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Effective Passive Roof Venting in the Event of a Fire – Literature Review

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Preface

This report was prepared as a result of a review of available literature on materials, designs and methods used for passive roof venting during a fire event and the relevant current international regulations and standards for design requirements and testing.

Acknowledgments

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The authors would also like to acknowledge the much appreciated assistance and cooperation of the New Zealand Fire Service and the Department of Building and Housing.

Note

This report is intended primarily for fire engineers, architects, code writers, regulators and researchers.

Mention of named manufacturers, commercial products or literature is not intended as a recommendation. Only generic material data has been used from these sources and is therefore referenced accordingly.

EFFECTIVE PASSIVE ROOF VENTING IN THE EVENT OF A FIRE – LITERATURE REVIEW

BRANZ Study Report SR 165(2007) **APR Edwards, E Soja and CA Wade**

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ABSTRACT

The intent of this research is to provide a basis for recommendations as to the appropriateness of the current New Zealand Building Code (NZBC) requirements and potential future research required to provide a robust technical basis for future performance requirement recommendations. This report summarises current effective passive roof venting standard test methods. In addition, current international building regulations and standards associated with passive fire venting are also summarised.

The motivation for this work is that fires in large industrial buildings can be very difficult for the fire service to control and extinguish. To assist fire service operations, the Building Code Compliance Document C/AS1 places a limit on the maximum compartment floor area in unsprinklered buildings (typically 1500 m^2). This is designed to limit the total fire load in a firecell to less than 2 million MJ. However, there need be no subdivision of the building if at least 15% of the roof area (distributed evenly throughout the firecell) is designed for effective fire venting. Subdividing large industrial buildings is often undesirable for functional reasons, and therefore the roof venting option is a popular one.

The purpose of roof venting is to allow for the efficient removal of smoke and heat from the building allowing better access for the fire service to locate and control the fire, and to reduce the overall severity of the fire on the building structure via the removal of heat from the building. The fire resistance rating (FRR) provided to some structural elements (that require an S rating) can be reduced by up to approximately 50% if roof venting for fire is provided. The use of the term "effective fire venting" (Paragraphs 4.2.3 and 4.2.4 of *NZBC C/AS1* 2005) implies that, in the event of a fire, fire venting will assist fire fighting operations. However, the New Zealand intent and requirements for "effective fire venting" are currently undefined.

Unproven materials, such as fibreglass reinforced plastic roofing panels, have often been specified by designers to meet the roof venting requirement. However these do not provide "effective" venting, for example the fibreglass reinforcing mesh remains in place during the fire preventing hot gases from venting efficiently. Other plastics roofing materials that melt easily would be more effective. Unfortunately, there is no detailed specification or standard currently referenced in the Compliance Document to ensure that fire venting is "effective". The current performance and effectiveness of these systems is therefore questionable.

Detailed guidance on how to assess the effectiveness of roof venting systems leading to appropriate specifications for them is desperately needed. Mechanically operated smoke and heat venting systems for fire are established technology overseas and various codes and standards do exist that may be suitable for use in New Zealand. Passive systems, such as drop-out panels, are less common and this project will document and review international practice in this area.

International building codes (e.g. *BCA* 2006 or *UBC* 1997) make use of standards for installation and test methods for fire venting systems (e.g. AS 2665, AS 2428, NFPA 204, UL 793 and UBC Standard 15–7).

Previous experimental work has been performed investigating passive roof venting (Thomas et al 1963, Hinkley and Theobald 1966, Hinkley 1986b, Duong 1990) including some material testing (e.g. for PVC). The results of these previous investigations indicate that passive roof venting is a valuable system in limiting fire spread and maintaining conditions for the seat of the fire to be located more easily. However, limited 'large-scale' and 'full-scale' testing has been performed and there is the potential for further useful testing to be carried out in this area. This could be performed, in conjunction with small-scale testing of materials and modelling of the full-scale set-ups to determine appropriateness of materials and vent design effectiveness in the New Zealand context of current fire venting practices.

There are two aspects to the problem created by the lack of defined requirements for fire venting for the New Zealand building stock; current building stock with ineffective fire venting; and ensuring effective fire venting and subsequent appropriate trade-offs for future building stock. Recommendations for future work also on this topic are discussed.

KEYWORDS

Fire venting, smoke and heat vents, roof venting, passive venting, plastic sheeting, large buildings, industrial, storage.

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Abbreviations

Amd.	Amendment
max.	maximum
constr.	construction
compart.	compartment

Acronyms

AMUBC	Australian Model Uniform Building Code
AUBRCC	Australian Uniform Building Regulations Co-ordinating Council
C/AS1	Fire Safety Compliance Documents (C Clauses), Acceptable Solution
FHC	Fire Hazard Category
FLED	Fire Load Energy Density
GRP	Glass-fibre Reinforced Polyester
NZ	New Zealand
NZBC	New Zealand Building Code
NZFS	New Zealand Fire Service
PC	Polycarbonate
PMMA	Polymethyl methacrylate (or acrylic)
PVC	Polyvinyl Chloride
US	United States (of America)

Nomenclature

A_i	total area of all inlets (m^2)
A_v	measured throat area of ventilators for the reservoir being considered (m^2)
$A_v C_v$	aerodynamic free area of natural ventilation (m^2)
C_i	entry coefficient for inlets (dimensionless)
C_v	coefficient of discharge (dimensionless)
c_p	specific heat of smoke (kJ/kg.K)
d_b	depth of smoke beneath ventilator (m)
FC	Froude number (dimensionless)
g	acceleration due to gravity (m/s^2)
h	height of the firecell (m)
$\dot{Q}_{conv}$	convective portion of the heat release of fire (kW)
$\dot{m}$	mass flow rate of smoke to be extracted (kg/s)
P	perimeter of the fire (m)
T_c	absolute temperature of smoke layer (K)
T_o	absolute temperature of ambient layer (K)
y	height of the clear layer (m)
ρ_o	ambient air density (kg/m^3)
θ_c	temperature rise of smoke layer above ambient (K)

1. INTRODUCTION

In large area single storey buildings, "…although a fire may involve only a relatively small area of the floor, the smoke and hot gases will quickly fill the building and experience has shown that the fire can be completely concealed before he arrival of the fire brigade." (Thomas et al 1963) Fire-fighting is then difficult and dangerous, since the fire must be located within the building and the smoke and heat conditions may be sufficiently severe to limit the fire brigade to conducting an external fire attack. External attacks are ineffective as fire hose streams rarely reach the seat of the fire to extinguish it and thus only results in more water damage and contaminated run-off. The temperatures of the hot layer trapped beneath the roof may also be sufficiently high to cause softening or failure of unprotected roof construction or ignite flammable roof materials.

A passive fire venting system relying on buoyancy of the hot fire products to provide the driving force for removal of the hot gases has advantages: simplicity, effectiveness in a wide range of fire conditions and independence from any available power supply that may be disrupted during a fire. For example, the rate of removal of hot gases is largely dependent upon the depth and temperature of smoke. Therefore if a fire grows larger than the assumed design point used to calculate the venting, then a larger depth and higher temperature of gases would lead to an increased flow rate through the vent (i.e. venting of the hot products would still occur, but the desired level of 'effectiveness' may not be achieved). Thus a passive fire venting system has an element of self-compensation (Morgan and Gardner 1990). However, as with all 'reliable' and 'effective' systems, the reliability and effectiveness must be determined through demonstration of design.

1.1 Motivation

The New Zealand Building Act (2004) does not require building owners to consider property protection. Consequently, most industrial buildings have been constructed in the expectation that insurers will cover the fire loss.

Fires in large industrial buildings can be very difficult for the fire service to control and extinguish. To assist fire service operations, the Building Code Compliance Document C/AS1 places a limit on the maximum compartment floor area in unsprinklered buildings (typically 1500 m^2). This is designed to limit the total fire load in a firecell to less than 2 million MJ. However, there need be no subdivision of the building if at least 15% of the roof area (distributed evenly throughout the firecell) is designed for effective fire venting. Subdividing large industrial buildings is often undesirable for functional reasons and therefore the roof venting option is a popular one.

The purpose of roof venting is to allow for the efficient removal of smoke and heat from the building allowing better access for the fire service to locate and control the fire, and to reduce the overall severity of the fire on the building structure via the removal of heat from the building. The FRR provided to some structural elements (that require an S rating) can be reduced by up to around 50% if roof venting for fire is provided. Unfortunately, there is no detailed specification or standard currently referenced in the Compliance Document to ensure that fire venting is "effective". The current performance and effectiveness of these systems is therefore questionable. Active or mechanically operated venting systems are outside the scope of this project.

There is also the question of the location or distribution of the panels over the area of the roof. An even distribution across the roof area is appropriate for flat or very shallow roofs, but venting in steep roofs would be more effective if located near the apex.

Detailed guidance on how to assess the effectiveness of roof venting systems leading to appropriate specifications for them is desperately needed. Mechanically operated smoke and heat venting systems for fire are established technology overseas and various codes and standards do exist that may be suitable for use in New Zealand. Passive systems such as dedicated units utilising drop-out panels are less common.

1.2 Objective

The objectives of this report are to summarise current passive roof venting standard test methods, in addition to current international building regulations and standards associated with passive fire venting systems, with a view to:

1. providing a basis for recommendations as to the appropriateness of the current NZBC requirements, and
2. suggesting future research to provide a technical basis for recommendations of appropriate requirements for future effective passive fire venting designs for use in New Zealand.

1.3 Scope

The scope of this report is limited to operable buoyancy-driven (natural) fire venting relying on the failure and subsequent dislodgement of thermoplastic materials to create the opening of the roof vent. Related systems are briefly introduced and discussed for comparison with this particular passive venting method. Mechanical smoke extract systems and specific smoke control for atria are not included within the scope of this report, however significant research has been performed in these related areas (e.g. Milke and Klote 1998, Morgan et al 1999, SFPE Handbook 2002).

2. REGULATORY REQUIREMENTS

A summary of the current regulatory requirements and subsequent trade-offs are presented in this section for New Zealand, Australia, England and Wales, and the United States of America.

2.1 New Zealand requirements

Fire venting is not defined in the NZBC Fire Safety Clauses Compliance Documents (NZBC C/AS1 2005). There are no quantitative prescriptive or performance requirements to determine the required level of effectiveness of fire venting.

Qualitative prescriptive requirements for fire venting are that:

- "… only roof venting which is specifically designed to open or melt rapidly in the event of fire shall be included …" (Table 5.1, Note 4 of NZBC C/AS1 2005)
- "… only those areas of external walls and roofs which can dependably provide airflow to and from the fire …" are to be included in the calculation of effective venting areas (Table 5.1, Note 4 of NZBC C/AS1 2005)
- fire venting openings "… should be located in the most practicable manner to provide effective cross-ventilation …" (Table 5.1, Note 3 of NZBC C/AS1 2005).

The quantitative prescriptive requirement for fire venting required for an unlimited unsprinklered firecell floor area is:

- "… no less than 15% of the roof area (distributed evenly throughout the firecell) is designed for effective fire venting …" (Paragraph 4.2.4, NZBC C/AS1 2005).

Qualitative performance requirements are implied as:

- fire venting "… reduces structural fire severity and facilitates fire-fighting operations …" (Table 5.1, Note 3 of NZBC C/AS1 2005).

Even though fire venting requirements are not well defined (with the majority of information pertaining to fire venting being included in Compliance Document table notes), and there are no quantitative performance requirements, providing "effective fire venting" in a design permits unlimited firecell floor areas and reductions in structural fire resistance (S) rating values.

2.1.1 Fire venting and unsprinklered firecell floor area

It is noted (Paragraph 4.2.3 Comment of NZBC C/AS1 2005) that the intention of limiting firecell floor area is to assist fire-fighting operations and to limit the total fire load to approximately 2 million MJ in unsprinklered firecells. A summary of the purpose groups typically of interest for large firecells with associated Fire Hazard Category (FHC), Fire Load Energy Density (FLED) values used in C/AS1 calculations and maximum firecell floor area is presented in Table 1.

"In an unsprinklered single floor building where the building elements supporting the roof are not fire rated, the firecell floor area may be unlimited provided that no less than 15% of the roof area (distributed evenly throughout the firecell) is designed for effective fire venting." (Paragraph 4.2.4 of NZBC C/AS1 2005; Paragraph C3/3.7.2 of NZBC C3/AS1 Amd.1 1993)

The situation where the building elements supporting the roof can be unrated, is where the roof is unrated (Paragraph 7.9.4 of NZBC C/AS1 2005) and primary elements supporting the roof are not required to be fire rated (Paragraph 7.9.5 of NZBC C/AS1 2005). That is, the elements supporting the roof are not part of an external wall required to be fire rated as defined from the application of the S rating of the firecell (Paragraph 5.3.2 of NZBC C/AS1 2005).

Table 1: Fire hazard category and maximum unsprinklered firecell floor areas for which an S rating applies. Extracted from (Paragraphs 2.2.1 and 4.2.3, and Table 2.1 of NZBC C/AS1 2005).

Fire hazard category	General description	Purpose groups	Range of FLED (MJ/m^2)	Design value of FLED (MJ/m^2)	Maximum firecell floor area (m^2)
1	Low fire load	WL – manufacturing, processing or storage with non-combustible or slow heat release rate materials	0 – 500	400	5000
2	Low fire load	WL – other low fire load spaces for working, business or storage	501 – 1000	800	2500
3	Medium fire load and slow/medium/fast growth rates* (e.g. < 1MW in 75 s)	WM	1001 – 1500	1200	1500
4	High fire load and slow/ medium/ fast fire growth rates* (e.g. < 1 MW in 75 s)	WH and WF (with ultra-fast growth rates)	>1500	–	By specific fire engineering design

Note: * Refer to NFPA 92B for more information on fire growth rates.

