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Study of Fire Test Methods Applicable to Flexible Fabrics, Duct Materials and Cables

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Preface

This scoping report was prepared as a result of a review of the available literature on the reaction to fire behaviour of flexible fabrics, ducts and cables to evaluate the need for a more comprehensive project or series of projects with reference to New Zealand conditions.

Acknowledgments

This work was funded by the Building Research Levy.

Note

This report is intended for Building Research, first as a background study to determine the feasibility of supporting a more extensive research project on the reaction to fire of flexible fabrics, duct materials and electrical cables. Secondly, recommendations are made on which materials and building components should be the subject of a full research project that will include reaction to fire tests and analysis of results to support proposals to the Department of Building and Housing (DBH) for amendments to C/AS1 that will improve the evaluation of the fire performance of materials and building components. Such a project would be a continuation of the theme of previous and current projects considering the reaction to fire of internal wall and ceiling finishes, and flooring materials.

STUDY OF FIRE TEST METHODS APPLICABLE TO FLEXIBLE FABRICS, DUCT MATERIALS AND CABLES

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Abstract

This study has shown that the present fire test requirements for the reaction to fire properties for flexible fabrics based on flammability testing do not adequately evaluate the actual fire performance where initial burning is difficult to establish, but the material has a high heat content that is not recorded by the existing test method and thus may present a significant risk in an actual fire. It is proposed that cone calorimeter testing be included and that the performance standard can be based on a combination of both the cone calorimeter and the flammability testing. This hypothesis should be tested in an experimental program comprising both small-scale and full-scale testing.

For duct materials as applied to HVAC systems, it has been recommended that the reaction to fire of the surface materials be included in the same provisions applying to surface linings. No further experimental work is justified based on the lack of evidence that duct materials feature significantly in the fire incident statistics, and therefore do not pose sufficient risk to warrant being treated differently to wall/ceiling linings.

For electrical cables, a substantial collaborative project involving European countries has been completed and is in the process of being implemented. At present there are limited requirements relating to cables in C/AS1 for New Zealand conditions, and the fire incident statistics do not identify cables as a significant fire risk. Given the extensive work completed internationally that was sponsored by specific electrical industry participants (where the security of electrical supply or reticulation is of prime importance to the business rather than the building sector imperatives such as life safety and property protection), a project where the New Zealand building industry is the beneficiary cannot be justified.

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Acronyms

ABCB	Australian Building Codes Board
BCA	Building Code of Australia
CFD	Computational Fluid Dynamics
CEN	European Committee for Standardisation
C/AS1	Compliance Documents Acceptable Solutions
DBH	Department of Building and Housing
DG	Distributed Generation
DIN	Deutsches Institut fűr Normung e.V.
DIS	Draft International Standard
EFH	Early Fire Hazard
EN	European Standards
FAA	Federal Aviation Administration
FI	Flammability Index
FIPEC	Fire Performance of Electrical Cables
HC	Heat of Combustion
HRR	Heat Release Rate
HVAC	Heating Ventilating and Air Conditioning
IEC	International Electrical Commission
ISO	International Standards Organisation
NIST	National Institute of Standards and Technology
NFPA	National Fire Protection Association
NZBC	New Zealand Building Code
NZFS	New Zealand Fire Service
SA	Standards Australia
SBI	Single Burning Item
SDI	Smoke Developed Index
SEA	Smoke Extinction Area
SFI	Spread of Flame Index
SNZ	Standards New Zealand
UL	Underwriters Laboratories Standard

1. INTRODUCTION

International research on reaction to fire over the past 15 years or so has predominantly focused on wall and ceiling linings (solid materials) and to a lesser extent floor coverings. Little new work has been done on how to best control the fire properties of suspended flexible fabrics and ducts. Extensive research has been done on the fire performance of electrical cables in Europe.

For flexible fabrics the current NZBC Compliance Document C/AS1 (DBH 2005) uses a Flammability Index (FI) derived from the small-scale test method AS/NZS 1530.2 *Methods for Fire Tests on Building Materials, Components and Structures – Part 2: Tests for Flammability of Materials* (SA/SNZ 1993). This subjects a vertical strip of material to a small flame at the bottom edge and the extent of vertical flame spread is measured. An FI is derived from the test, a maximum value of which is specified in the Compliance Document C/AS1 (DBH 2005). This method has been used to measure the fire performance of flexible fabrics to permit comparative assessment or ranking between materials rather than replicate real fire exposure conditions. More recently, the international emphasis has moved towards test methods that directly replicate realistic end use scenarios or that generate fire engineering data able to be interpreted or utilised in theoretical models for fire safety engineering.

For ducts in HVAC systems the current NZBC Compliance Document (DBH 2005) uses Early Fire Hazard (EFH) indices obtained using a long-established Australian fire test method AS/NZS 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* (SA/SNZ 1999). EFH indices of Spread of Flame Index (SFI) and Smoke Developed Index (SDI) are derived for the materials subjected to the test and maximum values are specified in the Compliance Document C/AS1 (DBH 2005) for both the internal and external surfaces of ducts. Following a general trend the emphasis has moved towards test methods that generate fire engineering data able to be interpreted or utilised in theoretical models for fire safety engineering.

The NZBC Compliance Documents (DBH 2005) do not have any performance or test requirements for the fire properties of electrical cables. A similar situation exists in Australia, whereby no specific requirements for the reaction to fire of electrical cables are found in the Building Code of Australia (ABCB 2006a). However, there are industry standards and test methods (European) that apply to the manufacture and installation of cables and these are more applicable to specific users, such as the electricity and telecommunication industries.

2. BACKGROUND AND CURRENT PRACTICES

Test methods have traditionally been used to measure the fire performance of a material or system to permit comparative assessment, rarely attempting to replicate real fire exposure conditions.

