FIRE CODE REFORM

FIRE CODE REFORM RESEARCH PROGRAM

Project 2
FIRE PERFORMANCE OF MATERIALS

Stage A
Wall and Ceiling Lining Materials

FINAL SUBMISSION
February 2001

comprising

Summary of Recommendations
Executive Summary
Final Report of the Technical Working Group
Final Research Report

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FCRC Project 2 - Fire Performance of Materials
Stage A - Wall and Ceiling Lining Materials

Summary of Recommendations

Following detailed consideration by an appointed Technical Working Group and review of research undertaken by the Fire Science and Technology Laboratories of CSIRO at both Highett in Victoria and North Ryde in NSW, the following recommendations are submitted by Fire Code Reform Centre Limited to the Australian Building Codes Board as the basis for changes to the testing and regulation of Wall and Ceiling Lining Materials that:

1 regulatory control of Wall and Ceiling Linings used in buildings be based on the material's "time to flashover" performance as indicated either, by physically testing the material in the ISO-9705 Room Fire Test or by prediction of its performance from data obtained by testing a material sample in a Cone Calorimeter in accordance with ISO Standard 5660.

2. Wall and Ceiling Lining materials be classified as follows, based on the performance evidenced by such testing or prediction:-

Group 1 - materials that do not reach flashover after exposure to 300 kW;
Group 2 - materials that do reach flashover after exposure to 300 kW;
Group 3 - materials that reach flashover in more than 120 seconds after exposure to 100 kW;
Group 4 - materials that reach flashover in less than 120 seconds after exposure to 100 kW.

3. regulations require that Wall and Ceiling Lining materials installed in sprinklered and unsprinklered BCA Occupancy Class premises comply with the relevant material Groups listed in Table 1 attached.

4. at this stage, regulation of smoke production is not recommended.
If such regulation is specifically required by the ABCB, a recommended criterion is that a material's smoke production should not exceed 25 MW/kg (Heat Release Rate times Specific Extinction Area) when tested by Cone Calorimeter in accordance with ISO Standard 5660 at a radiant flux of 50 KW/m^2.

5 that an overlap period of 1.5 to 2 years be allowed for industry adjustment after promulgation of any changes based on these recommendations, permitting in the interim continued use of materials successfully tested to existing BCA requirements.

Full explanations of the above recommendations are detailed in the Final Report of the Technical Working Group (specifically Section 9 to 11) and in the related FSTL/CSIRO Research Report.

Table 1 –TWG recommendations based on occurrence of flashover in the ISO Room FireTest

BCA Building Class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
Class 2 & 4 - Apartments					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Unsprinklered[1]	1	1	2	2	3	3	3	3
sprinklered[1]	1	1	3	3	3	3	3	3
Class 3 – Hotels & boarding houses					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2	3	3	3	3
sprinklered[1]	1	1	3	3	3	3	3	3
Class 3 – Accommodation for the aged, disabled and children					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	1	1	2	2	3	3
sprinklered[1]	1	1	2	2	3	3	3	3
Class 5 – Office buildings					**open-plan offices; aspect ratio >5**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2	3	2	3	3
sprinklered[1]	1	1	3	3	3	3	3	3
Class 6 - Shops					**large shops; aspect ratio >5**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2	3	2	3	3
sprinklered[1]	1	1	3	3	3	3	3	3
Class 7 – Car parks								
	Wall	*Ceiling*	*Wall*	*Ceiling*			*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2			3	3
sprinklered[1]	1	1	3	3			3	3

Table 1 – TWG recommendations based on occurrence of flashover in the ISO Room Fire Test (Continued)

BCA Building Class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
Class 7 and 8 – Warehouses & factories								
	Wall	*Ceiling*	*Wall*	*Ceiling*			*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2			3	3
sprinklered[1]	1	1	3	3			3	3
Class 9a – Health care buildings					**patient care areas**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	1	1	2	2	3	3
sprinklered[1]	1	1	2	2	3	3	3	3
Class 9b – Theatres, halls etc.					**auditoriums**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	1	1	2	2	3	3
sprinklered[1]	1	1	2	2	3	3	3	3
Class 9b – Schools					**classrooms**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2	3	2	3	3
sprinklered[1]	1	1	3	3	3	3	3	3

1 "Sprinklered" and "unsprinklered" refer to the whole building or fire compartment, rather than the location within the building. Sprinklers are not usually fitted in fire-isolated exits (see AS 2118.1).

2 Group 4 materials are not permitted under any circumstances.

FIRE CODE REFORM RESEARCH PROGRAM

PROJECT 2 - FIRE PERFORMANCE OF MATERIALS
Stage A - Wall and Ceiling Lining Materials

FINAL SUBMISSION
February 2001

Executive Summary

Adopted by the Fire Code Reform Centre Board of Directors

12 December 2000

FCRC FR 2000-01

FCRC Project 2 - Fire Performance of Materials
Stage A - Testing and Regulation of Wall and Ceiling Linings

Executive Summary

When the Fire Code Reform Centre's (FCRC) *Fire Code Reform Research Program* was developed in 1993, it was recognised that problems existed in regard to flammability testing of a number of material applications, including wall and ceiling linings for buildings. There was concern that the test results did not adequately evaluate fire performance in the end use. The purpose of FCRC's Project 2A - "Wall and Ceiling Lining Materials" was to investigate the need for control; the aptness of the test method in its application to buildings and additionally, if possible, to propose more appropriate testing and regulatory requirements for these materials.

Wall and ceiling materials are currently regulated in the BCA-96 with deemed-to-satisfy provisions stated in specification C1.10 in terms of *Spread-of-Flame* and *Smoke-Developed Indices*, as determined by the Early Fire Hazard (EFH) Test, in accordance with AS 1530 Part3.

Research work on this Project was carried out by the Fire Science and Technology Laboratory at CSIRO (FSTL/CSIRO) in Melbourne and Sydney. The tasks involved analysis of relevant major fires and fire statistics, large-scale fire experimental testing plus domestic and international review of appropriate regulatory activities and test methods.

The FSTL/CSIRO research outcomes and recommendations are summarised below:--

It was concluded that a test method that could assess the contribution of wall and ceiling materials to room flashover (a critical event in room fire spread and growth) was appropriate for regulatory purposes and the International Standard Organisation's ISO-9705 Room Fire Test was selected as most appropriate. Considering the costs of large scale testing, FSTL/CSIRO suggested the alternative use of small scale, cone calorimeter, testing that has been shown to correlate with the ISO Room Fire results. However at that time, correlation between the cone calorimeter and full-scale testing was based on only limited data.

The researchers also developed a materials classification (grouping) scheme based on the correlation of cone calorimeter results and predicted flash-over performance in the ISO Room Fire Test. It was suggested that any manufacturer having concern regarding classification of a product by the cone calorimeter method could require that testing in the ISO Room Fire Test be the final arbiter for classification purposes

The researchers recommended that, for regulatory control purposes, the classification scheme should be implemented by tabulating material groups that were permissible for use within specified locations of the several occupancy classes of the BCA. Concessions for the use of automatic sprinklers were also recommended.

Although both the ISO Room Fire and the cone calorimeter testing procedures include capability for measuring smoke, FSTL/CSIRO recommended that smoke measurement not be included in the regulatory requirements at this point in time. Nonetheless appropriate acceptance levels can be recommended if the ABCB prefers that smoke control be applied.

Technical Working Group Recommendations

A Technical Working Group (TWG) of FCRC's Research Supervisory Committee (RSC), working with the researchers, has reviewed FSTL/CSIRO's research results, its Final Report and its Supplement. Additional data relevant to the research were secured by the TWG members, following which the researchers were commissioned to further investigate correlation between cone calorimeter and ISO Room Fire testing. The results of the TWG investigation have confirmed full confidence in the recommended materials classification proposals. Based on all these considerations, the Technical Working Group submit the following recommendations to the Australian Building Codes Board as the basis for changes to the Building Code of Australia.

It is recommended that regulatory control of the materials used in building construction be based on the material's "time to flash-over" performance when either, physically tested in the ISO-9705 Room Fire Test or, predicted using data obtained by cone calorimeter testing of the material in accordance with ISO Standard 5660.

It is recommend the materials be grouped after testing as follows:-.
Group 1 - materials that do not reach flash-over after exposure to 300 kW;
Group 2 - materials that do reach flash-over after exposure to 300 kW;
Group 3 - materials that reach flash-over in more than 120 seconds after exposure to 100kW
Group 4 - materials that reach flash-over in less than 120 seconds after exposure to 100 kW

For regulatory control, it is recommended the use of materials within specified locations of BCA occupancy classes be based on the details in Table1 attached to this Executive Summary.

The TWG does not recommend regulatory control of product smoke production at this point in time but, if required by regulatory authorities, suggests that materials not exceed a smoke criterion of 25 Mw/kg (Heat Release Rate times Specific Extinction Area) when tested in the cone calorimeter at a radiant flux of 50 kW/m^2.

It is recommended a 1.5 to 2 year "phase-in" period be allowed for industry to conform to any new provisions of the Building Code of Australia that arise from these recommendations.

Comments in regard to these recommendations are included in Sections 9 through 11 of this Technical Working Group's Final Report and the related FSTL/CSIRO Research Report.

Table 1 –TWG recommendations based on occurrence of flashover in the ISO Room FireTest

BCA Building Class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
Class 2 & 4 - Apartments					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Unsprinklered[1]	1	1	2	2	3	3	3	3
sprinklered[1]	1	1	3	3	3	3	3	3
Class 3 – Hotels & boarding houses					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2	3	3	3	3
sprinklered[1]	1	1	3	3	3	3	3	3
Class 3 – Accommodation for the aged, disabled and children					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	1	1	2	2	3	3
sprinklered[1]	1	1	2	2	3	3	3	3
Class 5 – Office buildings					**open-plan offices; aspect ratio >5**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2	3	2	3	3
sprinklered[1]	1	1	3	3	3	3	3	3
Class 6 - Shops					**large shops; aspect ratio >5**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2	3	2	3	3
sprinklered[1]	1	1	3	3	3	3	3	3
Class 7 – Car parks								
	Wall	*Ceiling*	*Wall*	*Ceiling*			*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2			3	3
sprinklered[1]	1	1	3	3			3	3

Table 1 – TWG recommendations based on occurrence of flashover in the ISO Room Fire Test (Continued)

BCA Building Class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
Class 7 and 8 – Warehouses & factories								
	Wall	*Ceiling*	*Wall*	*Ceiling*			*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2			3	3
sprinklered[1]	1	1	3	3			3	3
Class 9a – Health care buildings					**patient care areas**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	1	1	2	2	3	3
sprinklered[1]	1	1	2	2	3	3	3	3
Class 9b – Theatres, halls etc.					**auditoriums**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	1	1	2	2	3	3
sprinklered[1]	1	1	2	2	3	3	3	3
Class 9b – Schools					**classrooms**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2	3	2	3	3
sprinklered[1]	1	1	3	3	3	3	3	3

1 "Sprinklered" and "unsprinklered" refer to the whole building or fire compartment, rather than the location within the building. Sprinklers are not usually fitted in fire-isolated exits (see AS 2118.1).

2 Group 4 materials are not permitted under any circumstances.

FIRE CODE REFORM RESEARCH PROGRAM

PROJECT 2 - FIRE PERFORMANCE OF MATERIALS
Stage A - Wall and Ceiling Lining Materials

FINAL SUBMISSION
February 2001

Final Report of the Technical Working Group

Adopted by the Fire Code Reform Centre Board of Directors

12 December 2000

FCRC FR 2000-01

FCRC Project 2 - Fire Performance of Materials
Stage A - Testing and Regulation of Wall and Ceiling Linings

Final Report of the Technical Working Group

1 Introduction

Well before the introduction of the Building Code of Australia, industry questioned use of the Early Fire Hazard Test and the way in which the results were applied. The purpose of FCRC's Project 2A was to investigate the need for control of wall and ceiling linings; the adequacy of the current test method and, as appropriate, to propose alternative requirements based on a logical approach.

In the late 1970's, work similar to that of Project 2 was conceived as Australian Building Regulations Coordinating Committee (AUBRCC) Project AP 73. Project AP 73 was a response by AUBRCC to industry concerns about the use of the Early Fire Hazard Test (EFH) to control materials in buildings in the new Australian Model Uniform Building Code[1,2].

Wall and ceiling materials are currently regulated in the BCA-96. The deemed-to-satisfy provisions are stated in Specification C1.10 in terms of *Spread-of-Flame Index* and *Smoke-Developed Index* as determined by the Early Fire Hazard Test (EFH) in accordance with Australian Standard AS 1530.3[3].

After completion of research activities undertaken by the Fire Science and Technology Laboratory of CSIRO (FSTL/CSIRO) in Melbourne and Sydney, a Technical Working Group (TWG) of FCRC's Research Supervisory Committee (RSC) was established to review the Project 2A Report[4] and to transfer appropriate research results into recommendations to the Australian Building Code Board (ABCB) for proposed changes to the BCA.

This TWG, designated TWG-A1 (Interior Finishes and Non-Combustibility) comprised Richard Custer, FCRC Technical Director [a] as Chair and Brian Ashe [b] Australian Building Code Board (ABCB) as Deputy Chair with additional members:-

Blackmore, Jane, Project Leader, Project 2A, FSTL/CSIRO
Delechatsios, Michael, Technical Director, FSTL/CSIRO (Observer)
Dunn, Andrew, Timber Development Association [c]
Gardner, David, State Forests of NSW [c]
Green, Tony, Department of Safety Science, University of NSW [c]
Oleszkiewicz, Igor, ABCB [d]

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[a] Chair, FCRC Research Supervisory Committee
[b] Project Manager, Fire research and Engineering at ABCB and Deputy Chair, FCRC Research Supervisory Committee
[c] Member, FCRC Research Supervisory Committee
[d] Fire Engineer for ABCB February 1999 – May 2000. And previous Deputy Chair of RSC and TWG- A1.

The following submission and recommendations of TWG-A1 on the testing and regulation of Wall and Ceiling Materials is based on its review of the results of the Project 2A research together with additional test reports, publications and other information made available during the TWG's deliberations. Specific references are cited in context in this Final TWG Report.

Summary of Project 2A Research

The following sections summarise the relevant issues relating to the general hazard of Wall and Ceiling Materials, current requirements of the BCA-96 and test methods as presented in the FSTL/CSIRO report.

2 Background

2.1 Need for Control of Fire Properties in the BCA

From the fire prospective, a major objective of the BCA is life safety and the protection of occupants from the consequences of fire. Since Wall and Ceiling Materials can play a role in fire spread and growth, particularly in those locations in buildings through which the occupants must egress, it is important that Wall and Ceiling Materials be regulated.

2.2 Details of the Early Fire Hazard (EFH) Test Problems

The EFH test was developed to evaluate the behaviour of wall materials when exposed to a minor fire. At the time, the materials being used for wall and ceiling materials were generally limited to cellulosics. Since the samples were tested in the vertical position, it was thought the results of the test could be used to set limits on the performance in the full scale application. Full scale work at FSTL/CSIRO in corridor testing for FCRC's Project 2A[5] and for State Forests of NSW[6] has shown that some wall and ceiling linings ignite and burn in realistic conditions regardless of having satisfactorily met the EFH test requirements.

2.3 Aim of the Research Project

The purpose of FCRC's Project 2A was to examine the need for control of wall and ceiling lining materials; to provide qualitative definitions of performance; to identify appropriate test methods and to recommend performance levels for different building locations and occupancies, having regard to the presence of other fire safety features required by regulations.

3. Research Approach and Methodology

3.1 Analysis of Major Fires

In the absence of detailed analyses for large numbers of fires that identified the role of wall and ceiling linings, the FSTL/CSIRO researchers reviewed 7 major fires in which wall and ceiling/roof linings played a major role in the growth and spread of fire and the development of smoke. The finish materials in these cases included carpet on walls and ceilings, plywood panelling, heavy layers of paint and wallpaper on walls and plastic materials on walls and ceilings. Most of these fires resulted in large life losses.

3.2 Analysis of Fire Loss Statistics

Analysis of available United States fire-loss statistics by FSTL/CSIRO revealed that spread of fire beyond the room of fire origin is more likely when the walls have combustible linings. The research also reported that combustible linings are a contributing factor to higher numbers of deaths. The small number of fires forming the Australian database did not allow for analysis of specific linings.

3.3 Large-scale Experiments

As part of the work on FCRC Project 2A, large-scale tests were conducted by FSTL/CSIRO involving wall and ceiling linings exposed to realistic fires.

3.4 Performance of Lining Materials by Occupancy and Location

The building occupancy classes considered were BCA Classes 2 to 9a. The researchers agreed that there were two possible ways in which linings might significantly decrease occupant safety. These were:

In the presence of an ignition source, linings might significantly reduce the time to untenable conditions.

In the presence of an ignition source, linings might significantly contribute to flame spread. Fire might then spread to areas remote from the area of fire origin, reducing the time to untenable conditions in these areas.

The effects of combustible lining materials were also considered relative to the location of their use within buildings - such as in fire-isolated exits, public corridors, sole occupancy units, patient care areas, etc.

4 FSTL/CSIRO Review of Current BCA Practice.

For each Part of the BCA, Objectives, Functional Statements and Performance Requirements are listed. In respect to fire safety the Objectives address the safety of building occupants, facilitation of emergency service activities, avoidance of spread of fire between buildings and protection of other property from physical damage caused by structural failure of the building as a result of fire.

The Objectives are restated in the form of more detailed Performance Requirements (CP2 and CP4) that provide guidance on the classes and locations within buildings that need to be considered and give an indication of the material properties that need to be controlled. In order to meet these objectives Wall and Ceiling Materials need to be regulated.

In regulating Wall and Ceiling Materials there are two performance issues, flammability and production of smoke. In selecting suitable tests, it is important to note that CP4 requires materials and assemblies to "resist the spread of fire to limit the generation of smoke and heat and any toxic gases likely to be produced".

The "deemed-to-satisfy" provisions are specified in terms of indices for *Spread-of-Flame* and *Smoke-Developed* as determined from the Early Fire Hazard (EFH) test results.

5 Review of candidate tests

The FSTL/CSIRO researchers considered a number of regulatory methods for wall and ceiling lining materials. Details are contained in the Project 2A Report. Essentially two types of tests were considered.

Large-scale fire tests – Room fire tests evaluate the effects of lining materials by exposure to small gas burner fires of varying heat output. The performance is determined in terms of the time to occurrence of flashover. These tests are essentially full scale. The ISO 9705 Room Fire Test[7] and the similar ASTM Room Fire Test were reviewed.

Small-scale fire tests – Small-scale tests evaluate the performance of materials with small samples and then attempt to extrapolate to performance in the end use application. Data from the EFH and the Cone Calorimeter (ASTM E-3154)[8] were evaluated.

6. Selection of Test Methods

In selecting test methods five criteria were chosen. The FSTL/CSIRO considered that selected tests should be:

- related to control of performance in real fires
- appropriate to the end use
- international
- repeatable and reproducible
- cost effective

In reviewing overseas practice, FSTL/CSIRO determined that, in Europe, individual countries use small-scale tests but the ISO Room Fire Test is used as the reference scenario. Thus it would appear appropriate - that a small-scale test that correlates well with a large-scale test (i.e. the ISO Room Fire Test) in regard to flashover prediction - could be used for regulatory control. The researchers selected a European correlation between cone calorimeter test results and time to flashover in the ISO Room Fire Test, developed by Kokkola, et al[9], for validation and development of a Group Classification basis for Wall and Ceiling Linings.

7 Setting Performance Criteria

The researchers based their proposed performance criteria on fire growth rate, time to flashover in the ISO room and escape time. It was suggested that any material that went to flashover in less than 120 seconds in the ISO Room Fire Test should be considered unacceptable. The four performance Groups proposed were expressed in terms of results achieved in the ISO Room Fire Test, as follows:

(a) materials that reach flashover in less than 120 seconds after exposure to 100 kW;
(b) materials that reach flashover in more than 120 secs after exposure to 100 kW;
(c) materials that reach flashover after exposure to 300 kW; and

(d) materials that do not flashover after exposure to 300 kW.

The researchers applied these Groups to tabulation of building occupancy classes and locations with and without sprinklers installed. The following Table 11.1 has been copied from the Project 2A Report.

8. FSTL/CSIRO Conclusions and Recommendations

The initial recommendations from FCRC's Project 2A Report were;-

1. Wall and ceiling linings should be controlled.

2. Requirements for control of wall and ceiling linings should depend upon:
   (a) building category;
   (b) location of the material within the building; and
   (c) the presence or absence of sprinklers.

3. Requirements for control of wall and ceiling linings should be in accordance with the criteria of acceptance as shown in Table 11.1 of the Project 2A Report.

4. Controls on linings should be based on occurrence of flashover in the ISO Room Fire Test, measured in accordance with ISO 9705. Flashover is defined as a heat release rate of 1 MW.

5. The controls should divide into the following groups:

   - Group a – materials that reach flashover in less than 120 seconds after exposure to 100 kW;
   - Group b – materials that reach flashover in more than 120 seconds after exposure to 100 kW;
   - Group c – materials that reach flashover after exposure to 300 kW;
   - Group d – materials that do not flashover after exposure to 300 kW;

6. Results of bench-scale tests used in conjunction with empirical models can provide a satisfactory method of predicting time to flashover in the ISO Room Fire Test.

7. The Cone Calorimeter is currently the only bench-scale test that provides data that best predicts time to flashover in the ISO Room Fire Test. The method of measurement should be in accordance with ISO 5660.

8. The classification indexes proposed by Kokkala, Thomas and Karlsson (Kokkala *et al* 1993) is a suitable method for calculating time to flashover in the ISO Room Fire Test from Cone Calorimeter data.

9. Other bench-scale tests could provide an acceptable method of control, if a satisfactory relationship to time to flashover in the ISO Room Fire Test can be developed.

10. If it is considered that control on smoke production in addition to time of flashover in the ISO Room Fire Test is needed, control should restrict the use of materials with an average rate of smoke production in the ISO Room Fire Test exceeding 1.2 m^2/s. Such materials should not be allowed in fire-isolated exits.

11. Materials that have an average specific extinction area of not more than 15 m^2/s in the Cone Calorimeter comply with the smoke production requirements and do not need to be tested in the ISO Room Fire Test.

In Table 11.1 of the Project 2A Report reproduced below:

a–represents materials that reach flashover in less than 120 seconds after exposure to 100 kW;
b–represents materials that reach flashover in more than 120 seconds after exposure to 100 kW;
c–represents materials that reach flashover after exposure to 300 kW;
d–represents materials that do not flashover after exposure to 300 kW;

NOTE: As explained in the following review of the FSTL/CSIRO recommendations the TWG recommend that the order of the proposed Groups be reversed and the letters be replaced with the numbers 1 through 4, such that Group1 is the best performing material and Group 4 is the worst.

Table 11.1 - Recommendations by FSTL/CSIRO for regulatory control of wall and ceiling lining materials, based on occurrence of flash-over in the ISO Room Fire test

BCA Building Class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
Class 2 & 4 - Apartments					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Unsprinklered[1]	d	d	c	c	b	b	b	b
sprinklered[1]	d	d	b	b	b	b	b	b

Class 3 – Hotels & boarding houses					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	d	d	c	c	b	b	b	b
sprinklered[1]	d	d	b	b	b	b	b	b

Class 3 – Accommodation for the aged, disabled and children					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	d	d	d	d	c	c	b	b
sprinklered[1]	d	d	c	c	b	b	b	b

Table 11.1 - Recommendations by FSTL/CSIRO for regulatory control of wall and ceiling lining materials, based on occurrence of flash-over in the ISO Room Fire test (Continued)

BCA Building Class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
Class 5 – Office buildings					**open-plan offices; aspect ratio >5**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	d	d	c	c	b	c	b	b
sprinklered[1]	d	d	b	b	b	b	b	b

Class 6 - Shops					**large shops; aspect ratio >5**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	d	d	c	c	b	c	b	b
sprinklered[1]	d	d	b	b	b	b	b	b

Class 7 – Car parks								
	Wall	*Ceiling*	*Wall*	*Ceiling*			*Wall*	*Ceiling*
unsprinklered[1]	d	d	c	c			b	b
sprinklered[1]	d	d	b	b			b	b

Class 7 and 8 – Warehouses & factories								
	Wall	*Ceiling*	*Wall*	*Ceiling*			*Wall*	*Ceiling*
unsprinklered[1]	d	d	c	c			b	b
sprinklered[1]	d	d	b	b			b	b

Class 9a – Health care buildings					**patient care areas**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	d	d	d	d	c	c	b	b
sprinklered[1]	d	d	c	c	b	b	b	b

Class 9b – Theatres, halls etc.					**auditoriums**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	d	d	d	d	c	c	b	b
sprinklered[1]	d	d	c	c	b	b	b	b

Class 9b – Schools					**classrooms**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	d	d	c	c	b	c	b	b
sprinklered[1]	d	d	b	b	b	b	b	b

1 "Sprinklered" and "unsprinklered" refer to the whole building or fire compartment, rather than the location within the building. Sprinklers are not usually fitted in fire-isolated exits (see AS 2118.1).

2 Group 4 materials are not permitted under any circumstances.

8.2 Supplemental Conclusions and Recommendations

Following completion of the Project 2A report, some issues were raised among them the validity of the Kokkola correlations and the control of smoke. An FCRC Review Group was convened and a Supplement to the Final Project Report was prepared to add detail and clarify to a number of matters.

9. Technical Working Group Discussion and Recommendations.

In general, the Technical Working Group agreed with the conclusions and recommendations of FSTL/CSIRO's Project 2A Report and Supplement.

9.1 Kokkola Correlation

Initially there was continued concern within the TWG regarding the Kokkola[9] model that correlated cone results with time to flashover in the ISO Room Test. It was considered that too little data was used in its development and validation. To resolve this issue, the TWG collected recent data from the Japanese Building Research Institute (BRI) for materials that had been tested in both the cone calorimeter and the ISO Room Fire test. The CSIRO was then commissioned to run additional analyses on this data using the Kokkola correlation. The outcome gave the TWG confidence that the results, classified in four Groups, can be used satisfactorily as basic "deemed to satisfy" regulatory requirements.

A generalised explanation of the way the cone data is used to develop the materials groupings (1-4) is of value. The classification of materials into Groups is based on the estimated time required to flashover in the ISO Room Fire Test in a test of a given material. Information about the history of the heat release data and the total amount of heat released in the cone test is used as input to an equation to predict the time to flashover in the ISO Room Test of that material. This equation is the Kokkola or VTT correlation and can be rapidly solved using a computer. Because the ISO room test procedure changes the gas burner heat release rate during the test from 100 to 300 kW, the time to flashover estimated from the Kokkola/VTT correlation can be used with the grouping criteria previously defined..

9.2 Modification of Classification Group Nomenclature

To reduce confusion, the TWG recommend that the alphabetical order of the Groups as initially proposed by the researchers be reversed, so that "a" identifies the best and "d" the worst fire performances. Furthermore the TWG recommend the letters a - d be replaced with numbers 1 to 4, so that "1" is the best performer and "4" is the worst. If ABCB desire to retain letters in the classification nomenclature, the TWG strongly recommend that Group 'a' identify the best performing materials and Group 'd' the worst.

Concern was also raised that, due to small variations in results from the cone calorimeter tests, some materials may perform near to the boundary of a classification and in consequence may fall into a material group that would impose more restriction on its use. In these situations the TWG recommend the ISO Room Fire Test should be used as the benchmark and final arbiter of the material's classification.

9.3 Smoke Controls

The TWG noted that in Europe, North America and elsewhere there are concerns that none of methods proposed for regulation of smoke adequately characterise the hazard although some countries have set requirements. Whilst smoke measurement in the ISO Room Test was recommended in the Project 2A Report the TWG emphasise that, for most materials, control of heat release rate indirectly provides some control on the material's smoke generation. Thus at this point in time, especially in the current absence of an acceptable correlation between the ISO Room Fire Test results and any appropriately defined smoke hazard levels - nor any correlation with cone calorimeter test data - the TWG do not recommend (nor do they consider necessary) any regulatory control of smoke.

The Cone does provide a measure of smoke production. In the work on FCRC's Project 2B/1 relating to flooring materials and coverings, CSIRO developed an index from cone calorimeter tests based on the product of the peak heat release rate (HRR) expressed in MW/m^2 and the average specific extinction area (SEA) expressed in m^2/kg. The TWG agree that the product of peak heat release rate and average SEA does represent a means of characterising smoke production, but if this approach were used for regulatory purposes situations would arise where materials classed "A" (those with a low peak HRR and a high SEA) would be undesirable just as would materials classed "B" (having a high peak HRR and a low SEA).

Described in other terms, the situation may be that "A" materials do not consume mass rapidly but produce a lot of smoke per unit mass consumed, whilst "B" materials do not produce much smoke per unit mass consumed but the mass is burned rapidly. The difficulty comes in establishing an acceptable value for a "deemed to satisfy" (DTS) regulation.

If it is determined that there should be DTS control for smoke in the BCA, the TWG recommend a smoke criterion, based on cone calorimeter testing of materials, of not greater than 25 Mw/kg (Heat Release Rate times Specific Extinction Area). This is a value that would permit materials that are currently acceptable and exclude those that are currently be unacceptable.

The value of 25 Mw/kg is based on an analysis of data from Tables 10 and 11 in Research Paper 7[10]. It should be noted that one plywood sample reported in Research Paper 7 (A10 in Table 10) has a calculated smoke value ranging from 34.3 to 23.4 with a mid-point of 28.5. This mid-point value would not pass a smoke requirement of 25 although results at the low end would. Having a passing threshold 30 would not necessarily let this material pass since its upper value is 34.3. Additionally, a value of 35 (that would let this material pass) might possibly let other, perhaps more unacceptable, materials pass. Further review of all timber product data from

Research Paper 7 reveals that 3 species and 5 manufactured products (including 3 plywood materials) fall below 20.2 at mid-point, with one reaching 27.5 at its high point. Only one timber product (A10) would not pass a criterion of 25 and that would be on the low end. While it might be justified to assume that product A10 is a statistical aberration and set the boundary criterion at 20, a compromise value of 25 seems appropriate.

10. Implications of Change

The following Table 1 details the TWG's recommended Classification Groups in the format where '1' relates to the best performing materials and '4' to the worst.

Table 1 is converted from the Project 2A recommendations and it details how the material Groups can be used for regulatory control purposes by building class and location. Concession for the use of sprinklers is also identified and recommended.

Tables 2 to 4 which are also included provide information on the performance and proposed classification Groups for both International and Australian materials (expressed in the TWG recommended numerical format). These tables indicate specific materials that will be permissible if the TWG recommendations are adopted.

Table 1 – TWG recommendations for regulatory control of wall and ceiling lining materials, based on the occurrence of flashover in the ISO Room Fire Test[2]

BCA Building Class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
Class 2 & 4 - Apartments					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Unsprinklered[1]	1	1	2	2	3	3	3	3
sprinklered[1]	1	1	3	3	3	3	3	3
Class 3 – Hotels & boarding houses					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2	3	3	3	3
sprinklered[1]	1	1	3	3	3	3	3	3
Class 3 – Accommodation for the aged, disabled and children					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	1	1	2	2	3	3
sprinklered[1]	1	1	2	2	3	3	3	3

Table 1 – TWG recommendations for regulatory control of wall and ceiling lining materials, based on the occurrence of flashover in the ISO Room Fire Test[2] (Continued)

BCA Building Class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
Class 5 – Office buildings					**open-plan offices; aspect ratio >5**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2	3	2	3	3
sprinklered[1]	1	1	3	3	3	3	3	3
Class 6 - Retail					**large shops; aspect ratio >5**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2	3	2	3	3
sprinklered[1]	1	1	3	3	3	3	3	3
Class 7 – Car parks								
	Wall	*Ceiling*	*Wall*	*Ceiling*			*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2			3	3
sprinklered[1]	1	1	3	3			3	3
Class 7 and 8 – Warehouses & factories								
	Wall	*Ceiling*	*Wall*	*Ceiling*			*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2			3	3
sprinklered[1]	1	1	3	3			3	3
Class 9a – Health care buildings					**patient care areas**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	1	1	2	2	3	3
sprinklered[1]	1	1	2	2	3	3	3	3
Class 9b – Theatres, halls etc.					**auditoriums**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	1	1	2	2	3	3
sprinklered[1]	1	1	2	2	3	3	3	3
Class 9b – Schools					**classrooms**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[1]	1	1	2	2	3	2	3	3
sprinklered[1]	1	1	3	3	3	3	3	3

1 "Sprinklered" and "unsprinklered" refer to the whole building or fire compartment, rather than the location within the building. Sprinklers are not usually fitted in fire-isolated exits (see AS 2118.1).

2 Group 4 materials are not permitted under any circumstances.

Table 2 (Table G1 in the Project 2A Report) groups European materials by time to flashover and Project 2AClassification Index

Table 2 – Grouping of European materials according to their time to flashover in the ISO 9705 Room Fire Test and according to the classification indexes

Code	*Material*	*Material grouping according to:*	
		Occurrence of flashover[a]	*Classification indexes*[b]
E1	Painted gypsum paper plasterboard	1	1
E4	Melamine-faced high-density non-combustible board	1	1
E5	Plastic-faced steel sheet on mineral wool	1	1
E8	FR particleboard	1	1
E13	FR plywood	1	–
E28	Gypsum board	1	1
E3	Textile wall covering on gypsum paper plasterboard	2	2
E10	PVC-wall carpet on gypsum paper plasterboard	2	2
E27	Paper wall covering on gypsum board	2	2
E6	FR particleboard, type B1	2	2
E22	Textile wall covering on gypsum board	2	2
E21	Plastic wall covering on gypsum board	2	2
E20	Melamine-faced particleboard	3	3
E9	Plastic-faced steel sheet on polyurethane foam	3	3
E14	Melamine-faced particleboard	3	–
E16	Particleboard	3	3
E2	Ordinary birch plywood	3	3
E24	Paper wall covering on particleboard	3	3
E12	Birch plywood	3	–
E18	Medium-density wood-fibre board	3	3
E19	Wood panel, spruce	3	3
E26	Expanded polystyrene	3	3
E7	Combustible-faced mineral wool	4	4
E11	FR extruded polystyrene foam	4	4
E15	FR polystyrene foam	4	–
E17	Insulating wood-fibre board	4	4
E23	Textile wall covering on rockwool	4	4
E25	Rigid polyurethane foam	4	4

[a] Determined from times to flashover in Table E1 of Project 2A Report.
[b] Determined from data published by Kokkala *et al.* (1993).

Table 3 (Table G2 in the Project 2A Report) is Australian Materials by occurrence of flashover in the ISO Room Test and Project 2AClassification Index

Table 3 – Grouping of materials according to their measured time to flashover in the ISO9705 Room Fire Test and according to the classification indexes

Code	Material	Material grouping according to: Occurrence of flashover[a]	Classification indexes[b]
A9	Plasterboard, paper-faced, glass-reinforced	1	1
A1	Glass-reinforced phenolic 70	(2 at best)	1[d]
A2	Glass-reinforced phenolic 71	(1 at best)	1
A3	Plasterboard (US)	(1 at best)	1
A4	FR plywood (US)	(1 at best)	1
A11	Hoop pine plywood, treated	3	3
A10	Lauan plywood	3	3
A7	FR polystyrene foam (US)	(1 at best)	3
A8	Hardboard	(3 at best)	3
A5	Plywood (US)	(3 at best)	3
A14	Blackbutt	(3 at best)	3
–	Tasmanian hardwood[c]	–	3
A6	FR polyurethane foam (US)	(3 at best)	4

[a] Determined from times to flashover in Tables E1, E2 and E3 in the Project 2A Report.
[b] Determined from Cone Calorimeter data on materials listed in Research Paper 7.
[c] Determined from Cone Calorimeter data courtesy of BHP Research.

Table 4 (Table 12.1 from the Project 2A Report) represents likely groupings of materials.

Table 4 Likely material groups

Materials group	Typical materials
1	Masonry; gypsum plaster, paper faced and painted; some fire-retarded timbers and timber products [a]
2	Most fire-retarded timbers and timber products; fire-retarded plastics wall coverings on masonry
3	Most non-fire-retarded timbers and timber products; insufficiently fire-retarded timbers and timber products; some fire-retarded polyurethane foams; some fire-retarded polystyrene foams
4	Non-fire-retarded and insufficiently fire-retarded polyurethane foams; non-fire-retarded and insufficiently fire-retarded polystyrene foams; low density fibreboard

[a] The TWG noted that in the data provided in the Project 2A Report, only one timber product was in this Group

11. Implementation Strategy

The TWG recommend that implementation of a regulatory change adopting the Cone Calorimeter be carried out in two stages.

11.1 Parallel "Deemed-to-Satisfy" for 1.5 to 2 years.

Allow existing products that meet the Early Fire Hazard (EFH) requirements to continue in the market place, and

Require all new products to comply with the material grouping and classification details in Table 1.

NOTE: The TWG does not recommend any control of product smoke production at this time but, if required by the regulatory authority, suggests that materials not exceed an SEA in the Cone Calorimeter of 25 MW/m^2 at a radiant flux of 50 kW/m^2.

11.2 After 1.5 to 2 years, all products in the marketplace should be required to comply with the material Groups and classification details in Table 1.

11.3 In the event of a manufacturer has concern regarding the classification of a product by the cone calorimeter method, the ISO Room Fire Test should be used to establish the material's full-scale fire performance and be the final arbiter in respect to its classification.

References

[1] Martin, K. G. & Dowling, V. P. 1979, 'Australian studies on fire hazard tests on internal linings of buildings', *Fire & Materials*, **3**, 202–210.

[2] Gardner, W. D. & Thomson, C. R. 1990, 'Fire growth and its regulation under the Building Code of Australia', presented to 2nd World Congress of Building Officials, October, Sydney.

[3] Methods for Fire Tests on Building Materials Components and Structures - Part 3: Simultaneous Determination of Ignitability, Flame Propagation, Heat Release and Smoke Release, AS 1530.3-1989, Standards Australia.

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[5] Research Paper 5-Large-scale Fire Experiments to Provide Data for Validation of Building Fire Performance Parameters

[6] Gardner, W. D. & Whitlock, J. A 1998, *Flame Spread in Corridors*, Research Report, Forest Research and Development Division, State Forests of New South Wales, Sydney.

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[9] Kokkala, M. A., Thomas, P. H. & Karlsson, B. 1993, 'Rate of heat release and ignitability indices for surface linings', *Fire & Materials*, **17**, 209–216.

[10] Webb, A. K., Dowling, V. P. and McArthur, N. A., Data from Large-Scale and Small-Scale Experiments on Wall and Ceiling Linings, Research Paper 7, FCRC Project 2A, CSIRO, Building Construction and Engineering, November 1999.

FIRE CODE REFORM RESEARCH PROGRAM

PROJECT 2 - FIRE PERFORMANCE OF MATERIALS
Stage A - Wall and Ceiling Lining Materials

FINAL SUBMISSION
February 2001

Final Research Report

Adopted by the Fire Code Reform Centre Board of Directors

12 December 2000

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FIRE PERFORMANCE OF WALL AND CEILING LININGS

Final Report

Fire Code Reform Centre

PROJECT 2
STAGE A

July 1998

Fire Performance of Wall and Ceiling Linings

Final Report

Fire Code Reform Centre

Project 2
Stage A

July 1998

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for

Fire Code Reform Centre Ltd

CONTENTS

EXECUTIVE SUMMARY

It has long been believed that certain lining materials will contribute to the spread and severity of fire in buildings, and hence some form of control on the use of materials has been included in building codes. Controls rely on a test to measure, in some way, the potential of the material to contribute to fire growth and spread, and limitations on the use of materials in different parts of buildings, in terms of the measured test performance. The Building Code of Australia (BCA) has included such requirements, based on requirements in the State regulations that were its antecedents, using the Early Fire Hazard Test as a measure.

