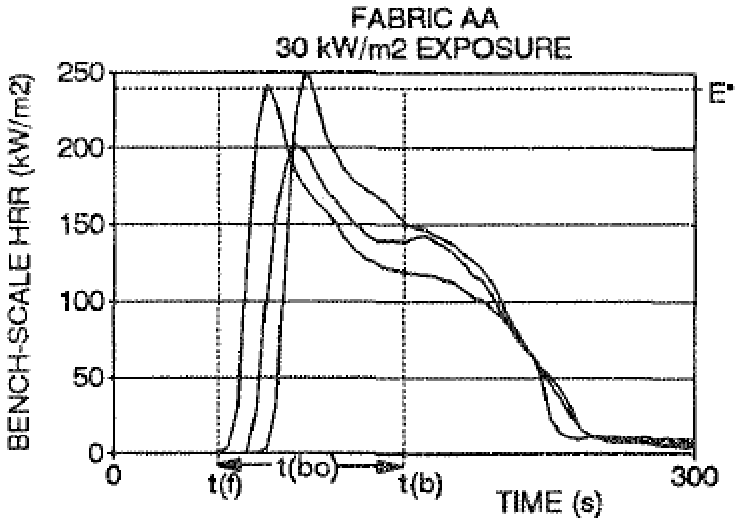


Figure 45 Cone calorimeter results for a textile wall covering (Fabric AA) adhered to a plasterboard substrate for an incident heat flux level of 30 kW/m². Extracted from Mowrer and Williamson (1991).

3.1.2.1 Plasterboard Classification without Further Testing

Plasterboard is also considered in the European classification without further testing (CWFT) scheme in Commission Decision 2006/673/EC. A summary of the plasterboard properties covered by the CWFT is presented in Table 40.

Table 40 Plasterboard properties considered in the classification without further testing (CWFT) scheme by Commission Decision 2006/673/EC

Nominal Board Thickness (mm)	Gypsum Core Density (kg/m³)	Paper Mass per Unit Area * (g/m²)	Class § (excluding floorings)
$6.5 \le t < 9.5$	≥ 800	No paper facing	A1
		$P_{mpa} \le 220$	A2-s1, d0
		$220 < P_{mpa} \le 320$	B-s1, d0
$t \ge 9.5$	≥ 600	No paper facing	A1
		$P_{mpa} \le 220$	A2-s1, d0
		$220 < P_{mpa} \le 320$	B-s1, d0

Table Notes:
* P_{mpa} = Paper mass per unit area. Contributing no more than 5% organic content to the board.
§ Class according to Table 1 of the Annex of Commission Decision 2000/147/EC.

3.1.3 Polymers

Foam plastics systems (predominantly including polyurethane foams) were included in other studies such as those reported by Tsantaridis and Östman (1989), Tsantaridis (1992) and Östman and Tsantaridis (1993) on the investigation of 13 building products in use in the Scandinavian market using the cone calorimeter, and Thureson (1991) for 11 building products in the European market. Similarly Azhakesan, et al. (1994) and Stoliarov, Crowley and Lyon (2009) also included foam plastic samples in their reported results. However foam plastics systems are outside of the scope of this research and therefore are not included in the summary here.

Quintiere et al. (1985, 1986) investigated a range wall linings, using the apparatus design by Ahmed and Faeth (1979) to investigate pyrolysis zones in a vertical specimen with the addition of a radiant panel (with incident heat fluxes of 25, 30 and 36 kW/m²), including PMMA, reporting an average heat release rate of 110 to 150 kW/m².

Stoliarov, Crowley and Lyon (2009) investigated the fire performance of non-charring polymers, namely polymethylmethacrylate (PMMA), and high-density polyethylene (HDPE). Cone calorimeter HRR results for three thickness of PMMA, and HDPE (thin = 3 to 3.4 mm thicknesses, medium = 7.7 to 9.4 mm thicknesses, and thick = 24 to 29 mm thicknesses) were reported for irradiance levels around 50 kW/m². The parameters used for characterising the tests were peak HRR (using a 10 s moving average), time to ignition (when the HRR exceeded 10 kW/m²) and time to peak HRR (as the middle of the 10 s interval for the peak HRR value), as summarised in Table 41, and Figure 46 and Figure 47. The repeatability of each of the materials for the medium thickness was also investigated using 5 specimens at an irradiance level of 50 kW/m².

Table 41 Summary of parameters reported for cone calorimeter tests of non-charring polymers of three thicknesses, and an estimated uncertainty based on 5 tests. Extracted from Stoliarov, Crowley and Lyon (2009).

Polymer	Sample Thickness	Peak HRR (kW/m²) [% uncertainty]	Average HRR (kW/m²) [% uncertainty]	Time to Ignition (s) [% uncertainty]	Time to Peak HRR (s) [% uncertainty]
PMMA	Thin	850	410	43	140
	Medium	990 [17%]	560 [7%]	44 [12%]	430 [17%]
	Thick	890	600	38	1210
HDPE	Thin	1080	390	60	200
	Medium	1480 [36%]	660 [28%]	99 [35%]	450 [45%]
	Thick	1440	610	74	1490

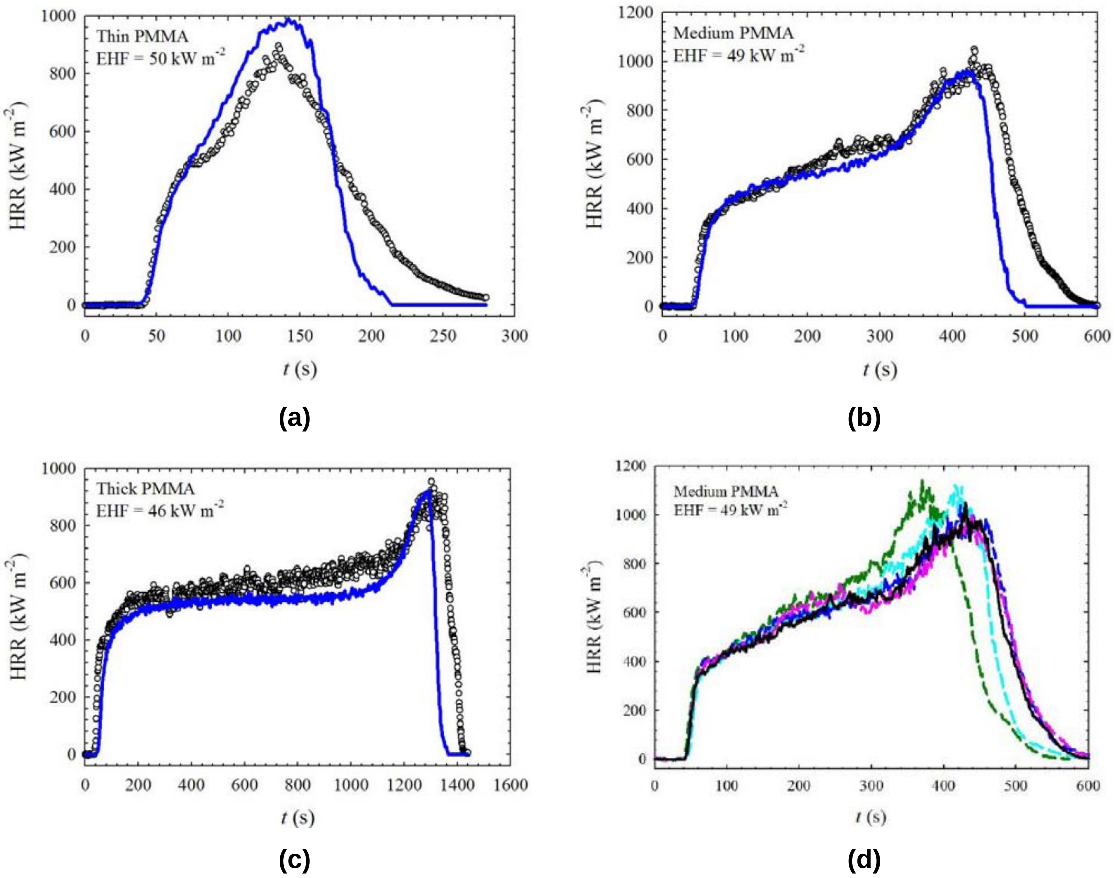
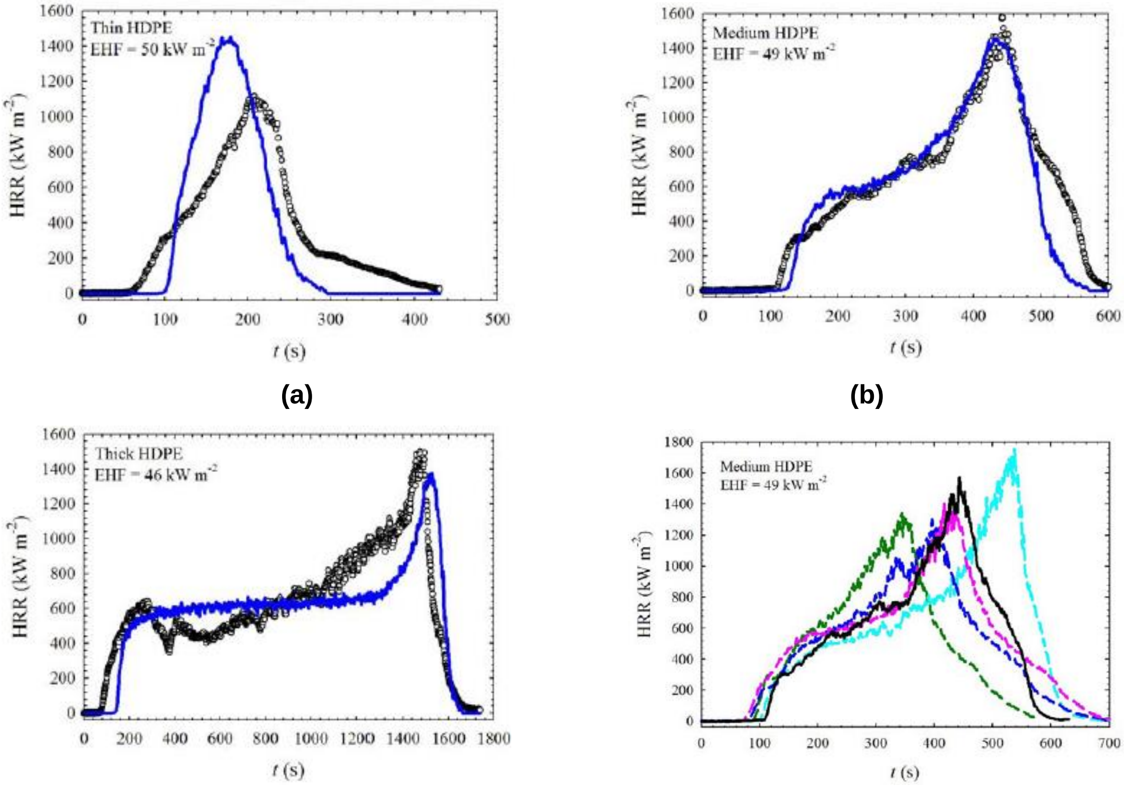


Figure 46 Cone calorimetry experiment results (open circles) for (a) thin, (b) medium and (c) thick thicknesses of polymethylmethacrylate (PMMA) specimens, and (d) five specimens of the medium thickness. Extracted from Stoliarov, Crowley and Lyon (2009).



(a) (b)

(b) (d)

Figure 47 Cone calorimetry experiment results (open circles) for (a) thin, (b) medium and (c) thick thicknesses of high density polyethylene (HDPE) specimens, and (d) five specimens of the medium thickness. Extracted from Stoliarov, Crowley and Lyon (2009).

As part of a project considering the fire performance of 10 various wall linings in a Building Code of Australia (BCA) context, Collier et al (2006) compared AS 3837 and ISO 9705 test results. A summary of the results for two polymeric substrates included in this project is presented in Table 29. In this case the smoke production for the two samples exceeded the AS 3837 SEA limit (of 250 m²/kg), but not the ISO 9705 SMOGRA limit (of 100 m²/s² x 1000) for the BCA context.

Table 42 Summary of the smoke production results for a polymeric substrates for AS 3837 and ISO 9705 tests for a BCA context. Extracted from Collier et al (2006).

Material	AS 3837 average SEA (m²/kg)	AS 3837 Total Heat Released (MJ/m²)	AS 3837 prediction of BCA Group number **	ISO 9705 Peak SPR60 (m²/s)	ISO 9705 SMOGRA (m²/s² x 1000)	ISO 9705 BCA Group number
Plastic co-polymer	531.2*	119.5	4	4.5	22.6	3
Synthetic rubber	322.5*	14.5	2(3†)	12.4	84.7	3

Table Notes:

* 250 m²/kg limit was exceeded, and BCA only permits use in sprinklered premises.

** Estimated according to BCA 2006 Volume One Spec A2.4-3. See APPENDIX 2 – Classification of data, Section 10.1.1 Predicting a material's BCA Group number.

† Prediction of BCA Group number using ISO 5660-1 end of test criteria.

3.1.4 Cement and Calcium-Silicate Board

Fisher (1979) investigated the fire properties of some building boards relative to BS476 Part 6, including cement board and calcium silicate board samples. A summary of the description of the samples is included in Table 43.

Table 43 A summary of BS 476 Part 6 (1968) results for cement and calcium-silicate type building boards (Fisher, 1979).

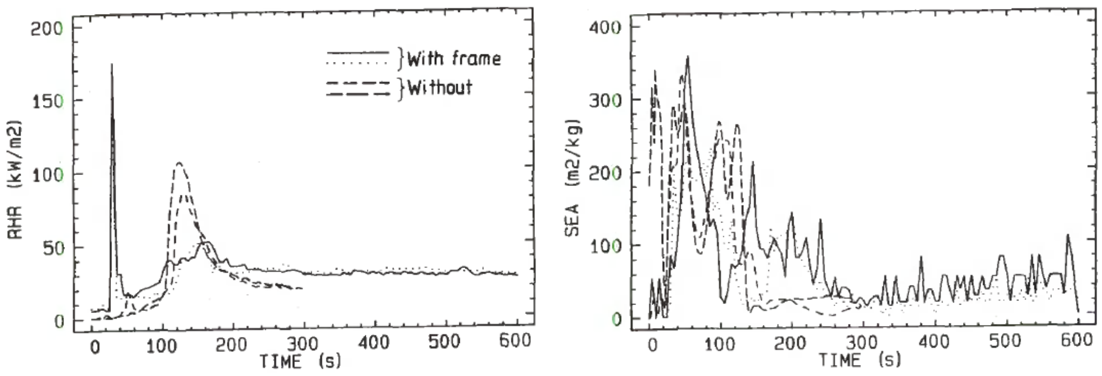
Material	Density (kg/m³)	Thermal Conductivity (W/m.K)	BS 476 test results		
			Combust-ibility	Fire Propagation	Surface spread of flame
Fibre reinforced calcium silicate insulating boards	Laminar: 875	0.17	Non	Class 0 (due to non-combustibility)	Class 0
	Monolithic: 450-720	0.18	Non	Class 0 (due to non-combustibility)	Class 0
Fire reinforced Portland cement insulating board	875	0.175	Non	Class 0 (due to non-combustibility)	Class 0
Vermiculite-silicate board	380-460	0.077-0.105	Non	Class 0 (due to non-combustibility)	Class 0

As part of the research supporting the European Classification without Further Testing, non-combustible board samples were also included in testing at 50 kW/m² irradiance in the cone calorimeter and have been reported on by Tsantaridis and Östman (1990), Tsantaridis (1992) and Thureson (1991). A summary of average test results is included in Table 37. Heat release rates and smoke specific extinction areas are included for some of the samples listed in Table 44 in Figure 48 and Figure 49.

Table 44 Summary of reported time to ignition and average effective heat of combustion for 50 kW/m² irradiance cone calorimeter tests and time to flashover in room test of substrates and coatings.

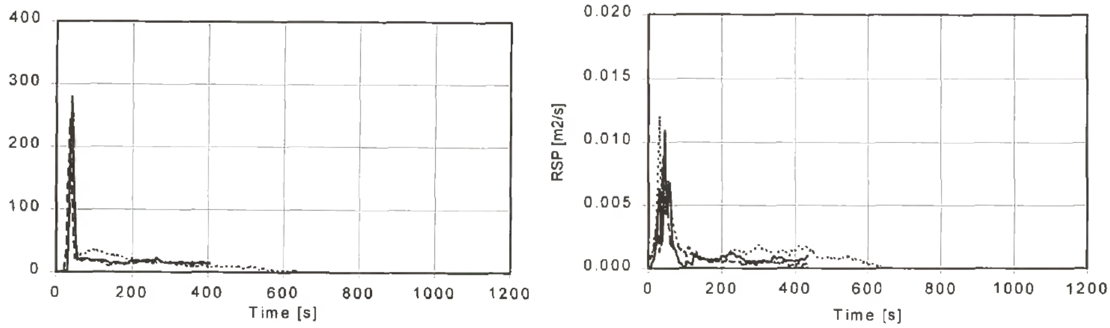
Material Description	Time To Flashover in ISO room (min:s) [Ref. E, F]	Time to Ignition in Cone Calorimeter (s)	Average Effective Heat of Combustion (kJ/g)	Total Heat Released (MJ/m²)	Average Rate of Smoke Production/ Rate of Heat Release (ob.m³/MJ)	Ref.
Insulating board P3, FR	NT	21	NR	NR	NR	D
Insulating board P0	NT	11	NR	NR	NR	D
Textile covering on calcium silicate board	> 20:00	31	28	5.7	N/A	

Table Notes:
Ref. refers to Reference for test results.
NR refers to Not Reported.
NI refers to No Ignition
FR refers to material had a Fire Retardant treatment.
- refers to not reported because of irregularities.
Ref. D: Results reported by Tsantaridis and Östman (1990).
Ref. F: Average results from three test reported by Tsantaridis and Östman (1999).



(a) **(b)**

Figure 48 (a) Heat release rate and (b) specific extinction area for 2 specimens of melamine-faced high-density non-combustible board at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis (1992), including data from Thureson (1991).



(a) **(b)**

Figure 49 (a) Heat release rate and (b) rate of smoke production for 3 specimens of textile wall covering on calcium silicate board at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis and Östman (1999).

Similar to the previous summary sections, to provide a comparison for the current New Zealand regulations, where sufficient published data was available material group numbers were calculated according to the description in the NZBC Verification Method C/VM2 (2013c). A summary of these results in included in each relevant section; Table 45 includes a summary for non-combustible board specimens that had been summarised by Kokkala, Thomas and Karlsson (1993), where indicative NZ material group numbers could be calculated.

Table 45 Summary of various reported tested specimens with a plasterboard substrate. Data extracted from initial analysis extracted from Kokkala, Thomas and Karlsson (1993) and Group Number from NZBC C/VM2 (2013c) application.

Description of Material	I_{ig} **(1/min)**	$I_{Q,m=34}$	$I_{Q,m=0.93}$	$I_{Q,10min}$	$I_{Q,2min}$	$I_{Q,12min}$	**NZ Group Number**
Melamine-faced high-density non-combustible board, 12.5 mm thick	0.57	2407	1143	6492	2380	1555	1
	0.52	2052	1083	6519	2389	1564	1

As part of the project conducted by Collier et al. (2006) that considered the fire performance of 10 various wall linings in a Building Code of Australia (BCA) context by comparing AS 3837 and ISO 9705 test results, a summary of the results for a cement fibreboard substrate is included in Table 46. In this case the smoke production for the plywood samples didn't exceed either the AS 3837 SEA limit (of 250 m²/kg) or the ISO 9705 SMOGRA limit (of 100 m²/s² x 1000) for the BCA context.

Table 46 Summary of the smoke production results for a vinyl wallpaper for AS 3837 and ISO 9705 tests for a BCA context. Extracted from Collier et al (2006).

Material	AS 3837 average specific extinction area SEA (m²/kg)	AS 3837 Total Heat Released (MJ/m²)	AS 3837 prediction of BCA Group number **	ISO 9705 SPR60 (peak) (m²/s)	ISO 9705 SMOGRA (m²/s² x 1000)	ISO 9705 BCA Group number
Fibre-cement board	118	3.8	1	1.5	1.4	1

Table Notes:
* 250 m²/kg limit was exceeded, and BCA only permits use in sprinklered premises.
** Estimated according to BCA 2006 Volume One Spec A2.4-3. See APPENDIX 2 – Classification of data, Section 10.1.1 Predicting a material's BCA Group number.
† Prediction of BCA Group number using ISO 5660-1 end of test criteria.

3.1.5 Mineral Wool

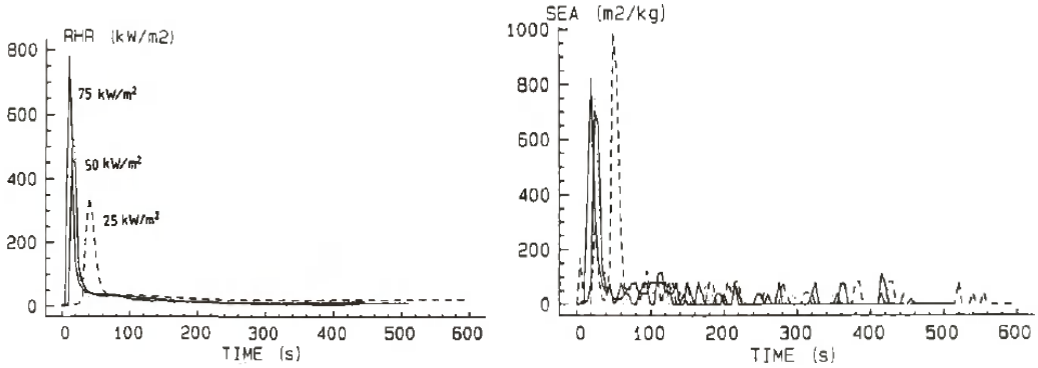
Although mineral wool would not be a typical interior building lining substrate, tests have been performed using a mineral wool substrate that provides another perspective for comparison and analysis of the test results. Therefore, where available, relevant test results are included in this report and for completion, mineral wool is included in the list of substrate materials.

As part of the research supporting the European Classification without Further Testing, mineral wool samples were also included in testing at 50 kW/m² irradiance in the cone calorimeter and ISO 9705 room testing and have been reported on by Tsantaridis and Östman (1989, 1999), Tsantaridis (1992) and Thureson (1991). A summary of average test results is included in Table 47. Heat release rates and smoke specific extinction areas are included for some of the samples listed in Table 47 in Figure 50 to Figure 56.

Table 47 Summary of reported time to ignition and average effective heat of combustion for 50 kW/m² irradiance cone calorimeter tests and time to flashover in room test of substrates and coatings.

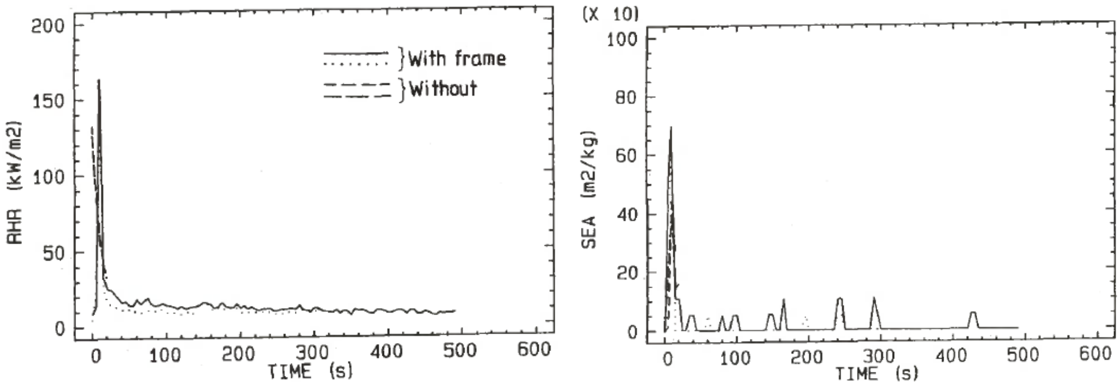
Material Description	Time To Flashover in ISO room (min:s) [Ref. E, F]	Time to Ignition in Cone Calorimeter (s)	Average Effective Heat of Combustion (kJ/g)	Total Heat Released (MJ/m²)	Average Rate of Smoke Production/ Rate of Heat Release (ob.m³/MJ)	Ref.
Unfaced mineral wool	> 20:00	NI	NI	NI	NI	F
Paper-faced glass wool	1:01	3.3	10	2.4		F
Combustible-faced mineral wool, 30 mm (total) thick	1:20	4.5 5	NR	1.7	NR	B C
Textile wall-covering on mineral wool, 42 + 0.5 mm thick	0:43	11	25	NR	26	A
Plastic-faced sheet steel on mineral wool, 25 mm (total) thick	> 20 :00	34 52	NR	3.6	NR	B C

Table Notes:
Ref. refers to Reference for test results.
NR refers to Not Reported.
NI refers to No Ignition
FR refers to material had a Fire Retardant treatment.
- refers to not reported because of irregularities.
Ref. A: Average results from two tests, as reported by Tsantaridis and Östman (1989).
Ref. B: Average results from two tests reported by Thureson (1991).
Ref. C: Average results from two tests reported by Tsantaridis (1992) for cone calorimeter testing at 50 kW/m² using a retainer frame. Comparison of test results performed with and without a retainer frame by two different laboratories was reported by Tsantaridis (1992) to have good repeatability for the products tested.
Ref. F: Average results from three test reported by Tsantaridis and Östman (1999).



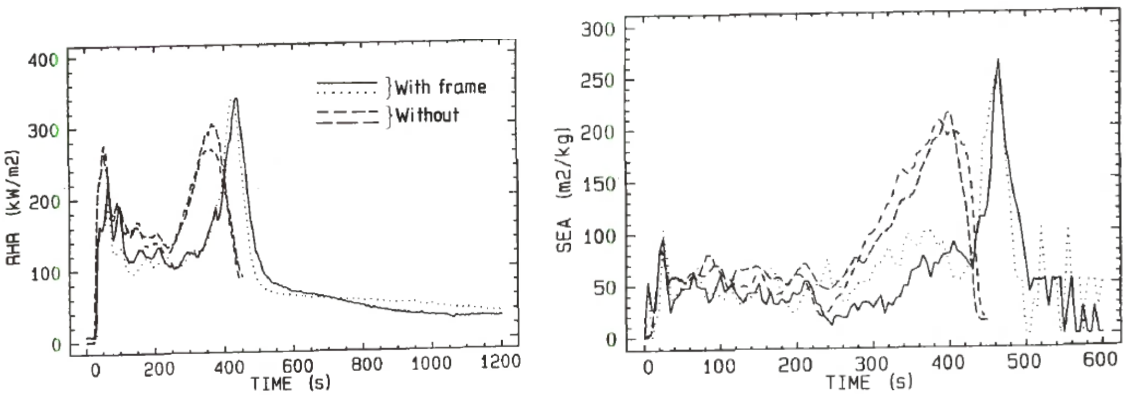
(a) **(b)**

Figure 50 (a) Rate of Heat Release (RHR) and (b) Specific Extinction Area (SEA) for 0.5 mm thick textile wall covering on 42 mm thick mineral wool. Two tests performed at 50 kW/m². Extracted form Tsantaridis and Östman (1989).



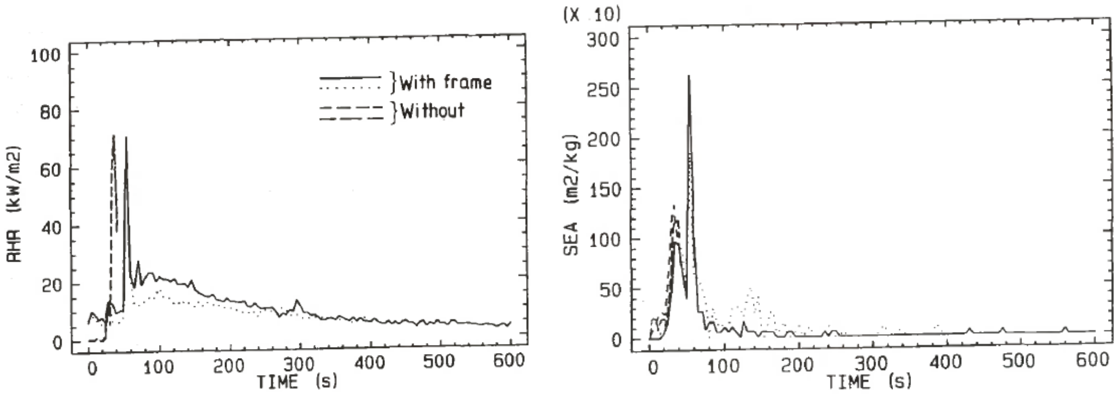
(a) **(b)**

Figure 51 (a) Heat release rate and (b) specific extinction area for 2 specimens of combustible-faced mineral wool at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis (1992), including data from Thureson (1991).



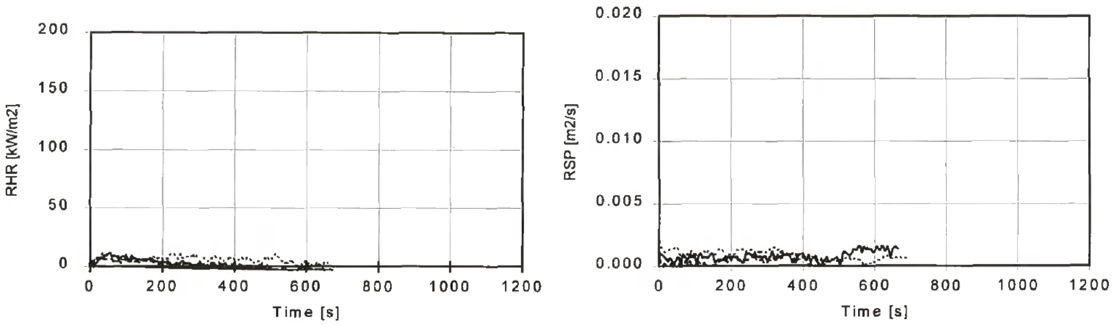
(a) **(b)**

Figure 52 (a) Heat release rate and (b) specific extinction area for 2 specimens of Birch plywood at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis (1992), including data from Thureson (1991).



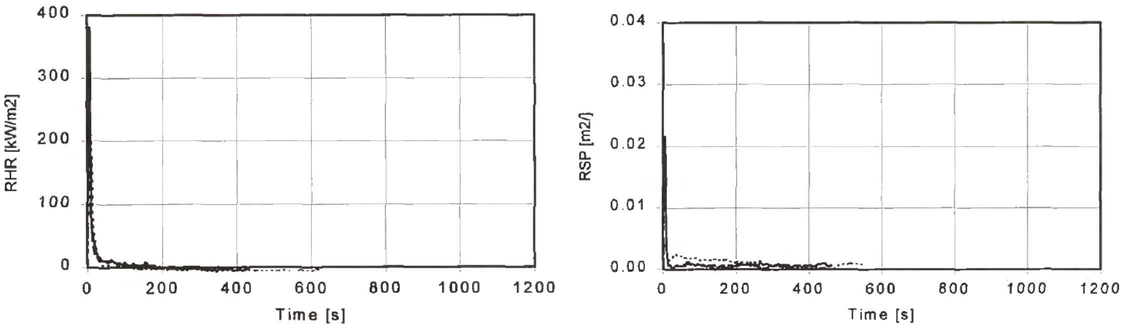
(a) (b)

Figure 53 (a) Heat release rate and (b) specific extinction area for 2 specimens of plastic-faced steel sheet on mineral wool at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis (1992), including data from Thureson (1991).



