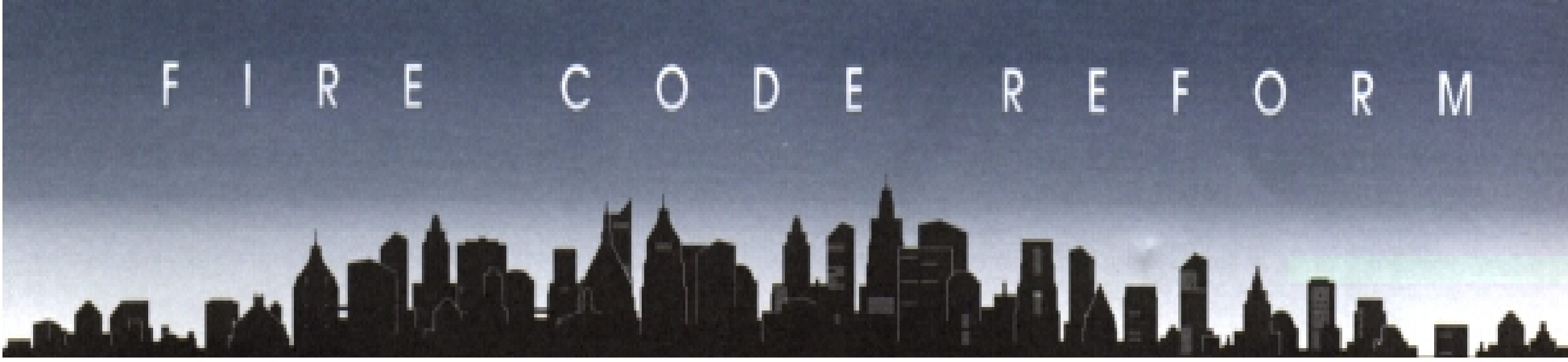

Project Report
FCRC PR 00-03

FIRE PERFORMANCE OF EXTERIOR CLADDINGS

FCRC Project 2 B-2
FIRE PERFORMANCE OF MATERIALS

Fire Code Research Reform Program
April 2000

Important Notice

Acknowledgements

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Comments

Comments on the content or other aspects of this document are always welcome and should be addressed to:- Fire Code Reform Centre Ltd, Suite 1201, 12th Floor, 66 King St, Sydney, NSW 2000, Australia. Tel. No: +61 (2) 9262 4358. Fax No: +61 (2) 9260 4255.

PROJECT FQ0490			
Date: April 2000			

BRANZ

THE RESOURCE CENTRE FOR BUILDING EXCELLENCE

BRANZ REPORT

FCR 1

Fire Performance of Exterior Claddings

C.A. Wade and J.C. Clampett

The work reported here was prepared for and funded by the Fire Code Reform Centre Limited, Australia.

Preface

This is a report on an investigation of fire performance and test methods for regulating the fire safety performance of exterior claddings in Australia.

Acknowledgments

This work was funded by the Fire Code Reform Centre Limited, Australia. Information from BRANZ research funded by the Foundation for Research Science and Technology (New Zealand) has also contributed to the project.

Note

This report is intended for regulatory authorities, fire researchers, fire engineers and manufacturers of external cladding materials and systems.

FIRE PERFORMANCE OF EXTERIOR CLADDINGS

By C. A. Wade and J.C. Clampett

REFERENCE

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ABSTRACT

This report discusses external vertical fire spread in multi-storey buildings with particular regard to the contribution made by combustible cladding systems. The historical fire record is reviewed with some examples presented, international research is discussed, various test methods described as well as an indication given of the performance of materials in a selected range of fire tests. Building regulations in Australia and in other countries are also reviewed and recommendations are made with respect to appropriate 'Deemed to Satisfy' requirements, with a recommendation that the 'Vertical Channel Test' developed in Canada be considered for use in Australia.

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1. EXECUTIVE SUMMARY

1.1 Introduction

This report investigates the fire safety performance of exterior cladding materials and the suitability of various methods of test or regulation that may be considered for inclusion into the Building Code of Australia (ABCB, 1996); it also provides a review of international research, relevant building regulations, applicable test methods and real fire experiences concerning fire spread via exterior walls. Recommendations for change to the Deemed to Satisfy provisions of the Building Code of Australia (BCA) are made with reference to a new proposed test method and new performance criteria.

1.2 The Historical Fire Record

There are relatively few documented cases of extensive external vertical fire spread involving combustible claddings, and there are even fewer cases where such spread has significantly compromised life safety. Part of the reason for this could be due to the historical use of non-combustible materials on facades as is required by many building codes around the world, so the small number of documented examples should not be taken to mean combustible claddings present insignificant risk. Furthermore, there have been a number of very serious examples of external vertical fire spread where a combustible cladding has not been involved, but where window configurations and combustible linings and contents located near windows have contributed significantly to 'leap-frogging' up the external façade.

Façade fires do not generally directly threaten building occupants but the concern is that fire spread through the openings into upper levels may result in secondary fires which can threaten occupants.

There appears to be no record of external vertical fire spread in fully sprinklered buildings.

It is recommended that collection of fire incident data be modified to allow for the identification of external vertical fire spread.

1.3 Combustible Facades (including External Insulation and Finish Systems)

Buildings should not be permitted to allow excessive upward fire propagation on claddings or facades in order that fire does not spread into upper floor levels and reach heights such that external fire-fighting becomes ineffective or impossible. Traditionally this has been achieved by requiring the use of non-combustible materials for claddings and within external wall construction. However, this precludes the use of other materials and composites which may have significant advantages (such as energy conservation). Therefore appropriate alternative methods of test and evaluation procedures are required to ensure that combustible cladding does not compromise life safety.

Full-scale tests are able to evaluate the performance of combustible cladding systems in a manner that is representative of the end-use installation. A bench-scale test such as the cone calorimeter, while useful for investigating the potential for ignition and flame spread over cladding materials, is not able to evaluate the performance of jointing and fixing methods. However, it may be possible to use a bench-scale test (in the same manner as the existing combustibility test) such that all materials/components of an external wall cladding system are separately evaluated for their potential contribution to fire spread. Alternatively small-scale tests may be used to supplement larger or full–scale tests.

The preferred solution is to use a full-scale test to assess performance of combustible facades with the leading candidate test being ISO 13785 Part 2 (which is still in development by ISO (ISO, 1999d)). Another option for a simpler and less expensive reduced-scale method, which may be more attractive from a building regulation perspective, is the Vertical Channel Test previously developed by the National Research Council of Canada and which has been shown to provide good correlation with the larger full-scale Canadian test method.

It is proposed that the Vertical Channel Test method be used for regulatory use (on the basis that satisfactory correlation with a larger-scale test exists). This requires the ASTM task group draft test method to be developed into an Australian Standard or other document able to be referenced by the BCA. The same performance criteria as proposed by the ASTM task group should be adopted (maximum flame spread distance of 5 m, and a maximum heat flux of 35 kW/m^2 at a distance of 3.5 m above the bottom of the specimen).

If a new method of test is to be adopted, a parallel implementation period is recommended (6-12 months), where either approvals based on either the new or existing requirements would be acceptable. Further work may be needed to identify whether accelerated weathering of test specimens is appropriate and if so, what method of weathering should be used.

1.4 Insulated Sandwich Panels

The major fire risk associated with insulated sandwich panel construction appears to be to fire-fighters where poorly designed panels (particularly ceilings) may collapse without adequate warning and trap fire-fighters in the building (anon, 1995). Panels containing thermoplastic insulants (e.g.polystyrene) tend to be more troublesome. While there may be circumstances in which building occupants are put at risk directly from burning sandwich panels, the evidence suggests that if the panels are the item first ignited, fire development will be fairly slow and contained and panels will only contribute to an already large and dangerous fire. The fire risk relating to these panels could be reduced by sealing the panel ends with a non-combustible or intumescent seal; using non-combustible cores such as mineral wool rather than foams; and installing sprinkler systems.

The most appropriate test method for regulatory purposes for self-supporting sandwich panels appears to be the ISO 13784 Part 1 intermediate scale test (ISO, 1999b) being developed by ISO TC92 SC1 WG7. This allows the sandwich panels to be assessed in their end-use situation using appropriate construction details. The sandwich panels are erected into a room (3.6 m x 2.4 m x 2.4 m high) configuration consisting of four walls and a ceiling and an opening in one of the walls. A gas burner (100/300 kW) is used for the fire source.

While recent activity in ISO is toward the development of full-scale room tests where the room is constructed from the panel assembly concerned, it is not clear that the existing building code requirements are entirely unsatisfactory. Full-scale testing of the type being considered by ISO will be considerably more expensive than the existing requirements, and regulatory authorities in Australia will need to be satisfied that the benefits of more realistic end-use testing over current requirements are sufficiently high to warrant any change. Unsatisfactory performance of sandwich panels in real fires is often a result of poor detailing of joints and inappropriate use of materials. Education and guidance to manufacturers and designers regarding appropriate design may suffice in the short term.

1.5 Curtain Wall Construction

Curtain wall construction has particular problems of fire spread through voids that appear between the curtain wall and the edge of the floor slab. Voids are created when the wall panels become distorted, or when such distortion allows fire-stopping to fall out.

The Loss Prevention Council (UK) recently investigated the potential for fire spread via curtain wall construction (Glocking, 1999). They found failure of the glazed window and spandrel panel units to occur after only 13 minutes, failure of the aluminium façade frames after 24 minutes and failure of the aluminium fixing brackets after 28 minutes. Compartment sprinklers were a very effective means of mitigating these effects. External and internal drencher systems were found to significantly delay (but not prevent) the break out of fire from the enclosure, while a fire resisting façade was shown to be able to survive the elevated temperatures and prevent break out and subsequent spread.

It is concluded that vertical external fire spread associated with the poor performance of curtain wall systems is generally confined to unsprinklered buildings. Fire stopping between the edge of the floor slab and a curtain wall needs to remain in place at least as long as the time taken to spread vertically via the glazed openings. The use of combustible interior finishes near the external wall openings can increase the rate and severity of external vertical fire spread.

Sprinkler systems or the use of fire resistant glazing are the only really effective means of preventing vertical fire spread via the curtain wall, although testing by the Loss Prevention Council indicated that the use of external and internal wall-wetting systems would serve to significantly delay the rate of upward fire spread. At this time, new regulatory testing regimes for curtain wall construction are not proposed.

1.6 Apron and Spandrel Panels

International research (particularly by the National Research Council of Canada (Oleszkiewicz, 1991)) has shown that spandrel walls need to be of impractical height (> 2.5 m) to be effective for controlling vertical fire spread (assuming window geometries which allow the flame to hug the wall above). It was shown that horizontal projections are many times more effective than spandrel walls. Applying the results of the Canadian research, an 1100 mm wide apron may reduce the exposure to the wall 1 m above the opening to about 10% of the exposure with a 900 mm spandrel present.

Therefore it is concluded that the 1100 mm wide apron requirement in the BCA is an appropriate control, while the option for a 900 mm spandrel is by no means equivalent and largely ineffective. For Type A construction where requirements for vertical separation of openings are given, consideration should be given to removal of the requirement for 900 mm high spandrels in favour of horizontal projections or sprinkler protection.

1.7 Building Regulations

The current BCA (ABCB, 1996) generally uses the combustibility test AS1530.1 (SA, 1984) and the early fire hazard test AS1530.3 (SA, 1999) to control materials used for external walls and claddings. The existing controls are in some cases not sufficiently specific, for example, the expression “it does not otherwise constitute an undue risk of fire spread via the façade of the building” seems out of place in a deemed-to-satisfy solution. The existing AS1530.3 requirements may also not be able to adequately evaluate the performance of full-scale cladding systems in their end-use installation.

Building codes which currently have full-scale test methods for vertical fire spread on combustible cladding systems include: Uniform Building Code (UBC, 1997) and the National Building Code of Canada (NRCC, 1995). Sweden also uses a full-scale test method (Hermodsson and Månsson, 1992). It is concluded that amendments to the BCA 1996 to provide for a more appropriate method of evaluating combustible exterior facades and claddings will be required and the Vertical Channel Test is proposed.

2. INTRODUCTION

This is a report of a study investigating the fire safety performance of exterior cladding materials and the suitability of various methods of testing or regulation that may be considered for inclusion into the Building Code of Australia (ABCB, 1996). The report provides a review of the international research, relevant building regulations, applicable test methods and real fire experiences concerning fire spread via exterior walls.

Test methods and the fire performance of cladding materials using these methods are also described, and recommendations for change to the Deemed to Satisfy provisions of the Building Code of Australia (BCA) are made with reference to a new proposed test method and performance criteria.

3. OBJECTIVES

The objectives of this research project include:

- Identifying the fire hazard posed by external vertical fire spread and the extent to which combustible cladding contributes to the hazard.
- Summarising previous research and current directions with respect to evaluating and regulating the use of combustible wall claddings.
- Reviewing the current requirements of the Building Code of Australia, identifying deficiencies (if present) and making recommendations for improvement and possible future amendment.

4. IGNITION AND FIRE SPREAD SCENARIOS

The key mechanisms by which exterior cladding systems may ignite and contribute to vertical fire spread include:

1. Flames projecting from broken windows in the room of fire origin, exposing the façade and any windows above. These upper windows may break allowing fire to enter the floors above.
2. Inadequate fire stopping of the gap between the edge of the floor slab and the exterior wall allowing flames and hot gases to pass through to the floor above. Particularly applies to curtain wall construction.
3. Heat induced distortion of low melting point metals or alloys, such as aluminium, causing fire stopping to become ineffective or fall out.
4. Direct contribution of combustible claddings to vertical fire spread. Ignition may be the result of radiation from an exposure fire in an adjacent building, or from an external fire near the wall, or from exposure to external flames projecting from window openings.

The first mechanism tends to be very spectacular, particularly when combustible materials on the upper floors were able to be ignited by the window fire plumes. This is demonstrated by the large fires in Sao Paulo, Brazil (Willey, 1972 and Sharry, 1974), the Las Vegas Hilton (anon, 1982) and the First Interstate Bank, Los Angeles (Klem, 1989; Morris, 1990).

The second mechanism of spread is not as spectacular as the first but can be a contributing factor in fire spread. Examples include: First Interstate Bank, Los Angeles (Klem, 1989; Morris, 1990) and the Avianca Building in Colombia (Sharry, 1974).

Examples of absent or ineffective fire-stopping include the President's Tower (Hartog, 1999) and the First Interstate Bank. Finally examples where combustible cladding directly contributed to vertical fire spread include an apartment building in Irvine Scotland (anon, 1999a), a motel in Albury NSW (NSWFB, 1999) and an apartment complex in Seattle (FEMA, 1991).

5. HISTORICAL FIRE RECORD

There are generally few reports of exterior wall fires involving combustible claddings. This may be because combustible claddings have not been widely used except on low-rise buildings. It is also often difficult to distinguish between the contribution made by the building fire compared with a combustible wall fire (Oleszkiewicz, 1989a). The examples cited in this section should not be considered to be comprehensive but are given as examples for which some information has been available from the literature. A brief review of the Fire Brigade incident data is also given but this would appear to be of limited value in assessing the extent of the problem because external vertical fire spread is not specifically captured by the reporting procedures.

There appears to be no record of external vertical fire spread in fully sprinklered buildings.

5.1 Fire Brigade Statistics

Fire brigade incident statistics do not directly capture data on external vertical spread of fire. However, Dowling and Ramsey (1997) have provided an analysis of the extent of flame damage for Australian building fires 1989-1993. Seventy-eight point two percent of fires were confined to the floor of origin, 15.7% extended beyond the floor of origin but were confined to the structure of origin, 2.2% extended beyond the structure of origin and 3.8% were not a structure fire or were unknown. Thus cases of external vertical fire spread would be included within the approximately 18% of fires that extended beyond the floor of origin but the actual proportion is unknown, but is likely to be only a small proportion of these.

A similar analysis by Kim (1990) of USA data for 305 fires in high-rise buildings in 1988 showed 6% of fires spread beyond the floor of origin.

Some case studies or examples where external vertical fire spread was observed, taken from the international literature, are now given.

5.2 Fires Involving Exterior Insulation and Finish Systems

5.2.1 Apartment Building, Munich, ~1996

A five-level apartment building with a façade made of a composite thermal insulation (about 100 mm thick) comprising polystyrene and foam plastics slabs and a reinforced covering layer. A rubbish container fire on the exterior ignited the cladding and created extensive damage. Windows were broken and flames spread into rooms at upper levels (Mayr, 1996).

Figure 1: Apartment building, Munich **(source: Mayr, 1996)**

5.2.2 Winnipeg, Manitoba, 1990

This was a fire in an eight-storey unsprinklered apartment building with an open-air parking garage located on the ground floor. The exterior walls were an exterior insulation and finish system (EIFS). The fire started in the garage and quickly involved all 25 cars that were parked there. Flames from the garage exposed and eventually ignited the EIFS on the exterior walls and the fire spread up the façade to the top of the fourth storey. Marks left on a non-combustible portion of the façade indicated that the flame from the garage reached the third storey, this being independent of the EIFS.

5.2.3 Manchester, New Hampshire, 1985

A fire exposed an adjacent seven-story office building located across a 6 m wide alley. The office building was clad with an EIFS. A flash fire on the exterior of the office building due to exposure to radiant heat was extinguished in a few minutes, however this short-duration fire was regarded as important because it revealed previously unrecognised fire performance characteristics of popular foam plastic exterior insulation and finish systems (Bletzacker and Crowder 1988 and Crowder and Bletzacker 1988).

5.2.4 Lakeside Plaza, Virginia, 1983

This was a 12-storey apartment building clad with the Dryvit™ EIFS system (EPS backing was 25 mm thick). The fire started in a trash chute on the fifth or sixth floor and there were openings into the chute at each floor level. Damage was limited to floors above the fire source and to areas where it had been directly exposed to heating from the flame (Belles, 1983). Thus extensive vertical spread did not occur in this case.

5.3 Fires Involving Insulated Sandwich Panels

Harwood and Hume (1997) reported on an investigation by the Fire Research Station of 21 fire incidents in the UK involving sandwich panels (and generally in single-storey or low-rise buildings). Only two of those incidents involved cold storage buildings, however 12 of the buildings involved food processing plants and a further five were factory buildings. There were only two deaths in these 21 incidents and these were both fire-fighters at the Sun Valley Poultry fire in 1993 (anon, 1995). In all cases the occupants had left the building safely before the fire had developed sufficiently to put them at risk.

5.4 Fires Involving Other Combustible Claddings

5.4.1 Apartment Building, Irvine, Scotland, 1999

The fire, which started in a flat on the fifth floor of a 13-storey apartment block, broke out through the window and quickly spread vertically up the exterior face of the building engulfing the upper nine floors within minutes. The building was of concrete construction but had full height composite window units comprising a GRP panel below the window and PVC window frames. The fire ignited the GRP panels and spread vertically. There was one death in the incident and that was in the apartment of origin (anon, 1999a; anon, 1999b). Therefore the combustible window components were unlikely to have contributed to the death.

Figure 2: Apartment building fire, Irvine, Scotland **(source: BBC Online Network, 1999)**

5.4.2 Country Comfort Motel, Albury, NSW, 1998

This was an eight-storey accommodation building generally of concrete/masonry construction but with fibreglass panels beneath the windows. A fire occurred at the third-floor level and following breakout through the window, flames rapidly spread to the top of the building via the fibreglass panels positioned vertically above the fire source. Fire penetrated into the third- and fourth-floor levels. There were no deaths associated with the vertical spread of fire (NSWFB, 1999).

Figure 3: Motel fire, NSW, Australia **(source: NSWFB, 1999)**

5.4.3 Te Papa (Museum of New Zealand), Wellington

This was a large multi-level national museum building under construction. The exterior cladding used comprised a thin aluminium-faced panel with a polyethylene core, mounted over extruded foam polystyrene insulation board and building paper. A worker, heat welding a roofing membrane, ignited the building paper and this quickly spread up the exterior façade involving the polystyrene and cladding panel. There were no deaths or injuries associated with the fire.