Well before the introduction of the BCA, industry questioned the use of the Early Fire Hazard Test and the way in which the results were applied. The purpose of Project 2 is to investigate the need for control and the aptness of the test method and its application to buildings, and to propose alternative requirements based on a logical approach.

This report covers the following areas: the need for control; key factors that affect the performance of lining materials and their influence on life safety; categorisation of buildings by key factors; principles for qualitative levels of performance; review and selection of test methods; selection of test criteria based on available test data; application of quantitative test performance levels; recommendations for change to the BCA; and recommendations for future work. The report makes reference to research papers on specific topics that were issued during the course of the Project.

Some of the main findings of the Project are:

1 While statistical records do not identify the influence of wall and ceiling linings in the development and spread of fires, case studies show that in some fires where there have been a number of deaths, linings have been a major contributor to fire spread. Some control on linings is therefore needed.

2 Key factors that influence the extent of control needed include: the use to which the building is put; the location of the lining within the building; the size and geometry of enclosures within the building; the contents of the enclosure; the number of people within the enclosure and how long they will take to leave in a fire; and the presence of other fire safety systems.

3 For the purpose of control of linings, buildings can be grouped into categories by taking into account the key factors.

4 The global objectives of the fire safety systems of the BCA identified by Fire Code Reform Centre Project 3 also apply to Project 2. These are: to keep loss of life in building fires to a very low level; to limit property damage by introducing measures to control fire size and to prevent fire spread from premises on fire to neighbouring premises; and to provide protection to firefighters in the execution of their duty.

5 An appropriate performance objective for the control of lining materials in buildings is that:

in the event of a fire, lining materials must not
significantly decrease the safety of occupants.

In the presence of an ignition source, linings might contribute in one of two ways. They might significantly reduce the time to untenable conditions; and they might significantly contribute to flame spread. Fire might then spread to areas remote from the area of fire origin, reducing the time to untenable conditions in these areas.

6 The possible effect of linings should be considered in all areas in all buildings. The influence of linings will be felt most while people are escaping, and the level of control will vary with progress along the escape route. People will progress from a room via a public corridor to a fire-isolated exit, where they might remain for a considerable time.

7 Tests are needed to assess the relevant performance of lining materials. Only those test methods that are readily available in Australia should be considered for inclusion in Australian regulation. Test methods that are recognised internationally are preferred.

8 No test will give a true measure of performance in the real world. Tests will, at most, give an indication of anticipated performance in a particular building (compartment size, fire load etc.). This anticipated performance can then be used to group materials according to their likelihood to contribute to fire growth and spread.

9 Time to flashover in a standard room fire test gives a good measure of the potential of linings to contribute to fire growth and spread. The ISO Room Fire Test is the large-scale test that has gained the most international acceptance.

10 While large-scale tests give a closer approximation to performance in real fires than small-scale tests, large-scale tests are expensive and the number required should be kept to a minimum. To reduce the number, calculation methods can be used to predict performance in room fire tests from results achieved in small-scale tests. The accuracy of the calculations can be demonstrated by comparing data from room fire tests with calculations and data from small-scale tests.

11 Small-scale tests that give suitable results to calculate time to flashover in the ISO Room Fire Test all measure: time to ignition; and rate of heat release per unit area. The Cone Calorimeter provides suitable data and, of the relationships that have been developed, the 'Classification Indexes' developed as part of the EUREFIC program give the best results. If satisfactory relationships can be developed for other small-scale tests, these could be used also.

12 Because of the variability of results, materials can be put into broad groups only. Groups are dictated by changes in the gas burner intensity in the ISO Room Fire Test. An additional group of materials with propensity to rapid fire growth under only moderate exposure is suggested, and it is recommended that materials that fall into this group not be used in buildings under any circumstances. The recommended groups are:

Group a–materials that flash over in less than 120 seconds after exposure to 100 kW;
Group b–materials that flash over in more than 120 seconds after exposure to 100 kW;
Group c–materials that flash over after exposure to 300 kW; and
Group d–materials that do not flash over after exposure to 300 kW.

13 At the present state of knowledge, the application of materials groups to building categories and locations within buildings must be subjective. In order to generate a logical structure, characteristic values must be found. For each building category a 'conservative' characteristic room size, occupancy and so on has been assumed.

14 Two locations in which 'real' performance is better known have been used to provide benchmarks from which performance in other locations can be estimated. The two benchmarks are a small room in a residential apartment (no sprinklers), and a sprinklered public corridor in the same building. In each of these areas, it has been shown that life safety is not threatened by the use of Group b materials.

15 Smoke produced in fires can have a major effect on life safety. Smoke can be produced by contents and by linings. By controlling the size of the fire, the main problem of smoke production (that of volume of smoke) will be controlled. The volume of smoke produced by linings can be controlled by controlling time to flashover in room fire tests, and recommendations for these controls are already proposed in 12 above. It is suggested that these provide sufficient control on smoke production from linings.

16 For smoke, as with fire spread, the Room Fire Test gives the closest approximation to reality. In the case of smoke, however, no correlation between small-scale tests, large-scale tests or real fires has been established. Should additional smoke controls be seen to be needed, they should only be introduced in those locations where people escaping the fire might be present for long periods. If this is the case, the recommendation is that materials that have an average smoke production rate of more than 1.2 m^2/s in the ISO Room Fire Test should not be allowed in fire-isolated exits. In order to reduce the number of room fire tests that need to be performed, it is recommended that those materials achieving an average specific extinction area of not more than 25 m^2/kg in the Cone Calorimeter can be assumed to meet this limit.

17 A description of the recommended usage of materials groups is given in the table on page x.

18 The proposed requirements have a logical basis that gives a more realistic picture of the performance of lining materials in fire. They are based on data that can readily be used in fire engineering calculations. The resultant controls (except for a few materials) are not substantially different from current BCA controls.

19 To avoid the expense of retesting materials, it can be recommended that, where current test certificates are valid, the current BCA requirements coupled with the current BCA application and current BCA requirements for non-combustibility, should remain acceptable for a period of five years. Any new testing should be done to the proposed new method.

20 During the course of the Project, some time was spent investigating the status of models to predict the influence of linings on fire growth and models to predict escape times of building occupants. Neither area is as yet sufficiently well developed to yield results useful for the control of wall and ceiling linings.

Materials groups by BCA Classes

BCA Class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Class 2 & 4 – Apartments					**sou**			
Unsprinklered	d	d	c	c	b	b	b	b
Sprinklered	d	d	b	b	b	b	b	b
Class 3 – Hotels & boarding houses					**sou**			
Unsprinklered	d	d	c	c	b	b	b	b
Sprinklered	d	d	b	b	b	b	b	b
Class 3 – Accommodation for the aged, disabled and children					**sou**			
Unsprinklered	d	d	d	d	c	c	b	b
Sprinklered	d	d	c	c	b	b	b	b
Class 5 – Office buildings					**open-plan offices; aspect ratio >5**			
Unsprinklered	d	d	c	c	b	c	b	b
Sprinklered	d	d	b	b	b	b	b	b
Class 6 – Shops					**large shops; aspect ratio >5**			
Unsprinklered	d	d	c	c	b	c	b	b
Sprinklered	d	d	b	b	b	b	b	b
Class 7 – Carparks								
Unsprinklered	d	d	c	c	—	—	b	b
Sprinklered	d	d	b	b	—	—	b	b
Class 7 & 8 – Warehouses & factories								
Unsprinklered	d	d	c	c	—	—	b	b
Sprinklered	d	d	b	b	—	—	b	b
Class 9a – Health care buildings					**patient care areas**			
Unsprinklered	d	d	d	d	c	c	b	b
Sprinklered	d	d	c	c	b	b	b	b
Class 9b – Theatres, halls etc.					**auditoriums**			
Unsprinklered	d	d	d	d	c	c	b	b
Sprinklered	d	d	c	c	b	b	b	b
Class 9b – Schools					**classrooms**			
Unsprinklered	d	d	c	c	b	c	b	b
Sprinklered	d	d	b	b	b	b	b	b

sou–sole-occupany unit, as defined in the BCA
a–represents materials that flash over in less than 120 seconds after exposure to 100 kW
b–represents materials that flash over in more than 120 seconds after exposure to 100 kW
c–represents materials that flash over after exposure to 300 kW
d–represents materials that do not flash over after exposure to 300 kW

PREFACE

The Fire Code Reform Centre Ltd (FCRC) was established in June 1994 to undertake a comprehensive program of research to reform the present fire regulations. The Centre represents collaboration between the regulatory authorities, industry and fire research organisations. The aim of the Centre is to identify and sponsor research, education and other activities necessary to bring about reform of the building regulations. It brings together the reform agenda of the regulatory authorities and the needs of designers and industry to move towards a more performance-oriented, engineering approach to fire safety. All of the collaborating parties contributed to the funding for the Centre and the program of research.

The aim of the FCRC Research Program is to introduce a cost-effective, fully engineered approach to fire safety regulations through a series of research projects on individual fire safety systems.

The purpose of Project 2 is to examine the need for controls of materials; to provide qualitative definitions of performance; to identify test methods; to recommend performance levels for different buildings, locations and presence of other fire safety measures; and to explore future applications to fire safety engineering. The scope of Stage A is wall and ceiling linings.

The work of Project 2 is under the general supervision of the FCRC Research Supervisory Committee. The FCRC appointed a Project Review Committee to assist the Project Working Group when it became necessary to institute a change of direction due to technical limitations in the original approach.

This report is the final report for Stage A of Project 2. It has been prepared by CSIRO Building, Construction and Engineering in conjunction with the Project 2 Working Group, and with assistance from the Project 2 Review Committee. The report reflects a consensus of views of members of the Working Group. It does not reflect exactly the views of any individual.

The Working Group comprised:

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The Project 2 Review Committee comprised:

Emeritus Prof. Len Stevens, Melbourne University
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The Project team underwent a number of changes during Stage A. The original Principal Research Consultant was Stephen Grubits, formerly of CSIRO, and the original CSIRO Project Leader was Dr Caird Ramsay.

The following people have also made contributions to Stage A of Project 2:

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1 — INTRODUCTION

Fire Code Reform Project 2 is one of a series of projects aimed at developing a cost-effective, fully engineered approach to fire safety regulation.

Project 2 was originally conceived as Australian Building Regulations Co-ordinating Committee (AUBRCC) Project AP 73. Project AP 73 was a response by AUBRCC to industry concerns about the use of the Early Fire Hazard Test to control materials in buildings in the new Australian Model Uniform Building Code (Martin & Dowling, 1979; Gardner & Thomson, 1990).

AUBRCC has since been replaced by the Australian Building Codes Board (ABCB), who produce the Building Code of Australia (BCA). With the advent of the FCRC program, ABCB requested that, due to continuing industry discontent with the Early Fire Hazard Test and its application in the BCA, the scope of Project AP 73 be included in the FCRC research program.

The purpose of Project 2 is to investigate the need to control fire properties of lining materials in buildings of Classes 2–9, and to make recommendations for appropriate test methods and criteria of acceptance. Control of linings can be considered as one of a number of fire safety systems that together help to ensure that building occupants have adequate time to use safe paths of egress in the event of a fire. The central strategy of the project is to produce a logical structure for any such controls. The Project is divided into two stages. Stage A concentrates on wall and ceiling linings, while Stage B studies floor linings and other building elements. This report covers Stage A.

During the Project, the suitability of the latest technologies to provide satisfactory and robust outcomes in line with the project objectives was assessed. The assessment showed that some technologies, such as room fire models and egress models, are not yet able to provide the quantitative data needed. As a result a more qualitative approach than originally envisaged has been adopted. This has generated minor changes to the Project's objectives and outputs.

The original project objectives and outputs were formulated prior to the development of the Performance BCA. The Project objectives have been updated to reflect the performance structure of BCA96.

The amended objectives and outputs, agreed to by the Research Supervisory Committee, are listed below.

Objectives

- to examine the basis and need for control on fire properties of materials in general;
- to provide qualitative definitions of performance for wall and ceiling linings in buildings;[1]
- to identify appropriate test methods to differentiate between lining materials;

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[1] For example, in the presence of an ignition source, linings will not significantly contribute to fire spread.

- to recommend quantitative test performance levels for different classes of building, locations and the presence of other fire safety measures;[2] and
- to explore future application of wall and ceiling lining properties to fire engineering design.

Outputs

- study of the need for control of lining materials;
- identification of key factors influencing fire spread and smoke generation;
- identification of classes of building and subsets for consideration;
- proposed principles for control of lining materials;
- study of available test methods;
- selection of relevant test methods;
- study of available test data;
- recommendations for quantitative test performance levels considering other fire safety systems;
- recommendations for changes to the BCA; and
- review of future possibilities.

The original objectives and outputs are given in Appendix A.

Seven Research Papers were produced during Stage A. These are itemised in Appendix B.

[2] Examples of other fire safety measures include sprinklers, alarms and smoke detectors.

2 — The Need for Control

2.1 Introduction

Before embarking upon an in-depth study of the control of lining materials, it is necessary to establish that there is a need for control. By reference to case studies and statistics, this chapter examines the influence of linings on the development of fires and consequent loss of life. Whilst there are many case studies of individual fires in the literature, few discuss the role of wall or ceiling linings in fire initiation, growth or spread. The case studies in the following sections specifically refer to the role of wall and ceiling linings in the fires.

In the absence of building contents, linings would be the sole cause of fire spread and the generation of smoke and toxic gases. However, buildings are rarely free of contents, and the influence that linings have on fire spread and smoke generation is affected by the presence and nature of the building contents.

The influence of linings is also affected by the presence of other fire safety systems, the time at which these operate and their effectiveness. Other fire safety systems include sprinklers, alarms and compartmentation.

2.2 Influence of Linings on Fire Spread and Smoke Generation

The greatest influence of linings will be in the area where the fire starts. The following case studies illustrate how linings can present a fatal hazard in the area where fire starts, or can be the agent for fire spread despite apparently adequate compartmentation.

2.2.1 Dance hall, St Laurent du Pont, France

On 1 November 1970, 144 people died in a fire at the Cinq–Sept dance hall at St Laurent du Pont. The dance hall had been built to look like a grotto. To achieve this effect, polyurethane foam had been spray-applied to all internal surfaces. Apart from this interior finish, the building was largely of 'non-combustible' construction.

The fire is believed to have been started by a cigarette or match igniting an upholstered footstool. This in turn ignited tapestries and the wall lining. The fire spread extremely rapidly. The rapid spread, in conjunction with woefully inadequate egress, resulted in only 21 people escaping from the fire area (Anon. 1971).

The wall and ceiling linings appeared to be of material that was inappropriate to use exposed under such circumstances.

2.2.2 Las Vegas Hilton Hotel

The fire at the Las Vegas Hilton Hotel in 1981 spread vertically up the exterior of the building, rapidly transferring from one elevator lobby to the next. Eight people died in the fire. Its rapid early development was attributed to the carpeting on the walls and ceiling, along with drapes and (minimal) furnishings (Jones 1981). The fire then spread from floor to floor through external windows, broken by the fire, by igniting the linings and contents on each floor.

From the photographic evidence in Jones (1981), the drapes and furnishings by themselves, without the contribution of the linings, would not have been able to sustain this sequence of ignitions.

2.2.3 High school, Indianapolis

A painted block wall was determined to be the agent for flame travel in a fire in 1994 in this high school gymnasium (Quintiere 1998). Quintiere also records that multiple coats of paint built up over many years have been implicated in fire spread on concrete walls in stairwells.

2.2.4 Office building, Atlanta

An 'intense, rapidly developing fire' occurred on the sixth floor of an office building in Atlanta, Georgia, in 1989. Five people died on the floor of origin. Multiple layers of wall coverings contributed to the total fire load in the corridor, and were identified as a contributing factor in the fire (Lathrop 1991, p. 191).

2.2.5 Nursing home, Springfield

A fire in a nursing home in Springfield, Illinois, in 1972 killed 10 of the 41 patients. The wood panel finish, especially in the stairway, was determined to have accelerated the fire spread (Lathrop 1991, p. 191).

2.3 Effect of Linings and Building Contents

In many buildings, the contents will play a dominant role and linings will only provide an alternative path for fire spread. In other buildings, the linings will significantly decrease fire safety despite the presence of flammable contents. The following case study shows how contents combined with linings and building geometry can lead to a fatal situation.

2.3.1 Stardust Club, Dublin

A fire swept through the Stardust Club, Dublin, on 14 February 1981. A public inquiry was held into the disaster in which 48 people were killed and 128 were seriously injured. The building was of predominantly 'non-combustible' construction. Seating was combustible and all the internal walls were covered with carpet tiling.

The tribunal found that the fire started in seating adjacent to a wall. The tribunal concluded that the rapid spread of fire was due to a combination of:

- the presence of seats containing combustible materials abutting a combustible wall lining;
- the presence of a low ceiling; and
- the presence of a large quantity of combustible seating (Pigott 1984).

This case study shows that despite the presence of combustible contents, inappropriate wall linings can contribute to a significant increase in risk to life.

2.4 Effect of Linings and Building Geometry

The size and shape of the enclosure will influence whether wall linings or ceiling linings have the dominant effect. In large open spaces there is a perception that ceilings play a greater role in flame spread than do walls. The following case study is an example of how fire can spread across a ceiling (in this case an unlined roof).

2.4.1 Summerland leisure complex, Isle of Man

The heart of the Summerland leisure complex was a large auditorium, four storeys high. The auditorium walls and roof were glazed with acrylic sheets. There was no ceiling in the auditorium. On 2 August 1973, a fire killed 50 of the 3000 people who were in the leisure centre.

The fire started away from the auditorium and grew inside a wall cavity between the outside skin of steel/asbestos/bitumen/polyester and the inside lining of fibreboard. Once the fire broke out of the cavity, it travelled rapidly across the fibreboard walls of rooms adjacent to the auditorium and ignited the walls and roof of the auditorium. In its report, the Commission set up to investigate the fire concluded that it was the combination of combustible linings and building design that was lethal (Anon. 1974).

One of the features of this fire was its rapid spread across the roof of the auditorium. Even though the acrylic did not become involved until 20 minutes after ignition, once ignited the roof was completely consumed in about 10 minutes, leading the commission to recommend that:

- acrylic sheet should only be used in limited areas; or
- if extensive areas of acrylic sheet were used exit widths should be increased.

The Commission's comments acknowledge the contribution of linings to fire spread times.

2.5 Statistical Evidence

A detailed analysis of fire incidence statistics is given in Research Paper 3. Chapter 6 of that Research Paper looks at building components involved in fires. The statistics show that, in buildings with all combustible wall linings in the room of fire origin, there is a greater likelihood of fire spread beyond the room of fire origin than for buildings where all wall linings are deemed not combustible. Similarly, in buildings said to have combustible ceiling linings in the room of fire origin, fire is more likely to spread beyond the room of fire origin.

In Chapter 4 of Research Paper 3 it was found that the number of deaths is considerably higher in fires that spread beyond the room of fire origin. This is in agreement with findings of Takeda and Yung (1991) and Hall and Cote (1997). It is therefore likely that combustible linings are a contributory factor to higher numbers of deaths. Christian (1974) claims that in the US combustible linings are a contributory factor in fatalities in over half of all fatal fires in dwellings.

The small database available in Australia does not allow for analysis of the hazard of specific linings by flame spread and the smoke they produce (see Research Paper 3).

2.6 CONCLUSIONS

Although their influence depends heavily on the presence of other fire safety systems, lining materials can be a major contributor to fatalities in fires in buildings. Therefore there is a need to control the fire behaviour of wall and ceiling linings in buildings in order to keep loss of life to an acceptable level. The extent of those controls will vary depending on the use of the building, the location in the building and the presence of other fire safety systems such as sprinklers and compartmentation.

3 — KEY FACTORS

3.1 INTRODUCTION

The previous chapter established that there is a need to control the behaviour in fire of wall and ceiling linings in buildings. This chapter looks at factors that may influence the necessary level of control of these linings.

The degree of control needed to achieve an appropriate level of safety will depend upon a range of factors as varied as how long the occupants might take to escape, the size of the enclosure in which the fire starts, and the humidity and wind direction on the day of the fire. Some of these factors cannot be controlled. Others are of varying significance, and only the more significant have been taken into consideration in this project.

Key factors that influence the level of control of wall and ceiling linings are those that affect the possibility of a fire starting; those that control its growth and spread throughout the building; and those that influence the speed at which people are able to evacuate the building.

3.2 IGNITION SOURCES

Ignition sources are present in all buildings, but the likelihood of an ignition source being present is related to the building use. Some industrial processes such as welding carry high risks of ignition (see Research Paper 3), while others pose little risk. Poor maintenance of equipment, especially electrical equipment, increases the risk that a fire will start.

The most frequent cause of ignition is cooking (see Research Paper 3), an activity that takes place in both residential and commercial occupancies. Only a small proportion of fires caused by cooking spread beyond the room of fire origin, probably because the enclosure occupants are alert and aware if fire starts.

An analysis of statistics on fire starts in Research Paper 3 shows that fires that start in bedding or upholstered furniture are more likely to spread beyond the room of fire origin than those that start in the kitchen.

3.3 BUILDING LAYOUT – LOCATION OF ENCLOSURE WITHIN BUILDING

The threat posed by linings to the safety of building occupants will vary according to the location of the lining within the building. Linings in rooms that are remote from the exit system, and do not form part of a public access route to a fire-isolated exit will, present a threat only to occupants of the room. Linings in corridors where people might be queuing awaiting their turn to use the stairs, and linings within fire-isolated exits where escapees might be present in large numbers and for long periods of time, could pose a considerable threat. It is therefore pertinent to consider the location of the linings along the escape route.

The components of an escape path for any building can be represented by the sketch in Figure 3.1.

The 'room' might be small (an office in a Class 5 building) or large (a theatre in a Class 9b building). The public corridor[3] might be long or short, wide (a shopping mall) or narrow or non-existent (a department store with exits leading directly to a road), and the fire-isolated exit might be a fire-isolated stair, ramp or corridor, or a door leading directly outside.

It should be acknowledged that linings will only spread flame or generate smoke if they are in close proximity to an ignition source. It is therefore only necessary to consider a fire that is within the enclosure in which the linings are situated. The fire might have been initiated in the enclosure in which the linings are situated, or it might have spread from an adjoining enclosure.

3.4 Enclosure Size and Geometry

The size of the enclosure and its geometry, including aspect ratio (which is expressed as floor width divided by wall height), will influence the need for control of lining materials. In all occupied enclosures, it will be necessary to ensure that untenable conditions are not reached, at least until all occupants have escaped. The main contribution of lining materials to the generation of untenable conditions will be as a source of heat and as a generator of smoke and toxic gases.

3.4.1 Small enclosures

Fires in small enclosures usually start with the ignition of building contents (see Research Paper 3). Once a fire becomes established, flashover might be reached and the whole room become involved in a relatively short time, probably before linings have become involved in the fire. Within the enclosure, the occupants will have received a visual cue and will have escaped before flashover is reached. There is therefore no need to discriminate between the behaviour of wall linings and the behaviour of ceiling linings in small enclosures, and it will only be necessary to control use of materials that might reduce the time taken for the room to go to flashover. The contribution of lining materials in small rooms as a source of spread of

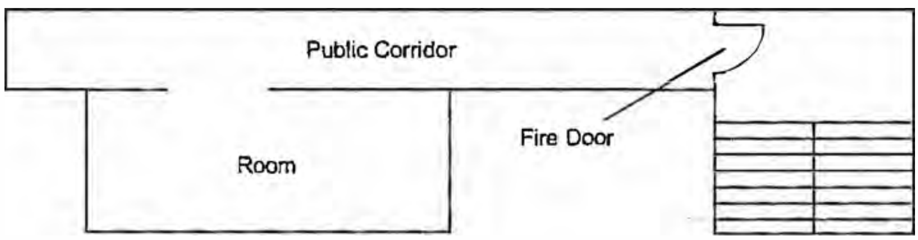

Figure 3.1 – Sketch illustrating building locations

[3] For the purposes of this report, 'public corridor' is as defined in BCA 1996 and includes areas that open onto a public corridor.

flame to other parts of the building might not be significant. Barriers surrounding the room will tend to contain flame spread until the fire is well developed, by which time the influence of the linings will be irrelevant.

3.4.2 Large enclosures

If it is assumed that there is the same likelihood of a fire starting anywhere in an enclosure, then in large enclosures the risk of it igniting wall linings will be less than in small enclosures. The contribution of the linings to the onset of untenable conditions might also be low because products of combustion will tend to be dispersed.

However, in large enclosures the contribution of linings to the control of flame spread becomes more important. If a wall lining becomes involved, the spread will initially be vertical and then horizontal once the ceiling is reached. The horizontal rate of spread along the wall will generally be quite slow compared to the vertical rate of spread. The spread across a ceiling will also be horizontal, but would be expected to be faster than horizontal flame spread on a single wall due to the fact that this process will be enhanced by the presence of hot gases moving across the ceiling. Thus, it is likely that the rate of flame spread across ceilings will be faster than that associated with walls in most large rooms.

In lofty enclosures, the most likely route for fire spread to the ceiling will be via the walls. Where ceilings are lower (i.e. where the enclosure has a large aspect ratio), the possibility of a fire at floor level directly attacking the ceiling must be considered.

3.4.3 Corridors

Rapid flame spread is also a possibility if both walls or the ceiling become involved in fire in corridors. Occupants will probably be queuing to escape and rapid flame spread should be avoided. Corridors may also provide the path for the fire to spread through a building. In corridors, the contribution of the linings to the development of untenable conditions can have a dominant effect, since there is usually very little building contents and the fire load is generally low.

3.5 VENTILATION OF ENCLOSURES

Ventilation is a key factor in the development of a fire and in the removal of smoke and toxic gases. In the absence of an air supply, a fire will not grow and linings will not pose a threat. Where there is sufficient ventilation for the fire to grow, it will consume building contents and linings if it is not suppressed. If the enclosure is well ventilated to the outside atmosphere, or becomes so in the early stages of a fire (e.g. by window breakage), heat will be lost from the fire and flashover might not occur. In such a fire, linings could make an important contribution to fire spread. Where ventilation is such that the fire grows but is insufficient to cool the fire, flashover is likely to occur within the enclosure and linings in the next enclosure, which is likely to be a public corridor, could be ignited.

In long narrow enclosures, flame spread may be particularly sensitive to the contribution of ventilation (Van Hees & Vandevelde 1997). Public corridors in residential buildings tend to have little natural ventilation, as doors to hotel rooms and units are usually closed. However, corridors may be used as return air-ducts, in which case the airflow may assist fire spread. Doors leading to public corridors in office buildings, storage areas and shops will often be left open or be frequently opened, leading to higher air movement.

3.6 Enclosure Contents

There is little point in controlling the fire properties of linings if their contribution to a fire is insignificant compared to that of the building contents. It is therefore necessary to consider the contents that are likely to be present in each location in each building.

The fire load present in a building varies with the nature of the occupancy (or building classification). It also varies from location to location within the building. Building contents include furniture, drapes, stored items, office workstations, vehicles and auditorium seating.

In fire-isolated exits there will be little, if any, contents. Here any contribution of the linings to the spread of fire or the development of untenable conditions may be significant. Public corridors are similarly (if not so extremely) low in building contents. Small rooms in residential buildings will usually have a relatively high level of contents that will dominate any contribution of the linings. The contents of shops, offices and other public buildings vary with usage, and generalisations on their likely contribution will have to be made.

3.7 Occupant Activity, Mobility and Density

Control of lining materials will reduce the risk of exposure of building occupants to life-threatening hazards. The extent of control needed to achieve an acceptable level of risk will be influenced by the amount of time that people might be present in various locations within a building from the start of a fire. These times therefore constitute a key factor in the control of lining materials.

The stages of occupant response to a fire emergency are generally accepted to be those of receiving and responding to a cue, coping with the situation (maybe by alerting other family members or fighting the fire) and finally by moving to a place of safety (FCRC 1996). The activities that occupants undertake in a building will affect their ability to escape, as will their mobility, their state of wakefulness, their knowledge of their surroundings and the number of people attempting to use the escape routes. In hospitals, patients might be totally unable to respond without assistance, whereas in offices where people are alert and familiar with their surroundings, the time taken to escape will be very much less. Escape times can be expected to be much longer in buildings where people are sleeping. A detailed study of the time taken to escape from different building classifications is given in Research Paper 2.

Although total evacuation times can be determined for different buildings, the influence of linings will vary from location to location within the building. The time spent in escape routes, or waiting to enter escape routes, will be much longer than the time taken to escape from the room of fire origin, especially in buildings with high population densities. In these buildings, conditions in escape routes must be kept tenable for long periods.

3.8 Other Fire Safety Systems

There will usually be other fire safety systems present in any building. The effect of linings cannot be considered without taking the effects of these systems into account. Barriers may restrict fire spread, alarms may hasten the response of building occupants, firefighters may suppress the fire and assist evacuation, and perhaps most important, sprinklers may suppress the fire and stop it spreading.

Many fire safety systems are required by prescriptive building regulation in certain buildings and so can be assumed to be present in those buildings. Where the design satisfies performance requirements rather than prescriptions, the level of safety should be equivalent to that achieved by following the prescription. Sprinklers are perhaps the only fire safety system the optional presence of which can affect the burning of linings. Consideration should be given to the benefits of sprinklers being present in a building, including those where they are not currently required by regulation.

3.9 Summary

The key factors that will be considered in this project are:

- ignition sources;
- building layout – location of enclosures within buildings;
- enclosure size and geometry;
- ventilation of enclosure;
- enclosure contents;
- occupant activity, mobility and density; and
- other fire safety systems.

4 – Building Categories

4.1 Introduction

In Chapter 3, key factors that influence the control of linings were identified. All of these key factors are to some extent dependent on the nature of the building and its use. In this chapter, buildings will be grouped into 'building categories' according to characteristics that determine the need for control of lining materials.

The BCA divides buildings into 13 'building classes' which are subsequently subdivided where necessary to accommodate different fire safety (and other) requirements. The classes are based on usage and provide appropriate (if broad) groups for Australian construction. The building categories derived in this chapter are based on the BCA Building Classes 2–9b.

4.2 Relevance of Key Factors to Building Category

The key factors identified in Chapter 3 can be divided into three groups. There are those that affect the possibility of a fire starting; those that control its growth and spread throughout the building; and those that influence the speed at which people are able to evacuate the building. Some key factors fall into more than one group. For example, building geometry will affect both evacuation times, and fire growth and spread.

The following aspects of fire safety will be considered for each group of buildings:

- likelihood of ignition;
- fire growth and spread; and
- egress time required.

4.3 Likelihood of Ignition

Although fire statistics identify the number of fires attended by the brigades for different building categories, they do not enable rate of fire starts to be determined. Therefore, in the absence of data to the contrary, the rate of fire starts will be assumed to be the same in all building categories (even though the nature and distribution of ignition sources change with building category). A Finnish study found that whilst ignition frequencies vary with building categories, the picture was distorted by the variation of ignition risk with the size of the building. When ignition frequency was divided by total floor area of buildings for a particular category, it was found that differences between building categories were small enough to be ignored (Rahikainen & Keski–Rahkonen 1998).

In Research Paper 3, ignition scenarios were determined for different building categories. It was found that the BCA building classes generally reflected the different fire histories in the various building categories. However, fires in schools (which are BCA Class 9b, assembly buildings) were found to have different ignition details to those in theatres and halls and the like (also BCA Class 9b). Therefore it was decided to create a separate category for schools.

Carparks were also considered to form a separate category, although the fire statistics in Research Paper 3 do not differentiate them from warehouses. Since carpark construction, usage and fire load is substantially different from warehouses, it was considered that there was no justification for assuming that they had similar fire histories to warehouses.

4.4 Fire Growth and Spread

Fire spread in a building can be affected by the layout and the type of building contents. For instance, apartment buildings tend to have spaces that are normally closed off from corridors, while factories have large interconnecting spaces. A warehouse used for storage might have a considerably higher fire load density than an apartment. This aspect appears to be reasonably addressed by the current break-up of building types in the BCA.

4.5 Egress Time Required

Ideally, calculation of required egress time for each location for each building category would be used to determine appropriate levels of materials control. Unfortunately neither the data nor the methodology is currently available to make such accurate and detailed predictions. A study of evacuation times in various buildings was carried out as part of the project (see Research Paper 2). The resultant ranges of egress times are given in Table 4 of that report. Although the method by which the absolute times were calculated is being reassessed, there was general agreement within the Working Group that the relative times were realistic.

In Research Paper 2, building categories were established by studying possible uses of buildings in each BCA Class and considering likely occupant characteristics. The data in Research Paper 2 suggests that, based on egress requirements:

- aged accommodation should not be treated the same as hotels and boarding houses – for aged accommodation, egress times appear to be similar to those for hospitals;
- schools should not be treated the same as theatres and halls; and
- warehouses and factories can be considered together.

The finding relating to aged accommodation can reasonably be extended to include accommodation for the disabled and children.

Subsequent work on Fire Code Reform Project 4 has shown that behavioural differences indicate that there might be a need to consider boarding houses separately from hotels and motels. There is currently insufficient data to warrant the creation of a separate category, but this issue is flagged for future attention.

4.6 Building Categories for Use in Project 2

The following building categories are used in Project 2:

- apartments;
- hotels and boarding houses;
- accommodation for the aged, disabled and children;
- office buildings;
- shops;
- carparks;
- warehouses and factories;
- health care buildings;
- theatres, halls and the like; and
- schools.

5 – PRINCIPLES FOR CONTROL

5.1 INTRODUCTION

The second objective of this project is to provide qualitative definitions of performance for wall and ceiling linings in buildings (see Chapter 1). This Chapter is concerned with deriving such 'qualitative definitions'.

An important first step in reviewing any regulatory requirement is to study its aims or objectives. Once a rational set of objectives has been agreed, quantified design options can be developed based on the fulfilment of these objectives.

The control of wall and ceiling linings can be considered to be a subsystem of the complete fire safety system of a building. While the aim of the complete fire safety system may be clearly defined, the aim of an individual subsystem is much harder to define as its role will depend upon the roles of other subsystems.

In order to arrive at a set of qualitative definitions of performance for wall and ceiling linings, it is helpful to consider:

- the global aims of design for fire safety;
- the contributory role of wall and ceiling linings; and
- the aims of requirements for particular locations within particular buildings.

5.2 GLOBAL OBJECTIVES

In the report on Part 1 of FCRC Project 3 – Fire Resistance and Non-combustibility, the following global objectives were identified as the intentions behind the provisions of the BCA:

- to keep loss of life in building fires to a very low level (it is assumed that there is a relationship between injury and loss of life in fire, such that the reduction in risk to life automatically implies a reduction in risk of injury);
- to limit property damage by introducing measures to control fire size and to prevent fire spread from premises on fire to neighbouring premises; and
- to provide protection to firefighters in the execution of their duty.

All aspects of the building design contribute together to achieve these aims. The control of lining materials contributes to all three by limiting the spread of fire. The further a fire spreads beyond the object of origin, the worse the fire becomes and the greater the likelihood of loss of life (and property) becomes. Therefore, keeping the fire small will result in less loss of life. In the absence of contents or fire suppression systems such as sprinklers, control of linings will be the main way that fire size is controlled within an enclosure. Control of linings will influence the time available for building occupants to escape and the tenability of the paths of egress – paths that are also used by firefighters in the execution of their duty.

5.3 System Performance

Having established the global objectives, it is possible to consider the individual system, in this case the materials control system, and establish more precisely its contribution to fire safety. Lining materials can play a significant role in the initial stages of a fire, contributing to fire spread and generating the heat, smoke and gases which make conditions untenable. But in many cases, the response of the building contents will dominate, making control of linings of little or no relevance to the overall safety of the occupants. It is therefore proposed that a suitable system performance objective for lining materials in buildings is that:

- in the event of fire, lining materials must not significantly decrease the safety of occupants.

Current technology does not allow us to measure the safety of occupants in terms of risk to life. It is therefore not possible to evaluate the risk with and without a certain lining material, decide on a percentage that is considered significant and make a quantified judgment on the suitability of use of the material as a lining. What we can do is consider what are reasonable expectations and make judgments based on experiment, experience and available knowledge.

5.4 Performance of Lining Materials by Occupancy and Location

The aim of this project is to derive logical prescriptive solutions for use within the BCA. To this end, the system objective will be achieved by developing controls for the use of lining materials, based on appropriate properties and dependent upon their location within the building. The controls will vary from occupancy to occupancy.

Considering the key factors described in Chapter 3, the system performance objective can be interpreted to describe acceptable fire performance of linings within each location for each building category. The descriptions will form the basis for a quantitative evaluation of controls, which will take into account the relative contributions of building contents and building linings to the spread of fire and generation of smoke.

The Working Group agreed that there were two possible ways in which linings might significantly decrease occupant safety. These were:

1 In the presence of an ignition source, linings might significantly[4] reduce the time to untenable conditions.
2 In the presence of an ignition source, linings might significantly contribute to flame spread. Fire might then spread to areas remote from the area of fire origin, reducing the time to untenable conditions in these areas.

Each statement was considered for each location in each building category. The results are listed in Table 5.1.

Initially, the Working Group derived Table 5.1 for enclosures with no building contents, when the behaviour of the linings would have maximum significance. It was later decided that this scenario, although realistic for fire-isolated exits and public corridors, would never occur in other areas, and in these areas minimal building contents were considered.

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[4] 'Significantly' is determined by considering the relative roles of the linings and the building contents.

Table 5.1 – Performance considerations

Building categories	*Fire-isolated exits*	*Public corridors*	*Specific areas*	*Other areas*
Apartments	1 & 2	1 & 2	1 & 2 (sou[a])	1 & 2
Hotels and boarding houses	1 & 2	1 &2	1 & 2 (sou)	1 & 2
Aged accommodation	1 & 2	1 & 2	1 & 2 (sou)	1 & 2
Office buildings	1 & 2	1 & 2	1 & 2 (open plan offices; aspect ratio >5[b])	1 & 2
Shops	1 & 2	1 & 2	1 & 2 (large shops; aspect ratio >5)	1 & 2
Carparks	1 & 2	1 & 2	1 & 2	1 & 2
Warehouses & factories	1 & 2	1 & 2	1 & 2	1 & 2
Health care buildings	1 & 2	1 & 2	1 & 2 (patient care area)	1 & 2
Theatres, halls etc.	1 & 2	1 & 2	1 & 2 (auditorium)	1 & 2
Schools	1 & 2	1 & 2	1 & 2 (classroom)	1 & 2

[a] Sole occupancy unit.
[b] Aspect ratio = minimum floor dimension/floor to ceiling height.

When the table was first derived, the Working Group did not consider tenability to be an issue in those areas remote from fire-isolated exits in buildings with low populations, and flame spread was not considered to be an issue in relatively small enclosures. After much deliberation, the table was amended to reflect the view that both flame spread and tenability required consideration for all locations in all occupancies. Thus, statements 1 and 2 now represent an expansion of the system performance statement.