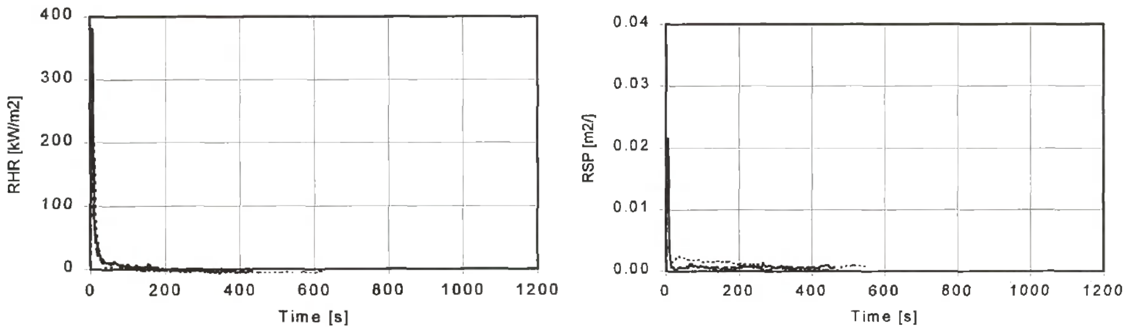
(a) (b)

Figure 54 (a) Heat release rate and (b) rate of smoke production for 3 specimens of unfaced mineral wool at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis and Östman (1999).



(a) (b)

Figure 55 (a) Heat release rate and (b) rate of smoke production for 3 specimens of paper-faced glass wool at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis and Östman (1999).



(a) (b)

Figure 56 (a) Heat release rate and (b) rate of smoke production for 3 specimens of paper-faced glass wool at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis and Östman (1999).

Similar to the previous summary sections, to provide a comparison for the current New Zealand regulations, where sufficient published data was available material group numbers were calculated according to the description in the NZBC Verification Method C/VM2 (2013c). A summary of these results in included in each relevant section; Table 48 includes a summary for mineral wool specimens (some also listed in Table 47) tested by Tsantaridis and Östman (1989) and Thureson (1991) (and summarised by Kokkala, Thomas and Karlsson (1993)), where indicative NZ material group numbers could be calculated.

Table 48 Summary of various reported tested specimens with a plasterboard substrate. Data extracted from Tsantaridis and Östman (1989) and Thureson (1991), initial analysis extracted from Kokkala, Thomas and Karlsson (1993) and Group Number from NZBC C/VM2 (2013c) application.

Description of Material	I_{ig} (1/min)	$I_{Q,m=34}$	$I_{Q,m=0.93}$	$I_{Q,10min}$	$I_{Q.2min}$	$I_{Q,12min}$	NZ Group Number
Plastic-faced steel sheet on mineral wool, 25 mm (total) thick	1.76	331	830	5849	2184	1359	1
	1.76	367	847	5849	2184	1359	1
Combustible-faced mineral wool, 30 mm (total) thick	12	893	1025	320	495	-330	4
	15	825	1034	-1300	0	-825	4
Textile wall covering on mineral wool, 42 + 0.5 mm thick	5.45	4370	1911	3857	1575	750	4

3.2 Wall and Ceiling Lining Coatings

This section summarises available results for various coatings on the substrates discussed in the previous section.

3.2.1 Paints

Multiple paint-coated surfaces, especially when not prepared correctly, have been suggested to have greater flammability (Rhodes, 2012), compared to intended paint systems (e.g. typically consisting of 1 or 2 layers of primer and 2 layers of topcoat on a clean substrate). Rhodes (2012) suggested the increase in flammability to be associated with the lack of adhesion between paint layers that increases the thermal insulation between the coating layers and the substrate. In addition, a highly insulating substrate was also suggested to have a significant influence on the paint coating layer.

McGraw and Mowrer (McGraw and Mowrer, 1999;Mowrer and McGraw, 1999;Mowrer 2001, 2004) tested more than 300 specimens of 15.9 mm thick plasterboard coated with 0 to 8 layers of either a latex-based or an oil-based interior paint. The specimens were tested using a cone calorimeter and subjected to incident heat fluxes of 35, 50 or 75 kW/m² for periods of 5, 10 or 15 minutes. Three replicates were tested for each combination of number of paint layers and incident heat flux level.

The oil-based paint (the components of which are listed in Table 49) layers consisted of a single layer of oil-based interior primer and a single layer of alkyd/oil semi-gloss enamel applied with a paint roller (Mowrer, 2001, 2004). Each coating of paint added 0.4 to 1.0 g of mass to the sample (as shown in Figure 57), with an average of approximately 0.7 g of mass per paint layer or 70 ± 30 g/m² (dry), which was approximately 72% of the manufacturer's recommended application rate (Mowrer, 2001, 2004).

Table 49 Composition of the alkyd/oil semi-gloss interior enamel used in the tests by Mowrer (2001, 2004). Extracted from Mowrer (2004).

Component	Percent of mixture
Calcium carbonate	6.2–25.2
Diatomaceous earth	0–2.6
Exempt mineral spirits	15.3–18.6
Hydrous aluminum silicate	0–16.1
Odorless mineral spirits	8.2–13.0
Oilseed compound	0–5.9
Synthetic resin complex	24.0–27.8
Titanium dioxide	0–21.6
Xylene	0.3–1.0
Zinc oxide	0–0.6

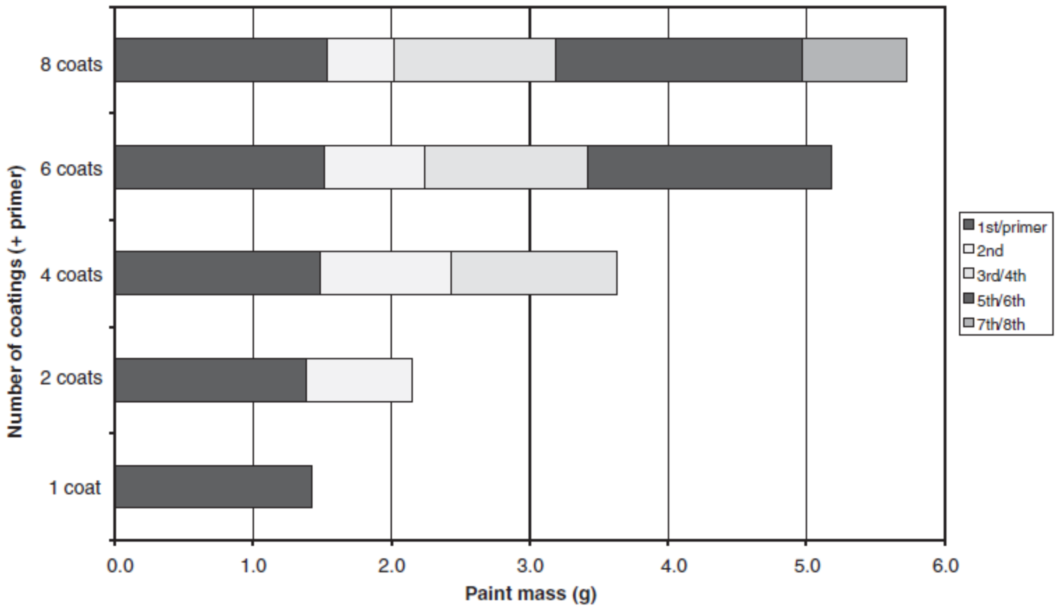


Figure 57 Average oil-based paint mass per specimen for the samples tested at an incident heat flux of 50 kW/m². Extracted from Mowrer (2004).

Average time to ignition results for the various numbers of coats of paint at an incident heat flux of 50 kW/m² are shown in Figure 58 (Mowrer, 2004). Results for peak heat release per unit area are summarised in Figure 59 and total heat release per unit area results are summarised in Figure 60 (Mowrer, 2004).

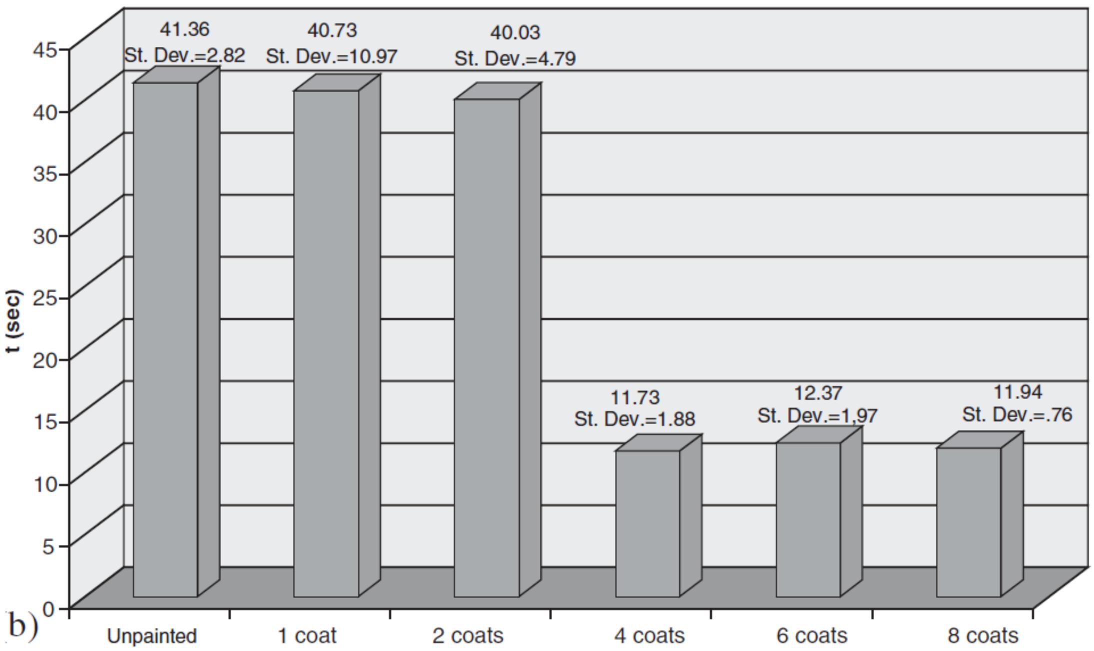


Figure 58 Average time to ignition relative to the number of coats of oil-based paint for an exposure of 50 kW/m² incident heat flux. Extracted from Mowrer (2004).

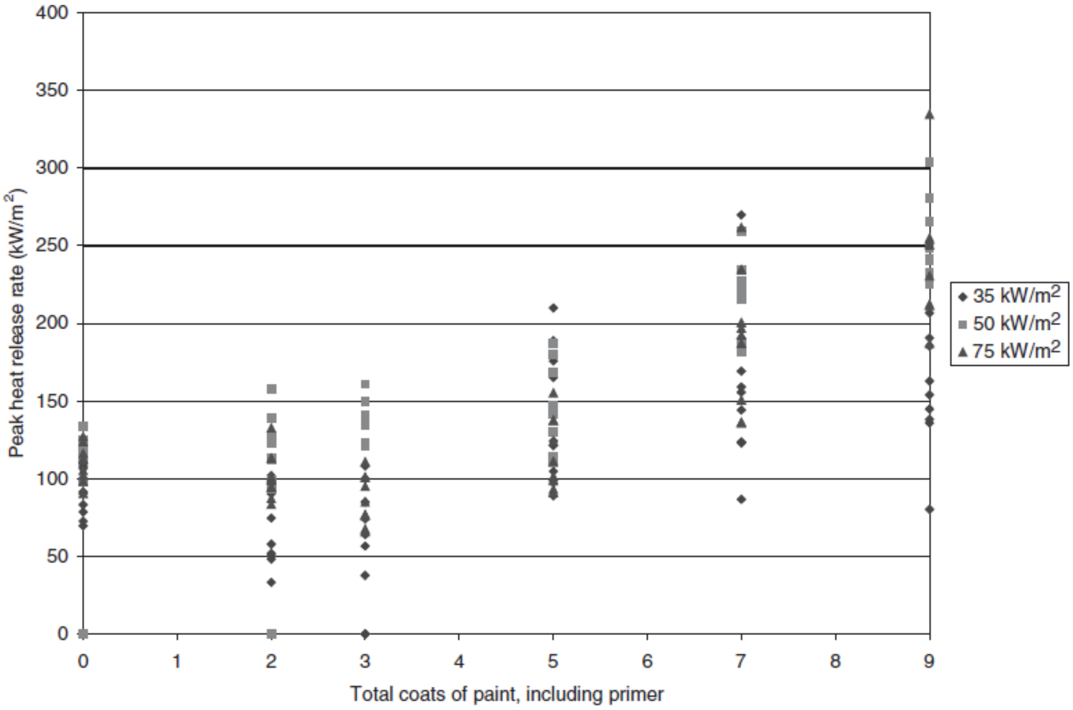


Figure 59 Peak heat release rate per unit area values for the number of oil-based paint coats and incident heat flux levels. Extracted from Mowrer (2004).

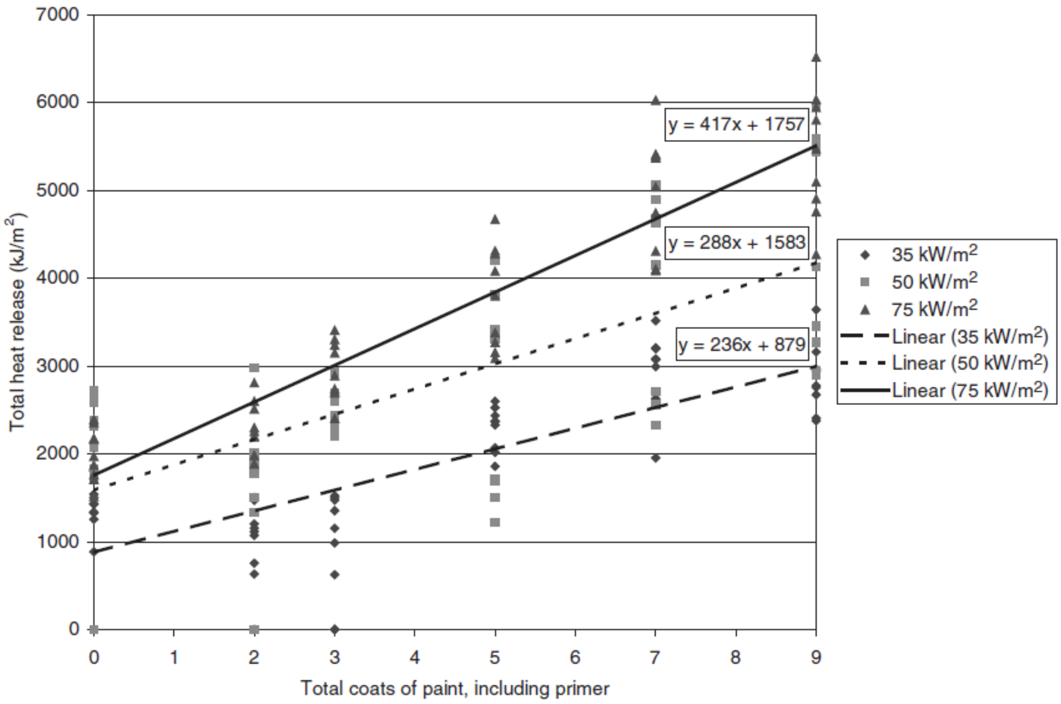


Figure 60 Total heat release per unit area values as a function of number of layers of oil-based paint and incident heat flux exposure. Extracted from Mowrer (2004).

When subjected to an incident heat flux of 50 kW/m² the latex-based painted samples had ignition times from 41 to 43 s, peak heat release rates per unit area from 211 to 240 kW/m², and burning durations of 11 seconds (McGraw and Mowrer, 1999).

Table 50 Summary of average cone calorimeter results for three specimens of plasterboard samples coated with various numbers of layers of latex-based paint exposed to an incident heat flux of 50 kW/m². Extracted from McGraw and Mowrer (1999).

Coats of Latex-based Paint	Time to Ignition (s)	Peak Heat Release Rate (kW/m²)	Total Heat Release (kJ/m²)	Burn Duration (s)
0	36.73	111.39	1561.38	14.07
2	40.74	210.85	2284.04	10.94
4	41.59	223.99	2359.08	10.68
6	44.29	240.30	2651.49	11.07
8	43.10	215.18	2366.07	11.06

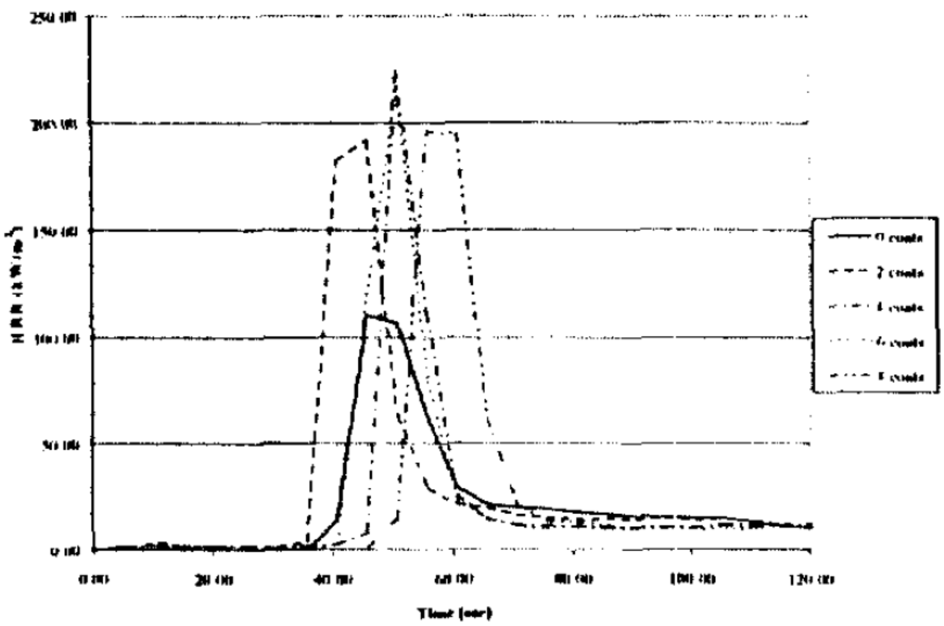


Figure 61 Exemplar heat release rate versus time curves for plasterboard samples with various numbers of latex-based paint coats subjected to an incident heat flux of 50 kW/m². Extracted from McGraw and Mowrer (1999).

Steen-Hansen and Kristoffersen (2007) tested 12.5 mm thick plasterboard specimens (primed with one coat of paint A and then a glued glass-fibre wallpaper facing) coated with multiple layers of paint in consideration of classification in Norwegian regulatory context. Two types of white water-based latex paint were used in the testing (designated as Paint A and Paint B). Numbers of coats tested were 2, 4, 6 and 8 layers, on top of one coat of a water-based primer. The amount of paint applied to specimens is summarised in Table 51 and was manually applied using a paint roller (it was acknowledged that a manual application method would not be expected to produce homogeneous layer thickness; however it was considered that this method would be representative of practice). Average results from cone calorimeter (ISO5660) tests at an irradiance of 50 kW/m² are summarised in Table 52, Figure 62 and Figure 63.

An ISO 9705 room corner test was also conducted for 8 coats of paint A. The time to flashover was 620 s, with a heat release rate maximum of 700 kW and average of 44 kW, and smoke production rate maximum of 1.2 m²/s and average of 0.04 m²/s. (Steen-Hansen and Kristoffersen, 2007)

The Norwegian regulations do not use cone calorimeter criteria for surface linings performance. The intention of performing these results was for use in a model to then compare with other test methods. (Steen-Hansen and Kristoffersen, 2007)

It was noted that here was not a significant difference in the time to ignition for the various numbers of paint coatings. However the specimens with 8 coats of either paint ignited faster than the specimens with less coats of the same type of paint. The peak heat release rate, total heat release and carbon monoxide production increased with increasing numbers of paint coatings. The largest increase in maximum heat release rate (of, on average, 150% and 21% for paint A and paint B, respectively) and total heat released (of, on average, 40% and 31% for paint A and paint B, respectively) took place between 6 and 8 paint layers. Based on the results of the project considering multiple layers of either paint or wallpaper, it was concluded that the different fire properties will change depending on the type of surface coat, the type of substrate, and the number and thickness of the coatings. It was also concluded that if there are 4 or more coats of paint on a surface in an escape route, this may imply that fire development may be too rapid and a fire safety assessment would be required. It was recommended that re-decoration and maintenance of escape routes should be documented and adequate fire safety be implemented to compensate for these changes. (Steen-Hansen and Kristoffersen, 2007)

Table 51 Estimates of amounts of paint applied to specimens. Extracted from Steen-Hansen and Kristoffersen (2007).

Number of paint coats	Paint type A [g/m^2]	Paint type B [g/m^2]
2	225	238
4	350	450
6	488	650
8	710	850

Table 52 Summary of average cone calorimeter results for three specimens of plasterboard (with glass-fibre wallpaper glued to the face) coated samples coated with various numbers of layers of two different types of paint exposed to an incident heat flux of 50 kW/m². Extracted from Steen-Hansen and Kristoffersen (2007).

Product	Paint A				Paint B			
Number of coats	2*	4	6	8	2	4	6	8
t_{ign} [s]	31	29	31	26	28	33	33	21
HRR_{max} [kW/m^2]	85	71	69	173	97	112	109	132
THR [MJ/m^2]	5.3	4.8	5.5	7.7	6.3	6.9	7.3	9.6
TSP [m^2]	0.4	1.0	1.1	1.0	0.7	0.8	0.9	0.8
CO_{tot} [g]	0.05	0.15	0.21	0.30	0.20	0.16	0.19	0.24

Table Notes: * Results are for 3 tests where ignition occurred. More than 3 tests were run.

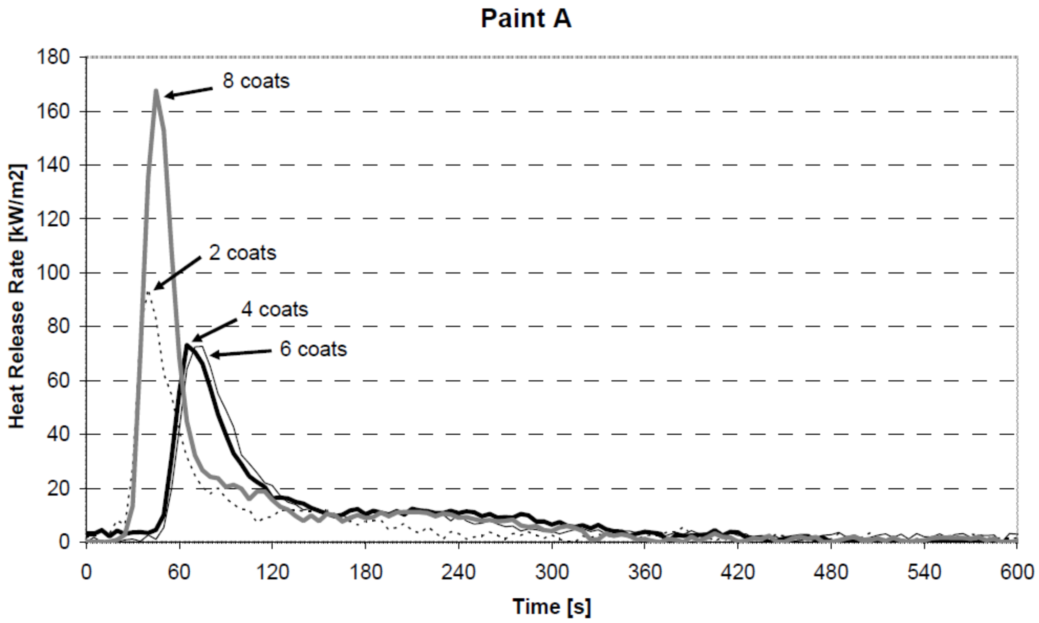


Figure 62 Heat release rates versus time for fibre-glass wallpaper faced plasterboard specimens with multiple coats of Paint A exposed to an incident heat flux of 50 kW/m². Extracted from Steen-Hansen and Kristoffersen (2007).

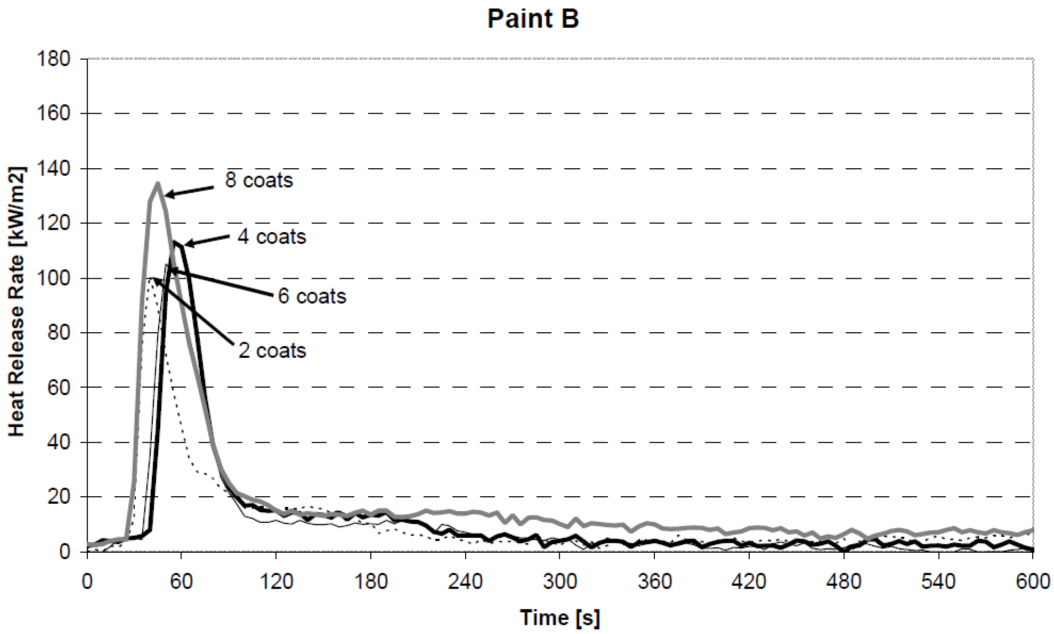


Figure 63 Heat release rates versus time for fibre-glass wallpaper faced plasterboard specimens with multiple coats of Paint A exposed to an incident heat flux of 50 kW/m². Extracted from Steen-Hansen and Kristoffersen (2007).

3.2.1.1 Blistering

McGraw and Mowrer (McGraw and Mowrer, 1999;Mowrer and McGraw, 1999;Mowrer 2001, 2004) noted that “blistering” of the painted surface was observed. This phenomenon was observed more commonly for oil-based coated specimens than for the latex-based coated specimens, where “blistering” of the latex-based specimen was only observed for 8 layers of paint. The “blistering” was associated with a decrease in the time to ignition by a factor of approximate 3 to 4 when compared to the same samples where no “blistering” was observed. “Blistering” was reported to have a limited effect on the burning times of the specimens.

When “blistering” occurred, a delamination of the paint film from the plasterboard substrate would occur and from one or more pressurized bubbles. Cracks would eventually form in the skin of the bubble, from which vapours were observed to be ejected and subsequently ignited above the sample (Mowrer, 2001, 2004). This behaviour resulted in the second peak in the heat release data of some specimens, as seen in the exemplar heat release curves shown in Figure 64.

Mowrer (2001, 2004) reported that, at 50 kW/m², “blistering” was observed for all samples with 4 or more coats of paint. No “blistering” was observed for samples with 2 coats of paint or less. This was evident in the time to ignition data summary for specimens subjected to 50 kW/m² incident heat flux, shown in Figure 65 and Figure 58.

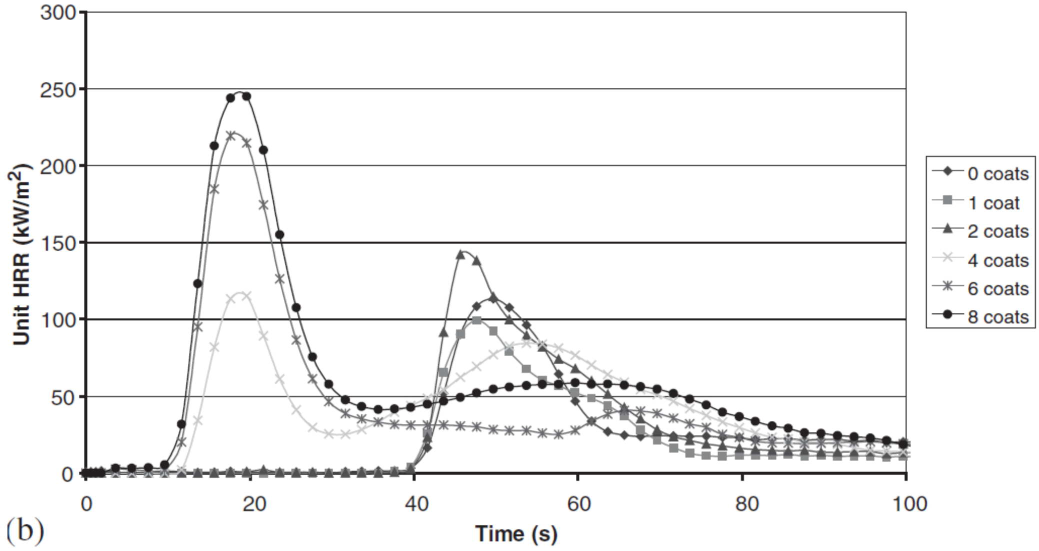


Figure 64 Exemplar heat release rates versus time for plasterboard specimens with 0 to 8 coats of oil-based paint subjected to an incident heat flux of 50 kW/m² in a cone calorimeter, where some specimens were observed to “blister” during the test. Extracted from Mowrer (2004).

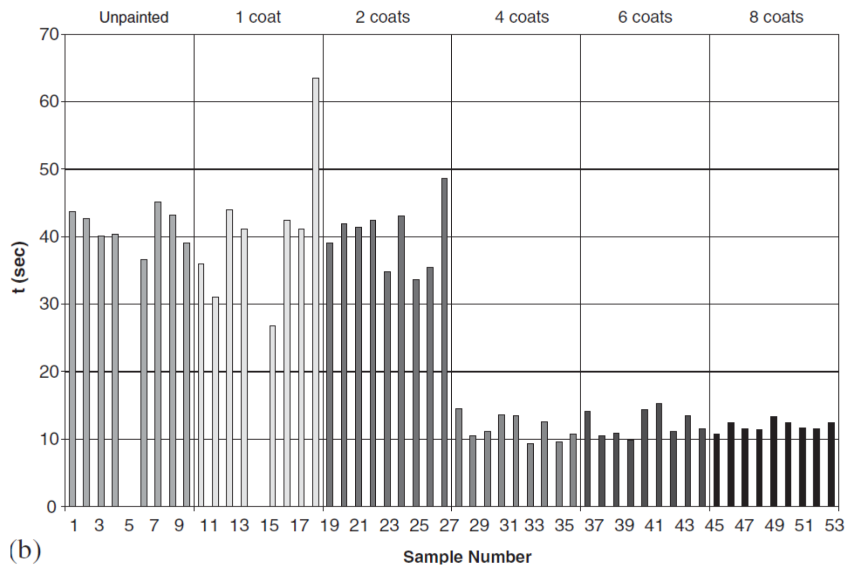


Figure 65 Summary of time to ignition for plasterboard specimens with 0 to 8 coats of oil-based paint subjected to an incident heat flux of 50 kW/m² in a cone calorimeter, where some specimens were observed to “blister” during the test. Extracted from Mowrer (2001).