2.1.2 Fire venting and structural FRR reductions

S ratings for firecells with FHC 1, 2 and 3 are calculated from ratios of vertical or horizontal opening areas and floor areas (P.5.5.3 of NZBC C/AS1 2005). The S rating values presented in Table 5.1 were based on unpublished overseas information used to develop a series of Eurocodes for structural fire safety design (Comment 5.5.3 of NZBC C/AS1 2005). Fire venting via roof vents is not the only venting method permitted for structural fire resistance (S) rating reductions. However it is the focus of this report. Therefore fire venting methods for vertical openings are not discussed in detail here.

Provision of "effective fire venting" allows the reductions when calculating the time equivalent (t_e) for the S ratings for Fire Hazard Categories 1, 2, and 3 (Table 5.1 of NZBC C/AS1 2005). The allowable reductions for horizontal and/or vertical openings are based on the Eurocode equation, Equation E3 from Annex E, Eurocode 1 (1996). These calculations assume a 3 m high compartment with a thermal inertia factor corresponding to the most severe conditions (i.e. those associated with the highest time equivalent value). It is noted in Table 5.1 that "… for firecells which differ from these assumptions, especially with regard to the materials of construction, more accurate answers may be obtained with specific fire engineering design, which is mandatory for fire hazard category 4 …" (Table 5.1, Note 7 of NZBC C/AS1 2005). The time equivalent reductions allowable for passive fire venting areas may not be conservative for some situations for large single firecells even with higher ceiling heights, depending on the specific usage and contents of the firecell (e.g. with rack storage located near to the roof), whether or not venting is 'effective' and the opening of the vent area (e.g. plastic sheeting versus AS 2665:2001, as discussed in Section 2.5.1).

Furthermore, "… for single floor buildings or the top floor of multi-floor buildings, where the structural system supporting the roof is non-rated and directly exposed to the fire (i.e. no ceiling installed), A_h/A_f may be taken as 0.2." (Table 5.1, Note 4 of NZBC C/AS1 2005). This 20% value is associated with the estimated roof integrity failure caused by thermal movement of unprotected portal frame systems (Clifton 2006). This forced opening of the roof, due to the heating of the vertical components of the frame, is a separate issue from effective roof venting as it would typically occur after the initial heating of the underside of the roof area, where the effective fire venting would be activated. Therefore areas designed for effective roof fire venting (such as required for unlimited firecell floor area) are in addition to any potential venting that may occur due to failure of the roof structure.

2.1.3 Fire venting and open-sided buildings

In addition, no less than 15% of the roof area is required to be self-venting (by either opening or melting rapidly) for open-sided buildings (according to P.7.8.8 of NZBC C/AS1 2005) closer to a relevant boundary than allowable by Paragraphs 7.8.9 c) and d) (P.7.8.10.a of NZBC C/AS1 2005). "Examples of open-sided buildings having a roof area exceeding 40 m² are canopies over forecourt areas at service stations, while those with roof areas of less than 40 m² could be structures such as carports associated with detached dwellings." (P.7.8.10 Comment of NZBC C/AS1 2005)

2.1.4 Roof vents and theatres

Theatres with an occupant load great than 1000 require "roof vents of no less than 5% of the stage floor area, located at the highest point above centre stage" (P.6.3.2.b of NZBC C/AS1 2005). These vents are required to have a positive device to keep them closed. Examples of suitable vents include counterbalanced shutter type, inclined falling type, centre pivot sash type or counterbalanced skylight type. The operation of these vents is required to be controlled by a heat sensing device located below the vent and above sprinkler discharge, in addition to manual control (P.6.3.2.b to e of NZBC C/AS1 2005).

Although "roof vent" is referred to rather than "fire vent", the method of activation and general description of operation is consistent with that of fire vents complying with AS 2665.

2.2 Australian requirements

Smoke and heat vents are one of the permitted options to increase an unsprinklered firecell size beyond the limits listed in Table C2.2 of the Building Code of Australia (2006) to up to 18,000 m² and 108,000 m³, where the building is separated from other property by a minimum of 18 m (C2.3 of BCA 2006). This is only available for Class 7 or 8 which covers carparking, storage, wholesale, production, assembling etc. Smoke and heat vents are also one of the permitted options for increasing the firecell floor area greater than 2000 m² (and up to 3500 m² for a building with a common walkway between shops or exhibition hall) for a single-storey Class 6 (retail) or Class 9b (exhibition hall only) unsprinklered building (Table E2.2b of BCA 2006). Smoke and heat vents are also one of the permitted options for increasing the firecell floor area in other unsprinklered classes of buildings such as Class 9b (theatres and public halls). (Table E2.2b of BCA 2006)

The maximum allowable firecell floor areas and volumes are summarised in Appendix A Table 13. A summary of the requirements for increases in firecell size beyond the maximum limits is presented in Appendix A Table 14. A list of the descriptions of the classifications used in the Building Code of Australia is also included in Appendix A in Table 12.

In all instances where smoke and heat vents (Specification E2.2c) are required, only automatically-opening or permanently-open vents complying with AS 2665 are acceptable (BCA 2006). No passive fire venting methods are mentioned.

2.3 Requirements of England, Wales and Ireland

A 10% equivalent floor area of low melting point rooflights requirement was introduced in the 1985 version of the Approved Documents (Build. Reg. Approved Doc. B/2,3,4 1985) and then removed in the 2000 version (Knight's Build. Reg. 2000, Approved Doc. B 2004). Currently the design of portal frames are required to adhere to the method set out in *Fire and steel construction: The behaviour of steel portal frames in boundary conditions* (Newman 1990). This document states that the structural protection that may be afforded by the passive roof venting is no longer needed when a portal frame is designed according to the methods described (Newman 1990).

It is recognised that "… venting can improve visibility and reduce temperatures, making search, rescue and fire-fighting less difficult …" (Paragraph B5.ii.e of Knight's Build. Reg. 2000, Approved Doc. B 2004). However, heat and smoke venting is only required in association with basements of buildings (Paragraph B5 of Knight's Build. Reg. 2000, Approved Doc. B 2004).

Furthermore it is noted that at the time the New Zealand acceptable solution was first written in circa 1990, the 1985 UK approved documents were a strong influence in an number of areas, building to building fire spread being another example.

2.4 Requirements of the United States of America

2.4.1 Uniform Building Code

According to Section 906 of the Uniform Building Code (UBC), smoke and heat venting in compliance with UBC Standard 15–7 or fixed openings is required for (UBC Vol.1 1997):

1. Single-storey Groups B, F, M and S Occupancies with more than 4645 m² in area, or

    a. Except for office and retail occupancies with less than 3.7 m storage, or bulk frozen food storage with automatic sprinkler protection.

2. Group H, Divisions 1 (detention facilities), 2 (agriculture), 3, 4 or 5 Occupancies any of which are over 1394 m² in area.

Vents:

- minimum effective area of 1.5 m²
- maximum centre to centre spacing is:
    - 36.5 m in Groups B, F, M and S, and
    - 30.4 m in Group H.
- minimum ratios of effective area of vent openings to floor areas is:
    - 1% in Groups B, F, M and S, and
    - 2% in Group H.

Draught curtains:

- minimum depth:
    - extend a minimum depth of 1.9 m from the ceiling, but there is no need to be closer than 2.4 m to the floor in Groups B, F, M and S, and
    - extend a minimum depth of 3.7 m from the ceiling, unless closer than 2.4 m to the floor then the minimum depth is 1.9 m from the ceiling in Group H
- maximum spacing:
    - the maximum distance between curtains is 76.2 m and maximum area is 4645 m² in Groups B, F, M and S, and
    - the maximum distance between curtains is 30.4 m and maximum area is 1394 m² in Groups H.

2.5 Standards

2.5.1 AS 2665: Smoke/heat venting systems: design, installation and commissioning

For buildings up to 6 m high with draught curtains no less than 1.5 m deep, effective aerodynamic vent-area in occupancies of "abnormal fire hazard" is required to be 3% of the floor-area in each compartment formed by draught curtains or 2% in other occupancies. For buildings of more than 6 m, or for draught curtains less than 1.5 m or for permanently open vents, a nomogram for the venting of a large but not fully developed fire is to be used to determine the appropriate size of the vents (AS 2665 2001).

AS 2665 (2001) covers the following:

- vents are defined as complying with automatic smoke/heat vents as specified in AS 2427

- vents are to be either permanently open or all vents in each draught curtain compartment are activated by the release of any thermally-released link (complying with AS 1890) in the reservoir

- operation temperature of vents is specified as 68ºC in non-sprinklered buildings, or 5ºC higher than the operation temperature of sprinklers if present

- if vent activation by smoke detection is required, smoke detectors are to be no more than 20 m apart and no more than 10 m from any wall, bulkhead or draught curtain

- manual override is required for vent operation

- position of all vents is open on the failure of any part of the control system

- maximum horizontal area of reservoirs formed by draught curtains is specified as 1500 m^2:

  - with a maximum distance between parallel draught curtains of 30 m in areas of abnormal fire hazard, 100 m in other areas, and 60 m in enclosed walkways and malls

- minimum draught curtain depth is 1.5 m

- draught curtain installation, including maximum leakage gap sizes, are specified

- inlet ventilation area is specified as twice the aerodynamic area of the vents over the largest single smoke reservoir.

The technical detail of AS 2665 is based on the paper of Thomas and Hinkley (1964) that is discussed in Section 3.1.1.

2.5.2 AS 2427: Smoke/heat release vents

AS 2427 specifies the requirements for buoyancy-driven smoke and heat vents that are intended to be mounted in roofs of buildings to release the hot products of combustion in the event of fire. (AS 2427 2004)

Specifications of AS 2427 (2004) cover:

- vent material selection – to ensure the vent operates and the effective vent area is not compromised

- vent operation via:

  - a thermally released link complying with AS 1890, and

  - if another sensing device is capable of initiating operation, the thermally released link must be able to override this device, and resistance to collapse during a fire, and

  - manual operation of the vent from floor level must be provided, and

  - vent failure position to be open

- vent operation tested according to AS 2428.3 for initiation, AS 2428.4 when in contact with flame, and AS 2428.5 to determine the discharge coefficient

- minimum required vent effective aerodynamic area is 1 m² (= actual area of the vent airway x discharge coefficient), with no less than 600 mm in any dimension and an aspect ratio of 3:2. Larger vent areas or unusual aspect ratios are only permitted upon a formal opinion, based on one or more full-scale tests

- vent performance to be tested for leakage in wind and rain (AS 2428.1), operation in wind conditions (AS 2428.2), operation under snow loading (AS 2428.6)

- labelling of the vent

- vent construction and location requirements to prevent any discharging flames and gases from impinging upon any adjacent structure

- requirements for cyclonic or non-cyclonic conditions (AS 2665 and AS 1170.2).

2.5.3 AS 2428: Methods of testing smoke/heat release vents

AS 2428 contains a series of standards that describe a range of test methods for determining the performance characteristics of buoyancy-driven smoke and heat vents, as summarised in Table 3.

2.5.4 AS 1668.3: The use of ventilation and air conditioning in buildings, Part 3: Smoke control systems for large single compartments or smoke reservoirs

AS 1668.3 (2001) specifies the minimum requirements for the design, installation and commissioning of both mechanical and buoyancy-driven smoke control systems. AS 1668.3 applies to areas where:

- the floor-to-ceiling or upper bounding layer height is 3 m or greater, and where a stable buoyant hot layer exists

- the smoke control zone is a single smoke reservoir

- smoke baffles have a minimum depth of one-fifth of the enclosure height

- maximum area of a smoke reservoir is 2000 m²

- the minimum dimension of a smoke reservoir is $\sqrt{(Compartment\ area/5)}$

- smoke reservoirs have a minimum volume of 10 times the design volumetric exhaust flow rate.

Some recommendations, specific for single-storey large compartment buildings such as warehouses, factories etc, include:

- the designed smoke layer height should not be less than 2000 mm above the highest occupied level and should not be greater than 80% of the depth of a bounding element of a smoke reservoir

- reservoirs with an aspect ratio of greater than 5:1 should be avoided

- the hot layer temperature should not be greater than 180ºC, unless all occupants have left the building.

Table 2: Summary table of the test methods of AS 2428.