Note that in Table 5.1, 'specific areas' are as described in parentheses. 'Other areas' are all areas other than fire-isolated exits, public corridors and the listed specific areas, and include shops and offices with an aspect ratio ≤5.

5.5 Contribution of Other Fire Safety Systems

The contribution of other fire safety systems in achieving the system performance was discussed in Chapter 3. In quantifying the performance considerations for different locations and building categories, it will only be necessary to consider the presence or absence of sprinklers.

5.6 Conclusion

In all locations in all buildings, the contribution of linings to time to untenable conditions and to flame spread must be considered for buildings with and without sprinklers. This does not necessarily imply that control will be necessary.

6 – SELECTION OF TEST METHODS

6.1 INTRODUCTION

It would be impractical to assess the performance of linings in real building fires. Fire tests are used to give an indication of the likely contribution of linings to flame spread and untenable conditions. This chapter describes tests that are available to measure the fire properties of lining materials and looks at their merits and disadvantages.

6.1.1 Overseas practice

Many countries control the use of lining materials in buildings and a number of tests have been developed to measure what are considered to be appropriate materials properties. Properties most commonly measured are related to flame spread and smoke production. Examples of controls used or being developed overseas include the following:

- The International Maritime Organisation has recently adopted the ISO Room Fire Test to classify wall and ceiling linings in high-speed craft. The classification is based on time to flashover, heat release and smoke production.
- In the United States, the Uniform Building Code uses the Steiner Tunnel (ASTM E 84[5]). American critics of the test (Babrauskas *et al.* 1997) point out that the measuring scale is arbitrary and results cannot be used for engineering computation. There is growing dissatisfaction with the Steiner Tunnel in the scientific and engineering community.
- In Europe, historically countries have developed their own small-scale tests. In the early 1980s the Nordic countries instituted a program to develop a uniform approach to the control of wall and ceiling linings based on a better understanding of the science involved. The major outcome was the recommendation that a Room Fire Test be used to classify building materials (Sundström & Göransson 1988). Later on the EUREFIC (EUropean REaction to FIre Classification) program was initiated, and involved more European countries. It finished in 1991. Recommendations included adoption of the classification scheme proposed by Sundström and Göransson (1988) for wall and ceiling linings. This scheme is based primarily on time to flashover in the ISO Room Fire Test, but includes heat release and smoke production criteria in some classes. Six classes were proposed, expressed as five classes and 'unclassifiable' materials. A number of models for predicting time to flashover and heat release in the ISO Room Fire Test, based on Cone Calorimeter data, were developed.

The European Community (EC 1994) has accepted the Nordic/EUREFIC proposal for the classification of building materials into six categories, but tests other than the ISO Room Fire Test will be used to determine to what classification a material belongs. It appears likely that the European Committee for Standardization (CEN) will allow classification by different tests

[5] The details of cited standards are given in Appendix C.

in each country. However, the ISO Room Fire Test will be used as the reference scenario for selecting material groups and resolving products with borderline results (CEN 1997). In most cases, a suite of tests will be necessary to determine the classification of a material. For instance, data could be obtained from the German 'kleinbrenner' test, a CEN version of the ISO non-combustibility test, the calorific potential test and the single burning item (SBI) test. Controls on material classes for use in buildings will be decided in individual countries.

While many test methods have been developed, no single test has gained international acceptance for use in codes or regulations.

6.1.2 Tests available in Australia

If a test is to be used for regulatory purposes, it must be readily accessible to the building industry. It was therefore deemed necessary to limit the tests under consideration to those that are readily available within Australia. The test methods under consideration in Project 2 were therefore limited to the following:

- Room Fire Test (ISO and ASTM);
- Early Fire Hazard Test;
- Cone Calorimeter;
- ISO Ignitability Test; and
- NBS Smoke Chamber.

6.2 Large- and Small-scale Tests and Real Fires

Fire tests for wall and ceiling linings can be divided into two groups. Large-scale tests (or room fire tests) which involve burning a whole room assembly, and small-scale tests which require only a small sample of a material to be burned. Both large- and small-scale tests will be considered in this project. Of the tests under consideration:

- the room fire tests are large-scale tests;
- the Early Fire Hazard Test and Cone Calorimeter are multi-parameter small-scale tests; and
- the ISO Ignitability Test and NBS Smoke Chamber test are single parameter small-scale tests.

If a fire test is to be used to assess the suitability of lining materials for use in buildings, a way must be found of showing that test results give a realistic interpretation of the required performance. In Chapter 5, it was agreed that the performance objective of the materials control system was:

- in the event of fire, lining materials must not significantly decrease the safety of occupants.

It was further agreed that:

- in the presence of an ignition source, linings might significantly reduce the time to untenable conditions; and
- in the presence of an ignition source, linings might significantly contribute to flame spread.

It is unlikely that data from small-scale tests will be able to provide, directly, the necessary controls. However, a more accurate measure of performance might be achieved in large-scale tests, and this might in turn allow prediction of performance in real fires. If links can be established between performance in small-scale tests, performance in large-scale tests and performance in real fires, then it might be possible to use small-scale test data to predict performance in real fires.

The technology is not yet available to establish a direct link between small-scale tests and performance in real fires. However, several models are available that link properties measured in small-scale fire tests with performance in large-scale fire tests (Delichatsios *et al.* 1991; Wickström & Göransson 1992; Kokkala *et al.* 1993; Quintiere 1993; Karlsson 1993; 1994; Östman & Tsantaridis 1994; Beyler *et al.* 1997). Some of these models are discussed further in Chapter 8. If it can be shown that there is a link between results obtained in a large-scale fire test and performance in a real fire, then the picture is complete and appropriate properties from small-scale tests can be used to predict performance in a real fire, via large-scale tests.

Large-scale tests do not necessarily represent the real world and if large-scale test results are to be used as an indication of performance in real fires, some link to reality must be established.

Fire statistics (Takeda & Yung 1991; Hall & Cote 1997) show that in residential buildings the death rate from fires that did not spread beyond the room of origin was far less than that from fires that spread beyond the room of origin. Nonetheless, fire deaths are more likely to occur in the area of fire origin (Hirschler 1996). This suggests that deaths occur because fires grow big enough to become a threat to life, rather than because fires spread.

In this project we are concerned with the effect of lining materials on the safety of building occupants. The contribution of lining materials to the propensity of fire to grow gives an indication of the effect on safety associated with the linings. The propensity of fires to grow in the presence of various lining materials can be assessed by measuring the time it takes for a fire to reach a certain size (a size that might threaten life) in a standard room. At a certain stage in the growth of the fire, the whole room becomes involved and flames will then issue from any opening. This stage is known as flashover and is very distinctive.

Once a fire reaches flashover, it is likely to spread beyond the area of fire origin. Time to flashover can therefore be used as a benchmark of performance in real fires. In room fire tests, time to flashover can be measured directly. Thus, a value for time to flashover in a standard room fire test can be established for any lining material. The value of time to flashover obtained from room fire tests can be used to calibrate small-scale tests. Small-scale tests can then be used to provide good estimates of the real-fire performance of the materials in question.

The relationship between fire tests and real fires is shown in Figure 6.1.

6.3 Selection Criteria

To select the most suitable test methods, criteria need to be established. The primary selection criterion should address the adequacy of the test as a measure of the required performance in real fires. The chosen test method must be suitable for use on wall and ceiling linings, it must be accessible to the industry and should, if possible, relate to international practice.

6.3.1 Relationship to performance in real fires

The purpose of the chosen test is to predict the performance of lining materials in a real fire. While small-scale tests provide an inexpensive means of measuring material properties, a clearer

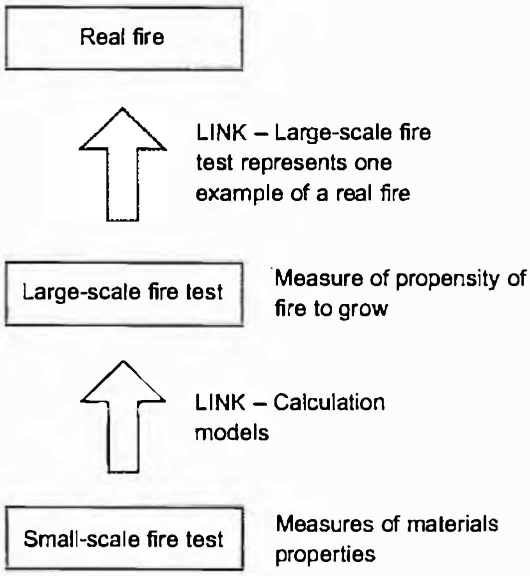


Figure 6.1 – Relationship between fire tests and real fires

indication of the affects of these properties on performance in real fires will be given by large-scale tests. If the large-scale test results are to represent real fire performance, the size of the test room and size of the fire must represent a possible fire scenario, and time to flashover in the test room must correspond to time to flashover in a real fire.

6.3.2 Appropriateness for controlling wall and ceiling linings

A test does not necessarily need to simulate real life performance, provided it can be shown to provide an accurate measure of properties that can be used to assess real performance.

In Section 6.2, it was shown that time to flashover in a standard room fire test was an appropriate property to assess performance of lining materials under real fire conditions. It therefore follows that any room fire test might be appropriate for controlling wall and ceiling linings. Appropriate small-scale tests will measure properties that can be used to calculate time to flashover in a room fire test. All the models referred to in Section 6.2 use the properties of rate of heat release per unit area (measured over a specified period of time) and ignitability (expressed as a function of time to ignition under specified conditions). Other properties might be appropriate if a reliable model linking small-scale test performance with time to flashover in a room fire test can be developed.

An appropriate test must give reliable measurements for the range of materials likely to be used as wall or ceiling linings. Material properties such as melting or intumescence need to be considered. The test should be capable of measuring all likely values.

6.3.3 International status

In 1992, Australia signed the GATT Technical Barriers to Trade (TBT) agreement. Under Articles 2.2 and 2.4 of the TBT Code, technical regulations must not be unnecessarily traderestrictive and consideration must be given to using international standards rather than national standards in regulations (SAA 1995).

Internationally portability is especially significant when testing is expensive. Fire tests, especially large-scale fire tests, are expensive. If tests can be found that are international in scope, then results will be transportable and additional testing to satisfy the needs of overseas markets can be avoided. An additional benefit of internationally accepted test methods is that the methods themselves are under constant scrutiny. This means that any shortcomings are noticed more quickly, and can be rectified more promptly.

The international status of a test can be assessed by its literature; its availability; it being the subject of standards; and finally, it being cited in codes or regulations.

6.3.4 Variability of results

The variability of results controls the extent to which the test can discriminate between materials. For instance, if different laboratories give different results for a material, this limits the degree to which materials can be discriminated, and limits the confidence that can be placed in results from the test. If no assessment of the variability has been made, then little confidence can be placed in the test results. The variability within a laboratory is termed the repeatability, and that between laboratories is termed the reproducibility. Methods for establishing these are contained in ISO 5725.

The importance of variability has only been acknowledged in the last two decades. For instance, the first mention of variability in the Early Fire Hazard Test is in the 1982 version of AS 1530.3.

6.3.5 Cost effectiveness

As well as the unit cost of the test, cost considerations should include the cost of producing suitable sized specimens of material to be tested, the number of tests to be performed, the utility of data, and any costs associated with introducing a change to the currently accepted method of test. Additional cost benefits are to be seen from tests that provide data suitable for use in fire engineering and product development applications. It is not within the scope of this project to provide a full cost–benefit analysis and only a brief assessment of these costs will be made.

6.3.6 Chosen selection criteria

The following selection criteria have been chosen for determining suitable fire tests for wall and ceiling linings. The fire tests should be:

- related to control of performance in real fires;
- appropriate to control wall and ceiling linings;
- international;
- repeatable and reproducible; and
- cost effective.

6.4 Room Fire Test

Large-scale fire tests of rooms with combustible linings have been carried out for many years (Wickström et al. 1983), and can be traced back to room burns conducted in the USA by the Forest Products Laboratory (FPL) and corner wall burns conducted in Australia by Ferris (1955) at CEBS (Williamson & Dembsey 1990; Kokkala 1993a). FPL may have been the first to use the room size now generally accepted, and Ferris may have been the first to use a gas burner (instead of wood cribs) in a corner configuration. It is only recently that attempts have been made to create a standard room fire test.

The room fire test discussed by ASTM (ASTM 1982) was first standardised by Nordtest as NT Fire 025 and then by ISO as ISO 9705 (Figure 6.2). These two standard methods are technically identical and require the same facilities. They employ a room 2.4 × 3.6 × 2.4 m high with a single doorway 0.8 m wide and 2.0 m high. The ceiling, walls and floor are constructed of non-combustible material of specified density and thickness over which the lining materials to be assessed are mounted. A gas burner is placed in one corner away from the door.

In the ISO 9705 method, the standard specimen configuration is to have three walls and the ceiling covered with the lining being assessed. The gas burner is set to 100 kW for 10 minutes and, if flashover has not occurred, the gas burner output is raised to 300 kW for a further 10 minutes. The test finishes at 20 minutes, or earlier if flashover occurs.

Flashover is generally understood to be the moment at which flames first issue from the doorway. For the purposes of measurement, it is defined as a heat output of 1 MW in a room of this size. Apart from the time of occurrence of flashover, other data that can be provided by the room fire test includes the following time histories:

- rate of heat release;
- rate of smoke production;

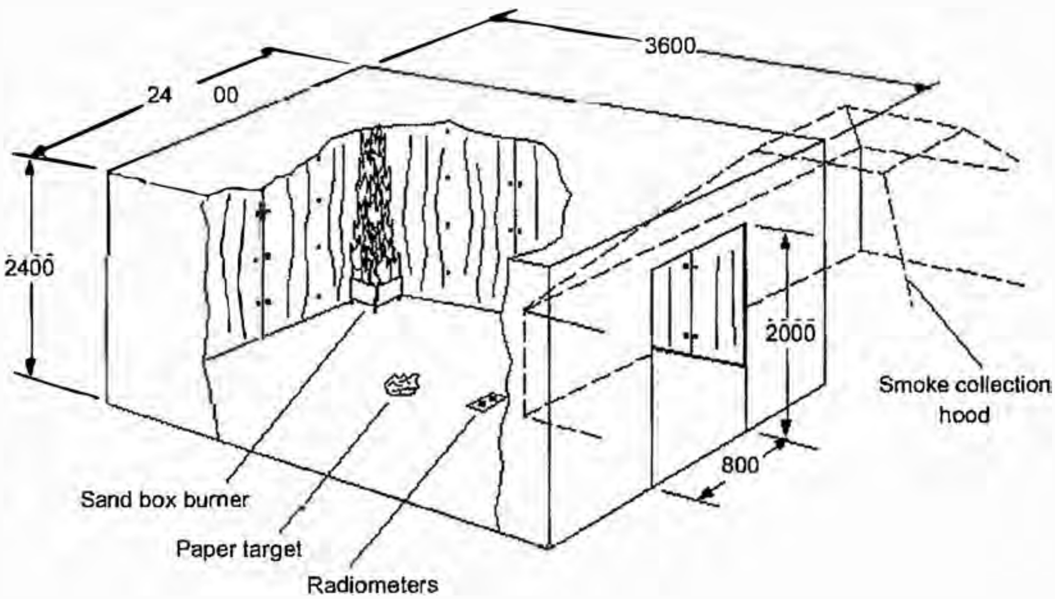


Figure 6.2 – Room fire test

- rate of production of gases such as carbon monoxide and carbon dioxide;
- rate of oxygen consumption; and
- radiation at floor level in the room.

From this data, peak, average and total values can be determined for each parameter. The rate of smoke production is related to optical density.

The proposed ASTM method uses the same facilities and instrumentation as the ISO method (ASTM 1983). In the ASTM method as originally proposed, only the three walls were lined with the material to be assessed. The gas burner was programmed to produce a gross heat output of 176 kW (ca 160 kW net) within 90 seconds of the start of the test. The burner was set to 25% of the maximum value at the start and increased by 25% steps at 30-second intervals. In the ASTM/ISO interlaboratory assessment (Beitel 1994) a different burner program was used. The gas burner was set to a net heat output of 40 kW for 5 minutes and, if flashover had not occurred, the burner output was raised to 160 kW for a further 10 minutes. In the proposed ASTM method similar measurements to those in the ISO method are made.

At this stage, ASTM has not published a standard, but is currently considering the adoption of the ISO standard (Babrauskas *et al.* 1997).

A variation of the ASTM method has been published by NFPA (NFPA 265) for the control of textile wall coverings. This uses a burner program of 40 kW for 5 minutes and 150 kW for 10 minutes. The T-shaped specimen is mounted in the corner adjacent to the gas burner and covers part of two walls only.

There is one room fire test facility in Australia which can be operated according to either ISO 9705 or to the ASTM proposed method (ASTM 1983). There are none in New Zealand.

6.4.1 Relationship to performance in real fires

The link between performance in a real fire and time to flashover in a room fire test was described in Section 6.2, but it is necessary to show that the test in question represents a possible reality.

The ISO Room Fire Test was set up to represent a 'real fire' in a small bedroom. The heat release rate from a bedroom fire is about 1 MW at flashover (Sundström 1991). The 100 kW burner output simulates a burning wastepaper basket (Wickström 1988). The 300 kW output is the equivalent of an upholstered chair (Sundström 1992). Ignition sources of 100 and 300 kW are illustrated in Figures 6.3 and 6.4. The characteristics of the flame are described in detail by Kokkala (1993b).

As discussed above, the ASTM version of the Room Fire Test has not yet been finalised, with a major point of dispute being the gas burner program. All early versions of the ASTM test used 160 kW as the 'test' exposure, with various preheating periods (Lee 1985a). The gas burner program used in the ASTM/ISO interlaboratory assessment (Beitel 1994) is designed to be a preheat period of 40 kW prior to the more severe exposure of 160 kW (Janssens 1991).

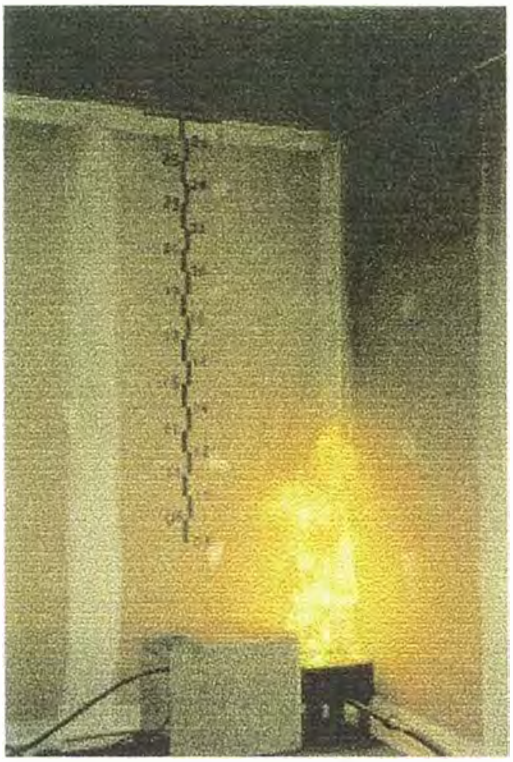


Figure 6.3 – Illustration of a 100 kW ignition source (2.7 m ceiling)

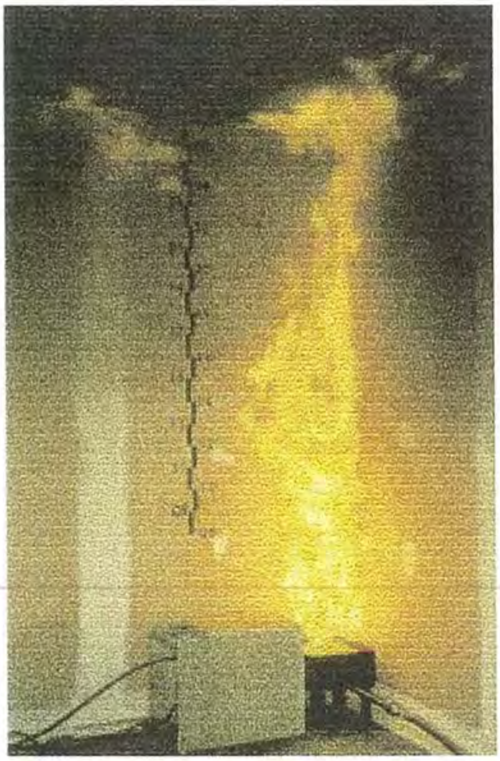


Figure 6.4 – Illustration of a 300 kW ignition source (2.7 m ceiling)

6.4.2 Appropriateness for controlling wall and ceiling linings

The present configuration of the ISO Room Fire Test grew out of studies to develop a large-scale fire test for wall and ceiling linings, and is the result of programs both in Scandinavia and the US (Wickström *et al.* 1983). Both ISO and ASTM now accept the configuration (or spatial layout) as an appropriate way to measure the performance of wall and ceiling linings.

6.4.3 International status

ISO 9705 is also the test used by the International Maritime Organisation (IMO) to classify 'fire-restricting materials' for high-speed craft (IMO 1994). As a result, some Australian manufacturers have already had wall and ceiling lining systems assessed in this test, both in Australia and overseas.

It has been proposed as the reference scenario that will be used to define class limits and to resolve disputes when the Euroclasses for wall and ceiling linings are adopted in Europe (EC 1994).

The Room Fire Test has been adopted in the US in the Uniform Building Code and has been proposed for the Standard Building Code. The method, for the control of textile wall coverings, is based on the NFPA 265 method (Belles 1997).

6.4.4 Variability of results

The ISO and ASTM versions of the Room Fire Test are conducted in identical facilities and have identical instrumentation. Therefore, assessments of variability are applicable to both versions. Kokkala (1993a) has found that the method is not particularly sensitive to small changes in room size or gas burner dimensions.

6.4.4.1 EUREFIC room fire test interlaboratory assessment

An interlaboratory assessment was carried out as part of the EUREFIC program (Mangs *et al.* 1991). This interlaboratory assessment, which involved five laboratories, is described in Appendix D. Each laboratory performed only single assessments on each material. Therefore, it was not possible to calculate repeatability and reproducibility according to ISO 5725. Instead, a simple estimate of the variation in the results was made assuming a normal distribution. The reproducibility was measured by using the 95% confidence interval for the mean. This data is included in Appendix D.

For the four materials assessed, two showed variable behaviour in the occurrence of flashover. In both cases this variability was attributed to variations in mounting techniques. In a subsequent interlaboratory assessment (see Section 6.4.4.2) mounting techniques were specified more precisely.

6.4.4.2 ASTM/ISO Room Fire Test interlaboratory assessment

The ASTM/ISO interlaboratory assessment (Beitel 1994) involved 12 laboratories in 8 countries. Each laboratory tested 2 or 3 of the 7 materials, usually in duplicate. More details of the inter-laboratory assessment are given in Appendix D. The data was evaluated according to ISO 5725. Data on variability of specific parameters is included in Appendix D.

Only two of the materials used in the interlaboratory assessment went to flashover. Those materials that did not flash over did not flash over in any of the laboratories, and those

materials that did flash over, flashed over at the same gas burner level in all tests in all laboratories.
In this interlaboratory assessment smoke production showed the greatest variability. Typically the repeatability within laboratories and reproducibility between laboratories for smoke were far worse than for other values measured (see Tables D2.1–D2.7 in Appendix D).

6.4.5 Cost effectiveness

Room fire tests are more expensive, both in terms of labour and materials, than small-scale tests. They require 11 sheets of material, each 2.4 × 1.2 m, for a single test. They cost about $6,000–$10,000, which is similar to fire resistance tests.

Because of their cost, it is usual for only a single test to be performed on a material.

Data from the room fire test is used to give confidence in the results of fire engineering calculations. It is also used in the later stages of product development.

6.5 Early Fire Hazard Test

The test method currently cited in the BCA for controlling combustible wall and ceiling linings is AS 1530.3, known as the Early Fire Hazard Test. In this test (Figure 6.5), a specimen 450 × 600 mm is vertically positioned on a mobile holder opposite a vertical gas-fired radiant panel. The holder and specimen are advanced, every 30 seconds, toward the radiant panel until ignition, or the 12-minute mark of the test, when the movement ceases. Two pilot flames are placed near the surface of the specimen to ignite pyrolysis gases produced by the heated specimen. The specimen holder has side shields placed on either side of the specimen to restrict the effects of draughts on the burning behaviour.

A radiometer viewing the heated face of the specimen records the radiation produced by ignition of the specimen. The radiometer moves with the specimen holder so that a set distance is maintained between the two. The smoke is collected by a hood, located over the radiant panel and specimen, and rises through a vertical duct where its optical density is recorded. The four parameters measured during the test are:

- time to ignition;
- increase in emitted radiation;
- total radiation emitted in two minutes following ignition; and
- maximum rate of smoke production, averaged over one minute.

These measurements are used to produce the Ignitability Index, Spread of Flame Index, Heat Evolved Index and Smoke Developed Index respectively.

The test duration is 20 minutes for specimens that do not ignite. For specimens that do ignite, the test is terminated according to certain criteria, but within 203 seconds after ignition.

This method was developed because of perceived shortcomings in the method previously in use to assess the hazard of wallboards (Ferris 1955). One shortcoming seen in the previous method was that it excluded ignitability, which was seen to be an important parameter. The new method (AS 1530.3) originally provided an 'Index of Early Fire Hazard', summing together

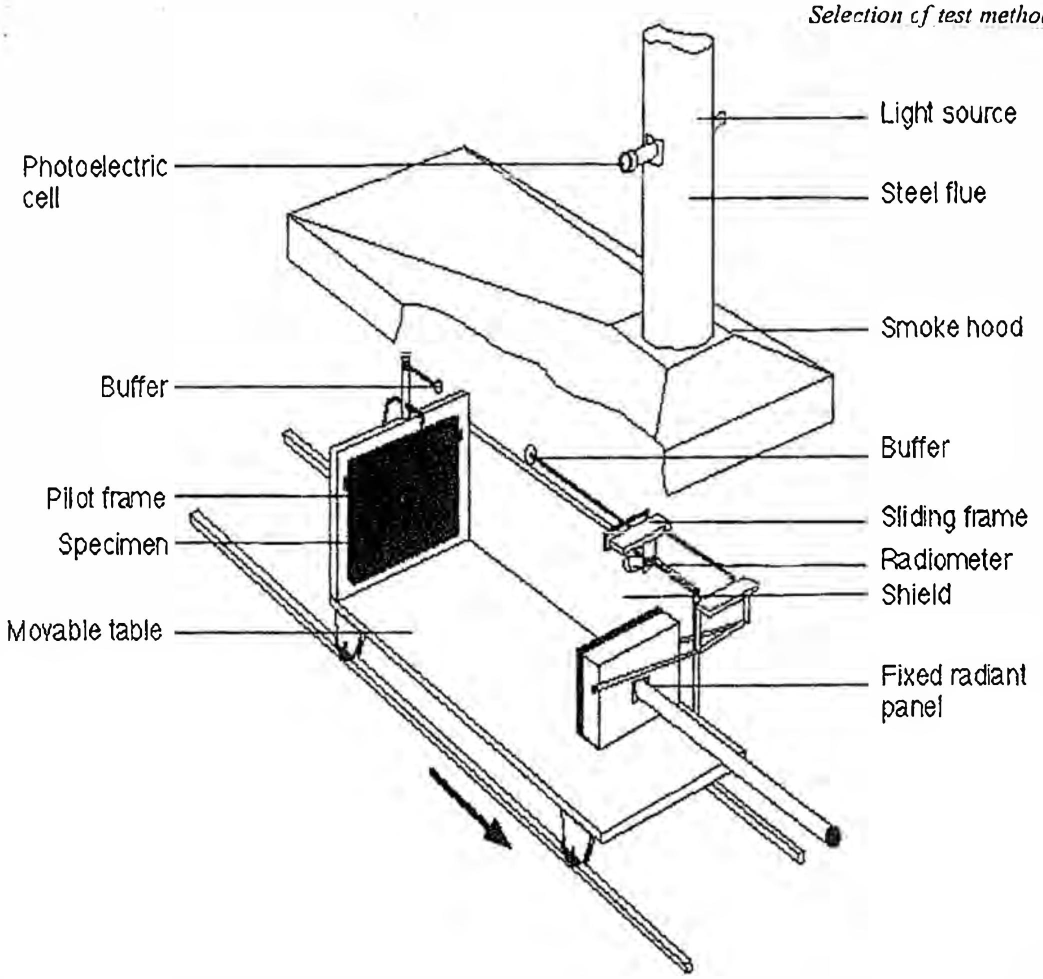


Figure 6.5 – Early Fire Hazard Test

results for 'ignitability', 'spread of flame' and (radiant) 'heat developed', because CEBS believed that the ignitability, spread of flame and heat evolved indexes were of little value individually as performance criteria (Wilson 1961). Ignitability was considered to be of paramount importance and was weighted to give half the score, a high score being a poor performer.

At a later stage, the practice of summing the three indexes to produce the Index of Early Fire Hazard was discarded, and a Smoke Developed Index added (Keough 1969), thereby reducing the emphasis on ignitability. In fact, the Ignitability Index was ignored in the former Australian Model Uniform Building Code (AMUBC), with only the Spread of Flame and the Smoke Developed Indexes being called up.

The Standard now requires actual results to be reported though allowing for assignment of Indexes for regulatory purposes.

Spread of flame is measured indirectly only. What is actually measured is a rate of increase in radiation emitted by the specimen following ignition. A relationship was developed between time for an increase of 1.4 kW/m^2 to occur, and flames to reach the 2.74 m ceiling in room corner experiments (Ferris 1955). The time at which the flames are steady on the ceiling was assumed to be a critical time in the growth of a fire (Ferris 1955; Moulen *et al.* 1980), though this has since been disputed (Gardner & Thomson 1988).

The test is available for commercial testing in two laboratories in Australia and three in New Zealand.

6.5.1 Relationship to performance in real fires

With the exception of the limited experiments carried out as part of Project 2, the Early Fire Hazard Test has not been directly compared with the ISO Room Fire Test.

The Early Fire Hazard Test has been re-examined in a number of studies (Moulen *et al.* 1980; Martin & Dowling 1979), but the original basis of the Flame Spread Index could not be verified. Attempts have been made to relate optical density of smoke in the Early Fire Hazard Test to smoke developed in the early stages of a fire in the corner of a room (Moulen *et al.* 1980), though not successfully (Quintiere 1982).

There is some data on materials examined in both the Early Fire Hazard Test and the ASTM Room Fire Test. It has been shown that there is no correlation between the Flame Spread Index of the Early Fire Hazard Test and time to flashover in the ASTM Room Fire Test (Gardner & Thomson 1988). Materials that had Flame Spread Indexes anywhere in the range of 0–10 in the Early Fire Hazard Test all went to flashover in the ASTM Room Fire Test shortly after the gas burner was turned up to 160 kW (see Appendix F, Figure F1). Correlations with other parameters will be studied in Chapter 7.

6.5.2 Appropriateness for controlling wall and ceiling linings

The test was developed as an ignitability apparatus for wall lining materials. It was not the intention of the inventor that it should be used in the manner currently cited in the BCA (Ferris 1955).

6.5.3 International status

The test is not available outside Australia and New Zealand. The few published papers assessing the test or providing data on materials from the test emanate primarily from Australia, whilst there are a handful from New Zealand. It is currently cited in building codes in Australia and New Zealand.

6.5.4 Variability of results

The only published information on variability of results in the Early Fire Hazard Test appears to be in the Standard itself. The statement on variability of results in AS 1530.3 is very limited. It provides some unsourced data on standard deviations of indexes (not actual data) to be expected on 'typical' materials. It does not contain any estimate of repeatability or reproducibility.

Mounting of specimens has presented many difficulties with this test, and is one cause of major discrepancies found between laboratories for some materials. Discussions on specimen mounting are still occurring in the Standards Australia committee overseeing this method.

6.5.5 Cost effectiveness

This test requires six 600 × 450 mm specimens, or nine specimens for variable products. If the testing laboratory is to retain a specimen for reference purposes, 10 specimens of this size must be supplied. It is therefore expensive of materials compared to the ISO Ignitability Test, NBS Smoke Chamber or Cone Calorimeter.

The cost of performing sufficient tests to obtain a certificate is about $600–$700.

Data obtained from the test has not been shown to be of use in fire engineering applications. The test is of limited value in the initial stages of development of new products where only very small samples are available.

6.6 Cone Calorimeter

The Cone Calorimeter was developed from extensive studies of calorimeter methods at the National Bureau of Standards (NBS) in the 1970s. The primary purpose of these studies was to find ways of measuring the heat release rate of products in order to estimate their contribution to a room fire (Babrauskas 1982). The Cone Calorimeter was one of the major outcomes of this program.

The Cone Calorimeter (Figure 6.6) uses the principle of oxygen consumption developed by Huggett (1980). A 100 × 100 mm specimen is subjected to radiation from a cone-shaped electrically heated element, which was originally developed in Australia (Grubits 1970). The cone shape ensures a constant radiation load at all points of the surface of the specimen. The radiation level can be set to any value from 0–100 kW/m^2. The specimen can be positioned vertically but most testing is done with the specimen in the horizontal orientation. An electric-

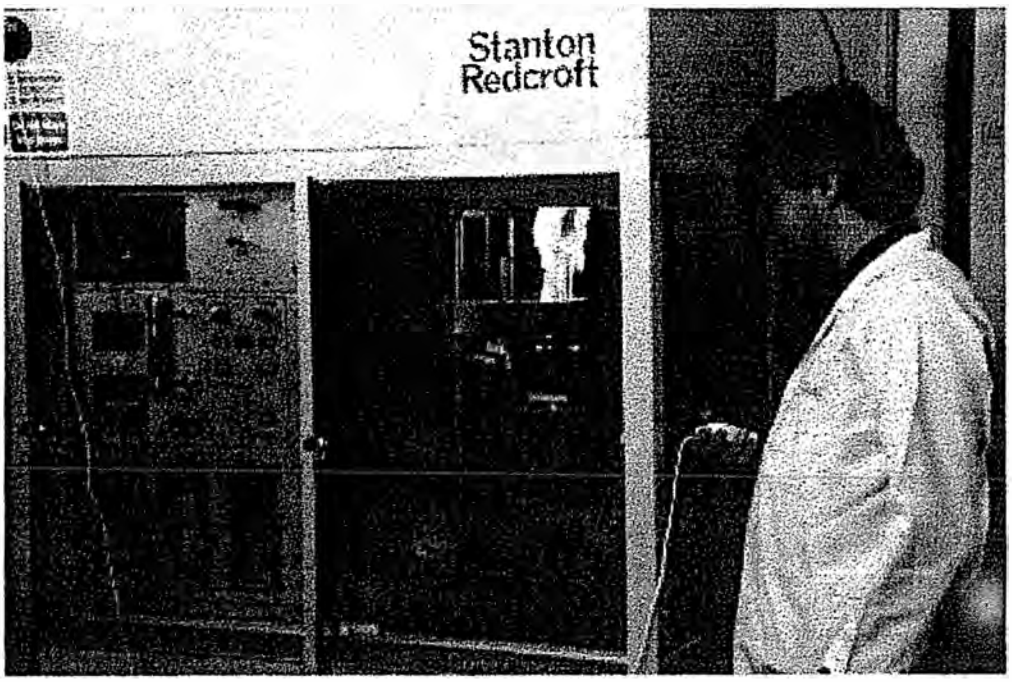


Figure 6.6 – Cone calorimeter

spark igniter placed close to the specimen surface ignites any combustible gas evolved from the heated surface. Smoke is collected in a hood and extracted down a duct, with the aid of a fan, at a set flow rate. The parameters measured include:

- time to ignition;
- rate of heat release;
- mass loss;
- smoke production; and
- production of O_2, CO and CO_2.

The Cone Calorimeter has been standardised by ISO (ISO 5660–1) and ASTM (ASTM E 1354). ASTM E 1354 is a general test method standard, whilst ISO 5660–1 is intended specifically for building materials, although there are moves in ISO to change this. ASTM E 1354 includes smoke measurement, whilst ISO 5660–1 excludes this. Apart from smoke measurement, the methods are technically identical.

In Australia there are currently five cone calorimeters, whilst New Zealand has two. A joint Australian/New Zealand standard for the Cone Calorimeter modelled on, and technically identical to, ASTM E 1354 has been developed.

6.6.1 Relationship to performance in real fires

A number of relationships have been developed which enable Cone Calorimeter data to be used for the prediction of time to flashover in the ISO Room Fire Test (Wickström & Göransson 1992; Kokkala *et al.* 1993; Östman & Tsantaridis 1994). Data from tests performed in the Cone Calorimeter and room fire tests will be examined in Chapter 8 to demonstrate its suitability as a predictor of time to flashover in room fire tests. Time to flashover in the ISO Room Fire Test has in turn been related to performance of linings in real fires. Data from the Cone Calorimeter has also been used in fundamental studies of flame spread on surfaces (Quintiere 1995).

6.6.2 Appropriateness for controlling wall and ceiling linings

The Cone Calorimeter was developed for assessing materials used in linings, furnishings and other applications in buildings (Babrauskas 1982). Its usefulness for wall and ceiling linings has been confirmed by projects such as the European EUREFIC program (Sundström 1991; Wickström 1988).

6.6.3 International status

The Cone Calorimeter, first standardised by ASTM in 1990, is now the subject of a number of standards – both general test methods and methods for specific products (Table 6.1). The Cone Calorimeter is currently under consideration in New Zealand for the control of exterior wall claddings (Cowles 1997).

The Cone Calorimeter is the subject of many hundreds of scientific papers in refereed international publications. Babrauskas (1992) has produced an annotated bibliography of over 200 papers published in the 1982–1991 period. By 1991, over 50 papers were being published each year.

Table 6.1 – Cone calorimeter standards for use with wall and ceiling linings

Standard	Current version	Applications	Comments
ASTM E 1354	1997	General	
ASTM E 1740	1995	Wall covering composites	
NFPA 264	1992	General	
ISO 5660-1	1993	Building materials[a]	No smoke measurement
ULC-S135	1992	Building materials	Determines 'degrees of combustibility'
MIL-STD-2031	1991	Composite material systems used in submarines	
AS 1530.6	(1998)	General	To be published in the near future

[a] ISO is now considering extending the scope of this Standard to make it a general standard.

There are now in excess of 100 cone calorimeters located in over 20 countries. It has not yet been cited in any building codes.

6.6.4 Variability of results

ASTM (1990) conducted an interlaboratory assessment using six laboratories and six materials. The values they obtained for repeatability and reproducibility, calculated according to ISO 5725, are included in Appendix D. The variability results were compared with variability data for ISO 5657, the only method for which comparable data could be found. For ignition time, both repeatability and reproducibility were 'substantially better' for the Cone Calorimeter than for the ISO 5657 test over almost the entire range.

The ASTM Institute for Standards Research conducted an interlaboratory assessment on six materials (Janssens 1995). This interlaboratory assessment involved a greater number of laboratories; 17 in all, located in North America, Europe and Asia. In this interlaboratory assessment, also discussed in Appendix D, greater variability was found. This was attributed to the inclusion of more fire-retarded materials, although the inclusion of a greater range of laboratories may also have contributed.