More recently, the emphasis has moved towards test methods that replicate both real fire exposure conditions and end use installation and orientation. While no standard fire test method will be able to replicate all real fires, internationally there are increasing attempts to devise test methods utilising at least as real a fire scenario as possible within the bounds of providing a standard test method to be applied equally to all similar products. In addition, the newer test methods are providing more detailed information on the fire growth potential, HRR and other material specific performance data that can be used directly with models for fire safety engineering.

2.1 Flexible fabrics

For the purposes of this study, flexible fabrics include materials used for curtains, drapes, blinds, building papers and wraps, tent and marquee fabrics, and sun shading canopies where the material is suspended either vertically or at an angle. In New Zealand, the present test method for the regulatory control of flexible fabrics is AS/NZS 1530.2 (SA/SNZ 1993). The test method comprises a vertically mounted specimen measuring 535 mm long by 75 mm wide mounted in a frame and exposed to a flame from a trough containing 0.1 ml of alcohol (methylated spirits). Measurements are taken of the vertical spread of flame up the fabric and of the temperature recorded in the flue and this data is used to obtain an FI for the material. In C/AS1 (DBH 2005) Table 6.2 (extract in Appendix A) the requirements for *Suspended flexible fabrics* permit a maximum FI of 12* (although 100 is possible for the worst performing materials). The FI obtained does not provide useful data for fire safety engineering.

The requirements to C/AS1 (DBH 2005) are as follows:

- **Suspended flexible fabrics**

  6.20.16 The requirements of Table 6.2 apply not only to curtains, drapes and similar ornamental fabrics which hang vertically, but also to flexible canopies which may lie at or near the horizontal.

- **Membrane structures**

  6.20.17 The fabric of structures such as tents, marquees or canopies used for purpose groups CM, CS and CL, shall pass the standard test for flammability (AS 1530.2) for membrane structures.

*The DBH (2007) is currently proposing changes to the flammability requirements for suspended flexible fabrics and membrane structures that will require an FI of 5. The reason for this is to align with the New Zealand Standard for building underlays.

AS1530.2, DR 99311 CP: *Methods for Fire Tests on Building Materials, Components and Structures – Part 2: Test for Flammability of Materials* is a draft revision of AS1530.2 (1993) and includes changes to the methods of calculating results using the existing test method rather than proposing any significant changes to the method itself. The changes relate to statistical evaluation of the test results, and a change in the speed factor formula, so that the flammability indices form a continuous range and a detailed form of test report.

Various other test methods that are used internationally to assess flexible fabrics are compared in Table 1. The methods are very similar in the intensity of fire exposure, using a very small fire source, and the results basically indicate a pass/fail without giving any fire engineering data that would be useful in a wider assessment of modelling context.

Table 1: Test Standards for flexible fabrics

Test method	Region	Exposure	Sample size h x w, mm	Assessment/classification
AS1530.2 *	Aust/NZ	meths flame	535 x 75 mm	Flammability index
NFPA 701 method 1**	USA	methane flame	400 x 150 mm <700 g/m^2 (thin specimens)	Pass/fail criteria based on degree of burning
NFPA 701 method 2*** 2004	USA	methane flame	1200 x 125 mm >700 g/m^2 (thick specimens)	Pass/fail criteria based on degree of burning
FAR 25.853***	USA(FAA)	gas burner	2000 x 500 or 1000 x 1000 approx	Flame propagation/penetration (very stringent and unsuitable for buildings)
BS 5438	UK	gas burner	220 x 170 or 670 x 170 mm	Flammability pass/fail criteria based on degree of burning
DIN 4102 Part 1, B2	Germany	gas burner	230 x 90 or 190 x 90 mm	Ignitability, flame spread <150 mm
ISO 11925-2	Europe	gas burner	250 x 90 mm	Ignitability, flame spread <150 mm

* Conditioning at 20°C and 65 % humidity for a minimum of 24 hours before test.

** AgResearch can do this test.

*** Conditioning at 105°C for 1–3 hours prior to test and tested within 2 minutes.

There is a concern that the small size of the ignition source, particularly when applied to materials with a large heat content and potential for a significant heat release, is not severe enough to give a fair test. This view was expressed by Marcelo Hirschler, a member of the review committee reporting on NFPA 701 (NFPA 2004a), and is equally applicable to the similar methods listed in Table 1. AS1530.2 (1993) and all the other methods using a small flame for ignition have the same problem as NFPA 701 (2004b) *Standard Methods of Fire Tests for Flame Propagation of Textiles and Films: Methods 1 and 2*, meaning no usable fire engineering data is delivered. FAA FAR 25.853 *Aircraft Seat Test, Vertical Flame Spread* is a test for material in aircraft cabins testing the ability of a material to self-extinguish once a small gas burner flame has been withdrawn and is obviously very stringent, especially considering the conditioning temperature of 105^{o}C. In fact it appears too severe for use in buildings, so much so that very few materials would ever be permitted.

Test methods that evaluate the flammability from a small heat source do not deliver any material performance data other than how easily the material is ignited and that is of limited value as fire engineering data. Whereas test methods, such as the cone calorimeter, that use a source of radiation from a heated element and oxygen consumption calorimetry to measure heat release rate (HRR) and obscuration to measure smoke production, provide data that give an indication of the hazard once the material is burning and can be used in fire engineering. Time to ignition is also recorded, but since this is most likely at high radiation levels (50 kW/m^2) there is difficulty in resolving that parameter, especially at the lower end of the flammability range. Experimental trials at lower heat fluxes in the range ~20-35 kW/m^2 may identify a critical flux between ignition and no ignition.

