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| (41) | | (K4)
Date August 1995

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REPRINT

No 133 (1995)

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From: Fire and Materials,
Vol 19, 127-132 (1995)

ISSN: 0111-7459

FIRE AND MATERIALS, VOL. 19, 127–132 (1995)

Fire Performance of External Wall Claddings Under a Performance-based Building Code

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New Zealand Building Code performance requirements relating to fire performance of external walls are considered and methods of evaluating the potential for vertical fire spread are discussed. Classifying external wall claddings on the basis of performance in the 'combustibility' test has proved overly restrictive where some external cladding materials are concerned. Performance criteria based on heat release or 'degree of combustibility' are proposed and they seem to provide a better classification scheme for external wall cladding materials. Heat release test data for ten different external wall cladding materials are presented.

INTRODUCTION

While performance-based building codes offer considerable flexibility in design and construction of buildings to resist fire, their implementation can create difficulties in situations where performance requirements are expressed in qualitative rather than quantitative terms, as is common in the New Zealand Building Code (NZBC). This paper summarizes research carried out at Building Technology Ltd (BTL)[a] resulting from a concern that the means of compliance for the fire properties of external wall claddings, published by the Building Industry Authority (New Zealand), were unnecessarily restrictive and unfairly penalized cladding systems which are generally recognized as not presenting a fire hazard in practice. The existing requirements in New Zealand are examined and the appropriateness of alternative classification schemes based on rate of heat release or 'degree of combustibility' are considered.

PERFORMANCE-BASED CODES—THE NEW ZEALAND EXPERIENCE

In July 1992 a reformed system of building controls was implemented in New Zealand.[1] A performance-based Building Code was introduced which sought to control buildings to the minimum extent necessary to ensure that they performed in such a way as to:

- Safeguard people from injury, illness, and loss of amenity
- Protect other property
- Make reasonable and adequate provision for people with disabilities
- Facilitate efficient use of energy
- Facilitate appropriate responses to fire emergencies.

With respect to fire safety, the Code does not seek to control the choices of building owners in matters of protecting their own property, nor the continued viability of business operations within buildings following fire. These are considered to be matters for the owners and their insurer to decide. However, the protection of adjacent property is a requirement of the Code (i.e. you may destroy your own property but not that of your neighbour).

The New Zealand Building Code (NZBC)[2] specifies how a building must perform, not how it must be designed or constructed. The Approved Documents[3] give options for how buildings may be designed or constructed so that they will comply with the New Zealand Building Code. The Approved Documents are not mandatory but are an accepted means of compliance with the code.

The relevant clause of the NZBC dealing with the fire performance of external walls in 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, being one approved means of complying with this clause, provides some specific requirements. Distances to relevant boundaries in relation to permissible areas of openings in the external wall are controlled, to limit fire spread from a burning facade to an adjacent facade due to the effects of radiation. Fire resistance requirements are also identified, depending on the nature of the building and the presence or otherwise of other fire-protection systems. These requirements are not the subject of this paper and will not be discussed further here.

A further requirement of C3/ASI seeks to reduce the likelihood of fire propagating vertically up a combustible facade, as a result of either direct flame impingement from an adjacent building on fire or flames projecting through openings at a lower level in the same building and igniting the facade in the vicinity of the opening. It is this aspect of performance with which this paper is concerned. The existing 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 Methods for Fire Tests on Building Materials, Components and Structures—Part 1: Combustibility test for materials[4] and Part 3: Simultaneous determination of ignitability, flame propagation, heat release and smoke release.[5]

CCC 0308–0501/95/030127–06

Received 6 January 1995
Accepted 6 February 1995

TEST METHODS

AS 1530 Part 3 exposes a vertical specimen to a gradually increasing heat flux up to a maximum of about 30 kW m^{-2} by moving the specimen closer to a radiant panel over a period of 20 min. The ignitability criterion of the NZBC requires that no ignition occurs under these conditions. Although ignitability is an important factor influencing vertical fire spread, in this case the heat flux level and the gradual heating conditions may be considered not severe enough to be representative of a window fire plume. This aspect will be discussed later in this paper.