3.2.2 Wallpapers

Chew and Lim (2000) investigated 10 substrates with 2 types of textured wallpaper (type-E and type-F) that were both rated as having 'class zero' flame spread (related to Fire Code 1997 for Singapore). The substrates (as summarised in Table 53) with no covering were used as a control, then each of the 2 types of wallpaper were affixed to each of the substrates and then tested using a cone calorimeter (complying with ISO 5660) in a horizontal orientation at an incident heat flux of 50 kW/m² for 900 s. The results for the substrates only are summarised in Table 54. The results for the two types of wallpaper affixed to each of the substrates are presented in Table 55 and Table 56. Comparisons of the results for the substrate only, and with each type of wallpaper affixed is included for each substrate in Appendix A, Figure 92 to Figure 100. A summary of the peak heat release rates is shown in Figure 66. A summary of the total heat release is shown in Figure 67.

The effect of the covering on the substrates was reported to have more of an impact on the peak hear release rates than the total heat release, for the specimens tested. It was recommended that combinations of substrate and linings needed to be tested. It was suggested that focus on a lining's contribution to increasing the peak heat release rate and not on the limited increase in total heat release rate, compared to the substrate alone, may lead to a poor classification of the surface-lined product. (Chew and Lim, 2000) However only one test was performed on each sample, no replicate tests were performed. It is also noted that the contribution of each type of wallpaper to the increase in peak heat release or total heat release is not consistent across each of the types of substrate.

Table 53 Substrates tested by Chew and Lim (2000)

Material	Thickness (mm)	Code	Fire Performance, related to Fire Code 1997 for Singapore	Mass (g)	Density (kg/m³)
proprietary type-P calcium silicate board	9	P	Non combustible	105.3	1108
proprietary type-S calcium silicate matrix reinforced with selected fibres and fillers	9	S	Non combustible - up to 240 minutes fire resistance	81.4	904
proprietary type-M calcium silicate matrix reinforced with selected fibres and fillers	9	M	Class zero - up to 60 minutes fire resistance	98.1	1090
proprietary mineral wool board multiply coated with ultra-white colour	14	T	Class zero	70.2	1170
proprietary cellulose reinforced Portland cement board	6	CP	Class zero	58.6	419
Gypsum plasterboard	15	G	Class zero	39.2	261
Standard core plasterboard	12.5	B	Class one	88.9	711
Proprietary fire-stop plasterboard	16	FR	Class one	133.5	861
Chipboard	19	BC	Class two	134.4	707
Plywood	9	TP	Class three	46.3	514

Table 54 A summary of the average cone calorimeter test results for substrates tested by Chew and Lim (2000)

Material	Code	Mass (g)	Density (kg/m³)	Peak Heat Release Rate (kW/m²)	Average Heat Release Rate (kW/m²)	Total Heat Release (MJ/m²)
proprietary type-P calcium silicate board	P	105.3	1108	0.0	0.0	0.0
proprietary type-S calcium silicate matrix reinforced with selected fibres and fillers	S	81.4	904	3.9	0.3	0.1
proprietary type-M calcium silicate matrix reinforced with selected fibres and fillers	M	98.1	1090	0.0	0.0	0.4
proprietary mineral wool board multiply coated with ultra-white colour	T	70.2	1170	1.6	1.0	0.3
proprietary cellulose reinforced Portland cement board	CP	58.6	419	5.1	0.5	3.0
Gypsum plasterboard	G	39.2	261	50.2	31.7	12.1
Standard core plasterboard	B	88.9	711	47.6	13.0	3.3
Proprietary fire-stop plasterboard	FR	133.5	861	63.2	49.9	3.0
Chipboard	BC	134.4	707	192.7	78.6	139.1
Plywood	TP	46.3	514	205.0	107.2	54.3

Table 55 A summary of some sample parameters and average teat results for substrates with wallpaper type-E affixed that were tested by Chew and Lim (2000)

Substrate Material	Code	Mass (g)	Density (kg/m³)	Peak Heat Release Rate (kW/m²)	Average Heat Release Rate (kW/m²)	Total Heat Release (MJ/m²)
proprietary type-P calcium silicate board	P1	62.8	1047	0.0	0.0	0.0
proprietary type-S calcium silicate matrix reinforced with selected fibres and fillers	S1	94.7	1052	5.8	2.0	1.0
proprietary type-M calcium silicate matrix reinforced with selected fibres and fillers	M1	90.2	1002	12.7	3.4	5.3
proprietary mineral wool board multiply coated with ultra-white colour	T1	70.2	1170	14.6	2.1	1.9
proprietary cellulose reinforced Portland cement board	CP1	55.4	396	13.9	6.1	5.0
Gypsum plasterboard	G1	34.5	265	87.8	43.3	14.7
Standard core plasterboard	B1	81.9	683	83.3	67.0	7.4
Proprietary fire-stop plasterboard	FR1	129	860	92.2	78.6	6.6
Chipboard	BC1	135.7	714	166.8	65.3	172.2
Plywood	TP1	48.0	505	210.6	55.3	60.7

Table 56 A summary of some sample parameters and average teat results for substrates with wallpaper type-F affixed that were tested by Chew and Lim (2000)

Substrate Material	Code	Mass (g)	Density (kg/m³)	Peak Heat Release Rate (kW/m²)	Average Heat Release Rate (kW/m²)	Total Heat Release (MJ/m²)
proprietary type-P calcium silicate board	P2	63.1	1052	89.6	19.4	5.9
proprietary type-S calcium silicate matrix reinforced with selected fibres and fillers	S2	94.2	856	94.0	29.7	7.4
proprietary type-M calcium silicate matrix reinforced with selected fibres and fillers	M2	30.9	866	195.2	118.8	6.3
proprietary mineral wool board multiply coated with ultra-white colour	T2	75.1	939	127.9	45.6	44.1
proprietary cellulose reinforced Portland cement board	CP2	62.4	347	80.8	12.5	14.8
Gypsum plasterboard	G2	35.9	211	306.9	34.4	15.5
Standard core plasterboard	B2	87.9	586	234.8	151.1	9.9
Proprietary fire-stop plasterboard	FR2	156.1	867	224.2	126.5	9.5
Chipboard	BC2	141.3	693	265.2	60.1	161.2
Plywood	TP2	47.8	416	346.2	87.6	70.7

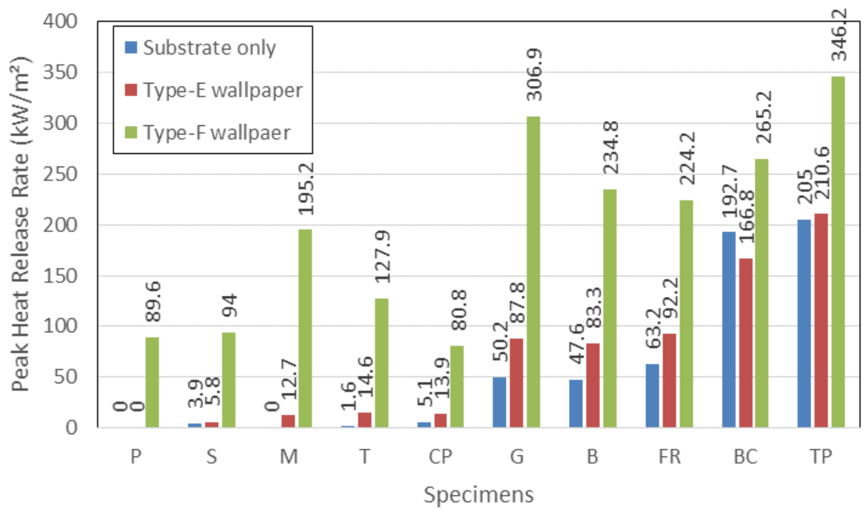


Figure 66 Summary of the peak heat release rate values from the cone calorimeter tests of substrates and two types of wallpaper investigated by Chew and Lim (2000).

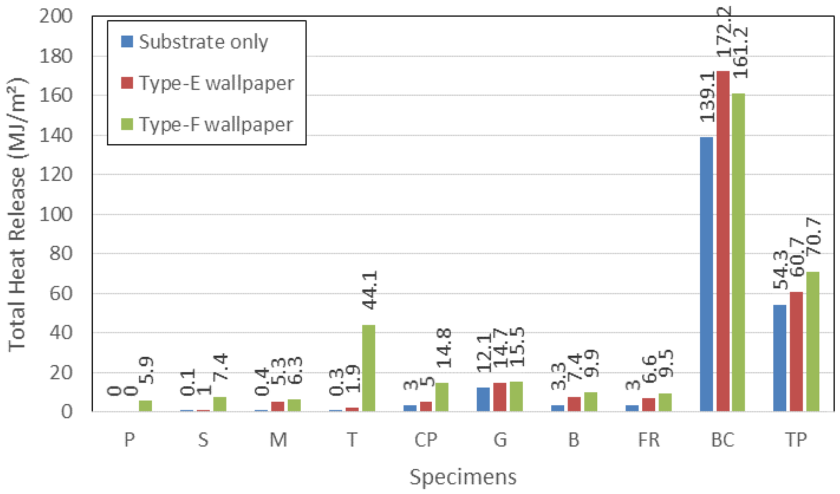


Figure 67 Summary of the total heat release values from the cone calorimeter tests of substrates and two types of wallpaper investigated by Chew and Lim (2000).

Collier et al (2006) included vinyl wallpaper (summarised in Table 57) in a selection of 10 various wall linings considered in a Building Code of Australia (BCA) context for fire performance, comparing AS 3837 and ISO 9705 test results. In this case the smoke production for the vinyl wallpaper exceeded the AS 3837 SEA limit (of 250 m²/kg), but not the ISO 9705 SMOGRA limit (of 100 m²/s² x 1000) for the BCA context.

Table 57 Summary of the group number and smoke production results for a vinyl wallpaper for AS 3837 and ISO 9705 tests for a BCA context. Extracted from Collier et al (2006).

Material	AS 3837 average specific extinction area SEA (m²/kg)	AS 3837 Total Heat Released (MJ/m²)	AS 3837 prediction of BCA Group number **	ISO 9705 SPR60 (peak) (m²/s)	ISO 9705 SMOGRA (m²/s² x 1000)	ISO 9705 BCA Group number
Vinyl wallpaper	256.9*	47.4	2	13.8	22.3	2

Table Notes:
* 250 m²/kg limit was exceeded, and BCA only permits use in sprinklered premises.
** Estimated according to BCA 2006 Volume One Spec A2.4-3. See APPENDIX 2 – Classification of data, Section 10.1.1 Predicting a material's BCA Group number.

As part of a project that also considered multiple coatings of paint on a plasterboard substrate, Steen-Hansen and Kristoffersen (2007) tested 12.5 mm thick plasterboard specimens, primed with one coat of paint A (a water-based latex paint) and then coated with one or two layers wallpaper, in consideration of classification in Norwegian regulatory context. Cone calorimeter results for an irradiance of 50 kW/m² results for the layered wallpaper specimens is shown in Figure 68 for heat release rates and summarised in Table 58.

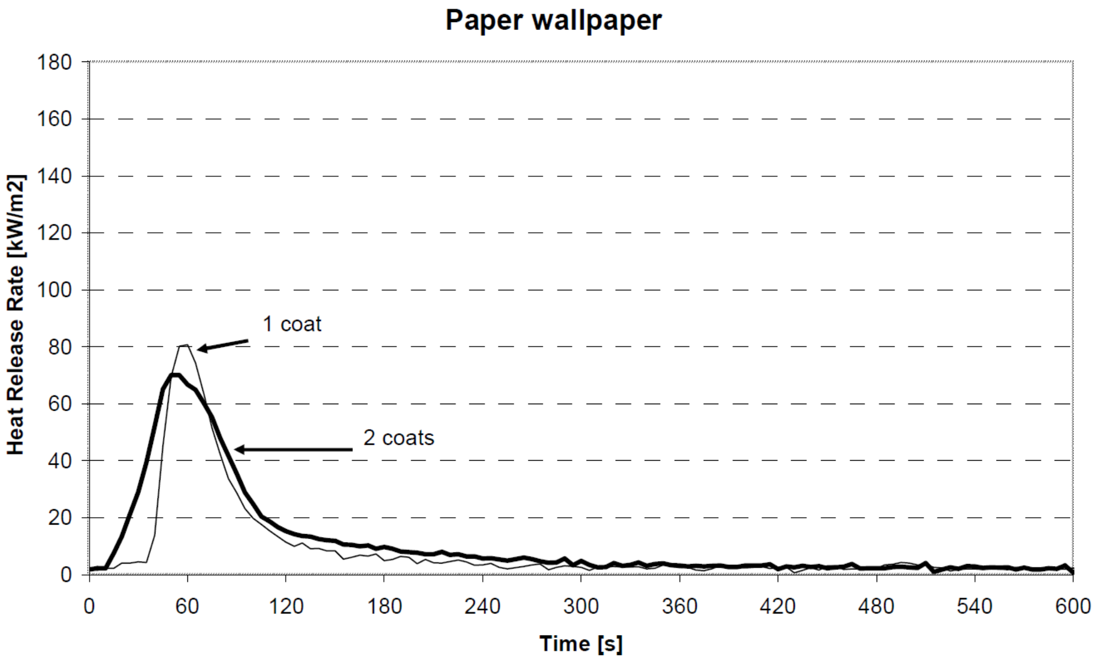


Figure 68 Heat release rates from cone testing at an irradiance of 50 kW/m² for a sample of one and two layers of wallpaper on plasterboard. Extracted from Steen-Hansen and Kristoffersen (2007).

Table 58 Summary of average cone calorimeter (at an irradiance of 50 kW/m²) results for one and two layers of a wallpaper on plasterboard. Extracted from Steen-Hansen and Kristoffersen (2007).

Cone Calorimeter Parameters	Paper wallpaper	
	1 layer	2 layers
Time to ignition (s)	36	24
Peak heat release rate (kW/m²)	83	80
Total heat release (MJ/m²)	5.2	6.6
Total smoke produced (m²)	1.1	1.1

BRE (2012) selected seven example types of wallpaper and decorative linings for investigation using the standardised large scale room corner test method for comparison with the European classification system. Three of these products demonstrated that flashover conditions could be reached. Details of the materials and results were not reported.

3.2.3 Textile Coatings

Fisher, et al. (1986) tested a range of textile wall covering materials in a room/corner facility. Also Belles et al. (1988) tested various textile wall linings (as listed in Table 59) on a 12.5 mm thick gypsum plasterboard substrate using ASTM E84. Most tests were conducted using either 1 foot or 2 feet wide sections of sample that covered the corner adjacent to the burner and along the two walls just below the ceiling, as a financial saving approach. Three tests were conducted using the fully lined walls of the test room (these were the 100% polyester knit plush, both of the 100% nylon woven specimens in Table 59). The textile wallcoverings were affixed to the substrate using a high-temperature mortar cement. This fixing method was chosen to limit the influence of the adhesive on the test results. A summary of the approximate heat release rate is include in Figure 70. A comparison of the peak heat release rate and flame spread rating for ASTM E-84 testing is shown in Figure 69.

Table 59 List of materials tested with ASTM E87 by Belles et al. (1988)

Sample Code	Material Type	Weight (Oz/Sq Yd)	Construction	Comments
GWB	½" Gypsum Wallboard	N/A		
G	100% Polyester	20.0	Needle Punched	
AA	70% Acrylic/30% Wool	22P – 38T	Tufted Wall Covering	Flame Spread 25
Q	100% Polyester	12.8	Knit Plush	Flame Spread 15
Qfr	100% Polyester	12.8	Knit Plush	Flame Spread 15
BB	75% Wool/25% Nylon	22P – 38T	Tufted Wall Covering	
C	55% Cotton/45% Rayon	11.5	Dobby Woven	
B	100% Polyester	9.8	Woven Panel Fabric	
Zfr	100% Wool	13.0	Woven Panel Fabric (fr)	
Lfr	100% Polyester	13.7	Woven	Flame Spread 15
R	100% Nylon	12.6	Woven	Flame Spread 15
H	85% Wool/15% Nylon	9.6	Woven Flannel	
L	100% Polyester	13.7	Woven (fr)	
Q	100% Polyester	12.8	Knit Plush	Flame Spread 15
PWfr	½" Plywood (fr)	N/A	½" Plywood (fr)	
R	100% Nylon	12.6	Woven	Flame Spread 15
R	100% Nylon	12.6	Woven	Flame Spread 15
Q	100% Polyester	12.8	Knit Plush	Flame Spread 15
Q	100% Polyester	12.8	Knit Plush	Flame Spread 15
Q	100% Polyester	12.8	Knit Plush	Flame Spread 15
R	100% Nylon	12.6	Woven	Flame Spread 15
R	100% Nylon w/o backing	12.6	Woven	Flame Spread 15
H	85% Wool/15% Nylon	9.6	Woven Flannel	
C	55% Cotton/45% Rayon	11.5	Dobby Woven	
B	100% Polyester	9.8	Woven Panel Fabric	
PP-95	100% Polypropylene	7.8	Woven	
PP-PF	100% Polypropylene	18.0	Non-Woven	
DD	100% Nylon	13.6	Woven	
113-9	100% Wool	19P – 37T	Tufted Wall Covering	
113-9	100% Wool	19P – 37T	Tufted Wall Covering	

Table Notes:
P refers to pile yarn
T refers to total (pile + backing)
fr refers to fire retardant treated

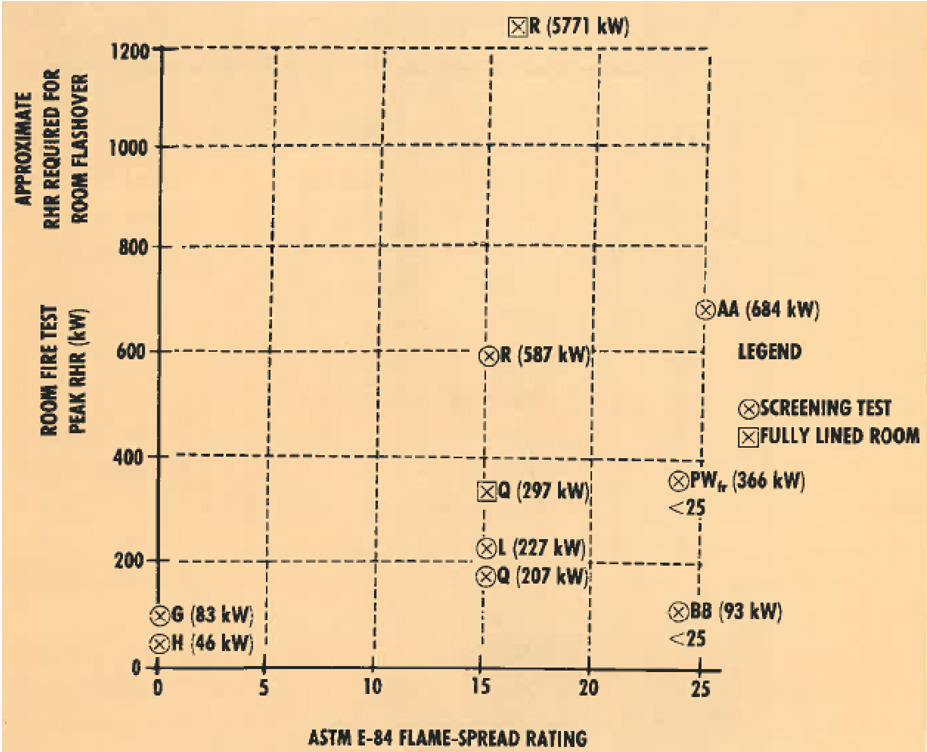


Figure 69 A comparison of the peak heat release rate and flame spread rating for ASTM E-84 testing. Extracted from Belles et al. (1988).

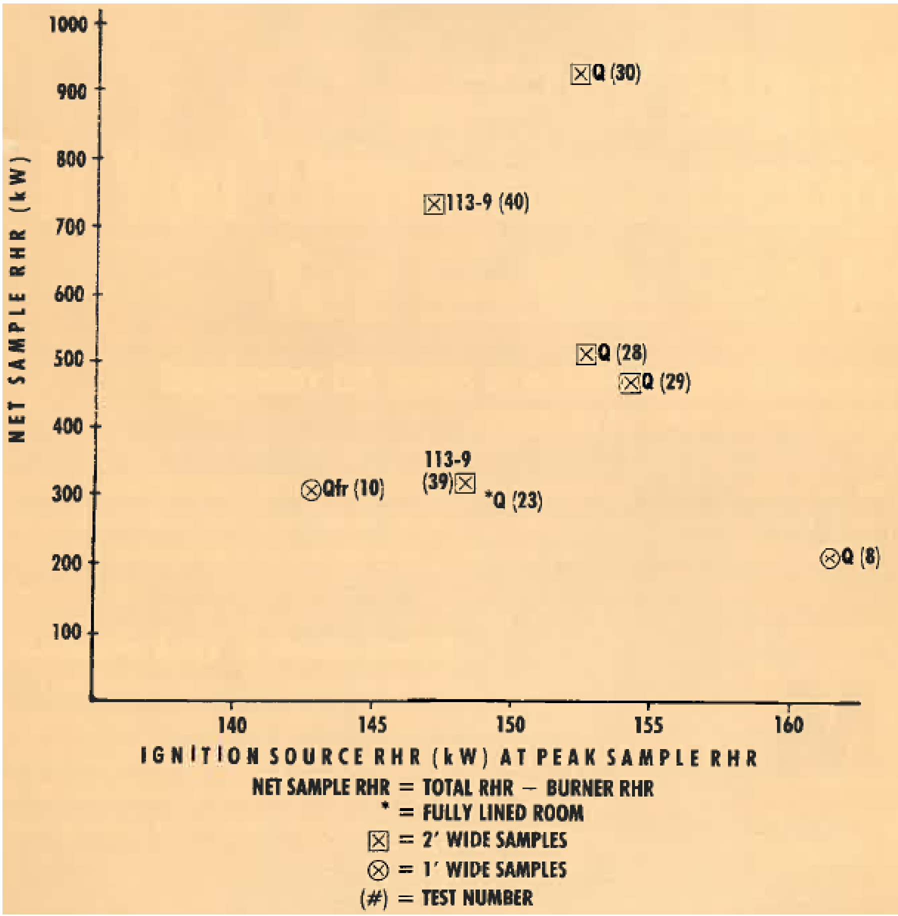


Figure 70 The effect of the adhesive used to affix wallcoverings to a plasterboard substrate was consider in terms of contribution to the net heat release rate when exposed to the ignition source heat release rate that occurred at the time of peak heat release rate of the covered specimen. Extracted from Belles (1988).

Harkleroad (1989) then reported LIFT and cone calorimeter results for 10 textile wall covering materials that had been previously tested by Fisher et al. (1986) and Belles et al. (1988). Harkleroad's specimens included woven, knit and needle punched polyesters, woven cotton and rayon blends, woven wool and nylon blends, nylon, and polypropylene products, as summarised in Table 60. The textiles were mounted on 12.7 mm thick gypsum plasterboard with a non-combustible adhesive (Sairmix-7). A summary of the peak heat release rates and total heat release for the specimens tested in a vertical orientation in the cone calorimeter is presented in Table 61 and in Appendix A Figure 101 to Figure 110.

Table 60 Description of textile wall coverings investigated by Harkleroad (1989).

Material	Mass per Unit Area * (kg/m²)	Construction	ASTM E84 Flame Spread Index	Rate of Heat Release from Room/Corner Tests by Fisher, et al (1986) (kW)	Code used in Table 62 and Figure 71
100% Polypropylene	0.61	Non-woven	-	1166 [2]	PP-PF
100% Nylon	0.43	Woven	15	590 [2]	R
100% Polyester	0.43	Knit plush	15	497 [2] 474 [2]	Q
100% Polyester	0.33	Woven panel fabric	-	298 [2]	B
85% Wool/ 15% Nylon	0.33	Woven flannel	-	160 [2]	H
55% Cotton/ 45% Rayon	0.4	Dobby woven loose complex weave with floating yarn	-	119 [2]	C
70% Acrylic/ 30% Wool	0.75P 1.29T	Tufted	25	684 [1]	AA
100% Nylon	0.43	Woven	15	587 [1]	R
100% Polyester	0.43	Knit plush	15	310 [1]	Q_{FR}
100% Polyester	0.43	Knit plush	15	207 [1]	Q
100% Polyester	0.33	Woven panel fabric	-	207 [1]	B
100% Polyester	0.68	Needle punched	-	83 [1]	G
55% Cotton/ 45% Rayon	0.40	Dobby woven loose complex weave with floating yarn	-	62 [1]	C
85% Wool/ 15% Nylon	0.33	Woven flannel	-	46 [1]	H
100% Polyester	0.43	Knit plush	15	5771 [full]	Q
100% Polyester	0.43	Knit plush	15	297 [full]	Q

Table Notes:

[1] 1 foot wide test specimen

[2] 2 foot wide test specimen

[full] fully lined room tire test

* P refers to pile weight, and T refers to total weight.

Table 61 Summary of vertically oriented specimens tested in the cone calorimeter results at an incident heat flux of 50 kW/m² investigated by Harkleroad (1989).

Material	Construction	Peak Heat Release Rate (kW/m²)	Total Heat Released (MJ/m²)	Code used in Figures
100% Polypropylene	Non-woven	262	17	PP-PF
100% Polyester	Knit plush	225	7	Q
100% Polyester	Woven panel fabric	247	6	B
85% Wool/ 15% Nylon	Woven flannel	105	4	H
55% Cotton/ 45% Rayon	Dobby woven loose complex weave with floating yarn	124	11	C
55% Cotton/ 45% Rayon	Dobby woven tight complex weave with floating yarn	132	5	C
70% Acrylic/ 30% Wool	Tufted	252	25	AA
100% Nylon	Woven	288	9	R
100% Polyester	Knit plush	213	8	Q_{FR}
100% Polyester	Needle punched	73	2	G

Mowrer and Williamson (1991) made a comparison of Fisher, et al.'s (1986) results for room and Harkleroad's (1989) cone calorimeter tests at an incident heat flux of 50 kW/m² with vertically oriented specimens (Table 62 and Figure 71).

Table 62 A summary of 1-foot and 2-foot-width-specimen room/corner test results (Fisher et al., 1986) and cone calorimeter test results (Harkleroad, 1989) for various textile wall coverings. Extracted from Mowrer and Williamson (1991).

FABRIC	CONE CALORIMETER RESULTS						kE" - t(f)/t(bo) k = 0.01; t(bo) = t(b)-t(f)			LARGE-SCALE PEAK HRR	
	30 kW/m2 EXPOSURE			50 kW/m2 EXPOSURE							
	t(f) (s)	t(b) (s)	E" kW/m2	t(f) (s)	t(b) (s)	E" kW/m2	30 kW/m2 -	50 kW/m2 -	COMBINED -	1 FOOT kW	2 FOOT kW
Q	175	188	165	33	50	265	-11.81	0.71	-7.64	207	497
Q-FR	192	205	219	33	65	230	-12.58	1.27	-3.70	310	
B	168	180	156	34	55	249	-12.44	0.87	-5.51	207	298
G	230	240	85	19	35	83	-22.15	-0.36	-13.55	83	
C2	85	100	119	34	55	135	-4.48	-0.27	-2.70	62	119
C1	80	95	130	25	45	140	-4.03	0.15	-2.60		
R	35	65	70	25	55	340	-0.47	2.57	2.23	587	590
AA	60	150	242	16	130	225	1.75	2.11	1.72	684	
PP-PF	80	120	217	29	65	286	0.17	2.05	0.64		1166
H	-	-	-	20	40	170	-	0.70	-	46	160

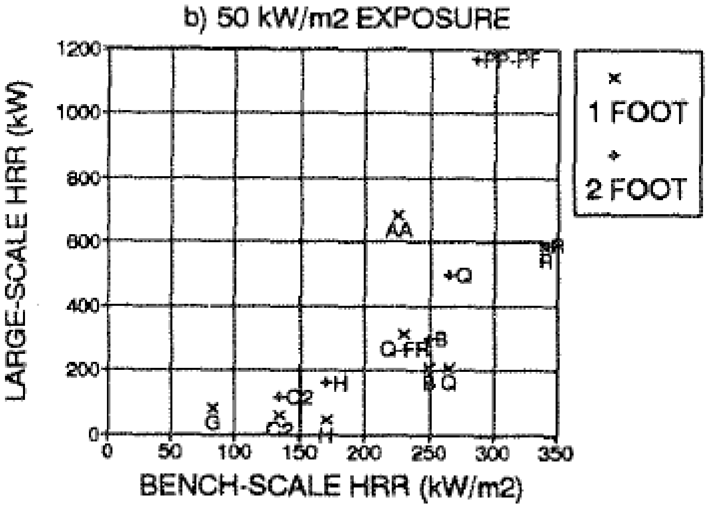


Figure 71 Comparison of heat release rates for room/corner tests (Fisher et al., 1986) and cone calorimeter tests (Harkleroad, 1989) for various textile wall coverings. Extracted from Mowrer and Williamson (1991).

As part of a project considering the fire performance of 10 various wall linings in a Building Code of Australia (BCA) context, Collier et al (2006) compared AS 3837 and ISO 9705 test results. A summary of the results for two polymeric substrates included in this project is presented in Table 29. In this case the smoke production for one of the two samples exceeded the AS 3837 SEA limit (of 250 m²/kg), but neither sample exceeded the ISO 9705 SMOGRA limit (of 100 m²/s² x 1000) for the BCA context.

Table 63 Summary of the smoke production results for a vinyl wallpaper for AS 3837 and ISO 9705 tests for a BCA context. Extracted from Collier et al (2006).

Material	AS 3837 average specific extinction area SEA (m²/kg)	AS 3837 Total Heat Released (MJ/m²)	AS 3837 prediction of BCA Group number **	ISO 9705 SPR60 (peak) (m²/s)	ISO 9705 SMOGRA (m²/s² x 1000)	ISO 9705 BCA Group number
100% Polyester wall covering	224.9	12.4	2	1.9	2.5	1
Modified polyester wall covering	414.4*	35.5	3	1.4	1.2	1

Table Notes:
* 250 m²/kg limit was exceeded, and BCA only permits use in sprinklered premises.
** Estimated according to BCA 2006 Volume One Spec A2.4-3. See APPENDIX 2 – Classification of data, Section 10.1.1 Predicting a material's BCA Group number.
† Prediction of BCA Group number using ISO 5660-1 end of test criteria.

3.2.4 Decorative Laminates, Films, Veneer and Foil Coatings

Veneered board construction was also considered in an assessment (WFRA, 2007a, 2007b, 2007c, 2007d;Paroz, 2002;EWFA, 2010) for the Timber Development Association (TDA, 2012), Australia. For a substrate of either particleboard or medium density fibreboard, a summary of the proposed substrate and veneer densities, veneer species, substrate thickness, veneer thickness, and adhesives as described in Table 64, a Building Code of Australia Classification of Group Number 3 and an average extinction area of less than 250 m²/kg was recommended.

Table 64 Summary of a proposed veneered board construction based on an assessment of various species. Extracted from EWFA (2010).

Substrate	
Material	Particleboard (Dry density nominally 700 kg/m³) MDF (Dry density nominally 560 to 740 kg/m³)
Thickness	6 mm (nominal)
Veneer	
Material	Unmodified timber or CCA Treated Radiata Pine (Dry density > 500 kg/m³) A species listed in Table 23
Thickness	0.6 to 0.85 mm (nominal)
Adhesive	PVA or Resorcinol
Position of Veneers	A timber veneer shall be applied to each face, though each side does not have to be the same species.