2.1.1 Fire incident statistics involving flexible fabrics

In order to evaluate the extent of the problem locally, the New Zealand Fire Service (NZFS) database (FIRS) (NZFS 2005) of fire incidents in building structures was searched for fires where flexible fabrics under the classification of curtains/blinds/drapes were a principal contributor.

The data in the NZFS (2005) database is collected by the senior officer at the fire. For those fires which involve significant structural damage, there will be a subsequent investigation by a trained and competent fire investigator. However, there is no guarantee that the original incident report is modified in light of the fire investigation. There are also no formal definitions or explanations given relating to each field in the database. The fire officer is offered a menu of choices and is expected to select the most appropriate option with no explanation proffered. Thus the definition could be considered to be what the common understanding of the term is among fire fighters.

The NZFS database extends back to 1986. However, data for incidents recorded from 2000 to 2005 has been used, as prior to that the recording of some parameters was not sufficiently complete to draw consistent conclusions.

The total number of reported fire incidents involving flexible fabrics in structures was 3448 between January 2000 and December 2005. Two categories were investigated, ‘Object Ignited First’ and ‘Object Ignited Second’ for all incidents in which the sub-classification of “curtains/blinds/drapes” and “treated paper” applying to building papers such as wax or tar papers were identified. The results are listed in Table 2.

Table 2: Summary of incidents involving flexible fabrics 2000–2005 (NZFS 2005)

Fire Incidents	**All building structure fires**	**Building structure fires with recorded first or second item ignited as “curtains/blinds/drapes” and “treated paper”***			
		All	**Single house fires**	**Flats apartments**	**Other building types**
Number of incidents	3448	226‡	162	27	33
Number of incidents with injuries or fatalities	378	40	29	9	2
Number of fatalities	84	3	3	0	0
Number of injuries	379	48	31	15	2

* Otherwise included as flexible fabrics.

‡ A breakdown of incidents as they occurred by building type is listed in Table 3.

Note: there is no reference to some of the other materials (tents, marquees or canopies) also considered as flexible fabrics in the NZFS Fire Incident Statistics.

Table 3: Building fire incidents involving flexible fabrics as first or second item ignited 2000–2005 (NZFS 2005)

Building type	Incidents	Injuries	Deaths
Single house	162	31	3
Flat, apartment, home unit	31	15	0
Industrial, manufacturing	1	0	0
Boarding house, half-way house, dormitory, rooming, lodging, home stay, backpacker	2	1	0
Commercial – not classified above	1	1	0
Community hall, marae, Maori cultural use	1	0	0
Construction, renovation, demolition site	2	0	0
Farming, horticulture, agricultural use	2	0	0
Hospital, hospice, rest home, rehabilitation centre	3	0	0
Hotel, motel, lodge, timeshare	2	0	0
Industrial, manufacturing	1	0	0
Office, bank, embassy, fire/ambulance station	1	0	0
Prison, correctional institution	1	0	0
Recreational use, theatre, indoor sports, pool, park, zoo, aquarium	2	0	0
Residential – not classified above	2	0	0
Restaurant, pub, tavern	2	0	0
School: pre-school through to secondary/high	5	0	0
Service/repair use, dry cleaner, laundromat, mechanical workshop	1	0	0
Shop, shopping mall, supermarket, service station, car yard, other sales use	2	0	0
Studio: radio, TV	1	0	0
Vacant building, section	2	0	0
TOTAL	226	48	3

It is significant that all injuries and deaths and the majority of incidents occurred in residential accommodation where there are currently no controls on the fire performance of flexible fabrics. The remainder of incidents in other buildings is 33, accounting for 14.6%.

The New Zealand statistics are compared with those available from the National Fire Protection Association (NFPA 2005) through their website. The USA statistics are shown in Table 4 for fires in homes where curtains, blinds drapery or tapestry are the first item ignited.

Table 4: NFPA statistics involving flexible fabrics – first item ignited (NFPA 2005)

Items First Ignited in Home* Fires
1999-2002 Annual Average, Unknowns Allocated

Items First Ignited	Fires		Civilian Deaths		Civilian Injuries		Property Damage (in Millions)	
Curtains, blinds, drapery or tapestry	*3,500*	*(0.9%)*	*23*	*(1%)*	*279*	*(2%)*	*$56.6*	*(1%)*

Curtain and Drape Fires in U.S. Homes*, by Cause
1999-2002 Structure Fires Reported to U.S. Fire Departments

Cause	Fires		Civilian Deaths		Civilian Injuries		Direct Property Damage (in Millions)	
Unintentional	2,420	(69%)	15	(64%)	218	(78%)	$40.6	(72%)
Failure of equipment or heat source	540	(15%)	6	(25%)	22	(8%)	$11.4	(20%)
Intentional	470	(13%)	3	(11%)	32	(12%)	$2.9	(5%)
Unclassified	70	(2%)	0	(0%)	6	(2%)	$1.4	(2%)
Act of nature	30	(1%)	0	(0%)	1	(0%)	$0.3	(1%)
Total	3,530	(100%)	23	(100%)	279	(100%)	$56.6	(100%)

In Table 5 the New Zealand and USA data is compared in the same format where only the first item ignited is considered and this shows some differences. The percentage of fires for New Zealand is greater but the casualties (deaths and injuries) are less. No New Zealand data is available for the cost of the damage.