The combustibility test, AS1530 Part 1 (and its equivalents[b] throughout the world, e.g. BS 476 Part 4,[6] ISO 1182,[7] ASTM E136[8]) is the general method for determining combustibility of building materials in New Zealand. It involves placing a small specimen into a furnace at 750°C and measuring differential temperature rises in the furnace, and on the specimen, and recording the duration of any sustained flaming. The test was also used in New Zealand prior to the NZBC for specifying fire properties of external wall claddings. The purpose of the test is stated to be 'to ascertain whether a material will contribute directly to fire development'. The standard acknowledges that the exposure condition is severe, and materials having an appreciable organic content will usually prove combustible. The test is well suited to solid homogenous materials, but is increasingly being applied to composite materials and systems. Application of the test method to exterior cladding materials is considered to be overly restrictive toward some materials, such as cellulose fibre cement sheets, which, although combustible, do not contribute significantly to fire development. This problem is circumvented in some building codes, e.g. the Building Code of Australia,[9] by deeming a product or material to be non-combustible. However this is not a favoured solution in New Zealand.

The concept of 'degrees of combustibility' has also been proposed[10–13] where it is suggested that rate of heat release could be used to rank building materials according to their 'degree of combustibility'. Test methods using a cone calorimeter to measure heat release have now been published by ASTM[14] and ISO,[15] and a draft Australian standard is also in preparation. Richardson and Brooks (Forintek Canada Corp.) have indicated a preferred exposure of 50 kW m^{-2} for 15 min duration in the presence of an external spark igniter.[11] Because the standard methods of measuring heat release are non-specific in terms of radiant flux exposure, a National Canadian Standard[16] was produced in 1992 (CAN/ULC-S135-92, Standard Method of Test for Determining Degrees of Combustibility of Building Materials Using an Oxygen Consumption Calorimeter).

Richardson and Brooks have also suggested criteria for classifying materials according to their 'degree of combustibility'. Their criteria utilize two performance parameters. The first is the peak rate of heat release and the second the total heat released in 15 min 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.

VERTICAL FIRE SPREAD

So far, the test methods considered have been aimed at evaluating either the ignitability of the cladding or its contribution to fire development, rather than evaluating flame spread directly. Research carried out at the National Research Council of Canada[17] indicated that existing flame spread and flammability tests were not suitable for the assessment of the flame spread propensity of combustible claddings, and that a full-scale test designed to produce a high fire exposure would be more appropriate. Subsequently, a ULC standard CAN/ULC-S134M 'Standard Method of Fire Test of Exterior Wall Assemblies'[18] was produced. It was also acknowledged that such tests are expensive and thus smaller, less expensive tests are still desirable provided they are able to distinguish between acceptable and unacceptable products.[17]

Thus what is the justification for using 'degrees of combustibility' as a measure of flame spread potential? To answer this we need to consider the factors which affect the rate of fire spread vertically on a wall cladding material. These are illustrated schematically in Fig. 1.

Quintiere[19] gives the following expression to qualitatively illustrate flame spread up a wall due to buoyancy-induced flow for a thermally thick case:

$$V = \frac{(\dot{q}'')^2 \Delta}{k\rho c(T_{ig} - T_s)^2}$$

where V = flame spread rate, $\dot{q}''$ = net heat flux to the surface, Δ = length of control volume (related to flame length), $k\rho c$ = thermal inertia, T_{ig} = surface ignition temperature, and T_s = initial surface temperature. The importance of total net heat flux incident on the surface of the material becomes immediately obvious, since the flame spread has a dependence on the heat flux raised to