Figure 4: Museum construction fire, Wellington **(source: NZFS, 1997)**

5.4.4 Villa Plaza Apartment Complex, Seattle, Washington, 1991

This was a four-storey wood frame building with an exterior walkway façade and it had decorative lattice screens of 2” x 6” vertical cedar boards (with oil-based stain). The ceiling of the walkway was also exposed tongue and groove cedar. The space between the cedar boards was about 180 mm and the boards ran the full height of the building. This meant that the exit paths were enclosed in readily combustible material on three sides which contributed to rapid fire spread, including spread to other apartments facing the walkway. A fire coming out of a broken front bedroom window caused the cedar screen to ignite and it provided a path for the fire to quickly extend vertically up the entire 12 m height of the screen and also horizontally across the screen. There were no fatalities in this fire (FEMA, 1991).

5.4.5 Knowsley Heights, Liverpool, 1991

This was an 11-floor apartment tower block. A deliberately lit fire, in the rubbish compound outside the building, spread up through a 90 mm gap between the tower’s rubberised paint-covered concrete outer wall and a recently installed rain screen cladding. The rapid spread of fire was thought to have been caused by the lack of fire barriers in the cavity gap passing all 11 floors and providing a flue for hot gases to rise. (anon, 1993). The fire destroyed the rubbish compound and severely damaged the ground floor lobby and the outer walls and windows of all the upper floors. No smoke or fire penetrated into the flats and the building was reoccupied by tenants later the same day (anon, 1992). The rain screen material was a Class O (limited combustibility) rated product using BS 476 parts 6 and 7 (BSI, 1981; BSI, 1987). Building regulations were changed as a result of this fire.

Figure 5: Knowsley Heights fire (source: anon, 1992)

5.4.6 Others

Butler House, Grays, Essex, 1997. Fire in the top flat of a 14-storey accommodation block caused uPVC window frames to melt and drip, which in turn caused some damage to the cladding (DoETR, 1999).

Apartment Building, Japan. Upward fire spread for over 12 storeys via a combustible balcony (Hokugo et al, 1999).

5.5 Fires Involving Non-Combustible Cladding

5.5.1 President Tower, Bangkok, 1997

This was a 37-storey retail, commercial office and hotel development. A sprinkler system installed was not yet operational as the interior fit out was not fully completed. An explosion and fire started on level seven causing the destruction of an aluminium framed curtain wall system. The effectiveness of fire stopping at the floor edge was compromised by floor to floor cabling. Window and spandrel glass shattered and collapsed before the structural silicone sealant bonds between the glass and aluminium were destroyed. Many heat strengthened glass panels sustained elevated temperatures but fractured and collapsed as they cooled. The vertical fire spread extended up to level 10 (Hartog, 1999).

5.5.2 One Meridian Plaza Building, Philadelphia, 1991

This was a fire which occurred on the 22nd floor of a 38-storey bank building. The building frame was structural steel with concrete floors poured over metal decks and protected with spray-on fireproofing materials. The exterior of the building was covered by granite curtain wall panels with glass windows attached to perimeter floor girders and spandrels. At the time of construction only the below ground service floors were fitted with sprinklers and since then they had been added to the 30th, 31st, 34th, and 35th floors and parts of floors 11 and 15. Fire broke through windows on the 22nd floor and the heat exposure from the window plumes ignited items on the floor above. The fire was stopped when it reached the 30th floor which was sprinklered (FEMA, 1991b, Klem 1991).

Figure 6: One Meridian Plaza fire (source: Klem, 1991)

5.5.3 First Interstate Bank Building, Los Angeles, California, 1988

The bank was a 62-storey tower with sprinkler protection only in the basement, garage and underground pedestrian tunnel. An automatic sprinkler system was being installed in the building at the time. The building had a structural steel frame with spray-on fire proofing with steel floor pans and lightweight concrete decking. The exterior curtain walls were glass and aluminium with a 100 mm gap between the curtain wall and the floor slab, where the fire stopping, comprised 15 mm gypsum board and fibreglass caulking. The fire started on the 12th floor and extended to the floors above primarily via the outer walls of the building. Flames also penetrated behind the spandrel panels around the ends of the floor slab where there was sufficient deformation of the aluminium mullions to weaken the fire stopping, allowing the flame to pass through even before the windows and mullions had failed. The flames were estimated to be lapping 9 m up the face of the building and the curtain walls including windows, spandrel panels, and mullions, were almost completely destroyed by fire. The upward extension stopped at the 26th floor level (FEMA, 1988; Chapman, 1988; Klem, 1989; Morris, 1990).

Figure 7: First Interstate Bank fire **(source: Morris, 1990)**

5.5.4 Westchase Hilton Hotel, Houston, 1982

This was a 13-storey tower of reinforced concrete construction containing 306 guest rooms. The fire was located in a guest room on the fourth floor and spread internally to the adjacent corridor. There was also vertical exterior fire spread to three guest rooms on the fifth floor. Smoke spread throughout the fire floor and to varying degrees throughout the building. The door to the room of origin (a guest room) was not closed due to a malfunctioning or inoperative door closer. There were 12 deaths and 3 serious injuries. The exterior walls were of tempered glass in aluminium floor to ceiling frames. Aluminium plates spanned the gap between the edge of the floor slab and the exterior cladding. Sprinklers were installed in the linen chutes only. Fire was propagated to the floor above through the broken window by impinging on the exterior glass walls. Fire fighters prevented further upward spread (Kim, 1990).

5.5.5 Las Vegas Hilton Hotel, 1981

This was a 30-storey hotel of reinforced concrete construction. Glass windows between floors were separated vertically by a 1 m spandrel prefabricated of masonry, plaster and plasterboard on steel studs.

Fire occurred on the eighth floor of the east tower lift lobby, where the fire involved curtains, carpeting on the walls, ceiling and floor, and furniture. The plate glass window to the exterior shattered allowing a flame front to extend upwards on the exterior of the building. It apparently took 20-25 minutes for exterior fire spread from the eighth floor to the top of the building (about 20 floors). Two mechanisms were identified for the vertical fire spread:

- Flames outside the upper windows radiated heat through the windows and ignited curtains, timber benches with polyurethane foam padding, which then ignited carpeting on room surfaces.

- Flames contacted the plate glass windows. It is believed that the triangular shape of the spandrels, and recessed plate glass caused additional turbulence which rolled the flames onto the windows resulting in early failure.

There were eight deaths in this fire. Three were in the eighth floor lift lobby, one by jumping/falling from the 12th floor, and four in hotel rooms in the east tower. The doors to the hotel rooms where the deaths occurred were open or had been opened during the fire. There were no fatalities in rooms where the door had been kept closed (anon, 1982). This suggests that internal rather than external fire spread was the main reason for the deaths.

Figure 8: Hilton Hotel fire **(source: anon, 1982)**

5.5.6 Joelma Building, Sao Paulo, Brazil, 1974

This was a 25-storey office building of reinforced concrete structure (beams, columns, floor slab) and an exterior curtain wall with hollow tiles rendered with cement plaster on both sides and windows with aluminium framing (Sharry, 1974). The floor slabs were poured in place and provided a 900 mm projection on the north wall and a 600 mm projection on the south wall. Fire started on the twelfth floor near a window. The fire spread externally up two of the facades to the top of the building, readily igniting combustible finishes inside the windows of the floors above which allowed the vertical spread to continue. There were 179 deaths.

5.5.7 Avianca Building, Bogota, Columbia, 1973

This was a 36-storey office building of reinforced concrete construction. The exterior walls consisted of glass and metal panels in metal frames set between concrete mullions (Sharry, 1974). Fire started on the thirteenth floor. Spaces between the cladding and the edge of the floor provided a path for the fire to spread floor to floor. Fire spread was a combination of internal and external spread. In contrast to the Joelma building the rate of vertical fire spread was relatively slow. Apparently there were not enough combustibles directly inside the windows to sustain the vertical spread. There were four deaths in this fire.

5.5.8 Pima County Administration Building, 1973

This was an 11-storey office building. The fire occurred on the fourth floor. Flames extended from windows of this floor and entered windows on the fifth and sixth floors. There were no deaths and fire was extinguished after 45 minutes with about half the fourth floor burned out and minor damage to the fifth and sixth floors (Stone, 1974).

Figure 9: Andraus Building fire **(source: Willey, 1972)**

5.5.9 Andraus Building, Sao Paulo, Brazil, 1972

This was a 31-storey department store and office building. The fire developed on four floors of the department store and then spread externally up the side of the building, involving another 24 floors. Wind velocity and combustible interior finishes and contents were contributing factors to the fire spread. The building construction was reinforced concrete. The building façade had extensive floor to ceiling glazed areas, with a spandrel only 350 mm high and projecting 305 mm from the face of the building. After fire broke through the windows they formed a front exposing the three to four floors above the department store. Radiant heat then ignited combustible ceiling tiles and wood partitions on each floor. The flame front then increased in height as more floors became involved. At its peak the mass of flame over the external façade was 40 m wide 100 m high and projecting at least 15 m into the street (Willey, 1972).

5.5.10 Miscellaneous, United Kingdom (DoETR, 1999)

Mercantile credit building, Basingstoke, 1991. Fire on the eight floor spread up the building. This was a 12-storey office block. Fire broke out on the eighth floor and spread externally behind glass curtain walling to the tenth floor, fanned by strong winds.

Three-storey block in Milton Keynes, 1995. Room destroyed.

Alpha House Coventry, 1997. Flames travelled up the outside of the block from the 13th to 17th floor. No fire penetration of the flats.

It is not known if combustible claddings were involved in these last two fires.

6. RESEARCH REVIEW

6.1 Flame Spread on Claddings

6.1.1 Canadian Research

The National Research Council of Canada (NRCC) designed and built a full-scale and reduced-scale test facility for the subsequent testing of combustible exterior wall assemblies in the late 1980's and early 1990's.

Full-scale tests were carried out on various cladding systems using the three-storey facility with a test specimen measuring 5 m wide by about 10.3 m high. The duration of the test was 25 minutes. Heat fluxes on the outer face of the wall and temperatures on the outside and on the outer face of each distinctive layer of the assembly were recorded. The exposure conditions were intended to provide a heat flux density of 45 ± 5 kW/m^2 measured 0.5 m above the opening and 27 ± 3 kW/m^2 measured 1.5 m above the opening on a non-combustible wall (Oleszkiewicz, 1990b). The test method was developed into the national Canadian Standard CAN/ULC-S134 (ULC, 1992). The National Building Code of Canada (NRCC, 1995) in calling up this test requires the flame spread distance to be less than 5 m above the opening and the heat flux measured 3.5 m above the opening to be less than 35 kW/m^2.

The performance of various assemblies were grouped according to the flame spread distance recorded. These performances can be categorised as:

- flame spread extending to the top of the wall (significant fire hazard)

- flame spread beyond the extent of the external flame but which stopped or receded before the end of the test (some incremental fire hazard)

- no flame spread beyond the extent of the external flame (negligible incremental fire hazard).

Because full-scale tests such as these are costly and many testing organisations did not have the facilities needed, the researchers turned their attention to developing a less expensive reduced-scale test. This new test needed to be adequate in discriminating good and bad performing exterior wall assemblies in terms of their flame spread propensity in real fire scenarios and therefore needed to show good correlation with the full-scale test. This led to the development of the reduced-scale 'Vertical Channel Test', which simulated the heat exposure conditions of the full-scale test but on a specimen that is narrower and slightly shorter than the full-scale specimen (Oleszkiewicz, 1990b, ASTM 1992a).

The research also evaluated other test methods for this purpose, namely, the Steiner tunnel test (ULC, 1978), IMO surface flammability test (IMO, 1985) and modified roof deck test (ASTM, 1988b), but only the Vertical Channel Test correlated well with the full-scale results.

The IMO test did not give a good correlation with the results of the full-scale tests, mainly due to the small size of the apparatus. The modified roof deck test did not heat the specimens sufficiently resulting in less penetration of fire into the assemblies than in the full-scale tests. There were also problems with debris falling on to the burners and obstructing them. The Steiner tunnel test was able to differentiate between some specimens on the basis of flame spread characteristics but it was not able to adequately predict the performance of multi-layered assemblies. The Vertical Channel Test gave indications of flame spread characteristics similar to those obtained in the full-scale tests. The Vertical Channel Test was not pursued further in Canada or USA because many manufacturers had already done full-scale testing so there was little incentive.

The Canadian full-scale test was for a flat façade and more recent research investigated the effect of re-entrant corners (Sumathipala, 1995a, 1995b). These tests indicated that the effect of these corners was significant, particularly when they are close to the edge of the opening. Full-scale test methods developed by The Building Research Establishment (UK) and ISO now include a re-entrant corner in the test specimen.

The concept of 'degrees of combustibility' has also been proposed by Canadian researchers (Tsuchiya and Mathieu, 1991; Richardson and Brooks, 1991; Richardson, 1994), where it is suggested that the rate of heat release might be used to rank building materials according to their 'degree of combustibility'. A test method using the cone calorimeter was proposed. Richardson and Brooks (1991) indicated a preferred radiant exposure of 50 kW/m^2 for 15 minutes duration in the presence of an external spark igniter. Because the standard methods of measuring heat release are non-specific in terms of radiant flux exposure, a National Canadian Standard was produced (ULC, 1992b).

Richardson and Brooks have also suggested criteria for classifying materials according to their 'degree of combustibility'. Their criteria utilise two performance parameters.

The first is the peak rate of heat release and the second the total heat released in 15 minutes from the commencement of the test. Thus, depending on the end use of the material and its location within the building, appropriate levels of performance in terms of peak rate of heat release and total heat release may be specified. This approach provides a classification procedure which is less severe than the traditional non-combustibility test and by setting the limit appropriately would allow materials such as paper-faced plasterboard and fibre-cement board (which add negligible heat to the fire) to be more suitability grouped with existing non-combustible materials. This has certain advantages over 'deeming' some combustible materials to be non-combustible in building regulations. This approach is also discussed by Babrauskas (1991).

The Canadian work led to the development of CAN/ULC-S135 (ULC, 1992b) which is a variation on the cone calorimeter method (ISO, 1993a; ASTM, 1992b). Babrauskas used the peak heat release rate from the bench-scale test and the Swedish SP 105 criteria for the large-scale test, to rank three products, and found the ranking to be the same as it is according to the large-scale test (for only three materials examined). CAN/ULC-S135 does not examine joints, edges and other points of weakness in the full-scale system (Babrauskas, 1996).

However, Clarke (1997) is critical of using the cone calorimeter method as a replacement for combustibility (using ISO 1182 or equivalent) because the cone calorimeter results are sensitive to sample thickness and orientation and because there is poor reproducibility at the low levels of heat release which characterise non-combustibility. He argues that bomb calorimetry (ISO, 1990b) is more appropriate because, like the cone calorimeter, it provides a continuous scale of combustibility but is scenario independent and more reproducible.

6.1.2 United Kingdom

The Building Research Establishment (BRE) carried out research on the fire performance of external thermal insulation for walls of multi-storey buildings (Rogowski et al, 1988). They used a four-storey rig, 9.2 m high, above a recessed opening within which a timber crib was placed producing 3 MW over a 25-minute period. Instrumentation was provided to measure the temperatures and heat flux at various locations on the rig and the radiated heat likely to fall on an adjacent building. They noted that heat radiated from the burning façade was not, by itself, intense enough to create an exposure risk to neighbouring buildings. They also recommended that timber cladding should continue to be used only in low-rise developments (up to 15 m) to avoid extensive self-propagating flame spread over the surface which is beyond the reach of fire-fighters.

The fire source was a wooden crib designed to provide at least 20 minutes of fully developed flaming impinging up to 2 m on the facade and with a heat flux of at least 100 kW/m^2 on the facade. Eight tests were carried out on systems where the insulation was sandwiched between the rendering and the wall, and seven on systems where there was a cavity between the insulation and the cladding. The following BRE recommendations are of interest:

- combustible insulants may be used without a specifically designed system of surface protection only if shown by a full-scale fire test to be satisfactory

- proposed systems incorporating combustible insulants with sheeted overcladding should be designed to incorporate fire barriers in the ventilated cavity every two storeys

- combustible insulants incorporated in non-sheeted systems are likely to suffer only limited fire spread if the following recommendations are applied: – cementitious rendered metal lathing over thermoplastic insulants should be provided with sufficient metal pins (about one every square metre) to stabilise the cladding and fire barriers should be installed every two storeys from the second floor upwards; – cementitious rendered metal lathing over thermosetting insulants should be provided with sufficient metal pins (about one per square metre) to stabilise the cladding; and

- in-situ sprayed polyurethane or polyisocyanurate foamed insulants protected only by a flame retardant coating are not suitable for multi-storey housing developments.

Stirling and Southern (1989) carried out an investigation into the effectiveness of existing methods for fixing claddings and the effect of fire barriers. The effect of fire barriers was determined by first testing a system without barriers and then with barriers. This comparison was carried out for lath and glass fabric claddings. The results of these experiments showed metal fixings are the most effective and, especially for glass fabric claddings over external insulation, horizontal fire barriers at every storey between the cladding and the wall provide support for the insulation, restrain the cladding and restrict damage. For rendered metal lath systems fire barriers at every second storey can significantly reduce fire damage. These systems can be adequately fixed using a combination of metal and plastic fixings, but not plastic fixings alone.

As a result BRE has published a Defect Action Sheet (Building Research Establishment 1989) which details the use of fire barriers in overcladding systems and how far apart they should be.

More recently BRE have participated in a sponsored research programme (involving three major manufacturers of external cladding systems) and have developed a large-scale test method and assessment procedure (Morris et al, 1998) to assess the fire performance of external cladding systems. This test method is intended to allow assessment of the behaviour of non-loadbearing exterior wall assemblies including cladding systems, rainscreen overcladding, EIFS and curtain walling when exposed to fire.

6.1.3 USA

South West Research Institute in San Antonio developed a two-storey apparatus to subject an exterior wall to a 30-minute fire exposure using wood cribs that produced a window plume from the first storey opening, which exposed the outside face of the test panels (Belles, 1986; Beitel and Evans, 1980).

This work has evolved into the more recent UBC Standard 26-9 (1997c) and NFPA Standard 285 (NFPA, 1998) being a method of test for the evaluation of the flammability characteristics of exterior, non-loadbearing wall assemblies containing combustible components, using the intermediate scale multi-storey test apparatus. However, it appears that it has not been embraced by ISO TC92/SC1/WG7 because it was seen as too complex compared to the alternatives available (Babrauskas, 1996).

6.1.4 Sweden

This work (Ondrus, 1985; Ondrus and Pettersson, 1986) was carried out in the Department of Building Fire Safety and Technology at Lund Institute of Technology. This research dealt with externally added thermal insulation as part of a cladding system for a facade.

The hazards examined were:

1. The surface spread of fire with the surface of the facade contributing to the fire.
2. Spread within the construction e.g., through burning of insulation, wall studs and via air cavities.
3. Spread via the windows.
4. Spread resulting from large sections of the insulation collapsing.

Initial tests were carried out using a three-storey test building as shown in Figure 10. The fire simulated a compartment fire with synthetic furnishings. This produces a thermal exposure of approximately 140 kW/m^2 on the facade and approximately 75 kW/m^2 on the second floor window and is equivalent to a fire load density of 110 MJ/m^2 of total internal surface area which is produced using a trough (0.5 m wide x 2.0 m long x 1 m deep) containing 60 litres of heptane. The test facility is constructed of aerated concrete and the system to be tested is attached to the front as it would be in practice.

The second series of tests looked at three types of external insulation systems:

1. Mineral wool insulation with wood studs and steel or aluminium sheet cladding;
2. Mineral wool insulation with a relatively thick layer of plaster;
3. Cellular plastic insulation and a relatively thin layer of plaster.

