Ministry of Business,
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Commentary
for Verification Method C/VM2

December 2012

Document history	
Date	Alterations
April 2012	First edition published
December 2012	Addition of Appendix B: worked example applying the 10 design scenarios

Contents

List of Tables

References

Extract from C/VM2: References

References

For the purposes of New Zealand Building Code (NZBC) compliance, the Standards and documents referenced in this Compliance Document (primary reference documents) must be the editions, along with their specific amendments, listed below. Where these primary reference documents refer to other Standards or documents (secondary reference documents), which in turn may also refer to other Standards or documents, and so on (lower-order reference documents), then the version in effect at the date of publication of this Compliance Document must be used.

Standards New Zealand		
NZS 4510: 2008	Fire hydrant systems for buildings *Amend: 1*	4.8
NZS 4512: 2010	Fire detection and alarm systems in buildings	3.4
NZS 4515: 2009	Fire sprinkler systems for life safety in sleeping occupancies (up to 2000 m^2)	Definitions
NZS 4541: 2007	Automatic fire sprinkler systems *Amend: 1*	Definitions
AS/NZS 3837: 1998	Method of test for heat and smoke release rates for materials and products using an oxygen consumption calorimeter	4.6
Standards Australia		
AS 1366:-	Rigid cellular plastics sheets for thermal insulation	
Part 1: 1992	Rigid cellular polyurethane (RC/PUR) *Amend: 1*	4.7
Part 2: 1992	Rigid cellular polyisocyanurate (RC/PIR)	4.7
Part 3: 1992	Rigid cellular polystyrene – moulded (RC/PS-M) *Amend: 1*	4.7
Part 4: 1989	Rigid cellular polystyrene – extruded (RC/PS-E)	4.7
AS 1530:-	Methods for fire tests on building materials, components and structures	
Part 1: 1994	Combustibility test for materials	4.7
Part 2: 1993	Test for flammability of materials	4.7
Part 4: 2005	Fire resistance tests for elements of construction	2.4
British Standards Institution		
BS 7273:-	Code of practice for the operation of fire protection measures	
Part 4: 2007	Actuation of release mechanisms for doors	4.10
International Standards Organisation		
ISO 1182: 2010	Reaction to fire tests for products – Non-combustibility test	4.7
ISO 5660:-	Reaction-to-fire tests	
Part 1: 2002	Heat release, smoke production and mass loss rate	4.6, 4.7, A1.1, A1.2, A1.3
Part 2: 2002	Smoke production rate (dynamic measurement)	A1.1
ISO 9239:-	Reaction to fire tests for floorings	
Part 1: 2010	Determination of the burning behaviour using a radiant heat source	4.7 Figure 1.1 h)

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ISO 9705: 1993	Fire tests – Full-scale room test for surface products	4.7, A1.1, A1.2 Figure 1.1 h)
ISO 13571: 2007	Life-threatening components of fire Guidelines for the estimation of time available for escape using fire data.	2.2.1
ISO 13784:-	Reaction-to-fire tests for sandwich panel building systems	
Part 1: 2002	Test method for small rooms	A1.1
ISO 13785:-	Reaction-to-fire tests for façades	
Part 1: 2002	Intermediate-scale test	4.6
European Committee for Standardisation		
Eurocode DD ENV 1991:-	Eurocode 1: basis of design and actions on structures,	
Part 2.2: 1996	Actions on structures exposed to fire	2.4 Comment, 2.4.4
National Fire Protection Association of America		
NFPA 285: 1998	Standard method of test for the evaluation of flammability characteristics of exterior non-load-bearing wall assemblies containing components using the intermediate scale, multi-storey test apparatus	4.6
BRANZ Ltd		
BRANZ Study Report No. 137: 2005	Development of the Vertical Channel Test Method for Regulatory Control of Combustible Exterior Cladding Systems, Whiting, P. N.	4.6
Australian Building Codes Board		
International Fire Engineering Guidelines (IFEG): 2005		1.3
Society of Fire Protection Engineers		
The Handbook of Fire Protection Engineering, 4th Edition,	National Fire Protection Association, Quincy, M.A, USA, 2008.	
	Gwynne, S.M.V, and Rosenbaum, E.R, "Employing the Hydraulic Model in Assessing Emergency Movement", Section 3 Chapter 13.	3.2 Comment 3.2.6 Comment
SFPE Engineering Guide to Predicting 1st and 2nd Degree Skin Burns	from Thermal Radiation, 2000	3.6.1
General publications		
Fire Engineering Design Guide (Centre for Advanced	Engineering, 2008)	2.4.4 Comment

References in Commentary document

Standards New Zealand		Commentary to:
AS/NZS 2918: 2001	Domestic solid fuel burning appliances	NZBC C2.2, C2.3
NZS 4512: 2010	Fire detection and alarm systems in buildings	Table 3.3 (example)
NZS 4541: 2007	Automatic fire sprinkler systems	Table 3.3 (example)
AS/NZS 3837: 1998	Method of test for heat and smoke release rates for materials and products using an oxygen consumption calorimeter	NZBC C3.4, Paragraphs 4.5, 4.7
AS/NZS 3869: 1999	Domestic solid fuel burning appliances – Design and construction	NZBC C2.3

Standards Australia		
AS 1530:-	Methods for fire tests on building materials, components and structures	
Part 1: 1994	Combustibility test for materials	NZBC C3.7, Paragraphs 4.5, 4.6
Part 2: 1993	Test for flammability of materials	Paragraph 4.7
Part 3: 1989	Simultaneous determination of ignitability, flame propagation, heat release and smoke release	Paragraph 4.7
Part 4: 2005	Fire resistance tests of elements of construction	Paragraph 4.5

British Standards Institution		
PD7974-6: 2004	The application of fire safety engineering principles to fire safety design' of buildings – Part 6: Human factors: Life safety strategies – Occupant evacuation, behaviour and condition (Sub-system 6)	NZBC C4.3, Paragraph 3.2.3, Table 3.3

International Organization for Standardization		
ISO 834: 2002	Fire-resistance tests	Paragraph 2.4.4
ISO 1182: 2010	Reaction to fire tests for products – Non-combustibility test	NZBC C3.7, Paragraph 4.5
ISO 5660:	Reaction-to-fire tests – Heat release, smoke production and mass loss rate	NZBC C3.4, C3.7 Paragraphs 2.3.3, 4.5, 4.6, 4.7
Part 1: 2002	Heat release rate (cone calorimeter method)	Paragraph 4.7
ISO 9239: Part 1: 2010	Reaction to fire tests for floorings Determination of the burning behaviour using a radiant heat source	NZBC C3.4, Paragraph 4.7

ISO 9705: 1993	Fire tests – Full-scale room test for surface products	NZBC C3.4, Paragraph 4.7
		Commentary to:
ISO 13571:2007	Life-threatening components of fire – Guidelines for the estimation of time available for escape using fire data.	NZBC C4.3

National Fire Protection Association of America

NPFA 72: 2010	National Fire Alarm and Signalling Code	Paragraph 2.3.1
NFPA 204: 2012	Standard for smoke and heat venting	Paragraph 2.3.1
NFPA 5000:2006	NFPA 5000: Building Construction and Safety Code	Part 4

National Institute of Standards and Technology

FDS Software Fire Dynamics Simulator (version 5):	Technical Reference Guide NIST SP 1018.5, NIST Special Publication 1018.5; Version 5, McGrattan K, Hostikka S, Floyd J, Baum H, Rehm R	Paragraph 3.4

BRANZ Ltd

BRANZFIRE Software	Wade, C.A., "BRANZFIRE Technical Reference Guide", Study Report No. 92 (revised 2004), BRANZ Ltd, Porirua, New Zealand, 2004	Paragraphs 2.3.3, 4.8 (example), Table 3.3 (example)
BRANZ Study Report No. 185: 2008	Soot Yield Values for Modelling Purposes – Residential Occupancies, Robbins, A. P. and Wade, C. A.	Paragraph 2.3.3
BRANZ Study Report No. 160: 2006	Fire Properties of Wall and Ceiling Linings: Investigation of Fire Test Methods for Use in NZBC Compliance Documents, PCR Collier, PN Whiting and CA Wade, 2006.	Paragraph 4.7
BRANZ Study Report No. 181: 2007	Fire properties of floor coverings – new test methods and acceptable solutions, PCR Collier	Paragraph 4.7
BRANZ Study Report No. 199: 2008	Effective Passive Roof Venting using Roof Panels in the Event of Fire. Part 3: Summary, Robbins A.P. and Wade, C. A.	Paragraph 4.8

Australian Building Codes Board

Building Code of Australia	NZBC C3.4, C3.8 Paragraph 4.7

Society of Fire Protection Engineers

	Commentary to:
The Handbook of Fire Protection Engineering, 4th Edition, National Fire Protection Association, Quincy, MA, USA, 2008.	
Gwynne, M V, and Rosenbaum, E R, "Employing the Hydraulic Model in Assessing Emergency Movement", Section 3 Chapter 13.	Paragraphs 3.2.5, 3.4
Tewarson, A., "Generation of Heat and Gaseous Liquid and Solid Products in Fires", Section 3 Chapter 13	Paragraph 2.3.3

New Zealand Fire Service

Emergency Incident Statistics 2005–2010	NZBC C3.7

General publications

Fire Brigade Intervention Model. (Australasian Fire and Emergency Services Authority Council (AFAC), 2006)	Paragraph 4.8
Babrauskas, V., "Fire Modeling Tools for FSE: Are They Good Enough?" *Journal of Fire Engineering*, 8 (2) 87-96, 1996. http://dx.doi.org/10.1177%2F104239159600800203.	Paragraph 2.3
Babrauskas, V., Ignition Handbook, Fire Science Publishers, and Society of Fire Protection Engineers, (2003),	NZBC C2.2
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'Fire Performance of Wall and Ceiling Lining Materials'. CRC Project 2 – Stage A, Fire Performance of Materials, Project Report FCRC – PR 98-02, Fire Code Reform Research Program (July and September 1998) (Fire Code Reform Centre.)	Paragraph 4.7
EUREFIC European Reaction to Fire Classification. Proceedings of the International EUREFIC Seminar, Copenhagen Denmark, September 1991, Interscience Communications Ltd (ICL)	Paragraph 4.7
Gildea, J R and Etengoff, S., "Vertical Evacuation Simulation of Critically Ill Patients in a Hospital", Prehospital and Disaster Medicine, (July 2005)	Paragraph 4.7, Table 3.3
Gwynne, S, Galea, E R, Parke, J and Hickson, J, "The Collection and Analysis of Pre-evacuation Times Derived from Evacuation Trials and Their Application to Evacuation Modelling", Fire Technology, 39, 173-195, 2003	Table 3.3
Kokkala, MA., Thomas PH., and Karlsson, B., "Rate of Heat Release and Ignitability Indices for Surface Linings." Fire and Materials Vol 17, p209-216. (1993.)	Paragraph 4.7

Ingason, H., *Heat Release Rate of Rack Storage Fires*, Proceeding of INTERFLAM 2001, Interscience Communication Limited, London, UK, 2001.	Paragraph 2.3
Sundstorm, B., *Fire Safety of Upholstered Furniture – the final report on the CBUF research programme*, Interscience Communication Limited, London, UK, 1995.	Paragraph 2.3.3

Definitions

Extract from C/VM2: Definitions

Definitions C/VM2

Definitions

The full list of definitions for italicised words may be found in the New Zealand Building Code Handbook.

Available safe egress time (ASET) Time available for escape for an individual occupant. This is the calculated time interval between the time of ignition of a fire and the time at which conditions become such that the occupant is estimated to be incapacitated (ie, unable to take effective action to escape to a *place of safety*).

Burnout Means exposure to fire for a time that includes fire growth, full development, and decay in the absence of intervention or automatic suppression, beyond which the fire is no longer a threat to building elements intended to perform loadbearing or fire separation functions, or both.

Computational fluid dynamics (CFD) Calculation method that solves equations to represent the movement of fluids in an environment.

Design fire Quantitative description of assumed *fire* characteristics within the *design scenario*.

Design scenario Specific scenario on which a deterministic *fire safety engineering* analysis is conducted.

Detection time Time interval between ignition of a *fire* and its detection by an automatic or manual system.

Evacuation time Time interval between the time of warning of a *fire* being transmitted to the occupants and the time at which the occupants of a specified part of a *building* or all of the *building* are able to enter a *place of safety*.

Fire decay Stage of *fire* development after a *fire* has reached its maximum intensity and during which the *heat release rate* and the temperature of the *fire* are decreasing.

Fire growth Stage of *fire* development during which the *heat release rate* and the temperature of the *fire* are increasing.

Fire load Quantity of heat which can be released by the complete combustion of all the *combustible* materials in a volume, including the facings of all bounding surfaces (Joules).

Fire load energy density (FLED) *Fire load* per unit area (MJ/M^2).

Fire safety engineering Application of engineering methods based on scientific principles to the development or assessment of designs in the built environment through the analysis of specific *design scenarios* or through the quantification of risk for a group of *design scenarios*.

Flashover Stage of *fire* transition to a state of total surface involvement in a *fire* of *combustible* materials within an enclosure.

Fractional effective dose (FED) The fraction of the dose (of carbon monoxide (CO) or thermal effects) that would render a person of average susceptibility incapable of escape.

Comment:
The definition for FED has been modified from the ISO definition to be made specific for this Verification Method. The ISO definition is "Ratio of the exposure dose for an insult to that exposure dose of the insult expected to produce a specified effect on an exposed subject of average susceptibility."

Fully developed fire State of total involvement of *combustible* materials in a *fire*.

Heat of combustion Thermal energy produced by combustion of unit mass of a given substance (kJ/g).

Heat release Thermal energy produced by combustion (Joules).

Heat release rate (HRR) Rate of thermal energy production generated by combustion (kW or MW).

Importance level As specified in Clause A3 of the *Building Code*.

Incapacitation State of physical inability to accomplish a specific task.

Insulation In the context of *fire* protection, the time in minutes for which a prototype specimen of a *fire separation*, when subjected to the *standard test* for *fire* resistance, has limited the transmission of heat through the specimen.

Extract from C/VM2: Definitions

Integrity In the context of *fire* protection, the time in minutes for which a prototype specimen of a *fire separation*, when subjected to the *standard test* for *fire* resistance, has prevented the passage of flame or hot gases.

Comment:
The precise meaning of *integrity* depends on the type of *building elements* being treated and how it is defined in the *standard test* being used.

Optical density of smoke Measure of the attenuation of a light beam passing through smoke expressed as the logarithm to the base 10 of the opacity of smoke.

Opacity of smoke Ratio of incident light intensity to transmitted light intensity through smoke under specified conditions.

Place of safety means either—

a) a *safe place*; or

b) a place that is inside a *building* and meets the following requirements:

  i) the place is constructed with *fire separations* that have *fire* resistance sufficient to withstand *burnout* at the point of the *fire source*; and

  ii) the place is in a *building* that is protected by an automatic fire sprinkler system that complies with NZS 4541 or NZS 4515 as appropriate to the *building's* use; and

  iii) the place is designed to accommodate the intended number of persons; and

  iv) the place is provided with sufficient means of escape to enable the intended number of persons to escape to a *safe place* that is outside a *building*.

Pre-travel activity time Time period after an alarm or *fire* cue is transmitted and before occupants first travel towards an exit.

Required safe egress time (RSET) Time required for escape. This is the calculated time period required for an individual occupant to travel from their location at the time of ignition to a *place of safety*.

Response Time Index (RTI) The measure of the reaction time to a *fire* phenomenon of the sensing element of a *fire safety system*.

Safe place A place, outside of and in the vicinity of a single *building* unit, from which people may safely disperse after escaping the effects of a *fire*. It may be a place such as a street, *open space*, public space or an *adjacent building* unit.

Comment:
The Fire Safety and Evacuation of Buildings Regulations 2006 use the term *'place of safety'* and allow the *place of safety* to be within the *building* provided that it is protected with a sprinkler system.

Separating element Barrier that exhibits fire *integrity*, *structural adequacy*, thermal *insulation*,or a combination of these for a period of time under specified conditions (in a fire resistance test).

Smoke production rate Amount of smoke produced per unit time in a *fire* or *fire* test.

Specific extinction area of smoke Extinction area of smoke produced by a test specimen in a given time period, divided by the mass lost from the test specimen in the same time period.

Structural adequacy In the context of the *standard test* for *fire* resistance, is the time in minutes for which a prototype specimen has continued to carry its applied load within defined deflection limits.

Surface spread of flame Flame spread away from the source of ignition across the surface of a liquid or a solid.

Travel distance Distance that is necessary for a person to travel from any point within a built environment to the nearest exit, taking into account the layout of walls, partitions and fittings.

Visibility Maximum distance at which an object of defined size, brightness and contrast can be seen and recognised.

Yield Mass of a combustion product generated during combustion divided by the mass loss of the test specimen.

Introduction
Verification Method C/VM2

This document is aimed at professional *fire* engineers and others interested in the application of New Zealand Building Code Clauses C1 to C6: Protection from Fire and Verification Method C/VM2.

It includes commentary on Clauses C1 to C6 and their subclauses, additional guidance for applying the Verification Method, and some insight into its development.

C/VM2 is intended to provide a robust and consistent design methodology for specific design that allows creative and flexible *fire* engineering solutions. It sets out a number of prescribed *design scenarios* against which the *fire* engineer must test his or her designs.

Reasons for change

Following the introduction of the *Building Act 2004*, a comprehensive, statutory review of the New Zealand Building Code was carried out to check that:

- the Code requirements were consistent with the purposes of the new Act, and
- its performance requirements were sufficiently specific.

This review found that the Code's *fire* safety performance requirements were not sufficiently clear or precise. There was no consistent approach to *fire* safety design, which was leading to disputes over the implied requirements of the Code and over the safety of *fire* designs for proposed *buildings*. The result: stifled innovation, more conservative designs, and lengthy and costly compliance debates.

The review recommended investigating the specification of *design scenarios* and performance requirements to be taken into account when designing for *fire* safety. It was proposed that these would be in line with the structural design process that specifies events and physical conditions on the structural performance of *buildings* such as wind, earthquake and snow.

A working group made up of external *fire* experts and Department staff was set up to research and develop a suitable *fire* safety design framework. *Fire* engineering practitioners then field-tested the prototype framework and designers were also invited to create parallel designs for *buildings* in their practice, both to identify any improvements and to highlight any unintended outcomes.

The final *design scenarios* and associated parameters are set out in Verification Method C/VM2, which applies to complex *buildings.* Simple *buildings* are covered by a suite of Acceptable Solutions C/AS1 to C/AS7.

Establishing the values

This document does not provide a comprehensive, technical justification of the values selected for use in Clauses C1 to C6 and Verification Method C/VM2. For a start, the *fire* research community simply has not provided methodologies for addressing many of the design issues faced in common engineering practice. In fact, there are a number of historic values within all of the international codes that are commonly accepted but have no technical basis.

When developing the *fire* safety design framework, the working group's approach was as follows:

- When there was obvious analysis available to support the chosen values in the existing Compliance Documents, it would first consider those existing Compliance Documents, and
- In other cases, it would investigate the approach of overseas building codes.

Some of the reasoning behind the working group's final decisions is included in later sections.

1. Explaining the Code Clauses
Verification Method C/VM2

This section contains the full wording of NZBC C1 to C6: Protection from Fire and provides some associated commentary.

Code Clauses C1 to C6 Protection from Fire

C1—OBJECTIVES OF CLAUSES C2 TO C6 (PROTECTION FROM FIRE)

Provisions	Limits on application
The objectives of clauses C2 to C6 are to: (a) safeguard people from an unacceptable risk of injury or illness caused by *fire*, (b) protect *other property* from damage caused by *fire*, and (c) facilitate firefighting and rescue operations.	

C2—PREVENTION OF FIRE OCCURRING

Provisions	Limits on application
FUNCTIONAL REQUIREMENT	
C2.1 Fixed appliances using controlled combustion and other fixed equipment must be designed, constructed, and installed in *buildings* in a way that reduces the likelihood of illness or injury due to *fire* occurring.	
PERFORMANCE	
C2.2 The maximum surface temperature of *combustible building materials* close to fixed appliances using controlled combustion and other fixed equipment when operating at their design level must not exceed 90°C.	
C2.3 Fixed appliances using controlled combustion and other fixed equipment must be designed, constructed and installed so that there is a low probability of explosive or hazardous conditions occurring within any spaces in or around the *building* that contains the appliances.	

Commentary to Code Clauses C1 to C6 Protection from Fire

Clause C2.2

Clause C2.2 defines the maximum surface temperature that a *combustible* surface shall not exceed, based on long-term exposure to elevated temperatures and surface radiation from a heating appliance. The intention of declaring a specific value as opposed to a temperature rise is to reduce any dispute about the appropriate ambient temperature to assume in the application of this clause.

At first, the value of 90ºC may appear to be significantly lower than typical piloted ignition temperatures of around 200ºC. However, a review of the literature shows that wood exposed to constant heating for long periods of time may change chemically and this can result in significantly lower ignition temperatures. The recommended limiting surface temperature for long exposure times accordingly varies from 66ºC to 110ºC. For example, Babrauskas states that it is possible to reliably conclude that any heating device of 77ºC or higher, if applied to a wood surface for a protracted period of time, presents a documented ignition hazard.

The value of 90ºC is also consistent with the maximum temperature rise above ambient of 65ºC that is used in Appendix B of AS/NZS 2918.

Clause C2.3

Clause C2.3 is intended to ensure that all fixed appliances using controlled combustion and other fixed equipment are *constructed* and installed according to an appropriate Standard, such as AS/NZS 2918 or AS/NZS 3869.

If a designer is not referring to a New Zealand Standard, it is his or her responsibility to demonstrate that the Standard used is equivalent to the appropriate New Zealand Standard.

C3—FIRE AFFECTING AREAS BEYOND THE FIRE SOURCE

Provisions	Limit on application
FUNCTIONAL REQUIREMENT	
C3.1 *Buildings* must be designed and constructed so that there is a low probability of injury or illness to persons not in close proximity to a *fire source*.	
C3.2 *Buildings* with a *building height* greater than 10 m where upper floors contain sleeping uses or *other property* must be designed and constructed so that there is a low probability of external vertical fire spread to upper floors in the *building*.	Clause C3.2 does not apply to importance level 1 *buildings*.
C3.3 *Buildings* must be designed and constructed so that there is a low probability of *fire* spread to *other property* vertically or horizontally across a *relevant boundary*.	

C3—FIRE AFFECTING AREAS BEYOND THE FIRE SOURCE (continued)

Provisions	Limit on application
PERFORMANCE	
C3.4 (a) materials used as internal surface linings in the following areas of *buildings* must meet the performance criteria specified below:	Clause C3.4 does not apply to *detached dwellings*, within *household units* in *multi-unit dwellings*, or *outbuildings* and *ancillary buildings*.

Area of *building*	**Performance determined under conditions described in ISO 9705: 1993**	
	***Buildings* not protected with an automatic *fire* sprinkler system**	***Buildings* protected with an automatic *fire* sprinkler system**
Wall/ceiling materials in sleeping areas where care or detention is provided	Material Group Number 1-S	Material Group Number 1 or 2
Wall/ceiling materials in exitways	Material Group Number 1-S	Material Group Number 1 or 2
Wall/ceiling materials in all *occupied spaces* in importance level 4 *buildings*	Material Group Number 1-S	Material Group Number 1 or 2
Internal surfaces of ducts for *HVAC systems*	Material Group Number 1-S	Material Group Number 1 or 2
Ceiling materials in crowd and sleeping uses except *household units* and where care or detention is provided	Material Group Number 1-S or 2-S	Material Group Number 1 or 2
Wall materials in crowd and sleeping uses except *household units* and where care or detention is provided	Material Group Number 1-S or 2-S	Material Group Number 1, 2, or 3
Wall/ceiling materials in occupied spaces in all other locations in *buildings*, including *household units*	Material Group Number 1, 2, or 3	Material Group Number 1, 2, or 3
External surfaces of ducts for *HVAC systems*	Material Group Number 1, 2, or 3	Material Group Number 1, 2, or 3
Acoustic treatment and pipe insulation within airhandling plenums in sleeping uses	Material Group Number 1, 2, or 3	Material Group Number 1, 2, or 3

Commentary to Code Clauses C1 to C6 Protection from Fire

Clause C3.4

Clause C3.4 is intended to reduce the risk of rapid flame spread on walls, floors, and ceilings, so that the *fire growth* rate does not significantly exceed that given in Verification Method C/VM2.

The hazards of rapid flame spread on *building* surfaces can result in extremely rapid *fire growth* that can easily exceed the *design fires* typically used in *fire* engineering design and, in particular, the *design fire* values given in Verification Method C/VM2. *Fire*s like those at the Cocoanut Grove, MGM Grand, and the Station Night Club demonstrate how quickly a *fire* can spread on *combustible* surface material. While it is not possible for the *Building Code* to control the contents of a *building*, it is appropriate to place controls on the *surface finishes* in certain areas of a *building*. Controlling the surface spread of flame significantly reduces the likelihood that a *fire* will exceed the growth rate given in Verification Method C/VM2.