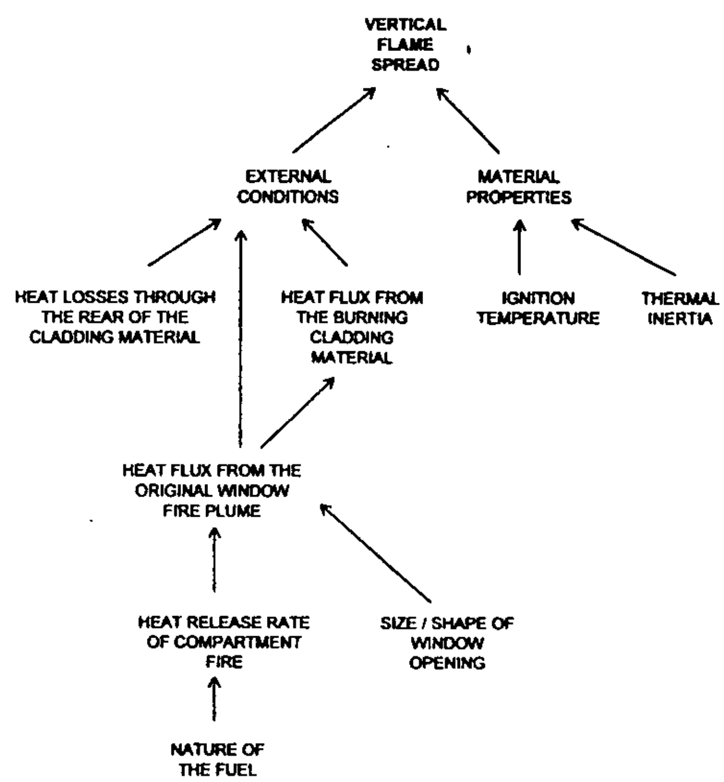

Figure 1. Factors affecting rate of fire spread vertically on a wall cladding.

the power of two. This total heat flux comprises that from the window fire plume and that from the burning material itself (i.e. the rate of heat release of the cladding material).

Therefore, in the event of unavailability of a full-scale flame spread test such as CAN/ULC-S134M[18] it seems possible to use a relatively inexpensive bench-scale test such as ASTM E1354[14] to measure rate of heat release as a basis for evaluating fire performance of wall cladding materials. However, it is considered that further research is still required to investigate the degree of correlation between the flame spread rate and the peak rate of heat release in this situation.

HEAT FLUXES TO WALLS ABOVE OPENINGS

The severity of an external wall's exposure resulting from a window fire plume varies depending on the nature of the fuel, size of the fire, and the size and geometry of openings. The exposure also decreases with an increase in vertical distance above the window and increases with the combustibility of the wall.[20] It has been noted that the most severe exposures occur in rooms ventilated with a single narrow opening. The lesser ventilation results in less combustion of volatiles occurring within the room and hence greater combustion of volatiles burning in the window fire plume where combustion air is available.[21]

Oleszkiewicz[17] has measured heat fluxes above window openings. In one test, using a propane gas burner to produce a 10.3 MW fire, and with an opening 2.6 m wide by 1.37 m high, a heat flux in excess of 200 kW m^{-2} was recorded 0.5 m above the top of the opening. However, more typically, fires up to about 6 MW did not produce more than about 50 kW m^{-2} at 0.5 m above the opening.

Oleszkiewicz[22] also describes a model of heat transfer to the wall surface which was in turn based on Law's work on exterior structural steel elements.[23] On the subject of such models, Quintiere and Cleary, who attempted to use dimensional analysis to examine heat transfer to vertical surfaces, state that it is critical to establish more definitive predictive methods for window flames impinging on a wall and that more systematic experiments are needed, given the limited data currently available.[24] Babrauskas[25] suggests that a heat flux of 50 kW m^{-2} may be a reasonable condition for many applications involving heat fluxes to the building facade from a window fire plume, and that while higher fluxes are certainly possible they require both very large fires and very large window openings.