AS 2428 part number	Title of part	Principle of test method	Failure criteria (where appropriate)
Method 1 (AS 2427.1 2004)	Determination of resistance to leakage during rain	"The smoke/heat release vent is mounted in a section of roof and subjected to an airstream into which water has been introduced to simulate wind-blown rain. The vent is monitored visually from inside the roof for signs of water penetration. The maximum wind velocity at which the vent resists the entry of water i.e. the rain leakage wind velocity v_r, is determined."	Qualitative determination of visible water penetration within the vent boundary
Method 2 (AS 2427.2 2004)	Determination of ability to operate under wind loading	"The smoke/heat release vent is mounted in a section of roof and subjected to an air stream. The ability of the vent to withstand the effects of wind and to operate in wind is observed. The maximum wind velocity at which the vent is capable of opening and remaining open i.e. the maximum wind velocity for operation v_o, is determined."	Failure of vent to operate at wind velocities less than or equal to 16 m/s
Method 3 (AS 2427.3 2004)	Determination of operating characteristics	"The smoke/heat release vent is mounted over a gas burner and the characteristics of its operation are observed at different temperatures."	Failure of the vent to open fully before reaching 300ºC for either the slow heating rate (10 ± 2 ºC/min) or the rapid heating rate (200 ± 20 ºC/min)
Method 4 (AS 2427.4 2004)	Determination of the effect of flame contact	"The smoke/heat release vent is mounted over a gas burner and the effect of contact with a specified flame is observed."	Failure of the vent to open fully within 30 min of the application of a 100 kW/m² flame or more than 10% of the throat area is obstructed or reduced
Method 5 (AS 2427.5 2004)	Determination of discharge coefficient and effective aerodynamic area	"The airflow and pressure drop through a smoke/heat release vent is measured. From the measurements, the discharge coefficient is determined and the effective aerodynamic area is calculated."	N/A
Method 6 (AS 2427.6 2004)	Determination of ability to operate under snow loading	"The smoke/heat release vent is uniformly loaded to simulate a cover of snow. The ability of the vent to operate under those conditions is observed."	Failure of the vent to fully open while a uniformly distributed load of 45 kg/m² is applied

Details of buoyancy-driven smoke control include:

- vent operability is required to comply with AS 2427 (covering rain and wind leakage, operation in wind, operation under snow load, structural adequacy and corrosion resistance of vent materials, with additional requirements for areas cyclonic conditions according to AS 1170.2)

- equations for the calculation of effective aerodynamic area, vent outlet area and vent inlet area are provided

- designed ratios of inlet to outlet effective aerodynamic vent areas as low as 1.25 are allowed.

Details of smoke reservoirs and zones include:

- maximum permitted size of a smoke reservoir is 2000 m²

- maximum horizontal distance between any two points within the smoke reservoir is 60 m

- minimum smoke curtain depth is one-fifth the height between compartment floor and imperforate ceiling/roof

- maximum smoke depth for calculations is one-sixth the height between compartment floor and imperforate ceiling/roof

- for high fire load areas, smoke reservoirs should extend to the maximum depth as practicable, ideally to within 3 m of the floor.

Vent control details include:

- automatic initiation of smoke control systems is required to be via smoke detection in addition to fusible links designed for simultaneous operation of all vents in the smoke reservoir

- initiation temperature should be no greater than 68ºC, unless elevated temperatures are associated with processes conducted in the building or geographical location etc

- vent operation is by electrical, pneumatic, fusible link or mechanical means, with remote manual operation provided.

An informative part of the Appendices notes that "… changes in the concept of natural ventilator operation from individually opened vents to every vent opening at once as early as possible has resulted from the outcome of research by the Building Research Establishment in the UK. This concept is still challenged by Factory Mutual in the US. This may be because they do not have the facilities to test ventilators in the configurations that are likely to be installed …" (AS 1665.3 2001)

2.5.5 NFPA 204: Guide for smoke and heat venting

NFPA 204 (2002) describes the general requirements (including inlet air and draught curtains), activation and operation of smoke and heat vents. A list of acceptable test methods is also provided.

NFPA 204 (2002) permits (normally closed) "mechanically opened" or "thermoplastic drop-out" vents listed and labelled according to either:

- UL 793 Standard for Automatically Operated Roof Vents for Smoke and Heat
- UBC Standard 15–7, Automatic Smoke and Heat Vents
- Factory Mutual Research Standard 4430, Heat and Smoke Vents, or
- other approved nationally recognised standards.

General vent requirements:

- actuation of vent(s) is required to be by activation of detector(s), including heat detector, smoke detector, fusible link, sprinkler water-flow switch etc
- thermoplastic drop-out vents are the only type of heat vent not required to fail in the open position
- thermoplastic vent materials:
    - polyvinyl chloride (PVC) and acrylic are given as examples of possible materials suitable for drop-out vents
    - ultraviolet light degradation of the thermoplastic is listed as a potential cause for failure of the vent to respond at the design activation temperature. Using vent dome materials with ultraviolet stabilisers is suggested as one possible means of prevention.
- Design fire:
    - steady fires are permitted for special hazards, such as storage with separation previously demonstrated to prevent flame spread
    - continuous-growth fires are assumed to take the t^2 form
- LAVENT is recommended for vent design, and the LAVENT user's guide and worked example is included in the Annexes of NFPA 204.

Air inlets:

- activated by detector in the event of a fire
- must fail in the open position
- air inlet size must be equal to or larger than required to service the largest smoke reservoir.

Draught curtains:

- must extend to cover a minimum of 20% of the height from the centre of the vent to the floor (the ceiling height)
    - for draught curtains extending to a depth of 30% or more, the maximum width of length of a draught curtain is 8 times the ceiling height, or

- for draught curtains extending to a depth of less than 30%, the maximum width of length of a draught curtain 1 times the ceiling height.

Inspection and maintenance:

- manual release is required and must be tested annually
- although thermoplastic drop-out vents do not allow non-destructive operation, inspection of the installed units must be carried out annually to ensure installation is in accordance with the manufacturer's instructions and that all components are in place, and free of damage or items that might interfere with the operation of the unit.

Mechanical smoke exhaust systems and venting in sprinkled buildings are also covered. However, this is not within the scope of this report (NFPA 204 2002).

2.5.6 UBC Standard 15–7: automatic smoke and heat vents

Universal Building Code Standard 15–7 describes activation, operation and test methods for automatic smoke and heat vents (UBC Vol.3 1997). UBC Standard 15–7 permits the method of vent activation to be either:

- a fixed-temperature device (activating at least 17ºC above the maximum expected ambient temperature)
- a rate-of-temperature-rise device, or
- an approved "heat-sensitive glazing designed to shrink and drop-out of the vent opening" (UBC Vol.3 1997).

Minimum live loads for vent operation to be tested under is 4 N/m², with any increase for snow loading to be determined by the local building official.

The requirement for operation is for the vent to be fully open within five minutes when subjected to a time-temperature gradient that heats the air from ambient to 260ºC in 5 minutes. The test method requires the specimen to be supported 890 mm above the floor. Two thermocouples are to be located 25.4 mm below the highest point of the vent cavity. Isopropyl alcohol is used as the heat source in a centrally located tray (305 × 305 mm with 13 mm deep fuel). Correction of the calibration of the test method is made by varying the height of the vent from the floor or the height of the fuel pan. No flame impingement is allowed on the sample during testing.

Each sample unit is to be tested successfully five times, however drop-out glazing only requires one successful test since release of the glazing is the expected successful test response.

Vents are required to be labelled with the name and location of the manufacturer, vent model and year of manufacture.

3. BACKGROUND FOR CURRENT NEW ZEALAND REQUIREMENTS

3.1 Definitions of fire venting

There was no mention of fire venting in the original predecessor to the Acceptable Solutions, NZS 1900 Chapter 5 (NZS 1900/5 1963).

However in the draft standard DZ 4226 that preceded the publication of the Acceptable Solutions for C1, C2, C3 and C4 of the Fire Safety Clauses of the Building Code, fire venting was defined as "… a fire safety measure whereby the effects of a fire are vented through the roof by an approved method, in order to limit the horizontal spread of fire in a storey …" (Definitions of DZ 4226 1984). Background (Woods 1972, Bastings 1988) for this document indicated that fire venting was included in this draft because it was recognised as adding value for controlling fires in single-storey buildings, and that although the technology was known and hardware available NZS 1900.5 did not require fire venting.

Furthermore, in the comment following the definition for 'opening', materials that would provide clear openings in the event of fire were discussed. Plain window glass and thermoplastic sheeting that shrinks, melts or burns readily when exposed to fire were specifically listed as appropriate materials that would fail and provide openings for ventilation in the event of a fire. It was noted also that quick opening to provide ventilation was important (Definitions of DZ 4226 1984).

The draft document (DZ 4226 1984) also had a number of paragraphs (3.2.3.7 and 7.10) specifically describing fire venting. Specifications included installation complying with AS 2427, size and operation, smoke reservoirs, draught curtains and air inlets.

Operation of fire vents was to be (Clause 7.10.2 of DZ 4226 1984):

- openings that were permanently open, or
- openings (as described in the definitions) that would open quickly when exposed to fire, or
- activated by heat sensors as well as manual operation.

It was noted that vents made from materials designed to soften and deform may not be approved if they were reinforced with a non-combustible material, such as might be used to prevent injury when the vent material impacts the floor below (7.10.2.b of DZ 4226 1984).

Sizes for effective vent areas were to be calculated as a percentage of the smoke reservoir floor area (7.10.2.d of DZ 4226 1984):

- 1.5% for low and medium fire severity use classes, and
- 3% for high fire severity use classes.

These values for effective fire venting areas were based on the requirements in the Australian Model Uniform Building Code (7.10.5 Comment of DZ 4226 1984). Furthermore, in background material for this draft it was noted that the values for vent areas were arbitrary (Woods 1972, Bastings 1988).

Smoke reservoirs were to have a maximum area of 1000 m^2 (7.10.3 of DZ 4226 1984). This value for the maximum smoke reservoir area was based on the requirements in the Australian

Model Uniform Building Code (Comment following 7.10.5 of DZ 4226 1984). Draught curtains (or smoke screens) were to have a minimum depth of 1.5 m (7.10.3 of DZ 4226 1984) and be constructed of non-combustible, non-shattering, rigid sheeting (7.10.4 of DZ 4226 1984). The values for maximum smoke reservoir area and depth of draught curtains were taken from the Australian Model Unified Building Code (Woods 1972, Bastings 1988).

In general, fire venting design was to be based on the method described in the BRE Research Technical Paper No. 10 – "Design of Roof Venting Systems for Single Storey Buildings", NFPA 204: "Guide for Smoke and Heat Venting", or "Smoke Control in Fire Safety Design" by EG Butcher and AC Parnell (7.10.5 and Comment of DZ 4226 1984). However, the chapter on "Smoke Control in the Fire Area" by Butcher and Parnell (Butcher and Parnell 1979) is primarily based on the research of Thomas and Hinkley et al (Hinkley and Theobald 1966, Thomas and Hinkley 1964, Thomas et al 1963).

3.1.1 BRE Fire Research Station investigations

The work performed by Thomas and Hinkley et al (Hinkley and Theobald 1966, Thomas and Hinkley 1964, Thomas et al 1963), cited in DZ 4226 (1984) and AS 2665 (2001), investigated the effect of a hot gas roof vent in a single-storey building experimentally and theoretically. The venting of small fires (using theoretical and experimental approaches) and large fires (using theoretical approaches and compared to small-scale testing) were considered. The primary conclusions of the work included:

- A significant increase in the effectiveness of roof vents caused by semi-compartmentation of the roof space using screens extending downwards from the ceiling, based on observations (Thomas and Hinkley 1964).

- Automatic initiation of vents is generally desired (Thomas and Hinkley 1964).

- "… Roof venting systems can be designed with small vents to provide clear layers of air at ground level, free from hot gases and smoke and thus enable the fire to be approached ..." (Thomas et al 1963).

- "Systems with large vents provide a means of restricting the spread of flames under the ceiling from fires covering large floor areas." (Thomas et al 1963).

- Required vent areas depend on the area of the fire, not the area of the building (Thomas and Hinkley 1964).

- "The larger the building the less valid the most frequently made objection to venting (i.e. that it makes the fire burn faster) since the longer it will be before the fire becomes starved." (Thomas and Hinkley 1964).

- Roof venting exposes nearby buildings sooner (Thomas and Hinkley 1964).

- Protection of the roof near vents is required (Thomas and Hinkley 1964).

- If rapid flame spread is permitted due to the flammability and deposition of materials on the floor, then the opening of roof vents may facilitate fire-fighting but would be unlikely to reduce the damage caused by the fire (Thomas and Hinkley 1964).

Further information on the experiments performed by Thomas and Hinkley are included in Section 4.5.1.

3.1.2 Australian Model Uniform Building Code

In summary, firecell area was permitted up to 18,000 m² for single-storey non-isolated unsprinklered building (of specified Type 2 or 3 construction) if appropriate roof venting was designed (Clauses 19.3 and 19.2 of AMUBC 1983). The roof venting design was to include smoke reservoirs, approved automatic smoke and heat vents and parapets. Unlimited firecell area (i.e. >18,000 m²) had the same requirements in addition to being sprinklered throughout. Relevant extracts from the Australian Model Uniform Building Code (AMUBC 1983) are included in Appendix A for completeness.

Smoke reservoir requirements included materials and thicknesses, depth (1.5 m), maximum areas (1000 m²), and maximum distance between opposite sides of a reservoir – 30 m in spaces of abnormal fire hazard (Clause 19.6 of AMUBC 1983). The activation temperature of the vents was not to be less than 5ºC above any sprinkler system activation temperature (Clause 19.7 of AMUBC 1983). The minimum effective compartment vent areas were 3% of each compartment floor area, for areas of abnormal fire hazard, and 1.5% of each compartment floor area, for all other cases (Clause 19.7 of AMUBC 1983).

3.1.3 UL 793 Standard for automatically operated roof vents for smoke and heat (1997)

Operation of the smoke and heat vents upon exposure to fire is either by:

- a fusible link, or
- a plastic dome shrinking and falling out of place.

Approved vents are listed after successful testing by the Underwiters Laboratory. Temperatures for operation are indicated in the individual listings (Underwiters Laboratory 2007). The test criteria used by both the Underwiters Laboratory and Factory Mutual for testing smoke and heat vents is that the vent must reach the fully open position within 5 minutes after initial exposure to 260ºC (C/S Group 2007).