Commentary to Code Clauses C1 to C6 Protection from Fire

Clause C3.4(a)

The *Group Number* methodology used in Clause C3.4(a) has been the subject of significant research in Europe and Australia, and more recently here in New Zealand. The current methodology applied in the Building Code of Australia is adopted as a model here.
This uses the ISO 9705 method as a reference scenario. AS/NZS 3837 (cone calorimeter) or ISO 5660 results have been correlated to the larger scale ISO 9705 room corner *fire* test and the correlation can be used for most materials. Surface linings are exposed to 100 kW for 10 minutes and then 300 kW for a further 10 minutes, and the time to reach *flashover* (when the *heat release rate* reaches 1 MW in a 3.6 m x 2.4 m x 2.4 m room) is then determined. Materials are classified from *Group Number* 1 (best) to *Group Number* 4 (worst) based on their measured time to *flashover* in the *fire* test.

Group Number 1 materials

These include non-*combustible* materials or those with limited *combustibility*. Examples are plasterboard and similar, low-hazard materials (no *flashover* in 20 minutes). These materials meet the *flashover* criteria of the performance requirement of Clause C3.4(a) for *exitways*.

Group Number 2 materials

These typically include many *fire retardant* treated timbers (no *flashover* in 10 minutes). These materials meet the *flashover* criteria of the performance requirement of Clause C3.4(a) for crowd uses.

Group Number 3 materials

These typically include ordinary timber or similar products (no *flashover* in 2 minutes). These materials meet the *flashover* criteria of the performance requirement of Clause C3.4(a) for all other areas.

C3—FIRE AFFECTING AREAS BEYOND THE FIRE SOURCE (continued)

Provisions	Limit on application
(b) floor surface materials in the following areas of *buildings* must meet the performance criteria specified below:	

Area of *building*	Minimum critical radiant flux when tested to ISO 9239-1: 2010	
	Buildings **not protected with an automatic *fire* sprinkler system**	***Buildings*** **protected with an automatic *fire* sprinkler system**
Sleeping areas and exitways in *buildings* where care or detention is provided	4.5 kW/m^2	2.2 kW/m^2
Exitways in all other *buildings*	2.2 kW/m^2	2.2 kW/m^2
Firecells accommodating more than 50 persons	2.2 kW/m^2	1.2 kW/m^2
All other occupied spaces except *household units*	1.2 kW/m^2	1.2 kW/m^2

(c) suspended flexible fabrics and membrane structures used in the construction of *buildings* must have properties resulting in a low probability of injury or illness to persons not in close proximity to a *fire source*.

C3.5 *Buildings* must be designed and constructed so that fire does not spread more than 3.5 m vertically from the *fire source* over the external cladding of multi-level *buildings*.

C3.6 *Buildings* must be designed and constructed so that in the event of *fire* in the building the received radiation at the *relevant boundary* of the property does not exceed 30 kW/m^2 and at a distance of 1 m beyond the relevant boundary of the property does not exceed 16 kW/m^2.

Group Number 4 materials

These typically include exposed polyurethane foams or similar products (*flashover* within 2 minutes). Note that these materials are potentially *hazardous* when installed as room linings and are not acceptable in *occupied spaces*.

See the commentary to Paragraph 4.7 of Verification Method C/VM2 for further background.

Clause C3.4(b)

Clause C3.4(b) applies to the floor surface or the floor covering if present. A minimum critical radiant flux (CRF) is specified depending on location in the *building* and whether sprinklers are present. The CRF is measured in the floor radiant panel test (ISO 9239-1). See the commentary to Paragraph 4.7 of Verification Method C/VM2 for further background.

Clause C3.5

Clause C3.5 is intended to reduce the risk of flame spread via the *external wall* surfaces of *buildings*. The intention is to reduce the likelihood of *fire* spreading into upper floor levels, or creating a *hazardous* situation for firefighters or occupants while escaping from the *building*.

Clause C3.5

Clause 3.5 applies to:

a) *Buildings* with upper floors containing sleeping occupancies or *other property*, and
b) *Buildings* of *building height* >10 m.

It does not apply to *importance level* 1 *buildings* (as specified in Clause A3 of the *Building Code)*.

See the commentary to Paragraph 4.6 of Verification Method C/VM2 for further background.

Clauses C3.6 and C3.7

Clauses C3.6 and C3.7 work in tandem to limit the probability of *fire* spread to adjoining property. C3.6 is a performance requirement that limits the received radiation at the relevant distances, while C3.7 limits the *combustibility* of *building* surfaces in order to moderate the radiation requirements from the *fire source building*.

In Clause C3.6, the maximum allowable received radiation on the *boundary* of 30 kW/m² recognises that the *construction* of the *external walls* within 1.0 m of the *relevant boundary* must meet separate criteria for ignitability as required by Clause C3.7. Therefore, the material can be expected to be able to withstand an exposure of 30 kW/m² at least until the Fire Service has arrived providing additional resources to prevent *fire* spread across the *boundary*.

Beyond 1.0 m across the *relevant boundary*, Clause C3.7 does not restrict the ignitability of materials that may be used on the *external wall*. Therefore, the maximum allowable received radiation at these locations is set at a lower value of 16 kW/m². As this value may not necessarily be small enough to prevent ignition or damage to all cladding materials, it is anticipated that the Fire Service will provide a secondary means of preventing *fire* spread in these situations if necessary.

C3—FIRE AFFECTING AREAS BEYOND THE FIRE SOURCE (continued)

Provisions	Limit on application
C3.7 External walls of *buildings* that are located closer than 1 m to the *relevant boundary* of the property on which the *building* stands must either: (a) be constructed from materials which are not *combustible building materials*, or (b) for *buildings* in importance levels 3 and 4, be constructed from materials that, when subjected to a radiant flux of 30 kW/m^2, do not ignite for 30 minutes, or (c) for *buildings* in Importance Levels 1 and 2, be constructed from materials that, when subjected to a radiant flux of 30 kW/m^2, do not ignite for 15 minutes.	
C3.8 *Firecells* located within 15 m of a *relevant boundary* that are not protected by an automatic *fire* sprinkler system, and that contain a *fire load* greater than 20 TJ or that have a floor area greater than 5,000 m^2 must be designed and constructed so that at the time that firefighters first apply water to the *fire*, the maximum radiation flux at 1.5 m above the floor is no greater than 4.5 kW/m^2 and the smoke layer is not less than 2 m above the floor.	
C3.9 *Buildings* must be designed and constructed with regard to the likelihood and consequence of failure of any *fire safety* system intended to control *fire* spread.	

Commentary to Code Clauses C1 to C6 Protection from Fire

While it is not possible to give 100% guarantee of timely Fire Service intervention, the history of past *fires* indicates that the risk of *fire* spread to adjacent property is small but not insignificant (approximately 3% of all structure *fires* according to NZFS Emergency Incident Statistics 2005-2010).

It should be noted that the design values for radiant flux given in this scenario and other assumptions implicit in the limiting distance method do not guarantee that *fire* spread will be prevented in all situations. Specifically, assumptions made such as: ignoring flame projection from openings; cladding properties representing timber with 15% moisture content; limited duration of exposure; and *fire* gas temperatures following a standard time-temperature curve may not be the most conservative cases. For this reason, it is anticipated that, in some instances, the Fire Service may also be called upon to provide a secondary means of helping to prevent *fire* spread. Means of facilitating this is included in the Design Scenario FO: Firefighting operations (see Verification Method C/VM2 Paragraph 4.8).

The intention of Clause C3.7 is to ensure that materials within 1.0 m of the *relevant boundary* are resistant to the level of radiation that they may be exposed to in that position.

If a *building* is to be *constructed* closer than 1.0 m to the *relevant boundary*, then it is the responsibility of the *owner* to reduce the probability of *fire* spread by reducing the likelihood of ignition of their property. This is achieved by having more stringent requirements on the ignitability of the exterior cladding for *buildings* within 1.0 m of the *relevant boundary*.

The *combustibility* (or non-*combustibility*) of materials can be assessed using AS 1530 Part 1 or ISO 1182. These test methods are severe and it can be assumed that if a material is classified as *non-combustible* then there will be no ignition at heat fluxes up to 30 kW/m^2. Alternatively, the time to ignition of cladding materials can be determined using ISO 5660. As ordinary timber claddings will ignite in less than 15 minutes when exposed to 30 kW/m^2, they do not meet the performance criteria of Clause C3.7.

Clause C3.8

Clause C3.8 recognises that Clauses C3.6 and C3.7 may, in some situations, be insufficient to protect *other property* without Fire Service intervention.

Note:

- 20 TJ is equivalent to 20 million MJ.
- The maximum area limit of 5,000 m^2 was set based on a *fire load energy density (FLED)* of 800 MJ/m^2 per metre height of storage, and a 5.0 m storage height.

C3—FIRE AFFECTING AREAS BEYOND THE FIRE SOURCE (continued)

Provisions	Limit on application
C3.7 External walls of *buildings* that are located closer than 1 m to the *relevant boundary* of the property on which the *building* stands must either: (a) be constructed from materials which are not *combustible building materials*, or (b) for *buildings* in importance levels 3 and 4, be constructed from materials that, when subjected to a radiant flux of 30 kW/m^2, do not ignite for 30 minutes, or (c) for *buildings* in Importance Levels 1 and 2, be constructed from materials that, when subjected to a radiant flux of 30 kW/m^2, do not ignite for 15 minutes.	
C3.8 *Firecells* located within 15 m of a *relevant boundary* that are not protected by an automatic *fire* sprinkler system, and that contain a *fire load* greater than 20 TJ or that have a floor area greater than 5,000 m^2 must be designed and constructed so that at the time that firefighters first apply water to the *fire*, the maximum radiation flux at 1.5 m above the floor is no greater than 4.5 kW/m^2 and the smoke layer is not less than 2 m above the floor.	
C3.9 *Buildings* must be designed and constructed with regard to the likelihood and consequence of failure of any *fire safety* system intended to control *fire* spread.	

Commentary to Code Clauses C1 to C6 Protection from Fire

For large, unsprinklered *buildings*, it is the intention to limit the maximum *fire* size and maximum allowable total energy level that can occur within a *firecell*. However, although these limits apply to all *buildings*, the limits set are only expected to affect large storage areas.

There is no direct analytical method to determine the values used in Clause C3.8 and, although they are noticeably larger than the 2 TJ of the previous Acceptable Solution C/AS1 (2011), the conventional explanation for that previous value was not well supported by sound engineering analysis. A number of international codes, including those of the UK, USA and Australia, were reviewed for comparative purposes. The values chosen for New Zealand are considered to be broadly comparable with these codes, even though direct comparison was limited by the differences in *fire*-resistive *construction* requirements, separation distances from *boundaries*, and controls on the total allowable energy.

For example, the Building Code of Australia considers *firecells* as specified in Clause C3.8 to be 'Excessive Hazard' and requires them to be sprinklered if there are *combustible* goods with an aggregate volume exceeding 1000 m^3 and storage to a height of more than 4.0 m. The Building Code of Australia also gives examples for stored *combustible* goods over a wide range of materials and items, which may be very dense (eg, rolled plastics) or relatively low-density furniture items.

To calculate the total energy of materials (ie, the *fire load*), use the following relationship:

$$Q = \rho V \Delta H_c$$

where:

Q = total energy (TJ)

V = aggregate storage volume (1000 m^3)

ρ = density (kg/m^3), and

ΔH_c = heat of combustion (TJ/kg; 1 TJ/kg $=10^6$ MJ/kg).

Table C1 Total energy calculations for a number of potential fuels stored in 1000 m^3

	PU foam (FR)	Flat wood	MDF[a]	Butter	Kerosene	Fuel oil	PP[b]	LDPE[c]	PS[d]
ΔH_C (MJ/kg)	27.5	16.0	16.0	38.5	43.2	39.7	43.2	43.6	39.7
ρ storage (kg/m^3)[e]	48	450	720	870	820	940	905	925	1050
Q Total energy (TJ)	1.3	7.2	11.5	33.5	35.4	37.3	39.1	40.3	41.7

C3—FIRE AFFECTING AREAS BEYOND THE FIRE SOURCE (continued)

Provisions	Limit on application
C3.7 External walls of *buildings* that are located closer than 1 m to the *relevant boundary* of the property on which the *building* stands must either: (a) be constructed from materials which are not *combustible building materials*, or (b) for *buildings* in importance levels 3 and 4, be constructed from materials that, when subjected to a radiant flux of 30 kW/m^2, do not ignite for 30 minutes, or (c) for *buildings* in Importance Levels 1 and 2, be constructed from materials that, when subjected to a radiant flux of 30 kW/m^2, do not ignite for 15 minutes.	
C3.8 *Firecells* located within 15 m of a *relevant boundary* that are not protected by an automatic *fire* sprinkler system, and that contain a *fire load* greater than 20 TJ or that have a floor area greater than 5,000 m^2 must be designed and constructed so that at the time that firefighters first apply water to the *fire*, the maximum radiation flux at 1.5 m above the floor is no greater than 4.5 kW/m^2 and the smoke layer is not less than 2 m above the floor.	
C3.9 *Buildings* must be designed and constructed with regard to the likelihood and consequence of failure of any *fire safety* system intended to control *fire* spread.	

NOTES:

a. Medium-density fibreboard
b. Polypropylene
c. Low-density polyethylene
d. Polystyrene
e. Raw density for the material. Aggregate density will vary with storage configuration.

Table 1 summarises these calculations for a range of common materials. The wide range of total energy values that results highlights the difficulties in selecting an ultimate value for total energy.

At the low end is low-density polyurethane foam, which has a total energy value of 1.3 TJ. In the mid range, manufactured timber products such as MDF give a total energy of 11.5 TJ. At the high end of the range are rolled plastics such as low-density polyethylene (LDPE): this often comes on bulk rolls for food wrap, bulk plastic bags or large sheet material for tarpaulins. Such rolls would be expected to have an aggregate volume (accounting for the hollow core and some reduction in raw density due to the product being rolled) of 50% of the raw density, giving a total energy of approximately 20 TJ. A somewhat lower total energy is expected for rolled carpet due to a reduced roll density resulting from a lower compression ratio caused by the fibres.

At the extreme end of the range are *combustible* liquids or edible fats such as butter, which would give a total energy as high as 40 TJ. However, these are considered to be too excessive and these materials are not explicitly mentioned in the Building Code of Australia.

Although a more rational or statistical design approach would have been preferred to determine the maximum total energy, no such analysis could be found. Therefore, this left the review of international codes and an analysis for the expected energy levels within storage occupancy. Ultimately the 20 TJ limit was a pragmatic decision.

Clause C3.9

Clause C3.9 recognises that certain *fire* safety features may not respond as intended. Therefore, the failure of individual *fire* safety features should be considered in performance-based design. The engineer is expected to evaluate their design under a specific scenario to address this concern, as well as to specify appropriate installation and maintenance standards for *fire safety systems.*

C4—MOVEMENT TO PLACE OF SAFETY

Provisions	Limits on application
FUNCTIONAL REQUIREMENT	
C4.1 *Buildings* must be provided with: (a) effective means of giving warning of *fire*, and (b) visibility in *escape routes* complying with clause F6.	
C4.2 *Buildings* must be provided with means of escape to ensure that there is a low probability of occupants of those buildings being unreasonably delayed or impeded from moving to a *place of safety* and that those occupants will not suffer injury or illness as a result.	
PERFORMANCE	
C4.3 The *evacuation time* must allow occupants of a building to move to a *place of safety* in the event of a fire so that occupants are not exposed to any of the following: (a) a *fractional effective dose* of carbon monoxide greater than 0.3: (b) a *fractional effective dose* of thermal effects greater than 0.3: (c) conditions where, due to smoke obscuration, visibility is less than 10 m except in rooms of less than 100 m^2 where visibility may fall to 5 m.	
C4.4 Clause C4.3(b) and (c) do not apply where it is not possible to expose more than 1 000 occupants in a *firecell* protected with an automatic *fire* sprinkler system.	
C4.5 Means of escape to a *place of safety* in *buildings* must be designed and constructed with regard to the likelihood and consequence of failure of any *fire safety systems.*	

Clause C.4.3

C4.3 is intended to define the minimum life safety criteria for use in performance-based *fire* safety design. Specifying values for the *fractional effective doses* (*FEDs*) and *visibility* gives a more consistent level of safety than that given by the previous qualitative description of performance.

According to ISO 13571, an *FED* of 1.0 is taken to be the level which would render occupants of average susceptibility incapable of effecting their own escape. Since the variability of human response to toxicological insults is best represented by a distribution, we can interpret an *FED* of 1.0 to be the point at which approximately 50% of occupants might be expected to be incapacitated. The Code clause requires a lower *FED* threshold of 0.3 and we interpret this level to correspond to the point at which approximately 11% of the population would be susceptible to less severe exposures. Lower threshold values would reduce that portion of the population. However, there is no threshold criterion so low as to be statistically safe for every exposed occupant.

Extract from ISO 13571

5.2 Given the scope of this International Standard, FED and/or FEC values of 1,0 are associated, by definition, with sublethal effects that would render occupants of average susceptibility incapable of effecting their own escape. The variability of human responses to toxicological insults is best represented by a distribution that takes into account varying susceptibility to the insult. Some people are more sensitive than the average, while others can be more resistant (see Clause A.5). The traditional approach in toxicology is to employ a safety factor to take into consideration the variability among humans, serving to protect the more susceptible subpopulations[1].

As an example, within the context of reasonable fire scenarios FED and/or FEC threshold criteria of 0,3 can be used for most general occupancies in order to provide for escape by the more sensitive subpopulations. However, the user of this International Standard has the flexibility to choose other FED and/or FEC threshold criteria as is appropriate for chosen fire safety objectives. More conservative FED and/or FEC threshold criteria may be employed for those occupancies that are intended for use by especially susceptible subpopulations. By whatever rationale FED and FEC threshold criteria are chosen, it is necessary to use a single value for both FED and FEC in a given calculation of the time available for escape.

NOTE At present, the distribution of human responses to fire gases is not known. In the absence of information to the contrary, a log-normal distribution of human responses is a reasonable choice to represent a single peak distribution with a minimum value of zero and no upper limit. By definition, FED and FEC threshold criteria of 1,0 correspond to the median value of the distribution, with one-half of the population being more susceptible to an insult and one-half being less susceptible. Statistics show [2] that at an FED and/or FEC threshold criteria of 0,3, then 11,4 % of the population is susceptible to less severe exposures (lower than 0,3) and, therefore, is statistically unable to accomplish their own escape. Lower threshold criteria reduce that portion of the population. However, there is no threshold criterion so low as to be statistically safe for every exposed occupant.

There is considerable uncertainty in the calculations used because of a limited amount of comparative data. Data used to develop the relationships are based on both human and animal research, and further refining the results would require additional experiments. Such data are not expected to ever be available.

C4—MOVEMENT TO PLACE OF SAFETY

Provisions	Limits on application
FUNCTIONAL REQUIREMENT	
C4.1 *Buildings* must be provided with:	
(a) effective means of giving warning of *fire*, and	
(b) visibility in *escape routes* complying with clause F6.	
C4.2 *Buildings* must be provided with means of escape to ensure that there is a low probability of occupants of those buildings being unreasonably delayed or impeded from moving to a *place of safety* and that those occupants will not suffer injury or illness as a result.	
PERFORMANCE	
C4.3 The *evacuation time* must allow occupants of a building to move to a *place of safety* in the event of a fire so that occupants are not exposed to any of the following:	
(a) a *fractional effective dose* of carbon monoxide greater than 0.3:	
(b) a *fractional effective dose* of thermal effects greater than 0.3:	
(c) conditions where, due to smoke obscuration, visibility is less than 10 m except in rooms of less than 100 m^2 where visibility may fall to 5 m.	
C4.4 Clause C4.3(b) and (c) do not apply where it is not possible to expose more than 1 000 occupants in a *firecell* protected with an automatic *fire* sprinkler system.	
C4.5 Means of escape to a *place of safety* in *buildings* must be designed and constructed with regard to the likelihood and consequence of failure of any *fire safety systems.*	

The data used were for young healthy adult humans and animals. These represent the least vulnerable populations. However, certain sub-populations such as the elderly and the very young, which are expected to be more vulnerable to the effects of *fire*, must be considered in design. Documents such as BS Published Document PD 7974-6: 2004 therefore recommend the use of the *FED* <0.3 as the acceptance criteria along with a visibility of 10 m. In cases where the occupants are considered to be a vulnerable sub-population, the *FED* may be set even lower.

The above discussion is mainly in relation to the toxicological effects of gases on people, but we have assumed that broadly similar principles apply to the thermal effects and we have accordingly used the same threshold criterion of *FED* <0.3.

Clause C.4.4

C4.4 removes the performance criteria for *visibility* and $FED_{Thermal}$ when it is not possible to expose more than 1000 occupants in a sprinklered *firecell*. This is intended to promote the use of sprinklers in *buildings* and to provide closer alignment with the requirements of the Acceptable Solutions. However, it also recognises the current limitations in accurately modelling sprinkler performance in controlling the *fire* and reducing the threat to life safety.

Although there may be a temporary increase in smoke production when a sprinkler activates, due to the expansion of steam generated from cooling the *fire*, this is quickly controlled and the threat to the *building*'s occupants is greatly reduced. Therefore, with sprinklers, only the FED_{CO} needs to be calculated unless there are very large numbers of occupants at risk. This places a practical limit on the maximum evacuation time in the rare cases where the *fire* may be shielded from the sprinkler or the system does not operate as designed.

Clause C.4.5

C4.5 recognises that certain *fire* safety features may not respond as intended. Therefore, the failure of individual *fire* safety features should be considered in performance-based design. The engineer is expected to evaluate their design under a specific scenario to address this concern, as well as to specify appropriate installation and maintenance standards for *fire safety systems.*

C5—ACCESS AND SAFETY FOR FIREFIGHTING OPERATIONS

Provisions	Limits on application
FUNCTIONAL REQUIREMENT	
C5.1 *Buildings* must be designed and constructed so that there is a low probability of firefighters or other emergency services personnel being delayed in or impeded from assisting in rescue operations and performing firefighting operations.	
C5.2 *Buildings* must be designed and constructed so that there is a low probability of illness or injury to firefighters or other emergency services personnel during rescue and firefighting operations.	
PERFORMANCE	
C5.3 *Buildings* must be provided with access for fire service vehicles to a hard-standing from which there is an unobstructed path to the *building* within 20 m of: (a) the firefighter access into the *building*, and (b) the inlets to automatic fire sprinkler systems or fire hydrant systems, where these are installed.	Performance requirements in clauses C5.3 to C5.8 do not apply to *backcountry huts, detached dwellings*, within *household units* in *multi-unit dwellings*, or to *outbuildings*, and *ancillary buildings*.
C5.4 Access for fire service vehicles in accordance with clause C5.3 must be provided to more than 1 side of *firecells* greater than 5,000 m^2 in floor area that are not protected by an automatic fire sprinkler system.	
C5.5 *Buildings* must be provided with the means to deliver water for firefighting to all parts of the *building*.	
C5.6 *Buildings* must be designed and constructed in a manner that will allow firefighters, taking into account the firefighters' personal protective equipment and standard training, to: (a) reach the floor of fire origin, (b) search the general area of fire origin, and (c) protect their means of egress.	

Commentary to Code Clauses C1 to C6 Protection from Fire

Clauses C5.3, C5.4, C5.5, C5.6 and C5.7

Clauses C5.3, C5.4, C5.5, C5.6 and C5.7 facilitate firefighter and rescue operations using methods that are conventional and easily anticipated by the Fire Service. It is not expected that performance-based design would be carried out in relation to the systems provided here. It would be expected that, in the unusual event of any solutions being proposed for firefighting and rescue operations that were considered 'out of the ordinary', these would be discussed in detail with and agreed to by the Fire Service in advance.

Clause C.5.4

Where Clause C5.4 applies for vehicle access, it is intended that the points should be distributed around the *building* and not located each side of a corner such that the same *hard-standing* is utilised. The purpose of this clause is to ensure firefighter vehicle access to very large unsprinklered *buildings*.

C5—ACCESS AND SAFETY FOR FIREFIGHTING OPERATIONS (continued)

Provisions	Limits on application
C5.7 *Buildings* must be provided with means of giving clear information to enable firefighters to: (a) establish the general location of the *fire*, (b) identify the *fire safety systems* available in the building, and (c) establish the presence of *hazardous substances* or process in the *building*.	
C5.8 Means to provide access for and safety of firefighters in *buildings* must be designed and constructed with regard to the likelihood and consequence of failure of any *fire safety systems*.	

Commentary to Code Clauses C1 to C6 Protection from Fire

Clause C.5.8

Clause C5.8 means that, where provided, *fire safety systems* including automatic detectors, sprinklers, hydrants, smoke/heat venting systems and use of *fire* rated *construction* elements shall meet acceptable standards for their design, *construction*, installation and maintenance to ensure that their level of reliability and effectiveness are appropriate for the particular application.

See the commentary to Paragraph 4.8 of Verification Method C/VM2 for further background.