In order to examine the concept of using rate of heat release to evaluate fire performance of external wall claddings, it was decided to test a range of exterior cladding materials and products (which are currently available within New Zealand) using the method of ASTM 1354[14] at a heat flux of 50 kW m^{-2}.

PERFORMANCE OF TYPICAL CLADDINGS

Ten different external wall cladding product/systems were tested[c] according to ASTM E1354-92[14] to establish

Table 1. Products tested for rate of heat release

Product no.	Product description
1	*Proprietary cellulose fibre cement board.* Unfinished. Nominal density 1430 kg m^{-3}. Sample thickness 7.5 mm.
2	*Proprietary compressed cellulose fibre cement sheet. Pre-finished with primer coats and a two-part-polyurethane top coat.* Colour white. Nominal density 1890 kg m^{-3}. Sample thickness 9 mm.
3	*Proprietary low-density Portland cement-based plaster containing polystyrene bead aggregate.* Finished with 2 mm thick finishing plaster and two coats acrylic paint. Sample thickness 18 mm.
4	*Radiata pine treated with copper-chrome-arsenic (CCA) to H3*[a]. Finished with an intumescent paint and acrylic paint top coat. Colour white. Sample thickness 19 mm.
5	*Proprietary Exterior Insulation and Finish System (EIFS).* Polystyrene foam insulation board finished with a Portland cement-based plaster, reinforced with fibreglass mesh and finished with two coats of acrylic paint. Sample thickness 43 mm.
6	*Proprietary extruded twin-wall uPVC weatherboard.* Colour white. Sample thickness 13 mm.
7	*Proprietary foamed cellular uPVC weatherboard.* Colour white. Sample thickness 6 mm.
8	*Radiata pine treated with copper–chrome–arsenic (CCA) to H3.* Unfinished. Sample thickness 19 mm.
9	*Radiata pine treated with copper–chrome–arsenic (CCA) to H3.* Finished with coats of oil-based stain. Colour cedar. Sample thickness 19 mm.
10	*Radiata pine treated with copper–chrome–arsenic (CCA) to H3.* Finished with three-coat acrylic paint system—colour brown. Sample thickness 19 mm.

[a] A level of timber preservative treatment used in New Zealand for elements exposed to the weather, but not in ground contact.

their indicative performance under the following conditions:

- Sample orientation: horizontal
- External heat flux: 50 kW m^{-2}
- External source of ignition present
- Two replicate samples of each material/system tested
- Sample size: 100 mm by 100 mm.

The product/systems are described in Table 1 and were selected because most of them are typical of claddings used in New Zealand building construction, although the range is by no means considered comprehensive. In the cases of painted and stained finishes on the radiata pine substrates, and for the Exterior Insulation and Finish System, the coatings were extended to cover the sides of the specimens.

Test samples were mounted horizontally as required by the test standard.[14] Since the mode of heating is by radiation, the effect of orientation is small. Greater uniformity of heat flux over the surface of the sample is achieved with horizontal mounting compared to vertical mounting, because of the convective boundary layer flow on a vertically mounted sample.[26]

The peak rate of heat release (in kW m^{-2}) and the total heat released in 15 min from the start of the test (in MJ m^{-2}) were determined based on a sample area of 0.01 m^2, and the average value taken of the two replicate tests. A summary of the test results giving time to ignition, peak rate of heat release, and total heat released in 15 minutes, is presented in Figs 2 to 4. All the materials ignited, with time to ignition ranging from 8 s for the radiata pine with acrylic paint finish to 384 s for the cellulose fibre cement compressed sheet (prefinished).

The maximum rate of heat release was measured for the radiata pine with acrylic paint finish at 345 kW m^{-2}, and this was significantly greater than for the same substrate with no applied finishing coat for which the peak rate of heat released was 214 kW m^{-2}. The least rate of heat release measured was 39 kW m^{-2} for the cellulose fibre cement board with no applied finish. The maximum total heat released in 15 min from the start of the test was measured at 109 MJ m^{-2} for the radiata pine with an oil stain finish, and the least amount of heat released was for the fibre cement compressed sheet at 8 MJ m^{-2}.