3.2 Fire venting and firecell area increases and S ratings

The current requirement of 15% roof area as effective fire venting for unlimited firecell floor area in an unsprinklered building is identical to the December 1993 amendment of the 1992 version of the Acceptable Solution (Paragraph 3.7.2 of NZBC C3/AS1 Amd.1 1993). "Only roof venting which is specifically designed to open or melt rapidly in the event of a fire shall be included in the area A_h." (Table 1 Note 3c of NZBC C3/AS1 Amd.1 1993)

Prior to this, there were no ventilation requirements for an unsprinklered single-floor building of unlimited firecell floor area and fire hazard categories 1 to 3 (Table 1 of NZBC C3/AS1 1992). However, 'adequate ventilation' was required for buildings for buildings of more than one storey with increases in S ratings required for lack of ventilation. Maximum firecell floor areas were prescribed for all buildings of more than one storey with no increases permitted for ventilation.

Adequate ventilation was described as, "… no less than 15% of the roof area of the firecell is available for venting, or the area of openings (A_v) in the external walls of a firecell with floor area A_f (m²) satisfies any of the following criteria:

1. $A_v = 0.2\ A_f$, where A_f is not >300 m²
2. $A_v = 60$ m² where A_f >300 m² but not >600 m²
3. $A_v = 0.1\ A_f$, where A_f >600 m²…" (Paragraph 3.7.2 of NZBC C3/AS1 1992).

There were no roof ventilation requirements in the previous regulations, NZS 1900 Chapter 5 (NZS 1900/5 1963; NZS 1900/5 1988).

Preceding the development of the new NZBC and the associated Approved Documents (NZBC C1,C2,C3,C4/AS1 1992) to replace the previous building regulations for fire safety (NZS 1900/5 1963), a draft standard was released for comment DZ 4226 Design for fire safety (1984). This document suggested a 50% increase in maximum storey areas (listed in Table 3) for single-storey buildings protected by fire venting – see Figure 1 (Clause 3.2.3.7 of DZ 4226 1984, Woods 1972). The comment associated with this clause suggested that fire venting decreases the risk of fire spread throughout the storey by releasing the effects of fire as well as improving visibility and fire-fighter access to the seat of the fire. It was also cautioned that fire venting is not the same as venting achieved after structural collapse of the roof (Clause 3.2.3.7 Comment of DZ 4226 1984). These recommendations were based on NFPA 206M Clause 503(c), AMUBC Clause 19.3, and research results of Woods (1972) (Bastings 1988).

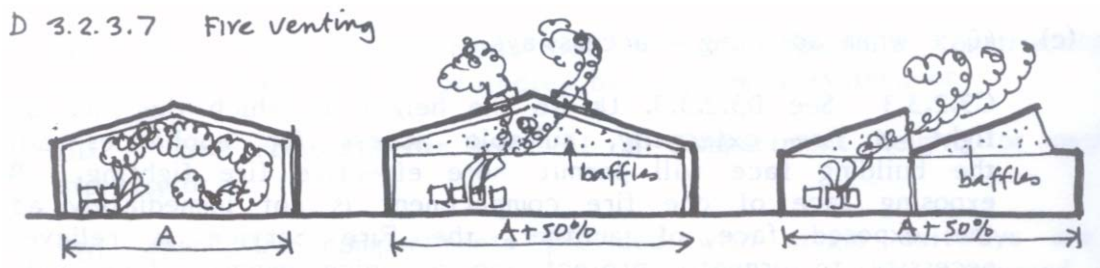

Figure 1: Schematics of fire venting as described in the draft of DZ 4226:1984. Extracted from (DZ 4226 1984).

Table 3: Maximum area of fire compartments. Adapted from (Table 3.1A and Comment of DZ 4226 1984, NZS 1900.5 1963).

	Maximum storey areas (m²)			
	Without sprinkler system			**With sprinkler system**
Maximum compartment height	4 m	13 m	31 m	No limit
Storey limit	Not over one	Not over four	Not over ten	Over ten
Maximum fire load density	20 kg/m²	40 kg/m²	80 kg/m²	
Use classes:				
AS, AM, AL, SC, SD, SA, SS, SH, CO, ML	4000	3000	2000	4000
MM, CS	3000	2250	1500	3000
MH	2000	1500	1000	2000

The data for maximum compartment sizes in DZ 4226 (1984) (as presented in Table 3) was taken directly from Table 1 in NZS 1900.5 (1963). The floor area was not taken as a proportion to the assumed/designed fire load. Larger than proportional floor areas were taken by the sub-committee because of assumptions that "… inefficient combustion conditions and heat losses through the external skin of the building, the full calorific impact of the fire load is usually unable to be applied within the fire compartment" (Bastings 1988).

The heights of compartments, as presented in Table 3, are controlled by the number of storeys or the height of the fire load ceiling. The values were based on the 1963 Bylaw (NZS 1900.5 1963). The 4000 m² permitted area was then reduced by 75% for up to four unsprinklered storeys, and by 50% for up to ten. It was suggested that the decrease in area should be proportional to the increase in fire load density (Explanation of Table 3.1A DZ 4226 1984).

3.3 Roof venting and FRR concessions

It was noted in the comment of the definition of 'opening' in the draft standard preceding the Acceptable Solution, that the quick-opening venting areas that admit air and allow heat to pass through were of vital importance in calculating the percentage of ventilation for determining FRR values (Definitions of DZ 4226 1984). However fire venting and roof venting caused by the failure of unprotected areas of roof are considered separately. Roof venting was not to be considered as providing ventilation. "Its principal effect is to release a great deal of the heat of a fire, and while this may be highly spectacular, it actually diminishes the danger to adjoining fire compartments through horizontal spread of fire: which is the reason for the reduced FRR to compartment separations …" (Paragraph 5.3.2.6 Comment of DZ 4226 1984).

FRR concessions were suggested for roof venting when (Paragraph 5.3.2.6 of DZ 4226 1984, see also Figure 2):

1. unprotected roof elements had been constructed over a minimum of two-thirds of the storey area (i.e. without any ceilings, or linings which could provide any form of FRR), or

2. in addition to the requirements of any fire vents, at least one-third of the storey area of the roof was designed to rupture relatively early in the development of a fire at the highest locations in the roof.

Again these roof areas were arbitrarily selected (Bastings 1988)

The relationship between percentage of ventilation of all exposed faces of the building and the FRR for unsprinklered buildings with unprotected roof construction is presented in Table 4 (Paragraph 5.3.2.7 and Table 3.5A of DZ 4226). The basis for these calculations was separations with half-hour FRR or less could burn through, and thus increase the area involved in the fire and subsequently lead to an increase in the ventilation area (Bastings 1988).

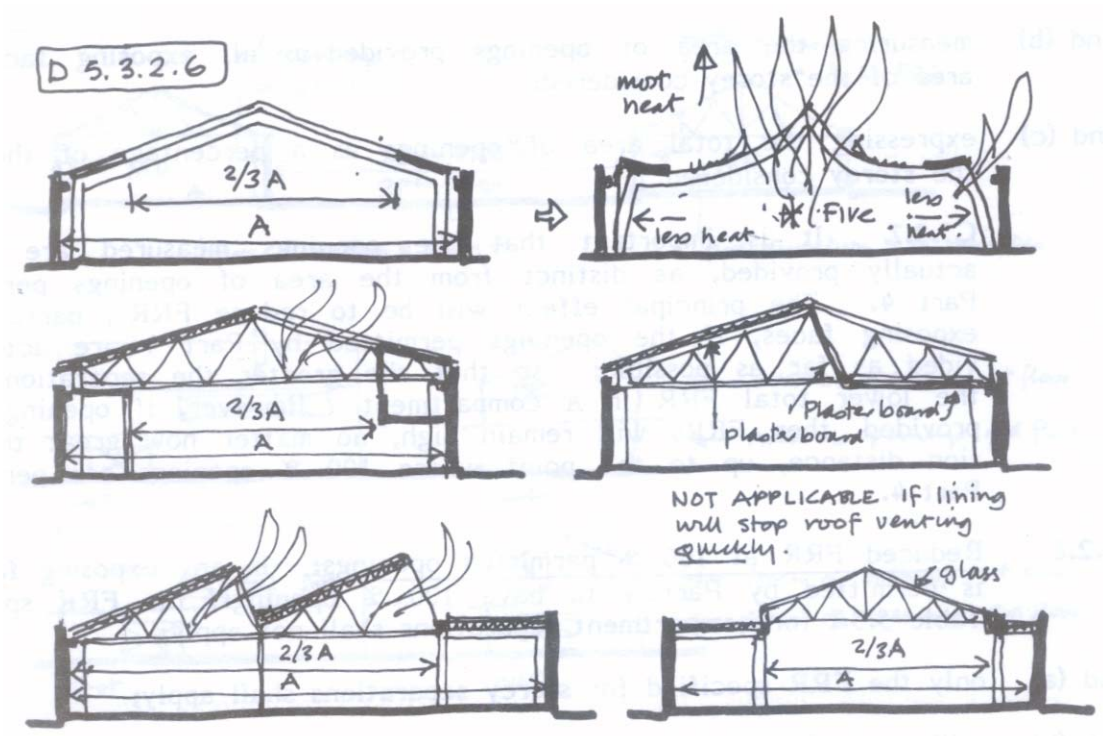

Figure 2: Schematics of non-rated roof construction areas for FRR concessions in addition to fire venting provisions as described in the draft of DZ 4226:1984. Extracted from (DZ 4226 1984).

Table 4: Minimum fire resistance ratings (in hours) for major elements of fire compartments for unsprinklered single-storey industrial/storage buildings, where the fire load ceiling is not over 4 m. Adapted from Table 5.2.A.1 of (DZ 4226 1984).

Use classes	Roof structure or compartment separation	Total area of openings provided, as percentage of storey area provided for							
		75% or more	50% min.	38% min.	25% min.	19% min.	12.5% min.	9.5% min.	6.5% min.
MxL, ML,	Roof	-	-	-	-	-	-	-	-
AS, AM, AO	Compart. inside face	½	½	½	½	½	¾	½	¾
SS, CO, GL	Compart. outside face	½	½	½	½	½	½	½	¾
MM	Roof	-	-	-	-	-	-	-	-
CS, GM min.	Compart. inside face	½	½	½	¾	1	1½	2	3
	Compart. outside face	½	½	½	½	½	¾	1	1½
MH	Roof	-	-	-	-	-	-	-	-
GH min.	Compart. inside face	½	¾	1	1½	2	3	4	4
	Compart. outside face	½	½	½	¾	1	1½	2	3
MxH	Roof	-	-	-	-	-	-	-	-
GH max.	Compart. inside face	1	1½	2	3	4	4	4	4
	Compart. outside face	½	½	1	1½	2	3	4	4

4. PRINCIPLES OF FIRE VENTING

The fire safety problems of fire venting are dependent on a range of time-dependent parameters including (SFPE Handbook 2002, Heskestad 1986, Butcher and Parnell 1979):

- fire characteristics
- geometry of the building, including where the openings are located
- plume dynamics
- thickness and temperatures of the smoke layer
- numbers and size of active vents.

A summary of the advantages of using venting smoke and heat in building design include (Cosgrove 1996, Hansell 1993):

- increases the duration and height of the lower layer, which:
  - facilitates a safe means of escape
  - aids fire-fighters accessing the seat of the fire
  - allows purging of smoke after the fire is under control
- increases the probability of controlling the fire, which:
  - reduces property and contents damage caused by smoke and hot gases
  - lowers the risk of explosion due to build-up of unburnt gases
- reduces compartment temperatures, which:
  - lowers the risk of flashover
  - limits the number of sprinklers activating (if present).

Fire venting or smoke control may be of limited value in terms of preventing flashover for some building configurations or situations. For example, the storage of combustible materials in high rack storage areas, where the proximity of other items and/or the location of items within the hot layer occurs, flashover is likely to transpire regardless of the presence of a smoke control system and venting is of little use (Hansell 1993, Butcher and Parnell 1979). However, if the configuration of combustible material is such that fire spread is primarily caused by heat radiated downwards from the hot layer below the roof, then venting is particularly valuable (Butcher and Parnell 1979).

The design principle of fire venting is that the hot gas layer forms beneath the roof, developing a pressure difference that would drive smoke through any roof vent. As the hot gas layer increases, the pressure driving the vent flow rate increases. Assuming a steady-state heat release rate, and that adequate make-up air is available to complement the flow of hot gases through the roof vents, at some stage an equilibrium will be reached and this is the design point for the venting system (Butcher and Parnell 1979).

Hinkley (1992) proposed a correlation between smoke mass rate production and vent size, such that for a 'large' fire, when the smoke production rate equals the vent flow rate then (in combination with Eqn 4):

$$A_v = 0.13\, P\, y^{3/2} / (h - y)^{1/2}$$ **Equation 1**

Where A_v = measured throat area of ventilators for the reservoir being considered (m²)
P = perimeter of the fire (m)
h = height of the firecell (m), and
y = height of the clear layer (m).

Similarly, another theoretical estimate of the aerodynamic vent area incorporating the ambient and hot layer conditions is given by (Milke and Klote 1998, Morgan and Gardner 1990):

$$A_v C_v = \frac{\dot{m}}{\rho_o} \sqrt{\frac{T_c^2 + (A_v C_v / A_i C_i)^2 T_o T_c}{2 g d_b \theta_c T_o}}$$ **Equation 2**

+ 10% if the total inlet area is twice the vent area, or

+ 35% if the total inlet area is equal to the vent area.