C6—STRUCTURAL STABILITY

Provisions	Limits on application
FUNCTIONAL REQUIREMENT	
C6.1 Structural systems in *buildings* must be constructed to maintain structural stability during *fire* so that there is: (a) a low probability of injury or illness to occupants, (b) a low probability of injury or illness to *fire* service personnel during rescue and firefighting operations, and (c) a low probability of direct or consequential damage to adjacent *household units* or *other property*.	
PERFORMANCE	
C6.2 Structural systems in *buildings* that are necessary for structural stability in *fire* must be designed and constructed so that they remain stable during *fire* and after *fire* when required to protect *other property* taking into account: (a) the *fire* severity, (b) any automatic fire sprinkler systems within the *buildings*, (c) any other active *fire safety systems* that affect the *fire* severity and its impact on structural stability, and (d) the likelihood and consequence of failure of any *fire safety systems* that affect the *fire* severity and its impact on structural stability.	
C6.3 Structural systems in *buildings* that are necessary to provide firefighters with safe access to floors for the purpose of conducting firefighting and rescue operations must be designed and constructed so that they remain stable during and after *fire*.	
C6.4 Collapse of building elements that have lesser *fire* resistance must not cause the consequential collapse of elements that are required to have a higher *fire* resistance.	

2. Rules and parameters for the design scenarios

Verification Method C/VM2

Sections 2 to 4 of this commentary document contain additional explanation and background for the Verification Method. The full text of Parts 2-4 of Verification Method C/VM2 is reproduced for ease of use, with associated commentary shown along side.

Extract from C/VM2: Paragraph 2.2.1

Part 2: Rules and parameters for the design scenarios

CONTENTS

2.1 Applying the design scenarios

This Verification Method sets out 10 *design scenarios* that must each be considered and designed for, where appropriate, in order to achieve compliance with NZBC C1-C6: Protection from Fire.

This section sets out the *fire* modelling rules, *design fire* characteristics and other parameters to be used in calculations required by the *design scenarios*. Occupancy criteria and calculations for the movement of people are provided in Part 3.

2.2 Fire modelling rules

The *fire* modelling rules in Paragraphs 2.2.1 and 2.2.2 shall be applied to the *design scenarios* as appropriate.

2.2.1 Fire modelling rules for life safety design

Fire modelling rules for life safety design shall be as follows:

a) Warning systems in accordance with Paragraph 3.4 shall be installed.

b) *Fire* and *smoke control doors* with self-closers complying with a recognised national or international Standard are assumed closed unless being used by occupants. During egress, when *occupant load* is low, doors are assumed to be open for three seconds per occupant. However, when the *occupant load* is high and queuing is expected, the door is considered to be open for the duration of queuing.

c) All doors not described in 2.2.1 b) shall be considered to be open during the analysis.

d) Doors being used for egress, when in the open position, are assumed to be half-width for smoke flow calculations.

e) Where zone modelling is used, leakage through non *fire*-rated walls shall be modelled as a tall narrow slot from floor to ceiling with the width of the vent determined by the calculated area. A single slot may be used to represent the total wall leakage in the compartment.

Commentary: Paragraph 2.2.1

2.2.1 a) Fundamental to Verification Method C/VM2 is the time-based analysis of *ASET* versus *RSET* which depends on the accurate, predictable and reliable means of alerting the occupants to a *fire* and thus a means of automatically alerting the occupants is required to use C/VM2. The only exception is a facility such as a warehouse where the *occupant load* is low and the ceiling is high. For this exception, the risk is reduced by keeping the *occupant load* low, while the high ceiling requirement allows the smoke layer to traverse the entire length of the *building* before the smoke can threaten the occupants. This provides time for the few occupants in the *building* to see the smoke travelling across the ceiling and evacuate before the onset of hazardous conditions.

2.2.1 b) A well-maintained *fire* or *smoke control door* is expected to operate as intended. The opening time of 3 seconds is used when the *occupant load* is low and queuing is not expected and so the occupants will arrive at the door at different times during the evacuation phase. The 3 seconds allows for the egressing occupant to open the door, travel through the opening and leave the door to self-close. When queuing is expected, the flow is assumed to be a continuous flow of people that will keep the door open.

2.2.1 c) A door without a self-closer cannot be relied on in the analysis. Assuming the door is open will maximise the smoke flow through the *building*.

2.2.1 d) The half opening area is to allow for the fact that the door is rarely fully open to provide a full unobstructed area. The door is either in the process of being opened or closing, or the occupant is passing through the opening and impeding the flow.

2.2.1 e) to g) Although the actual amount of leakage is never known for a space, a reasonable estimate should be included within the computer modelling. Within a zone model, the leakage is modelled as a vertical vent over the height of the *building*. This assumes that the leakage can be modelled as an equivalent area evenly distributed over the height of the space. For *CFD* modelling, the grid size is typically too large to include the leakage as a vertical slot. When the grid size is too coarse to include the leakage as a vertical slot, then the leakage can be modelled as two vents (one in the lowest grid cells of the space and one at the uppermost grid cells within the space). Two leakage vents (one high and one low in the space) are required to model the leakage for a space even if the grid size is large relative to the size of the vents required.

Fire resistant *construction* is designed and installed to minimise the flow of *fire* gases from the *fire* space to the adjacent space. Regular inspections of these walls should be part of the *building compliance schedule* to ensure that *fire* rated walls are installed correctly or not inadvertently compromised. Therefore, the *construction* is assumed to be sealed and with no leakage except for around the doors as specified in Paragraph 2.2.1 g) i) and ii).

Extract from C/VM2: Paragraph 2.2.1

f) Where *CFD* modelling is used, leakage shall be modelled either as a vertical slot as in zone modelling or as two vents, one at floor level and one at ceiling level, to fit within the computational grid.

g) Leakage areas assumed for modelling shall be as follows:

i) *smoke separations* and *smoke control doors* that comply with a recognised national or international Standard (including doors that have both *fire* and smoke control capability complying with a recognised national or international Standard) are assumed to have zero leakage area, except for a 10 mm gap under doors

ii) *fire* doors that are not *smoke control doors* are assumed to have a 10 mm gap over the height of the door

iii) *construction* having a *fire resistance rating* (excluding doors) is considered to have no leakage, and

iv) non *fire*-rated internal and *external walls* are assumed to have leakage areas that are proportional to the surface area of the walls. Leakage area is equal to the wall area multiplied by 0.001 m^2/m^2 (ie, 0.1%) for lined internal and *external walls* and 0.005 m^2/m^2 for unlined *external walls*.

h) *Smoke separations* that comply with recognised national or international Standards for use as a smoke barrier are assumed to remain in place up to the rated temperature or the time at which *flashover* occurs, whichever is sooner.

i) *Smoke separations* that are not tested (eg, non *fire* rated but imperforate *construction*) are assumed to remain in place until the average upper layer smoke temperature reaches 200°C.

j) Windows that are not *fire resisting glazing* are assumed to break (ie, glass falls out to become completely open) at the sooner of either average upper layer temperature reaching 500°C or when the *fire* becomes limited by ventilation. Windows that are *fire resisting glazing* may be assumed to remain in place up to the rated time.

k) The *fire* shall be located away from walls and corners to maximise entrainment of air into the fire plume. The base of the *fire* shall be located at a height of no more than 0.5 m above floor level.

l) *Fractional Effective Dose (FED)* for CO and thermal effects shall be calculated using the procedures described in ISO 13571. FED_{CO} shall include contributions from CO, CO_2 and O_2 gases. $FED_{thermal}$ shall include radiative and convective effects.

Also refer to Paragraph 2.3.3 for guidance on modelling post-*flashover fires* when evaluating life safety on *escape routes* that are not in the room of *fire* origin.

2.2.2 Fire modelling rules for resistance of fire separations and structural design

a) *Fire* modelling rules shall be as specified in Paragraphs 2.3.2 and 2.3.3 for *fires* reaching full *burnout*, for structural design and for assessing *fire* resistance required of *separating elements*.

b) The *design fire* severity for car parking areas incorporating a vehicle stacking system shall use the *FLED* specified in Table 2.2.

c) The *design fire* severity for car parking areas with overlapping interconnected floors shall be based on the worst case (floor area and effective openings available for ventilation) for one of the overlapping floors or for the worst combination of two adjacent (overlapping) floors.

d) For car parking areas, the area of vertical opening ventilation available to the *fire* shall be the area available via permanent openings to the outside environment in the perimeter walls and access ramps to a car parking level above. Access ramp area shall be taken as the projection on the vertical plane at the point where the ramp meets the floor of the car park at the level under consideration.

Commentary: Paragraph 2.2.1 (continued)

Any non-rated wall should include a leakage vent that is modelled as a vertical slot over the height of the room. The size of the vent is based on the surface area multiplied by 0.001 m^2/m^2 wall area for lined partition and 0.005 m^2/m^2 wall area for unlined *external walls*.

When a *smoke control door* is installed, it is assumed that the seals prevent leakage around the door except for the gap at the bottom of the door where seals are not fitted. *Fire doors* without smoke seals are assumed to have a 3 mm gap around the door that is modelled with an equivalent area vent of 10 mm over the height of the door.

2.2.1 h) and i) *Smoke separations* can provide the benefit of containing the smoke within a desired location. *Smoke separations* typically do not have a *fire* rating and so cannot be relied on to prevent smoke spread beyond *flashover*. Therefore, they are assumed not to exist as a barrier to smoke transport. If a *smoke separation* complies with a relevant national or international Standard such as achieving an *FRR* of 10/10/- in the *standard test* method, then it can be assumed to continue to stay in place up to *flashover*. If the *smoke separation* is not designed in accordance with a relevant national or international Standard, such as simply providing toughened glass, then the separation is assumed to disappear once the average upper layer temperature reaches 200°C. Although the separation may actually stay in place, it can no longer be relied on to function as a *smoke separation*.

2.2.1 j) Glass breaking is an active area of *fire* research and has received a considerable amount of attention in the last 20 years. The majority of the research has focused on when the glass cracks and not when the glass actually falls out of the frame. Fall out cannot be reliably predicted as there are many stochastic variables such as heating rate, frame design, properties of the glass and gasket design.

The impact of the glass falling out and providing ventilation for the *fire* is twofold: first, the more ventilation, the larger the *fire* can grow; and secondly, venting combustion products to the outside reduces the hazard to the occupants. Ultimately, glass fall out cannot be reliably predicted and relying on existing models to predict such behavior is not appropriate for design. A prudent approach has been adopted in Verification Method C/VM2 to address the two most likely situations. If the *fire* can grow to *flashover* without causing the glass to fall out, then the window is assumed to stay in place up to 500°C, which results in the maximum amount of smoke distributed within the *building*. If there is not enough ventilation for *flashover*, it is not unexpected that the window may still fall out, providing the ventilation needed for the *fire* to continue to grow. Both situations are valid and should be considered.

Extract from C/VM2: Paragraph 2.2.1

f) Where *CFD* modelling is used, leakage shall be modelled either as a vertical slot as in zone modelling or as two vents, one at floor level and one at ceiling level, to fit within the computational grid.

g) Leakage areas assumed for modelling shall be as follows:

i) *smoke separations* and *smoke control doors* that comply with a recognised national or international Standard (including doors that have both *fire* and smoke control capability complying with a recognised national or international Standard) are assumed to have zero leakage area, except for a 10 mm gap under doors

ii) *fire* doors that are not *smoke control doors* are assumed to have a 10 mm gap over the height of the door

iii) *construction* having a *fire resistance rating* (excluding doors) is considered to have no leakage, and

iv) non *fire*-rated internal and *external walls* are assumed to have leakage areas that are proportional to the surface area of the walls. Leakage area is equal to the wall area multiplied by 0.001 m^2/m^2 (ie, 0.1%) for lined internal and *external walls* and 0.005 m^2/m^2 for unlined *external walls*.

h) *Smoke separations* that comply with recognised national or international Standards for use as a smoke barrier are assumed to remain in place up to the rated temperature or the time at which *flashover* occurs, whichever is sooner.

i) *Smoke separations* that are not tested (eg, non *fire* rated but imperforate *construction*) are assumed to remain in place until the average upper layer smoke temperature reaches 200°C.

j) Windows that are not *fire resisting glazing* are assumed to break (ie, glass falls out to become completely open) at the sooner of either average upper layer temperature reaching 500°C or when the *fire* becomes limited by ventilation. Windows that are *fire resisting glazing* may be assumed to remain in place up to the rated time.

k) The *fire* shall be located away from walls and corners to maximise entrainment of air into the fire plume. The base of the *fire* shall be located at a height of no more than 0.5 m above floor level.

l) *Fractional Effective Dose (FED)* for CO and thermal effects shall be calculated using the procedures described in ISO 13571. FED_{CO} shall include contributions from CO, CO_2 and O_2 gases. $FED_{thermal}$ shall include radiative and convective effects.

Also refer to Paragraph 2.3.3 for guidance on modelling post-*flashover fires* when evaluating life safety on *escape routes* that are not in the room of *fire* origin.

2.2.2 Fire modelling rules for resistance of fire separations and structural design

a) *Fire* modelling rules shall be as specified in Paragraphs 2.3.2 and 2.3.3 for *fires* reaching full *burnout*, for structural design and for assessing *fire* resistance required of *separating elements*.

b) The *design fire* severity for car parking areas incorporating a vehicle stacking system shall use the *FLED* specified in Table 2.2.

c) The *design fire* severity for car parking areas with overlapping interconnected floors shall be based on the worst case (floor area and effective openings available for ventilation) for one of the overlapping floors or for the worst combination of two adjacent (overlapping) floors.

d) For car parking areas, the area of vertical opening ventilation available to the *fire* shall be the area available via permanent openings to the outside environment in the perimeter walls and access ramps to a car parking level above. Access ramp area shall be taken as the projection on the vertical plane at the point where the ramp meets the floor of the car park at the level under consideration.

Commentary: Paragraph 2.2.1 (continued)

The value of 500°C was chosen to define *flashover* within Verification Method C/VM2. Although 600°C may provide a more accurate prediction of *flashover* for a number of situations, temperatures in the range of 500°C have been observed in a number of experiments and, accordingly, this is a more appropriate value for design as it represents a more rapid onset of *flashover* that is still considered a realistic possibility.

2.2.1 k) Placing the *fire* in the centre of the room will maximise the entrainment into the plume and therefore cause the upper layer to drop faster than a *fire* against the wall or in a corner. This also gives the maximum time for detection by providing more entrainment, which dilutes the ceiling jet reducing the soot concentration, while also reducing the temperature and velocity and in turn increasing the time to detection. Although placing the *fire* against the wall or corner will cause the temperature in the upper layer to be hotter and therefore result in a shorter time to reach the $FED_{Thermal}$, the design is typically governed by *visibility*, which requires the layer to drop below 2.0 m. This occurs sooner when the *fire* is in the middle of the room.

Placing the *fire* 0.5 m above the floor is simply a pragmatic value. The lower the *fire* origin, the more entrainment into the plume and thus more smoke of lower temperature and concentration when compared to a *fire* that is higher in the room. Because Verification Method C/VM2 specifies the species yields that are considered to be at the upper end of the realistic range, in most cases once the smoke layer reaches 2.0 m the *visibility* criteria are exceeded. In rooms with low ceilings, assuming the *fire* at the floor level is considered to be overly conservative. Using 0.5 m as the maximum height was chosen to account for items such as desks, tables, chairs, beds and similar furniture items. Designers may choose to place the object lower, which may occur in *CFD* modelling where the grid is less than 0.5 m, but the designer is not permitted to assume the *fire* is any higher. When a *fire* is placed higher in the room, the detection would be faster and the layer would drop more slowly. This would lead to a longer *ASET* than when the *fire* is lower and is therefore considered a non-conservative estimate.

2.2.1 l) Fractional Effective Dose (*FED*) can be calculated using slightly different methodologies and assumptions. For Verification Method C/VM2, it is important that the methodology for calculating the *FED* is consistent. ISO 13571 provides a comprehensive methodology for calculating both the FED_{CO} and $FED_{Thermal}$ and this was considered appropriate for the Verification Method C/VM2.

The decision to include only the CO, CO_2 and O_2 gases in the calculation of *FED* for asphyxiant gases was based on the lack of confidence in the available data for other species which are highly dependent on the experimental methodology and ventilation. Research has also shown that CO in *fires* reaches toxic levels before other species and is present in all fires, which is why CO is considered the dominant toxicant in *fires*. The value for the CO chosen is near the upper end of the expected range to help account for this being the only toxic species in the analysis.

Extract from C/VM2: Paragraph 2.2.1

f) Where *CFD* modelling is used, leakage shall be modelled either as a vertical slot as in zone modelling or as two vents, one at floor level and one at ceiling level, to fit within the computational grid.

g) Leakage areas assumed for modelling shall be as follows:

i) *smoke separations* and *smoke control doors* that comply with a recognised national or international Standard (including doors that have both *fire* and smoke control capability complying with a recognised national or international Standard) are assumed to have zero leakage area, except for a 10 mm gap under doors

ii) *fire* doors that are not *smoke control doors* are assumed to have a 10 mm gap over the height of the door

iii) *construction* having a *fire resistance rating* (excluding doors) is considered to have no leakage, and

iv) non *fire*-rated internal and *external walls* are assumed to have leakage areas that are proportional to the surface area of the walls. Leakage area is equal to the wall area multiplied by 0.001 m^2/m^2 (ie, 0.1%) for lined internal and *external walls* and 0.005 m^2/m^2 for unlined *external walls*.

h) *Smoke separations* that comply with recognised national or international Standards for use as a smoke barrier are assumed to remain in place up to the rated temperature or the time at which *flashover* occurs, whichever is sooner.

i) *Smoke separations* that are not tested (eg, non *fire* rated but imperforate *construction*) are assumed to remain in place until the average upper layer smoke temperature reaches 200°C.

j) Windows that are not *fire resisting glazing* are assumed to break (ie, glass falls out to become completely open) at the sooner of either average upper layer temperature reaching 500°C or when the *fire* becomes limited by ventilation. Windows that are *fire resisting glazing* may be assumed to remain in place up to the rated time.

k) The *fire* shall be located away from walls and corners to maximise entrainment of air into the fire plume. The base of the *fire* shall be located at a height of no more than 0.5 m above floor level.

l) *Fractional Effective Dose (FED)* for CO and thermal effects shall be calculated using the procedures described in ISO 13571. FED_{CO} shall include contributions from CO, CO_2 and O_2 gases. $FED_{thermal}$ shall include radiative and convective effects.

Also refer to Paragraph 2.3.3 for guidance on modelling post-*flashover fires* when evaluating life safety on *escape routes* that are not in the room of *fire* origin.

2.2.2 Fire modelling rules for resistance of fire separations and structural design

a) *Fire* modelling rules shall be as specified in Paragraphs 2.3.2 and 2.3.3 for *fires* reaching full *burnout*, for structural design and for assessing *fire* resistance required of *separating elements*.

b) The *design fire* severity for car parking areas incorporating a vehicle stacking system shall use the *FLED* specified in Table 2.2.

c) The *design fire* severity for car parking areas with overlapping interconnected floors shall be based on the worst case (floor area and effective openings available for ventilation) for one of the overlapping floors or for the worst combination of two adjacent (overlapping) floors.

d) For car parking areas, the area of vertical opening ventilation available to the *fire* shall be the area available via permanent openings to the outside environment in the perimeter walls and access ramps to a car parking level above. Access ramp area shall be taken as the projection on the vertical plane at the point where the ramp meets the floor of the car park at the level under consideration.

Commentary: Paragraph 2.2.1 (continued)

FED_{CO}

The FED_{CO} is the fraction of the dose of CO that would render a person of average susceptibility incapable of escape. For design, the *Building Code* requires an escaping occupant to be exposed to an FED_{CO} of not greater than 0.3.

Where the CO_2 concentration exceeds 2% by volume, the CO concentration shall be increased by a factor to allow for the increased rate of CO uptake due to hyperventilation.

This factor shall be taken as: $\exp\left(\frac{\%CO_2}{5}\right)$. According to ISO 13571 this equation is derived from an empirical fit to human hyperventilation, corrected for uptake inefficiencies in the lung and is accurate to within ± 20%.

Following ISO 13571, the FED_{CO} is therefore calculated (for $\%O_2 \geq 13\%$ by volume and allowing for CO_2 hyperventilation) by summation over the relevant time increments using:

$$FED_{in,co} = \sum_{t_o}^{t} \frac{[CO].\Delta t}{35000} \exp\left(\frac{\%CO_2}{5}\right)$$

where:

$[CO]$ = average CO concentration in parts per million (or µL/L) over the time increment Δt

$\%CO_2$ = average % concentration of CO_2 (by volume) over the time increment Δt

Δt = time increment between successive readings of concentration in minutes

t_o = time at which exposure begins in minutes

t = time at which exposure ends in minutes

Where the $\%O_2 < 13\%$ by volume, the hypoxic effects of oxygen depletion shall also be calculated and included in the FED_{CO}.

$$FED_{in,02} = \sum_{t_o}^{t} \frac{\Delta t}{\left(\exp\left(8.13 - 0.54\left(20.9\% - \%0_2\right)\right)\right)}$$

where:

$\%O_2$ = average % concentration of O_2 (by volume) over the time increment Δt

Extract from C/VM2: Paragraph 2.2.1

f) Where *CFD* modelling is used, leakage shall be modelled either as a vertical slot as in zone modelling or as two vents, one at floor level and one at ceiling level, to fit within the computational grid.

g) Leakage areas assumed for modelling shall be as follows:

i) *smoke separations* and *smoke control doors* that comply with a recognised national or international Standard (including doors that have both *fire* and smoke control capability complying with a recognised national or international Standard) are assumed to have zero leakage area, except for a 10 mm gap under doors

ii) *fire* doors that are not *smoke control doors* are assumed to have a 10 mm gap over the height of the door

iii) *construction* having a *fire resistance rating* (excluding doors) is considered to have no leakage, and

iv) non *fire*-rated internal and *external walls* are assumed to have leakage areas that are proportional to the surface area of the walls. Leakage area is equal to the wall area multiplied by 0.001 m^2/m^2 (ie, 0.1%) for lined internal and *external walls* and 0.005 m^2/m^2 for unlined *external walls*.

h) *Smoke separations* that comply with recognised national or international Standards for use as a smoke barrier are assumed to remain in place up to the rated temperature or the time at which *flashover* occurs, whichever is sooner.

i) *Smoke separations* that are not tested (eg, non *fire* rated but imperforate *construction*) are assumed to remain in place until the average upper layer smoke temperature reaches 200°C.

j) Windows that are not *fire resisting glazing* are assumed to break (ie, glass falls out to become completely open) at the sooner of either average upper layer temperature reaching 500°C or when the *fire* becomes limited by ventilation. Windows that are *fire resisting glazing* may be assumed to remain in place up to the rated time.

k) The *fire* shall be located away from walls and corners to maximise entrainment of air into the fire plume. The base of the *fire* shall be located at a height of no more than 0.5 m above floor level.

l) *Fractional Effective Dose (FED)* for CO and thermal effects shall be calculated using the procedures described in ISO 13571. FED_{CO} shall include contributions from CO, CO_2 and O_2 gases. $FED_{thermal}$ shall include radiative and convective effects.

Also refer to Paragraph 2.3.3 for guidance on modelling post-*flashover fires* when evaluating life safety on *escape routes* that are not in the room of *fire* origin.

2.2.2 Fire modelling rules for resistance of fire separations and structural design

a) *Fire* modelling rules shall be as specified in Paragraphs 2.3.2 and 2.3.3 for *fires* reaching full *burnout*, for structural design and for assessing *fire* resistance required of *separating elements*.

b) The *design fire* severity for car parking areas incorporating a vehicle stacking system shall use the *FLED* specified in Table 2.2.

c) The *design fire* severity for car parking areas with overlapping interconnected floors shall be based on the worst case (floor area and effective openings available for ventilation) for one of the overlapping floors or for the worst combination of two adjacent (overlapping) floors.

d) For car parking areas, the area of vertical opening ventilation available to the *fire* shall be the area available via permanent openings to the outside environment in the perimeter walls and access ramps to a car parking level above. Access ramp area shall be taken as the projection on the vertical plane at the point where the ramp meets the floor of the car park at the level under consideration.

Commentary: Paragraph 2.2.1 (continued)

For the purposes of Verification Method C/VM2, Δt should be taken as not longer than 5 seconds (1/12 min). The concentration of CO, CO_2 and O_2 at a height of 2.0 m above the floor and along the path of the *escape route* shall be used. This calculation should be done for the last occupant to leave the room of *fire* origin, and should take into account their location in the *building* throughout the evacuation.

$FED_{thermal}$

The $FED_{Thermal}$ is the fraction of the dose of convected and radiated heat that would render a person of average susceptibility incapable of escape. For design, the *Building Code* requires an escaping occupant to be exposed to an $FED_{Thermal}$ of not greater 0.3.