These were then classified according to the following criteria:

1. No collapse of major sections of the external additional thermal insulation system.
2. The surface spread of flame and the fire spread within the insulation should be limited to the bottom part of the window on the third floor. External flames which could ignite eaves are not permissible.
3. There must be no spread of fire to the second floor through the windows - deemed verified if the total heat flow towards the centre of windows was 80 kW/m^2 or higher.

Figure 10: SP 105 Façade test arrangement.

All three criteria were to be applied to buildings over eight storeys and those between five and eight which did not allow for fires to be extinguished from the outside. For all other buildings only the first two were to be applied.

Thirteen different configurations were tested and the combination and order of the materials and constructional detailing were found to have more effect on the performance than the ignitability of the individual materials.

This test method is now specified as SP FIRE 105 and in Swedish building regulations facades have to be of non-combustible materials or have passed the full-scale test according to the above criteria.

The results of this test are likely to be conservative due to the use of a short wide window in the fire room. This is because Canadian research has shown this window configuration produces a flame plume which hugs the wall above the window causing a more severe exposure than in a normal square window.

Ondrus and Pettersson (1987) also investigated the hazard of plastics, aluminium and wood window frames using the same rig as before, and concluded that windows with PVC, polyurethane or aluminium alloy are not any more hazardous when exposed to fire than standard windows with wood frames.

6.1.5 New Zealand

New Zealand researchers (Wade, 1995; Cowles and Soja, 1999) have investigated the use of the cone calorimeter (at 50 kW/m^2) as a means of regulating flame spread on exterior claddings, based on a peak rate of heat release and total heat release in 15 minutes (following the Canadian degrees of combustibility approach). The classification system was also related to Karlsson's (1992) analytical flame spread solution for wind-aided or concurrent flow to distinguish between claddings which are likely to propagate flame over the surface and those which would not. This was intended to provide an improved methodology compared to existing regulatory methods in New Zealand based on AS1530.1 and AS1530.3 without reverting to the expense of full-scale testing. However, as for all bench-scale tests, the main limitation is an inability to evaluate the performance of joints and other large-scale effects.

6.1.6 ISO TC92 Developments

ISO TC92 is currently developing test methods for evaluating façade assemblies. After examining a range of methods, the ISO task group narrowed their interest to three proposals from Germany (DIN 4102 Part A point 4.3), Canada (ULC, 1992a) and Sweden (SP 105). The similarity between the German and Canadian proposal led them to develop a joint proposal to quantify the contribution from a façade assembly to cause fire spread to two floors above the floor of origin (Sumathipala and Kotthoff, 1997).

The current draft test method ISO 13785 (ISO, 1999d) is described later in this report.

6.2 Insulated Sandwich Panel Construction

The scope of this study is concerned with sandwich panels when used as part of external wall construction. Such panels are also used as internal walls and ceilings but these uses are not considered here.

The three main fire scenarios applicable to sandwich panel external wall construction are:

1. Interior fire impinging on the panel joint.
2. An exterior fire from combustibles stored near the wall e.g. rubbish, vehicles.
3. Fire in an adjacent building.

The first of these scenarios is generally the most severe because of the more intense heating due to fire in an enclosure.

Babrauskas (1997) defines a sandwich panel as:

- primarily self-supporting (i.e. they are not surface materials intended for application on substrate)

- comprising more than one layer of material
- having a low combustibility skin at or near the surface.

ISO (1999a) provides a general material description – "A sandwich panel is a term that has been used for multi-layered products consisting of three or more layers bonded together by adhesive or chemically. One layer is an insulating material, i.e. mineral wool, cellular foams or a natural material, e.g. corkboard protected by facings on both sides. The facing can be selected from a variety of materials and can be either flat or profiled".

ISO (1999a) also describes two construction types –

Type A supported structures

Sandwich panels are mechanically fixed to the outside or the inside of a structural frame work, normally steel, through the thickness of the panel. The ceiling / roof may be built traditionally or with sandwich panels. In most cases these kinds of sandwich panels are the exterior wall and/or the roof of an industrial building.

Type B free standing structures

Sandwich panels are assembled together to provide a room or enclosure which does not depend for its stability on any other structural frame work e.g. cold stores, food or clean rooms constructed normally within a weatherproofed shell. The ceiling of these constructions may be sometimes supported from above. These rooms stand mostly inside of an other building.

A series of large loss fires in the food industry in the UK involving insulated metal-faced panels has focussed attention on the behaviour of these systems in fire (anon, 1995). Panels made of polystyrene foams encased in PVC coated steel sheeting were particularly implicated. The concerns mainly related to:

- foamed plastics which is not totally encapsulated, with metal sheeting bonded to each face with only a very short fold onto the edge (or butt jointed) – the poor jointing detail allows flame penetration and ignition of the plastic foam at an early stage
- difficulties faced by fire fighters – such as linings peeling off and blocking escape routes and trapping fire fighters, greater quantities of smoke and higher risk of structural collapse.

The Fire Research Station (FRS), UK, identified that the safety of fire-fighters in buildings containing sandwich panels to be the main concern. Other factors were the possible large property losses and environmental pollution. Testing carried out using a large calorimeter supported the finding that the risks associated with sandwich panels are primarily in fire-fighting. While there may be circumstances in which building occupants are put at risk directly from burning sandwich panels, the evidence suggests that if the panels are the item first ignited, development will be fairly slow and contained and that panels will only contribute to an already large and dangerous fire (Harwood and Hume, 1997; Shipp et al 1999). It is also very difficult for fire-fighters to control this type of fire because the panels are designed to provide a water-tight surface for hygiene purposes. If there is no fire resistance requirement sudden collapse or delamination of the panels may occur in a fire. The combustible insulants also may contribute to fire development and in some cases spread unseen within the panels.

Research by the FRS suggests that the fire risk relating to these panels might be reduced in a number of ways, including sealing the panel ends with a non-combustible or intumescent seal; using non-combustible cores such as mineral wool rather than foam plastics; and installing sprinkler systems. FRS also investigated the potential for delamination in panels and found delamination to occur even when the core is not combustible. The panels also delaminated at temperatures below 300ºC and before ignition of the core material occurred (Shipp et al 1999).

The International Association of Cold Storage Contractors have now published a guide (IASC, 1999) on the design, construction, installation, commissioning and maintenance of temperature controlled insulated structures. The guide considers fire performance using the various types of panel core and reviews requirements of fire safety legislation and testing. The guide encourages the use of risk assessment techniques and in particular consideration of the following risk factors:

- the fire load
- ease of ignition
- speed of fire spread
- production of smoke and toxic gases
- susceptibility to mechanical damage
- fire resistance of panel assemblies.

Toxicity aspects have been investigated recently by Babrauskas (1997) who used ISO 9705 to test three steel clad sandwich panels with different foamed plastic cores but mounted the panels spaced out 5 cm away from the test room walls. This enabled all combustion products (including any from the rear face of the panels) to be collected by the hood. He concluded that a full-scale test is the best means of evaluating toxic fire hazards of sandwich panels.

In the USA, FMRC-approved insulation sandwich panels consist of a core of insulation between two sheets or facings. The core may be foamed polyurethane, foamed polyisocyanurate, glass-fire-reinforced foamed polyisocyanurate, glass fibre, mineral fibre, or honeycomb treated Kraft paper or aluminium. The facings may be of steel or aluminium (anon, 1997). Approvals are generally based on large-scale corner burn fire tests.

Briggs and Murrell (1994) describe the use of small-scale, intermediate-scale and full-scale tests on insulated sandwich panels so that end-use conditions (joints, air gaps) can be evaluated. They also describe a procedure for a fire hazard analysis.

Sommerfeld et al (1996) reviewed some full-scale tests of facades and roofs insulated with rigid polyurethane foam and concluded that conventional forms of these roofs and facades do not constitute an additional fire risk (subject to proper installation).

Cooke (1999) has presented a procedure for assessing the stability of metal-faced sandwich panels in fire.

6.3 Curtain Wall Construction

Curtain wall is defined as "an exterior non-loadbearing wall, usually more than one storey high supported by the structural frame, which protects the building's interior from weather, noise or fire" (Zicherman, 1992).

Full-scale fire testing of aluminium curtain walls by the South West Research Institute in 1986 highlighted particular problems of fire spread through voids that appear between the aluminium curtain wall and the edge of the floor slab. These voids are created when the test panels become distorted, or when such distortion allows fire-stopping to fall out (Belles and Beitel, 1988). This supported advice given by the Architectural Aluminium Manufacturers Association who published guidance on fire safety in high-rise curtain wall buildings (AAMA, 1979), including information on fire-stopping details and the need for fire-stopping to be permanently fixed in place.

The Loss Prevention Council (UK) recently completed a research programme to investigate the potential for fire spread up the outside of multi-storey buildings. The tests involved determining the chronology of key components of a typical glazed aluminium stick type façade and evaluating the suitability of active and passive fire techniques for overcoming identified problems (Glockling, 1999). The research considered performance of the aluminium fixing brackets; performance of the aluminium framework; performance of the window glazing and spandrel units; effect of sprinklers; effect of internal and external drencher systems; and use of fire-resisting construction.

For their particular tests they found failure of the glazed window and spandrel panel units to occur after 13 minutes, failure of the aluminium façade frames after 24 minutes and failure of the aluminium fixing brackets after 28 minutes. Compartment sprinklers were a very effective means of mitigating these effects, by reducing the gas temperatures to levels that were not threatening to the non-fire-resisting façade. External and internal drencher systems were found to significantly delay (but not prevent) the break out of fire from the enclosure, while a fire-resisting façade was shown to be able to survive the elevated temperatures and prevent break out and subsequent spread.

6.4 Exterior Insulation and Finish Systems

An exterior insulation and finish system (EIFS) is a non-loadbearing exterior wall cladding system consisting of an insulation board (usually foam polystyrene) which is adhered or mechanically attached to a substrate, a reinforced plaster base coat, reinforced with coated fibreglass mesh, and a finish coat. EIFS were originally developed in Europe after the second world war. The system has significant advantages where energy efficiency is a consideration.

Regarding fire behaviour, Creed (1982) presented the view of the Exterior Insulation Manufacturers Association (USA) back in the early 1980's supporting the modified

ASTM E-108 test (ASTM, 1983) for EIFS systems developed by Dr Brady Williamson at the University of California. The test consisted of a ten foot wall exposed to a 20 kW/m^2 (1.5 m high gas flame) heat source. The flame originates on and exposed only to the exterior side of the test panel. This level of exposure is low, in comparison to that indicated by research carried out in the last decade, but was justified at the time as being related to fire outside a window in a high-rise building. The use of this test has subsequently been replaced with the full-scale or intermediate-scale multi-storey tests developed by the Southwest Research Institute in San Antonio (discussed in Section 8 of this report).

As a result of a fire in an eight-storey apartment building, Oleszkiewicz (1995) commented that:

1. "The basic characteristics of any field applied system should be the same as those of a system tested for fire spread in a laboratory. Changing such characteristics as the foam thickness may change the fire performance of the system.

2. The installation of fire stopping every storey or every second storey should be seriously considered especially when using combustible EIFS on high-rise buildings".

Oleszkiewicz (1992) also concluded that since EIFSs are combustible, care must be taken in their design and installation. An assumption that passing a full-scale test provides equivalency to non-combustible claddings in all cases could be dangerous since it may lead to applications that were not envisaged by code-writing bodies. These applications could result in greater fire spread than experienced in the tested applications.

The detailing around penetrations and window openings is important with these type of systems and it is normally necessary to ensure that the fibreglass reinforcing and coating is returned around to the back face of the insulation board substrate. This helps to keep the protective coating intact, preventing fire spreading prematurely into the core material (Oleszkiewicz, 1999).

Schafer and McKechnie (1995) evaluated EIFS to performance requirements of the BCA (AUBRCC, 1990). They assessed fire test results to AS 1530.3 (early fire hazard) and to ASTM E1354 (cone calorimeter) and reviewed performance in three actual fire incidents. They concluded that EIFS with an EPS thickness of up to 40 mm and which was fully encapsulated within a backing medium and glass fibre-reinforced cement plaster coat will meet the performance required by the BCA. They also expressed concern about possible poor performance with polystyrene thicknesses of more than 100 mm and suggested in those cases fire separation within the EPS layer should be provided.

Christensen (1995) also reported on two full-scale façade fire tests of EIFS using a two-storey test rig with an internal corner and an external corner at the University of Karlsruhe, Germany. One of the assemblies had expanded polystyrene foam insulation, while the other had a mineral-based insulation. The mineral-based system showed only minor damage while the foamed-based system allowed fire spread into the upper room.

6.5 Performance of Apron and Spandrel Panels

6.5.1 Experimental Work

Ashton and Malhotra (1960) investigated storey to storey fire spread by conducting large-scale experiments on a four-storey building and concluded that a vertical separation of 3ft (~900 mm) or a horizontal separation of 2ft (~600 mm) was inadequate to prevent entry of external flame from a fire in a lower storey but did not determine what separation would be needed. Thus it has been known for almost forty years that these dimensions for apron and spandrel panels are not adequate.

Langdon-Thomas and Law (1966) went further and stated that to provide adequate protection it would be necessary virtually to omit all windows from the storey immediately above the one with window openings in it.

Early research by NRCC (Harmathy, 1974) concluded that "a spandrel wall was found not be to a practical means of protection against flaming issuing from an opening." In order to achieve a 50% decrease in exposure to the wall above the opening, a 2.5 metre high spandrel would be required.

Moulen (1974) used one-tenth scale models to investigate various combinations of vertical and horizontal separating construction between storeys. He concluded that spandrel wall construction above and below the floor slab could not necessarily be considered to have equal effect. He also found that a horizontal projection of 650 mm would allow flames to curl back onto the face of the building when there was no vertical wall construction directly below the floor slab. However, a 900 mm vertical separation below the floor slab in combination with a 650 mm horizontal projection was sufficient to cause flames to be projected away from the facade.

More recent investigations have considered more than just the size and position of the external flame, but also included measurement of the heat fluxes impinging on the façade above the window openings. This heat flux measurement is more informative with respect to whether vertical fire spread is probable or not.

For example, research at the National Research Council of Canada (Oleszkiewicz 1989b, 1990a) showed a significant drop in heat transfer from a window fire plume to a building façade above it when a horizontal panel was deployed immediately above the window opening. This suggested that horizontal projections of a given size were significantly more effective than a vertical separation of the same dimension. Experiments reported by Oleszkiewicz (1991) using a three-storey high burn facility with a window opening of 2.6 m wide by 1.37 m high and with compartment fire sizes of 5.75 MW and 6.9 MW, show horizontal projections installed above the window offered substantial protection as follows.

- A 300 mm horizontal projection reduced the exposure (at 1 m distance above the opening) by approximately 50%.
- A 600 mm horizontal projection reduced the exposure (at 1 m distance above the opening) by approximately 60%.
- A 1000 mm horizontal projection reduced the exposure (at 1 m distance above the opening) by approximately 85%.

Oleszkiewicz noted that these findings should be limited to fires producing external flames not exceeding three metres in height. The Canadian findings are also now reflected in the National Building Code of Canada (NRCC, 1995) where a 1 m horizontal projection (canopy) is specified in cases where control is considered necessary. Spandrels are not a prescribed solution.

The effect of a horizontal projection was noted in a fire in Illinois (Best, 1975) where fire was apparently prevented from spreading externally to the next floor because of a cantilever design which provided a six-foot (1.8 m) wide horizontal barrier between the adjacent storeys.

6.5.2 Calculation Tools and Modelling

Yokoi (1960) was one of the first researchers to develop a calculation method based on extensive testing. These calculations show the flame height out of a window depends on many parameters including the size and shape of the window, the shape of the fire room and the fire load.

Law also developed calculation procedures for predicting the shape of fire plumes projecting from window openings (Law 1978; anon 1979).

The work published by Oleszkiewicz (1989b) on the heat transfer from a window flame to the facade above describes a mathematical model of heat flow (an extension of the previous work by Law (1978)) and discusses its applicability in comparison with the results obtained in the full-scale experiments. Calculated values of the total heat flux density, at a particular height above the window, were generally higher than those measured. A comparison of the heat transfer to the wall above the window for "normal" fires produced calculated values which were mostly lower than those measured, with the values closer to the windows giving a better correlation. This model seems to be conservative but not excessively so.

Other researchers have undertaken studies of the fire dynamics of window fire plumes. These include:

- Klopovic and Turan (1998) who studied the effect of burn room ventilation and environmental conditions on venting plumes.
- Ohmiya et al (1998) have also developed a model for predicting a room fire in the fully developed stage to estimate the heat release due to combustion of excess fuel in window fire plumes.
- Sugawa and Momita (1997) conducted a reduced scale experimental study investigating the effect of wind on the flow behaviour of window plumes.

Galea et al (1996) used computational fluid dynamic (CFD) techniques in the analysis of fire plumes emerging from windows. They examined three window configurations; narrow, wide and wide with a 1 m deep external protrusion (apron). Figure 11 shows the results of the simulations with the plume being detached from the external wall for the narrow window, and attached for the wide window.

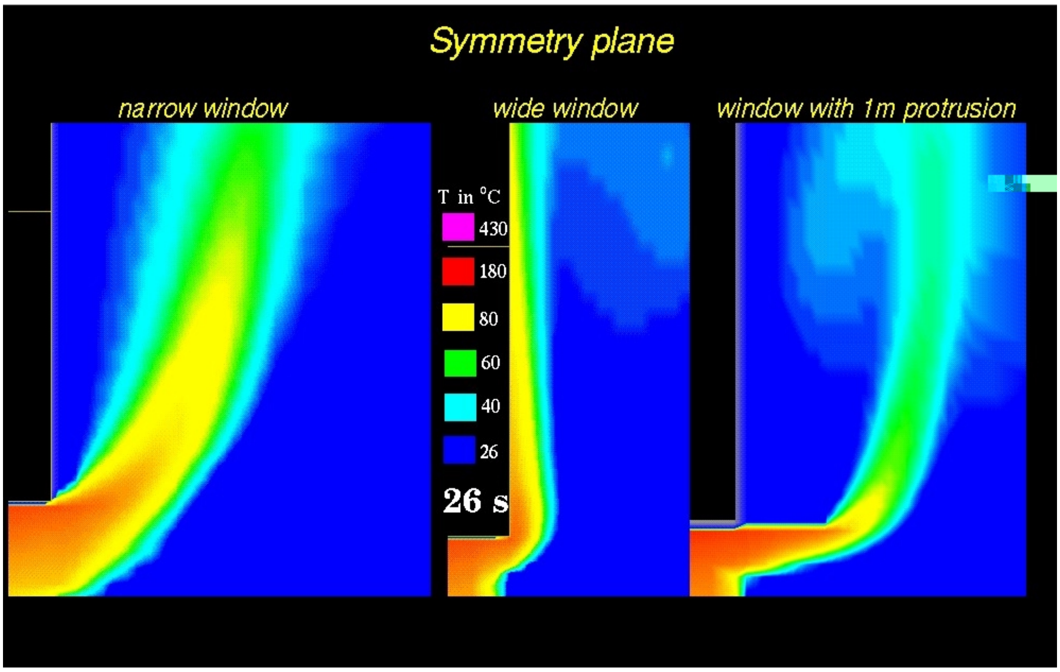

Figure 11: University of Greenwich simulation of window plumes **(source: UoG, 1999)**

7. REVIEW OF BUILDING REGULATIONS

7.1 Building Code of Australia 1996

The Building Code of Australia (ABCB, 1996) is a performance-based building code comprising objectives, functional statements, performance requirements, Deemed to Satisfy provisions and Verification Methods. Those identified here are directly relevant to external vertical fire spread.