Where $A_v C_v$ = aerodynamic free area of natural ventilation (m²)
A_v = measured throat area of ventilators for the reservoir being considered (m²)
A_i = total area of all inlets (m²)
C_v = coefficient of discharge (usually between 0.5 and 0.7)
C_i = entry coefficient for inlets (typically about 0.6)
$\dot{m}$ = mass flow rate of smoke to be extracted (kg/s)
ρ_o = ambient air density (kg/m³)
g = acceleration due to gravity (m/s²)
d_b = depth of smoke beneath ventilator (m)
θ_c = temperature rise of smoke layer above ambient (ºC)
T_c = absolute temperature of smoke layer (K), and
T_o = absolute temperature of ambient layer (K).

Equation 2 was further developed by Milke and Klote (1998), using the assumption of an adiabatic smoke layer, which is reasonable for tall clear height with modest temperature rise of the smoke layer (and an over-estimate for short clear heights). Therefore the temperature rise of the smoke layer above ambient could be estimated as:

$$T_c - T_o = \frac{\dot{Q}_{conv}}{\dot{m} c_p}$$ **Equation 3**

Where c_p = specific heat of smoke (kJ/kg.K), and
$\dot{Q}_{conv}$ = convective portion of the heat release of fire (kW).

Unfortunately, the 15% roof venting area required for unlimited firecell floor size and associated background information provides insufficient detail as to the design fire characteristics or steady-state flow conditions (including hot layer depth) that this value was based on. Therefore comparison with the above equations (Eqns 1 or 2) is not possible.

Individual fire vent sizes must be limited to prevent air from the clear layer below being extracted together with the gases from the hot layer (plug-holing) and large enough to limit throttling (or choked flow conditions) of the flow. Individual make-up-air vent sizes must also be large enough to limit throttling of the inlet flow (Hinkley 1992, Heskestad 1986). Hinkley suggested maximum critical vent sizes based on the Froude number, F_C. Then the maximum critical vent size is determined by the empirical relationship (Hinkley 1992):

$$(A_v)_{crit} = 0.707\, F_C\, (h - y)^2 / C_v \qquad \textbf{Equation 4}$$

Where A_v = measured throat area of ventilators for the reservoir being considered (m^2)

C_v = coefficient of discharge (typically about 0.6)

F_C = Froude number (2.0 for vents near the side of a smoke reservoir and 2.5 for vents near the centre of a smoke reservoir)

h = height of the firecell (m), and

y = height of the clear layer (m).

Natural vents will not work when sited in a position subject to positive wind pressures. However, powered smoke extraction is required in this situation. Powered vents and natural vents should not be used in the same smoke reservoir (Morgan and Gardner 1990).

4.1 Vent operation

The four general categories of vent operation are actuation by fusible-link, mechanical operation initiated by detector activation, manual operation, or drop-out panel or combination of these. Vents may be dependent on a single device or a group of vents may be ganged together and activated by a single device (*SFPE Handbook* 2002). A range of fire vents utilising these modes of operation are currently available in the New Zealand or Australian markets.

4.1.1 Fusible link actuation

Fusible link actuation relies on the melting of a eutectic strip, by forced convection of the hot fire gases, to release a mechanism to open the vent. For example, a spring-loaded mechanism may be released to open the vent upon thermal failure of the soldered restraint (Cooper 1998, 2000).

4.1.2 Mechanical operation

Mechanical operation of a vent or multiple vents in an area may be activated by a detector (e.g. a heat detector as required by AS 2665 2001).

4.1.3 Manual operation

Manual operation of a vent is a typical over-ride or safety feature required (e.g. AS 2665 2001).

4.1.4 Drop-out panel

Drop-out panels operate by opening of the vent area by the panel dropping out as a reaction to the local environment. A drop-out-type vent unit involves a vent frame, where the opening is covered by a vent dome. The dome is formed plastic sheeting designed to soften, shrink and drop-out of the frame when heated to an ‘activation’ temperature. The dropping-away of the vent material leads to the open vent configuration. Similar to the case of a fusible link, the heating of the drop-out panel vent is primarily by convective heat transfer from the high temperature gases flowing across the ceiling and across the lower surface of the vent-dome plastic (Cooper 1998, 2000).

This type of vent operation is the closest to the type of passive fire venting commonly used in New Zealand that utilises plastic sheeting and is the primary focus of this report. However unlike elsewhere, the most typical construction method practised in New Zealand does not use a frame, therefore there is no manual operation mode available. Failure of the venting material to form an opening requires the material to be physically broken out, which is a particularly dangerous option during a fire event.

4.2 Ceiling jet

The ceiling jet is an important factor when considering the operation of fire vents, whether the thermal response of fusible-links, passive material response (such as drop-out vents) or detectors are of interest. In all cases the convective heating of the device is dependent on the local time-dependent temperature and velocity distributions of the ceiling jet (SFPE Handbook 2002).

Ceiling jets have been the subject of a range of investigations (Cooper 1993; Dembsey, Pagni and Williamson 1995; Heskestad and Hamada 1993; Motevalli 1994; Tuovinen 1996; William 2002). However the majority of studies have focused on smaller compartment sizes than may be applicable for the scale of the enclosures of this research. Results from larger-scale investigations are discussed in Section 4.5.2.1. Results of investigations for the prediction of the interaction of ceiling jet temperatures and thermally activated devices are discussed in Section 4.5.2.

4.3 Smoke reservoirs

Smoke reservoirs are an integral part of a fire venting system. Smoke reservoirs serve to contain the initial hot fire products in the area above the fire, which limits the spread of the hot layer and allows the hot layer depth to increase faster, subsequently activating thermal devices sooner compared to a hot layer spreading across the entire firecell area. Smoke reservoirs can be designed using saw-tooth roof construction or internal partial partitions suspended from the roof (draught curtains). The ceiling jet in a curtained space of fire origin is approximated to have a depth of the order of 10% of the height between the seat of the fire and the ceiling (SFPE Handbook 2002). It is typically recommended that the minimum depth of draught curtains is approximately 20% of the height between the floor and ceiling (NFPA 204 1998, SFPE Handbook 2002). Construction details are provided in the appropriate standard(s) – see Section 2.5.

4.4 Flow of gases through horizontal ceiling vents

There have been several investigations into the flow of hot gases through horizontal ceiling vents. These are discussed further in the following Section (4.5).

A basic approach to estimating vent flow using Bernoulli's equation to estimate the assumed one-way flow through a horizontal vent predicts unidirectional flow where the direction is solely determined by the pressure difference across the vent (Emmons 2002). Epstein (Tu 1991) developed theoretical regimes for zero-pressure difference buoyancy-driven horizontal vent flow. Cooper (1989) extended Epstein's theoretical regimes to develop a uniformly valid general vent flow model based on pressure, vent diameter and gas density (Cooper 1989). Both density and pressure differences across the vent control the flow through horizontal ceiling vents in compartment fires.

4.5 Fire venting experiments and modelling

4.5.1 Fire venting experiments

A summary of the most directly relevant experiments published is included in Table 5.

Table 5: Summary of published passive roof fire venting experiments.

General description	Compartment height (from floor to centre of vents) (m)	Fire perimeter (m)	Type of fire	Convective heat output per unit area (kW/m^2)	Height of clear layer (m)	Reference
Pitched roof tests	0.7	1.22 and 0.7	Crib	270 – 340	0.27 – 0.42	(Thomas, et al 1963)
Box tests	1.35	4.3	Crib	350 – 610	0.28 – 1.1	(Thomas, et al 1963)
PVC rooflight tests	4.3	4.8 and 7.2	Crib	630 and 520	1.9 – 2.3	(Hinkley and Theobald 1966)
Colt International Portsmouth Fire Test	7.5	9.8	Crib	500	4.0	(Hinkley 1986b)
Aircraft hangar tests	15	5.4 and 16.2	Tray of Avtur	1800	13 – 14	(Duong 1990, Hinkley 1986b)

Hinkley and Theobald (1996) investigated 1.15 m square-sections of corrugated (0.156 m section) rigid PVC rooflights for use in fire venting for single-storey buildings. The conclusions from the experiments included:

- Results from experiments indicated that the PVC rooflights tested "… will soften and fall out leaving a clear area for venting when flames from a spreading fire are approaching the ceiling. They are therefore suitable for providing the large vent areas required for large free-burning fires…" (Hinkley and Theobald 1966).

- Most of the heating of the rooflights in the small fire experiments was attributed to radiation from the flames.

- To ensure sufficient heat transfer to melt the PVC rooflights used in these experiments, it was estimated that the hot gases beneath the roof would require a temperature of at least 300ºC if fully emissive (very smoky) or higher if not.

- The PVC used in the rooflight experiments had a melting temperature of approximately 200ºC. This temperature was high enough to cause damage on contact with exposed skin.

- Potential hazards were identified of intact rooflights or large softened areas of rooflight material falling from the roof, large enough to cover fire-fighters. In addition there is little information on the tenability of the compartment at the moment when rooflights fail. Therefore further experiments were recommended to assess the hazard to fire-fighters.

- The effect of wind on the venting performance was identified as being significant, and the size of individual vents may potentially need to be restricted.

Other experimental investigations have been performed to study the flow of hot gases through permanently-open horizontal vents (Than and Savilonis 1993, Thomas et al 1963, Tu 1991) using relatively small enclosures (cubes of approximately 0.4–0.6 m).

For example, Tu (1991) performed small-scale experiments in top-only vented compartments (0.43 m × 0.43 m × 0.43 m). The numbers quoted below follow for this example. In each similar experiment (Than and Savilonis 1993, Thomas et al 1963, Tu 1991), the flow through the single horizontal vent both released hot gases and allowed make-up air into the compartment either simultaneously or with an alternating unidirectional flow regime. Three general flow conditions were reported:

1. self-extinguishment of the pool fire (for vent diameters $0 < d < 0.089$ m and mass burning rates of approximately 0.09 kg/h)

2. erratic pulsing of the pool fire (with weak pulsation for vent diameters $0.089 \text{ m} < d < 0.102$ m, or strong pulsation for vent diameters $0.102 \text{ m} < d < 0.152$ m and mass burning rates of approximately 0.22–0.27 kg/h), or

3. strong steady burning of the pool fire (for a vent size of 0.305 m × 0.305 m and mass burning rate of approximately 0.5 kg/h).

In each case, it was concluded that the vent flow was simultaneously both in and out of different areas of the vent. Further investigation and larger-scale testing was recommended.

4.5.2 Modelling vent actuation and performance

Comparison of experimental results with several theoretical estimates of hot gas production rates (Hinkley 1986b) indicated the empirical relation of:

$$M = 0.188 P y^{3/2}, \qquad \textbf{Equation 5}$$

where M is the mass production rate of hot gases (kg/s), P is the perimeter of the fire (m), and y is the height of the clear/low-temperature layer (m), provided a better fit of the experimental data than other correlations, which were more soundly-based equations based on different experimental situations. The relation described in Eq. 1 was shown to have good correlation with previous experimental results for fires having heat outputs in the range of 200 to 750 kW/m² and linear dimensions of the height of the clear layer as small as 0.1 m.

Hinkley (1986, 1989, 1992) investigated sprinkler operation and venting using the zone model developed by Thomas et al (1963) specifically for modelling roof venting. Hinkley extended the model to include the estimation of the radial temperature distribution near to the ceiling above a fire. The focus of the study was primarily on the time of activation of the first sprinkler, rather than the effectiveness of venting. The model results were compared to some experimental work, although it was noted that more experimental work was required before the model could be fully validated.

Conclusions and recommendations were based on the indicative results of the model. The conclusions of the work included that venting was a relatively unimportant variable for the modelled fire size at time of sprinkler operation, except for small compartments with slow fire growth. Furthermore it was recommended that the effect of any potential delay in sprinkler activation times caused by venting would be negligible relative to the advantages of a clear atmosphere within the fire compartment (Hinkley 1986a, 1989, 1992). The near-ceiling temperature estimations used to predict the operation of sprinklers (Davis WD and Cooper 1991; Hinkley 1989, 1992) and thermal detectors (Stroup and Evans 1988) may also be useful in the prediction of passive fire venting operation, although previous research has not made use of this application in modelling to-date.

Poreh and Trebukov (2000) investigated the wind effects on passive smoke control systems for stairwells using a zone-model approach. Although the size of enclosures was smaller than are considered within the scope of this report, the results of this study indicated the strong influence of wind on the performance of a passive smoke control system (Poreh and Trebukov 2000). Therefore the wind effects need to be taken into account in both modelling and experimental approaches.

The computer program, LAVENT (fusible-Link-Actuated VENTs) (Davis WD and Cooper 1989), is listed in NFPA 204 (NFPA 204 1998) and noted in the SFPE Handbook (2002) as being able to simulate most of the time-dependent phenomena associated with ceiling jets and vent actuation for a wide range of fire types. It is noted that LAVENT uses the plume model expressed in the SFPE Handbook but it currently does not account for wind effects, reduced effectiveness of limited-area vents, or modifications of buoyancy-driven vent-flow. Cooper (1990a, 2000) used LAVENT to simulate the activation times of a three-element fusible-link-mounted vent using plunge-test data of the links. Simulated results compared well to results of a compartment experiment, when time for the solder-melt phenomenon to occur was included in the theory. A similar model is not currently available to predict the opening time of a drop-out type vent.

4.5.2.1 <u>Large-compartment fire modelling approaches</u>

Duong (1990) modelled a fire (4 and 36 MW) in an aircraft hangar (94 × 54 × 15 m) using various zone models. The building was modelled using multiple adjacent compartments. The results for the 4 MW fire scenario were in reasonable agreement compared to previous experimental data for all modelling considered. For the 36 MW fire, the model results using FAST over-predicted the experimental results. Also it was noted that selection of the plume equation influenced the model results for the large enclosure, because of the influence on the heat and mass transfer into the hot layer (Duong 1990).