Calculation of the time to incapacitation under conditions of exposure to convective heat from air containing less than 10% by volume of water vapour can be made assuming the exposed occupant is lightly clothed using:

$$t_{Iconv} = (5 \times 10^7) T^{-3.4}$$

Where:

T = gas temperature expressed in °C

t_{Iconv} = time to incapacitation under conditions of exposure to convective heat, expressed in minutes

As with toxic gases, an exposed occupant can be considered to accumulate a dose of convected heat over a period of time. The *FED* of convected heat accumulated per minute is the reciprocal of t_{Iconv}.

The tenability limit for exposure of skin to radiant heat is approximately 2.5 kW/m^2. Lesser levels of exposure can be tolerated for 30 minutes or more without significantly affecting time available for escape. Calculation of the time to incapacitation under conditions of exposure to radiant heat causing 2nd degree burning of the skin is given by:

$$t_{Irad} = (6.9) q^{-1.56}$$

Where

t_{Irad} = time to 2nd degree burns, expressed in minutes

q = radiant heat flux in kW/m^2

Extract from C/VM2: Paragraph 2.2.1

f) Where *CFD* modelling is used, leakage shall be modelled either as a vertical slot as in zone modelling or as two vents, one at floor level and one at ceiling level, to fit within the computational grid.

g) Leakage areas assumed for modelling shall be as follows:

i) *smoke separations* and *smoke control doors* that comply with a recognised national or international Standard (including doors that have both *fire* and smoke control capability complying with a recognised national or international Standard) are assumed to have zero leakage area, except for a 10 mm gap under doors

ii) *fire* doors that are not *smoke control doors* are assumed to have a 10 mm gap over the height of the door

iii) *construction* having a *fire resistance rating* (excluding doors) is considered to have no leakage, and

iv) non *fire*-rated internal and *external walls* are assumed to have leakage areas that are proportional to the surface area of the walls. Leakage area is equal to the wall area multiplied by 0.001 m^2/m^2 (ie, 0.1%) for lined internal and *external walls* and 0.005 m^2/m^2 for unlined *external walls*.

h) *Smoke separations* that comply with recognised national or international Standards for use as a smoke barrier are assumed to remain in place up to the rated temperature or the time at which *flashover* occurs, whichever is sooner.

i) *Smoke separations* that are not tested (eg, non *fire* rated but imperforate *construction*) are assumed to remain in place until the average upper layer smoke temperature reaches 200°C.

j) Windows that are not *fire resisting glazing* are assumed to break (ie, glass falls out to become completely open) at the sooner of either average upper layer temperature reaching 500°C or when the *fire* becomes limited by ventilation. Windows that are *fire resisting glazing* may be assumed to remain in place up to the rated time.

k) The *fire* shall be located away from walls and corners to maximise entrainment of air into the fire plume. The base of the *fire* shall be located at a height of no more than 0.5 m above floor level.

l) *Fractional Effective Dose (FED)* for CO and thermal effects shall be calculated using the procedures described in ISO 13571. FED_{CO} shall include contributions from CO, CO_2 and O_2 gases. $FED_{thermal}$ shall include radiative and convective effects.

Also refer to Paragraph 2.3.3 for guidance on modelling post-*flashover fires* when evaluating life safety on *escape routes* that are not in the room of *fire* origin.

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a) *Fire* modelling rules shall be as specified in Paragraphs 2.3.2 and 2.3.3 for *fires* reaching full *burnout*, for structural design and for assessing *fire* resistance required of *separating elements*.

b) The *design fire* severity for car parking areas incorporating a vehicle stacking system shall use the *FLED* specified in Table 2.2.

c) The *design fire* severity for car parking areas with overlapping interconnected floors shall be based on the worst case (floor area and effective openings available for ventilation) for one of the overlapping floors or for the worst combination of two adjacent (overlapping) floors.

d) For car parking areas, the area of vertical opening ventilation available to the *fire* shall be the area available via permanent openings to the outside environment in the perimeter walls and access ramps to a car parking level above. Access ramp area shall be taken as the projection on the vertical plane at the point where the ramp meets the floor of the car park at the level under consideration.

Commentary: Paragraph 2.2.1 (continued)

As with toxic gases, an exposed occupant may be considered to accumulate a dose of radiant heat over a period of time. The *FED* of radiant heat accumulated per minute is the reciprocal of t_{Irad}.

Following ISO 13571, the $FED_{Thermal}$ is calculated by summation over the relevant time increments using:

$$FED = \sum_{t1}^{t2} (1/t_{Irad} + 1/t_{Iconv})\,\Delta t$$

where

t_1 = time at which exposure begins in minutes

t_2 = time at which exposure ends in minutes

For design, the *Building Code* requires an escaping occupant to be exposed to an $FED_{Thermal}$ of not greater than 0.3. The *FED* and gas temperatures shall be assessed at a height of 2.0 m above the floor and along the path of the *escape route*.

For the purposes of Verification Method C/VM2, Δt should be taken as not longer than 5 seconds (1/12 min). The gas temperature and radiant flux at a height of 2.0 m above the floor and along the path of the *escape route* shall be used. This calculation should be done for the last occupant to leave the room of *fire* origin, and should take into account their location in the *building* throughout the evacuation.

Extract from C/VM2: Paragraph 2.3

e) For effective openings:

i) Only those areas of openings in *external walls* and roofs which can dependably provide airflow to the *fire* shall be used in calculating the *fire* severity. Such opening areas include windows containing non-*fire resisting glazing* and horizontal parts of a roof which are specifically designed to open or to melt rapidly in the event of exposure to *fully developed fire*.

ii) An allowance can be made for air leakage through the *external wall* of the *building* envelope. The allowance for inclusion in the vertical openings area shall be no greater than 0.1% of the *external wall* area where the wall is lined internally and 0.5% where the *external wall* is unlined.

iii) For single storey *buildings* or the top floor of multi-storey *buildings* where the structural system supporting the roof is exposed to view and has no dependable *fire* resistance (eg, less than 10 minutes), the ratio of A_h/A_f can be taken as 0.2.

2.3 Design fire characteristics

Analysis for a number of the *design scenarios* is based on the use of '*design fires*'. These are defined by one or more of the following parameters:

a) *Fire* growth rate

b) Peak *heat release rate*

c) *Fire load energy density*

d) Species production (CO, CO_2, water, soot)

e) Heat flux, and

f) Time.

Parameters and modelling instructions are given below for:

a) Pre-*flashover design fires*

b) Post-*flashover design fires*, and

c) Full *burnout design fires*.

The individual *design scenarios* in Part 4 specify where these *design fires* are to be used.

2.3.1 Pre-flashover design fires

The characteristics of the pre-*flashover design fire* are given in Table 2.1. In most cases (ie, for all *buildings*, including storage *buildings*, that are capable of storage to a height of less than 3.0 m) the *fire* is assumed to grow as a fast t^2 *fire* up to *flashover* or until the *HRR* reaches the peak given in Table 2.1 or becomes ventilation limited.

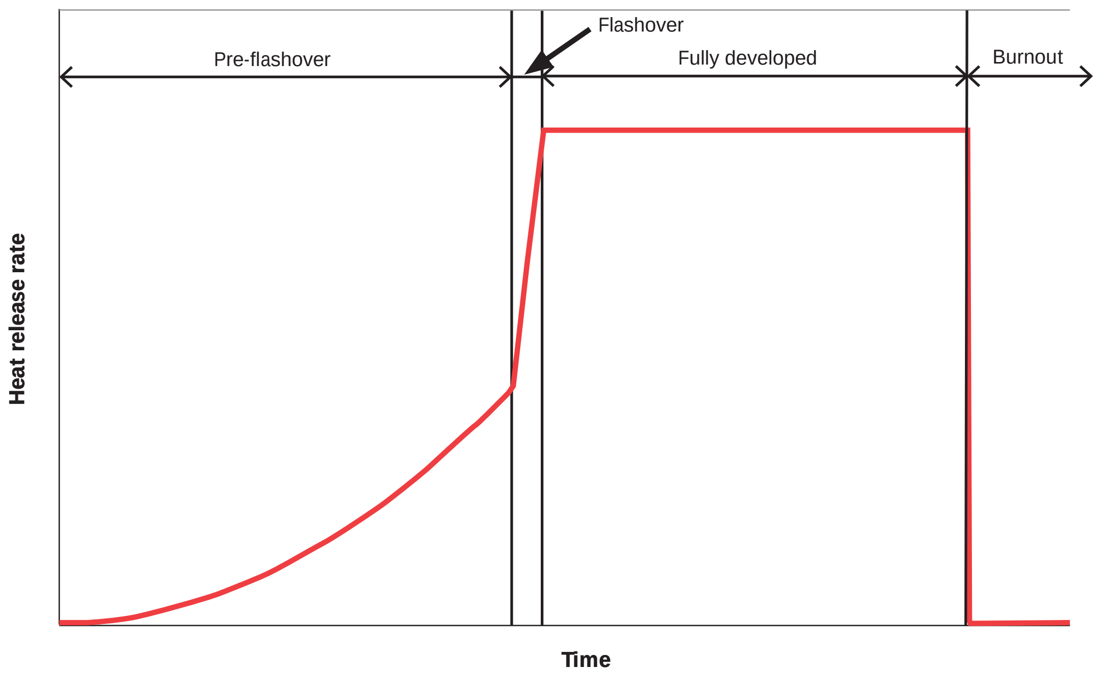
For life safety analysis in sprinklered *buildings*, the *fire* is assumed to be controlled (ie, with a constant *HRR*) after the sprinkler activates based on *RTI*, C-factor and activation temperature as specified in Table 3.2.

Commentary: Paragraph 2.3

2.3 The *design fire* is intended to represent a credible worst case scenario that will challenge the *fire* safety design of the *building*. Typically, the *design fire* is described in terms of the *heat release rate* from the *fire*. Indeed, the *heat release rate* history is considered the single most important variable in describing a *fire hazard* [Babrauskas and Peacock]. However, in some cases, the *design fire* includes an estimate of the size of the *fire*, the species production rates, and the effective heat of combustion. Unfortunately, it is not possible to derive the *design fire* from first principles and current state-of-the-art combustion models should not be used to attempt to predict a *design fire* for life safety analysis. Thus, Verification Method C/VM2 has chosen to use existing empirical correlations to develop the parameters used for the *design fire*.

Figure C1 shows the idealised *fire growth* rate history highlighting the stages used within Verification Method C/VM2. This depiction of the *design fire* is consistent with the conventional *fire* development and the transition of *flashover*. Although all *fires* are different and will yield different *fire* characteristics, the *design fire* in C/VM2 uses the internationally recognised methodology for *fire* safety design.

Figure C1: Idealised heat release rate history highlighting the four phases of conventional fire development and flashover



Extract from C/VM2: Paragraph 2.3

e) For effective openings:

i) Only those areas of openings in *external walls* and roofs which can dependably provide airflow to the *fire* shall be used in calculating the *fire* severity. Such opening areas include windows containing non-*fire resisting glazing* and horizontal parts of a roof which are specifically designed to open or to melt rapidly in the event of exposure to *fully developed fire*.

ii) An allowance can be made for air leakage through the *external wall* of the *building* envelope. The allowance for inclusion in the vertical openings area shall be no greater than 0.1% of the *external wall* area where the wall is lined internally and 0.5% where the *external wall* is unlined.

iii) For single storey *buildings* or the top floor of multi-storey *buildings* where the structural system supporting the roof is exposed to view and has no dependable *fire* resistance (eg, less than 10 minutes), the ratio of A_h/A_f can be taken as 0.2.

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Analysis for a number of the *design scenarios* is based on the use of '*design fires*'. These are defined by one or more of the following parameters:

a) *Fire* growth rate

b) Peak *heat release rate*

c) *Fire load energy density*

d) Species production (CO, CO_2, water, soot)

e) Heat flux, and

f) Time.

Parameters and modelling instructions are given below for:

a) Pre-*flashover design fires*

b) Post-*flashover design fires*, and

c) Full *burnout design fires*.

The individual *design scenarios* in Part 4 specify where these *design fires* are to be used.

2.3.1 Pre-flashover design fires

The characteristics of the pre-*flashover design fire* are given in Table 2.1. In most cases (ie, for all *buildings*, including storage *buildings*, that are capable of storage to a height of less than 3.0 m) the *fire* is assumed to grow as a fast t^2 *fire* up to *flashover* or until the *HRR* reaches the peak given in Table 2.1 or becomes ventilation limited.

For life safety analysis in sprinklered *buildings*, the *fire* is assumed to be controlled (ie, with a constant *HRR*) after the sprinkler activates based on *RTI*, C-factor and activation temperature as specified in Table 3.2.

Commentary: Paragraph 2.3

2.3 The details required for the *design fire* are dependent on the issues being addressed in the design. For example, the growth phase makes little difference if the engineer wishes to determine the appropriate *fire resistance rating* using the time equivalence formula. In Paragraph 2.3 the components of the *design fire* (ie, growth rate, species production rate, effective heat of combustion and *FLED*) are given along with the discussion where necessary. The decisions made in reaching the values given in Verification Method C/VM2 were not made in haste, but were chosen after an extensive review of the literature and a detailed sensitivity study applying the range of potential values to case study *buildings* designed according to Acceptable Solution C/AS1 (2011).

The incipient phase (a phase that immediately precedes the growth phase) is extremely complex and is considered too unpredictable to be included in design. Verification Method C/VM2 makes no attempt to analyse the incipient phase of the *fire*. The only place within C/VM2 that considers the incipient phase is the Design Scenario SF: Smouldering fire (see C/VM2 Paragraph 4.4) which only applies to sleeping rooms and is not intended to be analysed, but to simply require smoke alarms in sleeping rooms.

The growth phase is considered to begin when the radiation feedback from the flame governs the burning rate. Assuming the space is vented, the growth rate is primarily governed by the fuel properties and orientation. During the growth phase the *fire* spreads across the fuel surfaces, increasing the burning area and corresponding *heat release rate*. The *heat release rate* is assumed to be independent of the *fire* enclosure and governed more by the flame spread rate. Modelling the actual growth rate is extremely difficult and remains an area of active research. It is dependent on many factors which are not only a function of the burning object, but are also stochastic in nature, such as size and location of the ignition source, orientation of the object, proximity to other objects, proximity to *boundaries*, proximity to openings, and so on. It is true that most *fires* occurring during the life of a *building* will be quite minor and are likely to go unreported: it is the reasonable worst case *fire,* and not the most likely *fire,* that must be used for design.

There are several approaches to estimating the growth rate for a particular *design fire*. The most popular is the t-squared *fire growth* rate. Originally developed in the 1970s for predicting *fire* detector activation, the t-squared *fire* gained popularity when it was included in the appendix of NFPA 72. In NFPA 72 there are three categories for *fire growth*: slow, medium, and fast. These definitions are simply determined by the time required for the *fire* to reach 1055 kW (1000 BTU/s). A slow *fire* is defined as taking 600 sec or more to reach 1055 kW. A medium *fire* takes more than 150 sec and less than 300 sec, and a fast *fire* takes less than 150 sec to reach 1055 kW. Over time the definition for a t-squared *fire* has evolved to include an ‘ultra fast’ *fire* as well.

Extract from C/VM2: Paragraph 2.3.1

e) For effective openings:

i) Only those areas of openings in *external walls* and roofs which can dependably provide airflow to the *fire* shall be used in calculating the *fire* severity. Such opening areas include windows containing non-*fire resisting glazing* and horizontal parts of a roof which are specifically designed to open or to melt rapidly in the event of exposure to *fully developed fire*.

ii) An allowance can be made for air leakage through the *external wall* of the *building* envelope. The allowance for inclusion in the vertical openings area shall be no greater than 0.1% of the *external wall* area where the wall is lined internally and 0.5% where the *external wall* is unlined.

iii) For single storey *buildings* or the top floor of multi-storey *buildings* where the structural system supporting the roof is exposed to view and has no dependable *fire* resistance (eg, less than 10 minutes), the ratio of A_h/A_f can be taken as 0.2.

2.3 Design fire characteristics

Analysis for a number of the *design scenarios* is based on the use of '*design fires*'. These are defined by one or more of the following parameters:

a) *Fire* growth rate

b) Peak *heat release rate*

c) *Fire load energy density*

d) Species production (CO, CO_2, water, soot)

e) Heat flux, and

f) Time.

Parameters and modelling instructions are given below for:

a) Pre-*flashover design fires*

b) Post-*flashover design fires*, and

c) Full *burnout design fires*.

The individual *design scenarios* in Part 4 specify where these *design fires* are to be used.

2.3.1 Pre-flashover design fires

The characteristics of the pre-*flashover design fire* are given in Table 2.1. In most cases (ie, for all *buildings*, including storage *buildings*, that are capable of storage to a height of less than 3.0 m) the *fire* is assumed to grow as a fast t^2 *fire* up to *flashover* or until the *HRR* reaches the peak given in Table 2.1 or becomes ventilation limited.

For life safety analysis in sprinklered *buildings*, the *fire* is assumed to be controlled (ie, with a constant *HRR*) after the sprinkler activates based on *RTI*, C-factor and activation temperature as specified in Table 3.2.

Commentary: Paragraph 2.3

2.3 The t-squared *fire growth* can be thought of in terms of a burning object with a constant *heat release rate* per unit area in which the *fire* is spreading in a circular pattern at a constant flame speed. Obviously more representative fuel geometries may or may not produce a t-squared *fire* growth. However, the implicit assumption in many cases is that the t-squared approximation is close enough to make reasonable design decisions. It should be noted that the t-squared growth rate has been adopted well beyond the original intent; in some cases for *fires* as large as 30 MW. Such application has been questioned in the literature [Babrauskas, 1996] and has motivated the methodology that is incorporated in Verification Method C/VM2 Paragraph 2.3.3 to model post-*flashover* and under ventilated *fires*.

The final selection of the values given in Table 2.1 were based on a sensitivity study applying the range of potential values to case study *buildings* designed according to Acceptable Solution C/AS1 (2008) documents. In most cases, the early *fire growth* can be modelled using a fast t-squared *fire* with α = 0.0469 kW/s^2. The exceptions to the fast t^2 *fire* are for car parks and storage risks. Car parks are one of the few *risk groups* where the fuel characteristic can be bounded and the layout of the fuel is controlled. Therefore, there is a high degree of confidence in bounding the initial growth rate of the *fire* (prior to the *fire* being affected by the ventilation).

A review of the literature has shown that the early growth rate for cars can be modelled as a medium t^2 growth rate with α = 0.0117 kW/s^2. For storage occupancy, controlling the fuel and thus the *fire growth* rate and *FLED* can be extremely problematic. In addition, the large vertical surfaces are conducive to rapid *fire growth* rates far in excess of the fast t^2 growth. For storage up to 5.0 m, the *fire growth* rate is considered to be ultrafast with α = 0.188 kW/s^2, which can be found in NFPA 72 and NFPA 204. As racks get over 5.0 m, the growth rate will also increase with the taller vertical surface. Research by Ingason has shown that storage can be characterised by a $\alpha t^3 H$ *fire growth* rate. Although Ingason has identified that α can vary between 0.00877 to 0.00068, the results of the sensitivity analysis showed that the 0.00068 was suitable for Verification Method C/VM2.

Typically in the literature, experiments on *fire growth* use a relatively large ignition burner, of the order of 10 to 40 kW. When such a large ignition source is used, it effectively eliminates the incipient phase of the *fire*. By ignoring the incipient phase, Verification Method C/VM2 may be considered to slightly over-predict the early growth rate of the *fire*.

Extract from C/VM2: Paragraph 2.3.2

Table 2.1 Pre-flashover design fire characteristics

Building use	*Fire* growth rate (kW)	Species	Radiative fraction	Peak *HRR*
All *buildings* including storage with a stack height of less than 3.0 m	$0.0469\ t^2$	$Y_{soot} = 0.07$ kg/kg $Y_{CO} = 0.04$ kg/kg $\Delta H_C = 20$ MJ/kg $Y_{CO_2} = 1.5$ kg/kg $Y_{H_2O} = 1.0$ kg/kg	0.35	20 MW
Carparks (no stacking)	$0.0117\ t^2$		0.35	
Storage with a stack height of between 3.0 m and 5.0 m above the floor	$0.188\ t^2$		0.35	50 MW
Storage with a stack height of more than 5.0 m above the floor and car parks with stacking systems	$0.00068\ t^3\ H$		0.35	

NOTE:
t = time in seconds
H = height of storage in m
Y = *yield* kg/kg
ΔH_C = heat of combustion

2.3.2 Post-flashover design fires

Flashover is assumed to occur when the average upper layer temperature first reaches 500°C.

For uncontrolled *fires*, the burning rate is assumed to be governed by the ventilation limit or the peak *HRR*, whichever is less.

2.3.3 Modelling post-flashover fires

For life safety calculations (ie, *ASET*), modelling the *fire* into the post-*flashover* phase is unlikely to be required for sprinklered *buildings*. The *fire* is expected to be controlled (ie, with a constant *HRR*) after the sprinkler activates based on *RTI*, C-factor and activation temperature, and therefore *flashover* is not expected to occur. Sprinkler response calculations would be expected to confirm that this is the case.

However, note that for the full *burnout design fire* (see Paragraph 2.4), calculations of *fire* resistance shall be based on *burnout* without sprinkler or other intervention, except that the design *FLED* may be modified as described in Paragraph 2.4.1 where sprinklers are installed.

The following parameters shall apply:

a) Post-*flashover* species *yield* for soot is $Y_{soot} = 0.14\ kg/kg_{fuel}$

b) Post-*flashover* species *yield* for CO is $Y_{CO} = 0.40\ kg/kg_{fuel}$, and

c) Design *FLEDs* shall be as specified in Table 2.2 for activities within *buildings*.

The three steps for modelling the *fire* shall be as follows:

Step 1: Determine initial pre-*flashover fire growth* rate from Table 2.1; typically $q=0.0469t^2$.

Step 2: Run the *fire* model and determine which of the following five cases apply. If necessary adjust the input *HRR* to the model as described below and rerun the model.

Case 1 *Fire growth* reaches the peak *HRR* from Table 2.1 before T_{UL}=500°C

Fast *fire growth* to the peak *HRR* from Table 2.1

Species as given for pre-*flashover*

Case 2 Sprinklers activate before *fire growth* reaches the peak *HRR* from Table 2.1

Fast *fire growth* to sprinkler activation

Species as given for pre-*flashover*

Commentary: Paragraph 2.3.2

2.3.2 *Flashover* occurs when the radiation from the upper layer is so intense that all of the *combustible* surfaces in the space ignite. *Flashover* can be thought of as a transition from a small *fire* to full room involvement. This transition typically occurs over a short time span measured in seconds.

From an experimental point of view, *flashover* is considered to occur when the upper layer temperature reaches 500-600°C. The increase in radiation from the upper layer not only ignites all of the *combustible*s in the space, but also enhances the *heat release rate* of all the burning objects. Within Verification Method C/VM2, *flashover* is assumed to occur when the upper layer reaches 500°C, which is at the lower end of the expected temperature range. Using 500°C will lead to earlier prediction of *flashover* and hasten the onset of more *hazardous* conditions, thus making this a conservative assumption. From a design point of view, *flashover* is modelled as a linear transition from a growing *fire* to a fully developed *fire* over a 15 sec period. The 15 sec transition period was chosen as sufficiently rapid to simulate *flashover* observed experimentally and to be within the numerical capabilities of existing *fire* models.

Commentary: Paragraph 2.3.3

2.3.3 There are a number of sources available in the literature for the species production rate measured in the laboratory scale experiments such as the Cone Calorimeter Apparatus (ISO 5660). There is an extensive collection of experimental data in Tewarson's chapter of the SFPE Handbook. However, there is significant variance in the values reported within the literature, even within the SFPE Handbook. Even for nominally the same fuel, eg, flexible polyurethane, there is more than an order of magnitude difference in the soot yield ranging from 0.01 to 0.23. For the carbon monoxide yield, the range is not as broad and only varies by a factor of 4 and the effective heat of combustion can be seen to vary by ±25%.

The wide range in the properties is due to a number of factors including, but not limited to, different combustion conditions in the test methods and changes to the chemical composition due to different additives in the foam. A narrower range in the *yields* and ΔH_C can be found for wood but is still much wider than might be expected.

The wide range for the species *yields* in the data makes the selection of appropriate values for use in Verification Method C/VM2 challenging. The BRANZ Study Report No. 185 reviewed the values in the literature and relied heavily on the European CBUF study on upholstered furniture as well as their own modelling efforts in recommending a soot *yield* of 0.07. The final decision on the values used in C/VM2 was based on the review of the literature and sensitivity analysis mentioned previously.

Extract from C/VM2: Paragraph 2.3.2

Table 2.1 Pre-flashover design fire characteristics

Building use	*Fire* growth rate (kW)	Species	Radiative fraction	Peak *HRR*
All *buildings* including storage with a stack height of less than 3.0 m	$0.0469\ t^2$	$Y_{soot} = 0.07$ kg/kg $Y_{CO} = 0.04$ kg/kg $\Delta H_C = 20$ MJ/kg $Y_{CO_2} = 1.5$ kg/kg $Y_{H_2O} = 1.0$ kg/kg	0.35	20 MW
Carparks (no stacking)	$0.0117\ t^2$		0.35	
Storage with a stack height of between 3.0 m and 5.0 m above the floor	$0.188\ t^2$		0.35	50 MW
Storage with a stack height of more than 5.0 m above the floor and car parks with stacking systems	$0.00068\ t^3\ H$		0.35	

NOTE:
t = time in seconds
H = height of storage in m
Y = *yield* kg/kg
ΔH_C = heat of combustion

2.3.2 Post-flashover design fires

Flashover is assumed to occur when the average upper layer temperature first reaches 500°C.