7.1.1 Performance Requirements

Objectives relevant to external vertical fire spread:

CO1 The objective of this Section is to-
(a) safeguard people from illness or injury due to a fire in a building; and
(b) safeguard occupants from illness or injury while evacuating a building during fire; and
(c) facilitate the activities of emergency services personnel; and
(d) …
(e) …

Functional Statements relevant to external vertical fire spread:

CF2 A building is to be provided with safeguards to prevent fire spread-
(a) so that occupants have time to evacuate safely without being overcome by the effects of fire; and
(b) to allow for *fire brigade* intervention; and
(c) to *sole-occupancy units* providing sleeping accommodation; and
(d) to adjoining *fire compartments;* and
(e) …

Performance Requirements relevant to external vertical fire spread:

CP2 A building must have elements which will, to the degree necessary, avoid the spread of fire-
(a) …
(b) to sole-occupancy units and public corridors; and
(c) …
(d) in a building, appropriate to-
  (i) the function or use of the building; and
  (ii) the fire load; and
  (iii) the potential fire intensity; and
  (iv) the fire hazard; and
  (v) fire brigade intervention; and
  (vi) …
  (vii) the evacuation time.

CP4 A material and an assembly must, to the degree necessary, resist the spread of fire to limit the generation of smoke and heat, and any toxic gases likely to be produced, appropriate to-
(a) the *evacuation time*; and
(b) the number, mobility, and other characteristics of the occupants; and
(c) the function or use of the building; and
(d) any active *fire safety systems* installed in the building.

CP8 Any building element provided to resist the spread of fire must be protected, to the degree necessary, so that an adequate level of performance is maintained-
(a) where openings, construction joints and the like occur; and
(b) where penetrations occur for building services.

Therefore, under the performance provisions of the BCA, combustible claddings may be used in any circumstance provided sufficient proof of compliance with the above performance requirements is presented to the satisfaction of the approving authority.

7.1.2 Deemed to Satisfy Provisions

Section C of the BCA (ABCB, 1996) identifies type of construction (A, B or C) depending on building class and number of storeys. Only Type C construction allows combustible materials for the external face. The required type of construction is given in BCA Table C1.1 and shown here as Table 1.

Table 1: BCA Type of Construction

Type of Construction Required		
Rise in Storeys	**Class of Building**	
	2*, 3*, 9	**5, 6, 7, 8**
4 or more	A	A
3	A	B
2	B	C
1	C	C

* Two–storey Class 2 or 3 (residential) buildings may be of Type C construction provided certain conditions are met (Specification C1.5).

All building materials and assemblies in Class 2 to 9 buildings are required to comply with Specification C1.10 (fire hazard properties). This is more relevant to Type C construction since Types A and B are required elsewhere to be of non-combustible construction. The general requirements given in Clause 2 will be most applicable to external claddings as follows.

> Except where superseded by Clause 3 or 4, any material or component used in a Class 2, 3, 5, 6, 7, 8, or 9 building must-
>
> (a) in the case of a *sarking-type material*, have a *Flammability Index* not more than 5; or
>
> (b) in the case of other materials, have-
>
> (i) a *Spread-of-Flame Index* not more than 9; and
>
> (ii) a *Smoke-Developed Index* not more than 8 if the *Spread-of-Flame Index* is more than 5; or
>
> (c) be completely covered on all faces by concrete or masonry not less than 50 mm thick; or
>
> (d) in the case of a composite member or assembly, be constructed so that when assembled as proposed in the building-
>
> (i) any material that does not comply with (a) or (b) is protected on all sides and edges from exposure to the air; and
>
> (ii) the member or assembly, when tested in accordance with Specification A2.4, has a *Smoke-Developed Index* and a *Spread-of-Flame Index* not exceeding those prescribed in (b); and
>
> (iii) the member or assembly retains the protection in position so that it prevents ignition of the material and continues to screen it from access to free air for a period of not less than 10 minutes.

Specification A2.4 requires the smoke developed and spread of flame indices to be determined in accordance with AS1530.3. The ability of the assembly to prevent ignition and screen a core material is to be assessed in accordance with AS1530.4 and specimens no smaller than 900 mm x 900 mm may be used provided it will adequately represent the proposed construction in the building. The standard fire resistance test AS1530.4 is not primarily intended for the purpose described in (d) (iii) above and therefore some interpretation is required. As a minimum it is expected that the integrity criterion of the standard test as applied to the exposed "protective material" would need to be satisfied for a period of at least 10 minutes. This would not necessarily prevent a foamed plastics core from melting or vapourising and from spreading gases/molten product to an area more remote from the source of heat/fire and reigniting on mixing with air.

Specification C1.1 contains requirements for the fire-resisting construction of building elements. Clause 2.4 (a) gives requirements for attachments to fire rated walls not to impair fire resistance. This would also apply to any type of construction (A, B, C).

> a. A combustible material may be used as a finish or lining to a wall … which has the required FRL if –

(i) the material is exempted under Clause 7 of Specification C1.10 or complies with the Early Fire Hazard Indices prescribed in Clause 2 of Specification C1.10; and …

(ii) … ; and

(iii) it does not otherwise constitute an undue risk of fire spread via the façade of the building

b. The attachment of a facing or finish, … , to part of a building required to have an FRL must not impair the required FRL of that part.

Therefore, in item a (iii) above, the deemed to satisfy provisions open the door for consideration of performance approach, however no methodology or guidance is provided as to how this should be done. This generally seems to be an inappropriate clause for inclusion in a deemed to satisfy solution.

Specification C1.1 Clause 2.5 (d) provides a concession for curtain walls and panel walls –

> A requirement for an *external wall* to have an FRL does not apply to a *curtain wall* or *panel wall* which is of non combustible construction and fully protected by *automatic* external wall-wetting sprinklers.

Section C Part 2.6 covers requirements for vertical separation of openings in external walls. Unsprinklered Type A construction requires spandrels 900 mm high which are non-combustible and meet 60/60/60, or horizontal construction which projects out 1100 mm which is non-combustible and meets 60/60/60. If a spandrel is provided, at least 600 mm must be located above the level of the intervening floor. Subject to Table 1 these requirements would apply to buildings typically between three and eight storeys in height (below which provision for vertical separation is not required, and above which buildings are required to be sprinklered).

7.2 Asia

The regulations and test methods relevant to exterior claddings in countries such as Hong Kong, Malaysia and Singapore are generally decades old and are usually modified or directly taken from the USA, UK and Germany. The test methods that are in use in this region for determining external cladding materials performances include ASTM D2843 (ASTM, 1993a), BS 476 Part 4, 6, 7 & 11 (BSI, 1970; BSI, 1981; BSI, 1987; BSI, 1982) and DIN 4102 Part 1 (DIN, 1981). These test methods are generally not adequate for evaluation of the end-use performance of exterior claddings materials and systems. These countries usually look towards USA and Europe for relevant experiences and readily adopt controls and test methods developed and tested there (Yong, 1999).

7.3 Japan

In Japan, building and construction products are regulated by the Japanese Building Standard Law together with enforcement orders from Cabinet and Ministry notifications. Parts of buildings may be required to be of "fireproof construction", "quasi-fireproof construction" or "fire preventive construction" (The Building Centre of Japan, 1994) .

All materials which require fire performance properties are classified as non-combustible, quasi-non-combustible or fire retardant. Different bench-scale test methods are used to determine the classification of materials into these groupings (Hedskog and Ryber, 1998).

Non-combustible

This classification is determined by meeting the requirements of a non-combustibility test (JP Notification # 1828) and a surface test (JP Notification # 1828 and #1231). The Japanese non-combustibility test is similar to ISO 1182 (ISO, 1990a) but uses a cubical shaped specimen, also the measurement of temperature difference is slightly different. The surface test apparatus consists of an open furnace and smoke chamber.

Quasi-non-combustible

This classification is determined from measurements made in the Surface Test; the Reduced-Scale Model Box Test (JP Notification # 1231); the Hole Test (JP Notification # 1231) and the Gas Toxicity Test (JP Notification # 1231).

Fire retardant

This classification is determined from measurements made in the Surface Test and the Gas Toxicity Test (JP Notification # 1231).

The current building code requirements are prescriptive and use of new materials would only be permitted if their fire behaviour was shown to be equivalent to the existing materials prescribed for the application. There are no full-scale test methods for facades included within prescriptive requirements. Japan is in the process of reviewing their Building Regulations.

7.4 United Kingdom

Schedule 1 of the Regulations (DoE, 1991) contains functional requirements. Part B of Schedule 1 deals with fire safety and requirement B4(1) states: *"The external walls of the building shall resist the spread of fire over the walls and from one building to another, having regard to the height, use and position of the building".*

A method of compliance with this functional requirement is given in Approved Document B (fire safety). These provisions require external surfaces of walls closer than one metre to the boundary to be class "O" in order to reduce the risk of external spread between buildings.

Where a building is 20 metres or more in height, external wall surfaces which are more than 20 metres above ground are required to achieve a class "O" rating. Below this height timber cladding could be used. This is to reduce the risk of fire spread over the walls of tall buildings whilst allowing commonly used materials in positions where fire fighting from ground level could be effective (DoETR, 1999).

For rainscreen systems (which have ventilated and drained cavities), the surface of the outer cladding facing the cavity also needs to meet the above requirements. Also in buildings of more than 20 m in height any material used in the external wall construction should be of "limited combustibility".

The surface of materials (including cladding) are classified (i.e class "O") by reference to two test methods. These are a spread of flame test (BS 476 Part 7 (BSI, 1987)), which measures the distance flame will spread across the surface of a sample, and a fire propagation test (BS 476 Part 6 (BSI, 1981)), which assesses the contribution that the sample makes to fire development.

There is concern that the Class "O" classification is not adequate, by allowing inappropriate use of some materials. In the future, a new full-scale test method may be called up by the regulations based on a method proposed by BRE (Morris et al, 1998).

7.5 Canada

The National Building Code of Canada (1995) allows exterior non-loadbearing wall assemblies containing combustible components to be used in a building required to be of non-combustible construction, provided:

- the building is not more than three storeys unsprinklered or sprinklered if more than three storeys; and
- the interior surfaces of the wall assembly are protected with a thermal barrier; and
- the wall assembly is subjected to the test method of CAN/ULC S134 "Standard Method of Fire Test of Exterior Wall Assemblies" (ULC, 1992a) and flaming does not spread more than 5 m above the opening during or following the test, and the heat flux during flame exposure on the wall assembly is not more than 35 kW/m^2 measured 3.5 m above the opening.

In unsprinklered mercantile and medium/high hazard industrial occupancies, openings in the exterior wall that are located vertically below another opening in the storey above are required to be separated from the storey above using a fire rated canopy (apron) projecting not less than 1 m from the face of the building at the intervening floor level.

7.6 USA – Uniform Building Code

The Uniform Building Code (UBC, 1997a) requires external walls to be of non-combustible construction under certain circumstances. An exception is made to this for foamed plastics which may be used in all types of construction provided certain requirements are met. These can be summarised as:

- any fire rating required must not be adversely affected;
- thermal barriers are generally required to protect or separate the foamed plastics from interior rooms in the building;
- the combustible content of the foamed plastics is to be no more than 68.2 MJ/m^2;

- the components of the assembly must separately meet flame spread rating requirements;
- the product is required to be listed;
- the wall assembly is required to pass the conditions of acceptance of UBC Standard 26-4 (UBC, 1997b) or UBC Standard 26-9 (UBC, 1997c).

UBC Standard 26-4 (UBC, 1997b) is a method of test for the evaluation of flammability characteristics of exterior, non-loadbearing wall panel assemblies using foamed plastic insulation, and UBC Standard 26-9 (UBC, 1997c) is a method of test for the evaluation of flammability characteristics of exterior, non-loadbearing wall assemblies containing combustible components using the intermediate scale multi-storey test apparatus.

UBC Standard 26-9 is very similar to NFPA 285 (NFPA, 1998) and uses a gas burner as the fire source. This is a newer method covering the same scope as UBC 26-4, which is also a two-storey test arrangement but with wood cribs as the fuel source. Both tests require extensive instrumentation.

Vertical fire spread at external walls is also addressed by requiring any gap between the edge of a floor assembly and an external wall to be fire-stopped. Also in unsprinklered buildings of four or more storeys, openings in external walls which are above each other and less than 1524 mm apart, require the construction of a horizontal flame barrier (apron) 762 mm wide or a vertical flame barrier (spandrel) 914 mm high.

7.7 New Zealand

The relevant clause of the New Zealand Building Code (NZBC, 1992) dealing with the fire performance of external walls is Clause 3.3.5 which states:

"External walls and roofs shall have resistance to the spread of fire, appropriate to the fire load within the building and to the proximity of other household units and other property."

The Acceptable Solution C3/AS1 (BIA, 1992), being one approved means of complying with this clause, provides specific requirements. C3/AS1 seeks to reduce the likelihood of fire propagating vertically up a combustible facade, either as a result of direct flame impingement from an adjacent building on fire, or as a result of flames projecting through openings at a lower level in the same building and igniting the facade in the vicinity of the opening. The requirements seek to control either the ignitability or the contribution of the cladding to fire development (i.e. combustibility), and thereby indirectly influence the rate of vertical flame spread. The test methods specified are:

- AS 1530 Part 1 Methods for Fire Tests on Building Materials, Components and Structures - Combustibility test for materials (SA, 1984); and
- AS 1530 Part 3: Simultaneous determination of ignitability, flame propagation, heat release and smoke release (SA, 1989).

For external walls, the acceptable properties of exterior surface finishes depend on the purpose groups exposed to the fire hazard, the building height, and distance from the relevant boundary. The requirements do not apply where surface finishes are not more than 1.0 mm in thickness and are applied directly to a non-combustible substrate. In summary, there are no restrictions for any building located further than 7 m from a relevant boundary, and within 7 m many buildings will be required to have claddings meeting an Ignitability Index of 0 (AS 1530.3) if less than 25 m in height, or be non-combustible if over 25 m in height.

The New Zealand Building Code does not deem any materials to be non-combustible as is done by the BCA for example. Regulatory authorities in New Zealand are not satisfied with the existing solutions. Potential deficiencies include lack of any requirements for buildings over 25 m and located more than 7 m from a relevant boundary, and the low heat flux exposure in the AS 1530.3 test compared to heat fluxes from realistic window fire plumes.

New Zealand also has requirements for aprons (0.6 m wide) or spandrels (2.5 m high) to be provided in unsprinklered buildings containing sleeping accommodation on upper floors. The minimum spandrel height is likely to be reduced to 1.5 m in the near future. There are no requirements for aprons or spandrels in office buildings (sprinklers are required when building height is above 25 m).

7.8 Sweden

Facades are required to be of non-combustible construction or have passed the full-scale SP-105 test.

8. FIRE TEST METHODS

The fire test methods discussed here are those considered to be most relevant given the topic under consideration. The list is not necessarily comprehensive, and some methods are not specifically included here because of their similarity to another method.

8.1 Full-Scale or Intermediate-Scale Test Methods for Facades

8.1.1 BRE Test Method

The BRE test method assesses the fire performance of external cladding systems (Morris et al, 1998). It applies to non-loadbearing exterior wall assemblies, including external cladding systems, rainscreen overcladding systems, external insulation systems and curtain walling when exposed to an exterior fire. The method determines the comparative burning characteristics of exterior wall assemblies by evaluating fire spread over the external surface, fire spread internally within the system and mechanical response such as damage distortion and collapse. The facility consists of a 2.8 m wide vertical wall with a 1.5 m wide wing wall at right angles to, and 250 mm to one side of, the opening in the main test face. The main face has a 2 m by 2 m opening for the combustion chamber. The height of the wall is at least 6 m above the opening.

The test specimen is exposed to a heat flux of 90 kW/m^2 at a distance of 1 m above the opening. Performance is evaluated against three criteria:

i) external fire spread – when the temperature of an external thermocouple (5 m above opening) exceeds 600ºC for a 30 second period

ii) internal fire spread – when the temperature of an internal thermocouple (5 m above opening) exceeds 600ºC for a 30 second period

iii) mechanical response – observations made of collapse causing a hazard.

8.1.2 ISO Full-Scale Façade Test

The ISO 13785 Part 2 (draft) full-scale test (ISO, 1999d) for facades consists of a combustion chamber with volume in the range 20-100 m^3, with an opening in the front wall (2 m wide by 1.2 m high). The height of the test facility is 4 m above the window opening, with a main façade 3 m wide. A vertically held wing façade, 1.2 m wide, is also required to form a re-entrant angle of 90º. Any fuel can be used to produce a window flame which exposes the test specimen to a heat flux of 55 kW/m^2 at a height of 0.5 m above the opening, and 35 kW/m^2 at a height of 1.5 m above the top opening. Heat fluxes are measured 3.5 m above the top of the window opening, and thermocouples are installed at the top of the test specimen and at the top of the window opening. Evaluation or performance criteria are not included in the standard.

8.1.3 ISO Intermediate-Scale Façade Test

The ISO 13785 Part 1 (draft) intermediate-scale test for facades (ISO, 1999c) is intended for the screening or evaluation of sub-components or families of materials whereas the large scale test is intended to provide an end-use evaluation.

The test specimen consists of sufficient cladding or façade panels to cover two areas of 1.2 m wide x 2.4 m high and 0.6 m wide x 2.4 m high (at right angles to form a re-entrant corner). The bottom edge is closed by the method normally used for the inclusion of a window casement. Joints and fixings used are as they would be in practice. The apparatus consists of a specimen support frame and an ignition source. The ignition source is a propane burner having a right-angle top surface and a heat output of 100 kW. Temperature and heat flux measurements are made during the test and performance criteria are not included in the standard.

8.1.4 Swedish Full-Scale Façade Test (SP-105)

This method comprises a façade specimen 4.18 m wide and 6 m high with an opening at the bottom edge of the specimen. The fire source is a pan filled with 60 litres of heptane. The test specimen is mounted on a lightweight concrete structure. The test specimen includes two 50 mm deep indentations on the façade surface to represent (imaginary) window upper level openings. A heat flux meter is included at the centre of the second upper window. Thermocouples are also located at the top of the specimen and beneath a non-combustible eaves detail (Hermodsson and Månsson, 1992; Babrauskas, 1996).

8.1.5 Canadian Full-Scale Façade Test (CAN/ULC S-134)

The Canadian test method, developed by IRC National Research Council of Canada, was standardised in 1992 as CAN/ULC S-134, "Standard Method of Fire Test of Exterior Wall Assemblies (ULCa, 1992)". This requires a three-storey facility with burn room and propane burners. The window opening is 2.6 m wide by 1.37 m high. The test specimen measures 5 m wide by about 10.3 m high. The exposure conditions are intended to provide a heat flux density of 45 ± 5 kW/m^2 measured 0.5 m above the opening and 27 ± 3 kW/m^2 measured 1.5 m above the opening on a non-combustible wall. The acceptance criteria under the National Building Code of Canada were described in Section 7.5 of this report.

8.1.6 Vertical Channel Test

The Vertical Channel Test apparatus (see Figure 12) consists of a combustion chamber (1.9 m high, 1.5 m deep, and 0.85 m wide) with two openings in the front wall, one at the bottom (440 mm high by 850 mm wide) and one at the top (630 mm high by 850 mm wide). The test specimen measures 850 mm wide by 7320 mm high. Two full-height vertical panels are installed either side of the specimen projecting 500 mm forward of the face of the specimen. Propane burners are used to produce window flames which expose the test specimen to a heat flux of 50 kW/m^2 at a height of 0.5 m above the top opening, and 27 kW/m^2 at a height of 1.5 m above the top opening. The performance of the specimen is "acceptable" if the flame does not spread more than 5 m above the bottom of the specimen, and the heat flux density at a height 3.5 m above the top window opening does not exceed 35 kW/m^2. This is the same as for the full-scale test and as described in Section 7.5 of this report.