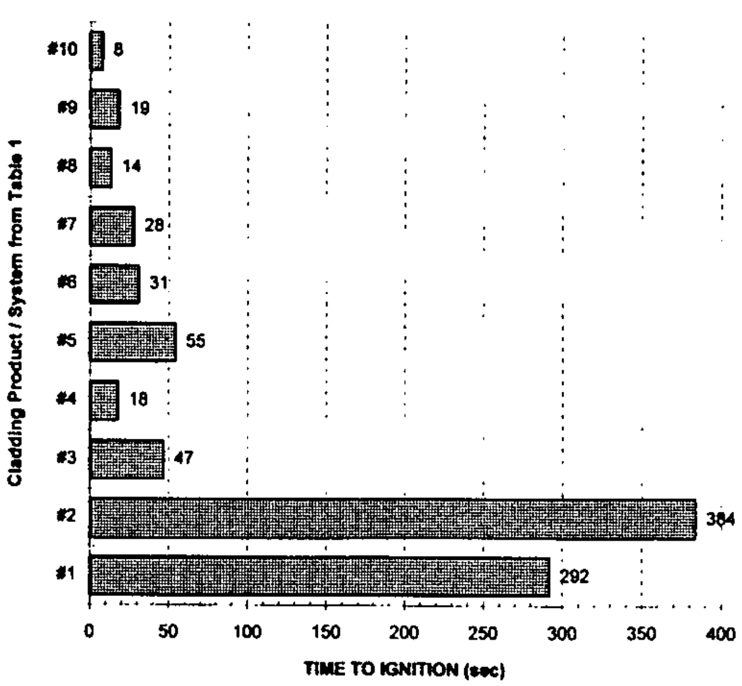

Figure 2. Time of ignition.

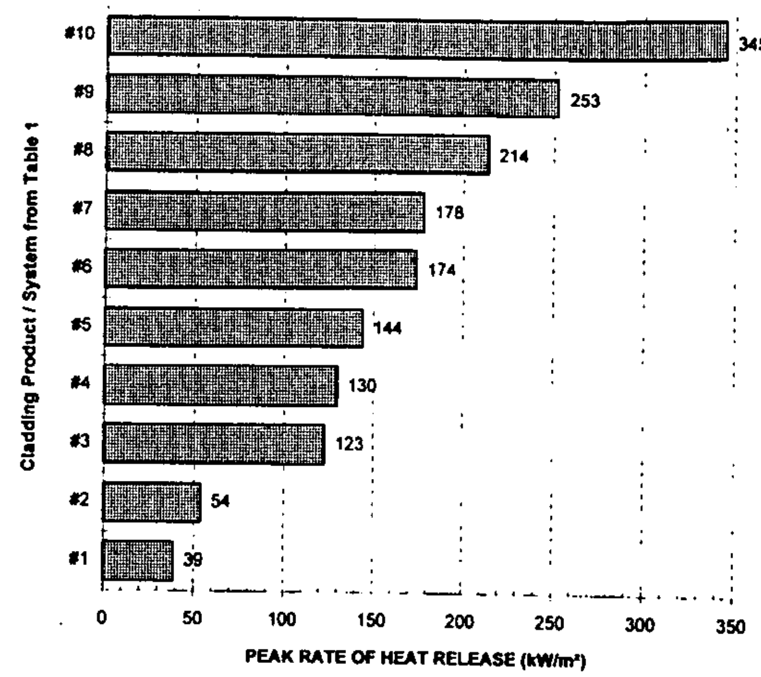

Figure 3. Peak rate of heat release.