For uncontrolled *fires*, the burning rate is assumed to be governed by the ventilation limit or the peak *HRR*, whichever is less.

2.3.3 Modelling post-flashover fires

For life safety calculations (ie, *ASET*), modelling the *fire* into the post-*flashover* phase is unlikely to be required for sprinklered *buildings*. The *fire* is expected to be controlled (ie, with a constant *HRR*) after the sprinkler activates based on *RTI*, C-factor and activation temperature, and therefore *flashover* is not expected to occur. Sprinkler response calculations would be expected to confirm that this is the case.

However, note that for the full *burnout design fire* (see Paragraph 2.4), calculations of *fire* resistance shall be based on *burnout* without sprinkler or other intervention, except that the design *FLED* may be modified as described in Paragraph 2.4.1 where sprinklers are installed.

The following parameters shall apply:

a) Post-*flashover* species *yield* for soot is $Y_{soot} = 0.14$ kg/kg$_{fuel}$

b) Post-*flashover* species *yield* for CO is $Y_{CO} = 0.40$ kg/kg$_{fuel}$, and

c) Design *FLEDs* shall be as specified in Table 2.2 for activities within *buildings*.

The three steps for modelling the *fire* shall be as follows:

Step 1: Determine initial pre-*flashover fire growth* rate from Table 2.1; typically $q=0.0469t^2$.

Step 2: Run the *fire* model and determine which of the following five cases apply. If necessary adjust the input *HRR* to the model as described below and rerun the model.

Case 1 *Fire growth* reaches the peak *HRR* from Table 2.1 before $T_{UL}=500°C$

Fast *fire growth* to the peak *HRR* from Table 2.1

Species as given for pre-*flashover*

Case 2 Sprinklers activate before *fire growth* reaches the peak *HRR* from Table 2.1

Fast *fire growth* to sprinkler activation

Species as given for pre-*flashover*

Commentary: Paragraph 2.3.3 (continued)

2.3.3 When modelling the *design fire*, it is crucial that *flashover* and ventilation control be incorporated. The following five cases are intended to be used as necessary to model the *fire* under harsh burning conditions expected within the *building* such that the reasonable pessimistic *fire* is used in the design.

In some of the cases presented, Verification Method C/VM2 requires the *heat release rate (HRR)* used as input to the *fire* model to be modified from the *design fire* given in Table 2.1. The modification is to adjust the input *HRR* to be 1.5 times the ventilation limited *HRR*, after *flashover* or after the ventilation limit is reached. If this is not done, then the input *HRR* would grow until the peak *HRR* from Table 2.1 is reached. This is not realistic for poorly ventilated spaces or where there is a large difference between the ventilation limit and the theoretical peak *HRR*, and could result in an excessive amount of unburned fuel being generated in the model (being the difference between the theoretical peak *HRR* and the ventilation limit). This may cause numerical problems with computer models as well.

In the examples given below, the same space is used in all cases. Only the ventilation is changed or, for Case 2, a sprinkler is added. The space is 15 m x 10 m x 4.0 m high with wallboard on the walls and ceiling and concrete on the floor. Only the ventilation opening is changed to force the *fire* into each condition. The *fire* was modelled using BRANZFIRE version 2011.2.

Extract from C/VM2: Paragraph 2.3.2

Table 2.1 **Pre-flashover design fire characteristics**

Building use	*Fire* growth rate (kW)	Species	Radiative fraction	Peak *HRR*
All *buildings* including storage with a stack height of less than 3.0 m	$0.0469\ t^2$	$Y_{soot} = 0.07$ kg/kg $Y_{CO} = 0.04$ kg/kg $\Delta H_C = 20$ MJ/kg $Y_{CO_2} = 1.5$ kg/kg $Y_{H_2O} = 1.0$ kg/kg	0.35	20 MW
Carparks (no stacking)	$0.0117\ t^2$		0.35	
Storage with a stack height of between 3.0 m and 5.0 m above the floor	$0.188\ t^2$		0.35	50 MW
Storage with a stack height of more than 5.0 m above the floor and car parks with stacking systems	$0.00068\ t^3\ H$		0.35	

NOTE:
t = time in seconds
H = height of storage in m
Y = *yield* kg/kg
ΔH_C = heat of combustion

2.3.2 Post-flashover design fires

Flashover is assumed to occur when the average upper layer temperature first reaches 500°C.

For uncontrolled *fires*, the burning rate is assumed to be governed by the ventilation limit or the peak *HRR*, whichever is less.

2.3.3 Modelling post-flashover fires

For life safety calculations (ie, *ASET*), modelling the *fire* into the post-*flashover* phase is unlikely to be required for sprinklered *buildings*. The *fire* is expected to be controlled (ie, with a constant *HRR*) after the sprinkler activates based on *RTI*, C-factor and activation temperature, and therefore *flashover* is not expected to occur. Sprinkler response calculations would be expected to confirm that this is the case.

However, note that for the full *burnout design fire* (see Paragraph 2.4), calculations of *fire* resistance shall be based on *burnout* without sprinkler or other intervention, except that the design *FLED* may be modified as described in Paragraph 2.4.1 where sprinklers are installed.

The following parameters shall apply:

a) Post-*flashover* species *yield* for soot is $Y_{soot} = 0.14$ kg/kg$_{fuel}$

b) Post-*flashover* species *yield* for CO is $Y_{CO} = 0.40$ kg/kg$_{fuel}$, and

c) Design *FLEDs* shall be as specified in Table 2.2 for activities within *buildings*.

The three steps for modelling the *fire* shall be as follows:

Step 1: Determine initial pre-*flashover fire growth* rate from Table 2.1; typically $q=0.0469t^2$.

Step 2: Run the *fire* model and determine which of the following five cases apply.
If necessary adjust the input *HRR* to the model as described below and rerun the model.

Case 1 *Fire growth* reaches the peak *HRR* from Table 2.1 before $T_{UL}=500°C$

Fast *fire growth* to the peak *HRR* from Table 2.1

Species as given for pre-*flashover*

Case 2 Sprinklers activate before *fire growth* reaches the peak *HRR* from Table 2.1

Fast *fire growth* to sprinkler activation

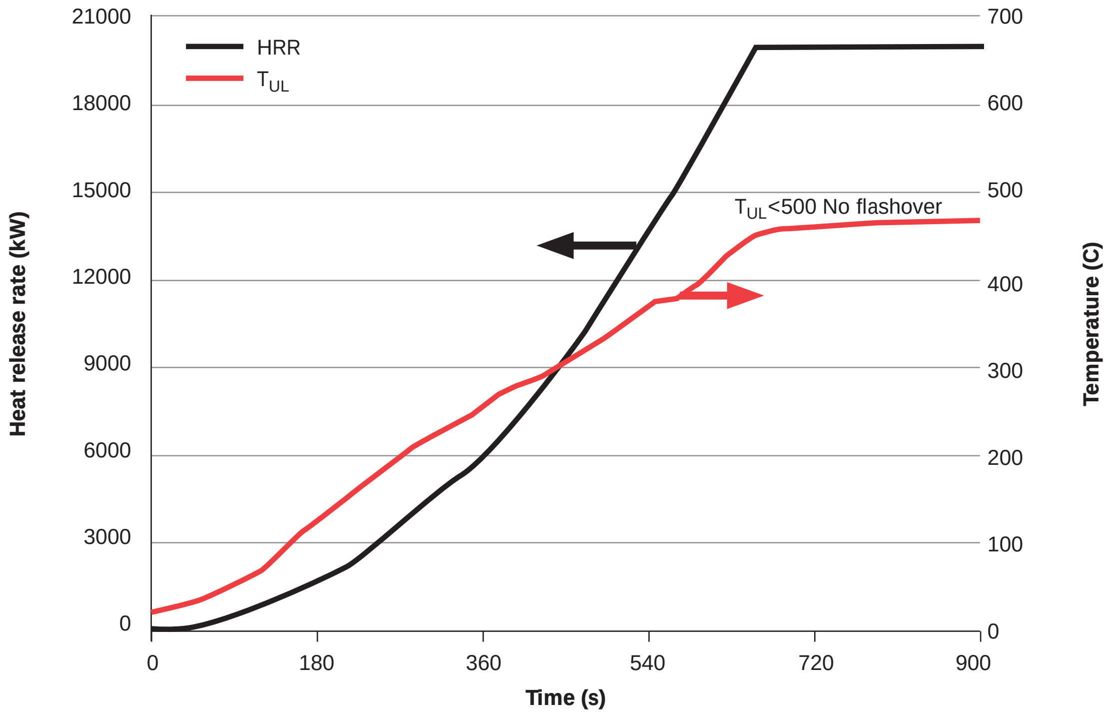
Species as given for pre-*flashover*

Commentary: Paragraph 2.3.3 Case 1

2.3.3

For Case 1, the *fire* is well ventilated and grows according to the values given in Table 2.1 (typically fast t^2) until the peak *HRR* is reached (normally 20 MW). The upper layer temperature (T_{UL}) within the space of origin never reaches *flashover*, (ie, T_{UL} <500°C). The exemplary graph below shows the fast t^2 growth rate to 20 MW and the upper layer T_{UL} versus time for the 15 m x 10 m space with an 8.0 m wide x 3.5 m high vent. With such a large vent, the *fire* grows nearly unaffected by the space. The engineer simply inputs the fast t^2 *fire* with a 20 MW peak *HRR* into the chosen model and uses the pre-*flashover* species production rates.

Figure C2 Case 1: Peak HRR before T_{UL} = 500°C



Extract from C/VM2: Paragraph 2.3.2

Table 2.1	Pre-flashover design fire characteristics			
Building use	*Fire* growth rate (kW)	Species	Radiative fraction	Peak *HRR*
All *buildings* including storage with a stack height of less than 3.0 m	$0.0469\ t^2$	Y_{soot} = 0.07 kg/kg Y_{CO} = 0.04 kg/kg ΔH_C = 20 MJ/kg Y_{CO_2} = 1.5 kg/kg Y_{H_2O} = 1.0 kg/kg	0.35	20 MW
Carparks (no stacking)	$0.0117\ t^2$		0.35	
Storage with a stack height of between 3.0 m and 5.0 m above the floor	$0.188\ t^2$		0.35	50 MW
Storage with a stack height of more than 5.0 m above the floor and car parks with stacking systems	$0.00068\ t^3\ H$		0.35	

NOTE:
t = time in seconds
H = height of storage in m
Y = *yield* kg/kg
ΔH_C = heat of combustion

2.3.2 Post-flashover design fires

Flashover is assumed to occur when the average upper layer temperature first reaches 500°C.

For uncontrolled *fires*, the burning rate is assumed to be governed by the ventilation limit or the peak *HRR*, whichever is less.

2.3.3 Modelling post-flashover fires

For life safety calculations (ie, *ASET*), modelling the *fire* into the post-*flashover* phase is unlikely to be required for sprinklered *buildings*. The *fire* is expected to be controlled (ie, with a constant *HRR*) after the sprinkler activates based on *RTI*, C-factor and activation temperature, and therefore *flashover* is not expected to occur. Sprinkler response calculations would be expected to confirm that this is the case.

However, note that for the full *burnout design fire* (see Paragraph 2.4), calculations of *fire* resistance shall be based on *burnout* without sprinkler or other intervention, except that the design *FLED* may be modified as described in Paragraph 2.4.1 where sprinklers are installed.

The following parameters shall apply:

a) Post-*flashover* species *yield* for soot is Y_{soot} = 0.14 kg/kg_{fuel}

b) Post-*flashover* species *yield* for CO is Y_{CO} = 0.40 kg/kg_{fuel}, and

c) Design *FLEDs* shall be as specified in Table 2.2 for activities within *buildings*.

The three steps for modelling the *fire* shall be as follows:

Step 1: Determine initial pre-*flashover fire growth* rate from Table 2.1; typically $q=0.0469t^2$.

Step 2: Run the *fire* model and determine which of the following five cases apply. If necessary adjust the input *HRR* to the model as described below and rerun the model.

Case 1 *Fire growth* reaches the peak *HRR* from Table 2.1 before T_{UL}=500°C

Fast *fire growth* to the peak *HRR* from Table 2.1

Species as given for pre-*flashover*

Case 2 Sprinklers activate before *fire growth* reaches the peak *HRR* from Table 2.1

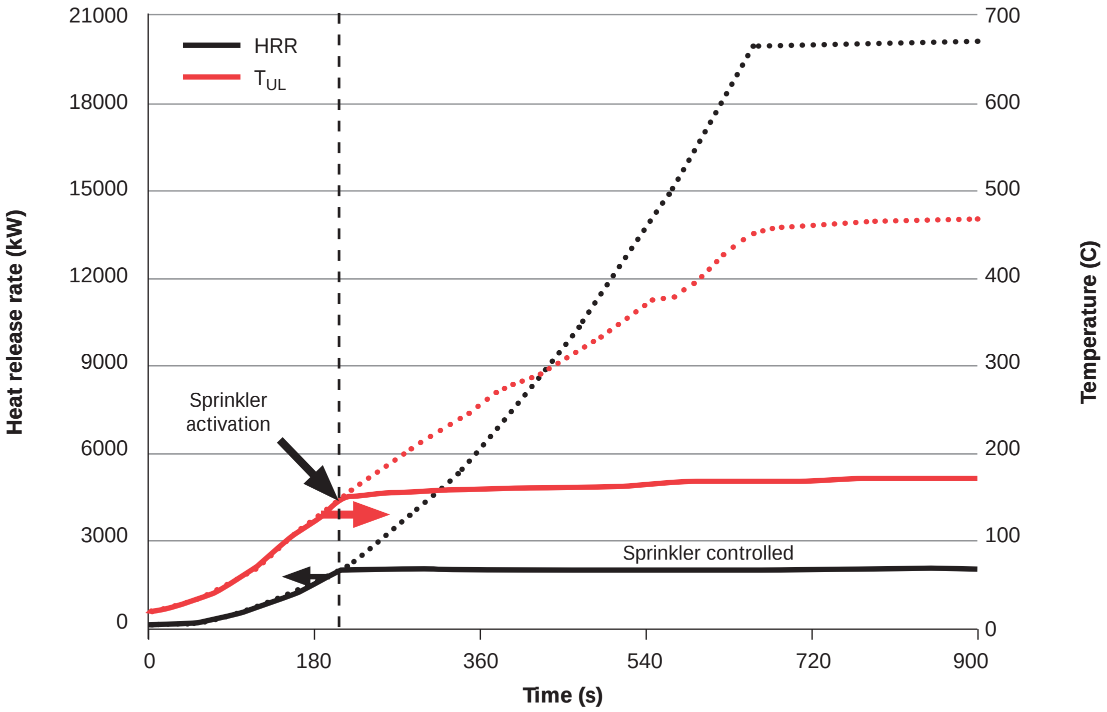
Fast *fire growth* to sprinkler activation

Species as given for pre-*flashover*

Commentary: Paragraph 2.3.3 Case 2

2.3.3 For Case 2 there is a standard response sprinkler head located 3.25 m radially from the centreline of the *fire*. The space is identical to Case 1 above, the *fire* is well ventilated, and the *fire* grows with a growth rate given in Table 2.1 until the sprinkler activates and controls the *fire*. The exemplary graph below shows the fast t^2 growth rate to 2 MW (sprinkler controlled) along with the T_{UL} versus time. Sprinkler is modelled as controlling the *fire* (ie, the *HRR* is held fixed on activation of the closest sprinkler. The dashed lines show how the *fire* would have developed if there was no sprinkler installed. The engineer simply inputs the fast t^2 with a 20 MW peak *HRR*. once the sprinkler activates, the *HRR* is capped at the *HRR* when the sprinkler activated. Some models do this automatically while others require the engineer to cap the *HRR* manually at the time of activation. The pre-*flashover* species production rates are used for this analysis.

Figure C3 Case 2: Sprinkler activation before Peak HRR



Extract from C/VM2: Paragraph 2.3.3

Case 3 T_{UL}=500°C before *HRR* reaches the peak from Table 2.1 and *fire* is not ventilation limited

Fast *fire growth* to T_{UL}=500°C

Species as given for pre-*flashover*

At T_{UL}=500°C ramp up the *HRR* to the peak *HRR* from Table 2.1 over a period of 15s

Species as given for post-*flashover*

Case 4 T_{UL}=500°C before *HRR* reaches the peak from Table 2.1 and *fire* is ventilation limited

Fire growth to T_{UL}=500°C

Species as given for pre-*flashover*

At T_{UL}=500°C (or ventilation limit, whichever occurs first) ramp up the *HRR* to 1.5 times the ventilation limit over a period of 15s

Species as given for post-*flashover*

Case 5 T_{UL}<500°C and *fire* is ventilation limited

Fast *fire growth* to ventilation limit

Species as given for pre-*flashover*

At ventilation limit ramp up the *HRR* to 1.5 times the ventilation limit over a period of 15s

Species as given for post-*flashover*.

For modelling purposes, the ventilation limit shall be taken as the *HRR* at the time when the predicted energy release first diverges from the *design fire* (given in Table 2.1) due to the lack of sufficient oxygen for complete combustion.

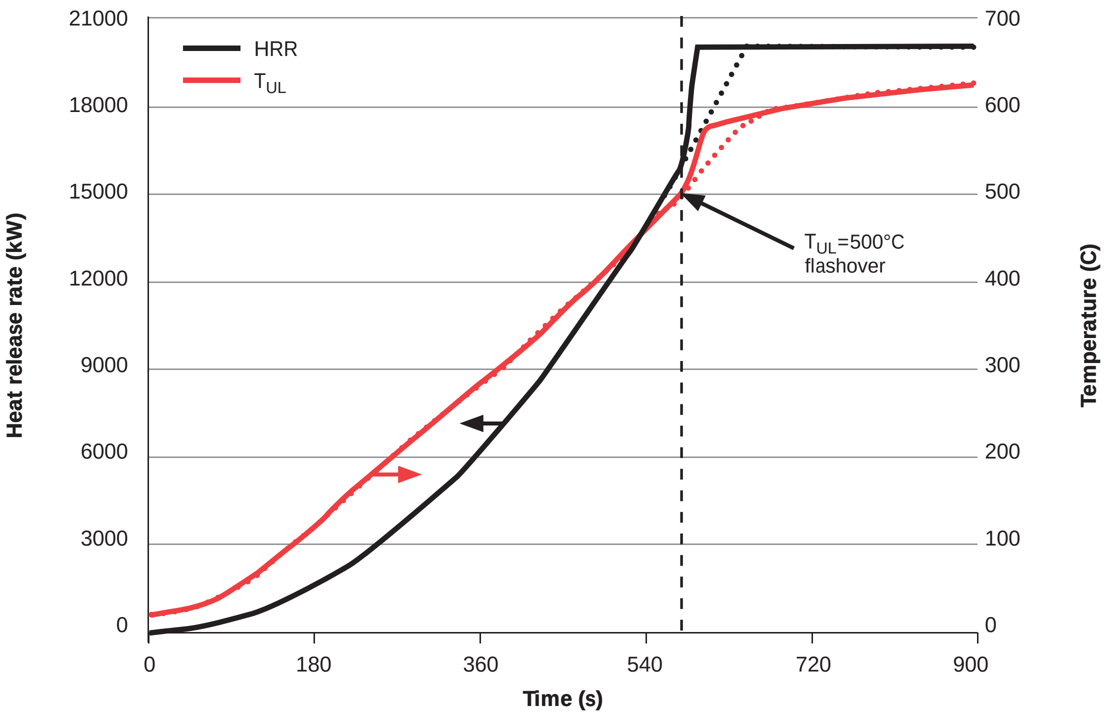
Comment:
Ventilation limit is determined by *fire* modelling. See the commentary document for this Verification Method for a calculation example.

T_{UL} is the average temperature of the upper layer.

Commentary: Paragraph 2.3.3 Case 3

2.3.3 For Case 3, the *fire* is well ventilated and grows with an appropriate growth rate given in Table 2.1 (typically fast t^2) until T_{UL} is greater than 500°C and *flashover* is assumed to have occurred. The exemplar graph below shows the fast t^2 growth rate to 20 MW along with the T_{UL} versus time for the 15 m x 10 m space with a 5.0 m wide x 3.0 m high vent. Once $T_{UL} \geq 500$°C, *flashover* is assumed to have occurred and the *HRR* must be increased to the peak *HRR* (normally 20 MW). The species production rates must also be increased to the post-*flashover* species production rate. To simulate this *flashover* condition, the engineer simply inputs the fast t^2 to the peak *HRR* of 20 MW. Once $T_{UL} \geq 500$°C, the model is stopped and the *HRR* curve is modified by linearly increasing the *HRR* to the peak *HRR* of 20 MW over a 15 sec period starting when $T_{UL} = 500$°C. Species production rates are also increased to the post-*flashover* rates. Within BRANZFIRE this can be done automatically, assuming the engineer has input the necessary parameters and chosen the correct algorithm for species production rates. The exemplary graph below shows the fast t^2 growth rate until $T_{UL} = 500$°C when *HRR* is linearly increased to 20 MW and the species production rates are increased to the post-*flashover* levels. In this example, *flashover* occurred at 583 sec. The impact of the *flashover* modelling can be seen in the figure where the dashed lines show the results if *flashover* was not modelled. Once the $T_{UL} \geq 500$°C, the species production rates are increased to the post-*flashover* level.

Figure C4 Case 3: T_{UL} = 500°C before Peak HRR (not ventilation limited)



Extract from C/VM2: Paragraph 2.3.3

Case 3 T_{UL}=500°C before *HRR* reaches the peak from Table 2.1 and *fire* is not ventilation limited

Fast *fire growth* to T_{UL}=500°C

Species as given for pre-*flashover*

At T_{UL}=500°C ramp up the *HRR* to the peak *HRR* from Table 2.1 over a period of 15s

Species as given for post-*flashover*

Case 4 T_{UL}=500°C before *HRR* reaches the peak from Table 2.1 and *fire* is ventilation limited

Fire growth to T_{UL}=500°C

Species as given for pre-*flashover*

At T_{UL}=500°C (or ventilation limit, whichever occurs first) ramp up the *HRR* to 1.5 times the ventilation limit over a period of 15s

Species as given for post-*flashover*

Case 5 T_{UL}<500°C and *fire* is ventilation limited

Fast *fire growth* to ventilation limit

Species as given for pre-*flashover*

At ventilation limit ramp up the *HRR* to 1.5 times the ventilation limit over a period of 15s

Species as given for post-*flashover*.

For modelling purposes, the ventilation limit shall be taken as the *HRR* at the time when the predicted energy release first diverges from the *design fire* (given in Table 2.1) due to the lack of sufficient oxygen for complete combustion.

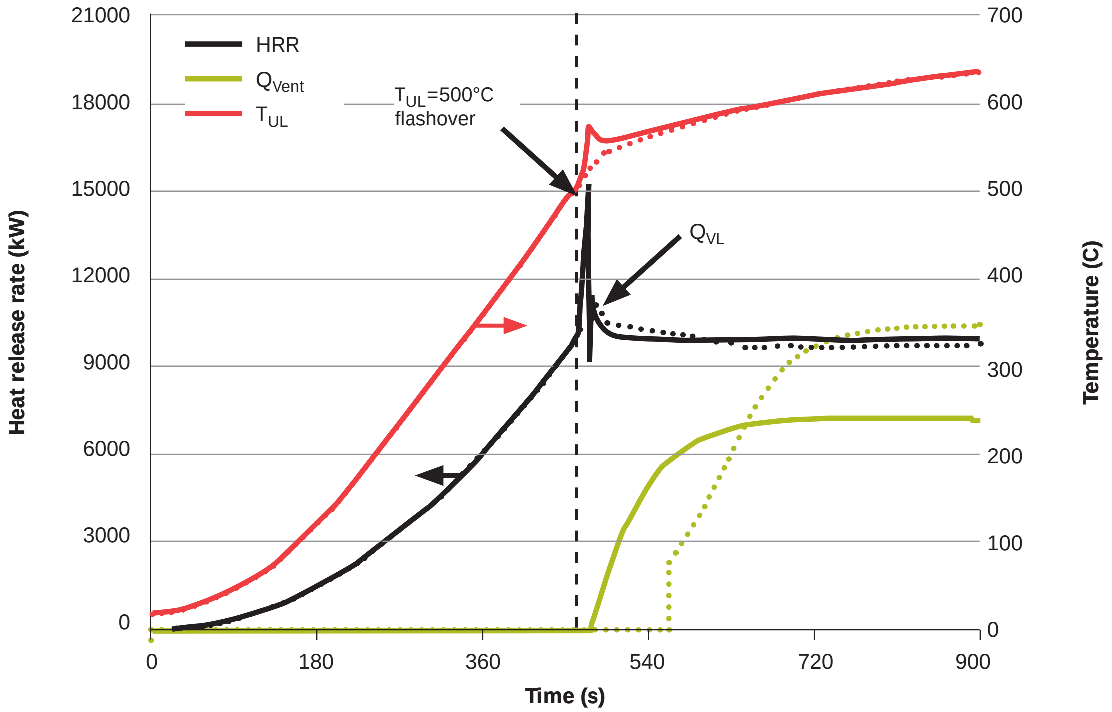
Comment:
Ventilation limit is determined by *fire* modelling. See the commentary document for this Verification Method for a calculation example.