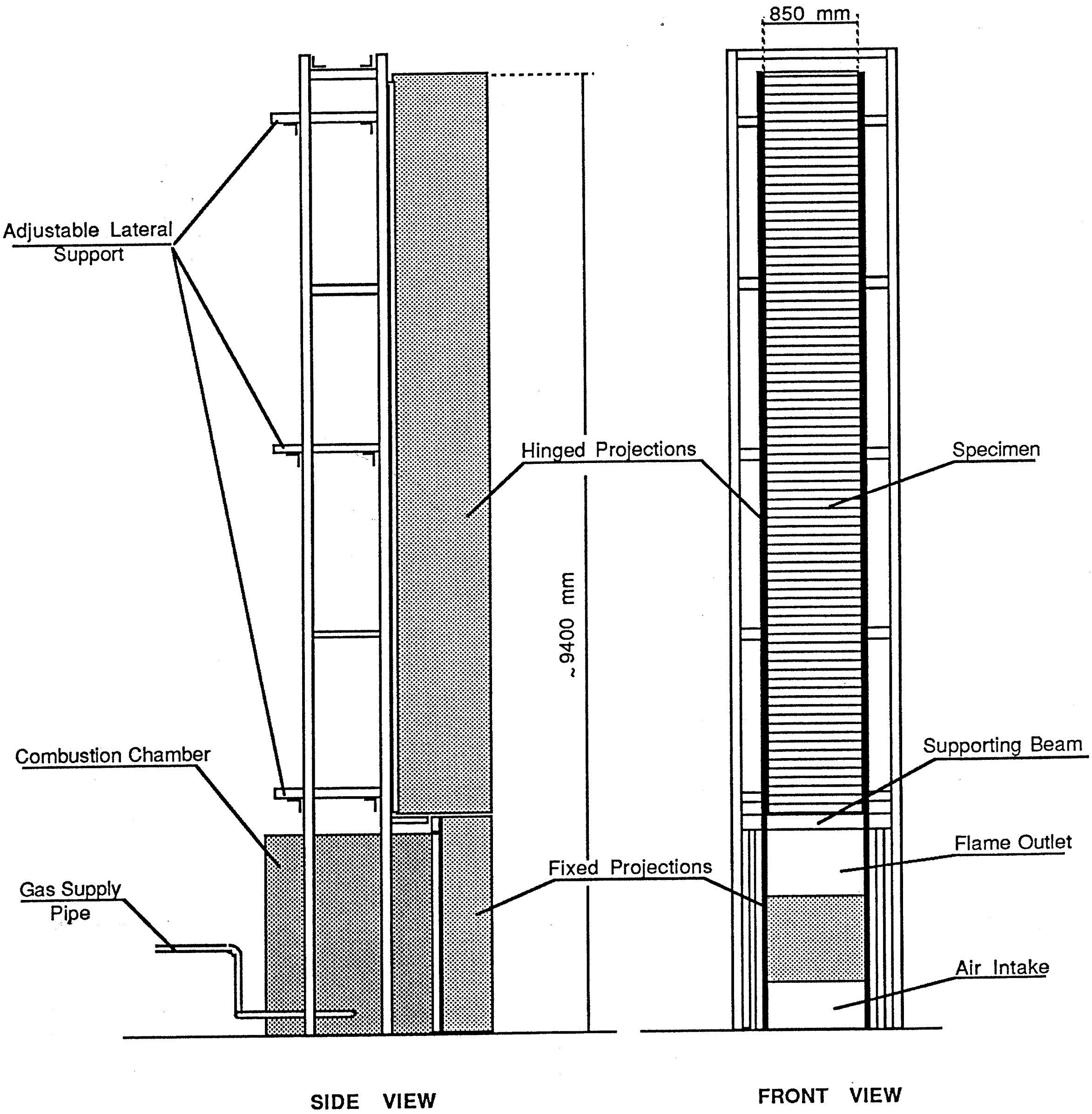

Figure 12: Vertical channel test apparatus.

8.1.7 NFPA 285

NFPA 285 Standard Method of Test for the Evaluation of Flammability Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components Using the Intermediate-Scale, Multi-storey Test Apparatus (NFPA, 1998).

This method is for determining the flammability characteristics of exterior non-loadbearing wall assemblies or panels. The performance is evaluated by:

- The capability of the test wall assembly to resist vertical spread of flame over the exterior face of the system.
- The capability of the test wall assembly to resist vertical spread of flame within the combustible core/component of the panel from one storey to the next.
- The capability of the test wall assembly to resist vertical spread of flame over the interior surface of the panel from one storey to the next.
- The capability of the test wall assembly to resist lateral spread of flame from the compartment of fire origin to adjacent spaces.

Figure 13: NFPA 285 Front view of wall system in frame.

This test comprises a two-storey test structure having overall dimensions 4.6 m high by 4.1 m wide. Each room has dimensions 3.05 m by 3.05 m with a floor to ceiling height of 2.13 m. There is a simulated window opening in the lower storey 760 mm high by 1981 mm wide and sill height of 760 mm. The test wall assembly is required to measure at least 5.33 m high by 4.06 m wide.

The performance of the test wall assembly is judged on the basis of visual observations in conjunction with temperature data.

Figure 14: NFPA 285 side view of wall system in frame.

8.2 Full-Scale or Intermediate-Scale Test Methods for Sandwich Panels

8.2.1 ISO Large Scale Sandwich Panel Test

ISO TC92 SC1 WG7 has been developing a large-scale test for industrial sandwich panels as ISO 13784 Part 2 (ISO, 1999a). This proposed test provides a procedure by which sandwich panels may be assessed in their end-use scale using construction details which are incorporated within their end use. The products can be evaluated either as self-supporting or with end-use joints and fixings where a steel framework is part of the construction. The sandwich panels are erected into a large room configuration consisting of four walls at right angles and a ceiling. The room has the following inside dimensions - 4.8 m long x 4.8 m wide x 4.0 m high. An opening 4.8 m wide x 2.8 m high is also included.

The ignition source is a propane gas burner (dimensions 0.3 m x 0.3 m) with a heat output of 100 kW for the first five minutes, 300 kW for the next five minutes, and 600 kW for the remaining five minutes of the test duration. The results of the test are reported in terms of temperatures recorded with time, observations of burning behaviour, extent of fire involvement, mechanical behaviour and extent of damage after the test is terminated. The draft Standard does not discuss any pass/fail criteria.

8.2.2 ISO Intermediate Scale Sandwich Panel Test

ISO TC92 SC1 WG7 has also been developing an intermediate-scale test for industrial sandwich panels as ISO 13784 Part 1 (ISO, 1999b). This proposed test is applicable only to self-supporting panel assemblies and not intended for products which are glued, nailed, bonded or supported by an underlying wall construction. A room is constructed using components of the test system consisting of four walls at right angles and a ceiling. The room has the following inside dimensions – 3.6 m long x 2.4 m wide x 2.4 m high. An opening 0.8 m wide x 2.0 m high is also included.

The ignition source is a propane gas burner (dimensions 0.17 m x 0.17 m) with a heat output of 100 kW for the first 10 minutes and 300 kW for the next 10 minutes.

Thermocouples are installed on the external surface and within the core to monitor flame spread. Heat and smoke release measurements can be made either by connecting the room to an ISO 9705 hood (which only measures heat and smoke from the room opening) or alternatively the sandwich panel construction is mounted within a larger enclosure with an opening connecting to an ISO 9705 hood. This enables smoke leaking from joints to also be included in the heat and smoke measurements.

The results of the test are reported in terms of temperatures recorded with time, observations of burning behaviour, extent of fire involvement, mechanical behaviour and extent of damage, time/rate of heat release, time/production of carbon monoxide and carbon dioxide, and time/production of light-obscuring smoke. The draft Standard does not discuss any pass/fail criteria.

8.2.3 Loss Prevention Council Test Method

LPS 1181 test method (LPC, 1990), room test, crib in corner 510 kW, max output 1 MW. This test is sometimes known as the ‘garage’ test and consists of either lining two 10 m x 4.5 m x 3 m rooms or constructing two free-standing rooms of the same dimensions. One room is exposed to a ‘slow burning’ crib and the other to a ‘fast burning’ crib. The test compares fire spread with that of a plasterboard lined room and no flashover.

8.2.4 Factory Mutual 25 ft and 50 ft Corner Tests

These tests may form part of the testing procedures carried out by Factory Mutual for insulated sandwich panels.

The tests simulate actual fire conditions where two walls and a ceiling abut each other. The test structure consists of two free-standing steel frame walls joined in a L-shaped assembly, over which there is a bar-joisted ceiling/roof framework with a corrugated steel ceiling. The product tested is attached to the entire surface of the two walls (and ceiling if required). The fire source is a pile of wood pallets located at a specified distance from the intersection of the walls. Then product is considered acceptable if the fire does not self-propagate to the end of each wall (anon, 1997; Maroni, 1972).

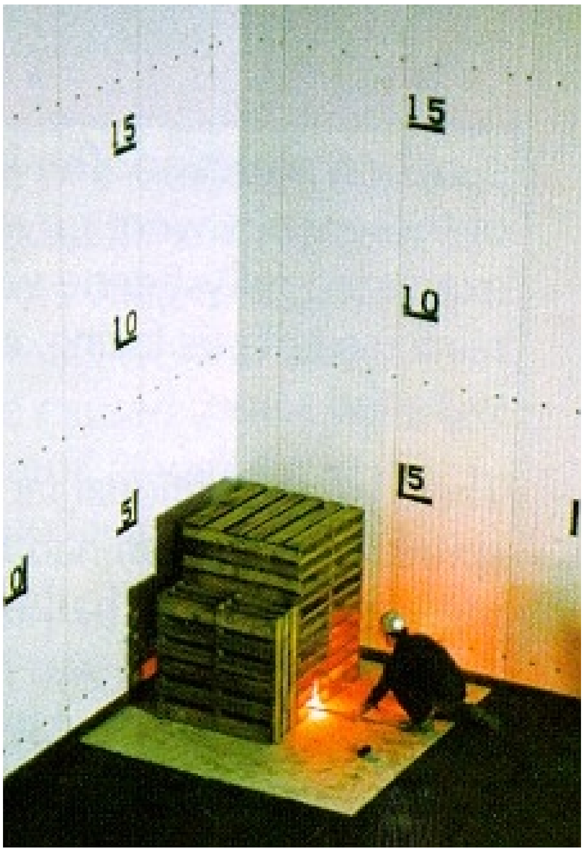

Figure 15: FMRC corner test (source: anon, 1997).

8.3 Small- or Bench-Scale Test Methods

8.3.1 Combustibility AS 1530.1

The combustibility test, AS1530 Part 1 (SA,1984) and its equivalents throughout the world (eg BSI, 1970; ISO, 1990a; ASTM, 1982), is the general method for determining combustibility of building materials. It involves placing a small specimen into a furnace at 750ºC and measuring differential temperature rises in the furnace, and on the specimen, and recording the duration of any sustained flaming. It is intended for homogenous materials, not products that are faced, coated or laminated. When the test was originally developed it was intended that materials with up to about 3% of organic content would be able to pass the test.

8.3.2 Early Fire Hazard AS 1530.3

AS 1530 Part 3 (SA, 1999) exposes a vertical specimen to a gradually increasing heat flux up to a maximum of about 25 kW/m^2 (Dowling and Martin, 1985), by moving the specimen closer to a radiant panel over a period of 20 minutes. The heat flux level and the gradual heating conditions may be considered not severe enough to be representative of a window fire plume.

8.3.3 Bomb Calorimeter ISO 1716

The ISO 1716 test method (ISO, 1990b) determines the gross calorific potential under constant volume. The apparatus consists of a calorimetric bomb, calorimeter (jacket, vessel, stirrer), ignition source and temperature measuring device. The gross calorific potential is calculated on the basis of the measured temperature rise in the test. Equivalent methods include ASTM D2015 (ASTM, 1993b) and NFPA 259 (NFPA, 1991).

8.3.4 Cone Calorimeter ISO 5660

The test apparatus consists of a conical electric heater, ignition source and gas collection system. The test specimen measures 100 mm x 100 mm with a thickness between 6 mm and 50 mm. The test specimen is exposed to a heat flux from the electric heater (in the range 0-100 kW/m^2). When the mixture of gases above the specimen surface becomes flammable it is ignited by a spark igniter. Measurements are made of the heat release rate, mass loss, time to ignition, carbon monoxide and carbon dioxide production and light-obscuring smoke (ISO, 1993a).

Also similar to ASTM E1354 (ASTM, 1992b), CAN/ULC-S135 (ULC, 1992b) and AS/NZS 3837 (SA, 1998).

8.3.5 Fire Propagation BS 476 Part 6

This test (BSI, 1981) provides a comparative measure of the contribution to the growth of fire made by an essentially flat material, composite or assembly. The result is given as a fire propagation index. The test specimens measure 225 mm square and can be up to 50 mm thick. The apparatus comprises a combustion chamber attached to a chimney and cowl (with thermocouples). The test specimens are subjected to a prescribed heating regime for a duration of 20 minutes and the index obtained is derived from the flue gas temperature compared to that obtained for a non-combustible material.

8.3.6 Surface Spread of Flame BS 476 Part 7

This test (BSI, 1987) is used to determine the tendency of materials to support lateral spread of flame. The test specimen is 925 mm long x 280 mm wide with thickness up to 50 mm. The vertical specimen is exposed, at an angle of 90 degrees, to a 900 mm square gas-fired radiant panel. Depending on the extent of lateral flame spread along the specimen, the product is classified as Class 1, 2, 3 or 4 with Class 1 representing the best performance.

8.3.7 The Intermediate Scale Calorimeter

The ICAL intermediate scale calorimeter (ASTM, 1994) was developed to measure the heat release rate from wall assemblies, particularly those composites and assemblies that cannot be tested in a cone calorimeter in a representative manner. The apparatus consists of a vertical radiant panel of approximate height 1.3 m and width 1.5 m. The test specimen measures 1 m x 1 m and is positioned parallel to the radiant panel. The maximum radiant flux received by the sample is set at 60 kW/m2 by adjusting the distance to the panel. The products of pyrolysis are ignited with hot wires located at the top and bottom of the specimen (but not in contact). The specimen is placed on a load cell to measure the mass loss during the test and both specimen and radiant panel are placed beneath an ISO 9705 hood for measurement of the heat release rate on the basis of oxygen consumption (Janssens, 1995).

9. PERFORMANCE IN SELECTED TEST METHODS

9.1 General

This section provides data on the performance of various external wall claddings and assemblies when subjected to a range of fire test methods. The data presented is taken from the general literature and from research findings by the authors. While it is acknowledged that much additional data and resource exists around the world, it is often of a proprietary nature and therefore often not generally available.

The scope of this section is confined to consideration of vertical fire spread (in multi-storey construction) as a result of flame spread over the exterior face of combustible cladding materials and assemblies. It does not cover fire spread issues associated with the use of non-combustible components and wall/window configurations such as curtain wall systems.

9.2 Performance of Claddings in Full-Scale Tests

9.2.1 Canada - CAN/ULC-S134

Full-scale tests were carried out on various cladding systems (Oleskiewicz, 1989a) using a three-storey facility with a test specimen measuring 5 m wide by about 10.3 m high. The duration of the tests was 25 minutes. Heat fluxes on the outer face of the wall and temperatures on the outside and on the outer face of each distinctive layer of each assembly were recorded. The exposure conditions were intended to provide a heat flux density of 45 ± 5 kW/m^2 measured 0.5 m above the opening and 27 ± 3 kW/m^2 measured 1.5 m above the opening on a non-combustible wall (Oleszkiewicz, 1990b). The test method was developed into the national Canadian Standard CAN/ULC-S134 (ULC, 1992a).

The performance of various assemblies were grouped according to the flame spread distance recorded. These performances can be categorised as three distinct behaviours:

- Flame spread extending to the top of the wall (significant fire hazard)
- Flame spread beyond the extent of the external flame but which stopped or receded before the end of the test (some fire incremental hazard)
- No flame spread beyond the extent of the external flame (negligible incremental fire hazard).

The results obtained for a range of different cladding assemblies are given in Table 2.

Table 2: Full-scale experiments at National Research Council of Canada

Assembly	Flame Distance (m)*	Heat Flux Density (kW/m^2)	
		@ 3.5 m	@ 5.5 m
Calibration Non-combustible Assembly			
Non-combustible board over concrete block wall	2.0	16	10
Assemblies not showing flame spread above the exposing flame			
Gypsum sheathing on glass fibre insulated wood frame wall	3.0	15	10
Assemblies showing flame spread which stops or recedes before end of test			
Vinyl siding on gypsum sheathing on glass fibre insulated wood frame wall	3.0	23	17
Aluminium siding on waferboard[i] on glass fibre insulated wood frame wall	4.5	70	20
12.7 mm flame retardant treated plywood on untreated wood studs, with phenolic foam insulation in cavities	3.0	29	20
Aluminium sheet (0.75 mm) on flame retardant treated wood studs, with phenolic foam insulation in cavities	3.2	20	12
76 mm polystyrene foam, glass fibre mesh, 7 mm synthetic plaster on gypsum sheathing, glass fibre insulated steel stud wall	4.5	31	8
Composite panels (6 mm FRP membranes, 127 mm polyurethane foam core) attached to concrete block wall	4.0	24	10
102 mm expanded polystyrene insulation bonded to gypsum sheathing, covered with glass fibre mesh embedded in 4 mm synthetic plaster	4.5	48	37
76 mm expanded polystyrene insulation bonded to gypsum sheathing, covered with glass fibre mesh embedded in 4 mm synthetic plaster	2.0	27	11
Assemblies showing flame spread to top of wall			
8 mm waferboard on glass fibre insulated wood frame wall	7.5	61	79
Vinyl siding on 8 mm waferboard on glass fibre insulated wood frame wall	7.5	82	111
Aluminium siding on 25 mm strapping, 25 mm expanded polystyrene, 19 mm plywood, glass insulated wood frame wall	7.5	30	31

* The flame distance refers to the distance between the top of the window opening and the highest observable instance of flaming on the wall – determined from video recordings.

The following proprietary wall cladding systems have passed the CAN/ULC-S134 (ULC, 1992a) test as reported by the Canadian Construction Materials Centre Registry of Product Evaluations (IRC, 1999).

"Dryvit Outsulation" manufactured by Dryvit Systems Canada. This is an EIFS system.

"Carea Exterior Wall Cladding System" manufactured by Productions CAREA Inc, Quebec. This is a prefabricated cladding system consisting of panels of polyester-glass fibre composite, highly filled with mineral particles.

"Sto Systems" manufactured by Sto Finish Systems Canada. This is an EIFS system.

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i A reconstituted wood board product

9.2.2 Canada - Vertical Channel Test

The Vertical Channel Test apparatus (see Figure 12) consists of a combustion chamber (1.9 m high, 1.5 m deep, and 0.85 m wide) with two openings in the front wall, one at the bottom (440 mm high by 850 mm wide) and one at the top (630 mm high by 850 mm wide) (ASTM, 1992a). The test specimen measures 850 mm wide by 7320 mm high. Propane burners are used to produce window flames which expose the test specimen to a heat flux of 50 kW/m^2 at a height of 0.5 m above the top opening, and 27 kW/m^2 at a height of 1.5 m above the top opening. The performance of the specimen is considered 'acceptable' if the flame does not spread more than 5 m above the bottom of the specimen, and the heat flux density at a height 3.5 m above the top window opening does not exceed 35 kW/m^2. The test was developed with the purpose of being less complex and less costly than the larger scale test but yet still be able to discriminate between the performance of wall assemblies in the same way as the larger scale test. The results for a range of wall assemblies are given in Table 3.

Table 3: Vertical channel experiments at National Research Council of Canada

Assembly	Flame Distance (m)*	Heat Flux Density (kW/m^2)	
		@ 3.5 m	@ 5.5 m
Acceptable			
Non-combustible board over concrete block wall	2.0	12	7
Vinyl siding on gypsum sheathing on glass fibre insulated wood frame wall	2.8	-	19
12.7 mm flame retardant treated plywood on untreated wood studs, with phenolic foam insulation in cavities	2.8	14	9
Aluminium sheet (0.75 mm) on flame retardant treated wood studs, with phenolic foam insulation in cavities	2.3	16	14
76 mm polystyrene foam, glass fibre mesh, 7 mm synthetic plaster on gypsum sheathing, glass fibre insulated steel stud wall	2.0	18	10
Not Acceptable			
Aluminium siding on waferboard on glass fibre insulated wood frame wall	4.5	45	24
Composite panels (6 mm FRP membranes, 127 mm polyurethane foam core) attached to concrete block wall	7.3	42	18
8 mm waferboard on glass fibre insulated wood frame wall	7.3	70	65
Vinyl siding on 8 mm waferboard on glass fibre insulated wood frame wall	7.3	67	60

* The flame distance refers to the distance between the top of the window opening and the highest observable instance of flaming on the wall – determined from video recordings.