Table 5: Comparing NZFS and NFPA statistics involving flexible fabrics – first item ignited only

Item first ignited	Fires	Deaths	Injuries	Property damage
NZFS curtains/blinds/drapes	124(3.6%)	0(0%)	20(0.5%)	NA
NFPA curtains/blinds/drapes	3,500(0.95%)	23(1%)	279(2%)	$5.6m(1%)

2.1.2 Shortfalls in current test methods

The problem with the test methods currently in use for flexible fabrics is that the means of ignition is by a very small flame with limited time of exposure. Consequently the result delivered is related to how easily the fabric catches fire and it may be quite difficult to actually get it burning with a small ignition source. Quite often a material can have significant heat content and potential for heat release but the hazard of this is not quantified without the application of sufficient heat exposure for the reaction to be sustainable. At best the flammability test methods are only suitable for screening purposes rather than qualification of materials. It has been extensively shown that materials that can perform adequately in a flammability test can have a very poor performance in actual use applications. Such a material may be difficult to ignite, but once burning it releases significant heat to sustain that burning (NFPA 2004a – report from Committee on fire tests with reference to NFPA 701).

Studies of the test methods used to evaluate the reaction to fire of passenger train car materials including curtains drapes and fabrics (Peacock, Bukowski and Markos 1998) (NIST 1999) compared the cone calorimeter with a range of flammability and ignitability test methods (FAR 25.853, ASTM E 162 *Standard Test method for Surface Flammability of Materials Using a Radiant Heat Energy Source*, ASTM D 3675 *Test Method for Flammability of Flexible Cellular Materials Using a Radiant Energy Heat Source*). Limited correlations were indicated and then contradicted demonstrating that the HRR from the cone calorimeter was a strong indicator of results from flammability tests for some materials, but equally there were cone calorimeter results that were not a good indicator. Similarly, a good correlation for smoke production was demonstrated between ASTM E 162 and the cone calorimeter. It was concluded that the HRR data from the cone calorimeter can provide part of an overall system of evaluation for new materials and designs. Moreover because of the uncertainties inherent in all of the test methods considered, it makes the use of a single test method of limited value in hazard analysis and a systems approach using a combination of tests is suggested.

2.1.3 Options for a more realistic test method

In order to deliver useful fire engineering data a test method is required to evaluate the material's initial reaction to fire when exposed to a small ignition source, and if there is limited reaction then increase the exposure level to a higher level to measure its contribution to the fire load. This is similar to the philosophy behind the ISO 9705 *Fire Tests – Full-scale Room Tests for Surface Products* (ISO 1993) test where the 100 kW exposure is equivalent to a waste basket fire and the 300 kW level is related to the initial spread to an item of furniture such as an upholstered chair. In terms of severity of exposure the ISO 9705 scenario may be too severe, and whatever product is being tested it will burn anyway. It is also relatively expensive at $8-10k for a single test. Table 6 considers the potential tests available for examining the reaction to fire performance of flexible fabrics.

Table 6: Range of tests available

Test method	Name	Cost	Result parameters
AS/NZS 1530.2 (SAA 1993)	Flammability	$500	Flammability Index
AS/NZS 3837 (SAA 1998)	Cone Cal	$1000	THR, SEA, HC
EN 13823 (CEN 2000)	SBI	$3k ~est	FIGRA, SMOGRA
ISO 9705 (ISO 1993)	ISO room	$8-10k	HRR, SPR, Group No.

The cone calorimeter (AS/NZS 3837 *Method of Test for Heat and Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*, ISO 5660 *Reaction-to-fire Tests – Heat Release, Smoke production and Mass Loss Rate – Part 1: Heat Release Rate*) may not be totally suitable as the sample is horizontal rather than vertical. However, it does serve to determine a heat of combustion for the material as well as time to ignition and smoke production.

The single burning item (SBI) (prEN 13823 *Reaction to Fire Tests of Building Products – Building Products Excluding Floorings – Exposed to the Thermal Attack by a Single Burning Item*) is a test protocol where a medium size (1 x 1.5 m(H) x 0.5 x 1.5 m(H) corner sample of the test material is exposed to 30 kW for 20 minutes. The products are collected for analysis using oxygen consumption calorimetry and measuring smoke obscuration.

Research shows that for the furniture calorimeter the rate of heat release is almost independent of the heat output of the ignition source. Söderbom, van Hees and Meirsschaert (1996) demonstrated that with tests on six different furniture items performed in the furniture calorimeter the test objects were exposed to three intensity levels of ignition source. The sources were: a large propane burner giving 30 kW (SBI size) duration 120 s and a smaller propane burner used at two levels of heat output, 1.7 and 5.8 kW for 90 s. The results showed that the burning behaviour of the furniture was very similar regardless of which burner was used. This was especially evident when the time regime between 50 and 400 kW was studied. The length of this period is a measurement of how quick untenable conditions develop in a single, well-ventilated compartment. Varying the ignition source size only affected the time to ignition and the fire development after that was relatively unaffected. The trials conducted with the 5.8 kW and 30 kW sources (comparing the size of the ignition sources with the respective peak HRR's for the trials) considered the ratio of the ignition source compared with the heat output. This ratio ranged from 0.36 to 1.1% for the 5.8 kW source to 2.1 to 5.9 % for the 30 kW source (or a 0.36% to 5.9% range overall). At the lower end the 1.7 kW source failed to get ignition in four out of the six trial items tested, so there is a lower limit where a representative test cannot be assured.

In support of the above methods, Babrauskas and Peacock (1992) justify 'heat release rate' as the single most important variable in evaluation of fire hazard. This is based on examples of typical fire histories which, even though they illustrate that fire deaths are primarily caused by toxic gases, show the heat release is still the best predictor of fire hazard. Relative toxicity of the combustion gases, and delays in the ignition time as measured by small flame tests, are shown to only have a minor effect on the development of fire hazard. Bench-scale tests such as the cone calorimeter provide data, including HRR and ignition measurements that can be processed to predict real-scale heat release. The role of the flammability test is of limited value if it can be outmoded by a HRR test that provides data to also access flammability.