T_{UL} is the average temperature of the upper layer.

Commentary: Paragraph 2.3.3 Case 4

2.3.3 For Case 4, the *fire* is under-ventilated and grows with an initial growth rate given in Table 2.1 (typically fast t^2) until T_{UL} is greater than 500°C and *flashover* is assumed to have occurred. The exemplar graph below shows the fast t^2 growth rate including *flashover* for a ventilation-controlled *fire* in the 15 m x 10 m space with a 2.5 m wide x 2.1 m high vent. Once $T_{UL} \geq 500$°C, *flashover* is assumed to have occurred. The post-*flashover* species production rate must then be applied and the *HRR* must be increased to account for compartment enhanced burning. Once the *HRR* starts to decline (Q_{VL}), the *fire* is ventilation limited as shown in the graph below. At this point, the computer model is stopped and the *HRR* input is modified by linearly increasing the *HRR* to 150% of the maximum ventilation controlled value (determined in the first computer simulation). The species production rates are also increased to the post-*flashover* levels. The graph below shows the impact of modelling *flashover* in this way. The solid lines are the *flashover* simulations and the dashed lines show the results if the *fire* was simply input as fast t^2 *fire* to the peak *HRR* = 20 MW (Case 1 above). The solid black line shows the modified *HRR* input into BRANZFIRE including the 1.5 Q_{VL}. The green lines show the *fire* that will occur outside the vent.

Figure C5 Case 4: T_{UL} = 500°C before Peak HRR (ventilation limited)



Extract from C/VM2: Paragraph 2.3.3

Case 3 T_{UL}=500°C before *HRR* reaches the peak from Table 2.1 and *fire* is not ventilation limited

Fast *fire growth* to T_{UL}=500°C

Species as given for pre-*flashover*

At T_{UL}=500°C ramp up the *HRR* to the peak *HRR* from Table 2.1 over a period of 15s

Species as given for post-*flashover*

Case 4 T_{UL}=500°C before *HRR* reaches the peak from Table 2.1 and *fire* is ventilation limited

Fire growth to T_{UL}=500°C

Species as given for pre-*flashover*

At T_{UL}=500°C (or ventilation limit, whichever occurs first) ramp up the *HRR* to 1.5 times the ventilation limit over a period of 15s

Species as given for post-*flashover*

Case 5 T_{UL}<500°C and *fire* is ventilation limited

Fast *fire growth* to ventilation limit

Species as given for pre-*flashover*

At ventilation limit ramp up the *HRR* to 1.5 times the ventilation limit over a period of 15s

Species as given for post-*flashover*.

For modelling purposes, the ventilation limit shall be taken as the *HRR* at the time when the predicted energy release first diverges from the *design fire* (given in Table 2.1) due to the lack of sufficient oxygen for complete combustion.

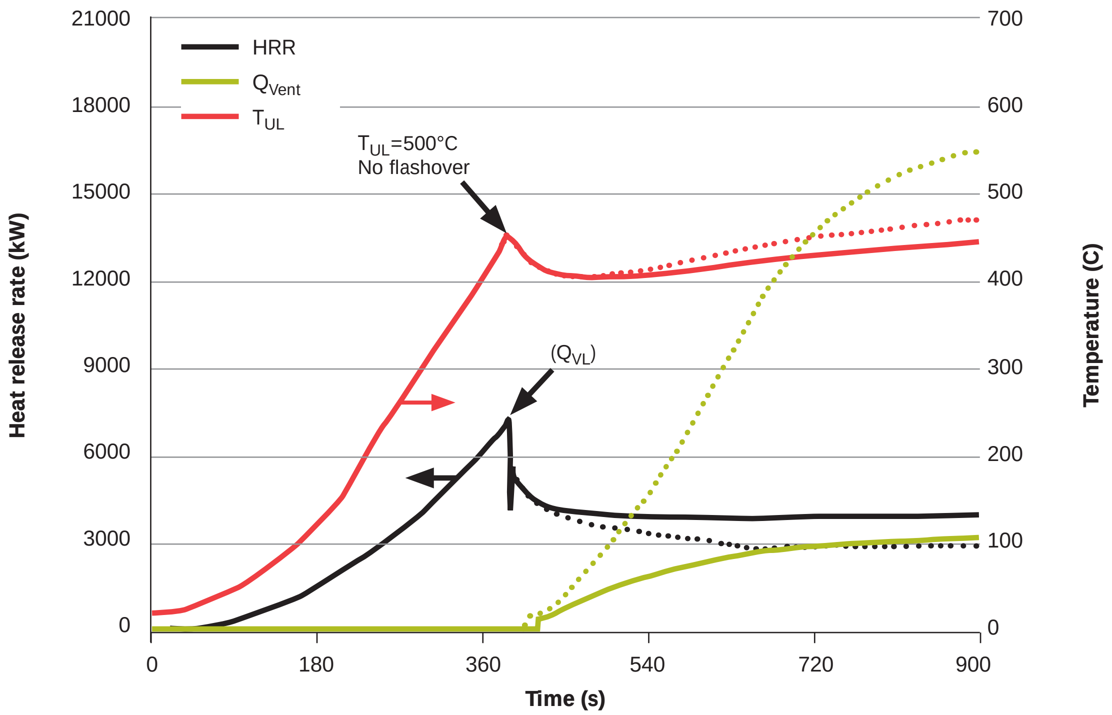
Comment:
Ventilation limit is determined by *fire* modelling. See the commentary document for this Verification Method for a calculation example.

T_{UL} is the average temperature of the upper layer.

Commentary: Paragraph 2.3.3 Case 5

2.3.3 For Case 5, the *fire* is under-ventilated and grows with an initial growth rate given in Table 2.1 until the *HRR* starts to diminish before $T_{UL} \geq 500°C$; thus *flashover* has not occurred. The exemplar graph below shows the fast t^2 growth rate until the *fire* becomes ventilation controlled in the 15 m x 10 m space with a 1.0 m wide x 2.1 m high vent. Once the *HRR* starts to decline, the *fire* is limited by the ventilation. The species production rate should be increased to account for the inefficient burning that occurs when the ventilation is limited. To simulate this ventilation limited non-*flashover* condition, the engineer simply inputs the fast t^2 with the 20 MW peak *HRR* cap into their chosen computer model. Once the *HRR* starts to decline, the *fire* is assumed to be ventilation limited as shown in the graph below. At this point, the computer model is stopped and the *HRR* input is modified by fixing the *HRR* at the ventilation limited value (determined in the first computer simulation). The species production rates are increased to the post-*flashover* levels. The graph below shows the impact of modelling the ventilation controlled *fire* when *flashover* does not occur. The solid lines are the ventilation controlled simulations and the dashed lines show the results if the *fire* was simply input as fast t^2 *HRR* to the peak *HRR* = 20 MW (Case 1 above). The solid black line shows the modified *HRR* input into BRANZFIRE capped at the Q_{VL}. The green lines show *fire* outside the vent.

Figure C6 Case 5: T_{UL} <500°C and ventilation limited



Extract from C/VM2: Paragraph 2.3.3

Step 3: Allow the *fire* to burn until all the fuel is exhausted, based on the design *FLED*. Use the design *FLEDs* provided in Table 2.2.

Table 2.2 Design FLEDs for use in modelling fires in C/VM2

Design *FLED* (MJ/m²)	Activities in the space or room	Examples
400	1. Display or other large open spaces; or other spaces of low *fire hazard* where the occupants are awake but may be unfamiliar with the *building*.	1. Art galleries, auditoriums, bowling alleys, churches, clubs, community halls, court rooms, day care centres, gymnasiums, indoor swimming pools
	2. Seating areas without upholstered furniture	2. School classrooms, lecture halls, museums, eating places without cooking facilities
	3. All spaces where occupants sleep	3. *Household units*, motels, hotels, hospitals, residential care institutions
	4. Working spaces and where low *fire hazard* materials are stored	4. Wineries, meat processing plants, manufacturing plants
	5. Support activities of low *fire hazard*	5. Car parks, locker rooms, toilets and amenities, service rooms
800	1. Spaces for business	1. Banks, personal or professional services, police stations (without detention)
	2. Seating areas with upholstered furniture, or spaces of moderate *fire hazard* where the occupants are awake but may be unfamiliar with the *building*	2. Nightclubs, restaurants and eating places, *early childhood centres*, cinemas, *theatres*, libraries
	3. Spaces for display of goods for sale (retail, non-bulk)	3. Exhibition halls, shops and other retail (non bulk)
1200	1. Spaces for working or storage with moderate *fire hazard*	1. Manufacturing and processing moderate *fire load* 2. Storage up to 3.0 m high other than *foamed plastics*
	2. Workshops and support activities of moderate *fire hazard*	3. Maintenance workshops, plant and boiler rooms
400/tier of car storage	Spaces for multi-level car storage	Car stacking systems. The design floor area over which the design *FLED* applies is the total actual car parking area
800/m height, with a minimum of 2400	1. Spaces for working or storage with high *fire hazard*	1. Chemical manufacturing and processing, feed mills, flour mills 2. Storage over 3.0 m high of *combustible* materials, including climate controlled storage
	2. Spaces for display and sale of goods (bulk retail)	3. Bulk retail (over 3.0 m high)

Commentary: Table 2.2

2.3.3 The values given in Table 2.2 for the *FLED* are similar to values found in previous Compliance Documents and are loosely based on the CIB study given in the references. The value of the *FLED* given in column 1 of Table 2.2 is to be used as the design value where *FLED* is required throughout Verification Method C/VM2. Other values should not be used as it is difficult to control the actual *fire load* in a *building* over the life of a *building*, even for a given occupancy.

Extract from C/VM2: Paragraph 2.4

2.4 Full burnout design fires

Comment:
Design fire characteristics include parameters for *FLED, fire growth* rate and heat of combustion. This means a post-*flashover* 'full *burnout design fire*' can be defined.

The 'full *burnout design fire*' for structural design and for assessing *fire* resistance of *separating elements* shall be based on complete *burnout* of the *firecell* with no intervention. However, the maximum *fire resistance rating* for a sprinklered *firecell* need not exceed 240/240/240 determined using AS 1530.4.

There are three choices for modelling the full *burnout design fire*:

a) Use a time-equivalent formula to calculate the equivalent *fire* severity and specify *building elements* with a *fire resistance rating* not less than the calculated *fire* severity. In this case, an equivalent *fire* severity of 20 minutes shall be used, if the calculated value is less.

b) Use a parametric time versus gas temperature formula to calculate the thermal boundary conditions (time/temperature) for input to a structural response model, or

c) Construct an *HRR* versus time structural *design fire* as described in Paragraph 2.3.3. Then, taking into account the ventilation conditions, use a *fire* model or energy conservation equations to determine suitable thermal boundary conditions (time/temperature/flux) for input to a structural response model.

Comment:
A common approach to use with this Verification Method is the 'equivalent fire severity' method described in Eurocode 1 Actions on structures, Part 2-2. This allows the equivalent time of exposure to the *standard test* for *fire* resistance to be estimated based on the compartment properties, *FLED* and available ventilation given complete *burnout* of the *firecell* with no intervention.

Commentary: Paragraph 2.4

2.4 The selection of the maximum *fire* resistance specified in the Verification Method was largely a pragmatic decision after considering a number of factors that act to reduce or mitigate the *fire* severity in a warehouse *building*. The major factors that were considered are summarised below:

1) The intensity of the *fire* exposure to the wall is a very complex, time-dependent problem. For a small space of the order of 200 m^2, the *fire* temperature within the space would be expected to be fairly uniform and the *fire* can be modelled as a single zone, well stirred reactor and the *fire* exposure to the walls is relatively uniform. However, as the space gets larger, say >1000 m^2, the *fire* becomes more complex and the burning rate is not as uniform as found in smaller spaces. Unfortunately, experimental results for large warehouse-scale *fires* are not very common and taking such a *building* to *burnout* experimentally is almost unheard of. Therefore the discussion is more qualitative then quantitative.

   In a large, open *building* the *fire* is expected to travel around the space and burn with varying intensity depending on the fuel distribution, geometry and *combustibility*. In addition, the ventilation will also have a significant impact on the *fire*'s intensity. The role of the roof vents, makeup air and eventually the structural failure of the roof will greatly affect the *fire's* intensity. Prior to the roof collapsing, the smoke and heat are contained within the *building*. This increases the *fire's* intensity by improving the heat transfer to the wall by radiation from the flame and convection from the hot gases. For most warehouse designs, the roof is non-rated and would be expected to fail early in the *fire*. Once the roof collapses, much of the heat and flame will no longer be contained. The intensity of the *fire* exposure will be governed by flame radiation and the convection will be greatly reduced, as the buoyant flow is allowed to evacuate the *building* instead of being contained by the roof.

2) When the *external walls* are on the *boundary*, the concern is the *fire* spread to an adjacent *building* that is also on the *boundary*. Typically, this would be a warehouse immediately adjacent to another warehouse. This would mean that there are now two 4-hour *fire* rated walls to reduce the likelihood of spread to the adjacent property.

3) Although Fire Service intervention is not normally used in design decisions, *fires* in warehouse facilities are relatively rare events and the positive influence the Fire Service can have on preventing a *fire* from spreading to an adjacent *building* cannot be ignored. In the event that 4 hours of *fire* resistance for *external walls* is insufficient, the Fire Service is expected to have adequate time to size up the *fire*, carry out rescue operations, secure an adequate number of personnel, establish a reliable water supply, and mount a defensive attack to reduce the likelihood of the *fire* spreading to the adjacent property.

Extract from C/VM2: Paragraph 2.4

2.4 Full burnout design fires

Comment:
Design fire characteristics include parameters for *FLED, fire growth* rate and heat of combustion. This means a post-*flashover* 'full *burnout design fire*' can be defined.

The 'full *burnout design fire*' for structural design and for assessing *fire* resistance of *separating elements* shall be based on complete *burnout* of the *firecell* with no intervention. However, the maximum *fire resistance rating* for a sprinklered *firecell* need not exceed 240/240/240 determined using AS 1530.4.

There are three choices for modelling the full *burnout design fire*:

a) Use a time-equivalent formula to calculate the equivalent *fire* severity and specify *building elements* with a *fire resistance rating* not less than the calculated *fire* severity. In this case, an equivalent *fire* severity of 20 minutes shall be used, if the calculated value is less.

b) Use a parametric time versus gas temperature formula to calculate the thermal boundary conditions (time/temperature) for input to a structural response model, or

c) Construct an *HRR* versus time structural *design fire* as described in Paragraph 2.3.3. Then, taking into account the ventilation conditions, use a *fire* model or energy conservation equations to determine suitable thermal boundary conditions (time/temperature/flux) for input to a structural response model.

Comment:
A common approach to use with this Verification Method is the 'equivalent fire severity' method described in Eurocode 1 Actions on structures, Part 2-2. This allows the equivalent time of exposure to the *standard test* for *fire* resistance to be estimated based on the compartment properties, *FLED* and available ventilation given complete *burnout* of the *firecell* with no intervention.

Commentary: Paragraph 2.4 (continued)

4) *Fire resistance ratings* greater than 4 hours in the NZS/ISO 834 standard *fire* test are unusual and very expensive. Wall designs with *fire* resistance >4 hours are either very thick, *constructed* with special lightweight aggregates, include a cavity within the wall design, or are *constructed* with high strength concrete with plastic fibres. Such complex *construction* details will add significantly to the *building's* costs and are not expected to significantly reduce the risk of *fire* spread to the adjacent property.

Taking account of the issues outlined above, a pragmatic solution to determining the maximum *fire* resistance of a *boundary* wall is appropriate. The cost of increasing the *fire resistance rating* of *boundary* walls beyond four hours is unlikely to provide significantly greater protection to the adjacent property. Therefore, the maximum *fire resistance rating* for a *boundary* wall in a sprinklered *building* is set at 4 hours.

Commentary: Paragraph 2.4 a) to c)

2.4 a) to c)

The majority of the *fire* resistance calculations will rely on a), the time equivalence formula option. Options b) and c) typically require both a structural engineer and a *fire* engineer to conduct the complex analysis. Normally the cost of such detailed analysis is not justified, except on large, complex *buildings* where a reduction in the *fire resistance rating* may be able to be justified.

Extract from C/VM2: Paragraph 2.4.2

2.4.1 Modifications to the design FLED

For assessing the *fire* resistance of structural and non-structural elements, the design *FLED* from Table 2.2 used for the *design fire* shall be modified by multiplying the *FLED* by the applicable F_m factor from Table 2.3.

For assessing *fire* duration for life safety calculations the design *FLED* from Table 2.2 shall be modified by multiplying the *FLED* by the applicable F_m factor from Table 2.3.

Table 2.3 **F_m factors to be applied to FLED**

	Sprinklered *firecell*	Unsprinklered *firecell*
Fire resistance of primary structural elements in any structural system which is unable to develop dependable deformation capacity under post-*flashover fire* conditions [1]	1.00	1.25
Fire resistance of primary structural elements whose failure would consequently lead to disproportionate extent of collapse [2]	1.00	1.25
All other structural and non-structural elements or for life safety calculations of *fire* duration.	0.50	1.00

Errata 1 Apr 2012

Notes

1. This factor accounts for non-uniformity of *fire load* and/or ventilation and hence local structural *fire* severity. The structural system comprises the individual members and the connections between these members. The dependable deformation capacity shall have been established by rational analysis supported by evidence from experimental testing. One example is composite floor systems comprising concrete slab on steel deck supported on steel beams.
2. Guidance on an extent of collapse which would be regarded as disproportionate is given in the commentary document for this Verification Method. One example is isolated columns near the base of a tall, multi-storey structure where the column would suffer sudden and complete loss of load-carrying capacity if subjected to the deformations expected in a severe *fire*.

2.4.2 Openings for full burnout fires

For the purposes of calculating A_v (the total area (m^2) of vertical windows and doors) in full *burnout design fire* calculations it shall be assumed that doors in *external walls* are closed. Wall areas clad in sheet metal shall not be included in the area A_v.

Comment:
Also refer to the *fire* modelling rules for full *burnout fires* in Paragraph 2.2.2 for effective openings.

2.4.3 Structural fire severity for interconnected floors

Where a space contains interconnected floors, separate calculations shall be made to determine the structural *fire* severity, first by considering the total floor area of the space and then by considering the interconnected floor at each level. The greatest magnitude of structural *fire* severity shall be applied to all levels, unless the structural system supporting floors is designed to dependably prevent collapse during the *fire*.

Extract from C/VM2: Paragraph 2.4.5

2.4.4 Time equivalence formula

The time equivalence formula shall be taken from Annex E of Eurocode DD ENV 1991-2-2.

Comment:
Further discussion can be found in the Fire Engineering Design Guide.

The required *fire resistance rating* must be greater than the time equivalence (t_e) value calculated using the equations 2.1 and 2.2:

$$t_e = e_f\, k_b\, k_m\, w_f \qquad \text{Equation 2.1}$$

where:

e_f = *FLED* given in Table 2.2 and as modified by Table 2.3.

k_b = conversion factor to account for the thermal properties of the material, as specified in Table 2.4

k_m = modification factor for the structural material.

and

w_f = ventilation factor.

$$w_f = \left(\frac{6.0}{H}\right)^{0.3}\left[0.62 + \frac{90(0.4-\alpha_v)^4}{1+b_v\alpha_h}\right] \geq 0.5 \qquad \text{Equation 2.2}$$

where

$\alpha_v = A_v / A_f \qquad 0.025 \leq \alpha_v \leq 0.25$

$b_v = 12.5\left(1 + 10\alpha_v - \alpha_v^2\right) \geq 10.0$

A_f = floor area of the *space*

A_v = area of vertical window and door openings (m^2)

A_h = area of horizontal openings in the roof (m^2), and

H = height of the space (m) (for pitched roofs, use the smallest value for H).

If $A_v < 0.025A_f$ then $A_v = 0.025A_f$ shall be used for the purpose of this calculation.

If $A_v > 0.25A_f$ then $A_v = 0.25A_f$ shall be used for the purpose of this calculation.

When $W_f < 0.5$ then use $W_f = 0.5$

When there are multiple vertical openings, the weighted average height (h_{eq}) of all of the openings is used.

For pitched roofs use the smallest value for H.

k_m = 1.0 for reinforced concrete, protected steel, timber, and a mix of unprotected and protected steel. For unprotected steel:

$$k_m = 13.7\, A_v \sqrt{h_{eq}} / A_t \geq 1.0$$

applicable over the range:

$$0.02 \leq A_v \sqrt{h_{eq}} / A_t \leq 0.20$$

Table 2.4 Conversion factor k_b for various lining materials

Typical values for $\sqrt{k\rho c}$ $J/m^2s^{0.5}k$	*Construction* materials	K_b
400	Very light highly insulating materials	0.10
700	Plasterboard ceilings and walls, timber floors	0.09
1100	Light weight concrete ceilings and floors	0.08
1700	Normal weight concrete ceilings and floors	0.065
>2500	Thin sheet steel roof and wall systems	0.04

NOTE:
k=thermal conductivity (W/m K)
ρ=density (kg/m^3)
c=specific heat (J/kg K)

Commentary: Paragraph 2.4.4

2.4.4 The time equivalence formula is used to calculate the equivalent time of exposure to the standard ISO 834 time/temperature curve that produces the same maximum temperature compared to a protected steel member exposed to a post-*flashover fire* in a specific space based on the fuel load, ventilation and materials of *construction*, and assuming the *fire* goes to *burnout*.

3. Movement of people

Verification Method C/VM2

Extract from C/VM2: Part 3 Movement of people

Part 3: Movement of people

CONTENTS

3.1 Occupant numbers

The occupancy of any space in a *building* shall be calculated using the occupant densities provided in Table 3.1.

Commentary: General

The following general requirements apply to *escape routes* which assist in the movement of people.

- The height of an *escape route* is to be a minimum of 2100 mm generally, except that doorways may have a minimum clear height of 1955 mm.
- Vision panels are required on doors leading into parts of an *escape route* where occupants can reasonably be expected to queue and on doors where the direction of escape for more than 10 people is in either direction and the door swings in both directions.
- All locking devices on doors on *escape routes* shall be clearly visible, located where such a device would normally be expected, easily operated without a key or other security device, and allow the door to open in the normal manner and 'fail safe' (operability, location/height).
- Automatic doors are required to automatically open and remain open or be pushed to an outward open position by building occupants in the event of loss of power to or failure of the door controller.
- Any doors that are electronically locked are required to be provided with a fail safe emergency door release which allows unobstructed escape.
- Specific hardware which rapidly unlatches door leaves is required on *doorsets* with double leaves on parts of an *escape route* where more than 100 people may queue to escape through the doorway.
- *Escape routes* are to be kept clear at all times. *Escape routes* shall not be obstructed by goods or *building* contents.
- Stairwell doors are not to be locked from within the stairwell, so that occupants are able to re-enter other levels of the *building* from the stair.
- Switches/buttons required as part of the *fire* safety design (eg, emergency door lock releases) shall be at a height and in a location readily accessible by all occupants including those with disabilities (refer to Acceptable Solution D1/AS1).
- Hold-open devices are to be fitted to *fire* and/or *smoke control doors* where the door is likely to need to be held open during the expected use of the *building*.

Extract from C/VM2: Part 3 Movement of people

Part 3: Movement of people

CONTENTS

3.1 Occupant numbers

The occupancy of any space in a *building* shall be calculated using the occupant densities provided in Table 3.1.

Commentary: Paragraph 3.1

3.1 The *occupant load* may need to be evaluated for:

a) A space or open floor area involving one or more activities, and
b) A floor, and
c) Any space bounded by *separating elements*, and
d) Each floor within a space bounded by *separating elements*.

Occupant loads are calculated from the occupant densities given in Table 3.1 based on the floor area of the part of the *building* housing the activity (see Figure C7). If a *building* space has alternative activity uses, the activity having the greatest occupant density shall be used. If an activity is not specifically described in Table 3.1, the nearest reasonable description shall be used.