On the basis on the two acceptance criteria (flame spread distance and heat flux density), the Vertical Channel Test correctly classifies all of the assemblies tested except one. The exception was the composite panel which did not meet the acceptance criteria in the Vertical Channel Test, yet was satisfactory in the larger scale test. However, since the Vertical Channel Test erred on the conservative side, this anomalous result should not be of significant concern.

9.2.3 BRE Full-Scale Testing of External Thermal Insulation

The Building Research Establishment (BRE) carried out research on the fire performance of external thermal insulation for walls of multi-storey buildings (Rogowski et al, 1988). They used a four-storey rig, 9.2 m high, above a recessed opening within which a timber crib was placed, producing 3 MW over a 25-minute period and producing a flame impinging up to 2 m on the facade and with a heat flux of 90 ± 20 kW/m^2 measured at 1 m above the opening. Instrumentation was provided to measure the temperatures and heat flux at various locations on the rig and the radiated heat likely to fall on an adjacent building. Eight tests were carried out on systems where the insulation was sandwiched between the rendering and the wall (i.e. non-sheeted external insulation systems), and seven on systems where there was a cavity between the insulation and a sheet cladding.

Table 4: Wall systems tested by BRE

Description	Performance and Comments
Polystyrene 50 mm thick, with a 4 mm glass fabric reinforced polymeric render on one side, adhered to a masonry wall, no fire barrier	Render detached, extensive degradation. Fire barrier and inorganic based surface render considered necessary with thermoplastic insulants.
Polystyrene 50 mm thick, with a 50 mm glass fabric reinforced polymer modified cementitious render on one side, adhered to a masonry wall, fire barrier comprised mineral wool barrier at each storey, glass fabric was returned onto the masonry to provide support.	Limited extent of degradation of insulation or finish. Restricted surface failure and barrier design prevented extensive damage of the insulant.
Polystyrene 40 mm thick, with a 25 mm metal lath reinforced cementitious render on one side, fixed using polypropylene fixings to a masonry wall, no fire barrier	Distortion of the metal lath allowed extensive damage to the polystyrene and flaming around upper windows. Heavy render needs rigid fixing of reinforcement to avoid distortion.
Polystyrene 40 mm thick, with a 20 mm metal lath reinforced cementitious render on one side, fixed using polypropylene fixings and one metal pin fixing per square metre to a masonry wall, fire barrier comprising mineral at every second storey	Very limited degradation, the provision of rigid pin fixings prevented the distortion of reinforcement and the fire barrier restricted damage of the insulant.
A render of polystyrene bead in cementitious matrix 65 mm thick with polymer finish, no fire barrier	Minimal degradation, each new product/system needs to be assessed on an individual basis.
Polyisocyanurate 45 mm thick with a 0.5 mm flame retardant coating, sprayed on masonry wall	Rapid vertical fire spread self-sustained. Severe damage with pieces of flaming foam detached. Not suitable for dwellings.
Polyurethane board 35 mm thick with a 25 mm metal lath reinforced cementitious render on one side, and one metal pin fixing per square metre to a masonry wall, no fire barrier	The insulant decomposed only where the render was directly affected by fire, support of reinforced render was effective and barrier unnecessary
Glass fibre insulation 40 mm thick and breather membrane, polypropylene fixings to masonry wall, no fire barrier	No fire spread but deformation of reinforced render. Adequate support of heavy render needed even with non-combustible insulant.
Polystyrene 50 mm thick, clad with aluminium sheet 0.9 mm thick supported by horizontal aluminium box rails at 1.2 m intervals, no fire barrier	The cladding melted allowing polystyrene to burn in the cavity and drip from base of cladding. Process slowly self-sustaining. The aluminium sheet requires fire barriers in the cavity to limit the extent of fire spread.

Description	Performance and Comments
Polystyrene 50 mm thick, clad with aluminium sheet 0.9 mm thick supported by horizontal steel box rails at 1.2 m intervals, fire barrier comprising mineral fibreboard 50 mm thick at first floor level	The fire barrier resulted in delay in failure of the cladding long enough to prevent progressive spread. Damage less extensive than above.
Polystyrene 50 mm thick, clad with aluminium sheet 0.9 mm thick supported by timber battens at 1.2 m vertical centres and horizontally between windows, fire barrier comprising mineral fibreboard 50 mm thick at second floor level	Localised flaming in the cavity. Extent of flame spread limited by the fire barrier. Positioning of barriers at two floor intervals limits extent of vertical spread of flame.
Polystyrene 50 mm thick, clad with steel sheet 0.6 mm thick supported by horizontal angle iron rails at 1.2 m vertical centres, no fire barrier	Extensive damage to insulation in cavity. Isolated external flaming.
Polystyrene 50 mm thick, clad with reinforced calcium silicate panels 50 mm thick supported by vertical aluminium rails at 0.5 m centres, no fire barrier	Spalling of sheeting, active cavity fire, extensive damage to insulant.
Mineral wool 25 mm thick, air cavity and breather membrane, clad with 20 mm thick timber siding supported by vertical timber battens at 0.6 m centres, no fire barrier	Self-sustained flame spread over siding accelerating following penetration of the cavity.
Mineral wool 50 mm thick, clad with 0.9 mm thick aluminium sheet supported by horizontal aluminium rails at 1.2 m centres, no fire barrier	Melting of directly exposed cladding and distortion of rails.

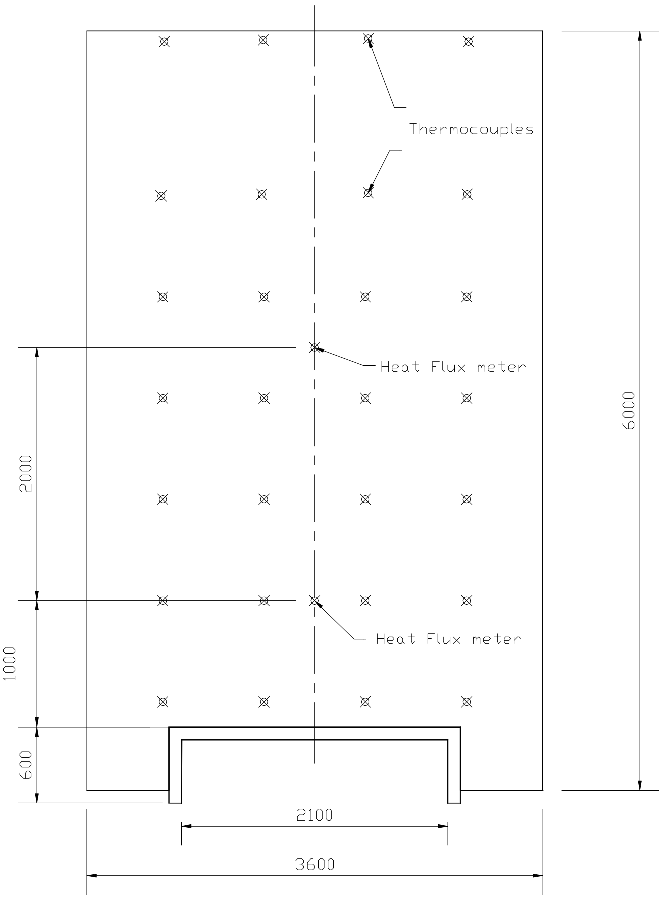

Figure 16: Front elevation full-scale cladding test rig (BRANZ).

9.2.4 Building Research Association of New Zealand (BRANZ)

BRANZ used a test facility (see Figure 16) consisting of a vertical wall of overall height 6 m and width 3.6 m to test four cladding materials. The main test face of the facility extended at least 5 m over the top of the opening 0.6 ±0.1 m (high) and 2.1 ±0.1 m (wide). The total heat flux at a location 1.0 ± 0.1 m above the opening on the centre line of the opening and in the plane of the facade of the system being tested was 70 ± 20 kW/m^2 over the period from 5 minutes to 15 minutes. The average value of total heat flux at the same location was intended to be 70 ± 5 kW/m^2 over the period from 5 minutes to 10 minutes. The heat source used was two fuel trays 1.0 m (length) by 0.25 m (width) and 0.1 m (depth) supported 0.1 m above the floor level and capable of holding approximate 40 l of liquid fuel. The liquid fuel was Pegasol AA by Mobil with a heat of combustion greater than 42 MJ/kg. The wall systems and their performance are described in Table 5.

Table 5: Wall claddings tested by BRANZ

Description	Performance and Comments
Cellulose fibre cement sheet, 7.5 mm thick	Flame spread did not occur, localised damage in the region directly exposed to the flame
Extruded foamed uPVC weatherboard with co-extruded UV protection uPVC exterior layer, rusticated profile	Flame spread reached top of specimen, extensive melting and damage to wall
Plywood, 5-ply radiata pine, rough sawn face containing a vertical grooved profile, 12 mm thick	Flame spread reached top of specimen
Reconstituted timber weatherboard manufactured from selected Australian hardwood, wood residues are incorporated into boards without synthetic resins	Flame spread reached top of specimen

9.2.5 Sweden – Lund University

Tests were carried out at Lund University (Ondrus, 1985) using a three-storey test building similar to that shown in Figure 10. The fire simulated a compartment fire with synthetic furnishings. This produces a thermal exposure of approximately 140 kW/m^2 on the facade and approximately 75 kW/m^2 on the second floor window and is equivalent to a fire load density of 110 MJ/m^2 (of total internal surface area), which is produced using a trough (0.5 m wide x 2.0 m long x 1 m deep) containing 60 litres of heptane. The test facility is constructed of aerated concrete and the system to be tested is attached to the front as it would be in practice.

This method comprises a façade specimen 4.18 m wide and 6 m high with an opening at the bottom edge of the specimen. The test specimen is mounted on a lightweight concrete structure. The test specimen includes two 50 mm deep indentations on the façade surface to represent (imaginary) window upper level openings. A heat flux meter is included at the centre of the second upper window. Thermocouples are also located at the top of the specimen and beneath a non-combustible eaves detail (Hermodsson and Månsson, 1992; Babrauskas, 1996).

The external insulation wall assemblies examined are described in Table 6.

Table 6: External insulation wall assemblies tested at Lund University

System No	Description
1.1	95 mm glass wool (22 kg/m^3) between horizontal and vertical wood studs 95 x 50 mm, asphalt felting fastened to the wood studs, profiled steel sheet 0.6 mm thick with PVF_2 lacquer finish
1.2	95 mm glass wool (40 kg/m^3) between horizontal and vertical wood studs 95 x 50 mm, wind-protective paper glued to mineral wool on fabric, profiled aluminium sheet 0.5 mm thick with metal lacquer finish
2.1	100 mm glass wool (60 kg/m^3), metal mesh 50 x 50 x 2 mm fastened with nails to aerated concrete façade through the glass wool, 30 mm thick layer of insulating plaster (EPS + cement) density 350 kg/m^3, 8 mm surface coating of cement mortar density 1800 kg/m^3
2.2	20 mm wooden wool (350 kg/m^3), 80 mm mineral wool (80 kg/m^3), metal mesh 25 x 25 x 1 mm (also in window splays) fastened to the wall by expander, angle and pin, 10 mm ground coating of cement mortar, 10 mm rude plaster and 8 mm surface coating of plaster
2.3	50-120 mm mineral wool (90 kg/m^3), special mobile expander for fastening of mineral wool and metal reinforcing mesh (4 expanders per m^2), metal reinforcing mesh 19 x 19 x 1.1 mm, 10 mm ground coating of cement mortar, surface coating of 15 mm cement coating and 7 mm light plaster
3.1	60 mm polyurethane foam (35 kg/m^3), fastened to the wall with cut nails and washers, glass fibre fabric 3.5 x 3.5 mm, 8 mm ground coating of plastic modified cement mortar (30% cement), 2 mm surface coating of synthetic resin with binding medium of vinyl, a gusset of steel at the upper edge of the windows
3.2	100 mm expanded polystyrene (20 kg/m^3), fastened to the wall by bolts, 19 x 19 x 1.05 mm metal reinforcing mesh fastened to the polystyrene (also in the window splays), 6 mm glass fibre reinforced cement mortar, coloured plaster
3.3	Adhesive mortar with organic agents, 100 mm expanded polystyrene (20 kg/m^3), glass fibre fabric 4 x 4 mm, 4 mm ground coating of adhesive mortar, 3-4 mm acrylic co-polymer surface coating
3.4	Adhesive mortar with organic agents, 60 mm expanded polystyrene (20 kg/m^3), glass fibre fabric 4 x 4 mm, 4 mm ground coating of adhesive mortar, 3-4 mm acrylic co-polymer surface coating
3.5	Adhesive mortar with organic agents, 60 mm expanded polystyrene (15 kg/m^3), glass fibre fabric 4 x 4 mm, 13 mm mineral light plaster with filling of Perlit (expanded volcanic material)
3.6	60 mm polyurethane foam (35 kg/m^3), fastened to the wall with plug nails and washers, 2 mm ground coating of cement mortar with 5% acrylic co-polymer, glass fibre fabric 4 x 4 mm, 3 + 3 mm layers of mortar, 2 mm surface coating (as per ground coating), a gusset of steel at the upper edge of the windows
3.7	80 mm extruded polystyrene (32 kg/m^3), anchor pins of metal and plastic, 19 x 19 x 1.05 mm metal reinforcing mesh fastened to the polystyrene by angle nails, 7 mm glass fibre reinforced cement mortar, coloured plaster, 200 mm thick strips of mineral wool were applied on framing of joists
3.8	55 mm polyurethane foam (30-35 kg/m^3), fastened to the wall by a combination of adhesive and plastic plugs, 6 mm ground coating of vinyl co-polymer with 30% cement, glass fibre fabric 4 x 4 mm coated with 45% PVC, 2 mm decorating synthetic resin of vinyl (no cement), a gusset of steel at the upper edge of the window

Performance in the full-scale tests were evaluated according to three criteria.

1. No collapse of major sections of the external additional thermal insulation system.

2. The surface spread of flame (a) and the fire spread within the insulation (b) should be limited to the bottom part of the window on the 3rd floor. External flame which can ignite eaves is not permissible.

3. There must be no spread of fire to the 2nd floor through windows – deemed to be verified if the total heat flow toward the centre of windows was ≤ 80 kW/m^2.

Only systems 1.2, 2.1, 2.2, 2.3 and 3.6 passed all the test criteria. None of the systems containing polystyrene passed the test criteria.

Table 7: Lund University - Results

System No	Criterion 1 (collapse)	Criterion 2 (a) (surface spread)	Criterion 2 (b) (spread within insulation)	Criterion 3 (heat flux)
1.1	failed	failed	passed	failed
1.2	passed	passed	passed	passed
2.1	passed	passed	passed	passed
2.2	passed	passed	passed	passed
2.3	passed	passed	passed	passed
3.1	passed	passed	passed	failed
3.2	passed	passed	passed	failed
3.3	failed	failed	failed	failed
3.4	failed	failed	failed	failed
3.5	passed	passed	passed	failed
3.6	passed	passed	passed	passed
3.7	passed	passed	passed	failed
3.8	failed	passed	failed	failed
wood panel facing	failed	failed	failed	failed

9.2.6 Modified Swedish Façade Test

The SP 105 test method was slightly modified by adding a re-entrant corner, 1 m wide, and mounted at the edge of the straight façade segment – its face was located 0.59 m from the edge of the opening (Babrauskas, 1996). The façade test rig was also situated underneath a large-scale products calorimeter allowing the heat release rate and other properties, such as production of smoke to be quantified. Three different EIFS specimens and a control were tested. Each of the three specimens were identical except for the type of insulation material.

The insulation material was fixed to the concrete substrate using a mineral type plaster. The reinforcing net was trowelled onto the surface on the insulation at an application density of 3 kg/m^2; the same plaster was used to adhere the insulation to the substrate. A surface plaster coat was sprayed onto the surface at a density of 3-3.5 kg/m^2 with a total thickness of 8 mm. The insulation material was 80 mm thick. The three types of insulation used were rock wool, EPS and PUR. Performance in the full-scale tests were evaluated according to three criteria.

1. Flame spread and fire damage may not reach above the bottom of the second storey window.

2. Large pieces of the façade may not fall down during the test.

3. The temperatures at the eaves may not exceed 500°C for more than 120 seconds or 450°C for more than 600 seconds. The heat flux meter readings may not exceed 80 kW/m^2 (for hospital occupancies only).

The performance of the wall assemblies is shown in Table 8.

Table 8: Performance in modified Swedish façade test

	Maximum Window Heat Flux (kW/m2)	Maximum Eaves Temp (C)	Maximum Damage
F0 – blank/control	43	260	None
F1 – rock wool	42	292	None
F2 – EPS	26	382	Top of 3rd storey window
F3 – PUR	60	299	Bottom of 3rd storey window

All the assemblies met the criteria for heat flux and eaves temperature, but specimens F2 and F3 did not meet the maximum damage criteria. The same cladding materials were also tested to CAN/ULC-S135 (ULC, 1992b) with some results given in Table 9. The ranking of the products is the same as for the full-scale test (from best to worse – F1, F3, F2).

Table 9: Performance in CAN/ULC-S135

	F1 Rock Wool	F2 EPS	F3 PUR
Peak HRR (kW/m2)	13	154	71
Total HR (MJ/m2)	4.0	27.9	25.0
Ignition Time (sec)	-	248	176

9.2.7 NFPA 285 – SWRI Multi-storey Apparatus

NFPA 285 is a standard method of test for the evaluation of flammability characteristics of exterior non-load-bearing wall assemblies containing combustible components using the intermediate-scale, multi-storey test apparatus (NFPA, 1998).

The performance is evaluated by:

- The capability of the test wall assembly to resist vertical spread of flame over the exterior face of the system.

- The capability of the test wall assembly to resist vertical spread of flame within the combustible core/component of the panel from one storey to the next.

- The capability of the test wall assembly to resist vertical spread of flame over the interior surface of the panel from one storey to the next.

- The capability of the test wall assembly to resist lateral spread of flame from the compartment of fire origin to adjacent spaces.

This test comprises a two-storey test structure having overall dimensions 4.6 m high by 4.1 m wide. Each room has dimensions 3.05 m by 3.05 m with a floor to ceiling height of 2.13 m. There is a simulated window opening in the lower storey 760 mm high by 1981 mm wide and sill height of 760 mm. The test wall assembly is required to measure at least 5.33 m high by 4.06 m wide.

The performance of the test wall assembly is judged on the basis of visual observations in conjunction with temperature data.

A predecessor of this method is the multi-storey apparatus at the South West Research Institute. Beitel and Evans (1980) reported on a multi-storey fire evaluation program using this apparatus and give results for several external wall systems.

Six full-scale tests on exterior wall systems were as described in Table 10. The overall objective was to evaluate the performance characteristics of foamed plastics insulated non-loadbearing wall systems.

Table 10: Wall systems tested using the SWRI multi-storey apparatus

System No	Description
A	Timber frame stud wall 100 x 50 mm, with 3 layers of 5/8” Type X gypsum wallboard on the fire side and 2 layers of 5/8” Type X gypsum wallboard on the non fire side
B	Steel panels (22g) insulated with 112 mm of glass fibre
C	Steel panels (22g) insulated with 50 mm of urethane foam, and a thermal barrier consisting of one layer of 12.5 mm Type X gypsum wallboard on the interior side
D	Steel panels (22g) insulated with 50 mm of urethane foam, no thermal barrier (Manufacturer A)
E	Steel panels (22g) insulated with 50 mm of urethane foam, no thermal barrier (Manufacturer B)
F	Steel stud, 12.5 mm regular gypsum wallboard inside, exterior grade gypsum wallboard on the outside, 100 mm polystyrene external insulation system (Manufacturer C)

Conclusions from the tests were:

- The wood crib fire source adequately produced a fire intensity similar to the ASTM E119 time temperature conditions for a period of 30 minutes.