Chow (1995) compared the results of modelling smoke filling in an atrium (16,000 m^3 in three different dimensional configurations) using zone models (FIRST, CFAST, CCFM.VENTS and the NBTC one-room model from FIRECALC) and a field model (which was self-developed). Chow (1996) also investigated the use of multiple compartments to model single large enclosures using zone-modelling approaches. Although these studies (Chow 1995, 1996) focused on smoke control instead of fire venting, the approaches used to model the large spaces and the indicative results are useful for determining the appropriate modelling approaches.

Chow suggested that the zone models were useful for a quick prediction of the probable smoke layer thickness and temperature induced by a fire in an atrium, whereas a more detailed prediction for the thermal environment within the enclosure would be available from a field model. The model results were not directly compared to specific experiment results, although general comparisons were made to previous large-scale experiments. Further experiments were recommended for comparison with both the zone- and field-model results for such large enclosures.

He et al (2002) investigated occupant safety for an example of an unsprinklered warehouse used to temporarily store tyres. The warehouse (192 × 240 × 16 m) had permanently open ridge vertical vents (2 × 2 m high) located in the centre of the building with a 4º pitched roof. Make-up air was supplied by six (4 m wide × 6 m high) open roller shutter doors. The warehouse was modelled using FAST with 20 (consisting of 16: 60 × 44 m enclosures and 4: 60 × 16 m enclosures along the ridge line) and 30 (consisting of finer spacing of the enclosures on one side of the ridge vent, 3 × 5 enclosures instead of 2 × 4) adjacent compartments, with each adjacent compartment wall fully open. A t^2 fire was assumed with the in-built FAST heat release rate limit of 90 MW in the compartment of fire origin with fire spread to adjacent compartments to a total of 1000 MW.

The focus of this investigation was on the life safety of the occupants and therefore the analysis focused on egress times. However, general conclusions included that for the scenarios considered the ridge vent provided sufficient time for evacuation of the occupant, and that the results from the 20- and 30-enclosure approaches were in reasonable agreement. However, it was suggested that the chimney effect revealed in the zone model be investigated using a CFD modelling method and experiments to achieve a greater degree of certainty (He et al 2002).

5. CURRENT PASSIVE FIRE VENTING METHODS AND MATERIALS

There are varieties of dedicated fire venting systems and units available in the New Zealand and Australian market and a wider selection internationally (e.g. Smoke Control 2007, Colt International 2006, C/S Group 2005, Bilco Company 2007, etc). However, the primary focus of this report is on the fire venting methods permitted by C/AS1 passive fire venting methods utilising roofing material properties. A summary of some common plastic roofing material properties are therefore presented below.

5.1 Plastic roofing materials

The most commonly available plastic roofing materials available (regardless of the appropriateness of the material for use in passive fire venting applications) are polyvinyl chloride (PCV), polycarbonate (PC), glass-fibre reinforced polyester (GRP) and polymethyl methacrylate (PMMA or acrylic). The available manufacturer's data for roof sheeting made of these plastics for the ranges of temperatures for heat distortion temperature, glass transition temperature and melting temperature are presented in Table 6. These temperatures may be indicative of the thermal response of the material. However, this does not provide a full indication of whether the material would provide a clear opening for effective fire venting. Other parameters, such as shearing forces required and fastening techniques, would also contribute to the overall effectiveness of the material as a fire vent.

Table 6: Softening and glass-transition temperatures for typical plastic roofing materials.

Material	Heat distortion temperature (ºC)	Glass transition temperature (ºC)	Melting temperature (ºC)	Decomposition temperature (ºC)
PVC		80 [e]		200 – 300 [e]
PC	135 [a]	150 [c]	250 [c]	
GRP	180 – 200 [a,b]			
PMMA	50 [e]	105 [d]	130 – 140 [c]	170 – 300 [e]

Notes: [a] From Alsynite NZ Ltd product literature www.alysnite.co.nz.
[b] From Ampelite (NZ) Ltd product literature ampelite.co.nz.
[c] From http://en.wikipedia.org/wiki/Polycarbonate.
[d] From http://biomems.uta.edu/Research/Poster.
[e] From Hilado (1990).

Not all plastic roof sheeting is appropriate for use in fire venting purposes. For example, GRP was permitted for use as rooflights in the Australian Model Uniform Building Code 1982, Amendment No. 4 1983, Clause 16.19.g. This was based on low increase to risk for single-storey buildings of Type 5 construction and that "… this material does not droop or drip when alight …" (AMUBC 1983), even though it does not meet the flame spread or smoke production requirements of Clause 16.19 AMUBC. That is, GRP was permitted for limited area and location use as an inexpensive and easy construction material to provide lighting. However fire venting is not mentioned or implied as an application for GRP. Other products are specifically designed to be fire resistant, which may further delay the material failing in the early fire development stages in order to provide effective fire venting.

Furthermore, the additives used to engineer the properties of plastics may affect the thermal response of the base material. Types of additives may include a plasticiser, heat stabiliser, ultraviolet absorber, flame retardant and/or biocide (Zumdahl 1989). Therefore a specific material tested and determined to be appropriate for use in fire venting is not indicative of the family of plastics using the same base or resin.

6. INTENT OF "EFFECTIVE FIRE VENTING"

The intent of "effective fire venting" is required to be defined. For example, the concessions for unlimited firecell floor area imply that "effective fire venting" is expected to assist in limiting the spread of fire, and the concessions for S rating values imply that "effective fire venting" is expected to reduce the fire intensity.

Appropriate quantitative performance criteria are required to assess "effective fire venting". For example, values for such parameters as visibility, radiation flux and temperatures may be appropriate for fire-fighting purposes.

7. NEW ZEALAND CASE STUDIES

Previous investigations (Charters et al 2002; Holborn, Nolan and Golt 2004; Sardqvist and Holmstedt 2000) have used fire incident data to estimate fire characteristics for use in probable risk assessments. The fire incident data used in these studies was collected by specialist teams with such specific uses of the data in mind. Unfortunately the building (such as the materials involved and the initial design of the building) and fire incident detail required and the size of the data set available for New Zealand is not currently suitable for such analyses. Therefore first-hand experience of roof venting during fire is a useful tool in indicating the effectiveness and practicality of the passive design.

Information on the specific influence that effective or ineffective fire venting has had on past fires in New Zealand is limited, since fire venting is only one component of the building and after a fire it can be difficult to identify the materials originally used in construction. Some first-hand New Zealand Fire Service (NZFS) experiences are noted here of fire events in buildings with passive roof fire venting.

The passive fire venting of the New Zealand Safety safety helmet manufacturing factory (North Shore, Auckland) failed to form openings during the fire on 2 July 1997. The building was of modern (1992) design, with a light-welded portal frame, walls approximately 6 m high, and an apex approximately 8–9 m high. The fire had been hot enough to glaze the concrete slabs. Yet fibrous matting of material that was expected to form fire venting had remained intact, holding hot gases within the building. After manually breaking out similar roofing material on other buildings during fire events, fire-fighters have also noted the increasing softening of the material on approaching the area of fire. Yet the fibrous reinforcing material of the vents, that were provided to allow hot gases to escape, remained intact (sometimes bulging outward with hot gases, while being illuminated by flames below) until manually perforated, and only then allowing hot gases to vent (Davis S 2006).

GRP roofing panels have often been included in designs where roof venting is required, selected based on natural lighting requirements with fire venting adequacy assumed. A GRP product was used in an ad hoc room experiment by the NZFS, and details are provided elsewhere (Davis S 2007). The vent (1.5 × 0.7 m × 3.3 to 4.0 m high, Figure 3a) was exposed to hot combustion products from four (0.59 × 0.84 m) 91% octane petrol-filled trays (located 4 m radially from the centre of the vent to the centre of the fire). Any flame impingement on the vent material was due to flaming of adjacent construction materials in the roof, not the initial heat source provided by the four trays.

During the test no opening of the vent material was observed. At the end of the test, it was noted that in areas where the thermosetting polyester resin no longer existed, a glass fibre mesh was still in place and intact (as shown in Figure 3b). These results are consistent with the noted fire-fighters' experiences of failed fire venting, when material had to be manually broken out to form a vent opening. Maximum temperatures located approximately 10 mm below the vent material of approximately 350°C were recorded. However it is noted that, as discussed in Section 5, depending on material engineering additives and resin-matrix construction methods (for composite materials) material properties may vary significantly from the base plastic. This result is therefore not necessarily indicative of all similar products. However, it does highlight the need for appropriate testing and performance criteria for fire venting in New Zealand.

(a) **(b)**

Figure 3: Photographs of the GRP vent from below (a) before and (b) after exposure to hot fire gases in a room. Areas of sheeting where the fibre mesh was exposed are indicated in red in (b).

8. CONCLUSIONS AND SUMMARY

8.1 Summary of Literature Review

Standards for installation and test methods of fire venting systems are available (e.g. AS 2665, AS 2428, NFPA 204, UL 793 and UBC Standard 15–7). International building codes make use of these standards for fire venting systems (e.g. BCA 2006, or UBC 1997).

"Effective fire venting" (Paragraph 4.2.4 of NZBC C/AS1 2005) implies that tenability is maintained for fire-fighting operations to proceed within the building in the event of a fire. However, the New Zealand requirements for "effective fire venting" are not currently clear.

Previous experimental work has been performed, investigating passive roof venting (Thomas et al 1963, Hinkley and Theobald 1966, Hinkley 1986b, Duong 1990), including some material testing (e.g. for PVC). The results of these previous investigations indicate that passive roof venting is a valuable system in limiting fire spread and maintaining conditions for the seat of the fire to be located more easily. However, the limited 'large-scale' and 'full-scale' testing has been performed and there is the potential for useful testing to be carried out in this area. This could be done in conjunction with small-scale testing of materials and modelling of the full-scale set-ups to determine appropriateness of materials and vent design effectiveness in the New Zealand context of current fire venting practices.

8.2 Conclusions

- New Zealand is the only country that uses passive fire venting that does not incorporate a dedicated frame or unit, or have a demonstrated level of performance.
- A passive fire venting system utilising material properties and installation of unprotected roof sheeting has cost and installation advantages over dedicated fire venting units, and if designed appropriately could potentially be effective for venting fire (and subsequently be competitive with currently established dedicated fire venting systems). However, appropriate performance criteria and design are essential.
- The current requirements and definitions in C/AS1 are lacking for effective fire venting. This has enabled the use of a range of materials, of which the passive fire venting performance is not known.
- Good fire venting design incorporates all the aspects involved in the venting of hot gases, including materials, vent operating characteristics, location of vents, smoke reservoirs and make-up air.

From this two potential problems emerge:

1. ensuring effective fire venting for future building stock designed in accordance with the appropriate regulatory definitions and requirements, and
2. ensuring current building stock with proven ineffective fire venting (depending on the future definition and performance criteria) is appropriately prepared for a fire event or alternative fire-fighting measures are available in the event of fire.

8.3 Recommendations for future work

Focusing primarily on the first point raised above, as well as determining the full extent of the problem underlying the second point raised above, the following are summaries of the recommended experimental and modelling work required to determine

1. a formal definition for "effective fire venting", including performance criteria

2. whether passive buoyancy-driven venting utilising roof sheeting provides "effective fire venting", and if so

3. the appropriate test methods and criteria to qualify as "effective fire venting".

Recommended Experimental Approach:

- Small-scale testing, in accordance with AS 2428 Parts 3 and 4, for comparison of the performance of passive buoyancy-driven venting utilising roof sheeting (materials and practices that are permitted by C/AS1 and currently used in construction) with thermally-activated buoyancy-driven venting (in accordance with AS 2665) experiment results.

- Large-/full-scale testing for comparison with small-scale experiment results to determine applicability of small-scale test results and appropriate performance criteria for passive buoyancy-driven venting utilising roof sheeting.

Recommended Theoretical/Modelling Approach:

- Comparison of the resulting performance of fire venting utilising roof sheeting material properties and design of venting complying with AS 2665 requirements (especially a comparison of results for the C/AS1 15% and AS 2665 2–3% floor-area criteria).

- Investigation of ratios of fire to compartment volume for modelling using different approaches for large buildings to determine appropriate limits for future design analysis.

- Investigation of modelling using small-scale experiment data compared to large-/full-scale experiment results to determine appropriate modelling limits and criteria for use in related design analysis.

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10. APPENDIX A: EXCERPTS FROM PREVIOUS REGULATIONS

10.1 NZS 1900 Chapter 5

Table 7: Maximum firecell floor area for unsprinklered commercial and industrial buildings as specified in NZS 1900 Part 5. Adapted from (*NZS 1900/5* 1963).

Fire risk division	No. building storeys	Central fire risk areas		Outer A fire risk areas		Outer B fire risk areas	
		Max. firecell area (m^2)	Type of constr.	Max. firecell area (m^2)	Type of constr.	Max. firecell area (m^2)	Type of constr.
Low	1	3700	2	2800 3700	4 3	700	5
	2	2800	2	2800	3	400	5
	2*	600	2	400 600	4 3	-	-
	>2	1900	2	1900	3	-	-
Moderate	1	2800	2	2200 2800	4 3	-	-
	2	1900	2	1900	3	-	-
	2*	500	2	300 500	4 3	-	-
	>2	1400	2	1400	3	-	-
High	1	1400	1	1900	1	-	-
	2	900	1	1400	1	-	-
	2*	-	-	-	-	-	-
	>2	500	1	900	1	-	-

10.2 DRAFT DZ 4226 and background

'Fire venting' was defined as "… a fire safety measure whereby the effects of a fire are vented through the roof by an approved method, in order to limit the horizontal spread of fire in a storey …" (Definitions of *DZ 4226* 1984)

The definition for 'opening' was "… any portion of the enclosing envelope, or of any element of construction, which either:

a) "allows the free passage of air through that element; or

b) "consists of plain non-fire-resistant glass; or

c) "consists of any material approved as having no more resistance to the passage of flame or air than plain non-fire-resisting glass, when subjected to fire."