ASTM D1360-98 (2011) describes a test method for determining the relative fire retardancy of coatings on a wood surface. The tested sample (consisting of the wood substrate and a coating or coating system) is directly exposed to an alcohol burner flame. The results are measured by mass loss and a charring flame rate index.

Garay (2012) compared veneer and melamine foil coatings of particleboard using the standard test method of ASTM D1360-98 (2011) and found no distinguishable difference between the samples tested for the charring flame rate index and did not show significant results from the particleboard alone (Garay and Henríquez, 2010).

It is noted that when PVC is used to make flexible wall coverings, its fire properties are less favourable compared to rigid PVC depending on the amount and types of plasticizers and other additives used, as summarised in Appendix A Figure 111 and Table 97 (The Vinyl Institute, 1996).

3.2.5 Carpet and Acoustic Coverings

Quintiere et al. (1985, 1986) investigated a range of wall linings, using the apparatus design by Ahmed and Faeth (1979) to investigate pyrolysis zones in a vertical specimen with the addition of a radiant panel (with incident heat fluxes of 2.5, 3.0 and 3.6 W/cm²), including a nylon/wool blend carpet, reporting an average heat release rate of 75 to 220 kW/m².

As part of the research supporting the European Classification without Further Testing, carpet wall covering samples were also included in testing at 50 kW/m² irradiance in the cone calorimeter and ISO 9705 room testing and have been reported on by Tsantaridis (1992) and Thureson (1991, 1992). A summary of average test results is included in Table 65. Heat release rates and smoke specific extinction areas are included for the sample listed in Table 65 in Table 71.

Table 65 Summary of reported time to ignition and average effective heat of combustion for 50 kW/m² irradiance cone calorimeter tests and time to flashover in room test of substrates and coatings.

Material Description	Time To Flashover in ISO room (min:s) [Ref. E, F]	Time to Ignition in Cone Calorimeter (s)	Average Effective Heat of Combustion (kJ/g)	Total Heat Released (MJ/m²)	Average Rate of Smoke Production/ Rate of Heat Release (ob.m³/MJ)	Ref.
PVC wall carpet on gypsum paper plasterboard (affixed with vinylacetate copolymers), 13 mm (total) thick	> 20 :00	14.5 15	NR	16.1	NR	B C

Table Notes:
Ref. refers to Reference for test results.
NR refers to Not Reported.
NI refers to No Ignition
FR refers to material had a Fire Retardant treatment.
- refers to not reported because of irregularities.
Ref. B: Average results from two tests reported by Thureson (1991).
Ref. C: Average results from two tests reported by Tsantaridis (1992) for cone calorimeter

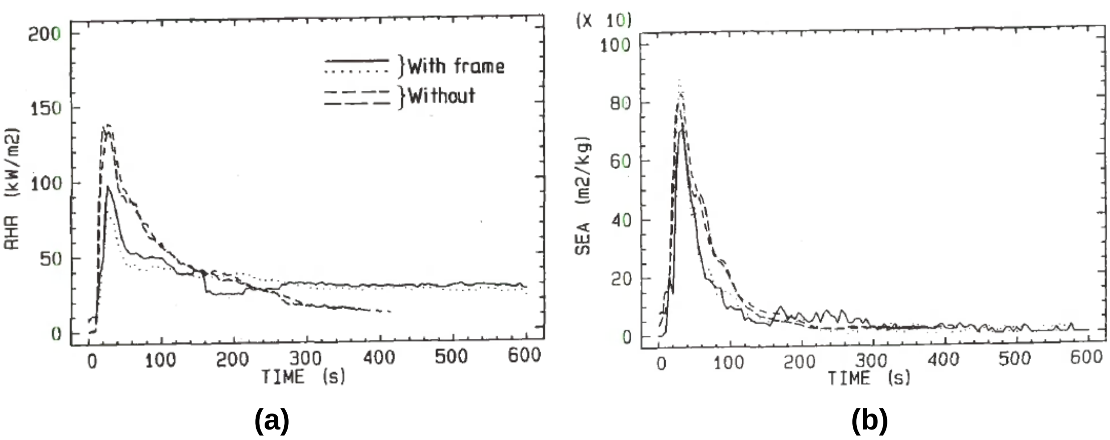


Figure 72 (a) Heat release rate and (b) specific extinction area for 2 specimens of PVC wall carpet on paper-faced gypsum plasterboard at 50 kW/m² in the horizontal orientation. Extracted from Tsantaridis (1992), including data from Thureson (1991).

3.3 Floorings

The following sub-sections summarising relevant available test results for flooring products is presented based on the estimated primary contributing element to the fire performance of the sample. For example Section 3.3.1 for wood and wood products includes results, where available, with and without coatings.

It is noted that the majority of the literature found related to floorings was associated with the wood and wood-products research that went into the development of the European classification without further testing (CWFT). Collier (2007) investigated the reaction of fire of various floorings and floor coverings for three types of test methods. The Australian Timber Database has a listing of critical radiant fluxes and smoke development rates for a range of 12 and 19 mm thick solid wood and 15 m thick plywood flooring (ATD 2013a).

3.3.1 Wood and Wood Products

As part of the five wood-product families of building materials were considered by Östman and Mikkola (2006) in terms of the reaction to fire performance, wood flooring was one of the wood-product types included in the study. The test methods used in this study were EN 13823 (2002) Single Burning Item (SBI) test, EN ISO 9239-1 (2002) Radiant panel test, and EN ISO 11925-2 (2002) Small flame test.

Generic Euroclass (EN 13501-1) values for wood-based products, according to BS/EN 13986 (2004), are based on three parameters:

4. An EN product grade reference,
5. Minimum density, and
6. Minimum thickness.

An example of the EN13501-1 classes using classification without further testing (CWFT) for generic products are presented in Table 36 (BS/EN 13986, 2004). Classifications are as provided for in Commission Decision 2000/147/EC Annex Table 2 for floorings. Examples of the generic grouping of products and the associated Class for the European classification without further testing scheme are included in Table 66 (Östman and Mikkola, 2006).

The solid wood species (spruce, sitka spruce, pine, beech, chestnut and oak) used in the testing by Tsantaridis and Östman (2004) were from various sources.

Tsantaridis and Östman (2004) and, this reiterated again by Östman and Mikkola, (2006), suggested that the influence of the surface coatings investigated was to either maintain or improve the fire performance (i.e. achieve a higher critical heat flux) in the Radiant panel test when compared to the uncoated substrate alone. A tabled summary of the results are included in Table 68, Table 69, Table 70 and Table 71. Visual summaries of these tabled results are included in Figure 73, Figure 75, Figure 76 and Figure 79.

It was reported that for SBI test results for the critical heat flux there was no clear trend with wood product density for either the uncoated or surface coated specimens tested when all the species were analysed together (e.g. Figure 75 and Figure 76). However when species were considered separately, the influence of the coating was more pronounced; either maintaining or improving the fire performance for the specimens investigated (Tsantaridis and Östman, 2004).

Tsantaridis and Östman (2004) reported that, for the specimens tested, flame spread was observed to be more rapid along the wood grain than transverse the grain (e.g. Table 68). Knots were reported to potentially improve the fire performance, and therefore small or no knots were considered the worst case scenario (Tsantaridis and Östman, 2004). For the samples of multilayer wood-product floorings tested, the type and amount of adhesive was observed to have a minor influence on the fire performance (Tsantaridis and Östman, 2004). For flooring thicknesses at least 14 mm, the layer behind this was suggested to have negligible effect. For thin multilayer products, the interlayers behind the flooring and the substrate may negatively affect the fire performance (Tsantaridis and Östman, 2004).

Table 66 Examples of Euroclass classification without further testing (CWFT) generically grouped wood-based products. (Extracted from Östman and Mikkola (2006).)

Wood-based panel product	EN product grade reference	Minimum density (kg/m³)	Minimum thickness (mm)	Class (for floorings)
Oriented Strand Board (OSB) *	EN 300	600	9	D_{FL}-s1
Particleboards *	EN 312	600	9	D_{FL}-s1
Fibreboards, Hard *	DN 622-2	900	6	D_{FL}-s1
Fibreboards, Medium *	DN 622-3	600	9	D_{FL}-s1
		400	9	E_{FL}
Fibreboards, Soft *	DN 622-4	250	9	E_{FL}
Fibreboards, Medium Density Fibre (MDF) (Dry process fibreboard) *	prEN 622-5	600	9	D_{FL}-s1
Cement-bonded particleboard (at least 75% cement) *	EN 634-2	1,000	10	B_{FL}-s1
Plywood *	EN 636	400	9	D_{FL}-s1
Solid wood panels *	EN 13353	400	12	D_{FL}-s1
Solid flooring of oak or beech with surface coating, glued to substrate ‡[b]	EN 13226 EN 13227 EN13228 EN 13629-1 EN 13990 EN 14761	Beech: 680 Oak: 650	8 Glued to substrate [a2]	C_{FL}-s1
Solid flooring of oak, beech or spruce with surface coating, with air gap ‡[b]	EN 13226 EN 13227 EN13228 EN 13629-1 EN 13990 EN 14761	Beech: 680 Oak: 650 Spruce: 450	20 With or without an air gap [a1]	C_{FL}-s1
Solid wood flooring with surface coating and not specified in the above two lines ‡[b]	EN 13226 EN 13227 EN13228 EN 13629-1 EN 13990 EN 14761	390	8 Without an air gap [a1]	D_{FL}-s1
			20 With an air gap	
Solid wood flooring and parquet without surface coating, with or without air gap underneath ‡	EN 13226 EN 13227 EN13228 EN 13629-1 EN 13990 EN 14761	400	6 With or without an air gap [a1]	E_{FL}
Multilayer wood parquet with a top layer of oak of at least 5 mm thickness and with surface coating ‡[b]	EN 13489	650 (top layer)	10 Glued to substrate [a2]	C_{FL}-s1
			14 With or without air gap [a1] and may have an interlayer [c1]	

Table 67 Table 66 continued: Examples of Euroclass classification without further testing (CWFT) generically grouped wood-based products. (Extracted from Östman and Mikkola (2006).)

Wood-based panel product	EN product grade reference	Minimum density (kg/m^3)	Minimum thickness (mm)	Class (for floorings)
Multilayer wood parquet with surface coating not specified in the above line ‡[b]	EN 13489	500	8 Glued to substrate [a1]	D_{FL}-s1
			10 Without air gap underneath [a1]	
			14 With our without an air gap & with an interlayer [c1]	
Solid wood (one layer) parquet of walnut without surface coatings ‡	EN 14761	Walnut: 650 Ash: 650 Maple: 650 Oak: 720	8 Glued to substrate with at least D-s2,d0	D_{FL}-s1
Multilayer parquet with oak top layer, at least 3.5 mm thick, without surface coating ‡	EN 13489	550	15 without an air gap [a1], and may have an interlayer [c2]	D_{FL}-s1
Solid wood flooring of pine, spruce oak or beech, without surface coating ‡	EN 13629 EN 13986 EN 13990	Pine: 480 Spruce: 400	14 Without an air gap [a1]	D_{FL}-s1
		Pine: 430 Spruce: 400 Beech: 700 Oak: 700	20 With or without an air gap [a1]	D_{FL}-s1
Veneered floor coving with surface coating ‡[b]	EN 14354	800	6 Without an air gap [a1], and may have an interlayer [c1]	D_{FL}-s1

Table References (see following page as well):

* BS/EN 13986 (2004). Samples were mounted without an air gap, directly against a Class A1 or A2-s1, d0 substrate with a minimum density of 10 kg/m^3, or at least a Class D-s2, d0 substrate with a minimum density of 400 kg/m^3.

§ BS/EN 14080 (2005). Samples were mounted with an air gap.

‡ BS/EN 14342 (2013). This standard does not apply to bamboo, plant products (such as aloe, coconut or cork), laminate flooring products, or flooring products designed for enhanced tactile and recognition. Where a substrate is used it is of at least Class D-s2, d0 and with a minimum density of 400 kg/m^3.

Table Notes:

[a1] Substrate materials are to be of at least Class D-s2, d0 with a minimum density of 400 kg/m^3 (BS/EN 14342, 2013).

[a2] Substrate materials are to be of at least Class A2-s1, d0 (BS/EN 14342, 2013).

[a3] To be mounted mechanically on a wood batten support frame, with the gap closed or filled with a substrate of at least Class A2-s1, d0 with a minimum density of 10 kg/m^3 or filled with a substrate of cellulose insulation material of at least Class E and with or without a vapour barrier behind.

[a4] An open air gap may include possibility for ventilation behind the product, while a closed air gap will exclude such ventilation. The substrate behind the air gap is of at least a Class A2-s1, d0 with a minimum density of 10 kg/m^3. Behind a closed air gap of a maximum 20 mm and with vertical wood pieces, the substrate may be of at least a Class D-s2, d0.

[a5] Mounded mechanically on a wood batten support frame, with or without an open air gap behind. The wood product shall be designed to be mounted without open joints.

[a6] Rectangular wood pieces, with or without rounded corners, mounted horizontally or vertically on a support frame and surrounded by air on all sides, mainly used close to other building elements, both in interior and exterior applications. Maximum exposed areas (all sides of

wood pieces and wood support frame) shall be not more than 110 % of the total plane area. Other building elements at distances from the ribbon:

- closer than 100 mm from the wood ribbon element (excluding its support frame) are required to be at least a Class A2-s1, d0,
- 100 mm to 300 mm are required to be of at least a Class B-s1, d0 and
- more than 300 mm are required to be of at least Class D-s2, d0.

[b] Surface coatings included are acrylic, polyurethane or soap, 50 – 100 g/m^2, and oil 20 – 60 g/m^2 (BS/EN 14342, 2013).

[c1] For parquet of 14 mm or more thickness, an interlayer of at least Class E and with maximum thickness 3 mm may be used (BS/EN 14342, 2013).

[c2] For parquet of 14 mm or more thickness, an interlayer of at least Class E, with maximum thickness 3 mm and a minimum density of 280 kg/m^3 may be used (BS/EN 14342, 2013).

Table 68 Summary of a series of ISO 9239-1 radiant panel test results performed on solid wood flooring at CTBA and Trätek. Extracted from Tsandaridis and Östman (2004).

Material Description	Total Thickness (mm)	Total Density (kg/m³)	Substrate	Surface Coating (Type, g/m²)	CHF (kW/m²)
Sitka spruce with larger knots	20	383	Part b	NC	4.6
Sitka spruce with large knots – transverse grain	20	383	Part b	NC	4.9
Sitka spruce with large knots	20	404	Air gap	NC	4.7
Sitka spruce with large knots – transverse grain	20	404	Air gap	NC	7.0
Sitka spruce with small knots	8	400	Part b	NC	4.3
	20	413	Air gap	NC	5.2
Spruce (new)	32	454	Air gap	NC	5.4
Pine	25	527	Air gap	NC	3.9
		511	Air gap	Soap, 100	6.7
		516	Air gap	Oil, 100	4.4
Beech (old)	21	672	Part b	NC	4.0
Beech (new)	21	663	Air gap	NC	6.7
Chestnut, resin content 1.9%	14	570	Part b	NC	2.6
Chestnut	14	570	Part b	acrylate, 85	3.6
Oak (old)	21	618	Air gap	NC	4.3
Oak (new)	21	835	Air gap	NC	4.5
Sitka spruce	18	433	Air gap	UV acrylate, 60	4.4
		430	Air gap	UV polyurethane, 60	5.1
		436	Air gap	UV oil, 20	5.5
Parquet, solid, 1 layer Beech, PVAc)	6	716	Part b	NC	3.7
Oak (new)	21	791	Air gap	UV acrylate, 60	5.5
	20	798	Air gap	UV acrylate, 120	5.4
		820	Air gap	UV polyurethane, 60	5.8
		741	Air gap	UP polyurethane, 120	4.3
		791	Air gap	UV oil, 20	5.2
		771	Air gap	UV oil, 60	5.5
Spruce	32	540	Air gap	Oil, 60	5.8
Beech	20	650	Air gap	Oil, 60	4.6
		665	Air gap	NC	4.5
Oak	21	790	Air gap	Oil, 60	5.7
		720	Air gap	Oil, 60	5.7

Table Notes:
Air gap refers to a minimum height of 40 mm.
UV refers to UV cured coating.

Table 69 Summary of a series of ISO 9239-1 radiant panel test results performed on multilayer parquet flooring at Trätek. Extracted from Tsandaridis and Östman (2004).

Total Thickness (mm)	Total Density (kg/m³)	Top Layer			Inter-layer	Substrate	Surface Coating (Type, g/m²)	CHF (kW/m²)
		Wood	Thickness (mm)	Glue (type, g/m²)				
10	574	Beech	2.5	UF, 100	-	Part b	UV acrylate, 60	5.0
	557				-	Part b	NC	3.2
	541			UF, 300	-	Part b	NC	4.1
	520			PVAc	-	Part b	NC	2.7
	519			UF	-	Part b	UV oil, 20	5.0
	557			UF	Paper	Part b	NC	3.2
	557			UF	Foam	Part b	NC	2.9
	574			UF	Softb.	Part b	NC	2.6
12	585	Beech	3.5	UF	-	Part b	NC	3.1
12	556	Oak	3.5	UF	-	Part b	UV acr, 60	4.1
	550						NC	3.4
	557				Softb	Part b	NC	3.0
14	565	Oak	3.6	UF	-	Part b	Acrylate	4.9
15	541	Oak	3.5	UF	Softb	Part b	NC	3.4
	540				Foam	Part b	NC	3.4
	550				-	Part b	NC	3.7
14	480	Pine	3.6	UF	-	Part b	Acrylate	4.3
14	540	Birch	3.5	UF	-	Air gap	UF acrylate, 98	3.7
	515		3.6		-	Part b	Acrylate	5.1
14	590	Jarrah	3.5	UF	-	Air gap	UF acrylate, 98	4.3
14	595	Alder	3.6	UF	-	Part B	Acrylate	6.0
14	630	Paraju	3.5	UF	-	Air gap	UF acrylate, 98	5.4
	640					Part b		5.5
	530				Foam	Part b		5.4
10	590	Merbau	3.5	UF	-	Part b	UV acrylate, 70	4.9
						Fibrecement		6.7
15	650	Merbau	4.0	UF	-	Part b	Acrylate	4.9

Table Notes:
NC refers to No Coatign
UV refers to UltraViolet cured coating.

Table 70 Summary of a series of ISO 9239-1 radiant panel test results performed on veneered flooring at Trätek. Extracted from Tsandaridis and Östman (2004).

Total Thickness (mm)	Total Density (kg/m³)	Top Layer			Inter-layer	Substrate	Surface Coating (Type, g/m²)	CHF (kW/m²)
		Wood	Thickness (mm)	Glue (type, g/m²)				
6	846	Ash	0.5	UF	-	Part b	UV oil, 20	7.6
	967						NC	7.0
10	820	Oak	2.5	UF	-	Part b	UV acrylate, 50	4.2
						Fibrecement		3.9

Table Notes:
NC refers to No Coating
UV refers to UltraViolet cured coating.

Table 71 Summary of a series of ISO 9239-1 radiant panel test results performed on solid wood flooring at BASF and VTT. Extracted from Tsandaridis and Östman (2004).

Material Description	Total Thickness (mm)	Total Density (kg/m³)	Substrate	Surface Coating (Type, g/m²)	CHF (kW/m²)
Particleboard	10	680	Part b	NC	3.8
	12	600			4.4
Medium-Density Fibreboard	9	765	Air gap	NC	4.8
Fibreboard, Mediumboard	9	840	Air gap	NC	3.6
Fibreboard, Hardboard	6	1050	Part b	NC	4.0
Plywood, spruce	9	480	Air gap	NC	3.9
Oriented Strand Board (OSB)	9	600	Air gap	NC	4.2

Table Notes:
NC refers to No Coating

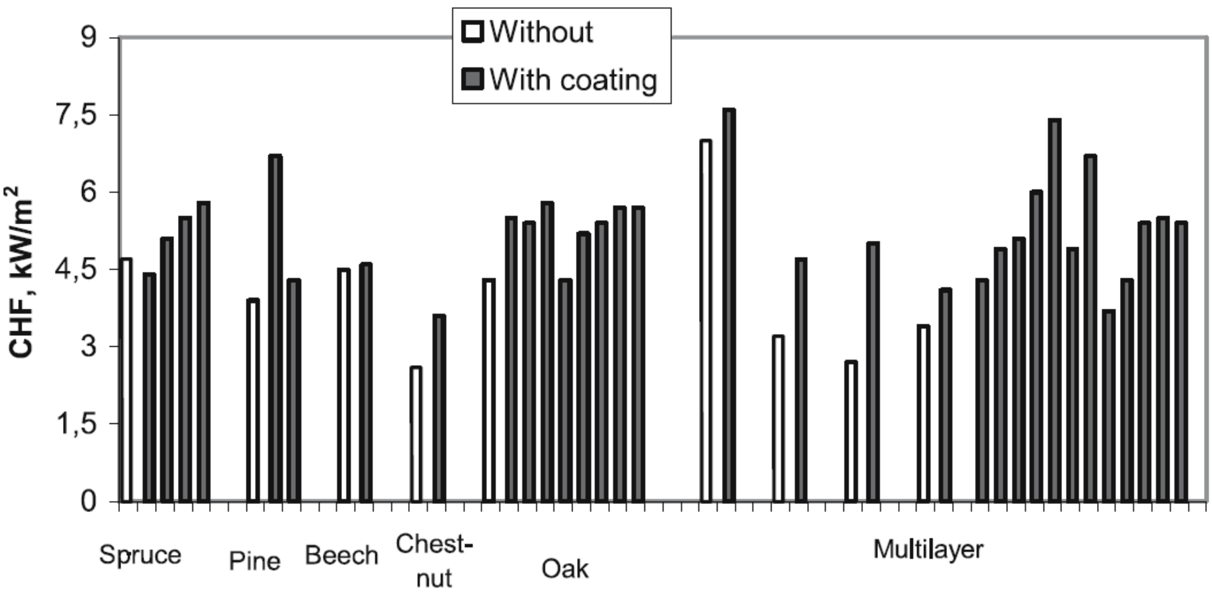


Figure 73 Radiant Panel Critical Heat Flux (CHF) for all wood floorings with and without a surface coat. (The coatings are as described in Table 68 and Table 69.) (Östman and Mikkola, 2006)

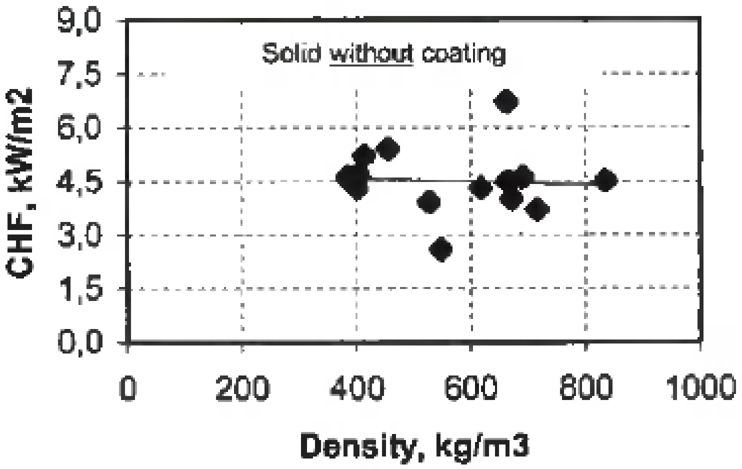


Figure 74 SBI Critical Heat Flux (CHF) versus density for solid wood floorings without a surface coating (Table 68). (Tsandaridis and Östman, 2004)

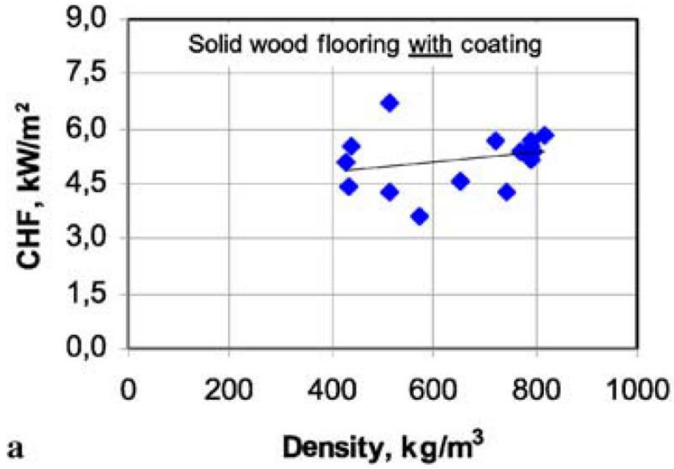


Figure 75 SBI Critical Heat Flux (CHF) versus density for solid wood floorings with a surface coating (Table 68). (Östman and Mikkola, 2006)

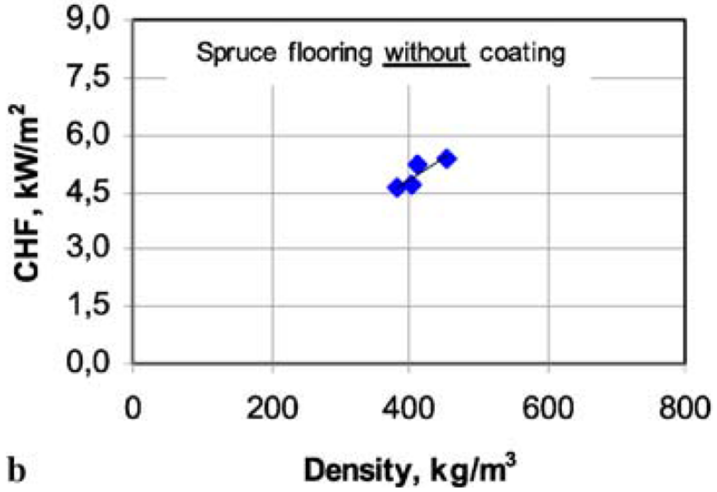


Figure 76 Critical Heat Flux (CHF) versus density for solid spruce floorings without a surface coating (Table 68). (Östman and Mikkola, 2006)

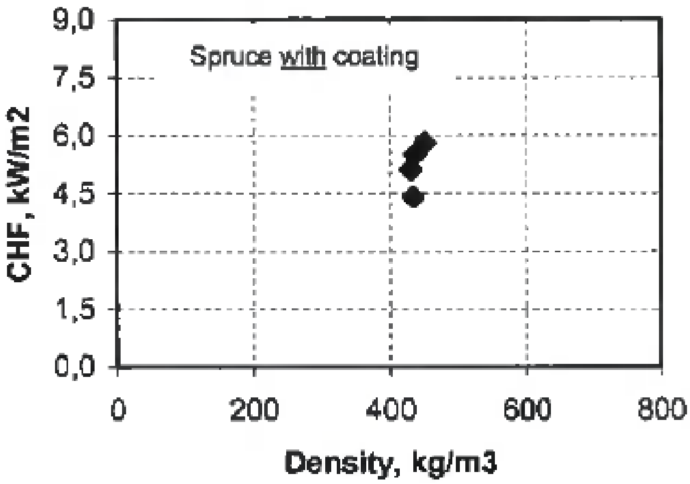


Figure 77 Critical Heat Flux (CHF) versus density for solid spruce floorings with a surface coating (Table 68). (Tsandaridis and Östman, 2004)

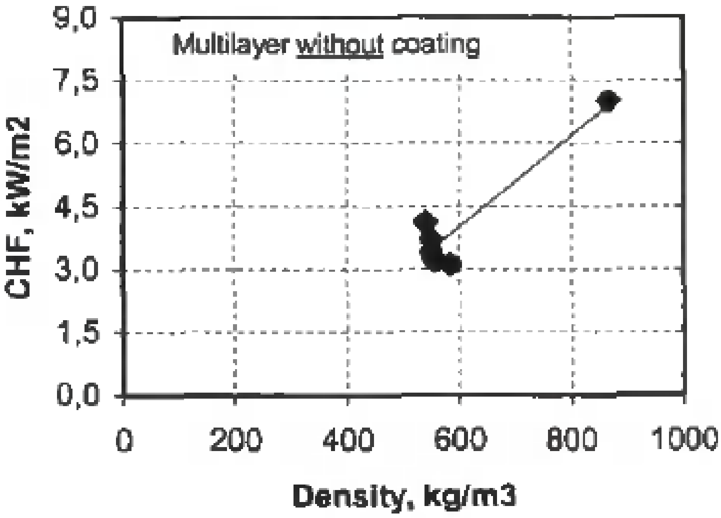


Figure 78 SBI Critical Heat Flux (CHF) versus density for multilayer wood floorings without a surface coating (Table 69). (Tsandaridis and Östman, 2004)

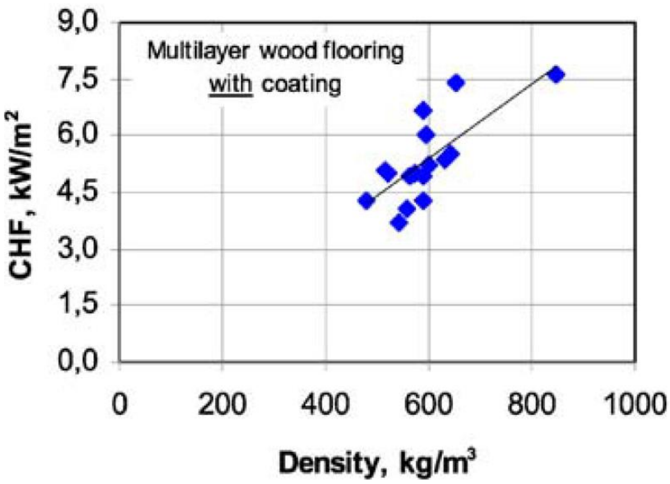


Figure 79 SBI Critical Heat Flux (CHF) versus density for multilayer wood floorings with a surface coating (Table 69). (Östman and Mikkola, 2006)

In a study by Collier (2007), the reaction of fire of floorings and floor coverings was investigated using three types of test methods:

- Hot metal nut (HMN) (BS 4790:1987),
- Flooring radiant panel (FRP) (EN ISO 9239-1:2002), and
- Cone calorimeter (CC) (ISO 5660-1:2002).

The material samples tested are summarised in Table 72, along with BCA group numbers for wall and ceiling classification. Critical radiative fluxes and smoke measurements from flooring radiant panel testing are summarised in Table 74. Heat release rate data from the cone calorimeter testing is summarised in Figure 80.

Table 72 Wood and wood product flooring samples tested by Collier (2007).

Flooring product type	Code	Thickness (nominal including backing) (mm)	Density (kg/m²)	Type of Tests Performed			BCA Group Number for Wall/Ceilings		
				CC	FRP	HMN	50 kW/m²	35 kW/m²	25 kW/m²
Flooring laminate (0.25 mm) on MDF	A	7	879	x	x	x	3	3	3
Flooring laminate (0.25 mm) (formica) on HDF	E	12	978	x	x	x	3	3	3
Flooring laminate 0.25 mm (formica) on HDF	F	8	896	x	-	-	3	3	3
Plywood flooring	I	20	511	x	x	x	3	3	3

Table Notes:
x Tested
- Not tested
* Data supplied by manufacturer

Table 73 Summary of flooring radiant panel testing results for wood and wood product flooring samples tested by Collier (2007).

Code	Flooring product type	Critical Radiant Flux (kW/m²)	Smoke (%.min)
A	Flooring laminate (0.25 mm) on MDF	7.5	131
C	Cork tile	5.3	106
D	Flooring laminate (0.25 mm) (formica) on 12 mm HDF	11.8	234
E	Flooring laminate (0.25 mm) (formica) on 8 mm HDF	11.8*	234*
H	Plywood flooring	5.8	185

Table Notes: * Sample not tested. Value was based on Sample D results.