Extract from C/VM2: Table 3.1

Table 3.1	Occupant densities
Activity	Occupant density (m^2/person)
Area without seating or aisles	1.0
Art galleries, museums	4
Bar sitting areas	1.0
Bar standing areas	0.5
Bleachers, pews or bench type seating	0.45 linear m per person
Classrooms	2
Consulting rooms (doctors, dentists, beauty therapy)	5
Dance floors	0.6
Day care centres	4
Dining, beverage and cafeteria spaces	1.25
Early childhood centres	Based on Education (Early Childhood Services) Regulations 2008 plus the number of staff
Exhibition areas, trade fairs	1.4
Fitness centres	5
Gaming and casino areas	1
Indoor games areas, bowling alleys	10
Libraries – stack areas	10
Libraries other areas	7
Lobbies and foyers	1
Mall areas used for assembly uses	1
Reading or writing rooms and lounges	2
Restaurants, dining rooms	1.1
Shop spaces and pedestrian circulation areas including malls and arcades	3
Shop spaces for furniture, floor coverings, large appliances, building supplies and Manchester	10
Showrooms	5
Spaces with fixed seating	As number of seats
Spaces with loose seating	0.8
Spaces with loose seating and tables	1.1
Sports halls	3
Stadiums and grandstands	0.6
Staffrooms and lunch rooms	5
Stages for theatrical performances	0.8
Standing spaces	0.4
Swimming pools: water surface area	5

Commentary: Table 3.1

3.1 When using Table 3.1 to calculate the *occupant load* note that:

a) The floor area to be used is the total enclosure floor area including that occupied by internal partitions and permanent *fixtures* (see Figure C7), and
b) The occupant densities in Table 3.1 already allow for a proportion of the floor area appropriate to the activity being occupied by furniture, partitions, *fixtures* and associated equipment.

Duplication shall be avoided by:

a) Ensuring that, where people may be involved in more than one activity, they are counted only once, and
b) Not including an *occupant load* for areas such as *exitways*, lift lobbies or sanitary facilities that are used intermittently by people already counted elsewhere in the *building*.

Fixed seating

Occupant load assessment shall take account of the actual arrangement and number of seats for fixed seating. Where additional floor area abuts the fixed seating, additional occupants may be allowed for based on standing space density, provided the *escape route* is not obstructed.

Justification for exceptions

If, in a particular situation, the *occupant load* derived from Table 3.1 is clearly more than that which will occur, the basis of any proposal for a lesser *occupant load* must be substantiated to the *building consent authority*. However, note that designing a *building* for a reduced *occupant load* can severely restrict future occupancy options and may involve significant expense in meeting the *means of escape from fire* provisions for increased numbers.

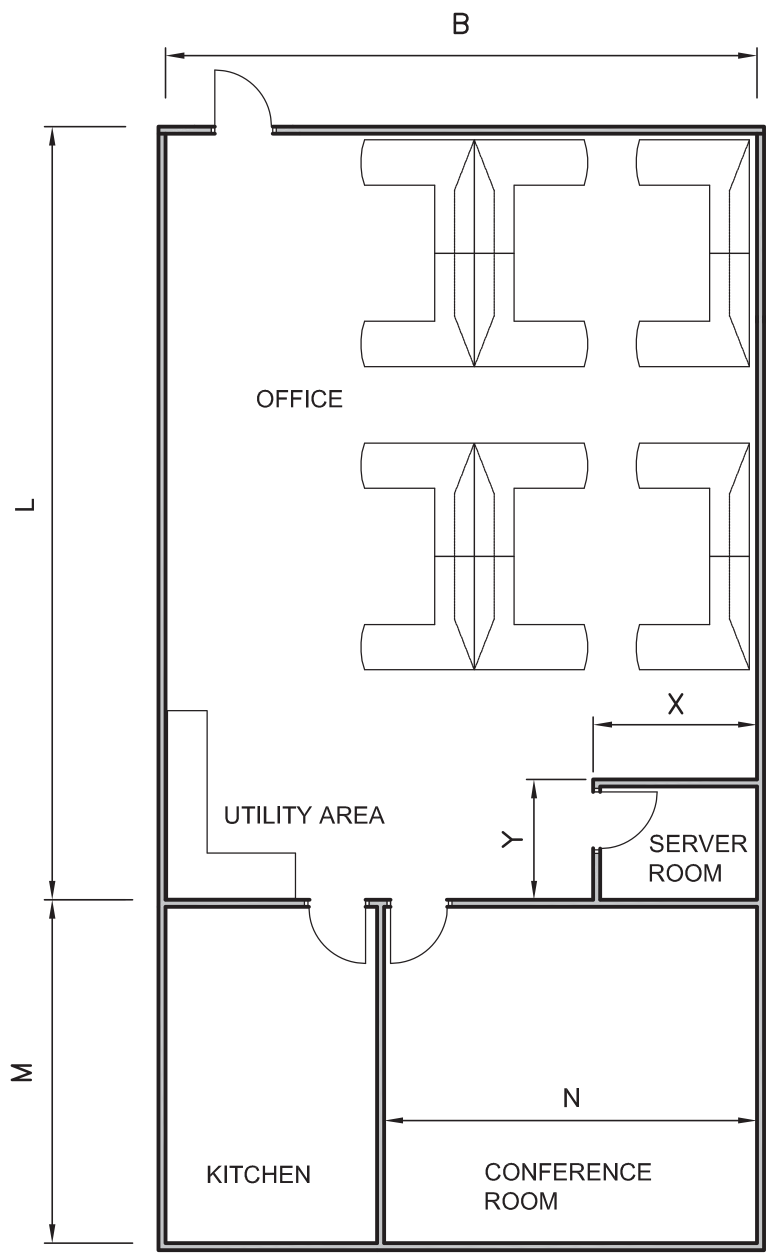
If the maximum *occupant load* is greater than that calculated from Table 3.1, the higher number shall be used as the basis for the *fire* safety design and will need to be justified to the *building consent authority*.

Extract from C/VM2: Table 3.1

Table 3.1 Occupant densities (continued)

Activity	Occupant density (m^2/person)
Swimming pools: surrounds and seating	3
Teaching laboratories	5
Vocational training rooms in schools	10
Bedrooms	As number of bed spaces and staff when appropriate
Bunkrooms	
Dormitories, hostels	
Halls and *wharenui*	
Wards in hospitals, operating theatres and similar	
Detention quarters	
Aircraft hangars	50
Bulk storage including racks and shelves (warehouses etc)	100
Retail and trading (storage >3.0 m high)	5
Call centres	7
Commercial laboratories, laundries	10
Computer server rooms	25
Heavy industry	30
Interview rooms	5
Commercial kitchens	10
Manufacturing and process areas	10
Meeting rooms	2.5
Offices	10
Personal service facilities	5
Reception areas	10
Staffrooms and lunchrooms	5
Workrooms, workshops	5
Boiler rooms, plant rooms	30
Parking *buildings*, garages	50

Figure C7 Calculation of floor area of firecell



Area of Fire Cell = (L x B) - (X x Y) + (M x N)

NOTE:

1. Occupant densities will be different for 'Office' and 'Conference Room'.
2. Server room and Kitchen will be intermittently occuped by the occupants of the office and this can be ignore for purposes of calculating occupancy. However, the maximum occupancy of the kitchen is required to ensure there is sufficient exit width and number of exits from the space.

Extract from C/VM2: Paragraph 3.2.1

3.2 Required safe egress time (RSET)

The *required safe egress time* (*RSET*), is the calculated time available between ignition of the *design fire* and the time when all the occupants in the specified room/location have left that room/location.

The *RSET* in a simple hydraulic model for evacuation (see Comment below) is:

$$RSET = (t_d + t_n + t_{pre}) + (t_{trav} \text{ or } t_{flow})$$

Equation 3.1

where:

- t_d = detection time determined from deterministic modelling
- t_n = time from detection to notification of the occupants
- t_{pre} = time from notification until evacuation begins
- t_{trav} = time spent moving toward a *place of safety*, and
- t_{flow} = time spent in congestion controlled by flow characteristics.

The requirements for establishing each of these times are set out in Paragraphs 3.2.1 to 3.2.5.

When calculating the flow from the room of origin, the occupants are assumed to be evenly distributed in the space. Therefore, the egress time is determined by the greater of the queuing time and the travel time to the exit.

Comment:
This Verification Method defines the minimum analysis required to demonstrate that the *fire* engineer's design meets the required performance criteria.
For more information on how to calculate *RSET*, refer to the SFPE Handbook of Fire Protection Engineering, Section 3 Chapter 13.

3.2.1 Detection time

The *fire* engineer shall establish the detection time from deterministic modelling or as described in Paragraph 3.4 for a manually activated warning system. It is expected that the model used to calculate the detection time for an automatic warning system will use an appropriate algorithm that includes at least a ceiling jet correlation or a *CFD* model code that solves for the velocity and temperature (and smoke/soot concentration) directly.

Regardless of the actual make/model and installation parameters of the detection device specified to be installed in the *building*, the values given in Table 3.2 for the detector shall be used in this analysis.

Table 3.2 Detector criteria

Heat detectors RTI = 30 $m^{1/2}s^{1/2}$ T_{act} = 57°C Radial distance = 4.2 m Distance below ceiling not less than 25 mm	**Extended coverage (sprinkler)** RTI = 50 $m^{1/2}s^{1/2}$ C = 0.65 $m^{1/2}s^{1/2}$ T_{act} = 68°C Radial distance = 4.3 m (maximum) Distance below ceiling not less than 25 mm
Standard response (sprinkler) RTI = 135 $m^{1/2}s^{1/2}$ C = 0.85 $m^{1/2}s^{1/2}$ T_{act} = 68°C Radial distance = 3.25 m Distance below ceiling not less than 25 mm	**Quick response (sprinkler)** RTI = 50 $m^{1/2}s^{1/2}$ C = 0.65 $m^{1/2}s^{1/2}$ T_{act} = 68°C Radial distance = 3.25 m Distance below ceiling not less than 25 mm
Spot/point smoke detectors Optical density at alarm = 0.097 m^{-1} Radial distance = 7 m Distance below ceiling not less than 25 mm	**Projected beam smoke detectors** Optical density at alarm to be determined based on beam path length and the design setting for the total obscuration for alarm[1]

NOTE:
1. The commentary document for this Verification Method provides a method for calculating the optical density for projected beam smoke detectors.

Commentary: Paragraph 3.2.1

3.2.1 Smoke optical density at alarm of 0.097 m^{-1} is taken from AS 1603.2 for a device of normal sensitivity. This is considered to be a conservative value for design purposes and would correspond to a detector with a sensitivity of 6.6%/ft. Most commonly used point smoke detectors would have sensitivities of 2-3%/ft.

Projected beam smoke detectors

In the case of projected beam smoke detectors, response sensitivities are typically in the range of 20% to 70% total obscuration (OBS) eg, I/I_o = 0.3 to 0.8.

Based on design inputs for the beam path length and the response sensitivity, and assuming a uniform optical density along the path length of the beam, the optical density at alarm is calculated as:

$$OD = -\frac{1}{L}\log_{10}\left(\frac{I}{I_o}\right) \text{ and } \frac{I}{I_o} = \frac{100 - OBS}{100}$$

where:

OD = optical density (1/m)
L = path length of beam (m)
I = intensity at receiver with smoke
I_o = intensity at receiver without smoke, and
OBS = total obscuration (%).

For example, if the beam path length is 10 m and the total obscuration for alarm is set at 50%, then:

$$OD = -\frac{1}{L}\log_{10}\left(\frac{100 - OBS}{100}\right) = -\frac{1}{10}\log_{10}\left(\frac{100 - 50}{100}\right) = 0.030 \ \ (1/m)$$

In practice, the optical density along the path length may not be uniform: eg, where a plume intercepts a beam. The engineer can account for this if they wish by dividing the path length into smaller sections and summing the optical density (OD/m x length of section) over all sections.

Extract from C/VM2: Paragraph 2.4.2

3.2.1.1 Smoke detection optical density criteria for spot detectors

The optical density at alarm criteria in Table 3.2 shall apply to spot detectors (ionisation and photoelectric).

3.2.1.2 Criteria for very high sensitivity air sampling smoke detectors

This type of detector requires specialised design, and the response depends on a range of factors including air flow rates, sampling tube length and alarm threshold levels. The response criteria in Table 3.2 shall be used in the analysis.

3.2.2 Notification time

For standard evacuation strategies, take the notification time as 30 seconds.

For non-standard evacuation strategies (for example, management investigating sole activation), take account of the extended notification time.

3.2.3 Pre-travel activity time

Use the values in Table 3.3 for *pre-travel activity times*.

Comment:
The incipient phase of the *fire growth* has not been considered in the *design fire*. This provides an implicit safety factor for the *pre-travel activity time*.

Commentary: Paragraph 3.2.3

3.2.3 There have been numerous studies on the time between hearing a *fire* alarm and the time the occupants start to evacuate a *building*, or '*pre-travel activity time*' as it is referred to in this Verification Method. There are many factors that influence the behaviour of the occupants within a *building* including, but not limited to: age, gender, training, familiarity, activity, family grouping and management. Unfortunately, there are no widely accepted values for the *pre-travel activity times*. The most comprehensive collection of *pre-travel activity times* can be found in PD7974-6. Within PD7974-6 there are a number of behavioural scenarios that use the occupant's alertness, familiarity, density and physical abilities to develop a collection of *pre-travel activity times* for engineering application.

Extract from C/VM2: Table 3.3

Table 3.3 Pre-travel activity times

Description of *building* use	*Pre-travel activity time(s)*
Buildings where the occupants are considered awake, alert and **familiar** with the *building* (eg, offices, warehouses **not** open to the public)	
Enclosure of origin	30
Remote from the enclosure of origin	60
Buildings where the occupants are considered awake, alert and **unfamiliar** with the *building* (eg, retail shops, exhibition spaces, restaurants)	
Enclosure of origin (standard alarm signal)	60
Remote from the enclosure of origin (standard alarm signal)	120
Enclosure of origin (voice alarm signal)	30
Remote from the enclosure of origin (voice alarm signal)	60
Buildings where the occupants are considered sleeping and **familiar** with the *building* (eg, apartments)	
Enclosure of origin (standard alarm signal)	60
Remote from the enclosure of origin (standard alarm signal)	300
Buildings where the occupants are considered sleeping and **unfamiliar** with the *building* (eg, hotels and motels)	
Enclosure of origin	60
Remote from the enclosure of origin (standard alarm signal)	600
Remote from the enclosure of origin (voice alarm signal)	300
Buildings where the occupants are considered awake and under the care of trained staff (eg, day care, dental office, clinic)	
Enclosure of origin (independent of alarm signal)	60
Remote from the enclosure of origin (independent of alarm signal)	120
Buildings where the occupants are considered sleeping and under the care of trained staff (eg, hospitals and rest homes)	
Enclosure of origin (assume staff will respond to room of origin first)	60 s for staff to respond to alarm then 120 s (per patient per 2 staff)[1]
Remote from the enclosure of origin (independent of alarm signal)	1800
Errata 1 Apr 2012 — Remote from the enclosure of origin (independent of alarm signal) where occupants are unable to be moved due to the procedure or other factor	1800 or as per specific requirements, whichever is the greater
Spaces within *buildings* which have only focused activities (eg, cinemas, *theatres* and stadiums)	
Space of origin (occupants assumed to start evacuation travel immediately after detection and notification time or when *fire* in their space reaches 500 kW, whichever occurs first)	0

NOTE:

1. This allows 120 s to move each patient from their room to the next adjacent *firecell*. This includes time for staff to prepare the patient and transport them to the adjacent *firecell*, and then to return to evacuate another patient. The commentary document for this Verification Method gives details of staff to patient ratios.

Commentary: Table 3.3

2.4.5 In addition to behavioural scenarios, the *building* characteristics were also identified as important parameters in developing a comprehensive collection of pre-travel activity values. The important *building* parameters include the warning system, management and training, and spatial complexity. The Verification Method C/VM2 gives a table that takes into account all of these factors.

Many of the factors that have been identified in PD7974-6 have been incorporated in the values given in the Verication Method. However, some of the parameters identified are considered to be country-specific. In New Zealand's case, the regulations governing evacuation procedures of *buildings* require most public non-residential *buildings* to have an evacuation scheme that enhances the *building fire* safety awareness and this leads to a culture of prompt evacuations. Therefore, in selecting the values given in Table 3.3 the most optimistic management values were chosen. Table C2 shows the values suggested by PD7974-6 in the last column. Pre-travel activity values are given for the time from alarm to movement of the first person (1^{st}%) and the time for the last person (99^{th}%) to start to evacuate. The value in brackets is the time when the last occupant is expected to start to evacuate. It is clear that the values given in C/VM2 are closely aligned, even though they were derived from the detailed sensitivity study and not simply extracted from PD7974-6.

The most notable change from the PD7974-6 was the acknowledgement that the people in the enclosure of origin are expected to have shorter *pre-travel activity times* because of the additional cues they are expected to receive that the remote occupants will not have. This results in shorter *pre-travel activity times* in the enclosure of origin. C/VM2 also acknowledges that, when people are in a focused activity, such as a *theatre* or sports arena, where all of the occupants' attention is focused on a single activity, it is expected that a *fire* within that area would be obvious to the occupants and that they would start to evacuate when the *fire* gets to 500 kW.

The evacuation of hospital ward areas has been expanded to more closely reflect the procedures followed in a hospital rather than specifiying a single fixed value. An example is given below to demonstrate how the values given in Table 3.3. are intended to be applied.

Extract from C/VM2: Table 3.3

Table 3.3	**Pre-travel activity times**
Description of *building* use	*Pre-travel activity time(s)*
Buildings where the occupants are considered awake, alert and **familiar** with the *building* (eg, offices, warehouses **not** open to the public)	
Enclosure of origin	30
Remote from the enclosure of origin	60
Buildings where the occupants are considered awake, alert and **unfamiliar** with the *building* (eg, retail shops, exhibition spaces, restaurants)	
Enclosure of origin (standard alarm signal)	60
Remote from the enclosure of origin (standard alarm signal)	120
Enclosure of origin (voice alarm signal)	30
Remote from the enclosure of origin (voice alarm signal)	60
Buildings where the occupants are considered sleeping and **familiar** with the *building* (eg, apartments)	
Enclosure of origin (standard alarm signal)	60
Remote from the enclosure of origin (standard alarm signal)	300
Buildings where the occupants are considered sleeping and **unfamiliar** with the *building* (eg, hotels and motels)	
Enclosure of origin	60
Remote from the enclosure of origin (standard alarm signal)	600
Remote from the enclosure of origin (voice alarm signal)	300
Buildings where the occupants are considered awake and under the care of trained staff (eg, day care, dental office, clinic)	
Enclosure of origin (independent of alarm signal)	60
Remote from the enclosure of origin (independent of alarm signal)	120
Buildings where the occupants are considered sleeping and under the care of trained staff (eg, hospitals and rest homes)	
Enclosure of origin (assume staff will respond to room of origin first)	60 s for staff to respond to alarm then 120 s (per patient per 2 staff)[1]
Remote from the enclosure of origin (independent of alarm signal)	1800
Remote from the enclosure of origin (independent of alarm signal) where occupants are unable to be moved due to the procedure or other factor	1800 or as per specific requirements, whichever is the greater
Spaces within *buildings* which have only focused activities (eg, cinemas, *theatres* and stadiums)	
Space of origin (occupants assumed to start evacuation travel immediately after detection and notification time or when *fire* in their space reaches 500 kW, whichever occurs first)	0

Errata 1
Apr 2012

NOTE:

1. This allows 120 s to move each patient from their room to the next adjacent *firecell*. This includes time for staff to prepare the patient and transport them to the adjacent *firecell*, and then to return to evacuate another patient. The commentary document for this Verification Method gives details of staff to patient ratios.

Table C2: Commentary to Table 3.3 Pre-travel activity times

Description of *building* use	*Pre-travel activity times(s)*	PD7974 1st% (99th%)
Buildings where the occupants are considered awake alert and **familiar** with the *building* (eg, offices, warehouses not open to the public)		
Enclosure of origin	30	30 (60)
Remote from the enclosure of origin	60	
Buildings where the occupants are considered awake alert and **unfamiliar** with the *building* (eg, retail shops, exhibition space, restaurants)		
Enclosure of origin (standard alarm signal)	60	30 (120)
Remote from the enclosure of origin (standard alarm signal)	120	
Enclosure of origin (voice alarm signal)	30	
Remote from the enclosure of origin (voice alarm signal)	60	
Buildings where the occupants are considered sleeping and **familiar** with the *building* (eg, sleeping residential)		
Enclosure of origin (standard alarm signal)	60	300 (300)
Remote from the enclosure of origin (standard alarm signal)	300	
Buildings where the occupants are considered sleeping and **unfamiliar** with the *building* (eg, sleeping accommodation)		
Enclosure of origin	60	900 (900)
Remote from the enclosure of origin (standard alarm signal)	600	
Remote from the enclosure of origin (voice alarm signal)	300	
Buildings where the occupants are considered awake and under the care of trained staff (eg, day care, dental office, clinic)		
Enclosure of origin (independent of alarm signal)	60	30 (120)
Remote from the enclosure of origin (independent of alarm signal)	120	
Buildings where the occupants are considered to be asleep and under the care of trained staff (eg, hospitals and rest homes)		
Enclosure of origin (Assume staff will respond to room of origin first)	60 s for staff to respond to alarm then (120s per patient per 2 staff)[1]	300 (600)
Remote from the enclosure of origin (independent of alarm signal)	1800	
Remote from the enclosure of origin (independent of alarm signal) where occupants are unable to be moved due to the procedure or other factor.	As per the specific requirements	
Spaces within *buildings* which have only focused activities (eg, cinemas, *theatres* and stadiums)		
Enclosure of origin (occupants assumed to start evacuation travel immediately after detection and notification time or when fire in their space reaches 500 kW, whichever occurs first)	0	No Equivalent

NOTE:

1. This allows 120 s to move each patient from their room to the next adjacent enclosure. This includes time for staff to prepare the patient and transport them to the adjacent enclosure, and then to return to evacuate another patient. The commentary document for this Verification Method gives details of staff to patient ratios.

Extract from C/VM2: Table 3.3

Table 3.3	Pre-travel activity times
Description of *building* use	*Pre-travel activity time(s)*
Buildings where the occupants are considered awake, alert and **familiar** with the *building* (eg, offices, warehouses **not** open to the public)	
Enclosure of origin	30
Remote from the enclosure of origin	60
Buildings where the occupants are considered awake, alert and **unfamiliar** with the *building* (eg, retail shops, exhibition spaces, restaurants)	
Enclosure of origin (standard alarm signal)	60
Remote from the enclosure of origin (standard alarm signal)	120
Enclosure of origin (voice alarm signal)	30
Remote from the enclosure of origin (voice alarm signal)	60
Buildings where the occupants are considered sleeping and **familiar** with the *building* (eg, apartments)	
Enclosure of origin (standard alarm signal)	60
Remote from the enclosure of origin (standard alarm signal)	300
Buildings where the occupants are considered sleeping and **unfamiliar** with the *building* (eg, hotels and motels)	
Enclosure of origin	60
Remote from the enclosure of origin (standard alarm signal)	600
Remote from the enclosure of origin (voice alarm signal)	300
Buildings where the occupants are considered awake and under the care of trained staff (eg, day care, dental office, clinic)	
Enclosure of origin (independent of alarm signal)	60
Remote from the enclosure of origin (independent of alarm signal)	120
Buildings where the occupants are considered sleeping and under the care of trained staff (eg, hospitals and rest homes)	
Enclosure of origin (assume staff will respond to room of origin first)	60 s for staff to respond to alarm then 120 s (per patient per 2 staff)[1]
Remote from the enclosure of origin (independent of alarm signal)	1800
Remote from the enclosure of origin (independent of alarm signal) where occupants are unable to be moved due to the procedure or other factor	1800 or as per specific requirements, whichever is the greater
Spaces within *buildings* which have only focused activities (eg, cinemas, *theatres* and stadiums)	
Space of origin (occupants assumed to start evacuation travel immediately after detection and notification time or when *fire* in their space reaches 500 kW, whichever occurs first)	0

Errata 1
Apr 2012

NOTE:

1. This allows 120 s to move each patient from their room to the next adjacent *firecell*. This includes time for staff to prepare the patient and transport them to the adjacent *firecell*, and then to return to evacuate another patient. The commentary document for this Verification Method gives details of staff to patient ratios.

Commentary: Table 3.3 (continued)

The literature on hospital evacuations primarily focuses on the evacuation of an entire hospital following a large-scale natural event such as an earthquake or hurricane. In C/VM2, the interest is in the early *fire* development where the patients may require evacuation to an adjacent enclosure. For care facilities it is expected that there will be an automatic fire sprinkler system installed to control the *fire* in *ASET* versus *RSET* analysis and that the sprinkler system functions as designed to control the *fire*. Although it is desirable to have comprehensive pre-travel activity studies in hospitals, there are few studies available due to the vulnerable nature of patients. There have only been a few cases of published data from trial evacuations with mock patients, as described by Gildea and Etengoff. These mock evacuations have been based on intensive care units with critically ill patients and required between three and eight minutes to prepare the patients (which included strapping the patients to stretchers). However, such conditions are considered extreme as the patients were transported vertically in *stairways*, as might be expected for complete evacuation of a facility. Within C/VM2, the 2 min/patient time is used, assuming that there is an adjacent enclosure available for horizontal evacuation. For outpatient areas, one study observed the *pre-travel activity time* of less than 60 sec in an unannounced evacuation drill described by Gwynne et al which supports the 60 sec *pre-travel activity time* for occupants considered awake and under the care of trained staff in Table 3.3.