"C. Plain window glass usually fractures very early in the development of a fire, and is then likely to fall out, admitting air to the fire, and allowing flames to pass through. This fact is of vital importance to both the percentage of ventilation on which FRR's in Part 5 are based, and to the safety of means of escape. Many thermoplastic sheet materials used in building (such as in skylights) will also serve as openings, if they either shrink, melt, or burn readily in the presence of fire. Materials and assemblies with are substandard are not necessarily considered as openings, as they may not collapse quickly enough to provide ventilation to a fire …" (Definitions of *DZ 4226* 1984)

“7.10 Fire Venting

“7.10.1 Approved specification: Where fire venting is installed as provided by 3.2.3.7 of Part 3 of this Code, as a means of increasing the permitted size of a fire compartment fire vents complying with AS 2427 shall be used.

“7.10.2 Size and operation: Where fire vents are installed under this clause, they shall be approved if:

a) permanently open; or

b) openings, except that they may not be approved if reinforced with a non-combustible material intended to prevent injury through impact fracture where the opening is made of a material which softens and deforms before allowing the passage of flame or smoke; or

c) openable automatically by approved heat sensors, as well as manually; and

d) have an effective vent area, as a percentage of the smoke reservoir area, as specified in 7.10.3 below of:

- i) 1.5% for low and medium fire severity use classes
- ii) 3% for high fire severity use classes.

“7.10.3 Smoke reservoirs: Where fire venting is installed under this clause, the roof area shall be subdivided into smoke reservoirs, of an average depth at least 1.5 m, by smoke screens (as specified in 7.10.4 below) such that the plan area of any reservoir shall not exceed 1000 m^3.

“7.10.4 Smoke screens: Smoke screens required by 7.10.3 above shall be constructed of approved non-combustible, non-shattering rigid sheet materials, and shall be fixed to the roof structure with non-combustible fastenings.

“7.10.5 Special design: The requirements of 7.10.2 and 7.10.3 above may be approved where a special design for a fire venting method is carried out as specified in 1.4 of Part 1 of this Code, if design for fire venting methods is based on BRE Research Technical paper No. 10 – “Design of Roof Venting Systems for Single Storey Buildings”, or NFPA 204: “Guide for Smoke and Heat Venting”.

“C7.10.5 The requirements of 7.10.2 and 7.10.3 are arbitrary, and have been selected from the requirements set out in the Australian Model Uniform Building Code. They are thought to provide an effective solution for many common building situations, but it is desirable that special (that is :specific) design solutions be used for preference. A further useful reference is contained in “Smoke Control in Fire Safety Design” by E G Butcher and A C Parnell.” (*DZ 4226* 1984)

Table 8: Use groups in DZ 4226: 1984. (Extracted from Schedule 2.3A of *DZ 4226* 1984).

Use group according to DZ 4226: 1984	Use class according to DZ 4226: 1984	Criteria for function for DZ 4226: 1984
Spaces used for assembly purposes A	AS	Enclosed rooms or suites containing not more than 100 occupants, but not less than 10 children or 30 adults
	AM	Enclosed rooms or suites containing not more than 500 occupants
	AL	Enclosed rooms or suites containing more than 500 occupants
	AO	Structures providing open-air seating or standing spaces, with or without shelter
Spaces used for sleeping S	SC	Enclosed rooms or suites used by occupants under institutional care because of mental or physical disability or illness
	SD	Enclosed rooms or suites to which occupants are confined while in institutional care or custody
	SA	Accommodation units or dwelling units sharing means of escape with other units or uses in the same fire compartment
	SS	Accommodation units or dwelling units in the same fire compartment but not sharing means of escape with any other unit or use
	SH	Fully detached accommodation units or dwelling units
Spaces for commercial purposes C	CO	Enclosed rooms or suites used as offices or to provide personal services
	CS	Enclosed rooms or suites used to display combustible goods for public sale or exhibition
Spaces used for manufacturing or storage purposes M	MxL	Manufacturing processes, or storage, with fire load density of less than 200 MJ/m²
	ML	Manufacturing or storage able to contain goods or substances or processes of a fire load density not more than 800 MJ/m² with average specific surface not higher than 0.11 m²/kg
	MM	Manufacturing or storage able to contain goods or substances or processes of a fire load density not more than 1600 MJ/m² with average specific surface not higher than 0.11 m²/kg or a fire load density not more than 800 MJ/m² with average specific surface higher than 0.11 m²/kg
	MH	Manufacturing or storage able to contain goods, substances or processes of a fire load density not more then 3200 MJ/m² with average specific surface not higher than 0.11 m²/kg
	MxH	Manufacturing or storage able to contain goods, substance or processes of a fire load density more than 3200 MJ/m² with average specific surface not higher than 0.11 m²/kg or a fire load density not more than 800 MJ/m² with average specific surface higher than 0.11 m²/kg or high hazard areas
Spaces used for functions or purposes which are generally auxiliary to any other use G	GL	Rooms, spaces or suites containing carparks or building services equipment not operating with any fuel
	GM	Enclosed rooms or suites containing carparks or building services equipment not operating with any fuel
	GH	Enclosed rooms or suites containing building services equipment operating on an integral fuel supply
	GP	Enclosed rooms or suites containing emergency power supply equipment or fire control systems needed to be operable in fire emergencies

"3.2.3.7 Fire venting: The storey areas permitted in Table 3.1A may be increased by 50% where the fire compartment is protected by fire venting." (*DZ 4226* 1984)

"C3.2.3.7 See D3.2.3.7. [Figure 1] Fire venting not only allows the effects of fire to escape from the affected storey thus minimising the risk of fire spread throughout the storey but also allows improved visibility and fire-fighting access to the seat of the fire. Fire venting must be as specified in Part 7, and should not be confused with roof venting through structural collapse." (Paragraph 3.2.3.7) (*DZ 4226* 1984)

Background to 3.2.3.7: "Fire Venting (permits increased area where fire venting is installed in the entire fire compartment) – applies only to single storey buildings – based on NFPA 206M clause 503(c), AMUBC clause 19.3, and as recommendations by (Woods 1972) 3.4 and 5(6)"

Background to Table 3.1A of DZ 4226: Data taken directly from Table 1 in NZS 1900.5. The floor area was not taken as a proportion to the assumed/designed fire load. Larger than proportional floor areas were taken by the sub-committee because "… inefficient combustion conditions and heat losses through the external skin of the building, the full calorific impact of the fire load is usually unable to be applied within the fire compartment" (Woods 1972). "… Amendments have been proposed to NZS 1900.5 over 20 years but in no instance has the case been made that, in a NZ context, the existing fire compartment sizes for use classes D1, D2 and D3 pose a recurring problem to either the Fire Service or the insurance industry. The comment has frequently been made, however, that New Zealand compartment sizes are too small when compared to sizes in other codes. Not only were the existing D1,D2 and D3 areas reused in Part 3 but the area adjustments for those uses in Table 1 of NZS 1900.5 for single storey, two storey and unlimited storeys… were reused, but applied to single storey, two and four storeys, and five to ten storeys. …" (Woods 1972)

"… the use of roof venting as a means of limiting fire and smoke spread and hence to reduce the extent of property damage in a fire, especially in industrial buildings…" (Woods 1972)

"C Table 3.1A note that the height is controlled either by the number of storeys, or by the maximum height of the fire load ceiling. Therefore, a single storey warehouse may have a fire load ceiling of 13 m, and if the total fire load density at that height is still less than 40 kg/m², its area must be limited to 3000 m², but if the total fire load density at that height is up to 80 kg/m², its area must be limited to 2250 m². On the other hand, a badminton hall could well have a fire load ceiling of no more than 3 m height because there is no "significant" fire load above that (see definition) and therefore could be well over 4 m height, but still have a storey area of 4000 m². But if it is a two storey building, then the area must be reduced to 3000 m².

"Exp. Table 3.1A The Table is based on the 4000 m² the area permitted for the D1 fire risk group in the 1963 Bylaw, which appears to be an acceptable size for fire-fighting purposes; and then reductions on this size which amount to 75% for up to four storeys, and 50% for up to ten (unsprinklered), and then returning again to the single storey that the 75% reduction should apply at two storeys, and that it should be 50% over that, on the grounds that, because of the possibility of façade spread of fire to an upper storey, within the 20 minute Fire Service response time, the Code should allow for two-storey burn-out giving the same maximum potential loss for two upper floors as for a single storey. Therefore, on that ground, storey areas for sprinklered compartments over 10 storeys should be no more than those for unsprinklered compartments between three and ten storeys high.

"Further, it has been pointed out that the decrease in areas with increasing fire severity should, logically, be to 50% and then 25% of the low fire severity uses, because the fire load density doubles and then quadruples for the higher fire severity uses.

"In making comment on this Table, reviewers should bear in mind that the primary aim is to keep total loss within the capacity of the Fire Service to control (and the only guidance are the D1, D2 and D3 sizes in the 1963 Bylaw), and therefore keep total loss within socially acceptable limits. But the figures should also have a rational relationship to both fire-fighting access (in terms of height) and the fire load density ranges on which this Code is based. The whole structure of the Table is a matter for careful study by Reviewers, but proposals should be clearly argued." (*DZ 4226* 1984)

"3.2.2 Reduced storey areas

"3.2.2.1 Excessive ventilation: When located within the Fire Control Zone, and not protected by a sprinkler system, fire compartments in the following use-classes shall have the maximum storey area specified in Table 3.1A reduced to 50%, where the FRR for storey separation is:

a) for CS and MM uses, in Table 5.3A.2, is less than ¾ hour;

b) for MH uses, in Table 5.3A.2, is less than 1 hour;

c) for CS and MM and MH uses, in Table 5.3A.3, is less than 1 hour.

"C3.2.2.1 Low FRR indicate short fire durations, which give the Fire Service little opportunity to control property damage. Accordingly the area at risk is reduced, in line with the requirement of 3.2.3.2.

"Exp.3.2.2.1 Exclusion of Table 5.3A.1 is because roof collapse is an integral feature of FRR for single storey buildings to which that Table applies. The fire durations corresponding to the FRR one step below those quoted are, respectively: 20 minutes, and 30 minutes. There was not complete unanimity about the justification for this provision." (*DZ 4226* 1984)

"5.3.2.6 Roof venting provisions: The FRR shown in Table 5.3A, section 5.3A.1, shall apply only when:

a) the roof elements have been constructed, over at least two-thirds of the storey area, without any ceilings, or linings which could provide any form of FRR;

b) the roof element has been designed, in addition to the provision of any fire vents as specified in Part 7, to allow at least one third of the storey area, at the highest peaks of the roof, to rupture relatively early in the development of a fire;

c) where a requirement for FRR is shown against "roof" in use classes A1, SA, SC and SD, then either:

   i) all structural elements supporting any area of roof which is over 100 m² in plan shall have the FRR shown; or

   ii) the entire roof construction, including all structural elements supporting it, shall have the FRR shown and fire vents provided as specified in Part 7." (*DZ 4226* 1984)

"C5.3.2.6 Roof venting can occur when a portion of a roof collapses, but this should not be assumed as also providing ventilation. Its principle effect is to release a great deal of the heat of a fire, and while this may be highly spectacular, it actually diminishes the danger to adjoining fire compartments through horizontal spread of fire: which is the reason for the reduced FRR to compartment separations, in this section of the Table, as compared with the second and later sections." (*DZ 4226* 1984)

Background for 5.3.2.6: “the assumptions on the required roof areas to trigger these requirements were arbitrary”, “see C.5.3.2.6 of the Draft and comment in this report on clause 5.1.2.7” (Woods 1972)

“5.3.2.7 Ventilation: The percentage of ventilation shown in Table 5.3A shall be calculated by:

a) considering separately each area of a storey which is separated from any other areas by fire separations having a FRR greater than ½ hour, and

b) measuring the area of openings provided in all exposing faces of the area of the storey considered; and

c) expressing the total area of openings as a percentage of the area of the storey considered.

“C5.3.2.7 It is important that the openings measured are the ones actually provided, as distinct from the area of openings permitted by Part 4. The principal effect will be to reduce FRRs, particularly for exposing faces, if the openings permitted by Part 4 are actually provided as far as possible; so that the greater the separation distance, the lower total FRR in a compartment. However, if openings are not provided, then FRRs will remain high, no matter how great the separation distance, up to the point where 100% openings are permitted by Part 4.” (*DZ 4226* 1984)

Background for 5.3.2.7: “(basis for calculations of ventilation percentages) it was considered that separations with ½ hour FRR or less could burn through, and so enlarge the involved area and lead to an increase in the ventilation area.” (Woods 1972)

“Table 5.3A Introduces the concept of perimeter venting to FRRs, relies on accelerating the burn out of contents to reduce fire ratings. Will certainly restrict design criteria and increase cost for simple single storey buildings.” (*NZS 1900.5 Revision* 1985)

10.3 Australian Model Uniform Building Code 1983

Clause 19.3

1) “A building containing only one storey and having a floor area not exceeding 18,000 m² shall not be subject to the floor-area limitations specified in clause 19.2 if –

   a. “An open space, not less than 18 m in width, is provided on or associated with the site of the building in accordance with clause 19.5: or

   b. “The building is of Type 2 or Type 3 construction and complies with the following requirements:

      i. “The space below the roof shall be divided into compartments in accordance with clause 19.6;

      ii. “The building shall be provided with approved automatic smoke-and-heat vents in accordance with clause 19.7;

      iii. “Every external wall facing the boundary of an adjoining allotment of land shall be provided with a parapet in accordance with clause 19.8, except where the provisions of the clause permit the height of the parapet to be reduced to nil; and

iv. “Windows and other openings in every external wall facing the boundary of an adjoining allotment of land shall be so limited in area as to comply with clause 19.9.