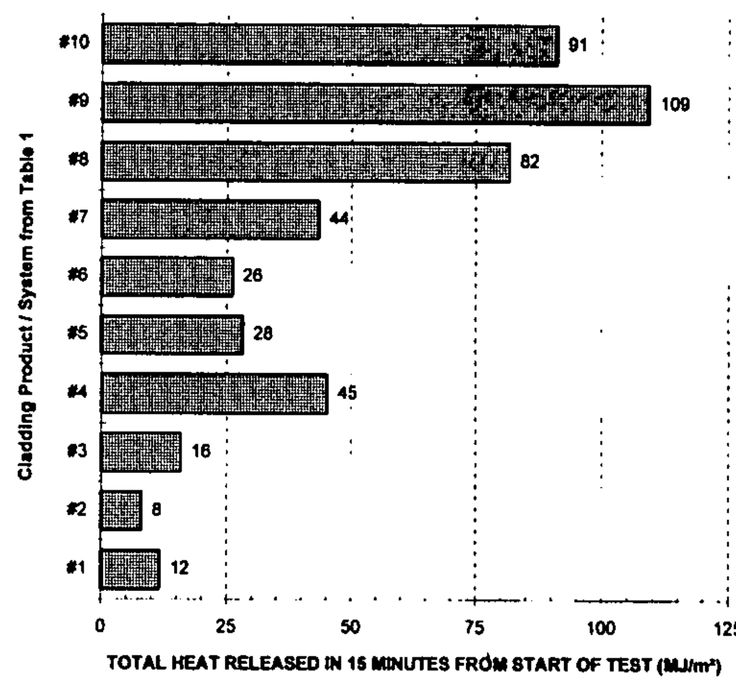

Figure 4. Total heat released in 15 min from start of test.

The results for the proprietary products can be considered to be only indicative. For example, in BTL's experience, other proprietary Exterior Insulation and Finish Systems are known to show a peak rate of heat release ranging between 160 and 290 kW m^{-2} under the same exposure conditions. Richardson and Brooks[11] give a peak rate of heat release of 382 kW m^{-2} for a proprietary rigid polystyrene foam insulation board on its own. The properties of the plaster and finishing coats are obviously very important.

Other data[11] show the peak rate of heat release for 19 mm thick red oak tongue-and-grooved planks as 222 kW/m^{-2} and total heat release in 15 min as 100 MJ m^{-2}, which is slightly higher but comparable to the results obtained for the radiata pine. They also give the peak heat release rate and total heat released for a 25 mm thick proprietary concrete slab made from Portland cement and chemically treated wood particles, as 22 $kW\,m^{-2}$ and 16 $MJ\,m^{-2}$ respectively.

SUGGESTED PERFORMANCE CRITERIA

The following discussion is intended to relate to the overall framework of the New Zealand Building Code, in that the primary concern is the life safety of building occupants. The Code is also concerned with fire spread from one building to an adjacent one, provided the adjacent building is under separate ownership or either building contains sleeping accommodation. In the case of a single-storey building it is suggested that in most instances the combustibility of the external cladding has little effect on life safety within the building. However, in the case of buildings where the occupants may not be able to escape without assistance (e.g. health-care and prisons) highly combustible claddings are undesirable and control is considered appropriate. Furthermore, to restrict fire spread between buildings where projecting flames could directly impinge on an adjacent building's facade (i.e. when the adjacent building is sited in the vicinity of the boundary), control of the combustibility of the cladding is also considered to be appropriate.

In multi-storey buildings, facade spread is possible, with it being desired that a cladding should not contribute significantly to fire spread between different levels in the building. Thus, again, a control on combustibility of the cladding is considered appropriate. The key question is, then, what level of control is necessary to ensure that the propensity for vertical fire spread is small? Quintiere[19] has commented on the existence of a critical energy release rate required to permit sustained acceleratory flame spread. Clearly this is an area worth further research.