An interlaboratory assessment has been conducted on the proposed Australian/New Zealand Cone Calorimeter standard (Apte & Fidler 1998). It was found that variability was similar to the ISO and ASTM studies.

6.6.5 Cost effectiveness

The Cone Calorimeter test requires quite small amounts of material. Typically three specimens 100 × 100 mm are required for each irradiance level. Testing with the Cone Calorimeter costs between $600 and $2000. Set-up costs are high and when large numbers of tests are being conducted the cost will be cheaper.

Data obtained from Cone Calorimeter tests can be used in fire engineering assessments. The small specimen size and the sophistication of the data obtained also make it a valuable tool for product development.

6.7 ISO Ignitability Test

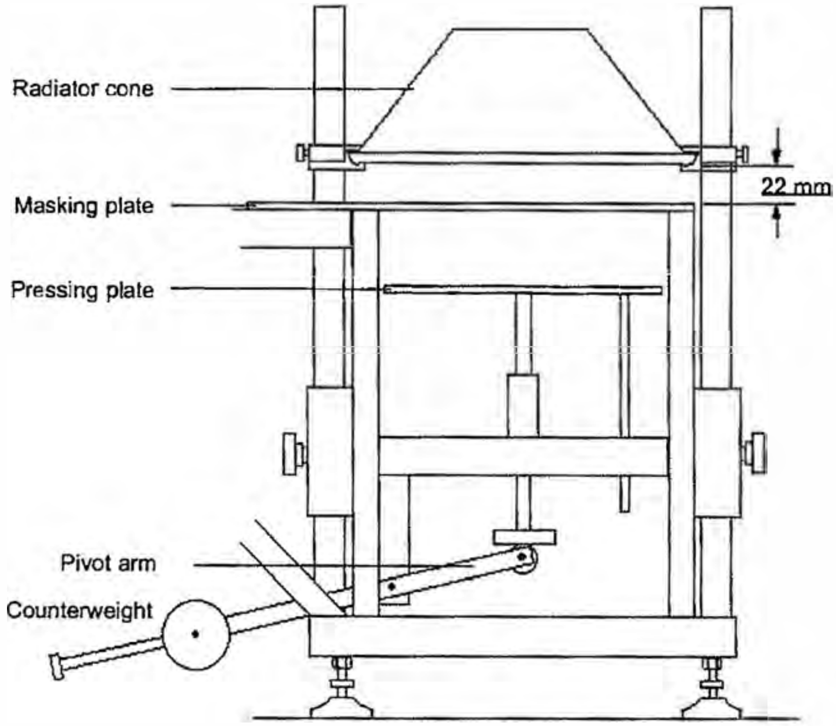


Figure 6.7 – ISO ignitability apparatus

The ISO Ignitability Test (ISO 5657) has been adopted in Australia as AS 1530.5. It uses a cone-shaped heater element, similar to that in the Cone Calorimeter, to radiate onto a horizontal specimen 165 × 165 mm (Figure 6.7). Each specimen is tested at irradiance levels of 10, 20, 30, 40 and 50 kW/m^2. A small pilot flame is dipped to within 10 mm of the surface every four seconds. The flame is reignited if necessary.

The parameter measured in this test is time to ignition at each irradiance level. The test is available at two laboratories in Australia.

6.7.1 Relationship to performance in real fires

The limits of applicability of this test are spelt out in AS 1530.5. The test does not provide any direct guidance on safety in fire.

6.7.2 Appropriateness for controlling wall and ceiling linings

The ISO Ignitability Test is designed to provide information on the ignitability of essentially flat systems, which include wall and ceiling linings.

A number of studies have been carried out comparing ignitability in the ISO Ignitability Test and the Cone Calorimeter (Babrauskas & Parker 1987; Östman *et al.* 1985; Östman & Tsantaridis 1990; Mikkola 1991). Whilst the results were generally similar, Östman and Tsantaridis (1990) concluded that the Cone Calorimeter should be used for the determination of ignitability instead of the ISO Ignitability Test.

6.7.3 International status

The ISO Ignitability Test is the subject of international standard ISO 5657.

6.7.4 Variability of results

The results of an interlaboratory assessment carried out in nine laboratories are reported in AS 1530.5. The parameter assessed was time to ignition. Repeatability within laboratories varied from 14–80%, depending on the material being assessed and the irradiance. Reproducibility between laboratories varied from 26–206%, once again depending on the materials and the irradiance. The greatest variability generally occurred at the lowest irradiances. The highest irradiance recommended in the standard is 50 kW/m^2. This is also the preferred irradiance for assessing building materials in the Cone Calorimeter. At this irradiance, the repeatability is 18–39% for different materials and the reproducibility is 26–64% for the same materials.

6.7.5 Cost effectiveness

The ISO Ignitability Test is not expensive either in materials or in testing cost.

6.8 NBS Smoke Chamber Test

The NBS Smoke Chamber Test was developed in the 1960s (Gross *et al.* 1966) as a means of ranking building materials by the visible smoke they produce. It was standardised as ASTM E 662 in 1979. The test is carried out in a small sealed chamber with a volume of about 0.5 m^3 (Figure 6.8).

Specimens 76 × 76 mm are positioned vertically in front of a radiation source. Tests are performed in both radiant-only mode and radiant with a small pilot flame impinging on the face of the test specimen. The smoke that is produced fills the unventilated chamber. The optical density of the smoke is measured throughout the test by a vertical light meter. The results of the test are expressed as specific optical density, a unit whereby the optical density is corrected for specimen area and chamber volume.

The test is available at two laboratories in Australia.

6.8.1 Relationship to performance in real fires

The current edition of ASTM E 662 warns that no basis is provided for predicting the fire hazard of materials or assemblies under fire conditions.

6.8.2 Appropriateness for controlling wall and ceiling linings

Whilst it was originally envisaged as a test that could be used for regulatory purposes, this is no longer the case. According to the current version of ASTM E 662, it is intended for use in research and development and not as the basis for ratings for control.

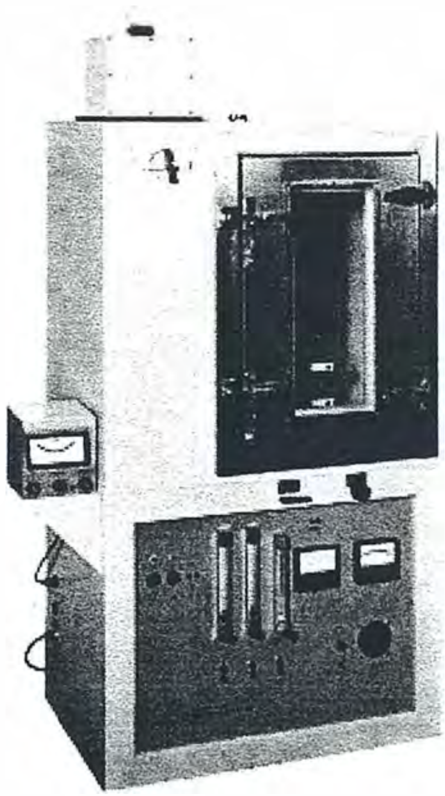


Figure 6.8 – NBS Smoke Chamber

6.8.3 International status

The test has not been standardised by ISO. There is little literature originating outside North America on this test.

6.8.4 Variability of results

ASTM has conducted an interlaboratory assessment on the NBS Smoke Chamber test using 25 materials and 20 laboratories. The results for variability in maximum optical density are reported in ASTM E 662. Repeatability within laboratories varied from 5–51%, depending on the material and whether it was flaming or non-flaming mode. Reproducibility between laboratories varied from 16–118%, once again depending on the materials and the mode.

As a result of the interlaboratory assessment, changes were made to the procedure and ASTM believes that should another interlaboratory assessment be conducted, better precision would be achieved.

6.8.5 Cost effectiveness

The NBS Smoke Chamber Test is not expensive either in materials or in operating cost.

Data obtained from the test is not suitable for fire engineering purposes. It has some use in product development and quality control.

6.9 Conclusions

- The real fire performance of lining materials can be assessed by considering time to flashover in a room fire. By equating the size of fire needed to cause flashover in the room fire test with the size of fire needed to cause flashover in a room, a test room representing a real fire scenario can be constructed. The time to flashover associated with various lining materials can then be measured. This provides a benchmark for performance against which various small-scale tests can be 'calibrated'.
- Time to flashover in both the ASTM and the ISO Room Fire Tests is a suitable measure of real fire performance for regulatory purposes. The variabilities inherent in these tests allow only broad distinctions to be made between materials.
- The ISO Room Fire Test is the subject of international standards and publications, and is currently to be preferred to the ASTM Room Fire Test. Consideration could be given to the ASTM test when that method has been standardised.
- The suitability of the Early Fire Hazard Test and the Cone Calorimeter for controlling the fire behaviour of lining materials will depend on how well they can predict time to flashover in the ISO Room Fire Test. This will be determined in Chapter 8.
- The ISO Ignitability Test does not provide sufficient data by itself to assess real fire performance. The NBS Smoke Chamber is not designed to provide data on hazard. Therefore these two tests will not be considered further.

7 – Available Test Data

7.1 Introduction

The data collected as part of Project 2 came from a limited number of sources. Whilst an enormous amount of data on the fire behaviour of wall and ceiling linings has been published, little of it adds information of direct use to this project. Often the data refers to national test methods not of interest in Australia, or it has been generated in non-standard experiments designed to demonstrate a particular performance characteristic of a material or to provide data for testing a particular mathematical model.

One major source of data was publications from the EUREFIC program. This research program, which has similarities to Stage A of Project 2, is described in Research Paper 1.

7.2 Data from Large-scale Experiments

Large-scale experiments are designed to simulate specific real life scenarios, and hence each experiment is different. Data from such experiments gives some insight into the behaviour of wall and ceiling linings in real fires, and helps provide a link between fire tests and real fires.

7.2.1 Experiments in ISO/ASTM room

Some experiments were carried out in the ISO/ASTM room by CSIRO as part of Project 2 (see Research Papers 5 and 7). Variables examined included ignition sources (standard ISO burner versus an armchair) and specimen configurations (walls only, ceilings only, walls and ceilings).

In Table 7.1, the ISO gas burner as an ignition source is compared with a burning armchair (described in Research Paper 5) for two wall linings – gypsum plasterboard and plywood. The initiating source for the armchair was a wood crib with a peak heat release rate of about 30 kW. The ISO gas burner in conjunction with gypsum plasterboard does not produce flashover in the ISO/ASTM room, whereas the armchair in conjunction with gypsum plasterboard does produce flashover. In Research Paper 5, it was shown that the heat release from the plasterboard is negligible. Therefore, in the experiment with the armchair, flashover is due almost entirely to the armchair.

In the experiments with plywood wall linings, the time to flashover is similar with both ignition sources. For the plywood in conjunction with the armchair, the time to flashover is less than for the gypsum plasterboard in conjunction with the armchair. Therefore, the plywood wall lining has reduced the time to flashover in the ISO/ASTM room with a burning armchair.

Table 7.1 – Time to flashover in the ISO/ASTM room with different ignition sources for two wall linings[a]

Ignition source	*Time to flashover (s)*	
	Gypsum plasterboard (A9)	*Plywood (A10)*
ISO gas burner	N[b]	163
Armchair	240[c]	160

[a] Ceilings were lined with gypsum plasterboard.
[b] No flashover.
[c] Video records showed that flashover was due entirely to the armchair.

Lee (1985b) conducted similar experiments. He was investigating the role played by wall linings and contents in fire growth in US Park Services (USPS) lodging bedrooms. He conducted room fire experiments in an ISO/ASTM room fitted out with contents typical for such a lodging, and with either gypsum plasterboard or plywood wall linings. The contents consisted of a double bed with mattress and base (both innerspring); bedding; wood headboard; wood night table; and a polyethylene wastepaper basket fitted with a polyethylene liner and filled with mainly paper and cardboard rubbish. The wastepaper basket contents were ignited by a match to initiate the fire. Comparable experiments were run in which the wall linings were plywood or gypsum plasterboard (Table 7.2). In all four experiments, the contents produced flashover, though it would appear that people with tidy habits have more escape time.

Room fire tests on furniture were also carried out as part of the CBUF (Combustion Behaviour of Upholstered Furniture) Program in Europe (CBUF 1995). In the ISO/ASTM room, they found it was not uncommon for items such as a three-seater sofa to cause flashover in 2 minutes in the absence of any contribution from wall or ceiling linings. The initiating source was a 30 kW gas burner.

The ignition source in the CSIRO corridor experiments (see Section 7.2.3) was a mock-up of a three-seater sofa. The sofa was located in an ISO/ASTM sized room opening onto the corridor. This mock-up sofa, when ignited with a match, produced flashover in the room within 2 minutes.

Table 7.3 shows data comparing the behaviour of materials as wall linings and as ceiling linings in the CSIRO room fire tests. The time from start of test to flashover is made up of two

Table 7.2 – Time to flashover in the ISO/ASTM room with standard USPS lodging bedroom fittings for two wall linings[a]

Initiating source	*Time to flashover (s)*	
	Gypsum plasterboard	*Plywood*
Wastepaper basket	233; 615[b]	293; 287[b]

[a] Ceilings were lined with gypsum plasterboard.
[b] Duplicate experiments; the slower time to flashover in the second experiment with gypsum plasterboard walls was attributed to the bedding being in less disarray.

Table 7.3 – Time to flashover in ISO/ASTM room for walls versus ceilings

Material	*Specimen configuration*[a]	*Time to ignition (s)*	*Time from ignition to flashover (s)*
Lauan plywood (A10)	Walls only	20	140
	Ceiling only	240	160
Hoop pine plywood, treated (A11)	Walls only	22	240
	Ceiling only	290	245

[a] Remaining walls/ceiling were lined with gypsum plasterboard.

components: the time to ignition of the lining; and the time from ignition of the lining to flashover. The time to ignition is similar for both materials in each configuration, and is dependent on the position of linings in relation to the gas burner. The time from ignition to flashover is primarily dependent on the nature of the lining and is less dependent on the location of the lining.

For all of these experiments, the ignition source was located at or near floor level. Different results could be expected if the ignition source was located near the ceiling, such as would be the case if the initiating source was flame licking from an adjoining room. This latter scenario is simulated in the corridor experiments described later.

7.2.2 Experiments in a larger room

In the EUREFIC program, fire experiments were carried out on wall and ceiling linings in a room that was much larger than the ISO/ASTM room (Kokkala *et al.* 1990; 1992). The linings assessed had previously been assessed in the ISO Room Fire Test. The purpose of these experiments was to determine whether there were scaling effects that limited the usefulness of data obtained in the ISO Room Fire Tests. Some results of the experiments and the important details of the rooms are shown in Table 7.4.

The experiments in the larger room were found to produce less severe exposure than the standard ISO Room Fire Test. Only those materials that went to flashover at 100 kW in the ISO room went to flashover in the larger room, and then only when the gas burner had been raised

Table 7.4 – Time to flashover in two different room sizes[a]

Material[b]	*Time to flashover (s)*	
	ISO room	*Large room*
Combustible-faced mineral wool (E7)	96	1300
Ordinary birch plywood (E2)	146	1170
PVC wall carpet on gypsum board (E10)	612	N
Textile wall covering on gypsum board (E3)	630	N
FR particleboard type B1 (E6)	934	N

[a] Details of the two rooms are:

	ISO room	Large room
Dimensions (L × W × H) (m)	2.4 × 3.6 × 2.4	6.7 × 9.0 × 4.9
Doorway (W × H) (m)	0.8 × 2.0	2.0 × 2.0
Gas burner (10-minute steps) (kW)	100/300	100/300/900

[b] Walls and ceiling.

to 300 or 900 kW.
It can be concluded that:

- in the presence of minimal contents, represented by the gas burner, flashover due to wall and ceiling linings is less likely in large rooms; and
- the ISO Room Fire Test, which is conducted in a small room, gives a conservative assessment of the hazard of wall and ceiling linings.

7.2.3 Experiments in corridors

A series of experiments was conducted by CSIRO as part of Project 2 in a facility comprising a room with an adjoining corridor. These are reported in Research Papers 5 and 7. The room has the same dimensions as an ISO/ASTM room, whilst the corridor is 10 × 1 × 2.1 m high. The room/corridor set-up is described in Research Paper 5. The scenario selected simulated a room fire with just sufficient fuel to attain flashover (1 MW) and then die back. The enclosure provided an ignition source for the wall or ceiling linings in the adjoining corridor, but did not contribute significantly to the spread of fire in the corridor. Ventilation for both the room and the corridor was from the remote end of the corridor only. Results from these experiments are given in Table 7.5.

In these experiments, ignition of the linings in the corridor occurred at about the same time irrespective of whether they were wall linings or ceiling linings. This was because the initiating flame, which emanated from the adjoining room, impinged on the ceiling and the upper walls. In the experiments involving wall linings, both sides of the corridor were ignited in all cases.

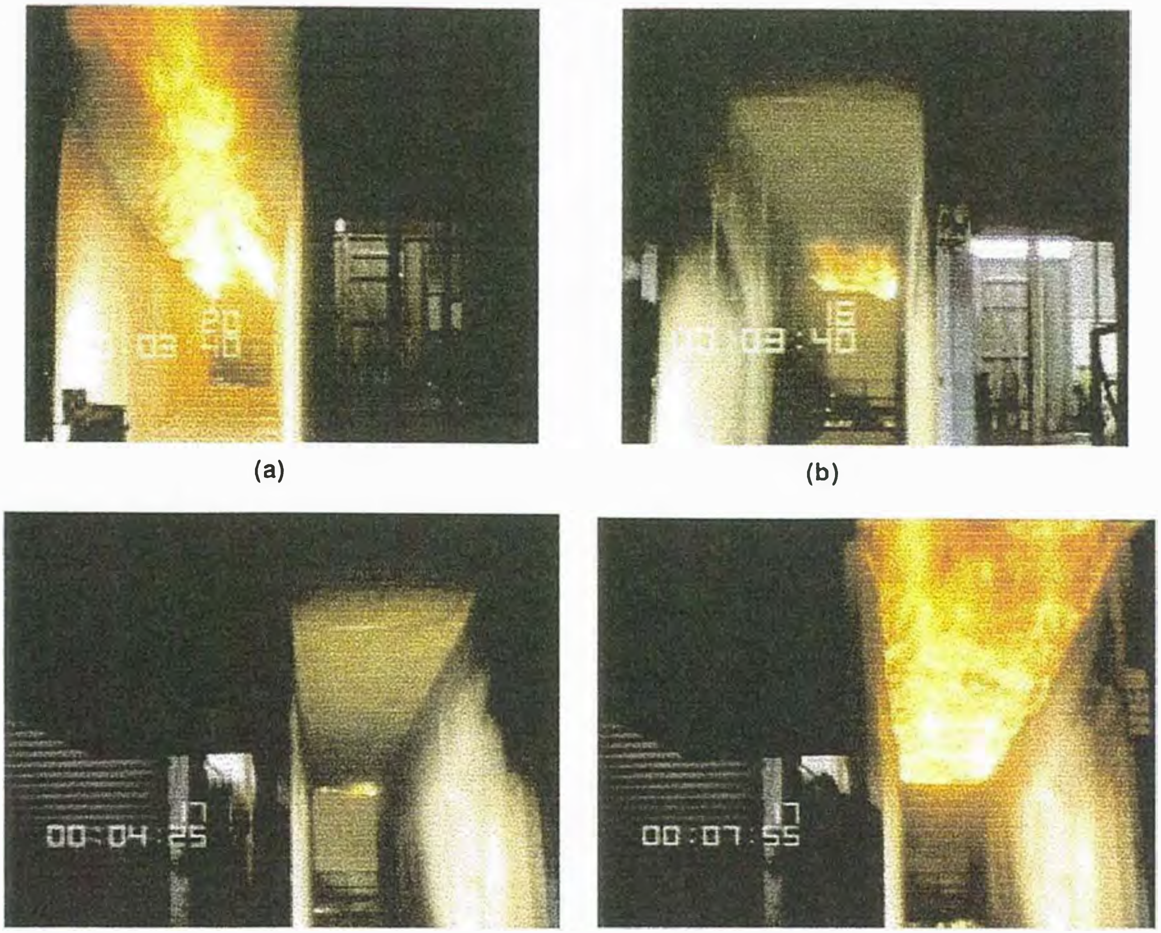
For the lauan plywood, the wall linings produced untenable conditions and spread flame more rapidly than the ceiling linings; for the treated hoop pine plywood, the ceiling lining spread flame and produced untenable conditions, whereas the wall linings did not (Figure 7.1). These experiments indicate that in corridors and other narrow spaces, there is little point in discriminating between controls on wall and ceiling linings.

Gardner and Whitlock (1998) carried out a series of fire tests in a corridor that was of the same

Table 7.5 – Flame spread and untenable conditions in CSIRO corridor experiments

Material	*Specimen configuration*[a]	*Time to ignition (s)*	*Time from ignition to untenable conditions*[b] *(s)*	*Time from ignition for flame spread*[c] *(s)*
Gypsum plasterboard (A9)	Walls & ceiling	N[d]	N	N
Lauan plywood (A10)	Walls	130	30	40
	Ceiling	135	85	105
Hoop pine plywood, treated (A11)	Walls	130	N	N
	Ceiling	140	260	275

[a] The remaining walls or ceiling were lined with ceramic fibreboard. The floor was cement sheet.
[b] Untenable conditions were defined as a hot layer boundary at 1.9 m.
[c] To end of corridor.
[d] Event did not occur.



(a) (b) (c) (d)

Figure 7.1 – Flame spread in an experimental corridor following a flashover fire in an adjoining room: (a) lauan plywood walls; (b) lauan plywood ceiling; (c) treated hoop pine plywood walls; and (d) treated hoop pine plywood ceiling

dimensions as the corridor described above and which represented a corridor in an apartment building. The tests were conducted for State Forests of New South Wales. The fire scenario was different from that in the Project 2 experiments described above. The ignition room was of masonry construction measuring 2.5 × 1.0 × 2.4 m high. An LPG burner was placed 0.5 m above the floor 1 m from the doorway leading to the corridor. A movable shutter mounted at the top of a solid-core timber door was used to simulate the door burning through. When the shutter had been opened, flame spread into the corridor. The gas burner was maintained at 0.8 MW output until four minutes after the shutter had been opened. The output was then increased to 1.6 MW for eight minutes and then to 1.9 MW for a further three minutes. The burner was extinguished 15 minutes after the shutter was opened.

Fresh air was taken in through vents in the lower part of one side wall, and combustion products were vented to the atmosphere through an opening in the lower half of the rear wall. The intent was to maintain a positive pressure in the upper half of the ignition room.

The behaviour of a number of wall and ceiling linings were studied, including one wall lining with and without sprinklers present. Some of the results are reproduced in Table 7.6.

Table 7.6 – Flame spread and untenable conditions in NSW State Forests/CSIRO corridor experiments

Material	*Specimen configuration*[a]	*Time to ignition* (s)	*Time from ignition to untenable conditions*[b] (s)	*Time from ignition for flame spread*[c] (s)
Sprinkler absent				
Gypsum plasterboard	Walls & ceiling	—	N[f]	N
Polyester/nylon textile	Walls	400	N	N
Particleboard, FR coated	Walls	485	N	N
Sheet vinyl	Walls	345	N	N
Mirrored polystyrene	Walls	380	190	100
Western red cedar	Walls	325	235	185
Wool/nylon carpet	Walls	285	145	135
Particleboard	Walls	380	210	170
Particleboard	Lower walls	N	N	N
Particleboard	Ceiling	375	N	435
Sprinklers present[d]				
Particleboarde[e]	Walls	N	N	N

[a] The remaining walls or ceiling were lined with gypsum plasterboard. The floor was concrete.
[b] Untenable conditions were defined as a temperature of 180°C at 1.85 m, 8 m into the corridor.
[c] To end of corridor.
[d] Sprinklers were located 2.3 and 6.9 m into the corridor.
[e] Sprinkler at 2.3 m operated at 310 s; sprinkler at 6.9 m did not operate.
[f] Event did not occur

The experiments with particleboard wall linings were conducted with and without sprinklers present. In the absence of sprinklers, both untenable conditions and flame spread to the end of the corridor were achieved. In the presence of sprinklers (conforming to AS 2118), neither untenable conditions nor flame spread to the end of the corridor were achieved. This experiment supports the view that sprinklers can prevent wall linings in corridors from spreading fire and causing untenable conditions.

Gardner and Whitlock (1998) compared one material – particleboard – as a wall lining and as a ceiling lining. They found that the particleboard wall linings produced untenable conditions more rapidly and spread fire more rapidly than particleboard ceiling linings. This finding agrees with the findings of the CSIRO Project 2 corridor experiments, and shows that in narrow corridors, untreated timber products used as wall linings can produce untenable conditions and spread flame more rapidly than untreated timber products used as ceiling linings.

Gardner and Whitlock also looked at the effect of lining only the lower half of walls in corridors with a combustible material, in this case particleboard. They found that when particleboard was used to line only the lower half of the walls, ignition did not occur. This demonstrates that in corridors, the lower half of the wall does not play as large a part in fire growth and spread as the upper half.

7.3 Data Showing Distribution of Results in Room Fire Test

Data produced in fire tests is not always continuous and care must be taken when analysing results as a function of time. Material behaviour might alter significantly when a particular test parameter is changed, leading to a grouping of results immediately following the change. The major variable measured in the Room Fire Test is time to flashover. In the Room Fire Test (both ISO and ASTM versions), the burner operates at a fixed output for a specified period of time, and at the end of that time, if flashover has not occurred, the burner output is raised to a new fixed level. For example, in the ISO Room Fire Test the burner output is increased from 100 to 300 kW after 10 minutes.

Figures 7.2 and 7.3 show the distributions of occurrence of flashover in the Room Fire Test, using the ISO and ASTM gas burner programs, for a variety of materials. It can be seen that the Room Fire Test, in each case, has identified three broad groups of materials, corresponding to steps in the burner function. In the case of the ISO Room Fire Test these groups are:

- materials that reach flashover after exposure to 100 kW;

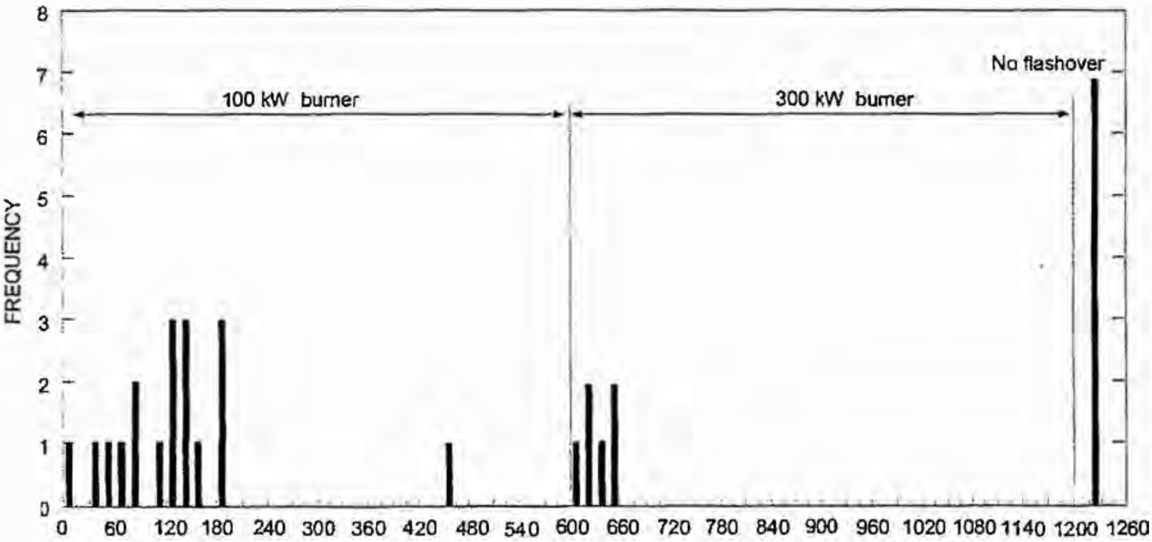


Figure 7.2 – Distribution of occurrence of flashover in the ISO Room Fire Test

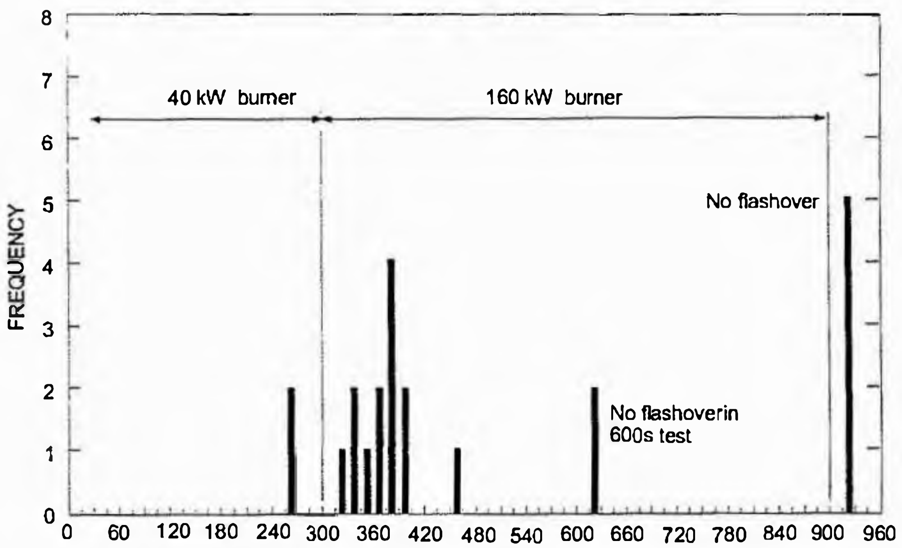


Figure 7.3 – Distribution of occurrence of flashover in the ASTM Room Fire Test

- materials that reach flashover after exposure to 300 kW; and
- materials that do not reach flashover after exposure to 300 kW.

The data used for Figures 7.2 and 7.3, and the list of materials from which it was obtained, are tabulated in Tables E1 and E2 of Appendix E.

7.4 Data from Small-scale Tests

A large volume of data from the Early Fire Hazard Test and the Cone Calorimeter has been published, but only data on materials for which large-scale fire test data is also available can be used in assessing the suitability of the small-scale tests. This data is presented in Appendix E in Table E4 for the Early Fire Hazard Test and Table E5 for the Cone Calorimeter.

Data on a number of materials for which there is no large-scale fire test data is also included in Table E4. These materials, identified by not having a code number, are useful in assessing the impact of change to the BCA (see Section 12).

7.5 Data for Comparing Small-scale Tests with Large-scale Tests

The ability of a small-scale test to predict the likely performance of a lining material in the event of a fire will depend upon its ability to predict time to flashover in a room fire test. The selection of the most appropriate small-scale test will depend upon the accuracy of these predictions. Therefore, data from materials that had been tested in both small-scale and large-scale fire tests was collected for comparison. The available data is shown in Figure 7.4.

To ensure that comparisons had a reliable basis and were not biased by uncharacteristic data, it was decided that comparisons should be made only where data was available to compare at least 10 materials in the same two tests. This meant that the following comparisons were possible:

- Cone Calorimeter with ISO Room Fire Test;
- Cone Calorimeter with ASTM Room Fire Test; and

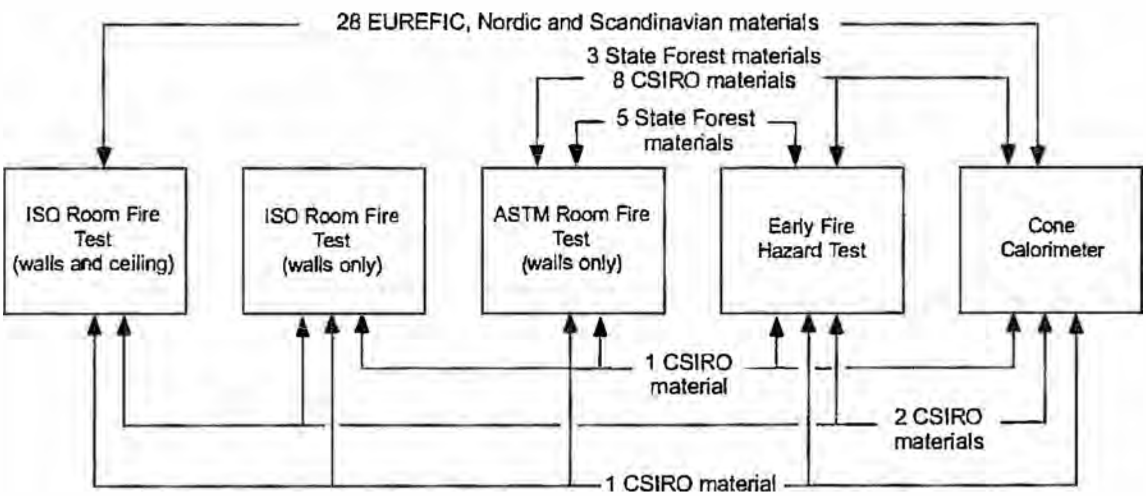


Figure 7.4 – Data available for comparing fire tests

- Early Fire Hazard Test with ASTM Room Fire Test.

These three comparisons are performed in Chapter 8.

8 – Relationship of Small-scale Tests to Large-scale Tests

8.1 Introduction

Chapter 6 examined available test methods, and concluded that the suitability of the Early Fire Hazard Test and the Cone Calorimeter for controlling the fire behaviour of lining materials will depend on how well they can predict time to flashover in the ISO Room Fire Test. Chapter 7 looked at data that is available for comparing small-scale tests with large-scale tests. This chapter uses the comparative data to assess the suitability of the candidate small-scale tests.

If a small-scale test can be shown to adequately predict the behaviour of wall and ceiling linings in the ISO Room Fire Test, then results from the small-scale test may form a reasonable basis on which to classify materials. If the classification of a material using a small-scale test is uncertain, the ISO Room Fire Test should remain the final arbiter.

8.2 Early Fire Hazard Test

In order to compare performance in the Early Fire Hazard Test with performance in the ISO Room Fire Test, similar or identical samples of material must be burned in both tests. The data available for comparing the Early Fire Hazard Test with various ISO/ASTM Room Fire Test configurations is as follows:

- walls and ceilings in conjunction with ISO gas burner program – 3 materials;
- walls only in conjunction with ISO gas burner program – 4 materials; and
- walls only in conjunction with ASTM gas burner program – 18 materials.

The first of these used the standard ISO configuration set out in ISO 9705, and referred to in this report as the ISO Room Fire Test. The third used the configuration for the ASTM/ISO inter-laboratory assessment (Beitel 1994) and referred to in this report as the ASTM Room Fire Test.

There is insufficient data to directly compare results from the Early Fire Hazard Test with those from the ISO Room Fire Test. However, there is sufficient data to compare the Early Fire Hazard Test with the ASTM Room Fire Test. Since the ISO Room Fire Test and the ASTM Room Fire Test are so similar, these comparisons will provide an indication of whether the Early Fire Hazard Test can be used to predict the occurrence of flashover in the ISO Room Fire Test.

The parameter from the Early Fire Hazard Test that is currently used in the BCA to control the flame spread of materials is the Flame Spread Index (smoke is discussed later). Gardner and Thomson (1988) have shown that the Flame Spread Index cannot be used to predict time to

flashover in the ASTM Room Fire Test. This conclusion is supported by CSIRO data reported in Research Paper 6. A comparison of the Flame Spread Index of the Early Fire Hazard Test with time to flashover in the ASTM Room Fire Test using the combined data is shown in Appendix F, Figure F1.
Two materials that recorded a Flame Spread Index of 0 in the Early Fire Hazard Test went to flashover in the ASTM Room Fire Test when the gas burner was turned up to 160 kW. These same materials would have certainly gone to flashover in the ISO Room Fire Test when the gas burner was turned up to 300 kW, if they had not already done so when the burner was at 100 kW. Thus, these two materials (with the lowest possible Flame Spread Index) will certainly go to flashover in the ISO Room Fire Test. These cases demonstrate that the Flame Spread Index is unable to predict the occurrence of flashover in the ISO Room Fire Test.

Ignitability in the Early Fire Hazard Test has been studied by Gardner and Thomson (1988). They found a correlation between time to ignition in the Early Fire Hazard Test and time to flashover in the ASTM Room Fire Test for a range of timbers with similar ignition times. A fire-retarded timber, which did not go to flashover in the ASTM Room Fire Test, did not provide the necessary data and so could not be included in their calculation. Inclusion of data from a wider range of materials shows a more scattered spread of results (Figure F2). All the non-fire-retarded timbers are grouped in the body of the chart, with all other materials (comprising fire-retarded timbers, plasterboards, and solid and foamed plastics) falling on the edges of the chart.

The correlation developed by Gardner and Thomson (1988) did not include any consideration of the step that occurs in the ASTM Room Fire Test gas burner outputs. This step needs to be taken into account if a correlation is to be applicable to a wider range of materials than those used in their study.

On this evidence, we do not believe that ignitability measured in the Early Fire Hazard Test is able to predict the occurrence of flashover in the ISO Room Fire Test.

There are no models available for predicting time to flashover in the ASTM or ISO Room Fire Tests from Early Fire Hazard Test data. In order to determine whether such a model could be developed, a simple relationship has been assessed and is described below.

A description of the relationship is given in Appendix F, and is plotted in Figure F3. It compares a factor based on the Ignition Index and Heat Evolved Index in the Early Fire Hazard Test with time to flashover in the ASTM Room Fire Test (see Appendix F). These parameters were chosen because models for predicting time to flashover in the ISO Room Fire Test always use time to ignition and rate of heat release per unit area from small-scale tests (Kokkala *et al.* 1993; Wickström & Göransson 1992; Karlsson 1993; Quintiere 1997). Unfortunately data from the Early Fire Hazard Test is in terms of rate of heat release, not rate of heat release per unit area (in this test only the radiant heat release rate is measured). The factor we are considering did not satisfactorily predict time to flashover in the ASTM Room Fire Test. Materials with similar factors flashed over in some cases but did not in others, whilst materials determined to have similar times to flashover had a wide range of factors. The proposed relationship is therefore not able to predict time to flashover in the ISO Room Fire Test.

All of the above approaches are limited in that they do not include any consideration of the steps that occur in the Room Fire Test burner outputs. Nevertheless, the spread of results in each case demonstrates that it is not possible to define even broad groups of linings, in terms of time to flashover in the ISO Room Fire Test, on the basis of Indexes from the Early Fire Hazard

Test.

8.3 Cone Calorimeter

There are at least three models that use Cone Calorimeter data to predict time to flashover in the ISO Room Fire Test. They are the SP model (Wickström & Göransson 1992); the Classification Indexes (Kokkala *et al.* 1993); and the Östman relationship (Östman & Tsantaridis 1994). All three models use ignitability and heat release rate per unit area data. All three were developed as part of the EUREFIC program.

8.3.1 SP model

Wickström and Göransson at the Swedish National Testing and Research Institute (SP) have developed a model that allows prediction of the heat release rate curve in the ISO Room Fire Test using Cone Calorimeter data.

The inputs from the Cone Calorimeter that are used are:

- time to ignition; and
- the complete heat release rate per unit area curve.

Calculation is done using existing computer programs. Software is commercially available from SP.