2.1.3.1 Option 1

A possible means of catering for a low flammability/high heat content phenomenon in testing requirements is with a combination of two or more tests. European classifications in accordance with BS EN 13501-1:2002 *Fire Classification of Construction Products and Building Elements – Part 1: Classification Using Test Data from Reaction to Fire Tests* require that most products under test simultaneously meet the requirements of two standards such as an ignitability test and a heat content test. In a New Zealand context that could mean for flexible fabrics the flammability is assessed as it is now for the FI AS1530.2, and with the addition of cone calorimeter testing to AS/NZS 3837 to determine the heat content in MJ/kg (effective heat of combustion) or MJ/m^2 (total heat evolved). A combination of the two tests would capture flexible fabrics that are difficult to ignite, but produce significant amounts of heat and smoke when they do.

2.1.3.2 Option 2

From the study of Söderbom, van Hees and Meirsschaert (1996) it would appear that the size of the ignition source has a relatively minor influence on the heat release (in the furniture calorimeter) provided it is above a certain minimum of the eventual peak HRR (the range being of the order of 0.36 to 5.9%). If this is compared with the ISO 9705 room, where the ignition source is 100/300 kW, and if the peak HRR is taken as flashover conditions at 1000 kW then the ignition source is 10 to 30% of the failure condition HRR. However, this increase from 100 kW to 300 kW changes the simulation of the fire progressing from an initial ignition source to a secondary large item at 10 minutes. A series of ad hoc trials using tests samples 2400 mm high in the corner of the ISO room using a range of ignition source sizes are proposed. This is to qualitatively gauge the performance as a preliminary to testing to strict ISO 9705 conditions.

In keeping with accepted test standards it is proposed the fire performance of suspended flexible fabrics also be examined for a selection of 2 or 3 materials at room-scale such as in the ISO 9705 room test to determine what level of real-world performance is actually achieved using realistic ignition sources, and to understand whether the current regulatory test method (or a proposed combination of tests from this study) is adequate or not. It may be that the size of the ignition source of 100 kW is too severe (although it is based on a waste-paper basket) and nearly always results in a burn, but the test will show how it spreads or self-extinguishes beyond the influence of the flames. Should it be evident that 100 kW is too large for the burner output (such that a significant fire event inevitably will occur without noticeable contribution of the flexible fabric material), then smaller sizes of ignition source could be utilised.

2.2 Ducts

Ducts refer to HVAC systems within buildings where the internal and external covering may present a fire hazard. The surfaces may be (a) an external wrap for insulation purposes (thermal or acoustical), and (b) the internal surface may be the protective finish for corrosion protection, or possibly paint following refurbishment activities.

The requirements to C/AS1 (DBH 2005) relating to ducts are:

> **6.1.2**
> d) Preventing the movement of *fire* and smoke through *concealed spaces* and services ducts.
>
> **6.3.2**
> f) The heat sensing device required by d) above, shall be interlocked with any heating or ventilating system, so that when activated, it closes all *fire dampers* in all ducts passing through the proscenium wall.
>
> **6.9.5** Air ducts passing through *exit ways* shall not include *combustible* materials.
>
> **Air ducts**
> **6.20.20** Air ducts serving more than one *firecell* in *purpose groups* SC, SD, SA, SR, IE, CS, CL and CM shall have interior and exterior *surface finishes* satisfying the provisions of Table 6.2.
>
> **6.20.21** Where air ducts are contained wholly within a *protected shaft,* provided the shaft does not also contain lifts, only the interior *surface finish* of the air duct is required to comply with Table 6.2.

At present the NZBC surface finish requirements for ducts for HVAC systems are covered in Table 6.2 of C/AS1 (in Appendix A). In the current requirements for the surface finishes of ducts applying to HVAC systems the internal and external surfaces are treated differently. The internal surface requirements are more stringent as the duct has the ability to transport smoke and products of combustion between compartments and therefore requires EFH indices (SFI and SDI's of 0 and 3 to AS 1530.3 (SA 1999) respectively), whereas the external surface requirements are 5 and 7.

Also required in C/AS1 (DBH 2005) is the provision of dampers between fire compartments that are designed to close in the event of fire.

In Australia the ABCB (2006a) requirements relating to the surfaces or material applied to the surfaces of rigid and flexible ductwork for air-handling systems in buildings are specified AS 4254 (SA 1995). EFH indices SFI 0 and SDI 3 to AS 1530.3 (SA 1999) are required for internal and external surfaces of ducts. The ductwork is also required to pass UL181 (2005) *Standard for Factory-Made Air Ducts and Air Connectors*, which is a burning test where the material on the duct is exposed to a Bunsen burner flame under specified conditions and is classified according to the spread of flame and smoke developed.

Overall the Australian ABCB (2006a) requirements for ducts are more stringent than those for New Zealand (DBH 2005), by requiring a higher level of fire testing.

2.2.1 Fire incident statistics involving ducts

Searching the NZFS database (NZFS 2005) for fire incidents for the period 2000 to 2005 where air-handling ducts are involved show that out of 3448 fires only 17 (0.5%) involved ducts. The role played by the ducts in 13 incidents was by providing a path for the transport of smoke. The remainder listed ducts in a broad category in 'first item ignited' that included ducts, pipes, conduits and hose where an exact description of the object actually responsible was not recorded. In those 17 incidents one minor injury was recorded. There is no indication that the ducts were the primary or secondary cause of any of the incidents.

The NZBC C/AS1 (DBH 2005) requires that dampers be fitted in ducts to prevent spread of fire and smoke between compartments, and it is not discernible from the statistics whether the presence or operational status of dampers affected the outcome in any of the above incidents.