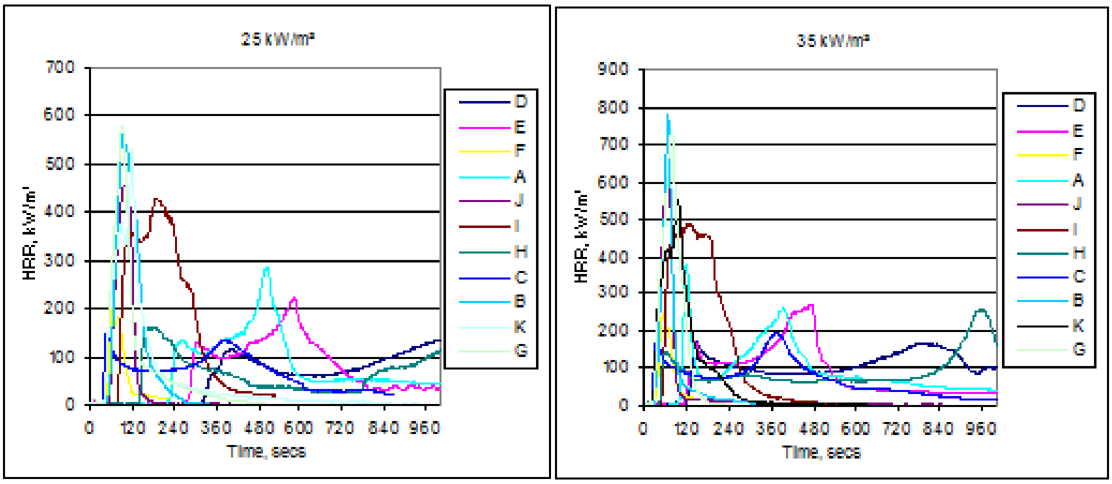


Figure 80 Heat release rates results at 25 and 35 kW/m² for various flooring material samples. (The key relates to those in Table 72.) Extracted from Collier (2007).

The Australian Timber Database (ATD 2013a) has published a list of test results for critical radiant fluxes and smoke development rates for a range of 12 and 19 mm thick solid wood types, as summarised in Table 74, and 15 m thick plywood flooring, as summarised in Table 75.

Table 74 Solid wood flooring critical radiative fluxes and smoke development rates. Extracted from ATD (2013a).

Wood Type	12 mm Thick or Greater		19 mm Thick or Greater	
	Critical Radiative Flux	Smoke Development Rate % - minute	Critical Radiative Flux	Smoke Development Rate % - minute
Ash, Alpine	-	<750	> 2.2 and < 4.5	<750
Ash, Mountain	> 2.2 and < 4.5	<750	> 2.2 and < 4.5	<750
Ash, Silvertop	> 2.2 and < 4.5	<750	> 2.2 and < 4.5	<750
Beech, Myrtle	> 2.2 and < 4.5	<750	≥ 4.5	<750
Blackbutt	> 2.2 and < 4.5	<750	> 2.2 and < 4.5	<750
Blackbutt, New England	> 2.2 and < 4.5	<750	≥ 4.5	<750
Blackwood	> 2.2 and < 4.5	<750	≥ 4.5	<750
Bloodwood, Red	> 2.2 and < 4.5	<750	≥ 4.5	<750
Box, Brush	> 2.2 and < 4.5	<750	≥ 4.5	<750
Box, Grey	> 2.2 and < 4.5	<750	≥ 4.5	<750
Brownbarrel	> 2.2 and < 4.5	<750	> 2.2 and < 4.5	<750
Cypress	> 2.2 and < 4.5	<750	≥ 4.5	<750
Gum, Blue, Sydney	> 2.2 and < 4.5	<750	> 2.2 and < 4.5	<750
Gum, Blue, Southern	> 2.2 and < 4.5	<750	≥ 4.5	<750
Gum, Manna	> 2.2 and < 4.5	<750	> 2.2 and < 4.5	<750
Gum, River Red	> 2.2 and < 4.5	<750	≥ 4.5	<750
Gum, Rose	> 2.2 and < 4.5	<750	> 2.2 and < 4.5	<750
Gum, Shining	> 2.2 and < 4.5	<750	> 2.2 and < 4.5	<750
Gum, Spotted	> 2.2 and < 4.5	<750	≥ 4.5	<750
Gum, Sugar	> 2.2 and < 4.5	<750	≥ 4.5	<750
Gum, Yellow	> 2.2 and < 4.5	<750	≥ 4.5	<750
Ironbark, Grey	> 2.2 and < 4.5	<750	≥ 4.5	<750
Ironbark, Red	> 2.2 and < 4.5	<750	≥ 4.5	<750

Table 75 Plywood flooring critical radiative fluxes. Extracted from ATD (2013a).

Plywood Type	Critical Radiative Flux
Hoop pine - 15 mm thick or greater	> 2.2 and < 4.5
Radiata pine - 15 mm thick or greater	> 2.2 and < 4.5
Slash pine - 15 mm thick or greater	> 2.2 and < 4.5

3.3.2 Carpets and Textiles

It is noted that carpet and textile material associated with aircraft fire safety applications (e.g. Lyon, 1998) were not included here, as the materials were not directly relevant to the scope of this research; however there is a significant amount of published data for a range of materials associated with this application.

As summarised earlier for wood and wood products, Collier (2007) investigated the reaction of fire of floorings and floor coverings using three types of test methods, namely the hot metal nut (HMN) (BS 4790:1987), flooring radiant panel (FRP) (EN ISO 9239-1:2002), and cone calorimeter (CC) (ISO 5660-1:2002). The material samples tested are summarised in Table 76, along with BCA group numbers for wall and ceiling classification. Critical radiant flux and smoke measurements from flooring radiant panel testing are summarised in Table 77. Heat release rate data from the cone calorimeter testing is summarised in Figure 81.

Table 76 Carpet flooring samples tested by Collier (2007).

Flooring product type	Code	Thickness (nominal including backing) (mm)	Density (kg/m²)	Type of Tests Performed			BCA Group Number for Wall/Ceilings		
				CC	FRP	HMN	50 kW/m²	35 kW/m²	25 kW/m²
Carpet tile (polyester)	B	4	347	x	x	x	4	3	3
Polypropylene carpet with latex backing	K	6	142	x	*	*	-	3	3
Polypropylene carpet bonded to polyolefin backing	L	6.2	337	x	*	*	-	4	3

Table Notes:
x Tested
- Not tested
* Data supplied by manufacturer

Table 77 Summary of flooring radiant panel testing results for carpet and textile product flooring samples tested by Collier (2007).

Code	Flooring product type	Critical Radiant Flux (kW/m²)	Smoke (%.min)
B	Carpet tile (polyester)	4.6	542
J	Polypropylene on latex	7.0	124
K	Polypropylene on polyolefin backing	4.2	660

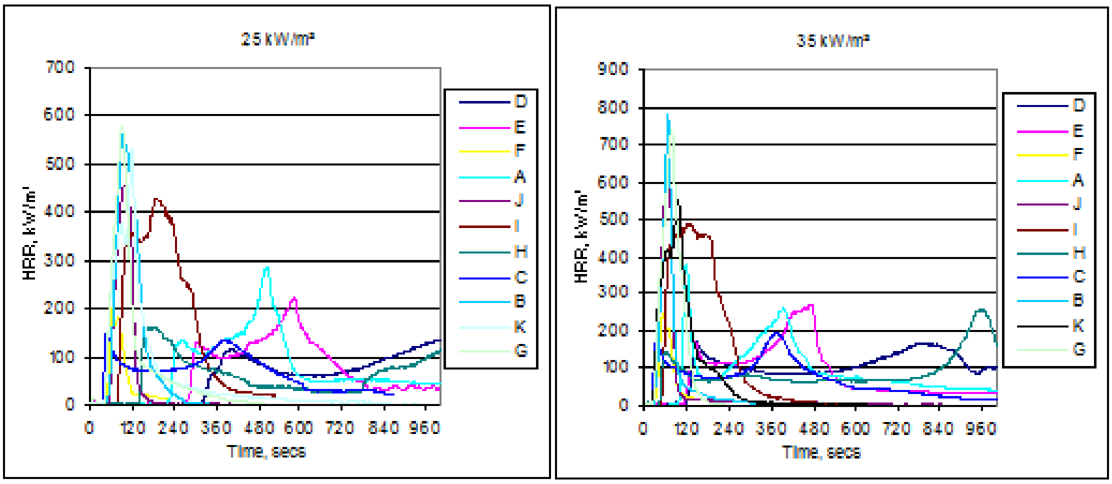


Figure 81 Heat release rates results at 25 and 35 kW/m² for various flooring material samples. (The key relates to those in Table 76.) Extracted from Collier (2007).

3.3.3 Polymers

Reaction to fire of other polymeric materials that were found were related to aircraft fire safety (e.g. Stoliarov et al., 2009), and therefore the specific materials were not directly relevant to the scope of this research.

As summarised earlier for wood and wood products, Collier (2007) investigated the reaction of fire of floorings and floor coverings using three types of test methods, namely the hot metal nut (HMN) (BS 4790:1987), flooring radiant panel (FRP) (EN ISO 9239-1:2002), and cone calorimeter (CC) (ISO 5660-1:2002). The material samples tested are summarised in Table 78, along with BCA group numbers for wall and ceiling classification. Critical radiant fluxes and smoke measurements from flooring radiant panel testing are summarised in Table 79. Heat release rate data from the cone calorimeter testing is summarised in Figure 82.

Table 78 Polymer product flooring samples tested by Collier (2007).

Flooring product type	Code	Thickness (nominal including backing) (mm)	Density (kg/m²)	Type of Tests Performed			BCA Group Number for Wall/Ceilings		
				CC	FRP	HMN	50 kW/m²	35 kW/m²	25 kW/m²
Vinyl tiles	G	1.5	898	x	x	x	2	2	1
Polyester, overlay	H	12	148	x	x	x	4	4	3

Table Notes:
x Tested
- Not tested
* Data supplied by manufacturer

Table 79 Summary of flooring radiant panel testing results for polymer product flooring samples tested by Collier (2007).

Code	Flooring product type	Critical Radiant Flux (kW/m²)	Smoke (%.min)
F	Vinyl tiles	11.7	158
G	Polyester, overlay	<1.1	629

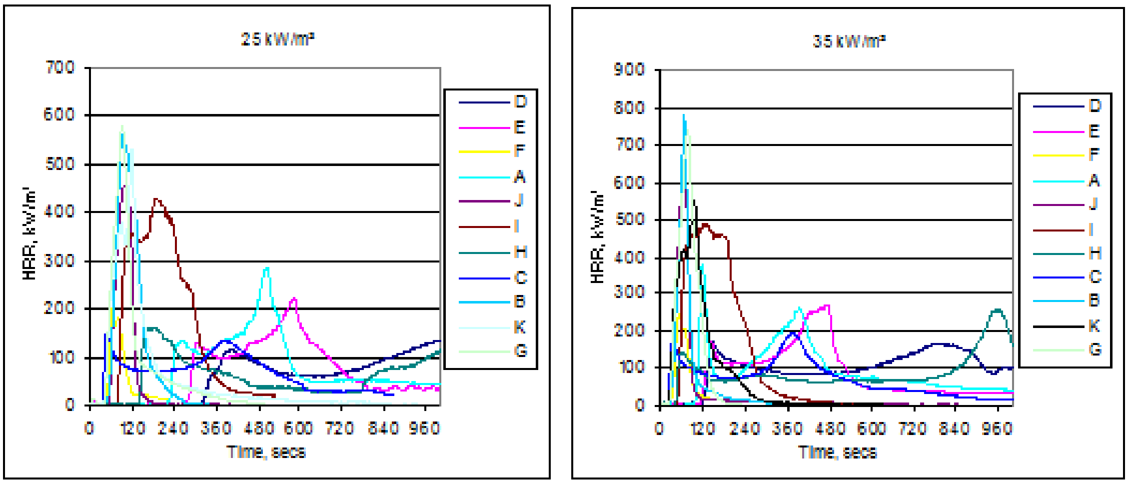


Figure 82 Heat release rates results at 25 and 35 kW/m² for various flooring material samples. (The key relates to those in Table 78.) Extracted from Collier (2007).

3.4 Other Building Components

Roofing products have similarly been considered in the European classification without further testing scheme (EN 14782, 2005). It is included in the discussion here as some discussion of paint is also included in the consideration, which has indirect applications to the focus of this work.

Flat or shaped metal sheets are considered “deemed to satisfy without the need for testing” for external fire performance with a minimum thickness of 0.4 mm and any inorganic external coating or a coating with a maximum gross heat of combustion value of 4.0 MJ/m² or a maximum mass of 200 g/m². (EN 14782, 2005; Commission Decision 2000/553/EC)

Flat or shaped metal sheets or panels are considered as Class B without further testing with coil coated galvanised or zinc-aluminium alloy coated steel of a minimum thickness of 0.4 mm with an organic coating on either the external or internal side, where the coating is a liquid-applied plastisol (a suspension of PVC particles in a liquid plasticiser) paint with:

- a maximum nominal dry thickness of 0.200 mm,
- a maximum gross heat of combustion of 8.0 MJ/m² and
- a maximum dry mass of 330 g/m².

The other side is to have an organic coating with a maximum gross heat of combustion value of 4.0 MJ/m² or a maximum mass of 200 g/m². (EN 14782, 2005; Commission Decision 2005/403/EC)

3.5 Impact of Ageing

Weathering and durability is outside the scope of this report. However some other research has perused this avenue of investigation and although the results are not summarised or discussed here, a range of the related publications were read as part of the background for the current work and are included in the Bibliography at the end of this document. Some example papers include Thureson and Nilsson (1994), Östman, Tsantaridis, et al. (2002), Östman and Tsantaridis (2003a), NT Fire 053 (2003), Östman and Tsantaridis (2004).

For instance, Wade et al. (2001) investigated three different types of simulated aging procedures for exterior and interior linings:

- Exposure to a fluorescent ultra-violet condensation weatherometer to simulate exterior exposure conditions,
- Changes in temperature and humidity within a chamber to simulate internal exposure conditions, and
- Manual washing to simulate periodic cleaning on interior surfaces.

The results for time to ignition were reported as increasing for the interior systems investigated after being subjected to the simulated aging and weathering. It was suggested that the delay in ignition was attributed to the changes in the fire behaviour of the protective top coat, for instance removal rather than any changes of the intumescent base coats. An example of the results for a plywood substrate and various applications of a fire retardant coating are shown in Figure 83 (Wade et al., 2001).

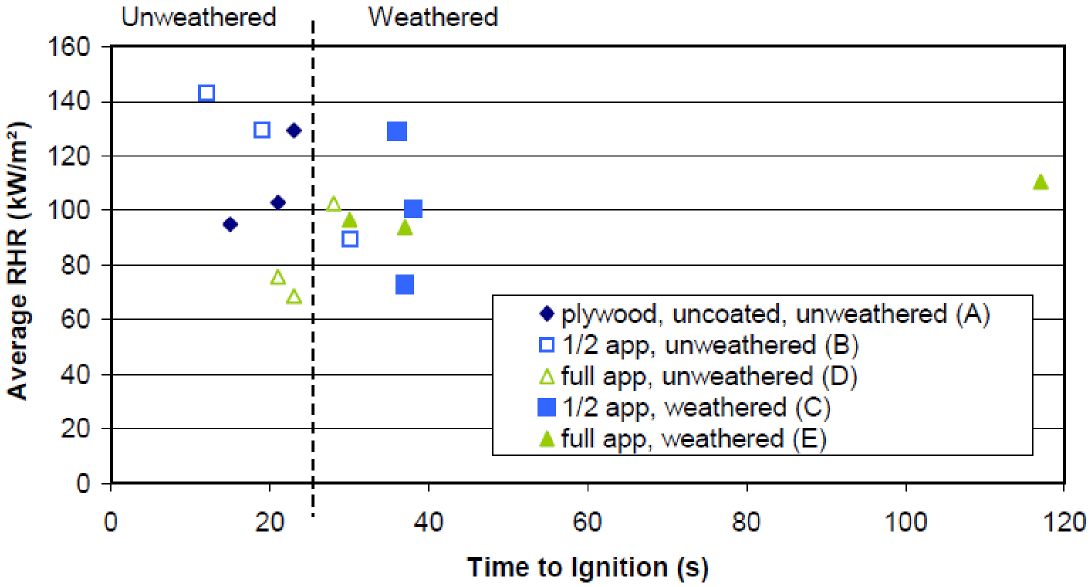


Figure 83 Summary mean average heat release rate versus time to ignition for the plywood specimens with various coatings. Extracted from Wade et al. (2001).

4. METHODS FOR CONSIDERATION OF UNTESTED PERFORMANCE

4.1 European Classification without Further Testing

European Commission approved tables of reaction to fire classification of different wood products are published in the European Commission's Official Journal. Classification without further testing (CWFT) is a documented procedure (DG Enterprise, CONSTRUCT 01/491, 2004) to identify generic "products which have been proven to be stable in a given European class (on the basis of testing to appropriate EN test method(s)) within the scope of their variability in manufacturing allowed by the product specification". (Östman and Mikkola, 2006)

Products claiming CWFT must be proven to have a safety margin above the lower class limits. Generally, a 20% margin or analysis of the statistical spread is required, based on the test results, above the lower class limit for each classification parameter for the relevant standard in the EN 13501 series. (Östman and Mikkola, 2006)

End-use applications of the products is essential for the classification of the reaction to fire. For example, the influence of substrates, air gaps, joints, surface profiles and fixings are influential on the results of the test methods. For example, for the investigation of structural timber and glued laminated timber products, various thicknesses of timber were tested with and without air gaps and with thermal insulation behind the product to ensure that the fire behaviour was fully independent of the underlying layers for the range of products tested. (Östman and Mikkola, 2006)

The classifications are included in the standards that are used for specifications for the products, e.g. EN 14342 Wood flooring – Characteristics, evaluation of conformity and marking. The product specifications standards prescribe which product properties have to be documented. (Östman and Mikkola, 2006)

4.2 Estimation of Flame Spread from Cone Calorimeter Results

McGraw and Mowrer (1999) considered the estimation of flame spread on painted paper-faced plasterboard using a flammability parameter based on cone calorimeter results and the flammability parameter developed by Quintiere et al. (1986, 1991 and 1992). The flammability parameter, b, $b \equiv k_f \dot{Q}'' - t_{ig} / t_b - 1$, has, in theory, a positive value when associated with the potential for thermal runaway and therefore flame spread across the surface. The flammability parameter was calculated for a range of specimens with a paper-faced plasterboard substrate and various numbers of coatings of a latex paint and various incident heat fluxes (McGraw and Mowrer, 1999), as summarised in Table 80.

The specimens exposed to an incident heat flux of 25 kW/m^2 did not ignite, which was suggested to be consistent with the reported critical heat flux values of 26 to 28 kW/m^2 for unpainted plaster board (McGraw and Mowrer, 1999). (This is consistent, if it is expected that the substrate is dominant of the flammability performance for these specimens.)

At an incident heat flux of 50 kW/^{2}, the flammability parameter values for the painted specimens were all negative (-2.63 to -2.75) as well as the uncoated plasterboard specimen (-2.55), suggesting that acceleratory flame spread was not likely (McGraw and Mowrer, 1999). However these comparative values indicate that the painted specimens would be less likely to have acceleratory flame spread than the uncoated specimen.

At an incident heat flux of 75 kW/m², the flammability parameter values for the painted specimens were all close to the critical limit of zero (-0.06 to +0.03), suggesting that acceleratory flame spread may occur. In comparison, the unpainted specimen had a flammability parameter value of -0.91, indicating that the unpainted specimen would be less likely to have acceleratory flame spread than the painted specimens. (McGraw and Mowrer, 1999)

Among other conclusions, McGraw and Mowrer (1999) suggested that the potential for flame spread on the painted surface was more sensitive to the incident heat flux than the number of coats of paint.

McGraw and Mowrer (1999) suggested that the estimation of flame spread be based on the estimation that wall flames typically generated heat fluxes of approximately 30 kW/m² in the pyrolysis zone, as reported by Tu and Quintiere (1991). Correlations with this estimation of the heat flux in the pyrolysis zone were found, by Mowrer and Williamson (1999), to yield relatively consistent results for textile wall coverings adhered to a plasterboard substrate, as summarised in Figure 84, based on a comparison of heat release rates from room/corner tests (Fisher et al., 1986) and flammability parameter values calculated by (Mowrer and Williamson, 1999) from cone calorimeter test results (Harkleroad, 1989).

Table 80 Summary of estimated flame spread on painted plasterboard specimens based on cone calorimeter results. Extracted from McGraw and Mowrer (1999).

Incident Heat Flux (kW/m^2)	Coats of Paint	t_{ig} (sec)	$\dot{Q}''_{peak}$ (kW/m^2)	Q'' (kJ/m^2)	t_b (sec)	b (-)	Flame Spread Indicated?
25	0	NI	N/A	N/A	N/A	N/A	No
25	2	NI	N/A	N/A	N/A	N/A	No
25	4	NI	N/A	N/A	N/A	N/A	No
25	6	NI	N/A	N/A	N/A	N/A	No
25	8	NI	N/A	N/A	N/A	N/A	No
50	0	37	111	1561	14	-2.55	No
50	2	41	211	2284	11	-2.65	No
50	4	42	224	2359	11	-2.69	No
50	6	44	240	2651	11	-2.63	No
50	8	43	215	2366	11	-2.75	No
75	0	14	134	1527	11	-0.91	No
75	2	15	206	2773	14	-0.06	No
75	4	16	210	2949	14	-0.02	No
75	6	17	215	3318	16	0.03	Yes
75	8	9	214	3378	16	0.60	Yes

NI = No Ignition

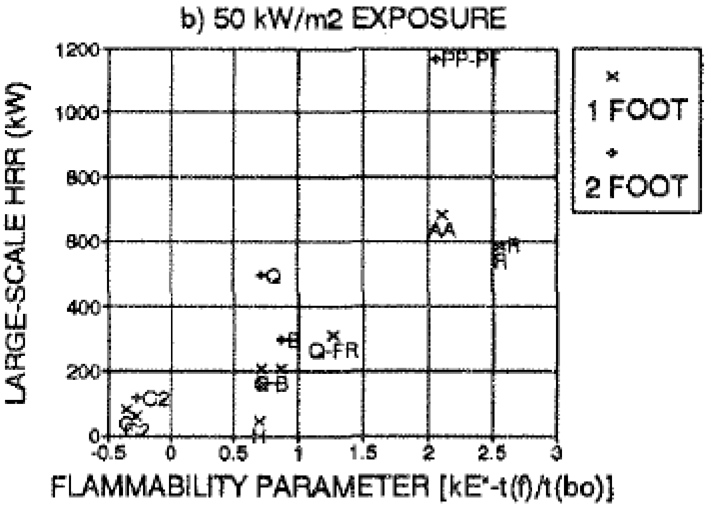


Figure 84 Comparison of heat release rates from room/corner tests (Fisher et al., 1986) and flammability parameter values calculated by (Mowrer and Williamson, 1999) from cone calorimeter results (Harkleroad, 1989)

4.3 Indicative Testing and Assessment

Estimation of the performance of untested materials products might be considered, by a person experienced with fire reaction performance testing and analysis, in relation to the analysis of available full test results for a range of products with similar material characteristics, geometry and applications and indicative test results.

5. DISCUSSION OF APPLICABILITY OF VARIOUS TEST OUTCOMES AND CLASSIFICATIONS OF LITERATURE

Reaction to fire classifications for various international standards and regulations are not necessarily directly comparable, the appropriate test methods need to be applied in each case (e.g. Östman and Tsantaridis (1993), Tsantaridis and Östman (1999)). For example, the comparison between time to ignition for a various building lining samples for the BS 476 Part 6 fire propagation test and ISO 5660 cone calorimeter test at an irradiance of 50 kW/m² (as shown in Figure 85 [Östman and Tsantaridis, 1990]), or classifications within Approved Document B (for UK national classifications) do not automatically equate with the European classifications (BRE, 2012). Similarly, the reaction to fire classifications from international standards and regulations are not intended to directly translate to New Zealand Building Code, (NZBR, 1992) Material Group Numbers (that have been abbreviated to 'NZ Group Number' for ease of reference in this document) (NOTE: NZ Group Numbers values apply to the specific specimen tested and are not to be used generically.). Therefore other classifications systems are discussed here in terms of the relative usefulness and to provide a broader context.

Furthermore, the composition of materials is expected to vary between countries and over time, therefore the results for any particular product are not expected to be identical to those currently available in the New Zealand market. Therefore care must be taken during the analysis and application of any of the summarised data or literature.

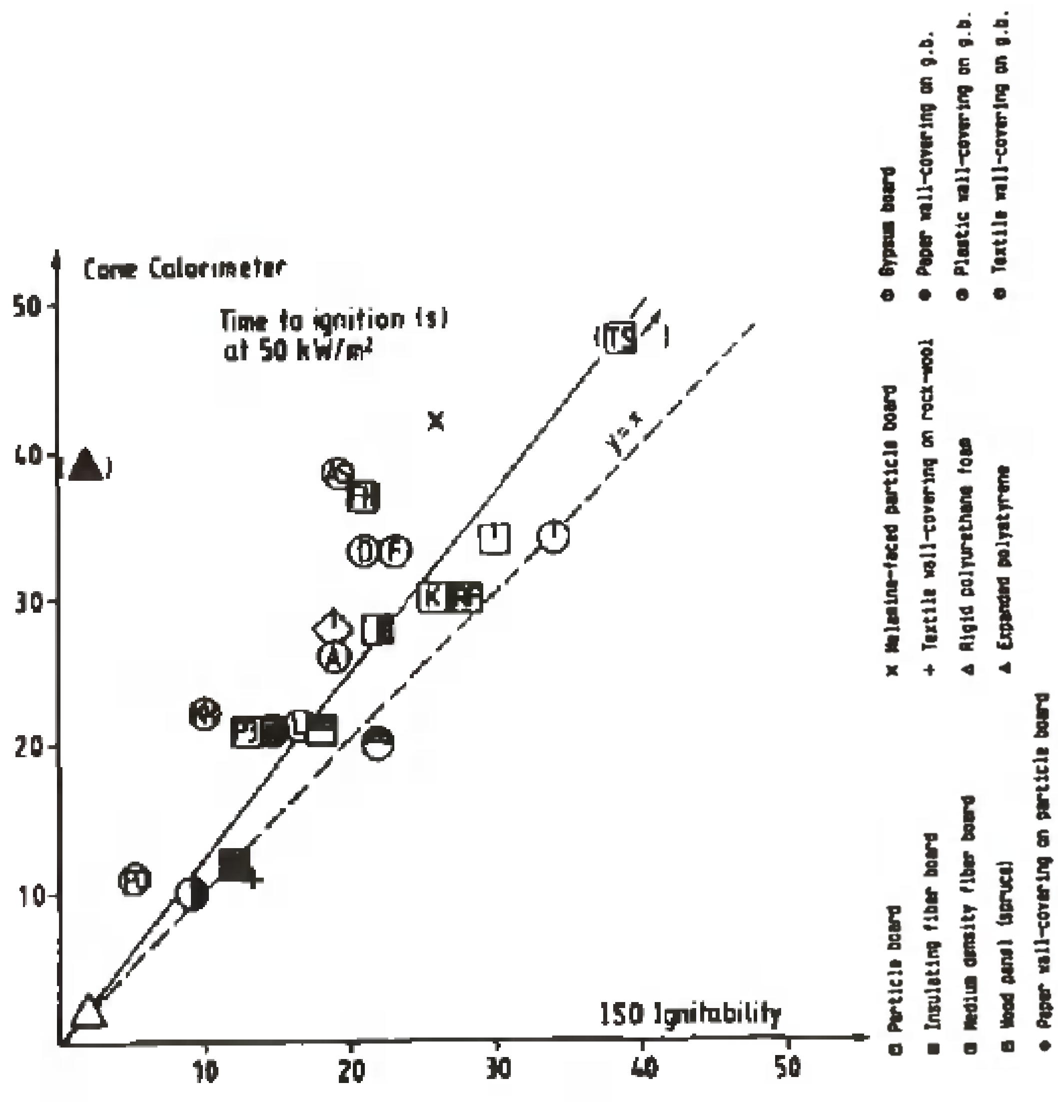


Figure 85 An example of a comparison of time to ignition for a various building lining samples for the BS 476 Part 6 fire propagation test and ISO5660 cone calorimeter test at an irradiance of 50 kW/m². Extracted from Östman and Tsantaridis (1990).

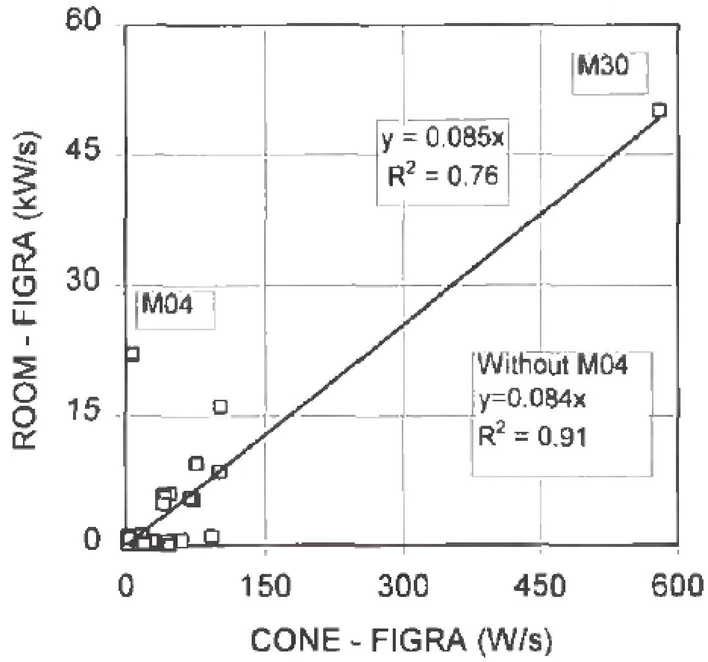


Figure 86 An example of ISO 9705 room test FIGRA compared to ISO 5660 cone calorimeter test FIGRA. Extracted from Tsantaridis and Östman (1999).