A description of the model can be found in Wickström and Göransson (1992). A brief overview of the model is contained in Appendix F. The model was developed on a series of 13 products. Wickström and Göransson (1992) have compared the predictions for these products and a further three products. They found that the predictions were reasonably good for all products, with no failures. The current version of the software employs data determined at 25 kW/m^2, which presents problems for materials that do not ignite at this irradiance in the Cone Calorimeter. When software that employs data obtained at 50 kW/m^2 is routinely available, this model should be suitable for use in calculations relating to the performance of wall and ceiling linings.

Sumathipala *et al.* (1994) have compared predictions using the SP model with experimental data for the ISO Room Fire Test. They found that the SP model provided good predictions for six out of seven materials. The seventh material (expanded polystyrene) did not ignite in the Cone Calorimeter at an irradiance of 25 kW/m^2, the irradiance on which they based their calculations. It did ignite at 50 kW/m^2, and these calculations should preferably utilise data determined at this irradiance.

8.3.2 Classification indexes

M. Kokkala at VTT Finland, P. Thomas of the UK and B. Karlsson of Lund University, Sweden, have developed a method of calculating an Ignition Index and a Heat Release Index from Cone Calorimeter data (Kokkala *et al.* 1993). These 'Classification Indexes' were developed by applying dimensional analysis and fire growth modelling to the ISO Room Fire Test. The indexes are used to predict the time to flashover in the ISO Room Fire Test.

The inputs from the Cone Calorimeter that are used are:

- time to ignition; and
- the complete heat release rate per unit area curve.

Calculation can be done by hand or by a simple computer program. Software is freely available from VTT Building Technology, Finland. The Classification Indexes are described in Kokkala *et al.* (1993).
A brief description of the calculation of the Indexes is given in Appendix F. The Indexes have been compared with experimental data for 28 materials (Kokkala *et al.* 1993). The Indexes correctly predicted flashover would occur at either 100 kW or 300 kW or not at all in every case. They also correctly predicted which material would go to flashover within two minutes at each of these levels. These materials are listed in Table G1 in Appendix G.

8.3.3 Östman relationship

Östman has developed an empirical relationship to estimate time to flashover in the ISO Room Fire Test using parameters measured in the Cone Calorimeter.

The following inputs from the Cone Calorimeter are used:

- time to ignition; and
- total heat release per unit area during 300 s after ignition.

The relationship is described in Östman and Tsantaridis (1994). Unlike the previous two relationships, it does not include any consideration of the step that occurs in the ISO Room Fire Test burner output. Therefore, this model is not suitable for the prediction of time to flashover in the ISO Room Fire Test for regulatory purposes.

8.3.4 Validation experiments

The above three models were developed using the data from the same set of 28 EUREFIC, Nordic and Scandinavian specimens. As part of Project 2, an additional three specimens were subjected to the ISO Room Fire Test and the Cone Calorimeter. The times to flashover, as determined by the ISO Room Fire Test and predicted by the SP model and the Classification Indexes, are shown in Table 8.1.

8.4 Discussion

Table 8.1 – Time to flashover for validation materials

Material	*Time to flashover (s)*	
	Measured ISO Room Fire Test	*Predicted Classification Indexes*
Gypsum plasterboard (A9)	N[a]	N
Lauan plywood (A10)	125	120–600
Hoop pine plywood, treated (A11)	190	120–600

[a] No flashover.

Research has shown that the best tests for assessing wall and ceiling linings are large-scale tests. The ISO Room Fire Test is the only standardised large-scale fire test that is suitable for assessing wall and ceiling linings. Therefore it is currently the best test for this purpose. The parameter that has been found to be the most suitable measure of performance for lining materials is time to flashover. In Chapter 7 it was shown that the ISO Room Fire Test could reliably divide materials into three groups. These are:

- materials that reach flashover after exposure to 100 kW;
- materials that reach flashover after exposure to 300 kW; and
- materials that do not reach flashover after exposure to 300 kW.

Any small-scale test that can reliably predict time to flashover in the ISO Room Fire Test can be used in lieu of the large-scale test for routine testing of materials. Data obtained from experiments conducted as part of this project, along with data collected from many sources, show that data from the Cone Calorimeter reliably predicts flashover in the ISO Room Fire Test.

Attempts to use data from the Early Fire Hazard Test to predict flashover in the Room Fire Test have only been successful for a limited range of timber products. One reason may be that the Early Fire Hazard Test is a benign test compared to the Room Fire Test. Babrauskas (1995) has recommended that all fire tests for linings should have an irradiance of at least 35 kW/m^2 in order to be sufficiently like real fires. The maximum irradiance in the Early Fire Hazard Test is 25 kW/m^2 (Martin & Dowling 1979).

On the evidence so far, no Indexes of the Early Fire Hazard Test reliably predict time to flashover in the ISO Room Fire Test. Therefore, the Early Fire Hazard Test is not suitable for use in performance-based codes for the control of wall and ceiling linings (see Appendix F, Section F1).

8.5 Summary

- Relationships have been developed that allow data from the Cone Calorimeter to be used in predicting how materials will perform in the ISO Room Fire Test. The best of these is the Classification Indexes developed as part of the EUREFIC program. It should be possible to use data from the Cone Calorimeter, in conjunction with the Classification Indexes, for routine testing of many wall and ceiling linings.
- There are no relationships that allow Early Fire Hazard Test data to be used in predicting the behaviour of linings in the ISO Room Fire Test.

9 – Quantitative Test Performance Levels

9.1 Introduction

Once performance considerations for each location within each building have been identified, a process for quantifying the considerations in terms of measurable properties of materials must be developed. Ideally, characteristic evacuation times would be developed for each location in each building occupancy, and the influence of linings on fire growth would be isolated using models that would predict the time available for escape. Since such models are not currently available, qualitative consideration of the factors that will influence fire growth and escape time have been considered. In addition, data is available to illustrate quantitatively the suitability of particular linings in specified occupancies. This data has been used to benchmark particular cases, against which other occupancies and locations can be assessed. This chapter discusses the factors involved in the quantification and describes the process used to establish benchmarks.

9.2 Performance Considerations – Test Performance Groups

Project 2 research has shown that the relevant properties of materials can be measured with a degree of accuracy to provide broad groups only (see Chapter 7). These groups are, based on results from the ISO Room Fire Test:

- materials that reach flashover after exposure to 100 kW;
- materials that reach flashover after exposure to 300 kW; and
- materials that do not reach flashover after exposure to 300 kW.

Furthermore, there are certain lining materials that will make a significant contribution to a reduction in time to untenable conditions and to an increase in flame spread no matter what the fire load due to the building contents, and which should not be used under any circumstances. These materials will reach flashover in the ISO Room Fire Test after only brief exposure to 100 kW, long before the burner power is increased to 300 kW. In other words, the first group needs to be subdivided. The challenge is to select a time to flashover that will protect against the use of unsuitable materials without disadvantaging materials known to be acceptable. The possible consequences of using unsuitable materials are clearly illustrated by the case history on the Dance Hall, St Laurent du Pont, France (see Chapter 2). Even in buildings protected by sprinklers, it is important to ensure that sprinklers are not overwhelmed by rapid fire spread via highly flammable materials.

The Project 2 Working Group agreed that any lining material used in building construction should offer at least an acceptable level of safety to the occupants of a small, sparsely furnished room – a situation where the linings could contribute significantly to the threat. The room might perhaps be a small bedroom in an apartment. The Working Group agreed that the following analysis supported the view that in such a room, commonly used lining materials (such as timber panelling) will not contribute to fire development until after the occupants have escaped. Escape time from the room can be calculated taking into account existing BCA requirements. In Class 2 buildings, the BCA currently requires residential sole-occupancy units to be fitted with smoke detectors between living and sleeping areas. In a series of ASTM Room Fire Tests conducted by Gardner and Thomson (1988), smoke detectors were fitted outside the room in order to determine their time to activation. Video records of the tests showed that the smoke detectors were activated within 30 seconds of the fire starting in the room when the door was left open. In another series of tests, an armchair was burnt in an ISO room with and without combustible linings (see Research Paper 5). Analysis of the data indicated that, had a smoke detector been present outside the room, the burning of the armchair alone would have activated it. The linings did not become involved until after 110 seconds (see Section 9.3.10).

Conservative estimates show that the response time of a sleeping adult to an alarm is 30 seconds (see Fire Code Reform Project 4) and that it takes a further 30 seconds to evacuate the unit. The room will therefore be evacuated within 90 seconds of the fire starting. If the room were to reach flashover within 120 seconds of the fire starting (in the ISO Room Fire Test, timbers flash over in 125–150 seconds, see Table E1), the occupants would be well clear of the fire by the time flashover occurred. Although the state of the door will affect the activation of the detector, experiment has shown that, for a very fast fire, there is sufficient leakage around a standard solid-core door to activate a standard smoke detector within 30 seconds (Paul England, pers. comm.). Research has shown that small smouldering fires that cause deaths almost always involve contents rather than linings (Hirschler 1996; Ohlemiller 1995) and are therefore not relevant to this discussion.

With the above analysis to support their case, the Working Group agreed that any material that went to flashover in less than 120 seconds in the ISO Room Fire Test should be considered unacceptable for use in buildings. The four test performance groups can be expressed in terms of results achieved in the ISO Room Fire Test as follows:

Group a—materials that reach flashover in less than 120 seconds after exposure to 100 kW;
Group b—materials that reach flashover in more than 120 seconds after exposure to 100 kW;
Group c—materials that reach flashover after exposure to 300 kW; and
Group d—materials that do not flashover after exposure to 300 kW.

This recommendation concurs with the findings of the EUREFIC program, which were based on consideration of materials rather than egress.

The EUREFIC program adopted a Nordic scheme for classification of materials (Sundström and Göransson 1988) in which any material that performed as well as wood was acceptable (with possible limitations on its use) as a lining material in buildings. It was believed that wood was a traditional material of historically known satisfactory performance. Materials that performed worse than wood were not acceptable under any circumstances. On this basis, the EUREFIC program recommended that any material that went to flashover in less than 120 seconds in the ISO Room Fire Test was not acceptable (Sundström 1991).

In qualitative terms, the test performance groups could be described as (Kokkala *et al.* 1993):

Group a—products with propensity to rapid fire growth under moderate exposure;
Group b—products with propensity to normal fire growth under moderate exposure;
Group c—products with propensity to normal fire growth under high exposure;
Group d—products with low propensity to fire growth.

Materials that fall into Groups a, b, c and d are listed in Table G1 in Appendix G.
In Table 9.1, Project 2 validation materials have been classified both according to their measured time to flashover and according to the predictions of the Classification Indexes, using data from the Cone Calorimeter. Material groupings for a larger range of materials determined by prediction and by measurement are given in Table G2 in Appendix G.

9.3 Application of Test Performance Groups to Building Categories and Locations

As a next step in the quantification process, the application of test performance groups must be considered for each location in each building category, taking into account the considerations listed in Table 5.1.

The factors influencing test performance groups are shown in Table 9.2. In filling in the table, the following contributory factors were taken into consideration. Values leading to conservative controls were adopted. In some cases, differences in contributory factors made it necessary to give separate consideration to specific areas within 'rooms' as described in Section 3.3.

9.3.1 Linings versus contents

In many cases, the contents of an enclosure will be such that in the event of a fire, the influence of wall and ceiling linings will not be significant. In some enclosures such as public corridors and fire-isolated exits, the lack of contents means that the role of linings in flame spread and production of untenable conditions may be much more significant than in those areas with substantial building contents (for details, see Section 3.6).

9.3.2 Room sizes

Room sizes were taken as typical for the building category. Plans of 'typical' building layouts were derived in Research Paper 2 (for details, see Section 3.4).

9.3.3 Ceilings and walls

In some locations, the influence of wall linings and ceiling linings will be sufficiently different to justify different controls. A general discussion on enclosure size and geometry and its affect on the behaviour of walls and ceilings is given in Section 3.4.

9.3.4 Occupied time

Table 9.1 – Classification of validation materials

Material	*Material Group*	
	Measured ISO Room Fire Test	*Predicted Classification Indexes*
Gypsum plasterboard (A9)	d	d
Lauan plywood (A10)	b	b
Hoop pine plywood, treated (A11)	b	b

Table 9.2 – Factors influencing test performance groups

Building category	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
Apartments					**sou**			
Contents	Low		Low		High		Medium	
Room size	—		Long, narrow		Small		Small	
Ceiling v. walls								
– unsprinklered	Equal influence		Equal influence		Equal influence		Equal influence	
– sprinklered	Sprinklers not installed		Equal influence		Equal influence		Equal influence	
Occupied time	Long		Medium		Short		Short	
Occupant density	—		—		Low		Low	
Ventilation	Low		Low		High		Low	
Test performance group	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Unsprinklered	d	d	c	c	***b bench-mark***	***b bench-mark***	b	b
Sprinklered	d	d	***b bench-mark***	b	b	b	b	b
Hotels & boarding houses					**sou**			
Contents	Low		Low		Medium		Low/medium	
Room size	—		Long, narrow		Small		Small/medium	
Ceiling v. walls								
– unsprinklered	Equal influence		Equal influence		Equal influence		Equal influence	
– sprinklered	Sprinklers not installed		Spread equally likely		Spread equally likely		Spread equally likely	
Occupied time	Long		Medium		Short		Short	
Occupant density	—		—		Low		Low	
Ventilation	Low		Low		Medium		Low	
Test performance group	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Unsprinklered	d	d	c	c	b	b	b	b
Sprinklered	d	d	b	b	b	b	b	b
Aged accommodation					**sou**			
Contents	Low		Low		High		Medium	
Room size	-		Long, narrow		Small		Small	
Ceiling v. walls								
– unsprinklered	Equal influence		Equal influence		Equal influence		Equal influence	
– sprinklered	Sprinklers not installed		Equal influence		Equal influence		Equal influence	
Occupied time	Long		Long		Medium		Short	
Occupant density	—		—		Low		Low	
Ventilation	Low		Low		High		Low	
Test performance group	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Unsprinklered	d	d	d	d	c	c	b	b
Sprinklered	d	d	c	c	b	b	b	b
Office buildings					**Open-plan offices; aspect ratio >5**			
Contents	Low		Low		Medium		Medium	
Room size	-		Long, narrow		Large		Small/medium	
Ceiling v. walls								
– unsprinklered	Equal influence		Equal influence		Spread via ceiling more likely		Equal influence	

continues...

Table 9.2 continued

Building category	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
– sprinklered	Sprinklers not installed		Equal influence		Spread via ceiling more likely		Equal influence	
Occupied time	Long		Medium		Medium		Short	
Occupant density	—		—		Medium		Low	
Ventilation	Low		Medium		Medium		Medium	
Test performance group	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Unsprinklered	d	d	c	c	b	c	b	b
Sprinklered	d	d	b	b	b	b	b	b
Shops					**Large shops; aspect ratio >5**			
Contents	Low		Low		High		High	
Room size	—		Long, narrow		Large		Medium	
Ceiling v. walls								
– unsprinklered	Equal influence		Equal influence		Spread via ceiling more likely		Equal influence	
– sprinklered	Sprinklers not installed		Equal influence		Spread via ceiling more likely		Equal influence	
Occupied time	Long		Medium		Medium		Short	
Occupant density	—		—		High		High	
Ventilation	Low		Medium		Medium		Medium	
Test performance group	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Unsprinklered	d	d	c	c	b	c	b	b
Sprinklered	d	d	b	b	b	b	b	b
Carparks								
Contents	Low		Low				Low	
Room size	—		Long, narrow				Large	
Ceiling v. walls								
– unsprinklered	Equal influence		Equal influence				Equal influence	
– sprinklered	Sprinklers not installed		Equal influence				Equal influence	
Occupied time	Long		Medium				Short	
Occupant density	—		—				Very low	
Ventilation	Low		Low				High	
Test performance group	*Wall*	*Ceiling*	*Wall*	*Ceiling*			*Wall*	*Ceiling*
unsprinklered	d	d	c	c			b	b
sprinklered	d	d	b	b			b	b
Warehouses & factories								
Contents	Low		Low				High	
Room size	—		Long, narrow				Large	
Ceiling v. walls								
– unsprinklered	Equal influence		Equal influence				Equal influence	
– sprinklered	Sprinklers not installed		Equal influence				Equal influence	
Occupied time	Long		Medium				Short	
Occupant density	—		—				Low	
Ventilation	Low		Low				Medium	

continues...

Table 9.2 continued

Building category	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
Test performance group	*Wall*	*Ceiling*	*Wall*	*Ceiling*			*Wall*	*Ceiling*
Unsprinklered	d	d	c	c			b	b
Sprinklered	d	d	b	b			b	b
Health care buildings					**Patient care areas**			
Contents	Low		Low		Medium		Medium	
Room size	—		Long, narrow		Medium		Medium	
Ceiling v. walls								
– unsprinklered	Equal influence		Equal influence		Equal influence		Equal influence	
– sprinklered	Sprinklers not installed		Equal influence		Spread via ceiling more likely		Equal influence	
Occupied time	Long		Long		Long		Short	
Occupant density	—		—		Low		Low	
Ventilation	Low		Low		Medium		Medium	
Test performance group	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Unsprinklered	d	d	d	d	c	c	b	b
sprinklered	d	d	c	c	b	b	b	b
Theatres, halls etc.					**Auditoriums**			
Contents	Low		Low		Medium		High	
Room size	—		Long, with some large spaces		Large, high		Medium	
Ceiling v. walls								
– unsprinklered	Equal influence		Equal influence		Equal influence		Equal influence	
– sprinklered	Sprinklers not installed		Equal influence		Spread via walls unlikely		Equal influence	
Occupied time	Long		Long		Medium		Short	
Occupant density	—		—		Very high		Low	
Ventilation	Low		Low		Medium		Medium	
Test performance group	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Unsprinklered	d	d	d	d	c	c	b	b
Sprinklered	d	d	c	c	b	b	b	b
Schools					**Classrooms**			
Contents	Low		Low		Medium		Medium	
Room size	—		Long, with some large spaces		Medium		Small	
Ceiling v. walls								
– unsprinklered	Equal influence		Equal influence		Equal influence		Equal influence	
– sprinklered	Sprinklers not installed		Equal influence		Equal influence		Equal influence	
Occupied time	Long		Medium		Medium		Short	
Occupant density	—		—		High		Low	
Ventilation	Low		Low		Medium		Medium	
Test performance group	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Unsprinklered	d	d	c	c	b	c	b	b
Sprinklered	d	d	b	b	b	b	b	b

The time for which people might be present in a location after the start of the fire has been taken into account. Relative total escape times for different building categories are listed in Research Paper 2. As people progress along escape routes, the time from the start of the fire will increase. There are likely to be people present in public corridors for longer after the start of the fire than in a room. In a fire-isolated exit, it is possible that people will be present for extended periods of time and so in this location only those products with a low propensity for fire growth should be used as wall and ceiling linings. In certain buildings with dense populations or large numbers of people who are unable to move fast, it is possible that people will be present in public corridors for long periods.

9.3.5 Occupant density

The BCA gives values for floor area per person according to building use. In Table 9.2 these values have been divided into low, medium and high. The occupant density will affect the speed of evacuation, especially in public corridors and fire-isolated exits. In buildings with high occupant densities, such as theatres or art galleries, those escaping from the building are likely to spend long periods in public corridors or even in the room.

9.3.6 Ventilation

Ventilation plays an important part in the development and spread of fire. Fire Code Reform Project 3 developed a table of 'typical' ventilation factors for enclosures in buildings of BCA classes. A brief discussion on ventilation in public corridors is given in Section 3.5 of this report. Taking these factors into account, low, medium and high values of ventilation where allocated to each location in each building category.

9.3.7 Fire-isolated exits

In fire-isolated exits there will be little, if any, contents and any contribution of the linings to the spread of fire or the development of untenable conditions could be significant. In addition, escaping occupants might be present in large numbers and for long periods of time.

Under such conditions, it is appropriate to choose linings that are unlikely to spread flame or produce untenable conditions even under high exposure. Therefore, only materials which have a low propensity to fire growth and do not go to flashover in the ISO Room Fire Test are considered suitable for use as wall and ceiling linings in fire-isolated exists. No discrimination need be made between the behaviour of walls and ceilings.

The same considerations apply to fire-isolated exits in all building categories.

9.3.8 Public corridors

Public corridors lead to fire-isolated exits and similar considerations to those for fire-isolated exits apply. Generally speaking, public corridors contain little contents and any contribution of the linings to the spread of fire or the development of untenable conditions might be significant. However, occupants are moving through public corridors to reach fire-isolated exits and the time for which they are present in public corridors is generally less than in fire-isolated exits. It is only necessary to maintain tenability and prevent flame spread until occupants have had

sufficient time to reach the fire-isolated exit, and this time will be affected by occupant mobility. Some occupants might choose to remain safely within their sole-occupancy unit with the door shut.
In some occupancies (for example, cinemas in shopping centres) large public spaces open onto public corridors. Where this is a possibility, more stringent controls should be applied to the ceiling, as the corridor becomes, in effect, a large room.

9.3.9 Sprinklers

The role of other fire safety systems was discussed in Section 3.8, where it was concluded that consideration should be given to the benefits of sprinklers being present in a building, including those where they are not currently required by regulation. While the presence of sprinklers in the building will not affect the need for control of linings in fire-isolated exits, as sprinklers are not installed here, it will have a considerable effect on performance considerations for public corridors and other areas.

When assessing the impact of sprinklers in various locations, it is important to remember that the likelihood of a fire growing past the initial stage is substantially less in a sprinklered building than it is in an unsprinklered building. It is assumed in this discussion that sprinklered buildings are fitted with sprinklers throughout all occupied areas except for fire-isolated exits, and that in the event of a fire the sprinklers will operate and suppress the fire.

The location and function of sprinklers might affect walls and ceilings differently. In some cases, rapid fire spread across the ceiling might overwhelm the sprinklers, while the slower spread of fire up and across walls will be suppressed.

Little data is available to help assess the effect of sprinklers on corridor fires, but a pair of residential corridor experiments conducted by Gardner and Whitlock (1998) provide an indication of anticipated performance. Using particleboard wall linings it was found that, while in the unsprinklered case the linings spread fire to the end of the corridor, in the sprinklered case the operation of sprinklers prevented fire from spreading to the end of the corridor. The linings contained no fire retardant, and so would fall into Group b. It can be tentatively concluded that, in the presence of sprinklers, Group b materials are acceptable as wall linings in public corridors in apartment buildings.

There is no similar data for ceiling linings in corridors. However, it should be noted that in the experiments the fire in the corridor was initiated by a fire in an adjoining enclosure. This situation is unlikely to occur in a sprinklered corridor, as the adjoining enclosure would also be sprinklered, and the chances of a fire developing and impinging on the walls or ceiling of the corridor would be very small. If a fire were initiated in the corridor, it would be unlikely to impinge on the ceiling before the sprinklers in the corridor brought the fire under control. Therefore it is reasonable to allow the same materials to be used on the ceilings of public corridors as are acceptable on the walls.

Data to compare the performance of ceiling linings with and without sprinklers is sparse. In experiments at BHP (Proe & Bennetts 1997), video records showed that flames from contents, in this case a workstation, can reach and involve the ceiling before sprinklers are activated (see Figure 9.1). It has been suggested that if inappropriate ceiling linings have been used, when

Figure 9.1 – BHP office fire experiment; flames on ceiling prior to sprinkler activation

the sprinklers are eventually activated so many may operate that the water supply may be insufficient to allow them to suppress the fire. In the absence of data to support this view, there should be some caution when choosing controls on ceiling linings in the presence of sprinklers. Whilst further experimentation is needed to determine what constitutes an 'inappropriate' ceiling lining, it can be envisaged that some if not all Group a materials may fall into this category. It is unlikely that any Group b materials will (*see data for typical timber products in Tables 7.1 and 7.2*). Further work is needed to determine the ability of sprinklers to control flame spread on ceilings.

The Working Group is of the opinion that, because fires are less likely to grow large in sprinklered buildings, lining requirements for sprinklered buildings should be one group less severe than those in unsprinklered buildings, with the following exceptions:

- there should be no change in fire isolated exits as sprinklers are not fitted here; and
- materials of Group a should not be permitted under any circumstances.

9.3.10 Setting a benchmark

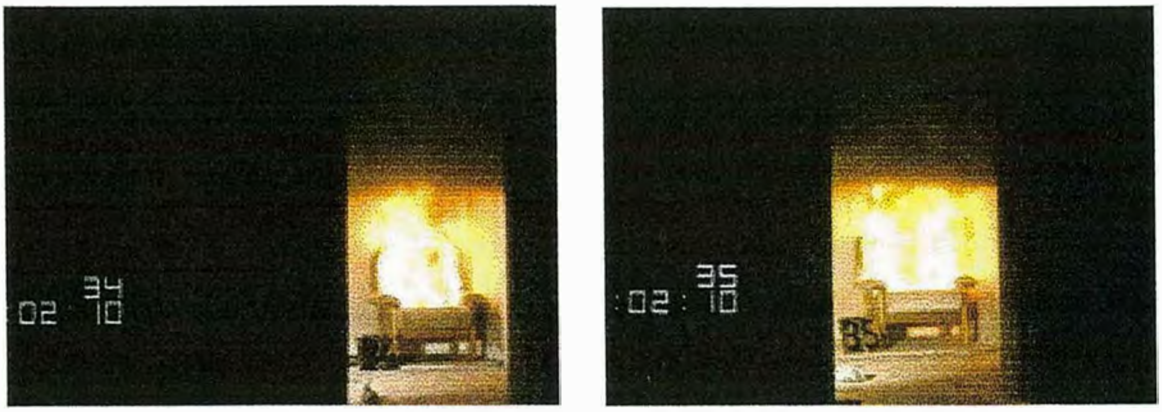
While the issues discussed above will give an indication of appropriate relative values for controls on wall and ceiling linings, actual values are needed for use in prescriptive regulations. It is therefore necessary to find convincing benchmarks against which tabulated values for other occupancies and locations can be compared. It has already been shown that Group b materials are suitable for wall linings in public corridors in apartment buildings protected by sprinklers (see Section 9.3.9). The Working Group agreed that another benchmark could be established by considering the behaviour of linings in a small room in a residential sole-occupancy unit.

A benchmark can be established by comparing results from comparative room fire experiments (with and without combustible linings) to determine the material control necessary to achieve the system performance, i.e. that in the event of a fire, lining materials must not significantly decrease the safety of occupants.

The room fire experiments conducted for this project involved the ISO room (a small room) and various ignition sources (see Research Paper 5). Some tests used an armchair, which was chosen to represent a typical fire load for such a small room (although a small room is unlikely to contain just one armchair, the heat release rate of this chair is typical for the likely contents of such a room). In one test the wall and ceiling linings were plasterboard (see Table 7.1), which falls into Group d (see Table 9.1). In the other test the wall linings were plywood, which falls into Group b. A comparison of these two experiments gives an indication of the significance of the effect of wall linings in the small room.

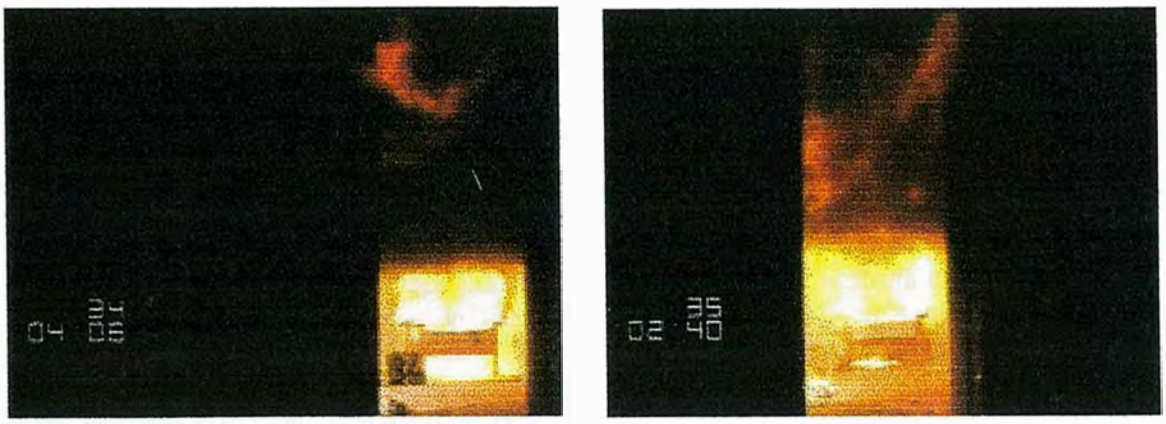
Video records of these two experiments show that the fires were similar for the first 130 s (see Figure 9.2). After this time, the fire in the room with plywood walls grew noticeably faster. There was some difference in the behaviour of the armchairs before the wall linings ignited, an indication of the variability that can be expected in such tests. Time to flashover was 240 s for the plasterboard walls and 160 s for the plywood walls (see Figure 9.3).

It is the influence of the linings in the early stages of the fire that is relevant to this discussion. Data from experiments, including radiation at floor level and temperatures within the room, show very little difference in the two scenarios up to 110 s (Research Paper 7), indicating that the linings did not become involved in the fire until after this time.



(a) (b)

Figure 9.2 – Burning armchair in ISO room after 130 s: (a) plasterboard walls and ceiling; and (b) lauan plywood walls and plasterboard ceiling



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(a) **(b)**

Figure 9.3– Burning armchair in ISO room at flashover: (a) plasterboard walls and ceiling; and (b) Lauan plywood walls and plasterboard ceiling

Similarly the experiments conducted by Lee (1985b; see Section 7.2.1) show that in a sparsely furnished small bedroom the contents still predominate, with Group b wall linings not reducing the time to flashover.

The safety of occupants will depend upon their ability to escape from the fire. In Section 9.2 it was shown that occupants would have escaped from a small bedroom in a Class 2 unit within 90 s of the fire starting. This is 20 s before the linings become involved in the fire. This analysis indicates that, in the time taken to respond to an alarm and leave the room, the linings had no significant effect on the tenability or flame spread within the room. Materials of Group b are therefore acceptable on the walls and ceiling of rooms in apartments.

Using the above scenarios as benchmarks, Table 9.2 shows recommended values for test performance groups for locations within building categories both with and without sprinklers. Note that even where sprinklers are present, Group a materials are not considered suitable.

9.4 Smoke Production

9.4.1 Nature of smoke

In Australia, the term 'smoke' often refers only to visible products of combustion. In technical discussions on smoke production, it is usually understood that smoke means the total volume of the hot layer of combustion products and entrained air. The second definition is more relevant to Project 2 and will be used in this discussion.

9.4.2 Smoke hazards

There are three aspects of smoke production that are relevant to the achievement of the system performance – that lining materials must not significantly decrease the safety of occupants. The first aspect is the optical density of the smoke – if building occupants are confronted by quantities of dense smoke, they will become disoriented and might be unable to find escape routes. The second aspect is the concentration of toxic gases produced by the fire. People who die from 'smoke inhalation' in fact die from the effects of toxic gases, especially carbon monoxide. The third aspect is the temperature of the hot layer. Inhalation of hot gases and radiation from the hot layer can disorient and incapacitate people. In each case, the volume of smoke produced is important – a little thick, hot or toxic smoke will not pose a threat to safety – and, given a fixed volume of smoke, the geometry of the building will influence the likelihood of exposure of building occupants. The four properties that require consideration are therefore:

1—the volume of smoke produced;
2—the optical density of the smoke;
3—the toxicity of the smoke; and
4—the temperature of the smoke.

9.4.3 Volume of smoke

In real fires the volume of smoke produced is closely related to the heat release rate (Heskestad 1995) and the volume of entrained air. The volume of entrained air will depend upon the building geometry and the ventilation conditions which are not related to properties of the burning material. The same relationship between volume of smoke and heat release rate exists for room

fire tests (Sundström & Göransson 1988; Sundström *et al.* 1997). The heat release rate of building materials can be measured in suitable small-scale tests, although the value measured may be greater than the heat released in a real fire (Heskestad 1995). Heat release rate, as measured in such tests, is in turn related to time to flashover in the ISO Room Fire Test.
Whether or not the volume produced impinges on the escaping occupants depends upon the geometry of the building enclosure. In lofty enclosures the hot layer will form in a reservoir which is usually well above the heads of those escaping, while in low-ceilinged enclosures the effects of smoke will be felt much sooner.

The total volume of smoke produced will depend upon the involvement of building contents in the fire. Most fires start with building contents (see Research Paper 3), which will often dominate in smoke production over linings.

The ability of the lining material to produce smoke is therefore only a minor influence in the parameters controlling volume of smoke and its influence on safety.

9.4.4 Optical density

Optical density of smoke is of interest because it can be related to visibility, but it should be noted that visibility in fire smoke also depends on irritating effects (Jin 1997). The optical density of smoke is related to the composition of the burning material and to ventilation conditions under which the material burns. Small-scale tests measure optical density under specific conditions, which are unlikely to simulate the use of the material in practice; some small-scale tests further relate optical density to a smoke production rate, by taking into account the flow rate in the exhaust and specimen mass loss. Smoke production rate can also be measured in the ISO Room Fire Test, but no mathematical relationship has yet been developed relating smoke production rates in small-scale tests to smoke production rates in room fire tests. Nor has any correlation been developed between smoke production rates in small- or large-scale tests to smoke production rates in real fires. The most that can be assumed is that those materials that have a high smoke production rate under test conditions are likely to have a high smoke production rate in real fires. Ventilation conditions are related to the building design and location of linings within the building.

9.4.5 Measuring optical density of smoke

As discussed in Chapter 6, parameters related to the optical density of smoke can be measured at the same time as other variables in the Room Fire Test, the Cone Calorimeter and the Early Fire Hazard Test. The reproducibility of smoke data in the Room Fire Test and the Cone Calorimeter (Appendix D) was considerably worse than for the reproducibility of the other parameters assessed (no similar data is available for the Early Fire Hazard Test). It would therefore be inappropriate to make fine distinctions between materials on the basis of smoke production, and the tests should be used only as an indication of the very worst-performing materials.

9.4.6 Toxicity

Many toxic gases are present in smoke, but carbon monoxide poisoning is the major cause of death from smoke inhalation (Hirschler *et al.* 1993). The production of carbon monoxide in large fires is related to the availability of oxygen (either through ventilation or other sources) and to the size of the fuel load (Debanne *et al.* 1992). There is only a minimal relationship to the chemical composition of the fuel. The quantity of toxic gases cannot be predicted from the optical density of the smoke. For example, smouldering fires that produce fatal doses of toxic gases may not produce smoke of high optical density (note that smouldering fires are more likely to involve contents than linings). However, the volume of smoke produced will give a good indication of the likelihood of exposure of building occupants to toxic doses of carbon monoxide (Purser 1989).

9.4.7 Temperature

The temperature of the hot layer will depend upon the total heat release rate for all burning materials and the ventilation conditions within the compartment. Building geometry and building contents will be major influences.

9.4.8 Level of control

The three aspects of smoke production (optical density, toxicity and temperature) that are relevant to the achievement of the system performance are dependent on the volume of smoke produced and its ability to impinge on escaping occupants. Time to flashover in the ISO Room Fire Test gives a fair estimation of the contribution of the linings to rate of fire growth and thus an indication of the volume rate of smoke production, and controls on this have already been set in Table 9.2. Currently the BCA controls optical density of smoke produced by lining materials used in specified areas, and it could be argued that some control on optical density might increase levels of safety. Although controls on smoke production rate in addition to controls on time to flashover in the ISO Room Fire Test were not seen to be necessary from a scientific point of view, it was felt that there might be political pressure for the BCA to include such a control. Information on overseas practice was sought, and the replies indicate that:

- the US has a single level of smoke control; and
- Canada has controls on smoke; in sprinklered buildings controls are waived or reduced in stringency.

No replies were received from Europe. However, at an open forum at the Mid-Term Review of Fire Code Reform Centre research program, Matti Kokkala of VTT, Finland observed that:

- only four European countries have additional controls on smoke; and
- controlling the size of the fire gives a first-order control on smoke production.

EUREFIC suggested an average 'smoke production rate' of 5 m^2/s measured in the Room Fire Test when calculated in accordance with Nordtest Fire 025 as the limit for their proposed classes B–D, based on Nordic work (Sundström & Göransson 1988). This corresponds to 1.2 m^2/s when calculated in accordance with ISO 9705.

We do not believe that there is a need for additional smoke control. However, if additional controls on smoke are desired, we recommend that such controls should:

- be applied in fire-isolated exits only; and
- eliminate only the worst smoke-producing materials. An average rate of smoke production of 1.2 m^2/s when calculated in accordance with ISO 9705 is suggested.

9.4.9 Use of small-scale tests

The ability of a lining material to satisfy the agreed level of control can be measured in an ISO Room Fire Test. However, the high cost of room fire tests is acknowledged in Section 6.4.5 and every effort should be made to reduce the number of tests that need to be performed. No mathematical relationship has yet been developed between small-scale tests and smoke production rates measured in the ISO Room Fire Test; nonetheless, small-scale tests can give a broad indication of the performance of a material in the ISO room. Table E6 in Appendix E shows that those materials that achieved an average specific extinction area not more than 25 m^2/kg in the Cone Calorimeter achieved an average rate of smoke production less than 1.2 m^2/s in the ISO Room Fire Test, while those that achieved an average specific extinction area greater than 30 m^2/kg in the Cone Calorimeter all achieved an average rate of smoke production creater than 1.2 m^2/s in the ISO Room Fire Test. Development of a good mathematical correlation between average specific extinction area in the Cone Calorimeter and average rate of smoke production in the ISO Room Fire Test will further reduce the need for full-scale testing.

It is therefore recommended that materials that achieve an average specific extinction area of not more than 25 m^2/kg in the Cone Calorimeter should be accepted as complying with the smoke production requirements without need for further testing. Those that achieve an average specific extinction area of greater than 30 m^2/kg in the Cone Calorimeter are unlikely to pass the ISO Room Fire Test criterion.

9.5 Comparison with Existing Requirements

The existing BCA requirements for wall and ceiling linings, based on recommendations of the Commonwealth Experimental Building Station (CEBS), are presented in Table 9.3. Requirements are taken from Specifications C1.10 and D1.12 of the BCA. The requirements are for compliance with the Flame Spread Index and Smoke Developed Index of the Early Fire Hazard Test, with an additional restriction on the thickness of combustible linings in fire-isolated exits.

In his advice to AUBRCC, Jack Keough of CEBS recommended that smoke control could be waived in many areas provided that suitable controls were placed on flame spread. Table 9.3 shows that the current controls on the Smoke Developed Index are waived in many areas if the lining materials have low Flame Spread Indexes. This acknowledges the fact that if you control the fire, you control the smoke production.

In the proposed changes, the Flame Spread Index has been replaced with criteria based on the occurrence of flashover when wall and ceiling linings are subjected to 100 and 300 kW fires in the corner of a small room, represented by the ISO Room Fire Test (ISO 9705). This is a more severe exposure than that which occurs in the Early Fire Hazard Test, and consequently some materials that do not ignite in the Early Fire Hazard Test do ignite in the ISO Room Fire Test.