- In all tests there was no flame penetration into the second storey during the 30-minute test period.

- In all tests there was total destruction of the core insulation to an elevation of about 12 feet.
- In all tests there was heat damage to the core insulation above the second floor line on the wall with the window opening.
- In all tests there was no significant flame propagation over the exterior face of the panels.

9.2.8 University of Karlsruhe, Germany – EIFS Tests

Two full-scale fire tests were performed in 1987 on a two–storey rig with an internal corner and an external corner. Two EIFS systems were tested, foam and mineral based to assess differences in fire behaviour (Christensen, 1995). The façade had two window openings. A room (5.1 m x 4.1 m) was behind the lower opening and included a total of 627.3 kg of wood (30 kg/m^2) in the form of twelve pine cribs situated in front of the window. The upper window contained a complete wood framed window with triple glazing, and a set of cotton curtains on the inside as indicators of fire spread into the room.

The foam□based system included expanded polystyrene 80 mm thick and density 15 kg/m^3 applied to the wall with an adhesive mortar and eight plastic fasteners per m^2. The reinforcing coat was 4 mm thick with a glass fibre reinforcing fabric. The top coat was a 2 mm thick synthetic resin. The mineral based system was the same except that rockwool slab 80 mm thick and density 150 kg/m^3 was used instead of the polystyrene. The glass fibre reinforcing mesh was not returned around the edge of the insulation to the rear face at the openings for the windows, but finished at the exterior edge hidden by timber window trim. Test observations from Christensen (1995) are given in Table 11.

9.3 Performance of Claddings in Small-Scale Tests

9.3.1 Combustibility AS 1530.1 / ISO 1182

The combustibility test, AS 1530 Part 1 (SA, 1984) and its equivalents throughout the world (eg BSI, 1970; ISO, 1990a; ASTM, 1982), is the general method for determining combustibility of building materials. It involves placing a small specimen into a furnace at 750ºC and measuring differential temperature rises in the furnace, and on the specimen, and recording the duration of any sustained flaming. If the temperature exceeds that of the furnace by more than a small amount, then the sample fails because combustion was required to produce the temperature rise (Clarke, 1997).

This type of test was developed over 50 years ago and has shortcomings. It was intended for homogenous materials, not products that are faced, coated or laminated. When the test was originally developed it was also intended that materials with up to about 3% of organic content would be able to pass the test. The range of materials passing the test is relatively restricted but would include concrete, brick, steel, aluminium and mineral fibre insulation.

The sole use of the combustibility test to determine the acceptability of external claddings, while safely conservative, would be overly restrictive on many wall assemblies that are shown to be satisfactory in full-scale façade testing representative of the end-use installation of the material or assembly.

Table 11: Test observations - EIFS systems

Foam-based System	
6-12 min	The impact of the flames from the fire room starts spoiling the window reveal; melted foam insulation starts to burn.
12-20 min	The area between the two windows starts burning. Melted foam insulation increases the fire’s intensity. The glass in the upper window starts cracking.
20-23 min	The fire expands to the left and right side of the window. The render starts burning and falling to the ground. The wooden window frame in the upper window ignites and glass begins falling from the upper window.
23-28 min	The fire expands to the internal corner. Major areas of render fall down. The façade fire increases in intensity. The fire breaks through the upper window and ignites the curtains.
28-33 min	All render and insulation on the façade and the internal corner have now fallen down and burned. Only the external corner is in intact.
Mineral□based system	
6-10 min	Minor discoloration of render between the two windows is visible.
10-20 min	Discoloration of the render continues. The outer layer of the glass in the upper window cracks, but does not fall from the window.
20-25 min	Fire intensity is diminishing.
25-33 min	A crack occurs in the render between the two windows.

9.3.2 Early Fire Hazard AS 1530.3

AS 1530 Part 3 (SA, 1999) exposes a vertical specimen to a gradually increasing heat flux up to a maximum of about 25 kW/m^2, by moving the specimen closer to a radiant panel over a period of 20 minutes. The heat flux level and the gradual heating conditions may be considered not severe enough to be representative of a window fire plume. This is supported in research by Oleszkiewicz (1990a), who found the radiant heat flux on an exterior wall from fire venting through a window typically ranges from 30 to 60 kW/m^2 for fire sizes in the compartment of up 8 MW.

Dowling and Martin (1985) tested the sandwich panel systems shown in Table 12 to AS 1530 Part 3, 1976. The results are given in Table 13.

Table 12: Sandwich panel systems – Description

System No	Core	Adhesive	Facings	Description
SP1a	Polystyrene 50 mm thick, 14 kg/m^3	Polyurethane	Galvanised steel 0.64 mm thick	Edged with channelling
SP1c	Polystyrene 50 mm thick, 14 kg/m^3	Polyurethane	Galvanised steel 0.64 mm thick	Unedged
SP1d	Polystyrene 50 mm thick, 14 kg/m^3	Polyurethane	Galvanised steel 0.64 mm thick	Unedged and clamped to the specimen holder by the back facing only

System No	Core	Adhesive	Facings	Description
SP1e	Polystyrene 50 mm thick, 14 kg/m^3	Polyurethane	Galvanised steel 0.64 mm thick	Damaged panel simulated by having the front facing peeled off to expose a surface of polystyrene foam and adhesive. Approximately 40% of the exposed foam was coated with adhesive. The remaining 60% comprised a rough surface of polystyrene foam, where part of the foam had been removed with the facing
SP2	Polyurethane 45 mm thick, 50 kg/m^3	Foamed in place	Fibre reinforced cement, 6.4 mm thick on the exposed face, 4.8 mm thick on the unexposed face	Unedged

Table 13: Sandwich panel systems – Results

System No	Ignitability Index	Spread of Flame Index	Heat Evolved Index	Smoke Developed Index
SP1a	0	0	0	3
SP1c	0	0	0	1
SP1d	12	9	8	8
SP1e	13	9	3	6
SP2	9	0	1	6

Table 14: AS1530.3 Results for various external claddings

System	Ignitability Index	Spread of Flame Index	Heat Evolved Index	Smoke Developed Index
cellulose fibre-cement sheet	0	0	0	0
foamed uPVC weatherboard	0	not given	not given	not given
galvanised powder-coated steel	0	0	4	0
EIFS	13	0	3	4
aluminium weatherboard	0	not given	not given	not given
EIFS	0	0	0	0

The AS 1530.3 test for regulating fire properties of external cladding has been used in New Zealand (specifically Ignitability Index) but this is not desirable. For example, the foamed uPVC weatherboard achieved an Ignitability Index of 0 (the best possible result) yet in full-scale testing by BRANZ, flame and fire spread propagated to the top of the test specimen (see Table 5). The results obtained for some proprietary systems are given in Table 14.

Schafer and McKechnie (1995) tested EIFS specimens, to AS1530.3-1989, comprising:

- A base of 600 x 450 x 5 mm compressed cement sheeting.
- 40 mm thick expanded polystyrene (S grade to AS 1366.1-1981) density 17 kg/m^3.
- A base coat of Portland cement, lime, sand and acrylic, reinforced with 160 g/m^2 woven coated E glass mat, total thickness about 2 mm.
- A textured finish comprising Portland cement, lime, sand, pigment and acrylics, total thickness about 1.5 mm.

The result achieved was:

Ignitability Index	0
Spread of Flame Index	0
Heat Evolved Index	0
Smoke Developed Index	0-1

The same result was obtained for the same textured finish applied directly to the compressed cement sheeting.

The same systems were also tested to ASTM E1354-90 Cone Calorimeter at an external heat flux of 50 kW/m^2 with no ignition occurring. With an external heat flux of 75 kW/m^2, there were two ignitions. The first at around 80 seconds and lasting for 165 seconds and the second at 1150 seconds which lasted for 650 seconds. The first ignition appeared to originate from the acrylics in the encapsulating mortar and finishing coat, while the second ignition was more indicative of the combustion of the polystyrene. The measured peak heat release rate was only 60 kW/m^2.

9.3.3 Bomb Calorimeter ISO 1716

The ISO 1716 test method (ISO, 1990b) determines the gross calorific potential under constant volume. The apparatus consists of a calorimetric bomb, calorimeter (jacket, vessel, stirrer), ignition source and temperature measuring device. The gross calorific potential is calculated on the basis of the measured temperature rise in the test. While this test has some of the same limitations as the combustibility test (not intended for composites, and not representative of end-use installation), it has the advantage of not being a pass/fail test. The results of this test can be related to the non-combustibility classification because about 3% of combustible material corresponds to 1500-2000 kJ/kg. The maximum gross calorific potential could therefore be set at a level somewhat greater than this, to encompass the traditional non-combustible materials and also others that are commonly accepted as not contributing significantly to a fire (eg cellulose fibre cement sheet, paper-faced plasterboard).

9.3.4 Building Research Association of New Zealand (BRANZ) – Cone Calorimeter

BRANZ developed an external cladding classification scheme based on cone calorimeter testing at 50 kW/m^2. Systems which achieve a peak heat release rate of ≤100 kW/m^2 and a total heat release in 15 minutes from the start of the test of ≤25 MJ/m^2 were proposed as acceptable for unrestricted use as an external cladding material/system. This level of performance was related to a theoretical model of propagating flame spread which suggests that flame will not be continuously propagated over the surface of a material (Cowles and Soja, 1999). This assumed an idealised behaviour of the cladding with a rate of heat release curve reaching a peak shortly after ignition and then showing an exponential decay as shown in Figure 17. This behaviour may not be applicable for all cladding systems. Also, for aluminium composite panel systems, the heating conditions in the small-scale test are often insufficient to cause the aluminium to melt and thus expose combustible materials beneath, as often occurs in the full-scale testing. The analytical flame spread solution is represented in a graphical form (from Karlsson, 1992) with a range of cladding materials superimposed on the graph (see Figure 18). Claddings which achieve a peak heat release rate of ≤ 100 kW/m^2, as shown by the vertical dashed line, also fall into the areas where upward propagation of flame is not expected for an imposed heat flux of 50 kW/m^2. The same level of performance was also proposed by Forintek Canada Corp as being suitable for “certain products which are permitted for use in non-combustible buildings as claddings and room lining materials” in the National Building Code of Canada (Babrauskas, 1991).

Table 15 gives the results of cone calorimeter tests (peak rate of heat release and total heat release in 15 minutes from the test start) undertaken by either BRANZ or WorkCover Authority, NSW as part of BRANZ research (Wade, 1995; Cowles and Soja, 1999).

Table 15: Cone calorimeter results for claddings from BRANZ research

Cladding Material / Description	Heat Flux Exposure (kW/m^2)	Peak Rate of Heat Release (kW/m^2)	Total Heat Release in 15 Minutes From Start of Test (MJ/m^2)
Proprietary external insulation and finish system with polystyrene board covered with a Portland cement-based plaster, reinforced with fibreglass mesh and finished with two coats of acrylic paint	50	88	4
Plaster coating, 21 mm thick applied to fibre–cement substrate, fibreglass mesh, finishing plaster and two coats of acrylic paint	50 75	76 110	6 10
Proprietary cellulose fibre-cement board, 6.5 mm thick, finished with two coats brown acrylic paint	50 75	58 84	5 7
Proprietary compressed cellulose fibre-cement sheet, 9 mm thick, 1890 kg/m^3, pre-finished with primer coat and a two part polyurethane top coat (white)	50	54	8

Cladding Material / Description	Heat Flux Exposure (kW/m^2)	Peak Rate of Heat Release (kW/m^2)	Total Heat Release in 15 Minutes From Start of Test (MJ/m^2)
Proprietary low density Portland cement plaster containing polystyrene bead aggregate, finished with 2 mm plaster and two coats acrylic paint	50	123	16
Radiata pine treated with copper-chrome-arsenic (CCA) to H3, finished with an intumescent paint and acrylic paint top coat, 19 mm thick, colour white	50	130	45
Proprietary extruded twin wall uPVC weatherboard, 13 mm thick, white	50	174	26
Proprietary foamed cellular uPVC weatherboard, 6 mm thick, white	50	178	44
Radiata pine treated with copper-chrome-arsenic (CCA) to H3, 19 mm thick, unfinished	50	214	82
Radiata pine-treated with copper-chrome-arsenic (CCA) to H3, 19 mm thick, finished with oil-based stain, colour cedar	50	253	109
Radiata pine treated with copper-chrome-arsenic (CCA) to H3, 19 mm thick, finished with three coat acrylic paint system, colour brown	50	345	91
Proprietary cellulose fibre-cement board covered with a skim coat of cementitious plaster and a polymer modified cement based plaster with acrylic paint finish	50	51	6
Plywood, 12 mm thick, phenol formaldehyde bonded Radiata pine veneers, treated with copper-chrome-arsenic (CCA) to H3	50 75	197 278	66 79
Hardboard shiplap cladding, 9.4 mm thick, two coats brown acrylic paint	50 75	325 300	93 111
Metal coil coated galvanised steel sheet, oven□ dried finishing paint coat, colour titania	50	0	0
Proprietary external insulation and finish system	50	295	~12
Proprietary external insulation and finish system	50	165	~12
Proprietary paper-faced plasterboard 10 mm thick	50	76	3
Aluminium weatherboard 14 mm thick, powder coated white	50	98	3

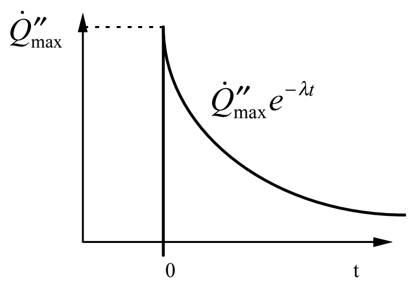

Figure 17: Idealised rate of heat release behaviour in cone calorimeter.

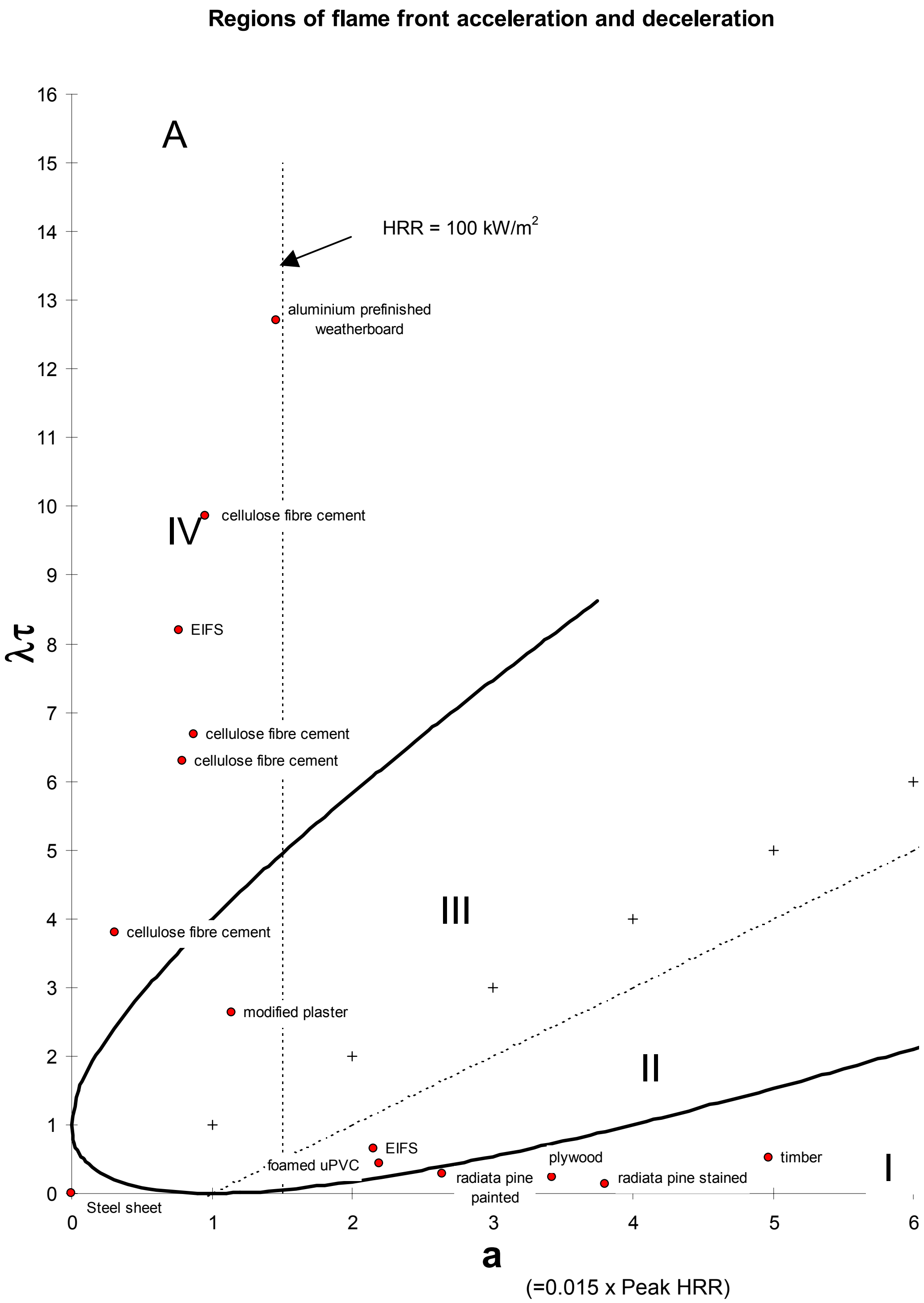

Figure 18: Graphical solution for analytical flame spread.

Region I Below the line $\lambda\tau = (1-\sqrt{a})^2$ materials will normally exhibit **exponentially accelerating flame spread** characteristics.

In **Region II** the flame exhibits **initial accelerating** but then decelerates and stops at a finite time.

For **Region III** the solution to the equation shows an **initial deceleration**. There is no acceleration until the velocity has been negative for some time.

Materials in **Region IV** exhibit flame spread velocities that **decelerate for all time**.

9.4 DISCUSSION

9.4.1 Full-Scale Tests

Heat flux exposure to the façade varies from method to method. Testing at Lund University used up to 140 kW/m^2, BRE used at least 90 kW/m^2 at 1.0 m above the opening and the National Research Council of Canada used about 50 kW/m^2 at 0.5 m above the opening (large scale and Vertical Channel Test). A strong heat flux gradient is likely to exist in the vicinity of the opening lintel, so the actual heat flux experienced by the façade just above the lintel will be greater than the specified values at the location of the heat flux meters.

ISO TC92 is currently developing test methods for the evaluation of façade assemblies. After examining a range of methods, the ISO task group narrowed their interest to three proposals from Germany (DIN 4102 Part A point 4.3), Canada (ULC, 1992a) and Sweden (SP 105). The similarity between the German and Canadian proposal led them to develop a joint proposal to quantify the contribution from a façade assembly to cause fire spread to two floors above the floor of origin (Sumathipala and Kotthoff, 1997). The current draft test method is ISO 13785 (ISO, 1999d).

The ISO 13785 Part 2 (draft) full-scale test for facades consists of a combustion chamber with volume in the range 20-100 m^3 with an opening in the front wall (2 m wide by 1.2 m high). The height of the test facility is 4 m above the window opening, with a main façade 3 m wide. A vertically held wing façade, 1.2 m wide, is also required to form a re-entrant angle of 90º. Any fuel can be used to produce a window flame which exposes the test specimen to a heat flux of 55 kW/m^2 at a height of 0.5 m above the opening, and 35 kW/m^2 at a height of 1.5 m above the top opening. Heat fluxes are measured 3.5 m above the top of the window opening, and thermocouples are installed at the top of the test specimen and at the top of the window opening. Evaluation or performance criteria are not included in the Standard.

This new test method appears to be the most appropriate one for future reference as providing a satisfactory representation of the performance of facades in their end-use situation. Because it is similar to the original Canadian full-scale test with respect to heat exposure levels, it is likely that the Vertical Channel Test would still provide a reasonable correlation with the results of the ISO draft method (subject to similar/compatible acceptance criteria).