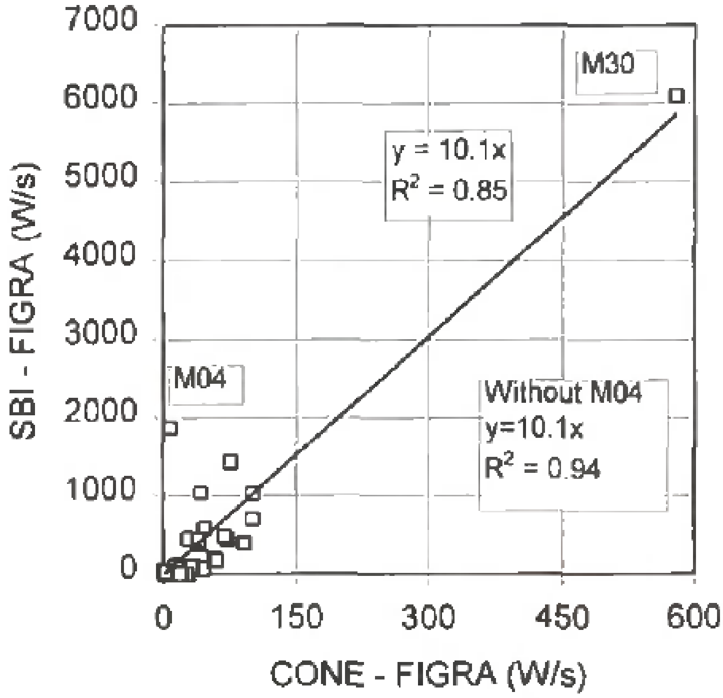


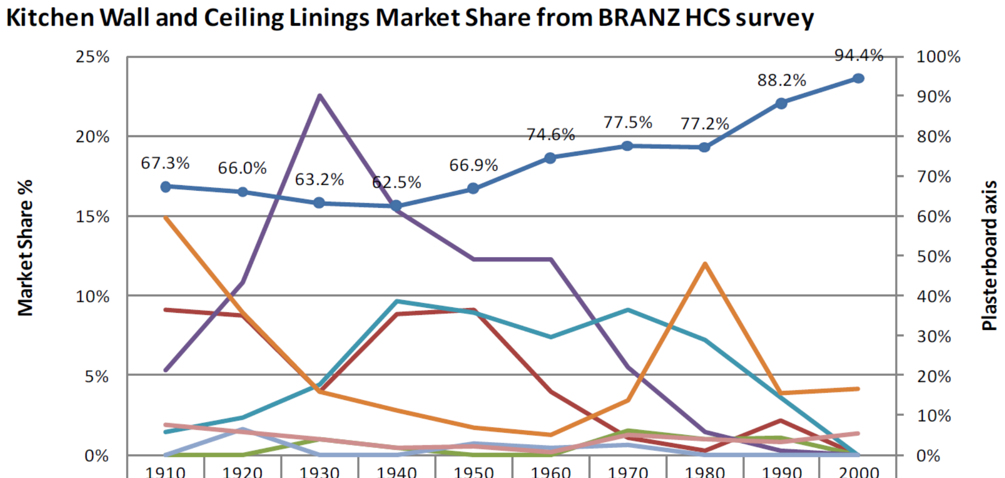
Figure 87 An example of SBI FIGRA compared to ISO 5660 cone calorimeter test FIGRA. Extracted from Tsantaridis and Östman (1999).

6. SUMMARY OF MOST COMMONLY USED INTERIOR SURFACE LINING MATERIALS IN THE NEW ZEALAND BUILDING STOCK

A summary of the most commonly used interior surface lining materials in non-residential buildings of the currently New Zealand building stock is not available. However previous work by Page and Fung (2010) utilising the 2005 BRANZ Home Condition Survey (Clark et al 2005) (that was a condition survey carried out in 1999 and 2004 of approximately 500 houses in the three main New Zealand centres) has provided indications for proportions of wall and ceiling lining substrate materials for kitchens (as summarised in Figure 88) and bedroom and living areas (as summarised in Figure 89) versus the year in which the house was built. From this summary plasterboard is consistently the most used substrate material in the existing building stock regardless of which year the house was built in. Other wall and ceiling substrate are timber, softboard, hardboard and particle board. However the types, nor prevalence, of coatings on the substrates was not also included in the summary. It is to be noted that this summary is only of detached dwellings, which are outside of the applicability of group number requirements considered here; therefore these summaries are only included as a general indication of the usage of various types of walling and ceiling substrates.

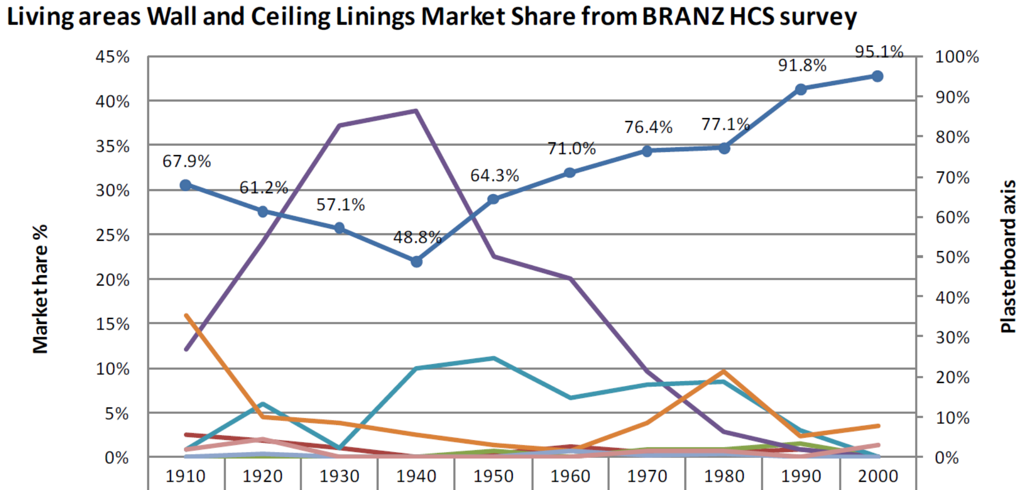
Similarly, Page and Fung also summarised the floor lining materials of the surveyed kitchen areas (as shown in Figure 90) and living areas (as shown in Figure 91). The most common floor linings for the surveyed detached dwellings were vinyl and tiles in the kitchen areas (Figure 90) and carpet in the living areas (Figure 91). Again, these are only indicative of the detached dwelling building stock and therefore only included for general consideration that may be useful in a multi-residential context.

Such a summary is not available for the multi-residential or non-residential sectors of the New Zealand building stock.



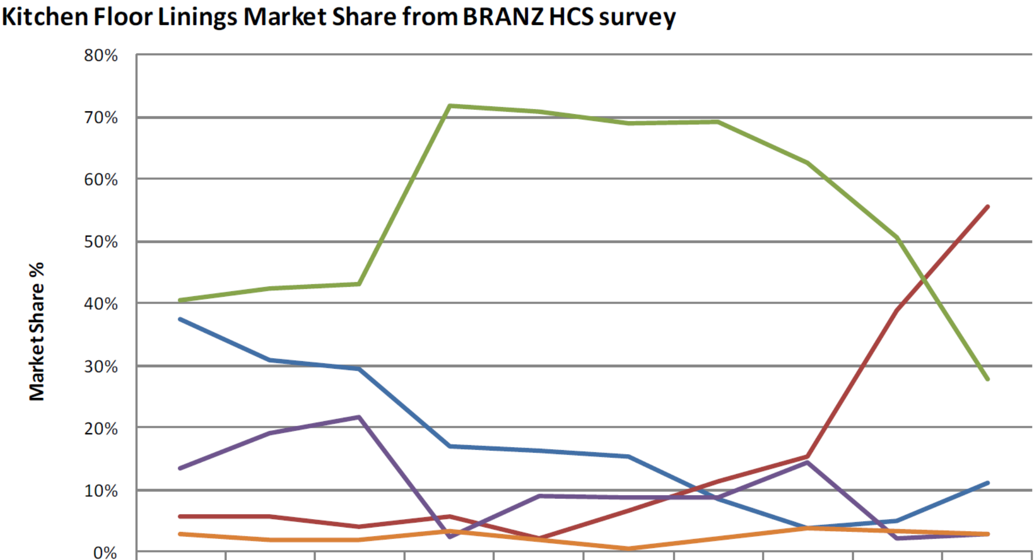
	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Hardboard	9.1%	8.7%	3.9%	8.9%	9.1%	4.0%	1.1%	0.2%	2.2%	0.0%
Particleboard/MDF	0.0%	0.0%	1.0%	0.4%	0.0%	0.0%	1.6%	1.0%	1.1%	0.0%
Fibrous plaster/lathe & plaster	5.3%	10.8%	22.5%	15.3%	12.2%	12.3%	5.5%	1.4%	0.3%	0.0%
Softboard	1.4%	2.4%	4.4%	9.7%	8.9%	7.4%	9.1%	7.2%	3.6%	0.0%
Timber boarding	14.9%	9.0%	3.9%	2.8%	1.7%	1.2%	3.4%	12.0%	3.8%	4.2%
Factory Finished panel	0.0%	1.7%	0.0%	0.0%	0.7%	0.4%	0.6%	0.0%	0.0%	0.0%
Other	1.9%	1.4%	1.0%	0.4%	0.6%	0.1%	1.3%	1.0%	0.8%	1.4%
Plasterboard	67.3%	66.0%	63.2%	62.5%	66.9%	74.6%	77.5%	77.2%	88.2%	94.4%

Figure 88 Estimates of proportions of wall and ceiling lining substrate materials used in house kitchens based on the 2005 BRANZ Home Condition Survey (Clark et al 2005). Extracted from Page and Fung 2010.



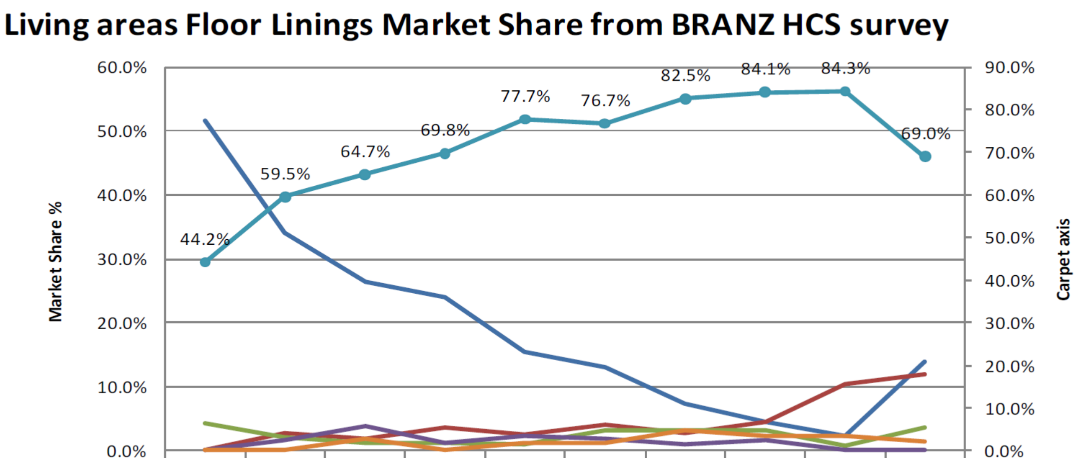
	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Hardboard	2.5%	1.9%	1.0%	0.0%	0.2%	1.2%	0.5%	0.5%	0.7%	0.0%
Particleboard/MDF	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.8%	0.8%	1.5%	0.0%
Fibrous plaster/lathe & plaster	12.1%	24.1%	37.2%	38.9%	22.4%	19.9%	9.6%	2.7%	0.7%	0.0%
Softboard	0.8%	6.0%	1.0%	9.9%	11.0%	6.5%	8.1%	8.5%	3.0%	0.0%
Timber boarding	15.8%	4.4%	3.8%	2.5%	1.3%	0.7%	3.8%	9.5%	2.2%	3.5%
Factory Finished panel	0.0%	0.3%	0.0%	0.0%	0.0%	0.7%	0.2%	0.3%	0.0%	0.0%
Other	0.8%	2.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.7%	0.0%	1.4%
Plasterboard	67.9%	61.2%	57.1%	48.8%	64.3%	71.0%	76.4%	77.1%	91.8%	95.1%

Figure 89 Estimates of proportions of wall and ceiling lining substrate materials used in bedroom and living areas of detached houses based on the 2005 BRANZ Home Condition Survey (Clark et al 2005). Extracted from Page and Fung (2010).



	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Timber	37.5%	31.0%	29.4%	16.9%	16.3%	15.3%	8.5%	3.8%	5.0%	11.1%
Ceramic, slate, marble Tiles	5.8%	5.7%	3.9%	5.6%	2.2%	6.6%	11.3%	15.4%	38.9%	55.6%
Vinyl	40.4%	42.4%	43.1%	71.8%	70.7%	68.9%	69.2%	62.5%	50.6%	27.8%
Cork Tiles	13.5%	19.0%	21.6%	2.4%	8.9%	8.7%	8.8%	14.4%	2.2%	2.8%
Other	2.9%	1.9%	2.0%	3.2%	1.9%	0.5%	2.2%	3.8%	3.3%	2.8%

Figure 90 Estimates of proportions of kitchen floor lining materials used in house kitchens based on the 2005 BRANZ Home Condition Survey (Clark et al 2005). Extracted from Page and Fung (2010).



	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Timber	51.7%	34.0%	26.3%	24.1%	15.4%	13.0%	7.3%	4.4%	2.2%	13.9%
Ceramic, slate, marble Tiles	0.0%	2.7%	1.9%	3.7%	2.5%	4.1%	2.8%	4.4%	10.4%	12.0%
Vinyl	4.2%	2.0%	1.3%	1.2%	1.0%	3.1%	3.2%	3.1%	0.7%	3.7%
Cork Tiles	0.0%	1.7%	3.8%	1.2%	2.2%	1.8%	1.0%	1.6%	0.0%	0.0%
Other	0.0%	0.0%	1.9%	0.0%	1.2%	1.2%	3.2%	2.3%	2.2%	1.4%
Carpet	44.2%	59.5%	64.7%	69.8%	77.7%	76.7%	82.5%	84.1%	84.3%	69.0%

Figure 91 Estimates of the proportions of market share of various floor linings in bedrooms and living areas of detached houses built in various decades based on the 2005 BRANZ Housing Condition Survey (Clark et al 2005). Extracted from Page and Fung (2010).

7. SUMMARY OF PUBLISHED WALL AND CEILING LINING FIRE REACTION

The following is a general summary of the literature available for the reaction to fire of wall and ceiling linings key to the current review:

- Substrate materials play an important part in a wall/ceiling lining reaction to fire. Coatings cannot be considered independently of the substrate. Estimating fire performance based on the substrate alone (i.e. without intended coating systems applied) was not recommended (e.g. Wade et al. (2001), Steen-Hansen and Kristoffersen (2007), Mowrer (2004)).
- Extensive research efforts have been spent investigating substrate reactions to fire, resulting in the European Classification without Further Testing (CWFT) scheme describing generic groups of substrate classifications (DG Enterprise, CONSTRUCT 01/491, 2004). Types of substrate materials included in this scheme are wood and wood products, plasterboard, metal, concrete, etc.
    - Coatings are not included in this scheme.
- Thickness of paint coatings influence test results.
    - Less than the manufacturer's specification amount (e.g. a half application versus a full application) of a painted coating may decrease the fire protection performance of the sample compared with a full application of the coating (e.g. Wade et al. (2001)). Influence of the variation in coating thicknesses may be different for different variables, for example the time to ignition may be more influenced markedly than the average heat release rate, peak heat release rate and total heat released.
    - More layers than the manufacturer's specification amount of paint may be initially associated with a comparative or small increase in fire protection performance for increasing numbers of layers, followed by a decrease in fire performance for continued increasing numbers of layers (e.g. McGraw and Mowrer (1999), Mowrer and McGraw (1999), Mowrer (2001, 2004), Steen-Hansen and Kristoffersen (2007)). The change in fire performance with numbers of layers differs for the paints with reported results.
- Blistering of painted coating systems has been reported to influence the shape of the instantaneous heat release rate versus time curve (e.g. McGraw and Mowrer (1999), Mowrer and McGraw (1999), Mowrer (2001, 2004)). Oil-based paints have been reported to form blisters, more consistently and at thinner coating thicknesses than latex paints, when exposed to a heat source.
- Combinations of different types of coatings (e.g. wallpaper and paint) have been suggested to have too much variation in test results to be treated using a generic scheme (e.g. Steen-Hansen and Kristoffersen (2007)).
- Paints, wallpapers, textiles and carpet wall and ceiling linings have a wide range of types of materials for the coatings and these ranges may also have a wide range of fire reaction behaviour (e.g. Chew and Lim (2000)). Therefore care must be taken when defining groups of types of coatings.
- Results of simulated weathering of laboratory painted samples indicated a tendency of a delayed time to ignition (Wade et al, 2001). Average heat release rate, peak heat release rate and total heat released shown little difference between weathered and unweathered results for the samples tested. Other papers have suggested a greater material flammability may be associated with poorly prepared samples, due to less adhesion between layers (Rhodes, 2012).

7.1 Recommendations for testing phase

Before the introduction of any generic classification of types of coatings can be considered at any level, categories of coatings to be grouped together must be defined, then further testing to support the both the generic grouping and performance.

It is suggested that paint coatings only be considered on a range of substrates for various thicknesses, learning from the published experiences and data sets summarised here.

8. SUMMARY OF PUBLISHED FLOOR LINING FIRE REACTION

The following is a general summary of the literature available for the reaction to fire of floor linings key to the current review:

- Similarly to the wall and ceiling lining fire reaction research, extensive efforts have been spent investigating wood and wood-product floor substrate reaction to fire, resulting in the European Classification without Further Testing (CWFT) scheme describing generic groups of substrate classifications (DG Enterprise, CONSTRUCT 01/491, 2004). Types of substrate materials included in this scheme are wood and wood products, plasterboard, metal, concrete, etc.
    - Floor coatings are not included in this scheme.
- The published floor lining data sets is significantly more limited than those available for wall and ceiling lining fire reaction test results.

8.1 Recommendations for testing phase

Consistent with the recommendations for testing for wall and ceiling lining fire reaction, before the introduction of any generic classification of types of coatings can be considered at any level, categories of coatings to be grouped together must be defined, then further testing to support the both the generic grouping and performance.

It is suggested that wall and ceiling linings be the focus of the testing phase of this work and then, based on the experience gained from that research, a proposal for an approach for generic wall covering classifications be developed.

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APPENDIX A COLLATED SUMMARIES OF DATA SETS

The following are collated summaries of data sets discussed in the body of this report and included here for completeness. The data sets are summarised by authors of the report, paper, etc.

A.1 Tsantaridis, Östman and Thureson (multiple years)

References summarised in this section:

- Tsantaridis and Östman (1989)
- Thureson (1991).
- Tsantaridis (1992)
- Tsantaridis and Östman (1990)
- Östman and Tsantaridis (1993)
- Tsantaridis and Östman (1999)

Table 81 Summary of reported time to ignition and average effective heat of combustion for 50 kW/m² irradiance cone calorimeter tests and time to flashover in room test of substrates and coatings.

Material Description	Time To Flashover in ISO room (min:s) [Ref. E, F]	Time to Ignition in Cone Calorimeter (s)	Average Effective Heat of Combustion (kJ/g)	Total Heat Released (MJ/m²)	Average Rate of Smoke Production / Rate of Heat Release (ob.m³/MJ)	Ref.
Wood						
Wood panel (spruce), 11 mm thick	2:11	21	15	NR	22	A
Pine, varnished	1:43	13	125	49.5	-	F
Spruce, unvarnished	1:48	21	123	45.5	-	F
Plywood						
Plywood, birch, 12 mm thick	2:30	26 30	NR	78.4	NR	B C
Plywood B, FR	-	NI	NR	NR	NR	D
Plywood K, FR	-	30	NR	NR	NR	D
Plywood A	-	26	NR	NR	NR	D
Plywood L	-	21	NR	NR	NR	D
Particleboard						
Particleboard, 10 mm thick	2:37	34	14	NR	21	A
Particleboard C, FR	-	48	NR	NR	NR	D
Particleboard H, FR	-	NI	NR	NR	NR	D
Particleboard D	-	33	NR	NR	NR	D
Particleboard F	-	33	NR	NR	NR	D
Melamine-faced particleboard, 13 mm thick	7:45	42	11	NR	201	A
Paper wall-covering on particleboard, 10 + 0.5 mm thick	2:23	27	12	NR	16	A
Fire retardant particle board (type German B1), 16 mm thick	10:30	19.5 21	NR	7.5	NR	B C
Fire retarded particle board, 12 mm thick	> 20 :00	196	NR	8.2	NR	B

		700				C
Intumescent coat on particleboard	11:44	411	60	97.6		F
Fibreboard						
Insulating fibre board, 13 mm thick	0:59	12	14	NR	26	A
Insulating board P3, FR	-	21	NR	NR	NR	D
Insulating board P0	-	11	NR	NR	NR	D
Melamine-faced high-density non-combustible board, 12.5 mm thick	> 20 :00	110 29	NR	7.4	NR	B C
Textile covering on calcium silicate board	> 20:00	31	28	5.7	-	
Low-density fibreboard	1:20	10	116	43.2	-	F
Medium density fibre board, 12 mm thick	2:11	28	14	NR	34	A
Melamine-faced medium density fibreboard	3:04	45	142	107	-	F
Fibreboard T5, FR	-	515	NR	NR	NR	D
Fibreboard FH, FR	-	37	NR	NR	NR	D
Fibreboard KH	-	22	NR	NR	NR	D
Hardboard						
Hardboard RF, FR	-	30	NR	NR	NR	D
Hardboard AS	-	38	NR	NR	NR	D
Plasterboard						
Plasterboard, 13 mm thick	> 20:00	34	-	NR	16	A
Paper wall-covering on plasterboard, 13 + 0.5 mm thick	10:40	21	-	NR	26	A
Plastic wall-covering on plasterboard, 13 + 0.7 mm thick	10:11	10	13	NR	29	A
Textile wall-covering on plasterboard, 13 + 0.5 mm thick	10:29	20	12	NR	26	A
Painted paper-faced plasterboard, 12 mm thick	> 20 :00	44 47 39	NR	3.9	NR	B C F
Textile wall-covering on paper-faced plasterboard, 12 mm (total) thick	11:00	21.5 25	NR	10.6	NR	B C
PVC wall carpet on gypsum paper plasterboard (affixed with vinylacetate copolymers), 13 mm (total) thick	> 20 :00	14.5 15	NR	16.1	NR	B C
Mineral Wool						
Unfaced mineral wool	> 20:00	NI	NI	NI	NI	F
Paper-faced glass wool	1:01	3.3	10	2.4		F
Combustible-faced mineral wool, 30 mm (total) thick	1:20	4.5 5	NR	1.7	NR	B C

Textile wall-covering on mineral wool, 42 + 0.5 mm thick	0:43	11	25	NR	26	A
Plastic-faced sheet steel on mineral wool, 25 mm (total) thick	> 20 :00	34 52	NR	3.6	NR	B C
Fibreboard						
Insulating board P3, FR		21	NR	NR	NR	D
Insulating board P0		11	NR	NR	NR	D
Textile covering on calcium silicate board	> 20:00	31	28	5.7		

Table Notes:
Ref. refers to Reference for test results.
NR refers to Not Reported.
NI refers to No Ignition
FR refers to material had a Fire Retardant treatment.
- refers to not reported because of irregularities.
Ref. A: Average results from two tests, as reported by Tsantaridis and Östman (1989).
Ref. B: Average results from two tests reported by Thureson (1991).
Ref. C: Average results from two tests reported by Tsantaridis (1992) for cone calorimeter testing at 50 kW/m² using a retainer frame. Comparison of test results performed with and without a retainer frame by two different laboratories was reported by Tsantaridis (1992) to have good repeatability for the products tested.
Ref. D: Results reported by Tsantaridis and Östman (1990).
Ref. E: Results reported by Östman and Tsantaridis (1993).
Ref. F: Average results from three test reported by Tsantaridis and Östman (1999).

Table 82 Summary of various reported tested specimens with a plasterboard substrate. Data extracted from Tsantaridis and Östman (1989) and Thureson (1991), initial analysis extracted from Kokkala, Thomas and Karlsson (1993) and Group Number from NZBC C/VM2 (2013C) application.

Description of Material	I_{ig} (1/min)	$I_{Q,m=34}$	$I_{Q,m=0.93}$	$I_{Q,10min}$	$I_{Q.2min}$	$I_{Q,12min}$	NZ Group Number
Wood							
Ordinary 12 mm birch plywood	2.31	15271	2088	5552	2093	1268	3
	2.31	14778	2099	5552	2093	1268	4
Wood panel (spruce), 11 mm thick	2.86	10907	1703	5255	2003	1178	3
Plasterboard							
Gypsum board, 13 mm thick	1.76	3299	1231	5849	2184	1359	1
Painted paper-faced plasterboard, 12 mm (total) thick	1.4	1618	1256	6044	2244	1419	1
	1.33	1452	1199	6081	2255	1430	1
Textile wall covering on gypsum paper plaster board, 12 mm (total) thick	3	3838	1618	5180	1980	1155	2
	2.61	3817	1595	5390	2044	1219	2
Plastic wall covering on gypsum board, 13 + 0.7 mm thick	6	3323	1338	3560	1485	660	2
Textile wall covering on gypsum board, 13 + 0.5 mm thick	3	4174	1537	5180	1980	1155	2
Paper wall covering on gypsum board, 13 + 0.5 mm thick	2.86	3408	1419	5255	2003	1178	2
PVC wall covering on gypsum paper plaster board, 13 mm (total) thick	4.29	4077	1355	4483	1767	942	2
	4	4187	1355	4640	1815	990	2
Particleboard							

Particle board, 10 mm thick	1.76	11927	1873	5849	2184	1359	3
Paper wall covering on particle board, 10 + 0.5 mm thick	2.22	10042	1766	5601	2108	1283	3
Melamine-faced particle board, 13 mm (total) thick	1.43	6059	1219	6027	2239	1414	3
Fire retarded particleboard (German B1), 16 mm thick	2.88	2798	1262	5244	1999	1174	2
	3.31	2155	1179	5012	1928	1103	2
Fire retarded particleboard, 12 mm thick	5	1758	1010	4100	1650	825	2
	0.22	0	0	6681	2438	1613	1
Fibreboard							
Insulating fibre board, 13 mm thick	5	8677	1711	4100	1650	825	4
Medium-density fibre board, 12 mm thick	2.14	11874	1864	5644	2121	1296	3
Cement board							
Melamine-faced high-density non-combustible board, 12.5 mm thick	0.57	2407	1143	6492	2380	1555	1
	0.52	2052	1083	6519	2389	1564	1
Mineral Wool							
Plastic-faced steel sheet on mineral wool, 25 mm (total) thick	1.76	331	830	5849	2184	1359	1
	1.76	367	847	5849	2184	1359	1
Combustible-faced mineral wool, 30 mm (total) thick	12	893	1025	320	495	-330	4
	15	825	1034	-1300	0	-825	4
Textile wall covering on mineral wool, 42 + 0.5 mm thick	5.45	4370	1911	3857	1575	750	4

A.2 Östman and Mikkola (2004, 2006)

Table 83 List of wood-based panels (subject to EN 13823) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood-based panel	Thick-ness mm	Density kg/m³	Flame spread, Fs, within 60 or 20 s, mm						Ref. No
			Exposure 30 s (Fs within 60 s)			Exposure 15 s (Fs within 20 s)			
			Surface	Edge	Vertical edge	Surface	Edge	Vertical edge	
Particleboards:									
Particleboard	10	675		< 150	-		< 150	-	3.1.1
Particleboard	10	710	0	0	-	0	0	-	3.1.3
Ordinary particleboard	12	710	0	0	-	0	0	-	3.1.2
Particleboard	12	770	0	0	-	0	0	-	3.1.3
Melamine faced particleb.	12	700	0	< 150	0	0	< 150	0	3.1.2
FR chip board	12	780	0	0	-	0	0	-	3.1.2
MDF:									
MDF	3	880	0	< 150	-	0		-	3.1.3
MDF	4	760	0	< 150	-	0		-	3.1.3
MDF	5	800	0	< 150	-	0	0	-	3.1.3
MDF	9	765	0	< 150	-	0	< 150	-	3.1.4
MDF	10	760	< 150	< 150	-	< 150	< 150	-	3.1.1
MDF	10	830	0	< 150	-	0		-	3.1.3
MDF	12	850	0	0	-	0	0	-	3.1.2
MDF	19	565	0	< 150	-	0	< 150	-	3.1.4
MDF	19	820	0	0	-	0		-	3.1.3
MDF	28	800	0	0	-	0		-	3.1.3
MDF	50	700	0	0	-	0		-	3.1.3
Melamine faced MDF	12	770	0	< 150	0	0	< 150	0	3.1.2
Fibreboards, hard:									
Hardboard	2	1010	0	> 150	-	0		-	3.1.3
Hardboard	3	960	0	< 150	-	0	< 150	-	3.1.3
Hardboard	6	1050	0	< 150	-	0	< 150	-	3.1.4
Fibreboards, medium:									
Medium board	9	850	0	< 150	-	0	0	-	3.1.4
Fibreboard	12	450	< 150	< 150	-	< 150	< 150	-	3.1.3
Fibreboards, soft:									
Softboard	9	350	> 150		-	< 150	< 150	-	3.1.3
Low density fibreboard	12	250	< 150	< 150	-	0	< 150	-	3.1.2
Softboard	13	275	> 150		-	< 150	< 150	-	3.1.3
Bitumen board	13	310	> 150	< 150	-	< 150	< 150	-	3.1.3
Plywood:									
Plywood, oak	4	490	< 150	> 150	(0)	< 150	< 150	(0)	3.1.3
Plywood, pine	7	660	0	< 150	(0)	0	-	(0)	3.1.3
Plywood, poplar	9	360	0	< 150	-	0	< 150	-	3.1.4
Plywood, spruce	9	480	0	< 150	-	0	< 150	-	3.1.4
Plywood, birch	9	675	0	0	(0)	0	0	(0)	3.1.3
Plywood, spruce	11	510	0	< 150	0	0	< 150	0	3.1.3
Plywood, poplar	12	410	0	0	< 150	0	0	< 150	3.1.4
Ordinary plywood	12	720	0	0	0	0	0	0	3.1.4
Plywood, birch	12	740	0	0	0	0	0	0	3.1.1
Plywood, spruce	18	465	< 150	< 150	0	< 150	< 150	0	3.1.3
OSB:									
OSB	9	690	< 150	< 150	-	< 150	< 150	-	3.1.5

Note: No ignition of filter paper occurred, i. e. no flaming droplets in the small flame test.

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3.1.3 Tsantaridis L: CEN Ignitability test results for wood building products. Trätek Report L 9702010, 1997.

3.1.4 Mollek V and Tsantaridis L: Reaction to fire testing of wood-based panels - Ignitability by single-flame source. Trätek test report No A12164/2001-03-28, 2001.