2.2.2 Effectiveness of current test methods

The analysis of the fire statistics above indicate that fires involving ducts as a significant contributor to the fire hazard are rare. An obvious reason for this could be that the fire performance requirements as controlled by the current test methods controlling the internal surface properties are effective in preventing fire spread. This could be either by limiting the combustibility of the internal surfaces or by the installation of dampers limiting the transport of fire and products of combustion.

Regarding the external surfaces, and in particular if insulating wraps are applied, no significant risk was identifiable from the incident statistics where EFH (AS 1530.3) indices of SFI 7 and SDI 5 is the New Zealand requirement. The Australian requirement for external surfaces of ducts is far more stringent, being the same as the internal surfaces with SFI 0 and SDI 3.

Considering the lack of incidents where HVAC ducts make a contribution to the outcome, there is insufficient evidence to present a case for improvement involving changes to the performance requirements on the basis that the current test methods are able to screen unsuitable surface products.

2.2.3 Alternative test methods

Based on the findings of BRANZ *Study Report SR 160* (Collier 2006) that investigated new test methods for wall and ceiling linings, a recommendation has been made to the DBH covering surface lining requirements, and insulation for ducts and pipes is included. The recommendation that has been put to the DBH is that where SFI and SDI's of 0 and 3 are required for internal and external surfaces respectively, that this be replaced with a BCA Group 1 number. Similarly, for SFI and SDI's of 5 and 7 respectively a Group 3 number is proposed. This would then mean that the surface products can be tested to ISO 9705 to obtain a group number directly or that cone calorimeter (AS/NZS 3837) testing on the material be used to predict a Group number using the method of Kokkala, Thomas and Karlsson (1993).

2.2.4 Other related research

While the brief for this project did not include pipe insulation, in the course of the literature review a completed Swedish study was considered on the basis of the similarities to duct insulation and electrical cable insulation.

In the NZBC Table 6.2 of C/AS1 in Appendix A the requirements for pipe insulation within air-handling plenums for purpose groups SC, SD, SA and SR are listed as SFI 5 and SDI 7, which are identical to the requirements of external surfaces of ducts considered in Section 2.2 above.

The motivation in the Swedish study for considering the reaction to fire of pipe insulation by separate testing was based on the difficulty of testing linear products (those supplied in lengths but with cylindrical surfaces such as pipe insulation, ducts and cables) which could not be tested and classified in their end use conditions in a fully satisfactory way. This is because considerably more surface area (cylindrical) may be exposed compared with the same space/volume for flat material which thus presents a greater hazard. The study by the SP Swedish National Testing and Research Institute (Sundstrom and Axelsson 2002) on the reaction to fire of pipe insulation has resulted in a Draft International Standard based on the ISO 9705 room corner test, and the provisions are identical except for the method of installation of the product being tested. The research focuses on pipe insulation and compares different types, in thicknesses of 25 and 50 mm, and although the focus was on pipework there is some relevance to ductwork. Three different versions of mounting the pipework were trialled and the lengths of pipework used were 90 m, 180 m, and 190 m representing surfaces areas of 65%, 130%, and 140% compared with the surface area that would be exposed in an ISO 9705 test where the walls and ceiling are covered. The majority of the pipework was at a height above the soffit of the doorway (2000 mm) and was therefore exposed to the more severe conditions in the upper hot layer.

Using the SBI (prEN13823) test comparisons between the same insulation material in sheet and tubular form clearly showed that the tubular form with greater exposed area delivered a greater HRR than the material in sheet form.

It was recommended in the report that Version 1 with 90 m of pipework representing 65% of surface area that would be exposed in an ISO 9705 test is adopted as the test protocol for pipework. A Draft International Standard ISO/DIS 20632 (ISO 2006) *Reaction to Fire Tests – Small Room Test for Pipe Insulation Products or Systems* has subsequently been circulated for comment. The test data that is required to be reported is essentially the same as for ISO 9705 with the time to flashover (HRR >1 MW) being the primary parameter for placing into Class or Group classifications, along with HRR and smoke production rate data.

Difficulties may arise in attempting to convert cone calorimeter test results as has been promoted for surface lining products, given the generally cylindrical shape of the piping insulation products and greater area in practice compared with a flat surface for which the relationship (Kokkala, Thomas and Karlsson (1993)) between full-scale room tests and small-scale cone calorimeter tests has been adopted by the BCA (ABCB 2006a).

This Swedish work supports the intent of the BRANZ recommendation above (that is in process to the DBH) to present the surface requirements Table 6.2 of C/AS1 (as shown in Appendix A) in terms of BCA Group number requirements rather than EFH (AS 1530.3) indices for ducts and pipe insulation.

2.2.5 Recommending a test method

As it stands at present, no further work can be justified to validate a method that already has a case for adoption and only applies to a relatively low risk based on the fire incident data. If a study of duct materials were to be undertaken it is likely it would follow the same rationale of the previous BRANZ research into surface linings and the Swedish study of pipe insulation using ISO 9705 room tests and cone calorimeter. The results of a new study would have a high probability of supporting the findings of the Swedish study and the current recommendation to the DBH to include duct materials with surface linings in general. The only major consideration is the difference in surface area between a flat surface and the surface area of four sides of a duct or a cylindrical surface and that could be accommodated for by calculation when assessing design variations.

2.3 Cables

At present NZBC C/AS1 (DBH 2005) exempts cables from the surface finish requirements applicable to other building components in Table 6.2. A similar situation applies to Australia as well where there are a number of materials that are excluded from compliance with fire hazard properties (ABCB 2006a), and electrical wiring associated with signage is one. Otherwise there are no specific requirements or mention of electrical cables.