Full scale facade fire tests are expensive and therefore should only be mandated under Building Codes if there is no reasonable alternative (from a technical, practical and economic perspective). It appears the Vertical Channel Test could be a suitable alternative.

9.4.2 Small-Scale Tests

Small-scale fire tests are not the most appropriate means for evaluating fire performance of claddings, and should only be considered if the general use of a larger-scale test is considered unsatisfactory by the regulatory authorities for economic reasons.

Of the available small-scale tests, the cone calorimeter AS/NZS 3837 (SA, 1998) appears to be the most appropriate, and may also be used in conjunction with full-scale tests for assessing the effect of minor variations to the composition or surface texture or geometry of a cladding system.

10. OPTIONS FOR REGULATORY CONTROL

10.1 General

BCA performance requirements require consideration of life safety, fire brigade intervention and property protection as expressed in functional statement CF2.

CF2 A building is to be provided with safeguards to prevent fire spread-

(a) so that occupants have time to evacuate safely without being overcome by the effects of fire; and
(b) to allow for *fire brigade* intervention; and
(c) to *sole-occupancy units* providing sleeping accommodation; and
(d) to adjoining *fire compartments;* and
(e) between buildings.

In addition to providing for life safety and fire brigade intervention, CF2 infers a requirement to limit fire spread from floor to floor where each floor is a fire compartment (or sole-occupancy unit), and to prevent spread to other buildings.

Realistic controls on the flammability of a cladding material alone will not necessarily prevent fire spread to the floor (or fire compartment) above as this will still most likely occur with a non-combustible cladding if unprotected openings in the exterior wall are present. It is therefore also necessary to make use of other design features such as sprinklers, spandrel walls or horizontal projections to fully achieve this objective. However, it was previously shown that spandrel walls are the least effective of these and the height of the spandrel wall required to prevent spread (2.5 m +) is not normally considered to be a practical option.

The highest risk of fire spread via the façade appears to be in those buildings which are unsprinklered (below 25 m), but that are sufficiently high (or alternatively have poor fire fighting accessibility) to make external fire-fighting efforts ineffective. This would particularly relate to unsprinklered buildings in the height range of say, 10-25 m (i.e. more than three floors).

History shows that there is no apparent record of façade spread in fully sprinklered buildings, but "history" has also required extensive use of non-combustible claddings and we need to now be able to allow for the development and use of new technology and materials. Nonetheless, it is unlikely that façade spread would occur due to a fire within a fully sprinklered building. The major risk for a sprinklered building would be from a fire originating from the exterior of the building (e.g. arson, rubbish hops, bushfires). Should an exterior fire occur there is potential for spread via the façade, allowing fire entry at multiple floor levels and possibly compromising the sprinkler system due to an excessive number of heads operating. Therefore, there should still be some limitations on the flammability of facades in a tall sprinklered building for achievement of life safety goals. A possible exception here could be where an external wall-wetting system was installed, if it could be shown that such a wall wetting system would be able to control a fire on the particular facade. This option is probably best left to be dealt with case by case as an Alternative Solution, rather than unnecessarily complicating a Deemed to Satisfy Solution.

A façade fire has the potential to increase the exposure hazard to a neighbouring building, mainly as a result of an increase in the 'area of the radiator' comprising the unprotected part of the external wall (e.g. opening) and any projecting flame from that opening. Provided controls (e.g. VCT test requirement) were put in place to prevent uncontrollable vertical fire spread, it seems unlikely that the additional radiation from a façade fire would be significant enough to require consequential change to the general requirements for building separation in the BCA, bearing in mind the assumptions and uncertainties associated with existing design procedures for determining safe separation distances between buildings.

Exposure of combustible cladding to a fire source feature (e.g. exposure due to fire in an adjacent building) is also unlikely to be a governing consideration for vertical fire spread as the expected received heat fluxes on the cladding due to a fire source feature are likely to be less than that produced by a external window fire plume in the region of the lintel. Thus addressing the vertical fire spread problem due to a window plume is likely to also deal with vertical fire spread resulting from an ignition due to an adjacent fire source feature.

10.2 Smoke Generation

BCA performance requirement CP4 requires a material or assembly to resist the spread of fire to limit the generation of smoke and heat, and any toxic gases likely to be produced. It is not considered necessary to consider and quantify the production of smoke and toxic gases for exterior cladding materials separately from the spread of fire because:

- limiting the extent of flame spread will indirectly influence the amount of heat generated (released) and the overall smoke production rate is directly related to the burning rate; and
- smoke release from external cladding materials is primarily on the outside face of the building, and is dissipated to atmosp 2Te relatively quickly and therefore does not present the same potential degree of hazard to occupants compared to smoke produced within the building from interior linings.

10.3 Options for Regulation

10.3.1 Combustible Claddings – Option A

The existing Deemed to Satisfy appears sufficiently conservative, that its continued use is unlikely to result in unsuitable materials on facades. Thus changes (if desired) to the Deemed to Satisfy provisions are not urgently required but can be implemented in a timely and well considered way. The first option is to keep the existing Deemed to Satisfy solution and allow the use of combustible facades on a case by case basis using the Alternative Solution provisions, and provide guidance on how the suitability of combustible cladding may be best determined. The main disadvantage of this would be inconsistent evaluations by designers and approving authorities. Also if guidance is to be provided, why not take the next step and incorporate it within the Deemed to Satisfy solution?

10.3.2 Combustible Claddings – Option B

Our recommended option prescribes a method of test for the evaluation of the flame spread propensity of facades being the ‘Vertical Channel Test’. While technically it is not considered superior to a larger-scale test, for regulatory purposes it offers the main advantages of:

1. Results appear to correlate well with a representative large-scale test;
2. Less expense for the manufacturers;
3. Less expensive set up costs for laboratories;
4. Faster erection/construction time for test specimens; and
5. Simpler instrumentation.

The main disadvantage is that international standards development is currently focusing on the large full-scale test methods, and if the Vertical Channel Test is adopted in Australia, the results may not necessarily be acceptable within other countries. However, approving authorities in Australia should be encouraged to view results from larger-scale tests (e.g. ISO 13785) favourably as an Alternative Solution to the Vertical Channel Test (or any other test method) since the ISO method is of larger scale and simulates a realistic end-use situation. Also if the Vertical Channel Test is adopted, further work is required to develop and process the current draft test method into a suitable form for referencing by the BCA (e.g. an Australian Standard).

It is suggested that the acceptance criteria for the Vertical Channel Test remain the same as that proposed by the Canadians. This restricts the flame spread distance to no greater than 5 m above the bottom of the test specimen, and limits the heat flux at a distance of 3.5 m above the bottom of the specimen to 35 kW/m^2. This level of performance would indicate that fire spread into the upper floor levels via the façade from a projecting window plume and burning façade will be tolerated for two levels above the fire floor, with the probability of spread three levels above being relatively low. It should be noted that even with a non-combustible façade, fire spread into the floor directly above is likely from the fire plume fed by building contents, and spread two floors above is certainly possible. Thus the 5 m flame spread limit seems to be a realistic criteria where combustible façade materials are used.

A consequence of this performance level is that there is little benefit in applying the test to facades of buildings three storeys or less, as its application is unlikely to prevent fire spread to the upper floors of the building. It also follows that for these low-rise buildings evacuation times are generally less and fire-fighting efforts are more efficient due to the height of the building, so that the hazard of vertical fire spread via the façade is likely to be sufficiently low that regulatory control (in excess of the minimum AS 1530.3 indices) seems unnecessary.

Since buildings of more than three floors are generally always classified Type A construction under the BCA, it would be appropriate for buildings of Type A construction to be required to have cladding materials which are either non-combustible or satisfy the requirements of the ‘Vertical Channel Test’.

If this recommendation were adopted, Specification C1.10, Clause 2.4 a) item iii) could be removed from the Deemed to Satisfy and replaced with the more appropriate and measurable test requirement. It should also be clearly understood that the Vertical

Channel Test is intended only for evaluating the surface flammability characteristics of combustible claddings and exterior wall assemblies. It is not a test suitable for investigating the performance of curtain walls, the stability of sandwich panels or the adequacy of floor/walls connections. There is currently no test method that purports to address all these issues in a single test, and if such a test could be developed it would by necessity need to be of large scale, complex in construction and instrumentation, and expensive to construct and operate. At this time, it is recommended that a narrower focus be adopted in selecting a new test method and performance criteria.

The test specimen should be a representative of the entire external wall construction, so that the results are not unduly influenced by cooling on the rear face of a surface cladding material. A copy of the proposed test method (as prepared in draft form by the ASTM Task Group E5.22.07 in 1992) is included as Appendix A.

Our recommendation is in favour of Option B.

10.3.3 Combustible Claddings - Option C

A third option is to maintain linkages to ISO and adopt the full-scale façade test currently under development. This option would reduce trade barriers and retesting requirements when importing/exporting manufacturing systems. The test method is arguably superior to the Vertical Channel Test (although that is not to say that the Vertical Channel Test is inadequate). The main disadvantages would be more expensive product development costs for manufacturers as the testing required would be more complex, time-consuming and expensive compared to the Vertical Channel Test. Therefore more opposition from local manufacturers might be expected. It will also be necessary to wait for the completion and publication of the test method.

10.3.4 Metal Clad Sandwich Panels

The existing deemed to satisfy requirements of Specification C1.10 Clause 2 d) are targeted at sandwich panel construction, requiring a combination of AS1530.3 and AS1530.4 fire tests to demonstrate the adequacy of a composite member or assembly. While recent activity in ISO is toward the development of full-scale room tests where the room is constructed from the panel assembly concerned, it is not clear that the existing building code requirements are entirely unsatisfactory. Full-scale testing of the type being considered by ISO will be considerably more expensive than the existing requirements, and regulatory authorities in Australia will need to be satisfied that the benefits of more realistic end-use testing over current requirements are sufficiently high to warrant any change. Unsatisfactory performance of sandwich panels in real fires is often a result of poor detailing of joints and inappropriate use of materials. Education and guidance to manufacturers and designers regarding appropriate design may suffice in the short term.

10.3.5 Aprons, Spandrel Panels and Curtain Wall Construction

In Type A construction, where requirements for vertical separation of openings are given, consideration should be given to removal of the requirement for 900 mm high spandrels in favour of horizontal projections or sprinkler protection. This action is likely to be unpopular with building owners, designers and developers who may resist the additional expense of a sprinkler system or dislike the aesthetic or site coverage implications of using horizontal projections in situations where previously spandrel panels would have been specified. Furthermore, horizontal projections can also lead to more rapid material degradation with the ponding of rain and pollutants, and provide resting places for birds.

Assuming horizontal projections are incompatible with curtain wall construction leads to the conclusion that sprinkler systems or the use of fire resistant glazing are the only really effective means of preventing vertical fire spread via the curtain wall, although testing by the Loss Prevention Council indicated that the use of external and internal wall-wetting systems would serve to significantly delay the rate of upward fire spread. At this time, new regulatory testing regimes for curtain wall construction are not proposed.

11. CONCLUSIONS

11.1 The Historical Fire Record

There are relatively few documented cases of extensive external vertical fire spread involving combustible claddings, and there are even fewer cases where such spread has significantly compromised life safety. Part of the reason for this could be due to the historical use of non-combustible materials on facades as is required by many building codes around the world, so the small number of documented examples should not be taken to mean combustible claddings present insignificant risk. Furthermore, there have been a number of very serious examples of external vertical fire spread where combustible cladding has not been involved, but where window configurations and combustible linings and contents located near windows have contributed significantly to 'leap-frogging' up the external façade.

Façade fires do not generally directly threaten building occupants but the concern is that fire spread through the openings into upper levels may result in secondary fires which can threaten occupants.

A search of the published literature undertaken for this project revealed no available record of external vertical fire spread in fully sprinklered protected buildings.

11.2 Combustible Facades (including EIFS)

Fires should not be permitted to show excessive upward propagation on claddings or facades in order that fire does not spread into upper floor levels and reach heights such that external fire-fighting becomes ineffective or impossible. Traditionally this has been achieved by requiring the use of non-combustible materials for claddings and within external wall construction. However, this precludes the use of other materials and composites which may have significant advantages (such as energy conservation). Therefore appropriate alternative methods of test and evaluation procedures are required.

Full-scale tests are able to evaluate the performance of combustible cladding systems in a manner that is representative of the end-use installation. Bench-scale tests such as the cone calorimeter, while useful for investigating the potential for ignition and flame spread over cladding materials, are not able to evaluate performance of jointing and fixing methods. However, it may be possible to use a bench-scale test (in the same manner of the existing combustibility test) such that all materials/components of an external wall cladding system are separately evaluated or as a screening device supplementing larger-scale test information.

The alternative is to use a full-scale test to assess performance with the leading candidate test being ISO 13785 Part 2 (which is still in development by ISO). Another option for a simpler and significantly less expensive reduced-scale method, which may be more attractive from a building regulation perspective, is the Vertical Channel Test developed by the National Research Council of Canada and which has been shown to provide good correlation with the larger full-scale Canadian test method. Both these methods are worthy of more detailed consideration.

It is concluded that:

- The ISO 13785 Part 2 (draft) full-scale test for facades is an appropriate end-use evaluation test of external claddings. The performance criteria need to be confirmed as part of the Standard, or alternatively the criteria used in the Canadian full-scale test might be used (flame does not spread more than 5 m above the bottom of the specimen, and the heat flux density at a height 3.5 m above the top window opening does not exceed 35 kW/m^2). Publication of the ISO standard is required before referencing of the document in regulations can be done.

- The less expensive and less complex Vertical Channel Test method should be used for regulatory use (on the basis that satisfactory correlation with a larger-scale test exists). This requires the ASTM task group draft test method be developed into an Australian Standard or other document able to be referenced by the Building Code of Australia. The same performance criteria as proposed by the ASTM task group should be adopted (maximum flame spread distance of 5 m, and a maximum heat flux of 35 kW/m^2 at a distance of 3.5 m above the bottom of the specimen).

- For assessment of minor variations (not joints or fixings) to the composition of wall assemblies previously tested to ISO 13875 or the Vertical Channel Test, cone calorimeter results should be permitted to be used in the assessment. It is expected that provided the peak HRR and the total heat release in 15 minutes are no greater than for the system tested at full-scale, the variation would be permissible.

- If a new method of test is to be adopted, a parallel implementation period is recommended (6-12 months), where either approvals based on either the new or existing requirements would be acceptable.

- Durability aspects of performance have not been discussed in this report. Further work may be needed to identify whether accelerated weathering of test specimens is appropriate and if so, what method of weathering should be used.

11.3 Insulated Sandwich Panels

The major fire risk associated with insulated sandwich panel construction appears to be to fire-fighters where poorly designed panels (particularly ceilings) may collapse without adequate warning and trap fire-fighters in the building. Panels containing thermoplastic insulants (e.g. polystyrene) tend to be more troublesome. While there may be circumstances in which building occupants are put at risk directly from burning sandwich panels, the evidence suggests that if the panels are the item first ignited, development will be fairly slow and contained and that panels will only contribute to an already large and dangerous fire. The fire risk relating to these panels could be reduced by sealing the panel ends with a non-combustible or intumescent seal; using non-combustible cores such as mineral wool rather than foams; and installing sprinkler systems.

The most appropriate test method for self-supporting sandwich panels for regulatory purposes appears to be the ISO 13784 Part 1 intermediate-scale test being developed by ISO TC92 SC1 WG7. This allows the sandwich panels to be assessed in their end-use situation using appropriate construction details. The sandwich panels are erected into a room (3.6 m x 2.4 m x 2.4 m high) configuration consisting of four walls and a ceiling and an opening in one of the walls. A gas burner (100/300 kW) is used for the fire source.

While recent activity in ISO is toward the development of full-scale room tests where the room is constructed from the panel assembly concerned, it is not clear that the existing BCA requirements are entirely unsatisfactory. Full-scale testing of the type being considered by ISO will be considerably more expensive than the existing requirements, and regulatory authorities in Australia will need to be satisfied that the benefits of more realistic end-use testing over current requirements are sufficiently high to warrant any change. Unsatisfactory performance of sandwich panels in real fires is often a result of poor detailing of joints and inappropriate use of materials. Education and guidance to manufacturers and designers regarding appropriate design may suffice in the short term.

11.4 Curtain Wall Construction

Curtain wall construction has particular problems of fire spread through voids that appear between the curtain wall and the edge of the floor slab. Voids are created when the wall panels become distorted, or when such distortion allows fire-stopping to fall out.

The Loss Prevention Council (UK) recently investigated the potential for fire spread via curtain wall construction. They found failure of the glazed window and spandrel panel units to occur after only 13 minutes, failure of the aluminium façade frames after 24 minutes and failure of the aluminium fixing brackets after 28 minutes. Compartment sprinklers were a very effective means of mitigating these effects. External and internal drencher systems were found to significantly delay (but not prevent) the break out of fire from the enclosure, while a fire resisting façade was shown to be able to survive the elevated temperatures and prevent break out and subsequent spread.

Sprinkler systems or the use of fire resistant glazing are the only really effective means of preventing vertical fire spread via the curtain wall, although testing by the Loss Prevention Council indicated that the use of external and internal wall-wetting systems would serve to significantly delay the rate of upward fire spread. At this time, new regulatory testing regimes for curtain wall construction are not proposed.

11.5 Apron and Spandrel Panels

International research (particularly by the National Research Council of Canada) has shown that spandrel walls need to be of impractical height (> 2.5 m) to be effective for controlling vertical fire spread (assuming window geometries which allow the flame to hug the wall above). It was shown that horizontal projections are many times more effective than spandrel walls. Applying the results of the Canadian research, an 1100 mm wide apron may reduce the exposure to the wall 1 m above the opening to about 10% of the exposure with a 900 mm spandrel present. Therefore the 1100 mm wide apron requirement in the BCA is an appropriate control, while the option for a 900 mm spandrel is by no means equivalent and largely ineffective.

In Type A construction where requirements for vertical separation of openings are given, consideration should be given to removal of the requirement for 900 mm high spandrels in favour of horizontal projections or sprinkler protection.

11.6 Building Regulations

The BCA generally uses the combustibility test (AS1530.1) and the early fire hazard test (AS1530.3) to control materials used for external walls and claddings. The existing controls are in some cases not sufficiently specific, for example, the expression "it does not otherwise constitute an undue risk of fire spread via the façade of the building" seems out of place in a deemed-to-satisfy solution. The existing AS1530.3 requirements may also not be able to adequately evaluate the performance of full-scale cladding systems in their end-use installation.

Building codes which currently have full-scale test methods for vertical fire spread on combustible cladding systems include: Uniform Building Code (UBC, 1997) and the National Building Code of Canada (NRCC, 1995). Sweden also uses a full-scale test method.

Requirements in the Deemed to Satisfy parts of the BCA relating to the use of combustible claddings and their evaluation for contribution to surface spread of flame would benefit from revision. Options for regulatory control have been presented.

It is also concluded that separate requirements addressing production of smoke and toxic gases from exterior cladding materials are not warranted, because firstly the risk to occupants is small from burning taking place on the exterior side of a building, and secondly smoke production is related to the burning rate of the materials involved and limiting the extent of flame spread on a material or cladding will indirectly reduce the quantity of smoke and gases generated.

12. RECOMMENDATIONS

It is recommended that:

- Collection of fire incident data be modified to allow for the identification of external vertical fire spread.
- The reduced scale vertical channel test method be developed as a means of evaluating the surface flame spread contribution of external cladding systems in their end-use condition and the Building Code of Australia be amended accordingly.
- The Building Code of Australia be amended to acknowledge the ineffective performance of spandrel walls.
- No new regulatory test requirements are proposed at this time for sandwich panel or curtain wall construction.

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Appendix A

(DRAFT)

Proposed Standard Test Method for Surface Flammability of Combustible Cladding and Exterior Wall Assemblies

ASTM Task Group E5.22.07 Vertical Channel Test

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