3.1.5 Small flame test, BRE FRS, SI test reference number RTF/639, Test report number 204886, 2001.

Table 84 Continued list of wood-based panels (subject to EN 13823) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood-based panels	Thickness mm	Density kg/m³	Substrate[1]	Heat		Smoke		Droplets		Class	Ref. No
				FIGRA W/s	THR_{600s} MJ	SMOGRA m^2/s^2	TSP_{600s} m^2	FDP 600s	FDP_{600s} >10s	EN 13501-1	
Particleboards:											
Particleboard	10	670	Ca sil.	495	27.1	3	27	no	no	D-s1, d0	3.1.13
Part. b. with str. vert. joint *	10	660	Ca sil.	515	26.7	4	57	no	no	D-s2, d0	3.1.14
Ordinary particleboard	12	710	Ca sil.	404	26.9	3	29	no	no	D-s1, d0	3.1.10
Particleboard, alcyd tr.	12	710	Ca sil.	496	23.8	7	69	no	no	D-s2, d0	3.1.12
Particleboard V313	12	710	Ca sil.	411	25.1	8	45	no	no	D-s1, d0	3.1.12
Melamine faced particleb.	12	700	Ca sil.	381	20.1	2	39	no	no	D-s1, d0	3.1.10
Paper wall cov. on part. b.	13	700	Ca sil.	479	26.7	2	18	no	no	D-s1, d0	3.1.10
Particleboard	22	690	Ca sil.	327	23.5	7	114	no	no	D-s2, d0	3.1.12
Flaxboard *	32	~400	Ca sil.	708	20.9	5	67	no	no	D-s2, d0	3.1.15
Particleboard, painted	18	550	Ca sil.	27	1.5	-	-	-	-	B	3.1.11
FR chip board	12	780	Ca sil.	25	2.3	12	101	no	no	B-s2, d0	3.1.10
MDF:											
MDF	9	740	Ca sil.	503	32.0	4	35	no	no	D-s1, d0	3.1.13
MDF	10	830	Ca sil.	456	38.8	11	30	no	no	D-s1, d0	3.1.12
MDF (1)	12	850	Ca sil.	436	33.4	1	21	no	no	D-s1, d0	3.1.10
MDF	19	570	Ca sil.	525	24.7	4	56	no	no	D-s2, d0	3.1.13
MDF (2)	19	800	Ca sil.	457	37.5	10	58	no	no	D-s2, d0	3.1.12
MDF	28	800	Ca sil.	410	34.7	11	79	no	no	D-s2, d0	3.1.12
Melamine faced MDF	12	770	Ca sil.	601	24.0	1	24	no	no	D-s1, d0	3.1.10
FR MDF (1)	12	820	Ca sil.	46	2.6	-	-	-	-	B	3.1.11
FR MDF (2)	12	820	Ca sil.	159	5.4	-	-	-	-	C	3.1.11
MDF	9	730	Rw [2,3]	606	45.7	13	113	no	no	D-s2, d0	3.1.13
MDF	9	730	Air [2,4]	>750 [5]	>15 [5]	>30 [5]	>200 [5]	no	no	E	3.1.13
Fibreboards, hard:											
Hardboard	5,5	900	Ca sil.	486	57.9	9	58	no	no	D-s2, d0	3.1.12
Hardboard	6	950	Ca sil.	407	56.8	3	37	no	no	D-s1, d0	3.1.13
Hardboard	6	950	Part.b.	439	68.2	15	156	no	no	D-s2, d0	3.1.13
Hardb., catalytic painted	3,3	970	Ca sil.	921	36.7	5	33			D-s1, d0	3.1.12
FR Hardboard	3,5	920	Ca sil.	137	8.1	-	-	-	-	C	3.1.11
Fibreboards, medium:											
Medium board	9	820	Ca sil.	527	40.0	2	20	no	no	D-s1, d0	3.1.13
Fibreboards, soft:											
Low density fibreboard	12	250	Ca sil.	1103	39.7	9	79	no	no	D-s2, d0	3.1.10
FR-painted LDF	12	350	Ca sil.	235	10.4	-	-	-	-	C	3.1.11
Plywood:											
Plywood, spruce	9	460	Ca sil.	570	23.1	6	61	no	no	D-s2, d0	3.1.13
Plywood, poplar *	9	410	Ca sil.	588	19.5	3	36	no	no	D-s1, d0	3.1.13
Plywood, spruce	12	480	Ca sil.	542	16.8	3	45	no	no	D-s1, d0	3.1.12
Plywood (pine surface)	12	540	Ca sil.	437	16.6	1	21	no	no	D-s1, d0	3.1.12
Plywood, phenol faced	12	660	Ca sil.	451	21.7	3	18	no	no	D-s1, d0	3.1.12
Ordinary plywood (birch)	12	720	Ca sil.	399	21.7	1	19	no	no	D-s1, d0	3.1.10
Plywood, poplar with multiple joints	12	420	Ca sil.	621	20.8	2	30	no	no	D-s1, d0	3.1.13
Plywood (2)	14	350	Ca sil.	682	16.2	-	-	-	-	D	3.1.11
Plywood	18	470	Ca sil.	434	15.8	2	28	no	no	D-s1, d0	3.1.12
Plywood, spruce	9	460	Rw [2,3]	463	30.4	7	71	no	no	D-s2, d0	3.1.13
Plywood, spruce	9	460	Air [2,4]	>750 [5]	>15 [5]	>30 [5]	>200 [5]	no	no	E	3.1.13
OSB:											
OSB	9	690	Ca sil.	374	26.5	2	37	no	no	D-s1, d0	3.1.16
OSB	9	690	Air [6]	647	69.6	12	82	yes	yes	D-s2, d2	3.1.17
OSB with T&G joints *	9	690	Ca sil.	384	29.0	2	26	no	no	D-s1, d0	3.1.18
Cement bonded particleb:											
Cement bonded particleb.	~10	~1000	Ca sil.	4.9	0.9	0	22	no	no	B-s1, d0	3.1.19

FIGRA — Fire Growth Rate
THR_{600s} — Total Heat Release during first 600 s
LFS — Lateral Flame Spread to edge
SMOGRA — Smoke Growth Rate
TSP_{600s} — Total Smoke Production during first 600 s
FDP_{600s} — Flaming Droplets or Particles during first 600 s

1) Panels screwed to standard substrate
2) Panels attached to wood studs (45x145 mm) cc 600 mm and open at the top
3) Gap filled with rockwool, Rw, 30 kg/m³
4) Gap empty
5) Tests terminated after 7-9 minutes due to high heat release
6) Free standing with 80 mm air gap
* Single test only (all others are duplicate tests)

References:

3.1.10 prEN 13823 Reaction to fire test for building products - Building products excluding floorings – exposed to the thermal attack by a single burning item (Table B.2 Statistical results), Final draft, 2000.

3.1.11 van Mierlo R, Janse E: Analysis of THR threshold values in the SBI draft test method. TNO-report 1999-CVB-R0904, 1999.

3.1.12 Hakkarainen T, Mikkola E: SBI test results of wood products, VTT Building Technology Internal report, Jan. 1998.

3.1.13 EPF, FEIC and FEROPA test program, SBI graphs and Summary, VTT Building and Transport, 2001.

3.1.14 SBI test report, BASF Fire Safety Department, Report-Nr.: 21.1-3343/12258, 2001.

3.1.15 SBI test report, BASF Fire Safety Department, Report-Nr.: 21.1-3343/12255, 2001.

3.1.16 SBI test, BRE FRS, SI test reference number RTF/480A-B, Test report number 204528 (a-b), 2001.

3.1.17 SBI test, BRE FRS, SI test reference number RTF/481A-B, Test report number 204530 (a-b), 2001.

3.1.18 SBI test, BRE FRS, SI test reference number RTF/482, Test report number 204532, 2001.

3.1.19 SBI test, Test Report WARRES No. 112089, 2000.

Table 85 List of structural timber (subject to EN 11925-2) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Timber product	Thick-ness mm	Density kg/m³	Flame spread within 60 s, mm		Ignition of filter paper	Class EN 13501-1	Ref. no
			Surface	Edge			
Spruce, planed	12	463	< 150	< 150	No	*	3.2.1
Spruce, planed, knot	12	430	< 150	< 150	No	*	3.2.1
Spruce, planed, joint	12	482	< 150	< 150	No	*	3.2.1
Spruce, planed, joint, knot	12	423	< 150	< 150	No	*	3.2.1
Spruce, unplaned	12	500	< 150	< 150	No	*	3.2.1
Spruce, unplaned, knot	12	488	< 150	< 150	No	*	3.2.1
Spruce, unplaned, joint	12	474	< 150	< 150	No	*	3.2.1
Spruce, unplaned, joint, knot	12	471	< 150	< 150	No	*	3.2.1
Spruce, planed	32	526	< 150	< 150	No	*	3.2.1
Spruce, planed, joint	32	477	< 150	< 150	No	*	3.2.1
Spruce, planed, joint, knot	32	482	< 150	< 150	No	*	3.2.1
Spruce, unplaned	38	494	< 150	< 150	No	*	3.2.1
Spruce, unplaned, knot	38	480	< 150	< 150	No	*	3.2.1
Spruce, unplaned, joint	38	495	< 150	< 150	No	*	3.2.1
Spruce, unplaned, joint, knot	38	482	< 150	< 150	No	*	3.2.1
Pine	20	515	< 150	< 150	No	*	3.2.1
Oak	22	700	< 150	< 150	No	*	3.2.2
Poplar	22	400	< 150	< 150	No	*	3.2.2
Sitka spruce	22	300	< 150	< 150	No	*	3.2.3

* Satisfies the small flame requirements for class D.

References

3.2.1 Tsantaridis L: CEN Ignitability test results for wood building products, Trätek report L 9702010, 1997.

3.2.2 Gaillard J-M: Reaction to fire test EN ISO 11925-2, CTBA Test Report N° 02/PC/PHY/277/3, 2002.

3.2.3 Tsantaridis L and Mollek V: Fire testing of Sitka spruce according to EN ISO 11925-2, Trätek Test Report A12323/2002-12-17, 2003.

Table 86 List of structural timber (subject to EN 11823) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Timber product	Thick-ness mm	Density kg/m^3	Sub-strate	FIGRA (W/s)	THR 600 (MJ)	SMOGRA (m^2/s^2)	TSP (m^2)	Burning Particles	Class EN 13501-1	Ref. no
Spruce (M12)	10	410	Ca sil.	440	16	3	47	None	D-s1, d0	3.2.4
Spruce (P191)	18	490	Ca sil.	438	18	4	36	None	D-s1, d0	3.2.5
Norway spruce t&g vertical	15	490	Ca sil.	452	17	3	34	None	D-s1, d0	3.2.6
Norway spruce t&g horisontal	15	490	Ca sil.	494	18	4	50	None	D-s1, d0	3.2.6
Norway spruce	20	500	Ca sil.	545	19	2	38	None	D-s1, d0	3.2.7
Pine	45	550	Ca sil.	587	24	12	54	None	D-s2, d0	3.2.6
Pine	21	550	Ca sil.	321	23	3	15	None	D-s1, d0	3.2.6
Pine	21	550	Air gap 1)	329	22	4	36	None	D-s1, d0	3.2.6
Oak horisontal orientation	22	700	Air gap 2)	250	14,5	9	36	None	D-s1, d0	3.2.8
Poplar horisontal orientation	22	400	Air gap 2)	449	18,0	16	52	None	D-s2, d0	3.2.8
Sitka spruce horisontal orientation	22	390	Air gap 3)	551	42	19	122	None	D-s2, d0	3.2.9
Sitka spruce vertical orientation	22	390	Air gap 3)	501	16	16	127	None	D-s2, d0	3.2.9
Sitka spruce vertical orientation	22	350	Air gap 3)	586	14	11	105	None	D-s2, d0	3.2.10
Sitka spruce vertical orientation	22	390	Glass wool 4)	553	13	3	46	None	D-s1, d0	3.2.9
Sitka spruce vertical orientation	2x22	390	Glass wool 4)	524	15	1	27	None	D-s1, d0	3.2.9

1) 45 mm air gap, battens 45 x 45 mm at 600 mm center, perpendicular to the orientation of the timber pieces.
2) 40 mm air gap, battens 40 x 40 mm at 500 mm center, perpendicular to the orientation of the timber pieces.
3) 44 mm air gap, battens 44 x 44 mm at 500 mm center, perpendicular to the orientation of the timber pieces.
4) 44 mm gap, filled with glass wool, 50 mm and 19 kg/m^3, battens 44 x 44 mm at 500 mm center, perpendicular to the orientation of the timber pieces

References

3.2.4 prEN 13823 Reaction to fire test for building products - Building products excluding floorings – exposed to the thermal attack by a single burning item (Table B.2 Statistical results), Final draft, 2000.

3.2.5 van Mierlo R, Janse E: Analysis of THR threshold values in the SBI draft test method. TNO-report 1999-CVB-R0904, 1999.

3.2.6 Hakkarainen T, Mikkola E: SBI test results of wood products, VTT Building and transport, Int. report, 1998.

3.2.7 Östman B: Wooden facades in multi-storey buildings, Proc. Fire and Materials Conf, San Francisco, Jan 2001.

3.2.8 Gaillard J-M: Reaction to fire test EN 13823, CTBA Test Report N° 02/PC/PHY/277/1-2, 2002.

3.2.9 Hakkarainen T: Fire test of Sitka spruce according to EN 13823:2002 (SBI) test procedure, VTT Research Report No RTE 136/03, 2003.

3.2.10 Paloposki T: Fire test of Sitka spruce according to EN 13823:2002 (SBI) test procedure, VTT Research Report No RTE 432/03, 2003.

Table 87 List of solid wood panelling and cladding (subject to EN 11925-2) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood product	Thick-ness mm	Density kg/m³	Flame spread within 60 s, mm		Ignition of filter paper	Class EN 13501-1	Ref. no
			Surface	Edge			
Spruce, planed	12	463	< 150	< 150	No	*	3.4.1
Spruce, planed, knot	12	430	< 150	< 150	No	*	3.4.1
Spruce, planed, joint	12	482	< 150	< 150	No	*	3.4.1
Spruce, planed, joint, knot	12	423	< 150	< 150	No	*	3.4.1
Spruce, unplaned	12	500	< 150	< 150	No	*	3.4.1
Spruce, unplaned, knot	12	488	< 150	< 150	No	*	3.4.1
Spruce, unplaned, joint	12	474	< 150	< 150	No	*	3.4.1
Spruce, unplaned, joint, knot	12	471	< 150	< 150	No	*	3.4.1
Spruce, planed	32	526	< 150	< 150	No	*	3.4.1
Spruce, planed, joint	32	477	< 150	< 150	No	*	3.4.1
Spruce, planed, joint, knot	32	482	< 150	< 150	No	*	3.4.1
Spruce, unplaned	38	494	< 150	< 150	No	*	3.4.1
Spruce, unplaned, knot	38	480	< 150	< 150	No	*	3.4.1
Spruce, unplaned, joint	38	495	< 150	< 150	No	*	3.4.1
Spruce, unplaned, joint, knot	38	482	< 150	< 150	No	*	3.4.1
Pine	20	515	< 150	< 150	No	*	3.4.1
Oak	22	700	< 150	< 150	No	*	3.4.2
Poplar	22	400	< 150	< 150	No	*	3.4.2
Sitka spruce	22	300	< 150	< 150	No	*	3.4.3
Red ceder	18	350	< 150	< 150	No	*	3.4.4

* Satisfies the small flame requirements for class D.

References

3.4.1 Tsantaridis L: CEN Ignitability test results for wood building products, Trätek report L 9702010, 1997.
3.4.2 Gaillard J-M: Reaction to fire test EN ISO 11925-2, CTBA Test Report N° 02/PC/PHY/277/3, 2002.
3.4.3 Tsantaridis L and Mollek V: Fire testing of Sitka spruce according to EN ISO 11925-2, Trätek Test Report A12323/2002-12-17, 2003.
3.4.4 DANAK Prøvningsrapport, Dansk Brand- og sikringsteknisk Institut, Sag nr PF11326, Løbe nr 8775, Ref MPA/DB, 2002-11-13.

Table 88 List of solid wood panelling and cladding (subject to EN 13823) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood product		Wood specie	Thick-ness mm	Profile min thickn mm	Density kg/m³	Orien-tation	Vapour barrier	Substrate	No of tests	FIGRA W/s	THR 600 MJ	SMOGRA m²/s²	TSP m²	Burning Particles	Class EN 13501-1	Ref. no
1	Panelling	Spruce	9	6	430	Vert	-	Closed air gap 40 mm	3	463±55	20±3	2	37±6	no	D-s1, d0	3.4.10
2	-“-	-“-	9	6	408	Vert	PE-Paper class F 3)	Min wool 5) class A2-s1,d0	3	547±63	32±2	2	33±9	yes/no	D-s1, d2	3.4.10
3	-“-	-“-	9	6	370	Vert	PE-LD class E/F 4)	-“-	1	657	36	3	37	yes	D-s1, d1	3.4.10
4	-“-	-“-	12	8	423	Vert	-	-“-	2	428±80	20±1	1	25±5	no	D-s1, d0	3.4.10
5	-“-	-“-	9	6	382	Vert	-	Insulation 7) class E/F	3	560±105	27±3	2	29±11	no	D-s1, d0	3.4.10
6	Cladding	-“-	21	12,5	399	Vert	-	Open air gap 21 mm	2	520±94	16±1	2	44±25	no	D-s1, d0	3.4.10
7	-“-	Sitka spruce	21	21 1)	400	Vert	-	-“-	1	543	12	4	40	no	D-s1, d0	3.4.10
8	-“-	Spruce	21	12,5	430	Hor	-	-“-	3	454±57	15±1	8	49±10	no	D-s1, d0	3.4.10
9	-“-	Sitka spruce	21	21 1)	397	Hor.	-	-“-	3	426±36	13±1	7	39±8	no	D-s1, d0	3.4.10
9a	Panelling	Spruce	9	6	399	Vert	-	Closed air gap 40 mm	1	481	18	3	45	no	D-s1, d0	3.4.10
9b	-“-	-“-	9	6	388	Vert	-	Min wool 5) class A2-s1,d0	3	503±18	27±2	0	24±10	no/yes	D-s1, d1	3.4.10
10a	-“-	-“-	10	10 1)	404	Vert	-	Closed air gap 40 mm	3	460±37	15±1	2	39±8	no	D-s1, d0	3.4.10
10b	-“-	-“-	10	10	388	Vert	-	Min wool 5) class A2-s1,d0	2	452 ± 44	23±0,9	0	25±1	no	D-s1, d0	3.4.10
12	-“-	-“-	12	8	405	Vert	PE-Paper class F 3)	-“-	2	447±85	19±2	2	34±8	no	D-s1, d0	3.4.10
30	-“-	Pinus pinaster	10	5 2)	545	Hor./Vert.	-	Min wool 6) class A2-s1,d0	4	458±98	46±9	2	47±14	no	D-s1, d0	3.4.5
31	-“-	-“-	10	5 2)	545	Hor./Vert.	-	Closed air gap 20 mm	4	406±54	43±10	8	89±34	no	D-s2, d0	3.4.5
32	-“-	Oak	11	11	740	Hor.	-	-“-	3	240±18	25±2	0	17±2	no	D-s1, d0	3.4.6
33	Cladding	Larch	19,5	12	640	Vert	-	-“-	3	239±7	12±0	8	49±10	no	C-s1, d0	3.4.7
34	-“-	Oregon pine	19,5	9	510	Vert	-	Closed air gap 35 mm	3	315±33	17±6	10	87±11	no	D-s2, d0	3.4.8
35	-“-	Red cedar	17,6	12	350	Hor	-	Open air gap 25 mm	3	689±57	15±1	12	98±17	no	D-s2, d0	3.4.9

1) No tougue and groove; 2) two profiles of type 'Grain d'Orge' and two profiles of type 'Mouchette';
3) PE-Paper (paper with plastic facing), 160 g/m², F class fire performance; 4) Rani PE-LD (plastic foil), 185 g/m², F/E class fire performance.
5) Thickness 100 mm, density about 11 kg/m³; 6) Thickness 20 mm; 7) Cellulose insulation, thickness 45 mm, density about 60 kg/m², F/E class fire performance.

Table 89 List of solid wood ribbons and panelling (subject to EN 13823) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood product		Wood specie	Thick -ness mm	Profile min thickn mm	Width mm	Spac-ing mm	Density kg/m^3	Orien-tation	Vap. Barr.	Substrate	No of tests	FIGRA W/s	THR 600 MJ	SMOGRA m^2/s^2	TSP m^2	Burn. Part.	Class EN 13501-1	Ref. no
10	Ribbons	Spruce	21	21 [1]	70	70	430	Hor. [4]	-	Open air gap [2] 46 mm	2	810±93	55±4	4	49±11	no	E	3.4.11
11	-"-	-"-	21	21 [1]	70	70	380	Hor. [5]	-	-"-	1 [9]	≈130	> 45	≈29	> 87	no	E	3.4.11
13	-"-	-"-	21	21 [1]	70	100	430	Hor. [4]	-	-"-	1	679	36	2	27	no	D-s1, d0	3.4.11
14	-"-	-"-	10	10 [1]	75	120	440	Vert [3]	-	-"-	1	895	62	8	85	no	E	3.4.12
15	-"-	-"-	21	21 [1]	70	140	450	-"-	-	-"-	1	553	46	4	51	no	D-s1, d0	3.4.12
16	-"-	-"-	21	21 [1]	70	100	450	Hor. [4]	-	-"-	1	664	41	2	34	no	D-s1, d0	3.4.12
17	-"-	-"-	10	10 [1]	75	100	440	-"-	-	-"-	2	600±21	33±3	1	36±0	no	D-s1, d0	3.4.12
18	-"-	-"-	21	21 [1]	70	150	450	Hor. [5]	-	-"-	5	670±37	74±3	7	67±12	no/yes	D-s1, d1	3.4.12
19	Panelling	-"-	9	6	87	-	445	Hor.	Al foil	Open air gap [7] + min wool [6]	3	413±20	39±6	17	77±26	no	D-s2, d0	3.4.13
20	-"-	-"-	10	10 [1]	92	-	450	Vert	-	Closed air gap [7] + particleboard	1	462	17	2	21	no	D-s1, d0	3.4.13
21	-"-	-"-	10	10 [1]	92	-	450	-"-	-	-"- [8]	1	340	14	2	34	no	D-s1, d0	3.4.13
22	-"-	-"-	10	10 [1]	92	-	450	Hor.	-	-"- [7]	1	398	18	7	33	no	D-s1, d0	3.4.13
22b	-"-	-"-	9	6	89	-	440	-"-	-	-"- [7]	2 [9]	(460)	21±2	(6)	32±1	no	Undef.	3.4.13
23	-"-	-"-	10	10 [1]	92	-	450	-"-	-	-"- [8]	1 [9]	(371)	19	(9)	42	no	Undef.	3.4.13

1) No tougue and groove; 2) Calcium silicate substrate behind the air gap; 3) with flat side at 45°; 4) with flat side vertical; 5) with flat side horizontal; 6) thickness 50 mm; 7) air gap 20-21 mm; 8) air gap 40 mm; 9) early termination of one test.

References

3.4.11 Paloposki T: Fire tests of wooden grating structures according to EN 13823:2002 (SBI) test procedure, VTT Research Report No RTE 3259 /03, 2003.
3.4.12 Hakkarainen T: Additional fire tests of wood grating structures according to EN 13823:2002 (SBI) test procedure, VTT Research Report No RTE 4148 /03, 2003.
3.4.13 Hakkarainen T: Additional fire tests of wood panelling and cladding according to EN 13823:2002 (SBI) test procedure, VTT Research Report No RTE 4212 /03, 2003.

Table 90 List of glue laminated structural timber (subject to EN 11925-2) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood specie	Glue 3)	Thick-ness mm	Density kg/m³	Lamella thickness mm	Flame spread within 60 s, mm		Ignition of filter paper	Class EN 13501-1	Ref. no
					Surface	Edge			
Spruce	Res.	40	384	18	< 150	< 150	No	*	3.3.1
-"-	PU	40	366	18	< 150	< 150	No	*	3.3.1
-"-	MUF	40	365	18	< 150	< 150	No	*	3.3.1
Douglas fir	MUF	40	482	18	< 150	< 150	No	*	3.3.1
Spruce, hor.	MUF	40	414	18	< 150	< 150	No	*	3.3.2
Spruce, vert.1)	MUF	40	414	18	< 150	< 150	No	*	3.3.2
Spruce, vert.2)	MUF	40	414	18	-	< 150	No	*	3.3.2
Larch, hor.	Res.	40	642	18	< 150	< 150	No	*	3.3.2
Larch, vert.1)	Res.	40	642	18	< 150	< 150	No	*	3.3.2
Larch, vert. 2)	Res.	40	642	18	-	< 150	No	*	3.3.2

1) flame impignement on wood; 3) Res.= Resorcinol; PU= Polyurethane; MUF=Melamine Urea formaldehyde glue;
*2) flame impignement on glue line; * Satisfies the small flame requirements for class D.*

References

3.3.1 Prüfbericht Nr. PB III/B-03-227 vom 06/08/2003 1. Ausfertigung, MFPA Leipzig GmbH
3.3.2 Fire test according to EN 13823, 2002 (SBI method), Report P300091A, 2003-03-18, SP Fire technology.

Table 91 List of glue laminated structural timber (subject to EN 11823) considered in the investigation by Östman and Mikkola (2004, 2006). Extracted from Östman and Mikkola (2004).

Wood specie	Glue 1)	Thick ness mm	Density kg/m³	Lam thick ness mm	Air gap mm	FIGRA (W/s)	THR 600 (MJ)	SMOGRA (m²/s²)	TSP (m²)	Burn. Part.	Class EN 13501-1	Ref. no
Spruce	Res.	40	388	18	40	661	15,8	6	78	No	D-s2, d0	3.3.3
-"-	PU	40	362	18	40	616	15,5	4	71	No	D-s2, d0	3.3.3
-"-	MUF	40	360	18	40	674	18,2	7	67	No	D-s2, d0	3.3.3
Douglas fir	MUF	40	438	18	40	422	13,5	6	64	No	D-s2, d0	3.3.3
Spruce	MUF	40	405	18	60	414 ± 28	13,2 ± 1,0	2 ± 0,4	45 ± 6,5	No	D-s1, d0	3.3.4
Larch	Res.	40	640	18	60	251 ± 16	13,5 ± 0,4	2 ± 0,1	36 ± 3,1	No	D-s1, d0	3.3.4

1) Res. = Resorcinol; PU= Polyurethane; MUF=Melamine Urea formaldehyde glue.

References

3.3.3 Prüfbericht Nr. PB III/B-03-226 vom 06/08/2003 1. Ausfertigung, MFPA Leipzig GmbH
3.3.4 Fire test according to EN 13823, 2002 (SBI method), Report P300091, 2003-03-18, SP Fire Technology.

A.3 Azhakesan, et al. (1994)

Azhakesan, et al. (1994) compared BS 476 Part 6 fire propagation test results with the previously published cone calorimeter results by Magnusson and Sundström (1985) and data from Sundström, stated to be internally published, that were summarised in the appendix of Azhakesan, et al. (1994). A summary of the BS 476 Part 6 heat release rates, estimated burning efficiencies and mass loss for a selection of potential building lining materials are included in **Error! Reference source not found.**.

Table 92 Heat release rates, estimated burning efficiencies and mass loss for a selection of potential building lining materials from BS 476 Part 6 fire propagation testing. Extracted from Azhakesan, et al. (1994).

Material	Heat Release over Mass Burn Period		Estimated Combustion Efficiencies		Cumulative Mass Loss (%)
	At 5 min (MJ/m²)	Linear Mass Burn Period (MJ/m²)	At 5 min (%)	Linear Mass Burn Period (%)	
Gypsum plasterboard, 12 mm thick	1.96	9.4	65	100	8.1
Polystyrene, 25 mm thick, backed with gypsum plasterboard, 9 mm thick	1.73	10.9	65	83	10.5
Fire retardant chipboard, 12 mm thick (JC)	3.80	42.3	29	42	22.0
Fire retardant chipboard, 12 mm thick (JM)	3.72	31.4	31	36	21.0
White melamine-faced chipboard, 15 mm thick	5.80	67.2	97	34	43.4
High-Density Hardboard, 12 mm thick	9.65	80.0	52	-	65.3
Plywood, 9 ply Birch, 12 mm thick	17.10	60.2	61	89	52.0

A.4 McGraw and Mowrer (1999)

Table 93 Cone calorimeter results for various numbers of latex interior paint coatings on a paper-faced plasterboard substrate, for various incident fluxes and times of exposure. Extracted from McGraw and Mowrer (1999).

Incident Heat Flux (kW/m^2)	Coats of Paint	t_{ig} (sec)	$\dot{Q}''_{peak}$ (kW/m^2)	Q'' (kJ/m^2)
25	0	NI	N/A	N/A
25	2	NI	N/A	N/A
25	4	NI	N/A	N/A
25	6	NI	N/A	N/A
25	8	NI	N/A	N/A
50	0	37	111	1561
50	2	41	211	2284
50	4	42	224	2359
50	6	44	240	2651
50	8	43	215	2366
75	0	14	134	1527
75	2	15	206	2773
75	4	16	210	2949
75	6	17	215	3318
75	8	9	214	3378

NI = No Ignition

0 coats of paint refer to the unpainted paper-faced plasterboard substrate.

A.5 Stoliarov, Crowley and Lyon (2009)

Table 94 Summary of parameters reported for cone calorimeter tests of non-charring polymers of three thicknesses, and an estimated uncertainty based on 5 tests. Extracted from Stoliarov, Crowley and Lyon (2009).

Polymer	Sample Thickness	Peak HRR (kW/m²) [% uncertainty]	Average HRR (kW/m²) [% uncertainty]	Time to Ignition (s) [% uncertainty]	Time to Peak HRR (s) [% uncertainty]
PMMA	Thin	850	410	43	140
	Medium	990 [17%]	560 [7%]	44 [12%]	430 [17%]
	Thick	890	600	38	1210
HIPS	Thin	900	380	49	140
	Medium	920 [10%]	500 [6%]	55 [34%]	440 [15%]
	Thick	900	580	54	1440
HDPE	Thin	1080	390	60	200
	Medium	1480 [36%]	660 [28%]	99 [35%]	450 [45%]
	Thick	1440	610	74	1490

A.6 Chew and Lim (2000)

Table 95 Substrates tested by Chew and Lim (2000)

Material	Thickness (mm)	Code	Fire Performance, related to Fire Code 1997 for Singapore	Mass (g)	Density (kg/m³)
proprietary type-P calcium silicate board	9	P	Non combustible	105.3	1108
proprietary type-S calcium silicate matrix reinforced with selected fibres and fillers	9	S	Non combustible - up to 240 minutes fire resistance	81.4	904
proprietary type-M calcium silicate matrix reinforced with selected fibres and fillers	9	M	Class zero - up to 60 minutes fire resistance	98.1	1090
proprietary mineral wool board multiply coated with ultra-white colour	14	T	Class zero	70.2	1170
proprietary cellulose reinforced Portland cement board	6	CP	Class zero	58.6	419
Gypsum plasterboard	15	G	Class zero	39.2	261
Standard core plasterboard	12.5	B	Class one	88.9	711
Proprietary fire-stop plasterboard	16	FR	Class one	133.5	861
Chipboard	19	BC	Class two	134.4	707
Plywood	9	TP	Class three	46.3	514

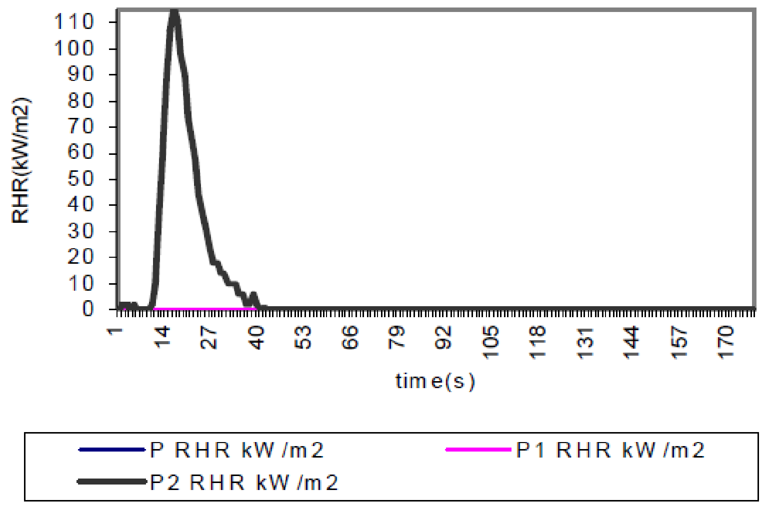

Figure 92 P-type calcium silicate substrate results for rate of heat release for base product alone, and lined with two different types of wallpaper. Extracted from Chew and Lim (2000).