2) “For the purposes of subclause (1) where the subject building is of Class VI, VII or VIII its floor area shall be determined in accordance with the provisions of clause 19.4 (2).” (*AMUBC* 1983)

Clause 19.4

1) “A Class VI, VII or VIII building containing only one storey and having a floor area exceeding 18,000 m² shall not be subject to the floor area limitations specified in clause 19.2 if –

   a. “An open space, not less than 24 m in width, is provided on or associated with the site of the building in accordance with clause 19.5; or

   b. “The building is of Type 2 or Type 3 construction and complies with the following requirements:

      i. “The space below the roof shall be divided into compartments in accordance with clause 19.6;

      ii. “The building shall be provided with approved automatic smoke and heat vents in accordance with clause 19.7;

      iii. “Every external wall facing the boundary of an adjoining allotment of land shall be provided with a parapet in accordance with clause 19.8, except where the provisions of the clause permit the height of the parapet to be reduced to nil;

      iv. “Windows and other openings in every external wall facing the boundary of an adjoining allotment of land shall be so limited in areas as to comply with clause 19.9;

      v. “An approved sprinkler system shall be installed throughout the building.

2) …” (*AMUBC* 1983)

Clause 19.6

“In a building required to have the space below the roof divided into compartments, the following requirements shall be met:

a) “The compartments shall be formed by –

   i. “vertical non-combustible non-shattering draught curtains (including asbestos-silica board and excluding asbestos-cement board) hung from the roof structure; or

   ii. “the use of a saw-tooth roof in which the vertical part of the “saw-tooth” comprises non-combustible, non-shattering material, or wired glass not less than 6 mm thick.

b) “The foregoing curtains or vertical part of the “saw-tooth” shall extend from the roof sheeting to a level not less than 1.5 m below the lowest part of the opening, to the outside air, of the lowest required smoke-and-heat vent.

c) “The holes through which any non-metallic curtains are fixed shall be not less than 10 mm in diameter over-size, and shall be so located as to allow expansion of the curtain in the event of fire within the building.

d) “None of the compartments so formed shall exceed 1000 m² in area, measured in a horizontal plane.

e) “In spaces of abnormal fire hazard specified in the Second Schedule –

   i. “The horizontal distances between the foregoing curtains or vertical part of the ‘saw-tooth’; and

   ii. “The horizontal distance between any external wall and the curtain or glazing, if any, nearest to it shall not exceed 30 m.

f) “A ceiling or like construction shall not be used in or below any such compartment.” (*AMUBC* 1983)

Clause 19.7

2) deleted

3) “In a building required to have approved automatic smoke and heat vents, the following requirements shall be met:

   a. “Each of the compartments below the roof and separated by the curtains or vertical part of the “saw-tooth” described in clause 19.6 shall have one or more approved automatic smoke and heat vents.

   b. “The automatic opening of the vents, if a sprinkler system is installed, shall be set for a temperature not less than 5º on the Celsius scale above that at which the sprinkler system is set to operate.

   c. “The aggregate airway of vent openings in each compartment shall bear not less than the following ratio to the area of the compartment:

      i. “Where the space vertically below the compartment is or includes a space of abnormal fire hazard specified in the Second Schedule – 3:100.

      ii. “In all other cases – 3:200.” (*AMUBC* 1983)

10.4 Building Code of Australia 2006

10.4.1 Summary tables

Table 9: Classes of buildings according to the BCA (BCA 2006).

Class	**Description**
Class 1	one or more buildings which in association constitute— (a) **Class 1a** — a single dwelling being— (i) a detached house; or (ii) one of a group of two or more attached dwellings, each being a building, separated by a fire-resisting wall, including a row house, terrace house, town house or villa unit; or (b) **Class 1b** — a boarding house, guest house, hostel or the like- (i) with a total area of all floors not exceeding 300 m^2 measured over the enclosing walls of the Class 1b; and (ii) in which not more than 12 persons would ordinarily be resident, which is not located above or below another dwelling or another Class of building other than a private garage.
Class 2	a building containing 2 or more *sole-occupancy units* each being a separate dwelling.
Class 3	a residential building, other than a building of Class 1 or 2, which is a common place of long term or transient living for a number of unrelated persons, including— (d) accommodation for the aged, children or people with disabilities; or (e) a residential part of a *health-care building* which accommodates members of staff; or (f) a residential part of a *detention centre*.
Class 4	a dwelling in a building that is Class 5, 6, 7, 8 or 9 if it is the only dwelling in the building.
Class 5	an office building used for professional or commercial purposes, excluding buildings of Class 6, 7, 8 or 9.
Class 6	a shop or other building for the sale of goods by retail or the supply of services direct to the public, including— (a) an eating room, cafe, restaurant, milk or soft-drink bar; or (b) a dining room, bar, shop or kiosk part of a hotel or motel; or (c) a hairdresser’s or barber’s shop, public laundry, or undertaker’s establishment; or (d) market or sale room, showroom, or service station.
Class 7	a building which is— (a) **Class 7a** — a *carpark*; or (b) **Class 7b** — for storage, or display of goods or produce for sale by wholesale.
Class 8	a laboratory, or a building in which a handicraft or process for the production, assembling, altering, repairing, packing, finishing, or cleaning of goods or produce is carried on for trade, sale, or gain.
Class 9	a building of a public nature— (a) **Class 9a** — a health-care building, including those parts of the building set aside as a laboratory; or (b) **Class 9b** — an assembly building, including a trade workshop, laboratory or the like in a primary or secondary *school*, but excluding any other parts of the building that are of another Class; or (c) **Class 9c** — an *aged care building*.
Class 10	a non-habitable building or structure— (a) **Class 10a** — a non-habitable building being a *private garage*, carport, shed, or the like; or (b) **Class 10b** — a structure being a fence, mast, antenna, retaining or free-standing wall, *swimming pool*, or the like.

Table 10: Summary of the maximum firecell floor areas and volumes. Extracted from Table C2.2 (*BCA* 2006).

Classification	Floor area or volume	Type of construction of building		
		Type A	Type B	Type C
5, 9b or 9c aged care building	Max. floor area	8 000 m²	5 500 m²	3 000 m²
	Max. volume	48 000 m³	33 000 m³	18 000 m³
6, 7, 8 or 9a (except for patient care)	Max. floor area	5 000 m²	3 500 m²	2 000 m²
	Max. volume	30 000 m³	21 000 m³	12 000 m³

Table 11: Summary of the exceptions to firecell area and volume limits. Extracted from C2.3 (*BCA* 2006).

Class	Firecell floor area (m²)	Firecell volume (m³)	Limit on storeys	Limit on distance to boundary (m)	Requirements
7 or 8	< 18 000	< 108 000	2	18 +	A, B, C, or D
					F *
5 or 9	< 18 000	< 108 000	-	-	E & F
Class 2 to 9	≥ 18 000	≥ 108 000	-	-	Compartment ceiling height ≤ 12 m & E & F & (B or C)
Class 2 to 9	≥ 18 000	≥ 108 000	-	-	Compartment ceiling height > 12 m E & F & B

Notes:

A. an automatic fire detection and alarm system complying with AS 1670.1 and monitored in accordance with Clause 7 of Specification E2.2a; or
B. an automatic smoke exhaust system in accordance with Specification E2.2b; or
C. automatic smoke-and-heat vents in accordance with Specification E2.2c; or
D. natural smoke venting, with ventilation openings distributed as evenly as practicable and comprising permanent openings at roof level with a free area not less than 1.5% of floor area and low level openings which may be permanent or readily openable with a free area not less than 1.5% of floor area; or
E. protected throughout with a sprinkler system complying with Specification E1.5
F. perimeter vehicular access complying with C2.4(b)

+ If buildings on the same allotment are within 6 m, then can be considered individually or as a single building (C2.3(c) of BCA 2006)

* NSW requirements (NSW C2.3 of BCA 2006)

10.4.2 Excerpts

The exceptions to the fire compartment size limits, presented in Table 13, are for large buildings where:

(a) “the building does not exceed 18 000 m² in floor area nor exceed 108 000 m³ in volume, if—

(i) the building is Class 7 or 8, it contains not more than 2 storeys and is provided with open space complying with C2.4(a) not less than 18 m wide around the building and—

A. an automatic fire detection and alarm system complying with AS 1670.1 and monitored in accordance with Clause 7 of Specification E2.2a; or

B. an automatic smoke exhaust system in accordance with Specification E2.2b; or

C. automatic smoke-and-heat vents in accordance with Specification E2.2c; or

D. natural smoke venting, with ventilation openings distributed as evenly as practicable and comprising permanent openings at roof level with a free area not less than 1.5% of floor area and low level openings which may be permanent or readily openable with a free area not less than 1.5% of floor area; or

(ii) the building is Class 5 to 9 and is protected throughout with a sprinkler system complying with Specification E1.5 and perimeter vehicular access complying with C2.4(b) is provided; or

(b) the building exceeds 18 000 m² in floor area or 108 000 m³ in volume, is protected throughout with a sprinkler system complying with Specification E1.5, is provided with a perimeter vehicular access complying with C2.4(b) and if—

(i) the ceiling height of the fire compartment is not more than 12 m, it has a smoke exhaust system in accordance with Specification E2.2b or smoke-and-heat vents in accordance with Specification E2.2c; or

(ii) the ceiling height is more than 12 m, it has a smoke exhaust system in accordance with Specification E2.2b; or

(c) there is more than one building on the allotment and—

(i) each building complies with (a) or (b); or

(ii) if the buildings are closer than 6 m to each other they are regarded as one building and collectively comply with (a) or (b).” C2.2 of (BCA 2006).

Except for NSW where C2.3(a) is deleted and substituted with:

NSW C2.3 Large isolated buildings

(a) “ the building does not exceed 18 000 m² in floor area nor exceed 108 000 m³ in volume, if—

(i) the building is Class 7 or 8, it contains not more than 2 storeys and is provided with open space complying with C2.4(a) not less than 18 m wide around the building; or

(ii) the building is a Class 5 to 9 and is protected throughout with a sprinkler system complying with Specification E1.5 and perimeter vehicular access complying with C2.4(b) is provided; or" NSW C2.3 of (BCA 2006)

SPECIFICATION E2.2c SMOKE-AND-HEAT VENTS

1. "Adoption of AS 2665

Automatic smoke-and-heat vents must be installed as a system complying with AS 2665 except that… permanently open vents may form part of the smoke/heat venting system provided they comply with the relevant criteria for automatic smoke-and-heat vents in AS 2665.

2. Controls

Where a smoke-and-heat vent system is installed to comply with Table E2.2b, the following must apply:

(a) In addition to thermally released link operation, smoke-and-heat vents must also be initiated by smoke detection complying with Clauses 5 and 7 of Specification E2.2a and arranged in zones to match the smoke reservoirs." Specification E2.2c (BCA 2006)

C2.4 "Requirements for open spaces and vehicular access

(a) An open space required by C2.3 must—

(i) be wholly within the allotment except that any road, river, or public place adjoining the allotment, but not the farthest 6 m of it may be included; and

(ii) include vehicular access in accordance with (b); and

(iii) not be used for the storage or processing of materials; and

(iv) not be built upon, except for guard houses and service structures (such as electricity substations and pump houses) which may encroach upon the width of the space if they do not unduly impede fire-fighting at any part of the perimeter of the allotment or unduly add to the risk of spread of fire to any building on an adjoining allotment." C2.4 a) of (BCA 2006)

10.5 Knight's Building Regulations 2000, Approved Document B

Paragraph 13.4 Note 3

"Existing buildings may have been designed to the following guidance which is also acceptable:

b. the column members are fixed rigidly to a base of sufficient size and depth to resist overturning;

c. there is brick, block or concrete protection to the columns up to a protected ring beam providing lateral support; and

d. there is some form of roof venting to give early heat release. (The roof venting could be, for example, pvc rooflights covering some 10 per cent of the floor area and evenly spaced over the floor area.)" (Knight's Build. Reg. 2000, Approved Doc. B 2004)

"In the Secretary of State's view the requirement of B5 will be met:

a. if there is sufficient means of external access to enable fire appliances to be brought near to the building for effective use;

b. if there is sufficient means of access into, and within, the building for fire-fighting personnel to effect rescue and fight fire;

c. if the building is provided with sufficient internal fire mains and other facilities to assist fire-fighters in their tasks; and

d. if the building is provided with adequate means for venting heat and smoke from a fire in a basement.

These access arrangements and facilities are only required in the interests of the health and safety of people in and around the building. The extent to which they are required will depend on the use and size of the building in so far as it affects the health and safety of those people." Paragraph B5 Performance (Knight's Build. Reg. 2000, Approved Doc. B 2004)