In the proposed requirements, separate controls on smoke production are not recommended. However, if any such controls are considered necessary, it is suggested that they be applied

Table 9.3 – Current BCA requirements for wall and ceiling linings[a]

BCA building class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Class 2 – apartments	0,2,nc	0,2,nc	0,5	0,5	9,8/5,–	9,8/5,– (sou)	9,8/5,–	9,8/5,–
Class 3 – hotels & boarding houses	0,2,nc	0,2,nc	0,5	0,5	9,8/5,–	9,8/5,– (sou)	9,8/5,–	9,8/5,–
Class 3 – accommodation for the aged, disabled & children	0,2,nc	0,2,nc	0,5	0,5	9,8/5,–	9,8/5,– (sou)	9,8/5,–	9,8/5,–
Class 5 – office buildings	0,2,nc	0,2,nc	9,8/5,–	9,8/5,–	9,8/5,– (open-plan offices; aspect ratio >5) 0,5 (stairways etc.[b])	9,8/5,– 0,5	9,8/5,–	9,8/5,–
Class 6 – shops	0,2,nc	0,2,nc	9,8/5,–	9,8/5,–	9,8/5,– (large shops; aspect ratio >5) 0,5 (stairways etc.[b])	9,8/5,– 0,5	9,8/5,–	9,8/5,–
Class 7 – carparks	0,2,nc	0,2,nc	9,8/5,–	9,8/5,–	–	–	9,8/5,–	9,8/5,–
Class 7 & 8 – warehouses & factories	0,2,nc	0,2,nc	9,8/5,–	9,8/5,–	–	–	9,8/5,–	9,8/5,–
Class 9a – health care buildings	0,2,nc	0,2,nc	0,5	0,5	2,5 (patient care areas)	0,3	9,8/5,–	9,8/5,–
Class 9b – theatres, halls etc.	0,2,nc	0,2,nc	0,5	0,5	6,5 (auditoriums unsprinklered) 9,8/5,– (auditoriums unsprinklered)	6,3 9,8/5,–	9,8/5,–	9,8/5,–
Class 9b – schools	0,2,nc	0,2,nc	0,5	0,5	9,8/5,– (classrooms)	9,8/5,–	9,8/5,–	9,8/5,–

[a] BCA Specification C1.10 unless otherwise noted. The entries are presented as follows: n1,n2,(nc), where n1 is the Flame Spread Index, n2 is the smoke developed index and nc means that a maximum thickness of 1 mm applies to combustible materials. Absence of a smoke requirement is denoted by '–'. Alternative requirements are separated by a slash (/).

[b] Non-required non-fire-isolated stairways and ramps – BCA Specification D1.12

only in fire-isolated exits. In all other areas, the only control on smoke produced by linings will be by control of the fire size.

The proposed requirements do not include 'non-combustibility' as a criterion. A detailed study of the need for controls on combustibility is being conducted under Fire Code Reform Project 3. However, the Working Group for Project 2 believes that the system performance requirement for lining materials can be satisfied by the four test performance groups described in Section 9.2. There is no doubt that current practice allows a limited number of inappropriate materials to be used in some areas. That such materials are not routinely used in practice is fortunate, and might be so because such materials have other properties that make them unattractive as wall or ceiling linings. The proposed requirements are better able to identify the fire hazard associated with the use of such materials as wall and ceiling linings.

There is no direct correlation between the existing requirements and the proposed requirements. However, leaving aside the materials discussed above, the proposed requirements allow similar usage of materials and probably represent overall less stringent requirements than those presently called for in the deemed-to-satisfy requirements of the BCA.

10 – CONCLUSIONS

This report, together with seven research papers prepared during the course of this project, constitute the outputs required by the project brief. The project brief was very ambitious, requiring the use of more sophisticated models than are currently available. Nonetheless, by

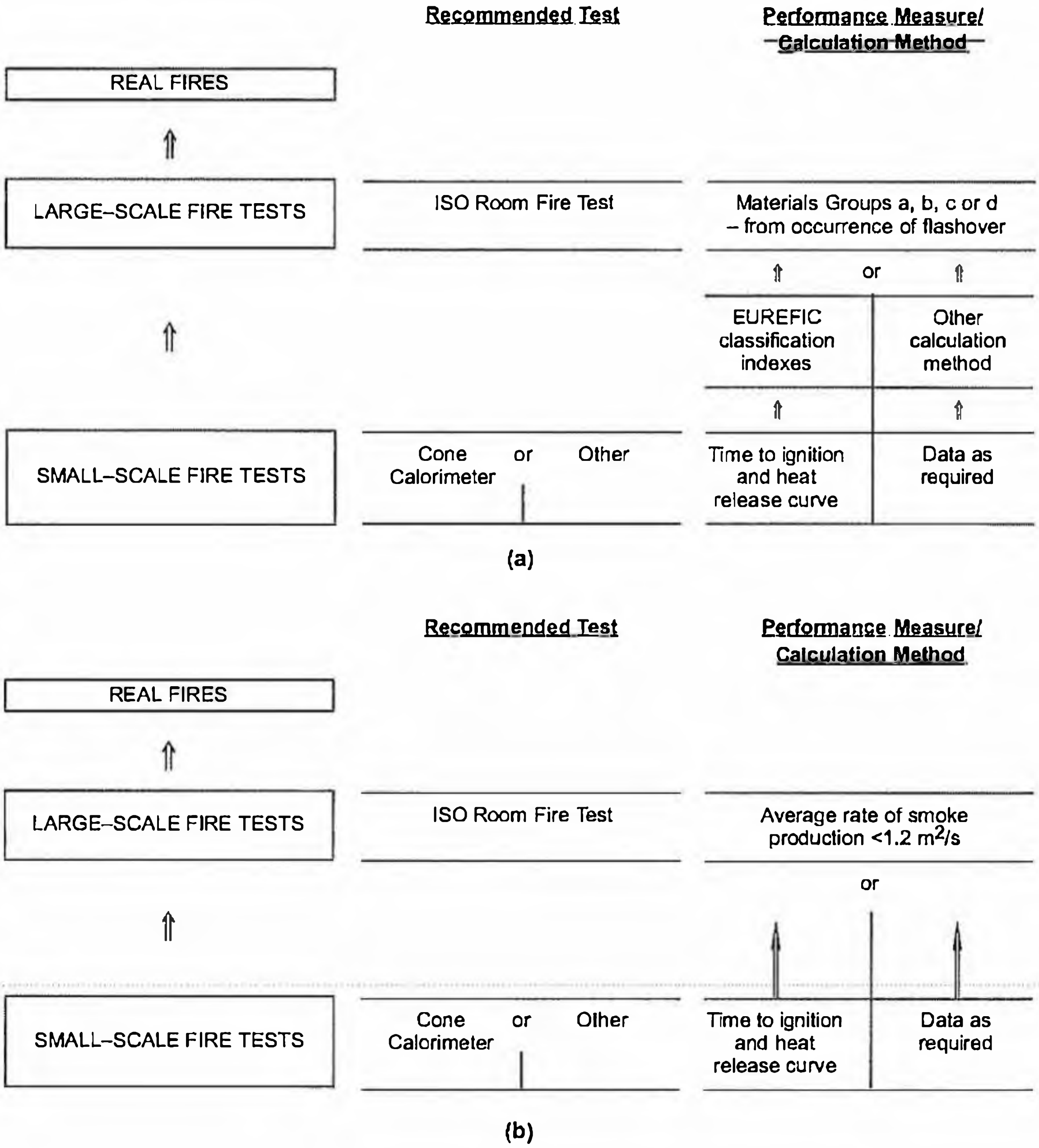

Figure 10.1 – System for control of wall and ceiling linings in buildings: (a) flame spread control; and (b) smoke production control (not recommended)

using as much available data as possible, a comprehensive and practical system for control of wall and ceiling linings has been developed.

A review of case studies of fires in which lining materials became involved in fire has shown that lining materials can be a major contributor to fatalities in fires in buildings. There is a need to control the fire behaviour of wall and ceiling linings in order to keep loss of life to an acceptable level.

Key factors that influence the level of control required have been identified and a list of building categories that might be expected to have unique sets of requirements has been derived. In all locations and in all building categories, the contribution of linings to time to untenable conditions and to flame spread has been considered.

Test methods that are available within Australia to measure the performance of wall and ceiling linings have been examined and the benefits and disadvantages of each have been considered. It has been found that the most appropriate test method currently available is the ISO 9705 Room Fire Test, and the parameter best suited to control wall and ceiling linings is time to flashover. While the ISO Room Fire Test allows three groups of materials to be clearly identified by time to flashover, an additional group of materials with a propensity to rapid fire growth has been recognised. A simple evacuation analysis has been used to select a suitable limit for this group, and the results obtained concur with recommendations of the EUREFIC program. Despite the different methodologies that have been used to derive limits, the group into which each material falls is ascertained by measuring time to flashover in the ISO Room Fire Test.

Time to flashover in the ISO Room Fire Test also gives adequate control on smoke production. Should additional controls be sought, it is recommended that these follow the recommendations of the EUREFIC program and apply limits to rate of smoke production in the ISO Room Fire Test.

Time to flashover in the ISO Room Fire Test can be estimated using data from small-scale tests. Relationships have been developed that allow data from the Cone Calorimeter to be used for such predictions. The same data can also be used in fire engineering calculations that meet the performance requirements of the BCA. The best available relationship is the Classification Indexes developed as part of the EUREFIC program. Data from the Early Fire Hazard Test cannot be used to reliably predict time to flashover in the ISO Room Fire Test because the Indexes are not based on appropriate parameters. Future developments might allow data from other small-scale tests to be used.

Although no correlation has been developed for predicting smoke production rate in the ISO Room Fire Test from small-scale tests, experimental results indicate that materials that have a low average specific extinction area in the Cone Calorimeter will have a low average rate of smoke production in the ISO Room Fire Test. In order to reduce the number of room fire tests that have to be conducted should additional controls on smoke production be considered necessary, a conservative limit on performance in the Cone Calorimeter has been selected to identify a group of materials for which room fire tests are not necessary. Above this limit, results from the Cone Calorimeter can be used to predict performance in the ISO Room Fire Test.

An outline of the proposed system of control of fire size is shown in Figure 10.1.

Any small-scale test that is selected for regulatory purposes should be able to provide data for fire engineering computations. Data from the Cone Calorimeter can be used for such purposes, while data from the Early Fire Hazard Test cannot.

Recommendations have been made for quantitative performance levels for different building classifications and different locations within buildings. The recommendations take into account the presence of sprinklers. For buildings with and without sprinklers, separate recommendations have been given for materials based on time to flashover in the ISO Room Fire Test. Although the use of lining materials under the recommendations is not dramatically different from current usage and practice, the recommendations provide a logical basis for controls. One suite of tests can be used to establish materials data that can be used in prescriptive and performance-based designs, and the effect of controls can be readily assessed for the introduction of more cost-effective 'deemed-to-satisfy' solutions to the BCA.

Limitations of current technology in establishing egress times (both available and required) and limitations of fire-spread models in the use of data on wall and ceiling linings have been acknowledged. Areas where further work would be beneficial, both in the derivation of deemed-to-satisfy solutions for the BCA and in fire engineering design, have been identified.

The Working Group is satisfied that the project objectives have been fulfilled.

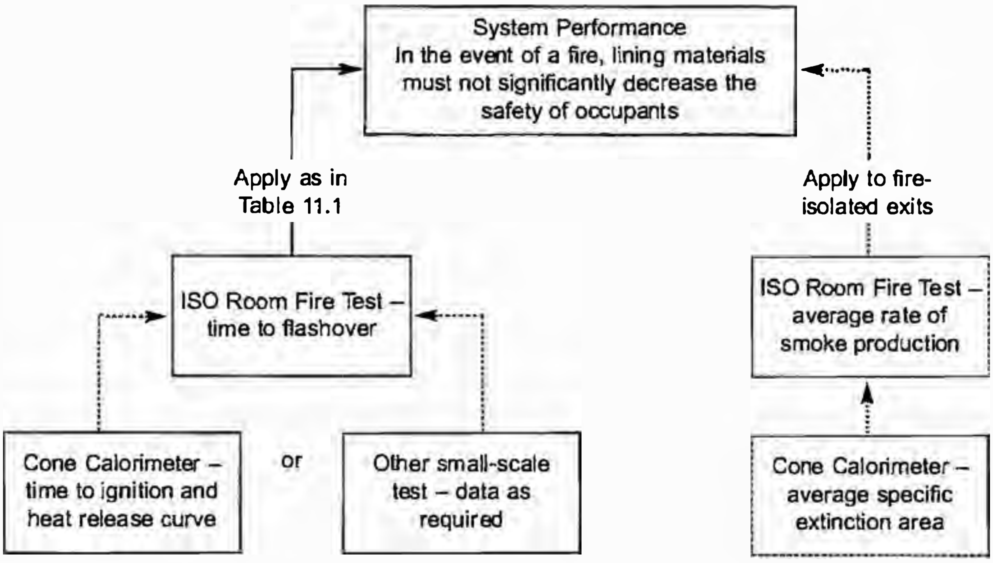

Figure 11.1 – Proposed control system for wall and ceiling linings

11 – Recommendations for Change to the BCA

11.1 Introduction

It has been established that there is a need for change to current controls on wall and ceiling linings in the BCA. Controls will vary with building category and with the location of the linings within the building. While current controls give inconsistent outcomes, time to flashover in the ISO Room Fire Test provides a satisfactory basis for control of the propensity of linings to spread fire and produce smoke. While the ISO Room Fire Test provides a basis, it is an expensive test that consumes a considerable quantity of material. A satisfactory alternative method of assessment is to use a small-scale test together with an appropriate model to predict behaviour in the ISO Room Fire Test. Currently, the only small-scale test for which a suitable model is available to predict fire spread is the Cone Calorimeter, which can be used in conjunction with the Classification Indexes to predict time to flashover in the ISO Room Fire Test. Any small-scale test that provides data from which a satisfactory correlation has been developed will ultimately be acceptable. The Early Fire Hazard Test does not provide suitable data. The ISO Room Fire Test can then be used as an arbiter in case of dispute.

It is recommended that time to flashover in the ISO Room Fire Test provides sufficient control on smoke production. Should it be considered necessary to provide additional controls, average rate of smoke production in the ISO Room Fire Test is a suitable measure. While the Cone Calorimeter can give a broad indication of the likely outcomes of smoke production in the ISO Room Fire Test, no correlation has yet been developed to allow such a test to be used on all materials. However, Cone Calorimeter criteria can be set that reduce the number of Room Fire

Tests that need to be conducted.

The proposed system of control can be further developed to allow the use of alternative test methods and to refine the application of test performance groups to locations in buildings. Recommendations for further work are given in Chapter 13. The proposed controls are shown in Figure 11.1.

11.2 Recommendations

It is recommended that:

1 Wall and ceiling linings be controlled.

2 Requirements for control of wall and ceiling linings should depend upon:
- building category;
- location within the building; and
- the presence or absence of sprinklers.

3 Requirements for control of wall and ceiling linings should be in accordance with criteria of acceptance as shown in Table 11.1.

4 Controls on linings should be based on occurrence of flashover in the ISO Room Fire Test, measured in accordance with ISO 9705. Flashover is defined as a heat release rate of 1 MW.

5 The controls should divide materials into the following groups:
Group a—materials that reach flashover in less than 120 seconds after exposure to 100 kW;
Group b—materials that reach flashover in more than 120 seconds after exposure to 100 kW;
Group c—materials that reach flashover after exposure to 300 kW; and
Group d—materials that do not reach flashover after exposure to 300 kW.

6 Results of small-scale tests used in conjunction with mathematical models provide a satisfactory method of predicting time to flashover in the ISO Room Fire Test.

7 The Cone Calorimeter is currently the only small-scale test that provides data that best predicts time to flashover in the ISO Room Fire Test. The method of measurement should be in accordance with ISO 5660.

8 The Classification Indexes proposed by Kokkala *et al.* (1993) is a suitable method for calculating time to flashover in the ISO Room Fire Test from Cone Calorimeter data.

9 Other small-scale tests could provide an acceptable method of control if a satisfactory relationship to time to flashover in the ISO Room Fire Test can be developed.

10 If it is considered that control on smoke production in addition to time to flashover in the ISO Room Fire Test is needed, control should restrict the use of materials with an average rate of smoke production in the ISO Room Fire Test of 1.2 m^2/s. Such materials should not be allowed in fire-isolated exits.

11 Materials that have an average specific extinction area of not more than 25 m^2/kg in the Cone Calorimeter comply with the smoke production requirements and do not need to be tested

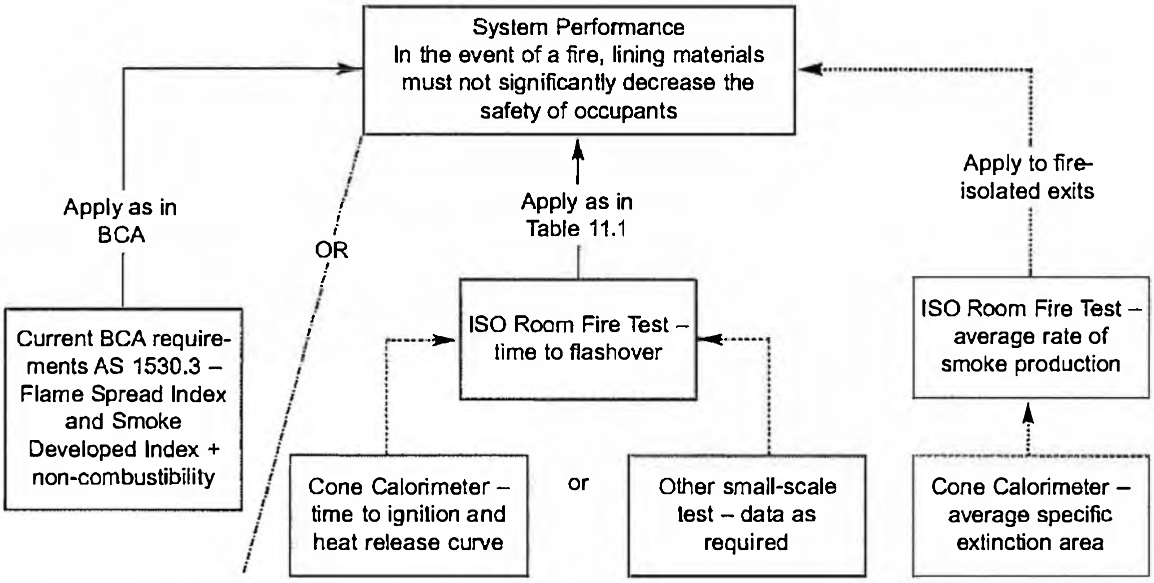

Figure 11.2 – Proposed parallel control system for wall and ceiling linings

in the ISO Room Fire Test.

Table 11.1 – BCA recommendations based on occurrence of flashover in ISO Room Fire Test[a]

BCA Building Class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Class 2 & 4 – apartments					**sou**			
Unsprinklered[b]	d	d	c	c	b	b	b	b
sprinklered[b]	d	d	b	b	b	b	b	b
Class 3 – hotels & boarding houses					**sou**			
Uunsprinklered	d	d	c	c	b	b	b	b
Sprinklered	d	d	b	b	b	b	b	b
Class 3 – accommodation for the aged, disabled and children					**sou**			
Unsprinklered	d	d	d	d	c	c	b	b
Sprinklered	d	d	c	c	b	b	b	b
Class 5 – office buildings					**Open-plan offices; aspect ratio >5**			
Unsprinklered	d	d	c	c	b	c	b	b
Sprinklered	d	d	b	b	b	b	b	b
Class 6 – shops					**Large shops; aspect ratio >5**			
Unsprinklered	d	d	c	c	b	c	b	b
Sprinklered	d	d	b	b	b	b	b	b
Class 7 – carparks								
Unsprinklered	d	d	c	c	—	—	b	b
Sprinklered	d	d	b	b	—	—	b	b
Class 7 and 8 – warehouses & factories								
Unsprinklered	d	d	c	c	—	—	b	b
Sprinklered	d	d	b	b	—	—	b	b
Class 9a – health care buildings					**Patient care areas**			
Unsprinklered	d	d	d	d	c	c	b	b

Sprinklered	d	d	c	c	b	b	b	b
Class 9b – theatres, halls etc.					**Auditoriums**			
Unsprinklered	d	d	d	d	c	c	b	b
Sprinklered	d	d	c	c	b	b	b	b
Class 9b – schools					**Classrooms**			
Unsprinklered	d	d	c	c	b	c	b	b
Sprinklered	d	d	b	b	b	b	b	b

[a] Group a materials are not permitted under any circumstances.

[b] 'Sprinklered' and 'unsprinklered' refers to the whole building or fire compartment rather than the location within the building. Sprinklers are not usually fitted in fire-isolated exits (see AS 2118.1).

While there is a need for change to provide for safety in a changing and often more complex built environment than that envisaged by earlier regulators, in the short term existing requirements and practice do not appear to pose a threat. It would therefore seem appropriate to allow the current BCA system of control and the new proposals to sit side by side for a limited time. A period of five years is suggested, during which time existing provisions should apply only to those materials whose fire properties are well known and in locations where they are currently in common use. During the five-year period, any new testing should be conducted in accordance with the proposed test method.

The system of parallel requirements is illustrated in Figure 11.2.

12 – Implications for Materials

Table 12.1 shows the Groups into which a range of lining materials are likely to fall. Subsequent tables reflect these Groups. Table 12.2 shows likely changes in usage of these materials. Appendix H contains a comparison by building category of materials that will be allowed under the proposed system with those that are currently allowed.

Overall the new Groups represent less stringent requirements than those presently called for in the deemed-to-satisfy requirements in Specifications C1.10 and D1.12 of the BCA.

One area where proposed requirements are more stringent than current requirements is in sole-occupancy units for accommodation for the aged, disabled and children. It was found in Chapter 6 that egress times in such accommodation are similar to those in hospitals and hence more stringent requirements are appropriate. The present BCA requirements for this building category are the same as for hotels and boarding houses.

More stringent requirements have also been proposed for ceilings in unsprinklered large spaces, where the possibility of rapid spread across uninterrupted ceilings must be considered. At present the BCA does not differentiate ceiling linings on the basis of area or aspect ratio.

An important consideration throughout this project has been the need to keep Australia in line with international practice. The Mid-term Review of FCRC's Research Program found that the test methods proposed for use were consistent with international research results (Kokkala *et al.* 1998). In Table I1 in Appendix I it is shown how the proposed material groups line up with the Euroclasses accepted for use in Europe.

Whilst it is not possible to briefly compare the proposed control of wall and ceiling linings for all buildings in Australia with overseas practice, discussions with M. Kokkala of VTT indicate that the approach is similar to that currently in force in Finland, a country of similar size to Australia. In both the proposed Australian approach and the Finnish approach:

- requirements are linked to building use;
- the fire behaviour characteristics controlled are ignition and heat release, the same characteristics that are used to predict flashover in room fire tests; and
- there are no separate controls on smoke production.

Table 12.1 – Likely groups of material

Group	*Typical materials*
d	Masonry; gypsum plaster, paper-faced and painted; some fire-retarded timbers and timber products
c	Most fire-retarded timbers and timber products; fire-retarded plastics wall coverings on masonry
b	Most non-fire-retarded timbers and timber products; insufficiently fire-retarded timbers and timber products; some fire-retarded polyurethane foams; some fire-retarded polystyrene foams
a	Non-fire-retarded and insufficiently fire-retarded polyurethane foams; non-fire-retarded and insufficiently

fire-retarded polystyrene foams; low density fibreboard

Table 12.2 – Likely changes by material type

Generic materials		*Changes*	
		Masonry products	
Masonry			
No change			
Gypsum plaster, paper-faced and painted			
No change			
		Timber products	
Some fire-retarded timbers and timber products[a]			
Permitted	Fire-isolated exits	Walls & ceilings	All buildings
Non-fire-retarded and some fire-retarded timbers and timber products			
Permitted			
Sprinklered	Public corridors	Walls & ceilings	Apartments, hotels & boarding houses, public assembly buildings, schools
	Patient care areas	Walls & ceilings	Health care buildings
Not permitted			
Unsprinklered	Public corridors	Walls & ceilings	All buildings other than apartments, aged accommodation, health care buildings, public assembly buildings, schools
	Sole occupancy units	Walls & ceilings	Aged accommodation
	Classrooms	Ceilings	Schools
	Offices, aspect ratio >5	Ceilings	Office buildings
	Shops, aspect ratio >5	Ceilings	Shops
Low density timber products			
Permitted			
Unsprinklered	Sole-occupancy units	Walls & ceilings	Apartments
	Classrooms	Walls	Schools
	Offices, aspect ratio >5	Walls	Office buildings
	Shops, aspect ratio >5	Walls	Shops
	Other areas	Walls & ceilings	All buildings
Sprinklered	Public corridors	Walls & ceilings	All buildings other than aged accommod-ation, health care buildings
	Sole-occupancy units	Walls & ceilings	Apartments
	Sole-occupancy units	Walls & ceilings	Aged accommodation
	Classrooms	Walls & ceilings	Schools
	Offices, aspect ratio >5	Walls & ceilings	Office buildings
	Shops, aspect ratio >5	Walls & ceilings	Shops
	Other areas	Walls & ceilings	All buildings
		Plastics products	
Fire-retarded plastics wall coverings on masonry			
Permitted			
Unsprinklered	Patient care area	Ceilings	Health care buildings
Sprinklered	Patient care area	Ceilings	Health care buildings
Not permitted			
Unsprinklered	Public corridors	Walls & ceilings	Aged accommodation, health care buildings
	Public corridors	Walls & ceilings	Public assembly buildings
Phenolic composites			
Not permitted			
Unsprinklered	Public corridors	Walls & ceilings	Aged accommodation, health care buildings

	Public corridors	Walls & ceilings	Public assembly buildings

continued...

Table 12.2 continued

Generic materials		*Changes*	
Fire-retarded polyurethane foams[b]			
Not permitted			
Unsprinklered	Public corridors	Walls & ceilings	Aged accommodation, health care buildings
	Public corridors	Ceilings	Public assembly buildings, schools
	Public corridors	Walls & ceilings	All buildings other than apartments, aged accommodation, health care buildings, public assembly buildings, schools
	Patient care areas	Walls	Health care buildings
	Sole-occupancy units	Walls & ceilings	Aged accommodation
	Auditoriums	Walls & ceilings	Public assembly buildings
	Classrooms	Walls & ceilings	Schools
	Offices, aspect ratio >5	Walls & ceilings	Office buildings
	Shops, aspect ratio >5	Walls & ceilings	Shops
	Sole-occupancy units	Walls & ceilings	Apartments, hotels & boarding houses
	Other areas	Walls & ceilings	All buildings
Sprinklered	Public corridors	Ceilings	Aged accommodation, health care buildings, schools
	Public corridors	Walls	Apartments, hotels & boarding houses, public assembly buildings, schools
	Public corridors	Walls & ceilings	All buildings other than apartments, aged accommodation, health care buildings, public assembly buildings, schools
	Patient care area	Walls	Health care buildings
	Sole-occupancy units	Walls & ceilings	Aged accommodation
	Auditoriums	Walls & ceilings	Public assembly buildings
	Classrooms	Walls & ceilings	Schools
	Offices, aspect ratio >5	Walls & ceilings	Office buildings
	Shops, aspect ratio >5	Walls & ceilings	Shops
	Sole-occupancy units	Walls & ceilings	Apartments, hotels & boarding houses
	Other areas	Walls & ceilings	All buildings
Fire-retarded polystyrene foams[b]			
Not permitted			
Unsprinklered	Public corridors	Walls & ceilings	All buildings other than apartments, aged accommodation, health care buildings, public assembly buildings, schools
	Sole-occupancy units	Walls & ceilings	Aged accommodation
	Auditoriums	Walls & ceilings	Public assembly buildings
	Classrooms	Walls & ceilings	Schools
	Offices, aspect ratio >5	Walls & ceilings	Office buildings
	Shops, aspect ratio >5	Walls & ceilings	Shops
Sprinklered	Auditoriums	Walls & ceilings	Public assembly buildings
	Offices, aspect ratio >5	Walls & ceilings	Office buildings
	Shops, aspect ratio >5	Walls & ceilings	Shops
Vinyl tiles			
Not permitted			
Unsprinklered	Public corridors	Walls & ceilings	All buildings other than apartments, aged accommodation, health care buildings, public assembly buildings, schools
	Patient care area	Walls	Health care buildings
	Sole-occupancy units	Walls & ceilings	Aged accommodation
	Auditoriums	Walls & ceilings	Public assembly buildings
	Classrooms	Ceilings	Schools
	Offices, aspect ratio >5	Ceilings	Office buildings
	Shops, aspect ratio >5	Ceilings	Shops

[a] Sufficiently fire-retarded to be classed as Group d materials.
[b] Insufficiently fire-retarded to be classed as Group b materials.

13 – Recommendations for Further Work

As agreed at the outset, this project has used currently available technology and information. During the course of the project, several gaps in current knowledge and data have come to light. In order to fill in the gaps and enhance the project output, research in the following areas is recommended. It should be acknowledged that several of these areas are the subject of current research, both in Australia and overseas, and a thorough review of state-of-the-art research would make a good starting point.

13.1 ASET Versus RSET

The central element in the approach that has been taken in Project 2 is time. Originally it was envisaged that timelines would be calculated for the development of the fire and for occupant evacuation. The fire timeline would allow quantitative determination of available safe egress time (ASET) for a variety of buildings and a variety of locations within buildings. The occupant timeline would allow quantitative determination of required safe egress time (RSET), also for a variety of buildings and a variety of locations within buildings. By comparing ASET with RSET it was hoped that a flexible system would be achieved that allowed solutions on a case-by-case basis for fire engineering purposes, and for generic groups of buildings for BCA 'deemed-to-satisfy' solutions.

The project has tested technology currently available throughout the world and found that it is far from ready for use in the control of lining materials in this way. Whilst the quantification of ASET and RSET for a variety of buildings and a variety of locations within buildings is a goal worth pursuing, it is unlikely to be developed to a state that is useful for the derivation of deemed-to-satisfy requirements for many years to come.

13.2 Fire Modelling

The project attempted to extend the range of reliable model predictions on the influence of linings on fire spread and development, using experimental and real fire experience. The data on a range of typical linings obtained in experiments was to be used to model the fire behaviour of linings in various sized enclosures, and to map the progress of the fire into adjacent enclosures.

After intensive assessment of fire models, it was concluded that it was not possible to use existing software in this fashion. The prime reason was that the models contained in the software were incapable of handling burning on walls or ceilings within enclosures.

The modelling of surface burning is a major area of international research. At the Fifth International Symposium of Fire Safety Science, held in Melbourne in March 1997, no fewer than 8 of the 100 papers discussed modelling flame spread on walls or ceilings (Hasemi 1997). Work by Wade (1996), Beyler *et al.* (1997), Quintiere (1993), Karlsson (1994) and Delichatsios *et al.* (1991) is of interest. Advances in this area should eventually enable the quantification of ASET for fires involving wall and ceiling linings. Australia needs to keep abreast of progress and be involved in future developments to ensure that they are applicable to Australian conditions.

13.3 Egress Modelling

Experience in a number of FCRC projects, especially Projects 2, 3 and 4, has shown that existing models for human behaviour in fire have serious shortcomings. Improved human behaviour models to enable the quantification of RSET for various buildings and locations in buildings, particularly for Australian conditions, need to be developed.

13.4 Need for Data

During the course of the project, extensive searches for data were conducted. Although an enormous amount of data on the fire behaviour of wall and ceiling linings has been published over the years, much of it was not relevant. The data actually utilised in Project 2 came from a limited number of sources. There is a need to produce or obtain more data relevant to the topics addressed by this project.

Such data should be relevant to Australian building practice and reflect the most commonly used wall and ceiling linings. In particular 'problem' materials need to be identified.

13.5 Correlation Between Small-scale Tests, Large-scale Tests and Real Fires

For flame spread, a link between lining performance in large-scale tests and lining performance in real fires has been established. While a suitable correlation exists between the Cone Calorimeter and the ISO Room Fire Test, further correlations need to be developed if alternative small-scale tests are to be used to predict performance in the ISO Room Fire Test.

For smoke, no correlation has been developed between small-scale tests, large-scale tests and real fires. If separate smoke controls are to be retained and the cost of testing kept low, such correlations need to be developed.

13.6 Ceiling Performance in Sprinklered Buildings

The application of material Groups to building categories and locations within buildings remains an area of subjective assessment. Little quantitative data is available, especially on the influence of sprinklers on ceiling lining performance in large spaces. An experimental program to investigate the effect of sprinklers on large-area ceilings would provide valuable data for the reassessment of provisions in sprinklered buildings.

13.7 Additional Smoke Controls

While Australian regulations have traditionally controlled the density of smoke produced by linings by measuring the smoke developed in the Early Fire Hazard Test, there is little evidence to show that the controls contribute to the safety of building occupants. Current recommendations are that controlling time to flashover in the ISO Room Fire Test is a sufficient control on smoke generation by linings. Further investigation might be helpful to confirm the recommendation. Should it be considered necessary to include additional controls, a detailed study of time spent in public corridors versus time spent in fire-isolated exits might prove beneficial in establishing where such controls should be applied.

13.8 Occupancies With Special Considerations

13.8.1 Kitchens

Kitchens in Classes 2–9 buildings are not currently subject to any special controls. More fires start in kitchens than in other areas but only a small proportion spread or become large (see Research Paper 3). This is partly due to the alert state of the occupants. An increase in control might therefore have little effect on current practice, but might catch the few errant occurrences. There is at present insufficient evidence to support separate controls for kitchen linings but this is an area for future consideration.

13.8.2 Boarding houses

Fire Code Reform Project 4 has found that the occupant characteristics of boarding houses are substantially different from those of hotels and motels. When sufficient data becomes available, a separate study on control of lining materials in boarding houses might be warranted.

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15 – References

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Appendix A – Original Objectives and Outputs

The original project objectives and outputs for Stage A are listed below.

Objectives

- To examine the basis and need for control on fire properties of materials in general.
- Identify the appropriate control tool [test method(s)] and the level of performance (in terms of that tool) required for different occupancy categories, considering any other required fire safety system component, for wall and ceiling linings.
- Provide definitions of level of performance that may be used in flexible performance-oriented regulations for wall and ceiling linings.

Outputs

- A comprehensive set of building and occupancy descriptors that will be used for later analysis.
- The relationship between reaction to fire properties of materials and design fires used in further engineering analysis for wall and ceiling linings.
- Recommendations for the appropriate control tool (test methods for control of fire growth and other hazards) for wall and ceiling linings.
- Statements of levels of performance for the control test methods for wall and ceiling linings.
- Recommendations on the different levels of performance that may be required with other fire safety system components for wall and ceiling linings.
- Recommendations for amendments to the Building Code of Australia for wall and ceiling linings.

Appendix B – Project 2 Research Papers

The following Research Papers were produced during Stage A of Project 2.

Research Paper 1	*Recent Approaches to Regulating the Fire Performance of Materials in Buildings*
Research Paper 2	*Report on Evacuation Times and Generic Building Occupancies Derived from the Building Code of Australia*
Research Paper 3	*Building Fire Scenarios – an Analysis of Fire Incident Statistics*
Research Paper 4	*Fire Modelling and the Control of Wall and Ceiling Linings in Buildings*
Research Paper 5	*Large-scale Experiments to Provide Data for Validation of Building Performance Parameters*
Research Paper 6	*Control of Wall and Ceiling Linings in Buildings*
Research Paper 7	*Data from Large-scale and Small-scale Experiments on Wall and Ceiling Linings*

Appendix C – Standards Cited

AS 1530.3 *Methods for Fire Tests on Building Materials, Components and Structures: Part 3 – Simultaneous Determination of Ignitability, Flame Propagation, Heat Release and Smoke Release*, Standards Association of Australia, Sydney.

AS 1530.5 *Methods for Fire Tests on Building Materials, Components and Structures: Part 5 – Test for Piloted Ignitability*, Standards Association of Australia, Sydney.

AS 2118 *Automatic Fire Sprinkler Systems*, Standards Association of Australia, Sydney.

ASTM E 84 *Standard Test Method for Surface Burning Characteristics for Building Materials*, American Society for Testing & Materials, Philadelphia. Pennsylvania

ASTM E 662 *Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials*, American Society for Testing & Materials, Philadelphia. Pennsylvania

ASTM E 1354 *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*, American Society for Testing & Materials, Philadelphia, Pennsylvania.

ASTM E 1740 *Standard Test Method for Determining the Heat Release Rate and Other Fire-Test-Response Characteristics of Wallcovering Composites Using a Cone Calorimeter*, American Society for Testing & Materials, Philadelphia, Pennsylvania.

ISO 2602 *Statistical Interpretation of Test Results – Estimation of the Mean – Confidence Interval, International Organization for Standardization*, Geneva (cited in Mangs *et al.* 1991).

ISO 5660–1 *Fire Tests – Reaction to Fire – Rate of Heat Release from Building Products*, International Organization for Standardization, Geneva.

ISO 5657 *Fire Tests – Reaction to Fire – Ignitability of Building Products*, International Organization for Standardization, Geneva.

ISO 5725 *Precision of Test Methods – Determination of Repeatability and Reproducibility by Inter-laboratory Tests*, International Organization for Standardization, Geneva.

ISO 9705 *Fire Tests – Full-scale Room Test for Surface Products*, International Organization for Standardization, Geneva.

MIL–STD–2031 *Fire and Toxicity Test Methods and Qualification Procedure for Composite Material Systems Used in Hull, Machinery and Structural Applications Inside Naval Submarines*, Department of Defense, USA.

NFPA 264 *Standard Method of Test for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*, National Fire Protection Association, Quincy, Massachusetts.

NFPA 265 *Standard Methods of Fire Tests for Evaluating Room Fire Growth Contribution of Textile Wall Coverings*, National Fire Protection Association, Quincy, Massachusetts.

NT Fire 025 *Surface Products: Room Fire Tests in Full Scale*, Nordtest, Helsinki.

ULC–S135 *Standard Method of Test for Determination of Degrees of Combustibility of Building Materials Using an Oxygen Consumption Calorimeter (Cone Calorimeter)*, Underwriters' Laboratories of Canada, Scarborough, Ontario, Canada.

Appendix D – Interlaboratory Assessments of Test Methods

Interlaboratory assessments have been held on the Room Fire Test and the Cone Calorimeter and the results published. Although an interlaboratory assessment has been held on the Early Fire Hazard Test, the results have not been published and all reference to such an interlaboratory assessment is in the process of being deleted from the standard.

D1 Room Fire Test

Two interlaboratory assessments have been performed on the Room Fire Test, the first by EUREFIC and the second by ASTM in conjunction with ISO.

D1.1 EUREFIC Room Fire Test interlaboratory assessment

A Room Fire Test interlaboratory assessment (Mangs *et al.* 1991) was conducted as part of the EUREFIC research program according to the Nordtest test method NT FIRE 025. This method is technically identical to the international standard ISO 9705. Five laboratories, in Denmark, Finland, Norway, Sweden and the United Kingdom, participated in the interlaboratory assessment.

Four materials were tested, namely:

- ordinary birch plywood;
- melamine-faced particleboard;
- fire-retarded plywood; and
- fire-retarded extruded polystyrene boards glued to an inert substrate.

The burner program was 100 kW for 10 minutes followed by 300 kW for 10 minutes. Linings were mounted on three walls and the ceiling.

Only one of the laboratories tested all four materials, with the other laboratories testing just two or three different materials. In general, only one test was conducted on each material in each laboratory. As a result, there was almost no information on the in-laboratory variance, which would be required to calculate both the repeatability r and the reproducibility R according to ISO 5725. An estimation of the variation in the test results was therefore made by assuming all the test results belong to the same population, with the normal distribution taken as the mathematical model for the probability distribution. The reproducibility was measured by using the 95% confidence interval for the mean. A statistical summary of the results is given in Table D1, and the results are discussed below.