2.3.1 Fire incidents involving electrical cables

An examination of the NZFS's database of fire incidents (FIRS) (NZFS 2005) in building structures for fires where the first or second item ignited involves electrical insulation shows 307 incidents from a total of 3448 in the period 2000–2005. On closer examination the majority of incidents are electrical faults causing the insulation to ignite, and typically fire spread is then to another building component. Most of the incidents occurred in residences and attributed electrical faults in the wiring as the cause, not as an avenue causing the spread of fire. Only three incidents list electrical cables as the equipment involved (as distinct from electrical wiring) and these occurred in vacant buildings where construction was in progress (no casualties were recorded).

On the basis of the FIRS data it is apparent that serious high loss fires involving cables in New Zealand are rare, although it is without doubt that if one were to occur in a power station or similar installation with dedicated vertical shafts and horizontal tunnels with high density cabling bundled in trays then it is possible the fire would spread (assuming the cables burn) and the losses would be significant. Another potential problem is redundant cable being left in buildings after IT upgrades when new cable is installed, but the old unused wiring is left in place.

2.3.2 International research in Europe

An extensive project headed by the SP Swedish National Testing and Research Institute known as the FIPEC project (Fire Performance of Electrical Cables) (FIPEC 1999, 2000) (van Hees, Green, Grayson, Vercellotti, Breulet 2001) involved several European organisations representing cable manufacturers, materials developers, cable users, government research bodies and electricity suppliers.

The objectives of the project were to:

- develop or modify cable fire test methods offering improvements on existing IEC (International Electrotechnical Commission) tests
- develop small-scale tests for electrical cables
- develop a correlation model for full-scale tests based on results of small-scale tests
- develop basis for calculation model for the prediction of realistic fire performance of electrical cables.

In the course of the project 70 real-scale tests, 225 full-scale tests and more than 1500 cone calorimeter tests were performed. Cables were assembled in horizontal and vertical trays to test actual installation practices in realistic fire exposures and the results were assessed using oxygen consumption calorimetry. Small-scale samples of cable and the insulation material only were tested in the cone calorimeter.

The results of the project returned:

- a full-scale test based on the IEC 60332.3:2000 *Tests on Electric Cables Under Fire Conditions – Part 3: Tests on Bunched Wires or Cables* has been established with a high discrimination level
- small-scale test procedures have been established for cables and materials, which can be used for modelling of full-scale tests and for product development
- the methods can be used for prescriptive codes e.g. Euroclasses for cables (DG "Distributed Generation" Industry) or for fire performance codes.

The measurement and testing aspects of the project supported:

- implementation of modern measuring techniques within cable fire testing allowing measurement of HRR, smoke production rate and content of smoke gases
- measurement of fire performance of cables in real, full and small-scale tests
- development of small-scale tests for product development.

The report gives a detailed review of the work undertaken during the three year project and presents the full findings, including draft standards guidance documents. The current European national cable fire assessment techniques are not sensitive enough to differentiate between cables with reasonable fire properties and those with very good properties needed for high hazard installations or for high density telecommunication installations. The project has developed sensitive methods for measuring the fire performance of electric cables based on correlations of real-scale tests with bench-scale tests such as the cone calorimeter and the application of sound engineering principles. The most significant parameter affecting the test results was shown to be the method of mounting the tested cables. As a result the developed method can be used both for prescriptive testing and for application in fire performance based codes where mounting procedures that are different to the prescriptive ones can be used. In other words, an assessment can be given for variations to a tested installation.

Different types of modelling were performed between the small, full and real-scale tests. This resulted in a number of correlations formulae, numerical flame spread models and advanced CFD modelling. The latter will allow prediction of cables in more complex situations. Also a novel composite pyrolysis model was developed allowing prediction of the fire behaviour of the cable by means of test results of the different materials used in the cable construction. Such a tool will be of great help in cable development.

2.3.3 International research in USA

A study by Hirschler (1997) analysing and correlating fire tests on electrical cables for use in hazard assessment draws on studies by Beland (1980, 1981, 1982a, 1982b) that investigated fires involving electrical cables. It is noted that while there is substantial evidence that electrical cables are heavily involved in fire scenes, much of that evidence is circumstantial and may even be misleading. The work of Beland focused on whether the cables themselves were responsible for the fires, perhaps by electrical faults such as arcing, where in the majority of cases the fires did not spread mainly due to the safety cut-outs by means of fuses and circuit breakers, this intervention generally prevented further development thus limiting the fires to immediate region of the fault. From the scene evidence it was a straightforward process to determine if arcing was responsible. If the copper was damaged and showing signs of melting (melting point 1030°C) then arcing was most likely to be responsible. If the copper and insulation was only damaged by fire, where the temperature was unlikely to exceed 1000°C, then melting of the copper would not be evident and the cause was by external ignition. To summarise, the focus of the incident research was more on the cause of the fires relating to electrical faults rather than the reaction to and the spread of fire attributable to the cables.

2.3.4 Application of FIPEC findings to New Zealand

The findings of the FIPEC project, while extensive, appear to have limited application to fire engineering in New Zealand as applied to buildings, especially when the fire incident statistics are unable to identify a problem and the Compliance Documents do not have any specific requirements. In Australia the BCA (ABCB 2006a) does not have any specific requirements that apply to the fire protection of electrical cables. Although AS/NZS 3000:2000 *Electrical Installations (known as the Australian/New Zealand Wiring Rules)* (AS/NZS 2000) makes reference to fire protection of wiring and cables by taking precautions to minimise the spread of fire, and by requiring cables to be installed in fire resistant enclosures along with other protective measures, no references are made to the fire performance of the cable itself.