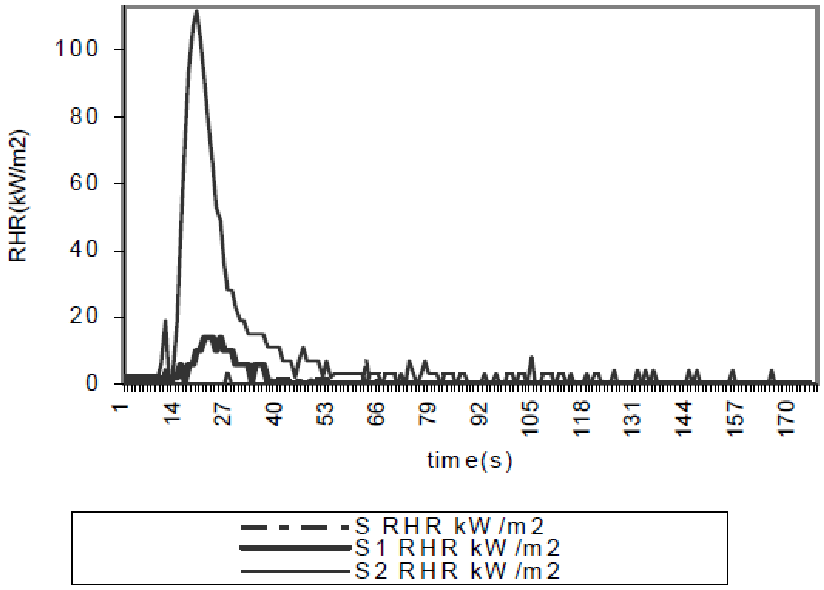

Figure 93 S-type calcium silicate substrate results for rate of heat release for base product alone, and lined with two different types of wallpaper. Extracted from Chew and Lim (2000).

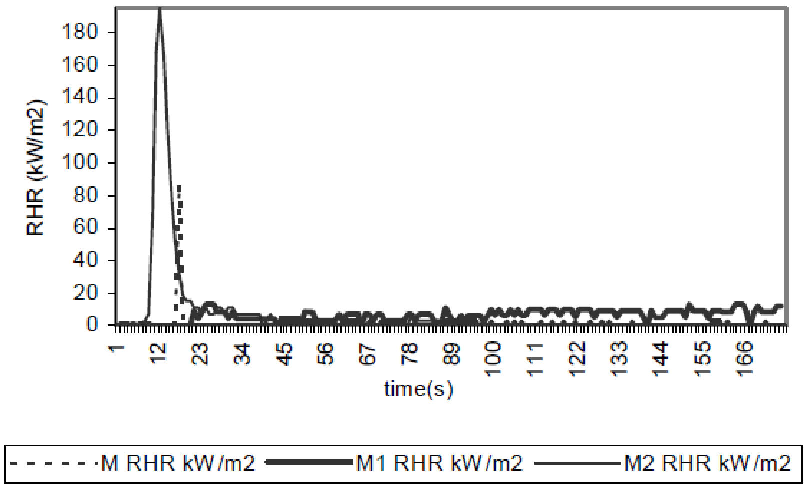

Figure 94 M-type calcium silicate substrate results for rate of heat release for base product alone, and lined with two different types of wallpaper. Extracted from Chew and Lim (2000).

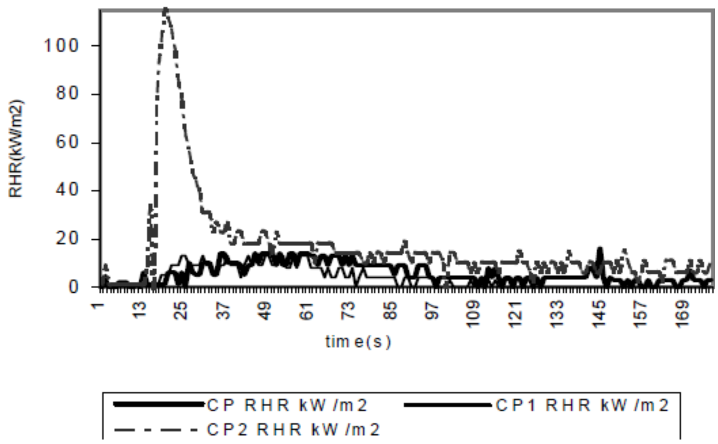

Figure 95 CP-type cellulose-based Portland cement substrate results for rate of heat release for base product alone, and lined with two different types of wallpaper. Extracted from Chew and Lim (2000).

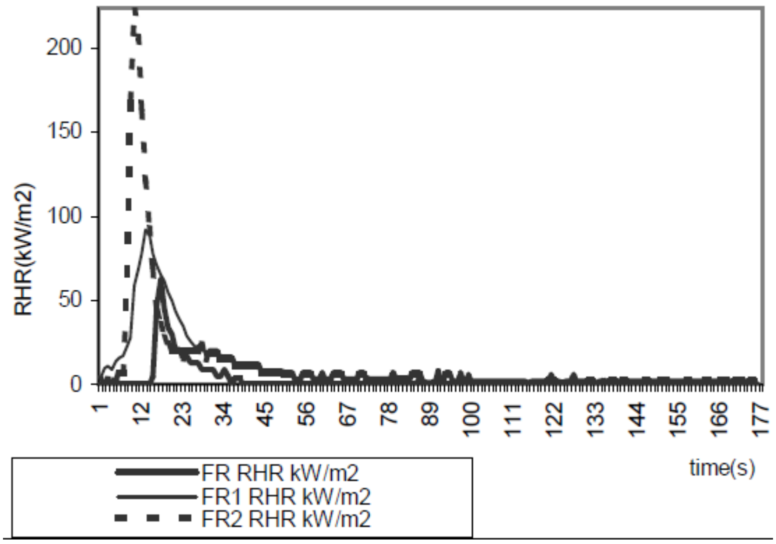

Figure 96 FR-type fire-resistant plasterboard substrate results for rate of heat release for base product alone, and lined with two different types of wallpaper. Extracted from Chew and Lim (2000).

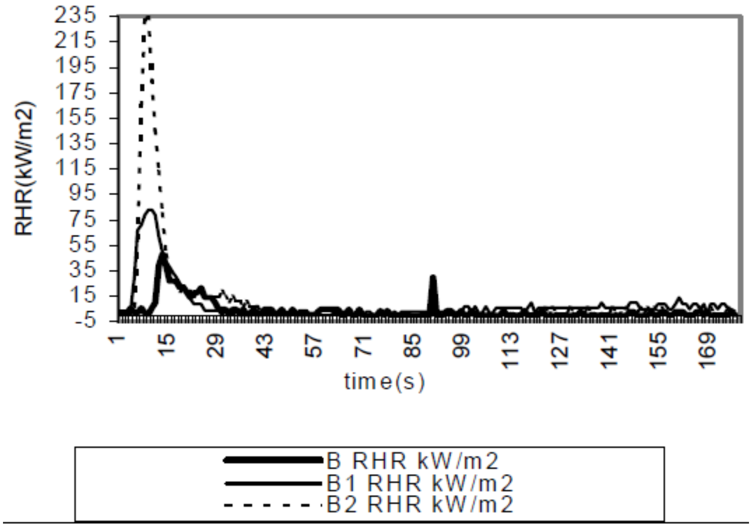

Figure 97 B-type plasterboard substrate results for rate of heat release for base product alone, and lined with two different types of wallpaper. Extracted from Chew and Lim (2000).

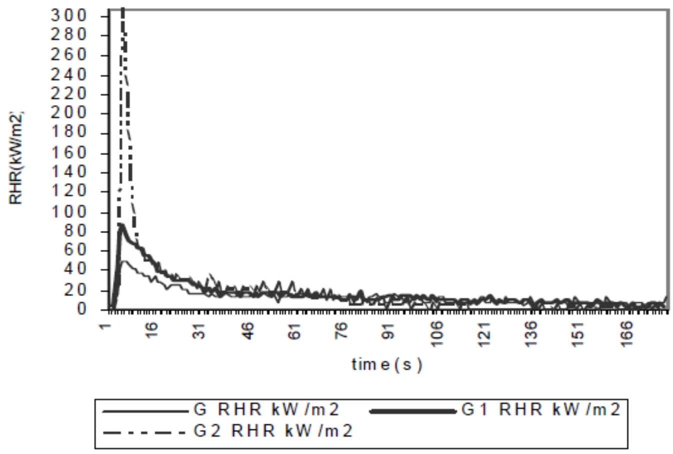

Figure 98 G-type gypsum plasterboard substrate results for rate of heat release for base product alone, and lined with two different types of wallpaper. Extracted from Chew and Lim (2000).

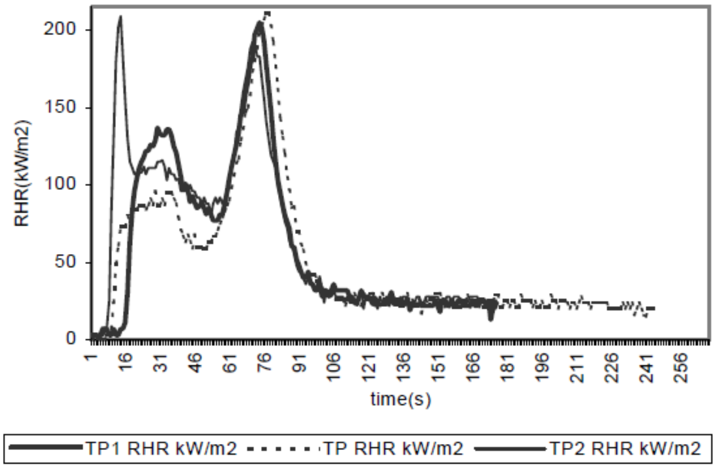

Figure 99 TP-type plywood substrate results for rate of heat release for base product alone, and lined with two different types of wallpaper. Extracted from Chew and Lim (2000).

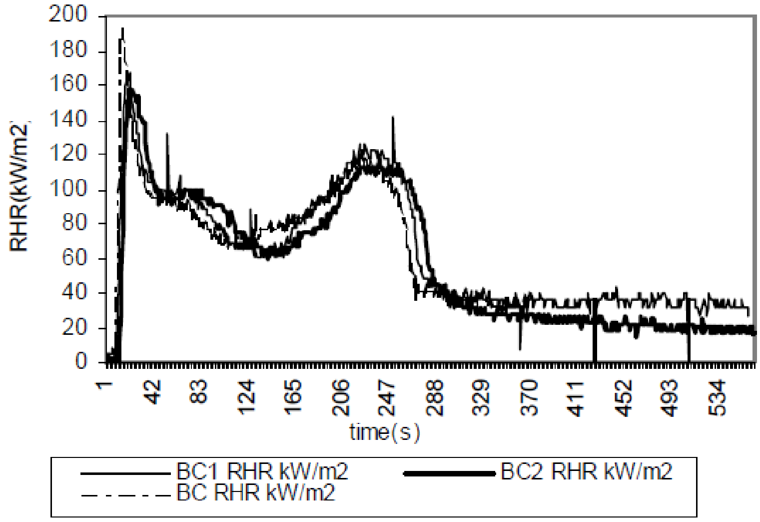

Figure 100 BC-type chipboard substrate results for rate of heat release for base product alone, and lined with two different types of wallpaper. Extracted from Chew and Lim (2000).

A.7 Harkleroad (1989)

Table 96 Description of textile wall coverings investigated by Harkleroad (1989).

Material	Mass per Unit Area * (kg/m²)	Construction	ASTM E84 Flame Spread Index	Rate of Heat Release from Room/Corner Tests by Fisher, et al (1986) (kW)	Code used in Table 62 and Figure 71
100% Polypropylene	0.61	Non-woven	-	1166 [2]	PP-PF
100% Nylon	0.43	Woven	15	590 [2]	R
100% Polyester	0.43	Knit plush	15	497 [2] 474 [2]	Q
100% Polyester	0.33	Woven panel fabric	-	298 [2]	B
85% Wool/ 15% Nylon	0.33	Woven flannel	-	160 [2]	H
55% Cotton/ 45% Rayon	0.4	Dobby woven loose complex weave with floating yarn	-	119 [2]	C
70% Acrylic/ 30% Wool	0.75P 1.29T	Tufted	25	684 [1]	AA
100% Nylon	0.43	Woven	15	587 [1]	R
100% Polyester	0.43	Knit plush	15	310 [1]	Q_{FR}
100% Polyester	0.43	Knit plush	15	207 [1]	Q
100% Polyester	0.33	Woven panel fabric	-	207 [1]	B
100% Polyester	0.68	Needle punched	-	83 [1]	G
55% Cotton/ 45% Rayon	0.40	Dobby woven loose complex weave with floating yarn	-	62 [1]	C
85% Wool/ 15% Nylon	0.33	Woven flannel	-	46 [1]	H
100% Polyester	0.43	Knit plush	15	5771 [full]	Q
100% Polyester	0.43	Knit plush	15	297 [full]	Q

Table Notes:
[1] 1 foot wide test specimen
[2] 2 foot wide test specimen
[full] fully lined room tire test
* P refers to pile weight, and T refers to total weight

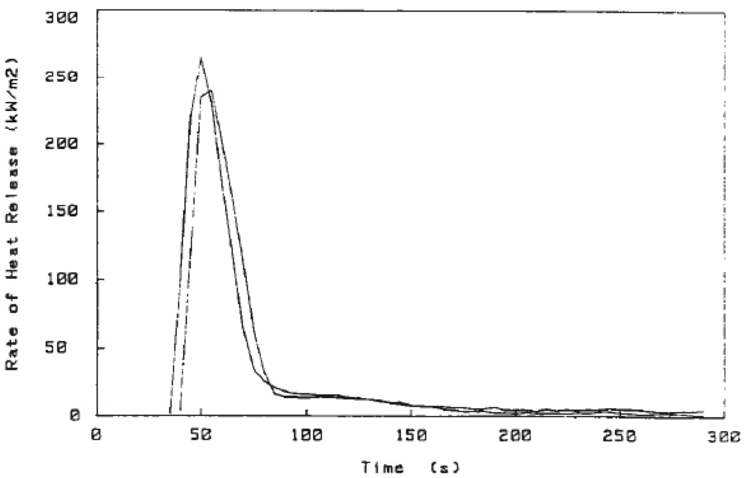

Figure 101 Polyester, knit plush, fabric on 12.7 mm thick plasterboard in a vertical orientation subject to an incident heat flux of 50 kW/m² in a cone calorimeter. Extracted from Harkleroad (1989).

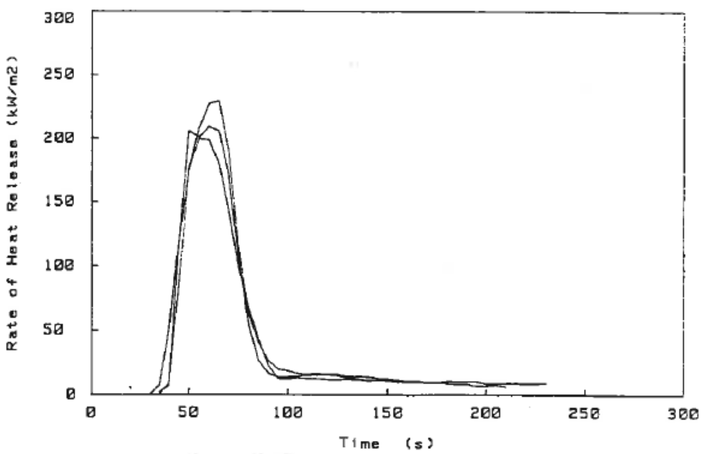

Figure 102 Fire retardant polyester, knit plush, fabric on 12.7 mm thick plasterboard in a vertical orientation subject to an incident heat flux of 50 kW/m² in a cone calorimeter. Extracted from Harkleroad (1989).

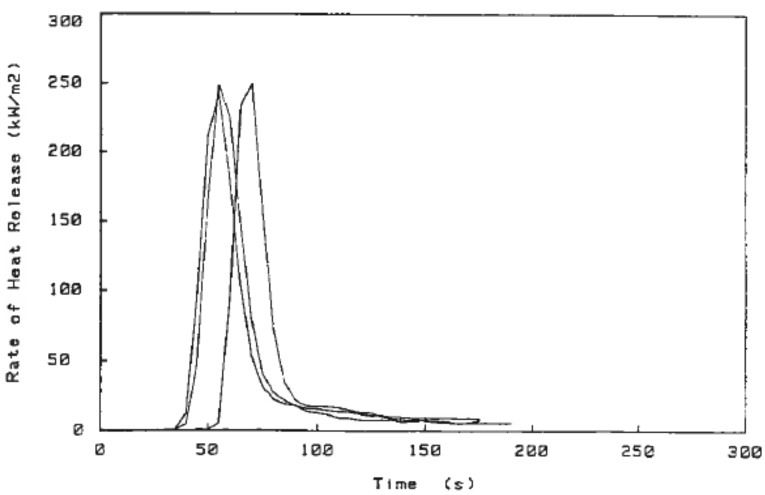

Figure 103 Polyester, woven, fabric on 12.7 mm thick plasterboard in a vertical orientation subject to an incident heat flux of 50 kW/m² in a cone calorimeter. Extracted from Harkleroad (1989).

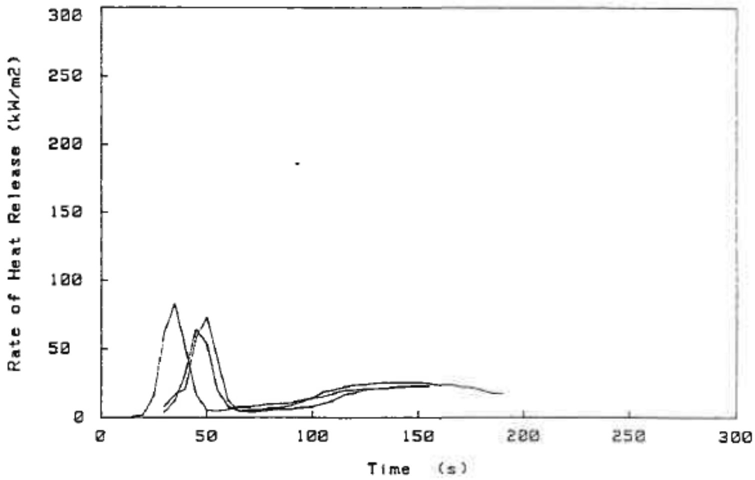

Figure 104 Polyester, needle point, fabric on 12.7 mm thick plasterboard in a vertical orientation subject to an incident heat flux of 50 kW/m² in a cone calorimeter. Extracted from Harkleroad (1989).

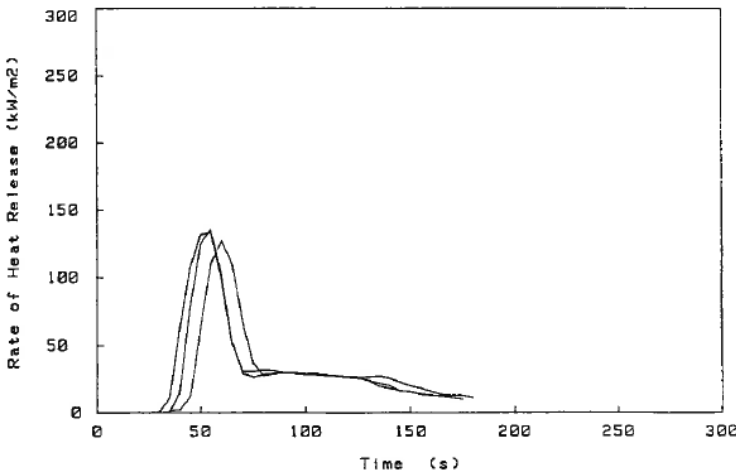

Figure 105 55% cotton/ 45% rayon, tight complex weave, fabric on 12.7 mm thick plasterboard in a vertical orientation subject to an incident heat flux of 50 kW/m² in a cone calorimeter. Extracted from Harkleroad (1989).

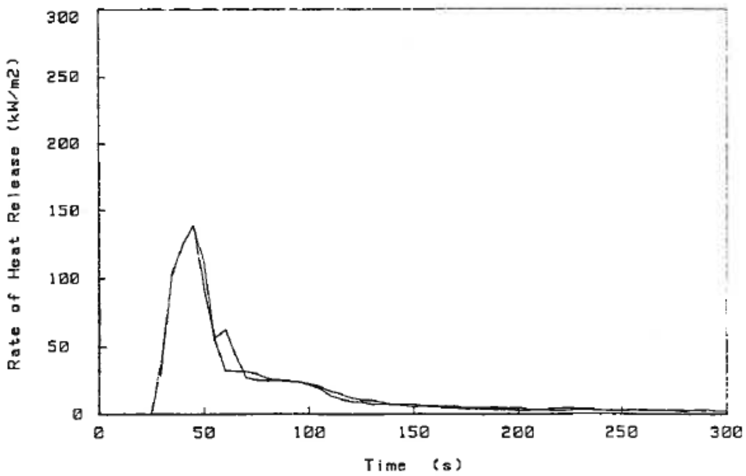

Figure 106 55% cotton/ 45% rayon, loose complex weave, fabric on 12.7 mm thick plasterboard in a vertical orientation subject to an incident heat flux of 50 kW/m² in a cone calorimeter. Extracted from Harkleroad (1989).

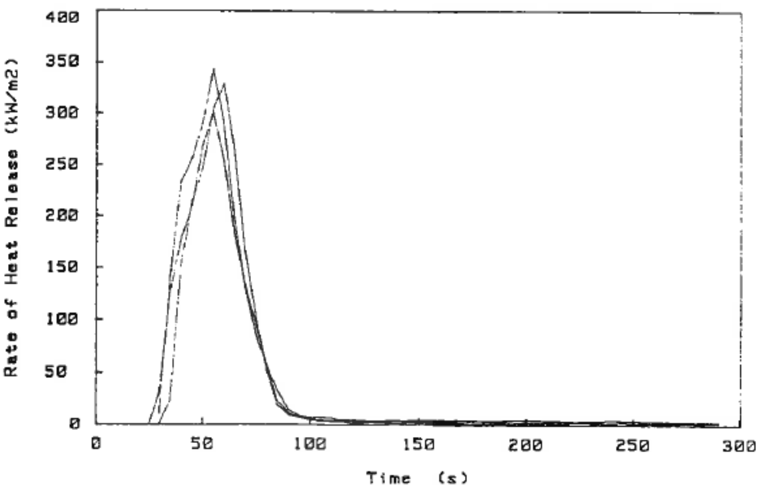

Figure 107 Nylon, with backing, fabric on 12.7 mm thick plasterboard in a vertical orientation subject to an incident heat flux of 50 kW/m² in a cone calorimeter. Extracted from Harkleroad (1989).

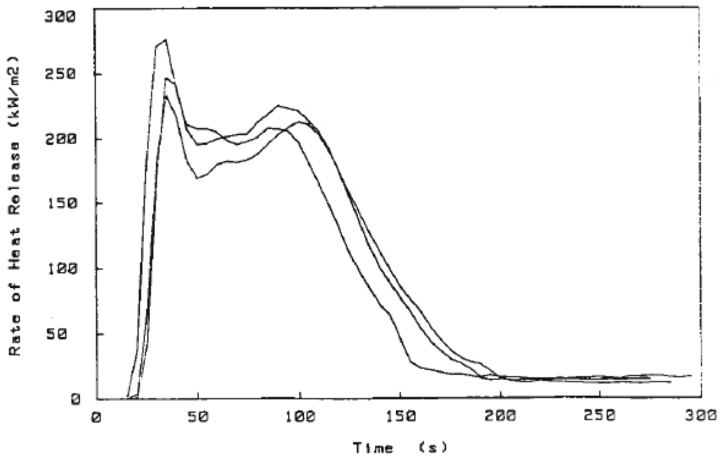

Figure 108 70% acrylic/ 30% wool, tuffed, fabric on 12.7 mm thick plasterboard in a vertical orientation subject to an incident heat flux of 50 kW/m² in a cone calorimeter. Extracted from Harkleroad (1989).

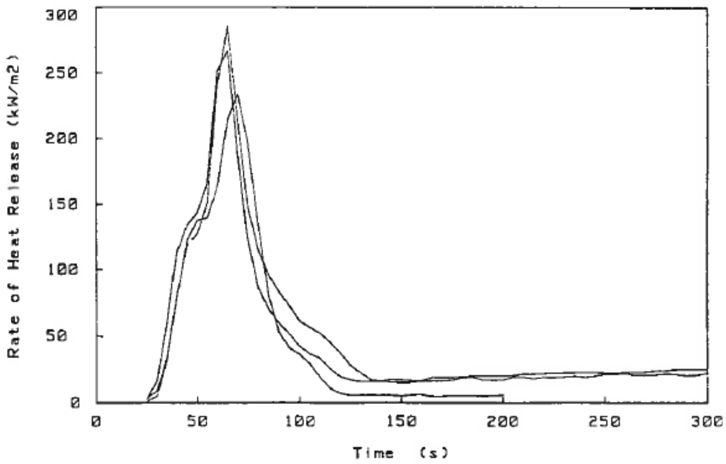

Figure 109 Polypropylene fabric on 12.7 mm thick plasterboard in a vertical orientation subject to an incident heat flux of 50 kW/m² in a cone calorimeter. Extracted from Harkleroad (1989).

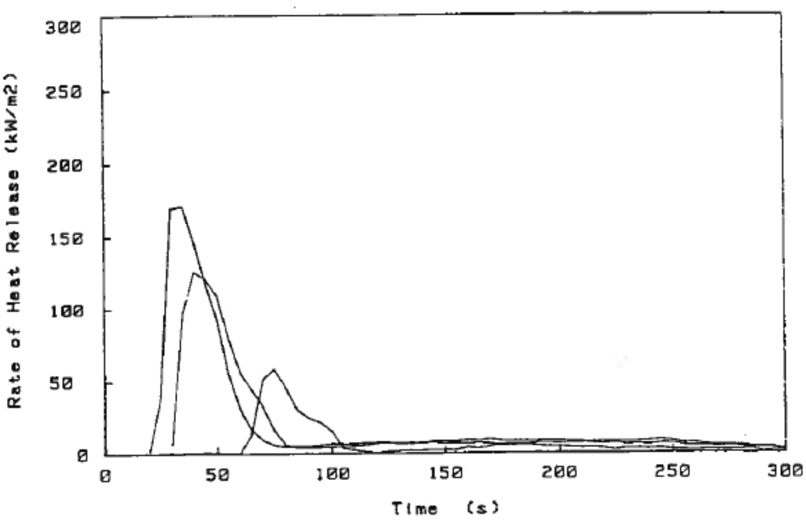

Figure 110 Polypropylene fabric on 12.7 mm thick plasterboard in a vertical orientation subject to an incident heat flux of 50 kW/m² in a cone calorimeter. Extracted from Harkleroad (1989).

A.8 The Vinyl Institute (1996)

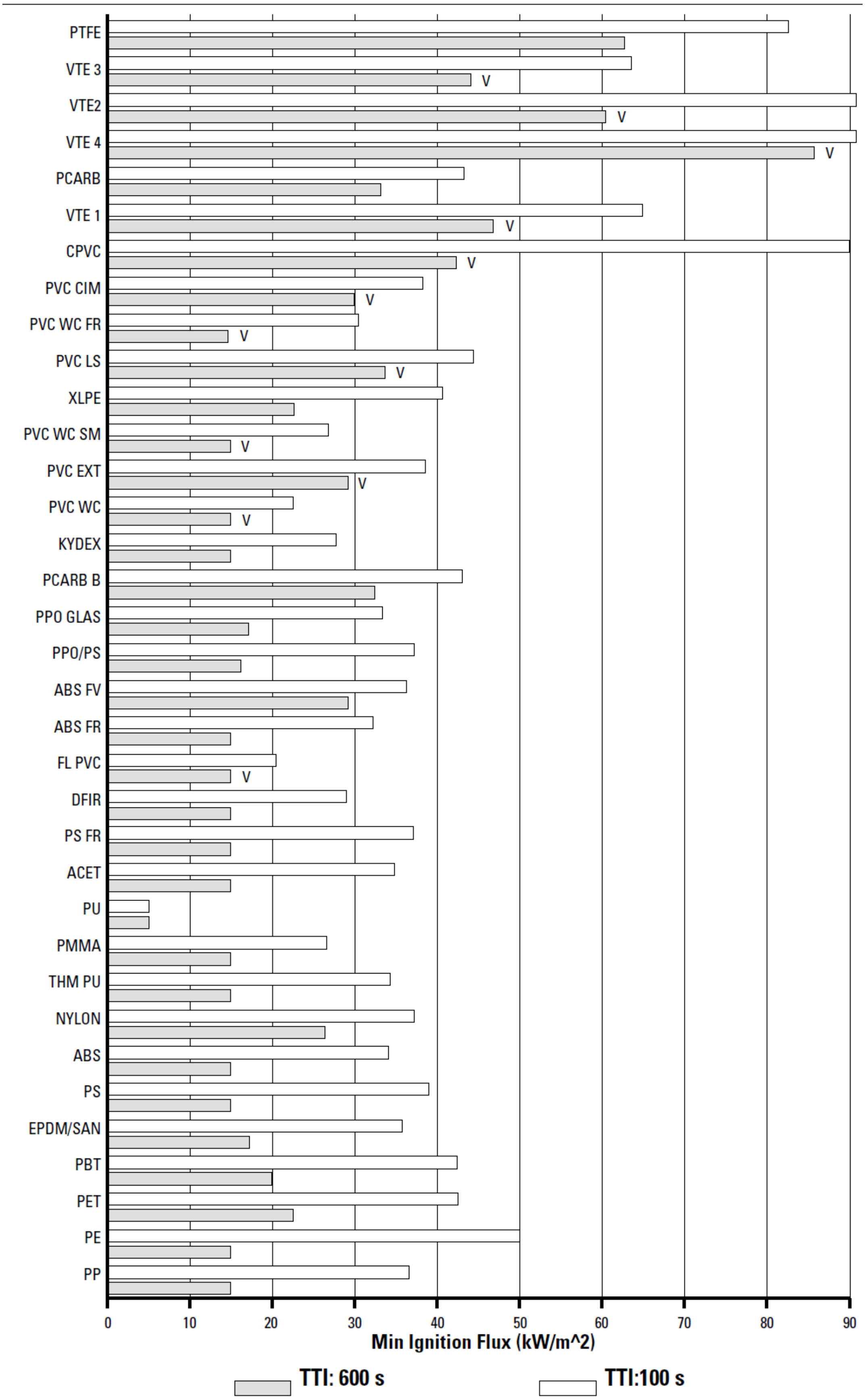

Figure 111 Summary of minimum ignition fluxes from ASTM E1354 tests for various polymers. Extracted from The Vinyl Institute (1996).

Table 97 Peak heat release rates for various cone calorimeter irradiance levels for polymeric materials. Extracted from The Vinyl Institute (1996).

Material	Pk RHR 20 kW/m^2	Pk RHR 40 kW/m^2	Pk RHR 70 kW/m^2
PTFE	3	13	161
VTE 3	4	43	70
VTE 2	9	64	100
VTE 4	14	87	66
PCARB	16	429	342
VTE 1	19	77	120
CPVC	25	84	93
PVC CIM	40	175	191
PVC WC FR	72	92	134
PVC LS	75	111	126
XLPE	88	192	268
PVC WC SM	90	142	186
PVC EXT	102	183	190
PVC WC	116	167	232
KYDEX	117	176	242
PCARB B	144	420	535
PPO GLAS	154	276	386
PPO/PS	219	265	301
ABS FV	224	291	409
ABS FR	224	402	419
FL PVC	233	237	252
DFIR	237	221	196
PS FR	277	334	445
ACET	290	360	566
PU	290	710	1221
PMMA	409	665	988
THM PU	424	221	319
NYLON	517	1313	2019
ABS	614	944	1311
PS	723	1101	1555
EPDM/SAN	737	956	1215
PBT	850	1313	1984
PET	881	534	616
PE	913	1408	2735
PP	1170	1509	2421