D1.1.1 Discussion

Birch plywood – All the results were similar, except for the results from one laboratory. The results from this laboratory were not included in the statistical data presented in Table D1 because the time to critical smoke value indicated that the test was an outlier according to Dixon's outlier test (ISO 2602).

Table D1 – Time to reach critical values[a] in the ISO Room Fire Test: average results for all tests conducted, and 95% confidence interval

Material	*Heat release*	*Smoke production*	*CO production*	*Heat flux*
Birch plywood	137 ± 37 s	126 ± 11 s	118 ± 12 s	N[b]
Melamine-faced particleboard	199 ± 18 s	171 ± 19 s	181 ± 36 s	N
FR plywood	634 ± 15 s	N	638 ± 41 s	625 ± 5 s
FR polystyrene	N	N	N	N

[a] Critical values used in above table:
- heat release: 1 MW, except for FR plywood where 700 kW was used;
- smoke production: 40 dB/m*m^3/s;
- CO production: 15 g/s, except for FR plywood where 10 g/s was used; and
- heat flux: 20 kW/m^2 for birch plywood and melamine-faced particleboard, and 10 kW/m^2 for FR plywood and FR polystyrene

[b] N denotes values for which 95% confidence levels could not be determined due to lack of results.

Melamine-faced particleboard – The results for the melamine-faced particleboard were claimed to be even more reproducible than those for plywood, but that statement would appear not to be entirely accurate. It would seem to be a correct statement for the rate of heat release (arguably the most important variable), but not for the smoke or CO results.

Fire-retarded plywood – In one test the heat release rate rose suddenly after 17 minutes of testing, and exceeded 1 MW in 1148 s. This was possibly due to charred boards falling from the walls and ceiling allowing the rear of the boards to contribute to the heat release. For the other two tests, the heat release rate did not exceed 1 MW for the duration of the test.

No critical values were given for the smoke production because the results for smoke differed by large amounts.

Fire-retarded polystyrene – For this case major variations were found. No estimates were made of the confidence intervals because of the largely differing results. The most probable cause of these differences was attributed to the different gluing processes used to glue the samples to the substrate.

D1.1.2 Conclusions reached

The authors of the report concluded that the reproducibility of the method was good and typical of other large-scale fire test methods, such as fire-endurance tests using large furnaces. Recommendations were made in the report that mounting methods be improved. These were adopted and incorporated in the instructions for the following interlaboratory assessment.

D1.2 ASTM/ISO Room Fire Test interlaboratory assessment

Beitel (1994) presents the results from an interlaboratory assessment on the proposed ASTM Room Fire Test (ASTM 1983). The study involved 12 laboratories and seven lining materials. The tested materials were:

- Douglas fir plywood;
- fire-retardant treated Douglas fir plywood;
- type X gypsum wallboard;
- extruded polystyrene foam insulation;
- rigid polyurethane foam insulation;

- composite panel – System 210; and
- composite panel – System 310.

Each laboratory, in general, tested just two of the materials in duplicate. This resulted in each material being subjected to between 5 and 10 tests in total. Details of the resulting values of *r* and *R* are provided in Tables D2.1–D2.7.

Table D2.1 – Plywood

Variable	*r (%)*	*R (%)*
Time to 1 MW	29	29
Time to 750 kW	33	34
Time to 600°C room	32	41
Time to 600°C door	27	30
Time to 20 kW/m^2	31	31
Total HR 0–5 minutes	70	85
Total smoke 0–5 minutes	46	103

Table D2.2 – Polyurethane foam

Variable	*r (%)*	*R (%)*
Time to 1 MW	31	32
Time to 750 kW	31	38
Time to 600°C room	30	41
Time to 600°C door	29	33
Time to 20 kW/m^2	31	34
Total HR 0–5 minutes	50	217
Total smoke 0–5 minutes	69	122

Table D2.3 – FR-treated plywood

Variable	*r (%)*	*R (%)*
Peak HRR	40	81
Total HR 0–15 minutes	10	40
Peak smoke	10	148
Total smoke 0–15 minutes	21	89
Maximum floor flux	15	56
Maximum room temperature	7	34
Maximum door temperature	8	29

Table D2.4 – Gypsum wallboard

Variable	*r (%)*	*R (%)*
Peak HRR	12	29
Total HR 0–15 minutes	25	34
Peak smoke	15	229
Total smoke 0–15 minutes	16	165
Maximum floor flux	7	32
Maximum room temperature	1	14
Maximum door temperature	3	5

Table D2.5 – Polystyrene foam

Variable	*r (%)*	*R (%)*
Peak HRR	77	77
Total HR 0–15 minutes	28	43
Peak smoke	144	144
Total smoke 0–15 minutes	29	70
Maximum floor flux	49	49
Maximum room temperature	43	45
Maximum door temperature	32	32

Table D2.6 – Composite panel System 210

Variable	*r (%)*	*R (%)*
Peak HRR	133	133
Total HR 0–15 minutes	48	51
Peak smoke	215	235
Total smoke 0–15 minutes	104	138
Maximum floor flux	153	154
Maximum room temperature	68	73
Maximum door temperature	65	68

Table D2.7 – Composite panel System 310

Variable	*r (%)*	*R (%)*
Peak HRR	17	40
Total HR 0–15 minutes	14	37
Peak smoke	78	167
Total smoke 0–15 minutes	63	140
Maximum floor flux	61	61
Maximum room temperature	18	39
Maximum door temperature	15	40

D1.2.1 Discussion

Two materials reached flashover, namely, plywood and polyurethane foam. The first five parameters reported in Tables D2.1 and D2.2 can be used as definitions of flashover. The following comments were provided for these materials:

- all the flashover criteria were nearly equivalent, except for the 600°C room temperature;
- the values of *r* and *R* were nearly equal, indicating no major differences between laboratories. Variations are probably due to variances in the materials; and
- total heat release rate and smoke values over the first five minutes are less repeatable, and significantly less reproducible.

The five other materials (gypsum wallboard, polystyrene, FR plywood, composite System 210, and composite System 310) did not proceed to flashover. The authors of the interlaboratory assessment report make the following comments on these materials:

- for gypsum wallboard (the only untreated material), *r* and *R* for heat release are reasonable, except for the 0–5 minute averages;
- for the same material, the smoke values of *R* were significantly worse. Poor interlaboratory smoke calibration was probably the reason for this;
- value of *r* and *R* for the floor flux and temperature measurements of the gypsum board were excellent;
- for the polystyrene foam and System 210, values of *r* and *R* were large and similar in size. This indicated that the material variability dominated, and the current ASTM test may not be appropriate for these materials; and
- FR plywood and System 310 performed reasonably well, in particular the 0–15 minute average heat release rate, and the door and room temperatures.

The authors considered the results to be good for this type of full-scale fire test. Measurements of heat release rate, room and doorway temperatures, and the floor heat flux appeared to show the best promise, while smoke measurements produce the greatest variation. The material performance during the test was also found to have an influence, e.g. melting (polystyrene) and delamination (composite System 210) increased the spread in the results.

The test results were considered credible in terms of overall material performance, since those materials that did not flash over, did not flash over in any of the laboratories, and for materials that did flash over, flashover was noted in all tests at all laboratories.

D2 Cone Calorimeter

A number of interlaboratory assessments have been performed on the Cone Calorimeter. In addition, there have been many studies on black polymethylmethacrylate (PMMA), which is used as a reference material.

D2.1 Studies with PMMA

Black PMMA is commonly used as a reference material to calibrate and check the performance of the Cone Calorimeter. It is chosen for this purpose because of its good reproducibility in the test. Table D3 lists the time to sustained flaming, t_{ig}, and the corresponding *r* and *R*, obtained from a variety of references.

Table D3 – Experimental values for time to sustained flaming of black PMMA in the Cone Calorimeter at 50 kW/m2

t_{ig} (s)	*r* (s)	*R* (s)	*Thickness* (mm)	*Reference*	*Notes*
23	7.7	—	25	Rhodes (1994)	Flame igniter
24	1.7	3.6	—	Bluhme (1989)	Average over 3 labs
22	2.2	4.8	—	Janssens (1989)	ISO 5660 interlaboratory assessment
30	4.8	—	6	Paul (1994)	
29	5.4	—	6	Paul (1994)	
20	2.0	8.2	6	ASTM (1990)	Interlaboratory trials – 6 labs

All the data in Table D3 refer to results obtained at an irradiance of 50 kW/m^2, and using a horizontal orientation. The values of r and R have been estimated using the following expressions:

$$r = 2.8\ S_r$$
$$R = 2.8\ S_R$$

where S_r and S_R are the sample-based standard deviations.

D2.2 Cone Calorimeter interlaboratory assessments

The method has been assessed in interlaboratory trials conducted by EUREFIC (Bluhme 1989), ISO (Janssens 1989) and ASTM (ASTM 1990). The purpose of these interlaboratory trials was to investigate repeatability of the method in individual laboratories and reproducibility between laboratories, and to determine whether changes in procedure were indicated. The outcomes were procedural changes, which have been incorporated in the published ASTM and ISO methods, and statements that both repeatability and reproducibility were satisfactory for a fire test of this type.

ASTM E 1354 provides expressions for estimating r and R of the test method for six variables. These expressions are based on interlaboratory trials conducted using six laboratories (ASTM 1990) and the following materials:

- fire-retardant ABS;
- particleboard;
- black PMMA;
- polyethylene;
- PVC; and
- rigid polyisocyanurate foam;

along with the results of a parallel set of interlaboratory trials conducted under the auspices of ISO.

The resulting expressions for r and R, based on a linear regression analysis of the results, are as follows:

- for time to sustained flaming, t_{ig}, in the range 5–150 s

$$r = 4.1 + 0.125\ t_{ig} \text{ and}$$
$$R = 7.4 + 0.220\ t_{ig}$$

- for peak heat release rate, $\dot{q}''_{max}$, in the range 70 to 1120 kW/m^2

$$r = 13.3 + 0.131\ \dot{q}''_{max} \text{ and}$$
$$R = 60.4 + 0.141\ \dot{q}''_{max}$$

- for average heat release at 180 s, $\dot{q}''_{180}$, in the range 70–870 kW/m^2 are:

$$r = 23.3 + 0.037\ \dot{q}''_{180} \text{ and}$$
$$R = 25.5 + 0.151\ \dot{q}''_{180}$$

- for total heat release, $\dot{q}''_{tot}$, in the range 5 to 720 MJ/m^2

$$r = 7.4 + 0.068\ \dot{q}''_{tot} \text{ and}$$
$$R = 11.8 + 0.088\ \dot{q}''_{tot}$$

- for effective heat of combustion, $\Delta h_{c,eff}$, in the range 7 to 40 kJ/g

$$r = 1.23 + 0.050\ \Delta h_{c,eff} \text{ and}$$
$$R = 2.42 + 0.055\ \Delta h_{c,eff}$$

- for average specific extinction area, σ_f, in the range 30–2200 m^2/kg

$$r = 59 + 0.076\ \sigma_f \text{ and}$$
$$R = 63 + 0.215\ \sigma_f$$

These results may be summarised as follows:

- repeatability
  - time to ignition 15–95%
  - 180-second average heat release rate 6–37%
  - average smoke production (SEA) 10–204%
- reproducibility
  - time to ignition 27–170%
  - 180-second average heat release rate 18–52%
  - average smoke production (SEA) 24–231%

A more recent interlaboratory assessment (Janssens 1995), using 17 laboratories, found significantly larger values of r and R. The materials tested were:

- plywood;
- FR plywood;
- gypsum board;
- polyurethane foam;
- extruded polystyrene foam; and
- wood composite.

Expressing r and R as linear functions in the form $r = a + bx$ and $R = A + Bx$, a linear regression analysis resulted in the following values for b and B:

Variable	b	B
t_{ig}	0.54	0.81
$\dot{q}''_{max}$	0.32	0.71
$\dot{q}''_{180}$	0.17	0.17
$\dot{q}''_{tot}$	0.29	0.57
$\Delta h_{c,eff}$	0.09	0.59
σ_f	0.28	0.55

These results may be summarised as follows:

- repeatability
  - time to ignition 26–104%
  - 180-second average heat release rate 24–42%
  - average smoke production (SEA) 10–182%
- reproducibility
  - time to ignition 68–127%
  - 180-second average heat release rate 39–75%
  - average smoke production (SEA) 54–242%

A possible explanation for the significant increase in *r* and *R* was that most materials used in this set were treated with fire retardants. The report recommends that the *r* and *R* values obtained from previous interlaboratory assessments be used as the most reliable estimate of the precision of the Cone Calorimeter.

An Asia–Oceania interlaboratory trial has been carried out by BRI Japan (Marchal *et al.* 1995). It involved 10 laboratories and 5 materials. No Australian or New Zealand laboratories were involved. The authors concluded that there was room for improvement as there were a high number of 'outliers'. The authors proposed that if any one of the heat release values among three replicates differed by more than 10% from the mean, then an extra three tests should be performed. The authors believed this procedure would eliminate most of the numerous outliers they found.

Following on from this interlaboratory trial, the authors organised another Cone Calorimeter interlaboratory assessment with broader scope on behalf of CIB W14. At least one Australian and one New Zealand laboratory participated in this interlaboratory assessment. At this stage the results have not been published.

APPENDIX E – FIRE TEST DATA

The following tables contain data, extracted from various sources, that have been used in the analyses in this report. The references contain additional data on these materials. Materials that have a code number have been assessed in more than one test.

E1 ROOM FIRE TEST DATA

The ISO Room Fire Test had a burner program of 100 kW for the first 600 s, followed by 300 kW for a further 600 s. The ASTM Room Fire Test had a burner program of 40 kW for the first 300 s, followed by 160 kW for a further 300 or 600 s. The materials in Table E1 covered three walls and the ceiling of the fire test room. The materials in Tables E2 and E3 covered three walls only of the fire test room.

Table E1 – ISO Room Fire Test results (walls and ceilings)

Code[a]	Material	Time to flashover (s)	Average rate of smoke production (m^2/s)[b]	Ref.[c]
A9	Plasterboard, paper-faced, glass-reinforced	N	0.3	1
E1	Painted gypsum paper plasterboard	N	0.4	2
E4	Melamine-faced, high-density, non-combustible board	N	2.0	2
E5	Plastic-faced steel sheet on mineral wool	N	1.5	2
E8	FR particleboard	N	3.3	2
E13	FR plywood	N	1.0	2
E28	Gypsum board	N	0.0	2
E3	Textile wall covering on gypsum paper plasterboard	660	0.4	2
E10	PVC wall carpet on gypsum paper plasterboard	655	2.5	2
E27	Paper wall covering on gypsum board	640	0.1	2
E6	FR particleboard, type B1	630	1.5	2
E22	Textile wall covering on gypsum board	629	0.1	2
E21	Plastic wall covering on gypsum board	611	0.8	2
E20	Melamine-faced particleboard	465	7.7	2
E9	Plastic-faced steel sheet on polyurethane foam	195	2.2	2
A11	Hoop pine plywood, treated	190	3.8	1
E14	Melamine-faced particleboard	182	2.6	2
E16	Particleboard	157	2.6	2
E2	Ordinary birch plywood	150	2.1	2
E24	Paper wall covering on particleboard	143	2.8	2
E12	Birch plywood	137	2.0	2
E18	Medium-density wood-fibre board	131	2.0	2
E19	Wood panel, spruce	131	1.9	2
A10	Lauan plywood 1	125	3.3	1
E26	Expanded polystyrene	115	7.9	2
E7	Combustible-faced mineral wool	80	0.6	2
E11	FR extruded polystyrene foam	80	1.2	2
E15	FR polystyrene foam	67	1.5	2
E17	Insulating wood-fibre board	59	2.1	2
E23	Textile wall covering on rockwool	43	5.0	2
E25	Rigid polyurethane foam	6	49.3	2

[a] Codes identify those materials for which small-scale data is also available.

[b] Although this quantity is referred to in the literature as 'average rate of smoke production (RSP); the data cannot be used to determine the quantity of smoke issuing from the fire test room unless the amount of additional air drawn into the exhaust system is known. The values are corrected to a volume flow of 1 m^3/s.

[c] References: 1 = Research Paper 7; 2 = Östman and Tsantaridis (1993). In reference 2 the data was calculated according to the former Nordtest Fire 025 relationship: RSP = 10 $(1/L) \log (I_0/I)$, where L = duct diameter, I_0 = emitted light intensity and I = transmitted light intensity. For this table it has been converted to make it consistent with ISO 9705, which uses the following relationship: RSP = $(1/L) \ln (I_0/I)$.

Table E2 – ISO Room Fire Test results (walls only)

Code[a]	*Material*	*Time to flashover (s)*	*Average rate of smoke production* $(m^2/s)^b$	*Ref.*[c]
A2	Glass-reinforced phenolic 71	N	0.3	1
A1	Glass-reinforced phenolic 70	837	0.8	1
A11	Hoop pine plywood, treated	260	2.0	1
A10	Lauan plywood 1	163	1.8	1

[a] Codes identify those materials for which small-scale data is also available.
[b] Although this quantity is referred to in the literature as 'average rate of smoke production (RSP)' the data cannot be used to determine the quantity of smoke issuing from the fire test room unless the amount of additional air drawn into the exhaust system is known. The values are corrected to a volume flow of 1 m^3/s.
[c] References: 1 = Research Paper 7.

Table E3 – ASTM Room Fire Test results (walls only)

Code[a]	*Material*	*Time to flashover (s)*	*Ref.*[b]
A1	Glass-reinforced phenolic 70	N_{900}[c]	1
A3	Plasterboard (US)	N_{900}	1
A4	FR plywood (US)	N_{900}	1
A7	FR polystyrene foam (US)	N_{900}	1
A9	Plasterboard, paper-faced, glass-reinforced	N_{900}	1
A13	Radiata pine, FRC	N_{600}[d]	2
—	Fire-retarded plywood	N_{600}	3
A14	Blackbutt	452	2
A5	Plywood (US)	405	1
A12	Particleboard	396	2
A15	Douglas fir	390	2
—	Douglas fir plywood	380	3
A19	Victorian ash	378	2
—	Redwood	378	3
A16	Radiata pine 1	366	2
A6	FR polyurethane foam (US)	365	1
A17	Western red cedar	354	2
—	Southern pine plywood	344	3
—	Particleboard	336	3
A8	Hardboard	325	1
A18	Lauan plywood 2	270	2
—	Oriented strand board	266	3

[a] Codes identify those materials for which room small-scale data is also available.
[b] References: 1 = Research Paper 6; 2 = Gardner and Thomson (1988); 3 = Janssens (1991).
[c] No flashover in 900 s.
[d] No flashover in 600 s.

E2 EARLY FIRE HAZARD TEST DATA

The data presented here is for the two indexes currently cited in the BCA.

Table E4 – Early fire hazard test results

Code[a]	*Material*	*Spread of flame index*	*Smoke developed index*	*Ref.*[b]
—	Glass-reinforced plaster (best[c])	0	0	1
—	Glass-reinforced plaster (worst[c])	0	0	1
—	Mineral fibre insulation batts (best)	0	0	1
—	Phenol formaldehyde	0	0	4
—	Polyurethane/steel sandwich	0	0	4
A3	Plasterboard (US)	0	1	6
A9	Plasterboard, paper-faced, glass-reinforced	0	1	6
A2	Glass-reinforced phenolic 71	0	2	6
—	Plasterboard (worst)	0	2	1
—	Plasterboard/acrylic paint	0	2	2
A1	Glass-reinforced phenolic 70	0	3	6
A4	FR plywood (US)	0	3	6
A6	FR polyurethane foam (US)	0	3	6
—	100% wool carpet (best)	0	3	1
—	Glass fibre insulation (worst)	0	3	1
—	FR melamine laminated board	0	3	8
—	Mineral fibre insulation batts (worst)	0	3	1
—	Plasterboard (best)	0	3	1
A12	Particleboard	0	4	7
—	Hoop pine plywood, FR2	0	4	7
—	Plasterboard/vinyl wallpaper	0	4	2
—	FR plywood (best)	0	4	1
—	FR polyester sheet, glass-reinforced (best)	0	4	1
—	Urea formaldehyde	0	4	4
A13	Radiata pine, FRC	0	5	7
—	Hoop pine plywood, FR1	0	5	7
—	100% wool carpet (worst)	0	5	1
—	FR plywood, coachwood veneer	0	5	8
—	FR Polystyrene foam (best)	0	5	1
—	FR Polyurethane foam (best)	0	5	1
—	Vinyl tiles	0	5	8
—	Woollen carpet, Axminster	0	5	8
—	Woollen carpet, Wilton	0	5	8
—	FR Australian hardboard	0	7	8
—	FR Australian softboard	0	7	8
—	Particleboard (best)	0	7	1
—	PVC sheet	0	7	8
—	Solid vinyl siding	0	7	9
—	FR polyester sheet	0	9	8
—	Vinyl tiles, high impact	2	5	8
—	Brush box	3	2	3
—	Timber – jarrah (best)	3	2	1
—	Polyurethane foam, FR2	3	7	8
—	Polyester sheet	4	9	8
—	Blackbutt plywood	5	2	7
—	Timber – jarrah (worst)	5	2	1

continued...

Table E4 continued

Code[a]	*Material*	*Spread of flame index*	*Smoke developed index*	*Ref.*[b]
—	Messmate	5	3	3
—	Timber – radiata pine (best)	5	3	1
—	Melamine laminated board	5	6	8
—	Jarrah	6	3	7
—	Australian hardboard	6	3	8
—	Oregon	6	3	8
—	FR acrylic carpet (best)	6	5	1
—	Hardboard/FR, melamine-faced	6	5	2
—	Hardboard, melamine-faced	6	5	2
—	FR melamine laminate on hardboard	6	5	9
—	Hardboard, intumescent paint	6	6	9
—	Hardboard/FR vinyl paint	6	6	2
—	Hardboard	7	2	9
—	Hoop pine	7	2	3
A8	Hardboard	7	3	6
A14	Blackbutt	7	3	7
—	Brush box	7	3	7
—	Hardboard, standard	7	3	7
—	Baltic pine	7	3	8
—	Hardboard	7	3	2
—	Hardboard (best)	7	3	1
—	Australian hardboard	7	3	5
—	Radiata pine	7	3	3
—	Acrylic sheet (best)	7	4	1
—	Linoleum (best)	7	4	1
—	Plywood, coachwood veneer	7	4	8
—	Acrylic sheet	7	5	8
—	Hardboard (worst)	7	5	1
—	Particleboard, melamine-faced	7	5	2
—	FR flexible vinyl on hardboard	7	6	9
—	FR vinyl-coated cotton on hardboard	7	6	9
—	Mountain ash	7	—	3
—	Hoop pine plywood	8	1	7
A5	Plywood (US)	8	2	6
—	Hardboard, exterior	8	2	7
A11	Hoop pine plywood, treated	8	3	6
A19	Victorian ash	8	3	7
—	Radiata pine 2	8	3	7
—	Particleboard (worst)	8	3	1
—	Plywood (worst)	8	3	1
—	Spruce weatherboard	8	3	9
—	Timber – radiata pine (worst)	8	3	1
A18	Lauan plywood 2	8	4	7
—	Victorian ash plywood	8	4	7
—	Melamine laminate on hardboard	8	4	9
A7	FR polystyrene foam (US)	8	5	6
—	Acrylic sheet (worst)	8	5	1
—	Polystyrene sheet	8	5	8
—	Acrylic carpet	8	8	8
A10	Lauan plywood 1	9	3	6

continued...

Table E4 continued

Code[a]	Material	Spread of flame index	Smoke developed index	Ref.[b]
A15	Douglas fir	9	3	7
A16	Radiata pine 1	9	3	7
—	Cypress pine	9	3	7
—	Australian softboard	9	3	8
—	Hardboard, acrylic paint	9	3	9
—	Hardboard/vinyl paint	9	3	2
—	Softboard	9	3	5
—	Hardboard/acrylic paint	9	4	2
—	Plywood/polyurethane finish	9	4	2
—	Hardboard/enamel paint	9	5	2
—	Linoleum (worst)	9	6	1
—	Polystyrene foam (worst)	9	8	1
—	Polyurethane foam, FR1	9	9	8
A17	Western red cedar	10	4	7
—	Western red cedar T&G	10	4	5
—	Acrylic carpet (worst)	10	7	1
—	FR polystyrene foam	10	8	8
—	Polyurethane slabstock	10	8	4
—	GRP flatsheet	10	9	2
—	Polyester sheet, glass-reinforced (worst)	10	9	1
—	Polyurethane foam (worst)	10	9	1

[a] Codes identify those materials for which Room Fire Test data is available.
[b] References: 1 = AS 1530.3; 2 = Moulen *et al.* (1980); 3 = Beesley *et al.* (1974); 4 = Dowling and Martin (1985); 5 = NBTC (1986); 6 = Research Paper 6; 7 = Gardner and Thomson (1988); 8 = Keough (1969); 9 = Brown and Martin (1983).
c 'Best' and 'worst' performers are as identified in AS 1530.3.

E3 Cone Calorimeter Data

The Cone Calorimeter produces a range of data as a function of time, including heat release and specific extinction area (a specific optical density of smoke measurement). The data presented in Table E5 are some of the typical outputs. The models described in this report use time history of heat release.

E4 Smoke Data

In Table E6, smoke data extracted from Tables E1 and E5 is ranked so that data from the Cone Calorimeter can be compared with data from the ISO Room Fire Test. No correlation is known to exist, nor is one suggested.

Table E5 – Cone calorimeter results at 50 kW/m²

Code	*Material*	*Total heat release during 300 s after ignition (MJ/m²)*	*Time to ignition (s)*	*Average specific extinction area[a] (m²/kg)*	*Ref.[b]*
A3	Plasterboard (US)	3.5	30	17	1
A9	Plasterboard, paper-faced, glass-reinforced	3.5	44	23	1
E5	Plastic-faced steel sheet on mineral wool	3.7	53	560	2
E7	Combustible-faced mineral wool	4.0	5	80	2
E28	Gypsum board	6.7	34		2
E1	Painted gypsum paper plasterboard	7.0	47	14	2
A6	FR polyurethane foam (US)	7.0	5	363	1
E23	Textile wall covering on rockwool	8.5	11		2
E13	FR plywood	8.7	469	23	2
E21	Plastic wall covering on gypsum board	9.2	10		2
E27	Paper wall covering on gypsum board	9.4	21		2
E4	Melamine-face,d high-density, non-combustible board	9.8	29	84	2
E6	FR particleboard, type B1	10.4	21	67	2
E10	PVC wall carpet on gypsum paper plasterboard	11.9	15	101	2
E22	Textile wall covering on gypsum board	12.1	20		2
E3	Textile wall covering on gypsum paper plasterboard	12.8	25	43	2
A4	FR plywood (US)	16.0	47	12	1
E9	Plastic-faced steel sheet on polyurethane foam	17.2	19	747	2
E25	Rigid polyurethane foam	17.4	2		2
A2	Glass-reinforced phenolic 71	19.6	226	141	1
E20	Melamine-faced particleboard	19.8	41		2
A7	FR polystyrene foam (US)	20.1	24	1281	1
E11	FR extruded polystyrene foam	22.3	31	1381	2
A11	Hoop pine plywood, treated	22.3	18	59	1
—	Tasmanian hardwood	24.1	36	5.3	1
E15	FR polystyrene foam	24.2	25	1224	2
E19	Wood panel, spruce	25.0	20		2
A1	Glass-reinforced phenolic 70	25.9	180	222	1
A10	Lauan plywood 1	27.1	30	65	1
E24	Paper wall covering on particleboard	29.8	33		2
E18	Medium-density wood-fibre board	32.6	31		2
E26	Expanded polystyrene	32.8	39		2
E14	Melamine-faced particleboard	32.9	34	32	2
E17	Insulating wood-fibre board	33.2	12		2
A5	Plywood (US)	33.2	22	52	1
A14	Blackbutt	33.3	36	17	1
A19	Victorian ash	35.4	22	14	1
E12	Birch plywood	35.5	28	58	2
A12	Particleboard	37.8	30	50	1
E2	Ordinary birch plywood	38.0	30	68	2
E16	Particleboard	45.9	34		2
A8	Hardboard	59.4	37	44	1
E8	FR particleboard	0.0	N	35	2

[a] Specific extinction area (SEA) is a unit of smoke production that links optical density to flow rate in the exhaust and specimen mass loss.
[b] References: 1 = Research Paper 7; 2 = Östman and Tsantaridis (1994).

Table E6 – Smoke results from ISO Room Fire Test (walls and ceilings) and Cone calorimeter at 50 kW/m^2

ISO Room Fire Test			*Cone Calorimeter*		
Code	*Material*	*Average rate of smoke production (m^2/s)*	*Code*	*Material*	*Average specific extinction area (m^2/kg)*
A9	Plasterboard, paper-faced, glass-reinforced	0.3	E1	Painted gypsum paper plasterboard	14
E1	Painted gypsum paper plasterboard	0.4	A9	Plasterboard, paper-faced, glass-reinforced	23
E3	Textile wallcovering on gypsum paper plasterboard	0.4	E13	FR plywood	23
E7	Combustible-faced mineral wool	0.6	E14	Melamine-faced particleboard	32
E13	FR plywood	1.0	E8	FR particleboard	35
E11	FR extruded polystyrene foam	1.2	E3	Textile wall covering on gypsum paper	43
E5	Plastic-faced steel sheet on mineral wool	1.5	A11	Hoop pine plywood, treated	59
E6	FR particleboard, type B1	1.5	E12	Birch plywood	58
E15	FR polystyrene foam	1.5	A10	Lauan plywood 1	65
E4	Melamine-faced high-density non-combustible board	2.0	E6	FR particleboard, type B1	67
E12	Birch plywood	2.0	E2	Ordinary birch plywood	68
E2	Ordinary birch plywood	2.1	E7	Combustible-faced mineral wool	80
E9	Plastic-faced steel sheet on polyurethane foam	2.2	E4	Melamine-faced high-density	84
E10	PVC-wallcarpet on gypsum paper plasterboard	2.5	E10	PVC wall carpet on gypsum paper	101
E14	Melamine-faced particleboard	2.6	E5	Plastic-faced steel sheet on mineral wool	560
E8	FR particleboard	3.3	E9	Plastic-faced steel sheet on polyurethane	747
A10	Lauan Plywood	3.3	E15	FR polystyrene foam	1224
A11	Hoop pine plywood, treated	3.8	E11	FR extruded polystyrene foam	1381

Appendix F – Comparison of Small-scale Tests with Large-scale Tests

F1 Comparison of Early Fire Hazard Test with Room Fire Test

Figures F1 and F2 show comparisons between particular indexes of the Early Fire Hazard Test and the ASTM Room Fire Test. These comparisons are discussed in Chapter 8. The coded data for time to flashover are identified in Tables E3 and E4.

When it became obvious that neither the Flame Spread Index nor the Ignitability Index could reliably predict time to flashover in the ASTM Room Fire Test, a different approach was tried. The models that have been used to predict time to flashover in the ISO Room Fire Test all use relationships in which time to flashover is a function of ignition time and an inverse function of heat release rate per unit area. Whilst the Ignitability Index from the Early Fire Hazard Test is a function of ignition time, it is not possible to calculate heat release rate per unit area. However, if it is assumed that the same area of specimen is involved in all tests, then the Heat Evolved Index can be used as a function of heat release rate per unit area. Using the Ignitability Index and Heat Evolved Index, a relationship can be expressed as:

$$t_{fo} \propto \frac{1}{(I_{HE}/(20 - I_I)}$$

where t_{fo} is time to flashover in the ASTM Room Fire Test; I_{HE} is the Heat Evolved Index of the Early Fire Hazard Test; and I_I is the Ignitability Index of the Early Fire Hazard Test

In Figure F3 this relationship is plotted against time to flashover in the ASTM Room Fire Test. It can be seen that this simple approach does not offer any insight into the development of a suitable relationship.

F2 Comparison of Cone Calorimeter with Room Fire Test

The models that are used to predict time to flashover in the ISO Room Fire Test use the time history of rate of heat release per unit area from the Cone Calorimeter in conjunction with time to ignition. Brief comments on two of these models, which have been found to reliably predict time to flashover, are included below.

F2.1 SP model

The SP model, developed by Wickström and Göransson (1992), is a simplified model which is specifically directed at predicting the time to flashover and the full-scale heat release rate

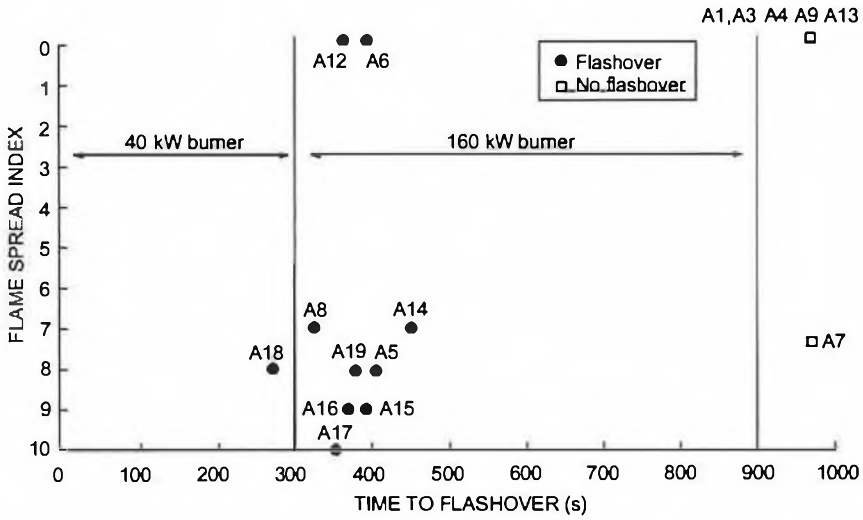


Figure F1 – Comparison of Early Fire Hazard Test Flame Spread Index with time to flashover in the ASTM Room Fire Test

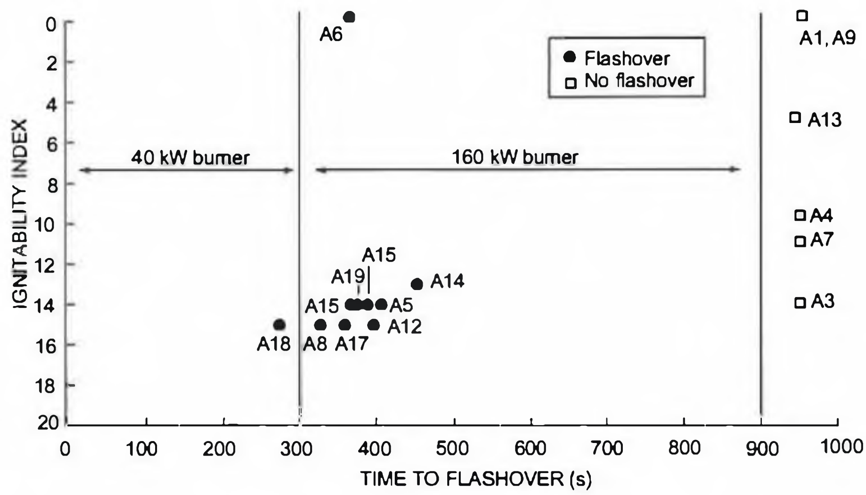


Figure F2 – Comparison of Early Fire Hazard Test Ignitability Index with time to flashover in the ASTM Room Fire Test

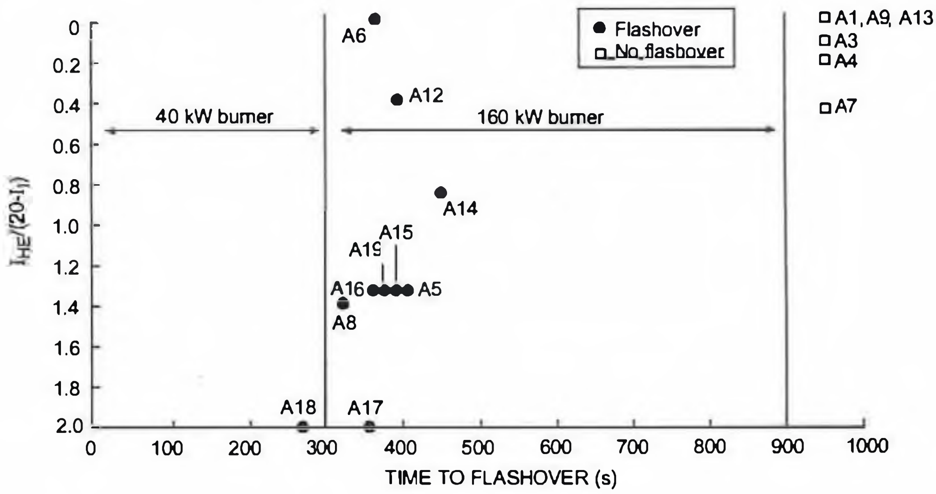


Figure F3 – Comparison of a relationship based on Early Fire Hazard Test Ignitability Index and Heat Evolved Index with time to flashover in the ASTM Room Fire Test

curve of an ISO Room Fire Test using both wall and ceiling linings. The material is tested in the Cone Calorimeter and data is converted into a format suitable as input data for the computer model.

The model is based on an assumption of an initial material burning area behind the ISO Room Fire Test burner for each of the various gas burner output rates. The model uses the Cone Calorimeter heat release rate curve and the time to ignition to calculate the time to flashover and produce the full-scale heat release rate curve. The current version of the software uses data that has been collected at an irradiance of 25 kW/m^2. As some materials that go to flashover in the ISO Room Fire Test do not ignite at 25 kW/m^2 in the Cone Calorimeter, predictions for such materials are not reliable. Therefore it will be necessary to make a minor modification to the software so that data obtained at 50 kW/m^2 can be used. Predictions determined using data obtained at 50 kW/m^2 have been published (Kokkala *et al.* 1993).

A variation of the method has been used to predict the time to flashover in the ASTM Room Fire Test (Sumathipala *et al.* 1994).

F2.2 Classification Indexes

The Classification Indexes were developed by Kokkala *et al.* (1993) by applying dimensional analysis and fire growth modelling to the ISO Room Fire Test. The following steps describe the procedure used to determine the material grouping. As these calculations are based on the material classification recommended in the EUREFIC program, they assume boundaries between classes at 2, 10, 12 and 20 minutes. The boundaries selected for Groups in this project are 2, 10 and 20 minutes.

1. The specimen is tested in the Cone Calorimeter at 50 kW irradiance.
2. The data is converted into a form suitable for input for the index classification software.
3. The software calculates the ignition time (t_{ig}) (which is defined as the time for the heat release rate to reach 50 kW/m^2), and the ignition index (I_{ig}), which is the reciprocal of the ignition time.
4. The software calculates rate of heat release index (I_Q) from the following equation:

$$I_Q = \int_{t_{ig}}^{t_f} \left[\frac{\dot{q}''(t)}{(t - t_{ig})^m} \right] dt$$

   where $\dot{q}''$ is the rate of heat release per unit area; and m is an exponent determined empirically.
5. Values of I_Q are determined for two values of m; 0.34 and 0.93. These values are compared with criteria established empirically for determining whether flashover occurs:

   - either before 10 minutes or before 20 minutes; or
   - either before 2 minutes or before 12 minutes.