The ability of the local fire services to damp down exposed building facades may also be considered, and perhaps different 'degrees of combustibility' should be applied if this is reasonably likely. Thus, building height becomes important, with more stringent requirements applying to taller buildings. Furthermore, The New Zealand Building Code Acceptable Solutions include numerous trade-offs for buildings which are sprinklered. For example, firecell areas may be increased (unlimited), fire resistance ratings may be reduced, and controls on the flame spread characteristics of interior surface finishes are relaxed. It is suggested that a less stringent 'degree of combustibility' on external wall claddings could be also accepted as reasonable, where the building is sprinklered.

Suggested performance criteria based on rate of heat release and total heat release, and incorporating the concepts discussed in the preceding paragraphs, are included as Table 2. These criteria are not considered definitive, but rather are put forward to be subjected to debate and to be further refined as appropriate.

Using the criteria of Table 2, the tested wall cladding products/systems would be classified as follows:

(1) Peak rate of heat release $\leqslant$ 100 $kW\,m^{-2}$ and total heat released in 15 min $\leqslant$ 25 $MJ\,m^{-2}$:
- Fibre cement board [#1]
- Fibre cement compressed sheet (prefinished) [#2]

(2) Peak rate of heat release $\leqslant$ 150 $kW\,m^{-2}$ and total heat released in 15 min $\leqslant$ 50 $MJ\,m^{-2}$:
- Low-density Portland cement-based plaster with polystyrene aggregate [#3]
- Radiata pine with an intumescent paint finish [#4]
- Exterior insulation and finish system [#5]

(3) Peak rate of heat release > 150 $kW\,m^{-2}$ or total heat released in 15 min > 50 $MJ\,m^{-2}$:
- Extruded twin-wall uPVC weatherboard [#6]
- Foamed cellular uPVC weatherboard [#7]

Table 2. Suggested performance requirements

Building height	Performance requirement (Testing of horizontal specimens to ASTM 1354 or similar at an irradiance of 50 $kW\,m^{-2}$ in the presence of an external spark igniter)
Single-storey	Health-care and detention purpose groups or any purpose group where the wall is within the vicinity of a boundary. Peak rate of heat release $\leqslant$150 $kW\,m^{-2}$ Total heat released in 15 min$\leqslant$50 $MJ\,m^{-2}$
	All other purpose groups No requirements
Up to a height where fire services are able to apply water	Health-care, detention and accommodation purpose groups or any purpose group where the wall is within the vicinity of a boundary. Peak rate of heat release$\leqslant$150 $kW\,m^{-2}$ Total heat released in 15 min$\leqslant$50 $MJ\,m^{-2}$
	All other purpose groups Peak rate of heat release $\leqslant$300 $kW\,m^{-2}$ Total heat released in 15 min$\leqslant$125 $MJ\,m^{-2}$
Above height where fire services are able to apply water	All unsprinklered purpose groups Peak rate of heat release$\leqslant$100 $kW\,m^{-2}$ Total heat released in 15 min$\leqslant$25 $MJ\,m^{-2}$
	All sprinklered purpose groups Peak rate of heat release$\leqslant$150 $kW\,m^{-2}$ Total heat released in 15 min$\leqslant$50 $MJ\,m^{-2}$

- Radiata pine (unfinished) [#8]
- Radiata pine (stained) [#9]
- Radiata pine (acrylic paint finish) [#10]

CONCLUSIONS

Classifying external wall claddings on the basis of performance in the 'combustibility' test has proved overly stringent where some cladding materials are concerned. It is possible to develop performance criteria based on the peak rate of heat release and the total heat released in 15 min from the start of the test which seem to provide a better classification of external wall cladding products and materials. Performance criteria have been suggested in this paper. Conditions leading to self-propagation of fire on wall cladding materials, and further measurement of heat fluxes resulting from window fire plumes, are areas worth further investigation and research.

NOTES

[a] BTL is a company wholly owned by the Building Research Association of New Zealand.
[b] The tests are not identical, but essentially serve the same purpose.
[c] Testing was carried out by Londonderry Occupational Safety Centre, Workcover Authority, NSW 2733 Australia, under contract to Building Technology Ltd.

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