Similarly, AS/NZS 3013:2005 *Electrical Installations – Classifications of Fire and Mechanical Performance of Wirings Systems* (AS/NZS 2005) dismisses the standards IEC 60331, IEC 60332 and BS 6387 that are available for fire testing of cables in favour of AS1530.4 as the basis for fire protection classification of wiring system elements. However, the purpose of the test method is to assess the ability of cables and busways to maintain circuit integrity under fire conditions, rather than limit the spread of fire.

The findings by Hirschler in Section 2.3.3 further raise the question as to what the real problem is: fires caused by electrical events or the cables burning in fire and contributing to spread. In a New Zealand context fire spread by electrical cables in buildings could not be substantiated.

The promotion of the FIPEC project findings in respect of product development of cables is an application to the industry involved in manufacturing and is therefore outside our sphere of interest. Similarly the findings are also applicable to the electricity generating industry who, along with cable manufacturers, supported the FIPEC project.

There is a conceivable benefit in the application of the FIPEC project to use small-scale test results for cables and materials for modelling of full-scale tests that may be used in prescriptive fire codes. It was an objective of the project to develop calculation methods for fire performance of electrical cables, and it is reported that initial advances in numerical modelling have been achieved. So there is a possibility that some time in the future fire engineering solutions will be possible in cable applications.

3. RECOMMENDATIONS / FUTURE WORK

3.1 Flexible fabrics

As a result of this study it is recommended that a series of tests on a variety of products using the flammability apparatus (AS 1530.2) and cone calorimeter (AS 3783) in accordance with Option 1 above be conducted on various flexible fabrics. The intention of this approach is to capture the products within a wider selection that have a low flammability, and so are difficult to ignite, but once they are burning have a high heat content and prove to be quite hazardous as a result.

The flammability and cone test results can then be analysed to develop a combination assessment method that ties in the ease of ignition with the magnitude of heat release once burning. The validated method will be required to discriminate between the different levels of performance of flexible fabric products and if possible provide more realistic engineering data. It will be presented to the DBH in the form of a recommendation to include improved reaction to fire requirements in the Acceptable Solution C/AS1.

At the conclusion of the experimental trials with the flammability apparatus (AS 1530.2) and cone calorimeter (AS 3783) larger scale preliminary trials will be conducted on a selection of flexible fabrics in the ISO room to qualitatively evaluate the performance. These will be followed by two or three (rigorous) ISO 9705 room tests to demonstrate that a product identified as having a low risk of ignition may present a serious hazard once alight. A heat flux meter may be included on the floor to confirm that radiation from burning fabrics above is a significant hazard.

Therefore it is recommended that a research project be undertaken to assess fire test methods that are able to identify the significance of the fire properties and hazards of individual flexible fabrics, specifically ease of ignition and rate of heat release.

3.2 Ducts

Considering the low number of fire incidents involving ducts and the similarities of duct materials to surface linings, a continuing project to examine the reaction to fire of duct materials cannot be justified.

Using the results of previous research a recommendation has already been made to the DBH on the basis of findings in BRANZ *Study Report 160* (Collier 2006). This is included in the recommendation for modifying the fire requirements of surface linings whereby the internal and external surfaces of ducts are treated in the same manner as surface finishes in general and require a Group 1 or Group 3 rating respectively. Acoustic treatment and pipe insulation has been similarly recommended as requiring a Group 3 rating and the testing regime is also to ISO 9705. The Swedish study (Sundstrom and Axelsson 2002) recommends that Version 1 with 90 m of pipework representing 65% of surface area that would be exposed in an ISO 9705 test is adopted as the test protocol for pipework. A Draft International Standard ISO/DIS 20632 (ISO 2006) *Reaction to Fire Tests – Small Room Test for Pipe Insulation Products or Systems* has subsequently been circulated for comment. The test data that is required to be reported is essentially the same as for ISO 9705 with the time to flashover (HRR >1 MW) being the primary parameter for placing into Class or Group classifications, along with HRR and smoke production rate data.

As an alternative to ISO 9705 testing the cone calorimeter offers a small-scale alternative using the method of Kokkala, Thomas and Karlsson (1993) to predict a BCA Group number. However, some additional guidance would be required to convert that data for uses involving ducts and pipes. Considering the low incidence of fires involving ducts and the close similarity (including the recommendation following on) to a previous

BRANZ project, a continuing project repeating the process on duct materials is not recommended.

3.3 Cables

Since the NZBC C/AS1 exempts cables from the surface finish requirements applicable to other building components in Table 6.2, and there are very few fire incidents that involve fire spread on the surface of cables, it is difficult to justify recommending that such provisions be included.

Considering the extensive research on the fire performance of cables in Europe, anything that BRANZ could undertake would be on a much smaller scale and be unlikely to advance the findings effectively. It is therefore not recommended that a research project on the 'reaction to fire' performance of cables be undertaken at this time.

3.4 Summary of recommendations

Flexible fabrics – recommend a project to test a selection of flexible fabrics in the flammability apparatus (AS 1530.2) as currently required by C/AS1 (DBH 2005) and the cone calorimeter (AS 3837) to identify performance parameters that may deliver a favourable test result in one test and not the other (or vice versa) and thus allow potentially hazardous materials into usage. It is a possible outcome that two test methods may be required to effectively screen all types of products in the flexible fabrics category. ISO 9705 room tests are also proposed on two or three products to confirm full size performance.

Ducts – no further project recommended.

Cables – no further project recommended.

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APPENDIX A

PART 6: CONTROL OF INTERNAL FIRE AND SMOKE SPREAD — *Acceptable Solution C/AS1*

Amend 5 Oct 2005

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

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

Notes:

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

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* The DBH (2007) is currently proposing changes to the flammability requirements for suspended flexible fabrics and membrane structures that will require an FI of 5. The reason for this is to align with the New Zealand Standard for building underlays.