   This enables materials to be divided into four groups:

   - materials that go to flashover before 2 minutes (before 2/12 and before 10/20 min.);
   - materials that go to flashover in 2–10 minutes (after 2/12 and before 10/20 min.);
   - materials that go to flashover in 10–12 minutes (before 2/12 and after 10/20 min.); and

• materials that do not go to flashover (after 2/12 and after 10/20 min.).

The values for the limits are:

- $I_Q = 6800 - 540\ I_{ig}$ for the 10 or 20 minute criterion;
- $I_Q = 1650 - 165\ I_{ig}$ for the 12 minute criterion; and
- $I_Q = 2475 - 165\ I_{ig}$ for the 2 minute criterion.

For these calculations:

$m = 0.34$ is used to compare to the 10 or 20 minute criterion; and
$m = 0.93$ is used to compare to the 2 and 12 minute criteria.

If:

$I_{Q(m=0.34)} > 6800 - 540\ I_{ig}$ then flashover is expected before 10 minutes or before 20 minutes.
$I_{Q(m=0.93)} > 1650 - 165\ I_{ig}$ then flashover is expected after 10 minutes and before 12 minutes.
$I_{Q(m=0.93)} > 2475 - 165\ I_{ig}$ then flashover is expected before 2 minutes.

Otherwise flashover is not expected.

APPENDIX G – MATERIAL GROUPS

G1 EUREFIC MATERIALS

The materials listed in Table G1 were tested in the Nordic, Scandinavian or EUREFIC programs. They were all used in the development of the Classification Indexes described in Chapter 8.

Table G1 – Groups of materials according to their time to flashover in the ISO 9705 Room Fire Test and according to the Classification Indexes

Code	*Material*	*Group according to*	
		Occurrence of flashover[a]	*Classification Indexes*[b]
E1	Painted gypsum paper plasterboard	d	d
E4	Melamine-faced, high-density, non-combustible board	d	d
E5	Plastic-faced steel sheet on mineral wool	d	d
E8	FR particleboard	d	d
E13	FR plywood	d	—
E28	Gypsum board	d	d
E3	Textile wall covering on gypsum paper plasterboard	c	c
E10	PVC wall carpet on gypsum paper plasterboard	c	c
E27	Paper wall covering on gypsum board	c	c
E6	FR particleboard, type B1	c	c
E22	Textile wall covering on gypsum board	c	c
E21	Plastic wall covering on gypsum board	c	c
E20	Melamine-faced particleboard	b	b
E9	Plastic-faced steel sheet on polyurethane foam	b	b
E14	Melamine-faced particleboard	b	—
E16	Particleboard	b	b
E2	Ordinary birch plywood	b	b
E24	Paper wall covering on particleboard	b	b
E12	Birch plywood	b	—
E18	Medium-density wood-fibre board	b	b
E19	Wood panel, spruce	b	b
E26	Expanded polystyrene	b	b
E7	Combustible-faced mineral wool	a	a
E11	FR extruded polystyrene foam	a	a
E15	FR polystyrene foam	a	—
E17	Insulating wood-fibre board	a	a
E23	Textile wall covering on rockwool	a	a
E25	Rigid polyurethane foam	a	a

[a] Determined from times to flashover in Table E1.
[b] Determined from data published by Kokkala *et al.* (1993).

G2 Australian Materials

The materials in Table G2 have been tested independently of the EUREFIC program, either as part of Project 2 or as part of other projects. Groups according to time to flashover were determined in the ISO 9705 validation experiments performed as part of Project 2. Groups according to the Classification Indexes were calculated using Cone Calorimeter data files and the software available from VTT. There is no equivalent procedure using data from the Early Fire Hazard Test.

Groups according to the occurrence of flashover were determined from data in Tables E1–E3. Groups are based on time to flashover in the ISO Room Fire Test of walls and ceilings. Where data referred to ISO tests of walls only and ASTM tests of walls only, likely outcomes were predicted wherever possible according to the following rules:

- for materials listed in Table E2 (ISO/walls only) for wall and ceiling linings, flashover will occur at the latest at the same gas burner level;
- for materials in Table E3 (ASTM/walls only) for wall and ceiling lings, flashover will occur at the latest at the next higher gas burner level in the ISO Room Fire Test; and
- that as the total heat output of the gas burner in the first 10 minutes is the same for both Room Fire Tests (60 MJ), materials in Table E3 (ASTM/walls only) which go to flashover within 10 minutes would also go to flashover within 10 minutes in the ISO Room Fire Test.

Table G2 – Grouping of materials according to their measured time to flashover in the ISO9705 Room Fire Test and according to the classification indexes

Code	*Material*	*Groups according to*	
		Occurrence of flashover[a]	*Classification Indexes*[b]
A9	Plasterboard, paper-faced, glass-reinforced	d	d
A1	Glass-reinforced phenolic 70	(c at best)	d[c]
A2	Glass-reinforced phenolic 71	(d at best)	d
A3	Plasterboard (US)	(d at best)	d
A4	FR plywood (US)	(d at best)	d
A11	Hoop pine plywood, treated	b	b
A10	Lauan plywood	b	b
A7	FR polystyrene foam (US)	(d at best)	b
A8	Hardboard	(b at best)	b
A5	Plywood (US)	(b at best)	b
A14	Blackbutt	(b at best)	b
—	Tasmanian hardwood[d]	—	b
A6	FR polyurethane foam (US)	(b at best)	a

[a] Determined from times to flashover in Tables E1, E2 and E3.
[b] Determined from Cone Calorimeter data on materials listed in Research Paper 7.
[c] This prediction was borderline between 'c' and 'd' and was made on data obtained from specimens tested without an edge frame, whereas ISO 5660 requires an edge frame for building materials.
[d] Determined from Cone Calorimeter data courtesy of BHP Research.

APPENDIX H – IMPLICATIONS OF CHANGE

Table H1 lists some probable changes in materials usage the proposed deemed-to-satisfy requirements. The examples are chosen to give a broad overview. It should be noted that the following are the likely results for generic groups of materials. They cannot be taken as automatic acceptance or rejection of any particular product.

In constructing Table H1, Early Fire Hazard Test data on the materials in Table E4 has been compared with Room Fire Test data on the same or apparently similar materials in Tables E1–E3. Assumptions were the same as in Section G2.

Materials that are considered unacceptable for use in all buildings are listed in Table H2.

Table H1 – Comparison of materials allowed in various buildings and locations under current and proposed systems for control of wall and ceiling linings

Current requirements		*Proposed requirements*
	A – Unsprinklered buildings	
Fire-isolated exits		
All buildings – walls and ceilings		
Spread of Flame Index	0	Group d
Smoke Developed Index	2	(Average rate of smoke production <1.2 m^2/s)
Combustible	<1 mm	
		Materials permitted
		Some fire-retarded timber products
Public corridors		
Aged accommodation, health care buildings, theatres, halls etc. – walls & ceilings		
Spread of Flame Index	0	Group d
Smoke Developed Index	5	
		Materials not permitted
		Some phenolic composites
		Some fire-retarded polyurethane foams
		Some fire-retarded plastics on masonry
		Some fire-retarded plastics on plasterboard
		Some fire-retarded timber products
Apartments, hotels & boarding houses, schools – walls & ceilings		
Spread of Flame Index	0	Group c
Smoke Developed Index	5	
		Materials not permitted
		Some fire-retarded polyurethane foams

continued...

Table H1 continued

Current requirements		*Proposed requirements*
		A – Unsprinklered buildings
Public corridors		
All other buildings – walls & ceilings		
Spread of Flame Index	9	Group c
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials not permitted Most non-fire-retarded timber products Some fire-retarded timber products Some fire-retarded polyurethane foams Some vinyl tiles Some fire-retarded polystyrene foams
Patient care areas		
Health care buildings – ceilings		
Spread of Flame Index	0	Group c
Smoke Developed Index	3	
		Materials permitted Some fire-retarded plastics on masonry Some fire-retarded plastics on plasterboard
		Materials not permitted Some fire-retarded timber products Some fire-retarded polyurethane foams
Health care buildings – walls		
Spread of Flame Index	2	Group c
Smoke Developed Index	5	
		Materials not permitted Some vinyl tiles Some fire-retarded polyurethane foams Some fire-retarded timber products
Sole-occupancy units		
Aged accommodation – walls & ceilings		
Spread of Flame Index	9	Group c
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials not permitted Most non-fire-retarded timber products Some fire-retarded timber products Some fire-retarded polyurethane foams Some vinyl tiles Some fire-retarded polystyrene foams

continued...

Table H1 continued

Current requirements		*Proposed requirements*
	A – Unsprinklered buildings	
Sole-occupancy units		
Apartments, hotels & boarding houses – walls & ceilings		
Spread of Flame Index	9	Group b
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials permitted Some low-density timber products
		Materials not permitted Some fire-retarded polyurethane foams Some fire-retarded polystyrene foams
Auditoriums		
Theatres, halls etc. – walls		
Spread of Flame Index	6	Group c
Smoke Developed Index	5	
		Materials not permitted Some non-fire-retarded timber products Some fire-retarded timber products Some fire-retarded polyurethane foams Some vinyl tiles Some fire-retarded polystyrene foams
Theatres, halls etc. – ceilings		
Spread of Flame Index	6	Group c
Smoke Developed Index	3	
		Materials not permitted Some non-fire-retarded timber products Some fire-retarded timber products Some fire-retarded polyurethane foams Some vinyl tiles Some fire-retarded polystyrene foams
Classrooms		
Schools – ceilings		
Spread of Flame Index	9	Group c
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials not permitted Most non-fire-retarded timber products Some fire-retarded timber products Some fire-retarded polyurethane foams Some vinyl tiles Some fire-retarded polystyrene foams

continued...

Table H1 continued

Current requirements		*Proposed requirements*
A – Unsprinklered buildings		
Classrooms		
Schools – walls		
Spread of Flame Index	9	Group b
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials permitted
		Some low-density timber products
		Materials not permitted
		Some fire-retarded polyurethane foams
		Some fire-retarded polystyrene foams
Offices, shops, aspect ratio >5		
Office buildings, shops – ceilings		
Spread of Flame Index	9	Group c
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials not permitted
		Most non-fire-retarded timber products
		Some fire-retarded timber products
		Some fire-retarded polyurethane foams
		Some vinyl tiles
		Some fire-retarded polystyrene foams
Office buildings, shops – walls		
Spread of Flame Index	9	Group b
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials permitted
		Some low-density timber products
		Materials not permitted
		Some fire-retarded polyurethane foams
		Some fire-retarded polystyrene foams
Other areas		
All buildings – walls & ceilings		
Spread of Flame Index	9	Group b
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials permitted
		Some low-density timber products
		Materials not permitted
		Some fire-retarded polyurethane foams
		Some fire-retarded polystyrene foams

continued...

Table H1 continued

Current requirements		*Proposed requirements*
	B – Sprinklered buildings	
Fire-isolated exits		
All buildings – walls and ceilings		
Spread of Flame Index	0	Group d
Smoke Developed Index	2	(Average rate of smoke production <1.2 m^2/s)
Combustible	<1 mm	
		Materials permitted Some fire-retarded timber products
Public corridors		
Aged accommodation, health care buildings, theatres, halls etc. – walls and ceilings		
Spread of Flame Index	0	Group c
Smoke Developed Index	5	
		Materials not permitted Some fire-retarded polyurethane foams
Apartments, hotels & boarding houses, schools – walls and ceilings		
Spread of Flame Index	0	Group b
Smoke Developed Index	5	
		Materials permitted Most timbers Most timber products
		Materials not permitted Some fire-retarded polyurethane foams
All other buildings – walls and ceilings		
Spread of Flame Index	9	Group b
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials permitted Some low-density timber products
		Materials not permitted Some fire-retarded polyurethane foams Some fire-retarded polystyrene foams
Patient care areas		
Health care buildings – ceilings		
Spread of Flame Index	0	Group b
Smoke Developed Index	3	
		Materials permitted Most timbers Most timber products Some fire-retarded plastics on masonry Some fire-retarded plastics on plasterboard

continued...

Table H1 continued

Current requirements		*Proposed requirements*
B – Sprinklered buildings		
Patient care areas		
Health care buildings – walls		
Spread of Flame Index	2	Group b
Smoke Developed Index	5	
		Materials permitted Most timbers Most timber products
		Materials not permitted Some fire-retarded polyurethane foams
Sole-occupancy units		
Aged accommodation – walls and ceilings		
Spread of Flame Index	9	Group b
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials permitted Some low-density timber products
		Materials not permitted Some fire-retarded polyurethane foams Some fire-retarded polystyrene foams
Apartments, hotels & boarding houses – walls & ceilings		
Spread of Flame Index	9	Group b
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials permitted Some low-density timber products
		Materials not permitted Some fire-retarded polyurethane foams Some fire-retarded polystyrene foams
Auditoriums		
Theatres, halls etc. – walls & ceilings		
Spread of Flame Index	9	Group b
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials permitted Some low-density timber products
		Materials not permitted Some fire-retarded polyurethane foams Some fire-retarded polystyrene foams

continued...

Table H1 continued

Current requirements		*Proposed requirements*
		B – Sprinklered buildings
Classrooms		
Schools – walls and ceilings		
Spread of Flame Index	9	Group b
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials permitted Some low-density timber products
		Materials not permitted Some fire-retarded polyurethane foams Some fire-retarded polystyrene foams
Offices, shops, aspect ratio >5		
Office buildings, shops – walls & ceilings		
Spread of Flame Index	9	Group b
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials permitted Some low-density timber products
		Materials not permitted Some fire-retarded polyurethane foams Some fire-retarded polystyrene foams
Other areas		
All buildings – walls & ceilings		
Spread of Flame Index	9	Group b
Smoke Developed Index	8	
or		
Spread of Flame Index	5	
		Materials permitted Some low-density timber products
		Materials not permitted Some fire-retarded polyurethane foams Some fire-retarded polystyrene foams

Table H2 – Materials that are unacceptable for use in all buildings

Current	*Proposed*
Non-fire-retarded polyurethane foam Some fire-retarded polystyrene foam Some low-density timber products	Some fire-retarded polyurethane foam Some fire-retarded polystyrene foam

APPENDIX I – COMPARISON WITH OVERSEAS PRACTICE

I1 EUROCLASSES

Europe is moving to a common classification system for building materials. The application of the Euroclasses to control of linings in buildings is a matter for each individual country.The ISO Room Fire Test will be used as the reference scenario for selecting material groups and resolving borderline products (CEN 1997). The proposed Groups are compared with the Euroclasses in Table I1.

Table I1 – Comparison of proposed material groups and Euroclasses

Criterion when assessed to ISO 9705	*Proposed Groups*	*Euroclass*
Materials that reach flashover in less than 120 s after exposure to 100 kW	a	Unclassifiable
Materials that reach flashover in more than 120 s after exposure to 100 kW	b	E
Materials that reach flashover after exposure to 300 kW	c	C, D
Materials that do not reach flashover after exposure to 300 kW	d	A, B

SUPPLEMENT TO
FINAL REPORT
FIRE PERFORMANCE OF WALL AND CEILING LININGS
FIRE CODE REFORM CENTRE
PROJECT 2A

September 1998

Introduction

This document has been prepared at the request of Fire Code Reform Centre (FCRC) as a supplement to the Final Report for Project 2 Stage A, the Fire Performance of Wall and Ceiling Linings. The report was discussed at a meeting called by FCRC on Friday 4 September at which the researchers and FCRC representatives from the Research Supervisory Committee, industry and the ABCB were present. Those present at the meeting were in agreement with many of the recommendations of the report, including:

The structure of the report and the general methodology employed.
The need for control.
The objectives of control.
The use of the ISO Room Fire Test as the primary test for control of linings.
The use of the Cone Calorimeter to predict performance in the ISO Room Fire Test.

The meeting agreed that, while the report reflected a consensus of the views of those present at the Working Group meetings, there were areas where additional discussion, revision or minor change of direction would assist in the process of adoption of the recommendations by the ABCB. This supplement addresses those issues.

Decisions of the Working Group

CSIRO forwarded its final report on Project 2 Stage A to FCRC in August 1998. The report has undergone extensive change since the Draft Final Report was first tabled in December 1997. Changes have been discussed in detail at Working Group meetings and the final report reflects a consensus of views of those members of the Working Group in regular attendance. The report does not reflect exactly the views of any individual. It is the best "engineering" judgement of a group of individuals with specialist knowledge in the field concerned, based on the limited data available. Also present at many of the meetings were members of the FCRC internal review group, who made a valuable contribution to the discussions.

Justification for requirements or justification for change?

The process used by the project was to determine the objective of controls on lining materials, select appropriate test methods, group materials according to test performance and control the use of materials by specifying which groups are acceptable in different locations within buildings. The resulting controls are therefore the minimum considered necessary by the researchers to achieve the specified objective and justification is for minimum requirements rather than for change from the status quo.

While the BCA is committed to providing minimal control, the ABCB is also obliged to justify any change from existing regulation. The researchers have used their judgement to justify the existence of a requirement, but the regulators must justify change (even where there is no tangible justification for the existing requirements). In the absence of supportive data, the two approaches lead to different conclusions (the ABCB will advocate retaining an existing requirement while the researchers will argue that without justification the requirement should not exist). This supplement acknowledges the view of the regulators, and takes steps to formulate suitable requirements where data to justify change is lacking.

The need for change

Problems with existing test method

While the report addresses the need for control of wall and ceiling linings, it does not provide much detail on the need to change the existing requirements. The Early Fire Hazard Test was developed in an attempt to simulate the early stages of a fire, and in some respects the research leading to the test was ground-breaking. In particular the attempt to link behaviour of materials in the test to behaviour in large-scale experiments has been acknowledged internationally as being ahead of its time. Nevertheless, the test has shortcomings when used for compliance testing.

Firstly, the Early Fire Hazard Test in its present form is not seen to provide useful information on the likely contribution of wall and ceiling linings in the event of a fire.

- The maximum radiation that any specimen is exposed to is 25 kW/m^2. This is a very low level, even in the early stages of a fire. Some materials (including materials that did not exist at the time the test was developed) that are known to ignite and burn when exposed to a gas burner in a corner of a room do not ignite in the Early Fire Hazard Test. The test does not give a true prediction of their likely behaviour in fire.
- A Flame Spread Index is determined by first measuring the rate of increase in radiation emitted by the specimen following ignition. An approximate relationship was developed between time for a particular increase in radiation to occur, and the time flames took to reach the ceiling in room corner experiments. From this data arbitrary Spread of Flame Indexes were assigned. Unfortunately the relationship has been shown to be inconsistent, and materials that behave in a similar manner in a room fire test may obtain different Flame Spread Indexes in the Early Fire Hazard Test. This has been demonstrated by comparing Western Red Cedar with other timbers. Western Red Cedar was not among the materials considered when the test was developed.
- The specimen is mounted on a moving trolley, which is stopped once ignition has occurred. This means that materials are assessed for flame spread, heat evolved and smoke developed under different levels of impressed radiation. Consequently the ranking of materials by these parameters is inconsistent.
- The method for measuring smoke is arbitrary and is technically flawed. The maximum rate of smoke production over a 1-minute period is measured and presented as an optical density. This is converted to Smoke Developed Indexes using a logarithmic scale justified by reference to visibility through accumulated smoke. Consequently materials that produce a short burst of smoke, such as wood prior to ignition, are penalised compared with materials that produce smoke continuously following ignition. The actual measurement of smoke obscuration is conducted in an exhaust hood in which the flow rate of combustion products is neither measured nor controlled. Thus the smoke reading varies with varying fire intensity, introducing uncontrolled errors into the measurement.

As can clearly be seen, the test does not consistently provide useful information on the likely contribution of wall and ceiling linings in the event of a fire.

Secondly, there are problems with the way in which data from the Early Fire Hazard Test is used in the BCA. The test was developed primarily as an ignitability test, and as discussed above, flame spread, heat evolved and smoke developed are determined under different levels of impressed radiation, depending on their ignition time. Ignitability is the only reliable index, but it is the only one not called up in the BCA. Manufacturers designing their products to meet BCA criteria can ignore ignitability and still develop a compliant product.

It has to be concluded that the way the test is used in the BCA does not ensure that materials are ranked in a meaningful way. The addition of a criterion based on ignitability in the Early Fire Hazard Test at this stage would be a retrograde step. It would retard the move to international methods, and would not eliminate those materials that do not ignite in Early Fire Hazard Test but do ignite and burn readily in large-scale tests.

Identifying performance of little-used materials

Statistics can be misleading, and care must be taken to ensure that the environment in which they are gathered is clearly understood. Buildings are not always built to the minimum safety levels dictated by the regulations. In some cases common practice exceeds the safety demanded and potentially unsafe situations (which could theoretically occur despite compliance with the regulations) do not show up in statistics. For example, in large shops and offices it is not common practice to construct ceilings of materials other than those that fall into Group d. Hence there is little evidence of fires spreading rapidly across ceilings in these occupancies. The report recommends a tightening of controls on ceilings in shops and offices with a high aspect ratio (floor width divided by wall height) as the researchers believe that there is a real danger of rapid fire spread if Group b materials are used. The recommendation is based on experience and judgement, as is the selection of an aspect ratio >5. Additional data might lead to the refinement of these values in years to come.

Selection of test methods

International status as a selection criterion

Some advantages of the use of internationally recognised tests are outlined in the report. In addition the advantages of future research and availability of data should not be overlooked. One of the major problems of research in this area is the shortage of data for comparison and correlation. The Early Fire Hazard Test is unique to Australia and the only data that will support its use as a suitable test method will be generated within Australia. The prospect of data becoming available to support the use of internationally accepted methods is far greater, as is the prospect of further research into its performance. Australia can only gain by taking the lead in changing to an internationally accepted test.

Proposed method not the ultimate method

Test methods can only approximate reality and all test methods have limitations. While the Cone Calorimeter measures appropriate parameters and provides repeatable and reproducible results, it is not without problems. Firstly, the method can be used only for materials or products that have planar or nearly planar surfaces. Secondly, data is not reliable if explosive spalling or excessive swelling or shrinking of the specimen occurs. It is probable that in future years better tests will be developed. The recommendations for change to the BCA leave room for such development and for improvement in the Early Fire Hazard Test.

"Flashover"

"Time to flashover" is defined in the report as "a heat output of 1 MW" in a room the size of the ISO room. The term "time to reach a heat output of 1 MW in the ISO 9705 room" should be used in the recommendations as this paints a clearer picture in the mind of the reader. In larger rooms "flashover" will not be reached by some materials that reach flashover in the ISO 9705 room. In very large rooms "flashover" might not be reached at all.

ISO v ASTM

While it is accepted that the ISO Room Fire Test is the test that best indicates real fire performance of lining materials, data from materials burned in the various versions of the non-standardised 'ASTM' room can be used to demonstrate the success of the proposed system. This has already been done in the report (see Appendix G Table G2).

Available test data

Data for verification

More data is needed to show that predictions from the Cone Calorimeter correspond well with behaviour in the ISO Room Fire Test. The researchers have conducted an extensive search for data from materials that have been burned in a room fire test or a corridor test and also in the Cone Calorimeter. Most of the readily available data was used to derive the Classification Index system and is therefore unsuitable for verification purposes. While it would be desirable to find additional data to demonstrate the success of the proposed system, it is unlikely that much exists.

The report acknowledges that the only known use of the ISO Room Fire Test to control materials is by the International Maritime Organisation (IMO) (controls are for materials used in high-speed craft). To avoid expensive testing, manufacturers often use the Cone Calorimeter to predict behaviour in the ISO Room. However, since IMO only permits the use of materials that perform better than Group d, manufacturers only perform ISO Room Tests on those materials that are likely to be Group d. There is unlikely to be data available, even proprietary data, that verifies the accuracy of the predictions for Groups a, b and c. FCRC suggested that their authority might allow them to access data from sources as yet untapped. If data can be obtained, it will certainly enhance the project.

Relationship of small-scale tests to large-scale tests

Acceptance criteria for small-scale tests

In order to predict performance of a lining material in the ISO room fire test from data obtained in small-scale tests a way must be found to link parameters measured in the small-scale test with performance in the ISO room fire test. Such a method must:

- use data from a relevant small-scale test; and
- correctly predict the time to 1MW in the ISO Room Fire Test for a broad range of lining materials.

The Early Fire Hazard Test and the Cone Calorimeter are small-scale tests that can provide relevant data. There are currently no calculation methods that use data from the Early Fire Hazard Test to predict time to flashover in the ISO room fire test. Nor is it possible to develop an acceptable method, as it has already been demonstrated that materials that go to flashover in room fire tests, even in tests less severe than the ISO room fire test, do not all ignite in the Early Fire Hazard Test as it is currently performed. If ignition does not occur in the Early Fire Hazard Test then the prediction must be that flashover will not occur in the ISO Room Fire Test.

Three calculation methods that use data from the Cone Calorimeter were considered. These were the Östman model, the SP model and the Classification Indexes. The Östman model was rejected because it does not consider the specific gas burner program in the ISO room fire test and therefore cannot reliably predict material performance. The SP model was rejected because it currently uses data determined at 25 kW/m^2 in the Cone Calorimeter. If ignition does not occur at this level, the method is not able to predict time to 1 MW in the ISO Room Fire Test (this is the same problem encountered when attempting to use data from the Early Fire Hazard Test). The Classification Indexes method is the only method that fully meets the above criteria. Its scientific credentials are extremely good, having been developed jointly by Prof. Matti Kokkala of Finland (leader of the FCRC's International Review Team), Dr Philip Thomas of the UK and Dr Björn Karlsson of Sweden.

It is likely that new calculation methods will be developed in future, using data from the Cone Calorimeter or other small-scale tests. If the methods meet the above criteria they will be acceptable. Further definition of the "correct" prediction of time to 1 MW in the ISO Room Fire Test will assist in the acceptance of alternatives and this should be flagged as an area for future development.

Alternatively, it is possible that criteria could be developed based directly on results from the Cone Calorimeter. Data from other small-scale tests might be used to predict behaviour in the Cone Calorimeter and hence time to 1 MW in the ISO Room Fire Test. Once appropriate ranges for each material Group have been agreed, a simple, direct translation of the current proposals could be made. This approach is currently being considered in Europe and is again flagged as an area for future development. In each of the above cases the ISO Room Fire Test would remain the reference scenario and arbiter test.

Quantitative test performance levels

Approach taken by working group

It must be accepted that there is a high level of subjective judgement in assigning test performance levels to locations within buildings. The step from real buildings to generic classifications is not easy, and is based on informed perception. There is little hard data available to assist in determining which material groups are appropriate for each location. The recommendations for quantitative test performance levels were made after many hours of discussion. Benchmarks were established by relating just two of an infinite number of possible real fire scenarios to tests with known wall and ceiling linings. The dimensions of the rooms in the benchmark scenarios are very small and therefore represent extreme cases. Other values were established taking into account a number of factors. Assessment of the relative influence of each factor was a matter of judgement, based on the best data and experience available. Table 9.2 draws together much of the data considered, to give the reader an idea of the situations envisaged by the researchers. In future years additional data might serve to confirm or amend the recommendations. Meanwhile, Table 9.2 represents the best judgement of the Working Group.

Indexes, 'Material Groups' and values

The Standard for the Early Fire Hazard Test (AS 1530.3) has traditionally expressed results as Indexes based on arbitrary ranges of measured values and the BCA has used these Indexes as criteria for wall and ceiling linings. It is only in more recent editions that the standard has required actual results to be reported. The standards for both the ISO Room Fire Test and the Cone Calorimeter require results to be expressed directly as measured values. Regulatory controls can be expressed as ranges of acceptable values.

In the Project Report, four material Groups based on time to 1 MW in the ISO Room Fire Test were identified and designated material Groups a, b, c and d. The Groups are described below, with times in the ISO Room Fire Test indicated in brackets:

Group a — materials that reach a heat output of 1 MW in less than 120 seconds after exposure to 100 kW (less than 120 s);

Group b — materials that reach a heat output of 1 MW in more than 120 seconds after exposure to 100 kW (120 s to less than 600 s);

Group c — materials that reach a heat output of 1 MW after exposure to 300 kW (600 s to less than 1200 s); and

Group d — materials that do not reach a heat output of 1 MW after exposure to 300 kW (1200 s or greater).

Whether these criteria are expressed in the BCA in terms of Group a, b, c and d, or in terms of an acceptable range of performance times in the ISO Room Fire Test, is a matter of choice for the ABCB. The possibility of expressing criteria for the Cone Calorimeter in terms of ranges of parameters has been discussed under "Relationships of small-scale tests to large-scale tests" above.

It should be pointed out that classification of materials into classes, whilst not currently common practice in Australia, is common practice overseas, and is the way materials are soon to be controlled throughout Europe.

Concessions for sprinklers

The report recommends a reduction from current requirements for lining materials in sprinklered buildings. There is insufficient data to isolate the effect of sprinklers on the performance of lining materials, but a review of statistics for Project 3 concluded that the presence of sprinklers in the room of fire origin significantly reduce the likelihood of fire spread beyond the room of origin. The recommendations of the report are again based on the best judgement of the Working Group in the light of present knowledge. The proposals are believed to be conservative, but only the analysis of data which has yet to be generated will confirm or further reduce the requirements.

Smoke control

The report suggests that controlling the time to flashover in room fire tests provides sufficient control on the volume of smoke produced by linings (see 9.4.3 Volume of smoke). It concludes that the introduction of a control on the optical density of smoke produced is not warranted, as there is little evidence to show that this parameter bears any relationship to life safety.

The BCA however currently requires materials used in certain locations to achieve a specified Smoke Developed Index in the Early Fire Hazard Test. The ABCB representatives felt that there was insufficient justification to drop the current controls and asked that recommendations for equivalent controls, based on the Cone Calorimeter and ISO Room Fire Test rather than the Early Fire Hazard Test, should be provided. A detailed study to justify the recommendations of the report, relating smoke density to escape times, should be considered in future when more data becomes available. In particular, the study should address the need for smoke controls in public corridors.

The existing smoke controls on wall and ceiling linings in the BCA are detailed in Clauses 2, 3 and 4 of Specification C1.10. They are based on the Smoke developed Index of the Early Fire Hazard Test. We suggest that the following scheme should be adopted for generating "equivalent" smoke controls:

1 Smoke controls should be based on average rate of smoke production in the ISO Room Fire Test.
2 The level of smoke control should be an average rate of smoke production of not more than 1.2 m^2/s. This is in line with the recommendations of the EUREFIC program.
3 Separate smoke controls should not be included where only the general requirements of Clause 2 of the BCA currently apply. The current BCA requirements expressed in Clauses 3 and 4 are shown in Table 1.
4 Separate smoke controls should be imposed in all places where they are already required by Clauses 3 or 4 of Specification C1.10. They should not be imposed anywhere else.
5 Wherever the average rate of smoke production measured in the ISO Room Fire Test is required to be not more than 1.2 m^2/s then materials with an average specific extinction area measured in the Cone Calorimeter of not more than 25 m^2/kg are considered to meet that requirement. Materials with an average specific extinction area of more than 25 m^2/kg can be used subject to satisfactory performance in the ISO Room Fire Test.

Table 2 shows the controls generated by applying the above rules. The following points should be considered if requirements are to be incorporated into the BCA:

- The Early Fire Hazard Test is not directly equivalent to either the ISO Room Fire Test or the Cone Calorimeter Test, as discussed previously. It is therefore impossible to draw a direct analogy between the two systems.
- At present the BCA does not distinguish between sprinklered and unsprinklered buildings in the control of wall and ceiling linings, except in the case of auditoriums. ABCB may wish to reconsider the need for smoke controls in sprinklered buildings.
- Appendix D of the report shows that there is large variability in measurements of optical density of smoke. It is therefore recommended that only one level of control should be adopted.

Table 1 – Current BCA smoke requirements for wall and ceiling linings in Clauses 3 and 4 of Specification C1.10[a]

BCA building class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
Class 2 – apartments	2	2	5	5	– s.o.u.[b]	–	–	–
Class 3 – hotels & boarding houses	2	2	5	5	– s.o.u.	–	–	–
Class 3 – accommodation for the aged, disabled & children	2	2	5	5	– s.o.u.	–	–	–
Class 5 – office buildings	2	2	–	–	– open-plan offices; aspect ratio >5	–	–	–
Class 6 – shops	2	2	–	–	– large shops; aspect ratio >5	–	–	–
Class 7 – car parks	2	2	–	–	–	–	–	–
Class 7 & 8 – warehouses & factories	2	2	–	–	–	–	–	–
Class 9a – health care buildings	2	2	5	5	5 patient care areas	3	–	–
Class 9b – theatres, halls etc.	2	2	5	5	5 auditoriums unsprinklered[c] – auditoriums sprinklered[c]	3 –	–	–
Class 9b – schools	2	2	5	5	– classrooms	–	–	–

[a] The entries are Smoke Developed Indexes. Absence of a specific smoke requirement in Clauses 3 or 4 of Specification C1.10 is denoted by '–'.

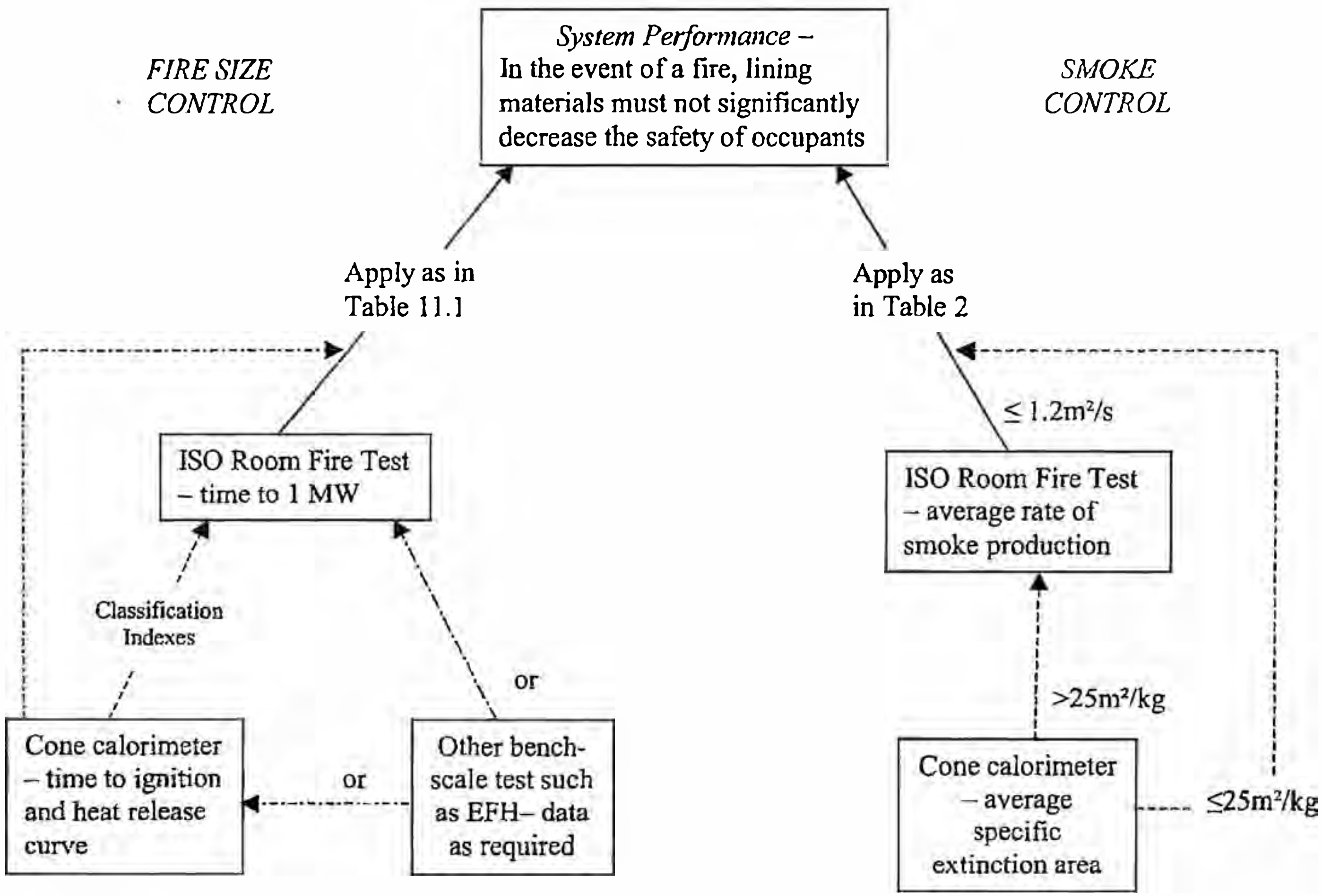
[b] s.o.u. stands for sole-occupancy unit, as defined in the BCA.

[c] "Sprinklered" and "unsprinklered" refers to the whole building or fire compartment, rather than the location within the building. Sprinklers are not usually fitted in fire-isolated exits (see AS 2118.1).

Table 2 – BCA recommendations based on average rate of smoke production in the ISO Room Fire Test

BCA Building Class	*Fire-isolated exits*		*Public corridors*		*Specific areas*		*Other areas*	
Class 2 & 4 - Apartments					**s.o.u.**[b]			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered[c]	1.2	1.2	1.2	1.2	–	–	–	–
sprinklered[c]	1.2	1.2	1.2	1.2	–	–	–	–
Class 3 – Hotels & boarding houses					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered	1.2	1.2	1.2	1.2	–	–	–	–
sprinklered	1.2	1.2	1.2	1.2	–	–	–	–
Class 3 – Accommodation for the aged, disabled and children					**s.o.u.**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered	1.2	1.2	1.2	1.2	–	–	–	–
sprinklered	1.2	1.2	1.2	1.2	–	–	–	–
Class 5 – Office buildings					**open-plan offices; aspect ratio >5**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered	1.2	1.2	–	–	–	–	–	–
sprinklered	1.2	1.2	–	–	–	–	–	–
Class 6 - Shops					**large shops; aspect ratio >5**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered	1.2	1.2	–	–	–	–	–	–
sprinklered	1.2	1.2	–	–	–	–	–	–
Class 7 – Car parks								
	Wall	*Ceiling*	*Wall*	*Ceiling*			*Wall*	*Ceiling*
unsprinklered	1.2	1.2	–	–			–	–
sprinklered	1.2	1.2	–	–			–	–
Class 7 and 8 – Warehouses & factories								
	Wall	*Ceiling*	*Wall*	*Ceiling*			*Wall*	*Ceiling*
unsprinklered	1.2	1.2	–	–			–	–
sprinklered	1.2	1.2	–	–			–	–
Class 9a – Health care buildings					**patient care areas**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered	1.2	1.2	1.2	1.2	1.2	1.2	–	–
sprinklered	1.2	1.2	1.2	1.2	1.2	1.2	–	–
Class 9b – Theatres, halls etc.					**auditoriums**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered	1.2	1.2	1.2	1.2	1.2	1.2	–	–
sprinklered	1.2	1.2	1.2	1.2	–	–	–	–
Class 9b – Schools					**classrooms**			
	Wall	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*	*Wall*	*Ceiling*
unsprinklered	1.2	1.2	1.2	1.2	–	–	–	–
sprinklered	1.2	1.2	1.2	1.2	–	–	–	–

Figure 1 Proposed Control System for Wall and Ceiling Linings



------ Alternative compliance route

-.-.-.- Possible future development