Example: Hospital evacuation

This brief example is not intended to be a comprehensive design analysis but a simple application of the Table 3.3 *pre-travel activity time* values to a hospital ward.

In this example, there is a *fire* in one of the patient rooms of a ward that includes 12 patient rooms with a central nursing area and a closed store room (as shown in Figure a). There is one patient per room and there are two staff in the ward, with two additional staff outside the ward available to assist with the evacuation. Actual staffing levels may be different depending on the size of the hospital. The *fire* is in patient room #1 and the door to the *fire* room is open and all other doors are closed.

The *fire* room is assumed to be open for the entire evacuation time and all other doors are closed causes the upper layer in the corridor to descend more quickly and thus hastens the time to untenable conditions that the staff are exposed to. Under normal evacuation procedures, it is expected that the hospital staff will close the door to the *fire* room after the patients from that room have been evacuated.

The *building* is sprinklered and a full smoke detection system is installed. The smoke detector is assumed to be 7.0 m away from the *fire* and the sprinkler head 2.8 m away. Although these values could be considered excessive, they are within the confines of the patient room and within the limits allowed by NZS 4512 and NZS 4541. The BRANZFIRE geometry is set up with two rooms, one being the 8.0 m x 4.0 m patient room #1 and the other being 5.0 m wide x 32 m long which is an equivalent volume to the corridor and nurses' area combined. Both rooms are 2.4 m in height. Figure b shows the BRANZFIRE geometry for the two rooms. The doors between the patient rooms and the corridor are assumed to be 1.2 m wide to accommodate patient beds.

The essential BRANZFIRE results required to calculate *ASET* and *RSET* are summarised in Table a for patient room #1 and the corridor. The smoke detector in patient room #1 activates 46 sec after ignition. The *building* is sprinklered so control is assumed, and the *HRR* capped at activation. In this example, the sprinkler in the patient room activates at 112 sec which gives a controlled *HRR* of 565 kW. *Visibility* 2.0 m above the floor in the patient room drops below 10 m just 23 sec after ignition and 86 sec in the corridor. The $FED_{Thermal}$ exceeds 0.3 at 2.0 m height 118 s after ignition in the patient room and 628 sec in the corridor. Because the building is sprinklered, the FED_{CO} of greater than 0.3 is the only performance criteria that is invoked. In the patient room, FED_{CO} exceeds 0.3 at 586 sec and 863 sec in the corridor, which is the *ASET* for the respective spaces.

Figure a – Hospital ward floor plan for egress example

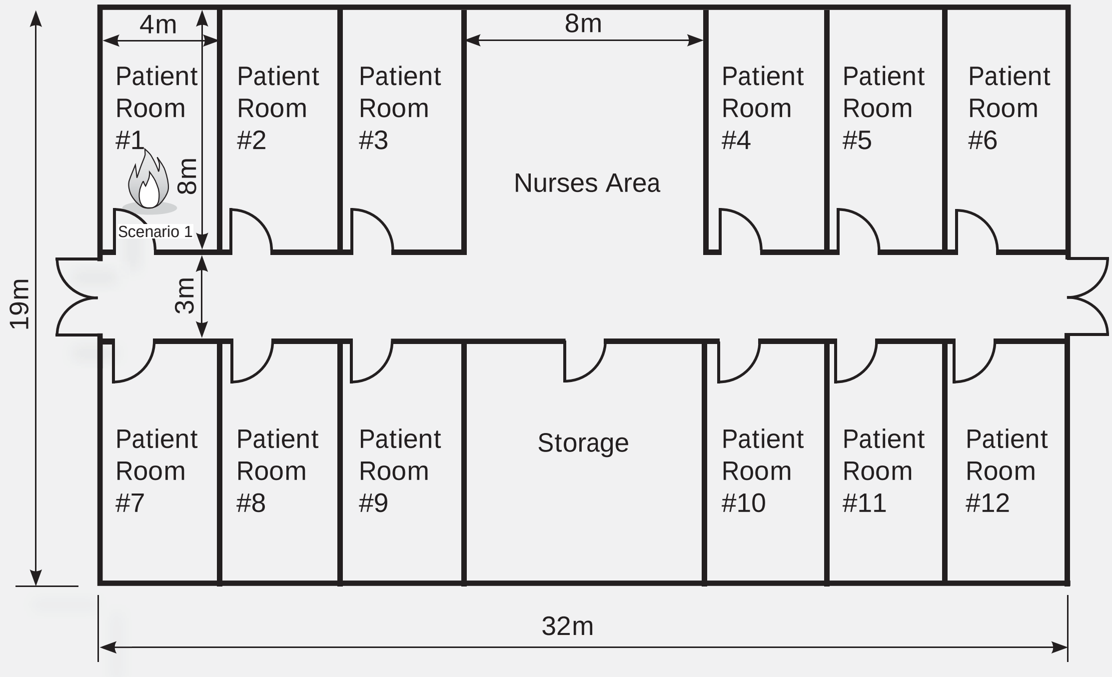


Figure b – BRANZFIRE geometry for the hospital ward floor plan for egress example

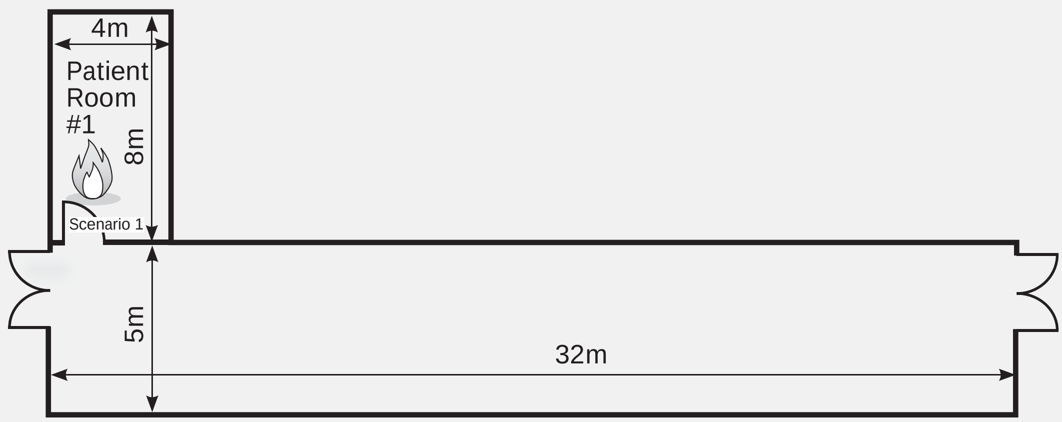


Table a – Summary results from BRANZFIRE zone model analysis

Key event	Patient room #1 (sec)	Corridor (sec)
Smoke detector activation	46	–
Sprinkler activation	112	–
10 m *visibility* patient room #1	23	86
$FED_{Thermal}$ patient room #1	118	628
FED_{CO} patient room #1	586	863

Table b summarises the *RSET* analysis results. The alarm is assumed to activate 30 sec after the smoke detector first acknowledges the presence of *fire* phenomenon, 76 sec (46+30) in this example. The Verification Method allows 60 sec for the staff to respond to the alarm and start to evacuate patients. It is assumed that all patients are non-ambulatory and the staff must manually move the patients which requires two staff members per patient, and that it takes 120 sec to move a patient from their room to the next adjacent enclosure. This translates into 256 sec to clear the room of *fire* origin (patient room #1) and 856 sec to clear the entire ward, which represents the *RSET* for these spaces respectively. Thus the *RSET* exceeds the *ASET* for both the room of origin and the entire ward.

Table b – Summary of key times for calculating the RSET for the hospital ward

Key events	Time (sec)
Detection time	46
Alarm verification time	30
Time for nurses to arrive	60
Time to evacuate *fire* room 1 patient (2 min/patient)	120
Time to evacuate all 12 patients 12 patients (2 min/patient)/2 teams	720
RSET (fire room) (46+30+60+120)	256
RSET (ward) – Assume 4 staff in evacuation (46+30+60+720)	856

Extract from C/VM2: Paragraph 3.2.4

3.2.4 Travel time

Travel time within a space is governed by:

a) The time taken to travel to the doorway (t_{trav}), or

b) The flow time (ie, the time taken for all the occupants to flow through a restriction, typically a doorway, when queueing is necessary).

The greater of these two times is the evacuation time from the space.

For **horizontal travel**, the travel time shall be calculated based on the estimated walking speed. Horizontal travel speed shall be calculated using equation 3.2 with a maximum travel speed of 1.2 m/s.

$$S = K - akD \qquad \text{Equation 3.2}$$

where:

S= horizontal travel speed (m/s)

D= occupant density of the space (persons/m^2)

k = 1.4 for horizontal travel, and

a =0.266.

Travel time (t_{trav}) is calculated by using equation 3.3:

$$t_{trav} = L_{trav}/ S \qquad \text{Equation 3.3}$$

where:

t_{trav} = travel time (s), and

L_{trav} = travel distance (m).

The maximum horizontal travel distance (L_{trav}) shall be determined by either:

a) The measured length around furniture if this is known, or

b) Adding together the length and width measurements of the room.

For **vertical travel**, equation 3.2 applies but the values used for k are a function of the stair riser and tread size as given in Table 3.4.

Table 3.4 Maximum flow rates for use in equation 3.2 for horizontal and vertical travel speeds

Exit route elements		k	Speed m/s
Corridor, aisle, ramp, doorway		1.40	1.19
Stair riser (mm)	Stair tread (mm)		
191	254	1.00	0.85
178	279	1.08	0.95
165	305	1.16	1.00
165	330	1.23	1.05

Extract from C/VM2: Paragraph 3.2.5

3.2.5 Time if flow governs

Flow rate shall be calculated using equation 3.4:

$$F_c = (1 - aD)kDW_e \qquad \text{Equation 3.4}$$

where:

F_c = calculated flow (persons/sec), and

D = occupant density near flow constriction (ie, for doors, use 1.9 persons/m^2)

W_e = effective width of component being traversed in metres.

The effective width is equal to the measured width minus the boundary layer, where the thickness of the boundary layer is given in Table 3.5.

Comment:
Equation 3.4 is most commonly used for doorway flows to estimate the queuing times. However, it is useful in many situations, as shown by the variety of exit route elements listed in Table 3.5.

Table 3.5 Boundary layer width for calculating the effective width of an exit component

Exit route element	Boundary layer on each side (m)
Stairway – walls or side tread	0.15
Railing or *handrail*	0.09
Theatre chairs, stadium bench	0.00
Corridor wall and ramp wall	0.20
Obstacle	0.10
Wide concourse, passageway	0.46
Door, archway	0.15

For doorway flows, the maximum flow rate is limited to 50 people per minute for each standard door leaf that has a self-closing device fitted. If there is no self-closing device, equation 3.4 shall be used with no upper limit on the flow rate.

Comment:
This requirement applies to standard, manual, self-closing side-hinged doors and not to automatic sliding doors. In the case of automatic sliding doors, the effective width of the opening may be used in equation 3.4 from the time when the doors are opened and remain open. The same applies to manual sliding doors. They may be assumed to remain fully open once the first occupant has passed through the door.

The maximum flow rate corresponds to a door of 0.95 m wide with a boundary layer each side of 0.15 m and a total effective width of 0.65 m.

3.2.6 Direction of opening

Doors on *escape routes* shall be hung to open in the direction of escape and, where escape may be in either direction, doors shall swing both ways. These requirements need not apply where the number of occupants of spaces with egress using the door is no greater than 50. Manual sliding doors are permitted where the relevant number of occupants is no more than 20.

Comment:
This Verification Method does not provide a comprehensive guide to egress analysis, but highlights the level of rigour expected in the egress calculations. Refer to the SFPE Handbook of Fire Protection Engineering, Section 3 Chapter 13, for further details regarding egress calculation procedures, including flow transitions.

Commentary: Paragraph 3.2.5

3.2.5 The 50 person/min/door leaf is a relatively recent development in egress analysis and has appeared in the 4th edition of The SFPE Handbook section titled 'Employing the Hydraulic Model in Assessing Emergency Movement'. The reason for the cap is the impact of the door interfering with the egressing occupants. If the door is somehow held open, or does not have a self-closer, then the flow through the opening is calculated using equation 3.4 with the appropriate effective width. For the case of double doors where both doors have self-closers, the maximum possible flow would be 50 persons/min/leaf and therefore 100 persons/min in total. This is the maximum flow through a double door with or without a mullion.

Under special circumstances, the occupants may not be assumed to be evenly distributed (eg, in a *theatre* with fixed seating). In these cases, specific allowances for the flow constraints should be taken into account.

Extract from C/VM2: Paragraph 3.4

3.3 Requirements for delayed evacuation strategies

Buildings and parts of *buildings* that have occupants that are required to stay in place or where evacuation is to a *place of safety* inside the *building* (eg, where occupants may either be detained or undergoing treatment such as in an operating theatre or delivery suite) must comply with the definition of '*place of safety*'.

Comment:
As these spaces usually have a climate controlled environment, special care should be taken with the design of smoke detection and air handling system smoke control.

3.4 Alerting people with warning systems

There must be warning systems installed to NZS 4512 to alert the occupants of a *fire*.

Manual activation of a warning system shall only be permitted in a space where the average ceiling height ≥5 m, the occupants are awake and familiar with their surroundings, and where the occupant density calculation results in an *occupant load* of fewer than 50 persons. In all other situations automatic detection is required.

Where only manual systems are installed occupants are assumed to be aware of the *fire* when the ceiling jet flow has traversed the entire length of the space from a *fire* at the opposite end of the space.
No additional pre-evacuation time need be included. The time required for the ceiling jet to completely traverse the ceiling can either be determined using *CFD* modelling or by the following relationship if zone modelling is used:

For storage height ≤ 5.0 m (ultrafast fire growth):

t_d=10 + 2.4 L when L ≤ 1.4 w, and

t_d=10 + w + 1.7 L when 1.4 w < L ≤ 4 w, and

For storage height >5 m (rack growth):

t_d=25 + 1.7 L when L≤1.4 w, and

t_d=25 + w + L when 1.4 w<L≤4 w,

where:

w = width of the space in metres (shortest dimension)

L = length of the space in metres (longest dimension).

3.5 Fire modelling to determine ASET

For the *design scenario*: CF Challenging fire (see Paragraph 4.9), the designer must demonstrate that the occupants have sufficient time to evacuate the *building* before being overcome by the effects of *fire*.

In *fire* engineering terms, the *available safe egress time* (*ASET*) shall be greater than the *required safe egress time* (*RSET*).

ASET is defined as the time between ignition of the *design fire* and the time when the first tenability criterion is exceeded in a specified room within the *building*. The tenability parameters measured at a height of 2.0 m above floor level, as specified in NZBC C4.3, are:

a) Visibility

b) $FED_{(thermal)}$, and

c) $FED_{(CO)}$.

Exceptions can be applied, as outlined in NZBC C4.4 (a *building* with an automatic sprinkler system and more than 1000 people cannot be exposed to conditions exceeding the *visibility* limits or $FED_{thermal}$ limits).

Comment:
Visibility will generally be the first tenability criterion exceeded in the calculations unless any exception is applied.

Calculate the *ASET* by choosing a *fire* model and using the *design fire* as specified in Part 2.

In most cases there will be a number of locations for the *fire* that could produce the lowest *ASET* for a given *escape route*. Check a number of rooms to determine the limiting case.

Commentary: Paragraph 3.4

3.4 Applications of the Verification Method C/VM2 are dependent on the reliable predictions of the alerting time of the occupants in order to develop the *RSET* for comparison with the *ASET*. With an automatic alarm system, the alarm time becomes deterministic using the *fire* model of choice. However, predicting the activation of an alarm by manual call points can be problematic because it relies on human interaction to trigger the alarm. Initially, the intention was not to rely on manual call points within C/VM2 and only rely on automatic means of triggering an alarm. However, the use of manual call points in certain classes of *buildings* has been allowed for many years and is considered appropriate in spaces with high ceilings (≥5.0 m) and low *occupant loads* (<50 people).

Predicting human behaviour is difficult and no existing methodology for predicting manual call point activation was found in the literature. After careful deliberation, it was decided to take a pragmatic approach to estimate when it would be reasonable to assume that the *fire* was seen and manual alarm activated and familiar occupants would become aware of a *fire*. A number of approaches were considered, including: time to a critical *fire's* size; time for flames to reach the ceiling; and time for the smoke to travel the length of the *building*. After a review of the three possible criteria, it was decided to use the transport time for smoke to travel the length of the *building* as the time delay between ignition and activation of the alarm. No other *pre-travel activity time* or alarm notification time is included. Manual call point systems are simple systems and are expected to activate immediately after the call point is activated.

With a *CFD* model, it is a simple exercise to model the flow of smoke across the ceiling. A series of monitoring points at the first grid cell below the ceiling can be used to track the flow. However, for zone modelling, the transient nature of the ceiling flow is beyond the physical capability of the zone model. Not wanting to eliminate the zone model from analysing these *buildings*, a correlation for the velocity of the ceiling flow was developed.

A total of 34 *buildings* were analysed in FDS5 to develop the methodology. *Buildings* included aspect ratios from 1 x 1 to 1 x 4 with the characteristic dimensions of 20 m, 40 m and 60 m. This gave *buildings* ranging from 20 m x 20 m to 60 m x 180 m. (It was intended to run the largest *building* of 60 m x 240 m, but this proved to be too large to obtain a result in a timely manner.) There were three different *building heights* used for the *buildings*: 6.0 m, 8.0 m and 12 m. Storage height was assumed to be 1.0 m below the ceiling; ie, 5.0 m, 7.0 m and 11 m. The *fire source* was two fixed obstructions 1.0 m x 1.0 m in plan and extending from the floor to 1.0 m below the ceiling, simulating rack storage with a heat release per unit area following the storage growth rates in Table 2.1 up to the peak *HRR* of 50 MW. The *fire* was centred along one of the short walls and placed 1.0 m off the wall. The progress of the ceiling flow was tracked using *visibility* devices 0.25 m below the ceiling.

Extract from C/VM2: Paragraph 3.4

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Buildings and parts of *buildings* that have occupants that are required to stay in place or where evacuation is to a *place of safety* inside the *building* (eg, where occupants may either be detained or undergoing treatment such as in an operating theatre or delivery suite) must comply with the definition of '*place of safety*'.

Comment:
As these spaces usually have a climate controlled environment, special care should be taken with the design of smoke detection and air handling system smoke control.

3.4 Alerting people with warning systems

There must be warning systems installed to NZS 4512 to alert the occupants of a *fire*.

Manual activation of a warning system shall only be premitted in a space where the average ceiling height ≥5 m, the occupants are awake and familiar with their surroundings, and where the occupant density calculation results in an *occupant load* of fewer than 50 persons. In all other situations automatic detection is required.

Where only manual systems are installed occupants are assumed to be aware of the *fire* when the ceiling jet flow has traversed the entire length of the space from a *fire* at the opposite end of the space. No additional pre-evacuation time need be included. The time required for the ceiling jet to completely traverse the ceiling can either be determined using *CFD* modelling or by the following relationship if zone modelling is used:

For storage height ≤ 5.0 m (ultrafast fire growth):

t_d=10 + 2.4 L when L ≤ 1.4 w, and

t_d=10 + w + 1.7 L when 1.4 w < L ≤ 4 w, and

For storage height >5 m (rack growth):

t_d=25 + 1.7 L   when L≤1.4 w, and

t_d=25 + w + L   when 1.4 w<L≤4 w,

where:

w = width of the space in metres (shortest dimension)

L = length of the space in metres (longest dimension).

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In *fire* engineering terms, the *available safe egress time* (*ASET*) shall be greater than the *required safe egress time* (*RSET*).

ASET is defined as the time between ignition of the *design fire* and the time when the first tenability criterion is exceeded in a specified room within the *building*. The tenability parameters measured at a height of 2.0 m above floor level, as specified in NZBC C4.3, are:

a) Visibility

b) $FED_{(thermal)}$, and

c) $FED_{(CO)}$.

Exceptions can be applied, as outlined in NZBC C4.4 (a *building* with an automatic sprinkler system and more than 1000 people cannot be exposed to conditions exceeding the *visibility* limits or $FED_{thermal}$ limits).

Comment:
Visibility will generally be the first tenability criterion exceeded in the calculations unless any exception is applied.

Calculate the *ASET* by choosing a *fire* model and using the *design fire* as specified in Part 2.

In most cases there will be a number of locations for the *fire* that could produce the lowest *ASET* for a given *escape route*. Check a number of rooms to determine the limiting case.

Commentary: Paragraph 3.4 (continued)

The results summarised here are at the limits of the *buildings* analysed. Figure C8 shows the distance travelled by the leading edge of the ceiling flow versus time for all of the 20 m wide *buildings* for the *building* lengths ranging from 20 m to 80 m. The results show *travel distance* has two slopes indicating two different velocities during the spread. The two velocities are the result of the spread being in the radial direction in the initial stage and then becoming one dimensional after the ceiling jet reaches the side walls and the flow becomes confined. It can also be seen that the results are grouped by *building height* which correlates to the growth rate. Looking at the equations given in Paragraph 3.4, there are two sets of equations: one for storage 5.0 m and below, which has an ultra fast *fire growth* rate; and the other set of equations for storage height greater than 5.0 m, which has the 0.00068 t^3H growth rate. The 6.0 m high *building* is the slowest ceiling jet because the *fire growth* is the slowest at ultrafast. The fastest ceiling jet is the 12 m high *building* because it is the fastest growing *fire* with the rack growth rate that increases with rack height.

Figure C9 shows the distance versus time of the ceiling flow front for the 20 m x 80 m *building* for the 6.0 m and 12 m high ceilings. The results show the FDS5 result with the solid marker line and the prediction developed for C/VM2 is the unfilled marker line.
The correlation was designed with two objectives: first, to be simple to use; and secondly, to give predictions that are reasonably accurate but would not under-predict the time for the leading edge of the ceiling flow to reach the opposite wall of the warehouse.

Extract from C/VM2: Paragraph 3.4

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Comment:
Visibility will generally be the first tenability criterion exceeded in the calculations unless any exception is applied.

Calculate the *ASET* by choosing a *fire* model and using the *design fire* as specified in Part 2.

In most cases there will be a number of locations for the *fire* that could produce the lowest *ASET* for a given *escape route*. Check a number of rooms to determine the limiting case.

Commentary: Paragraph 3.4 (continued)

Figure C8 Results for all 20 m buildings

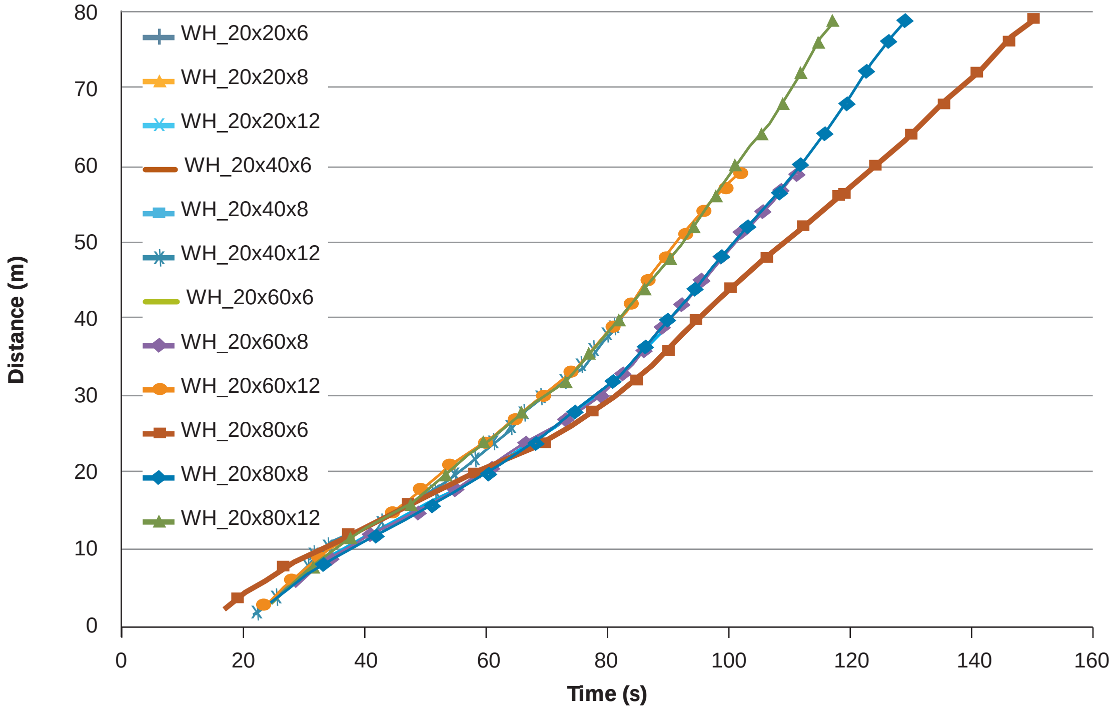
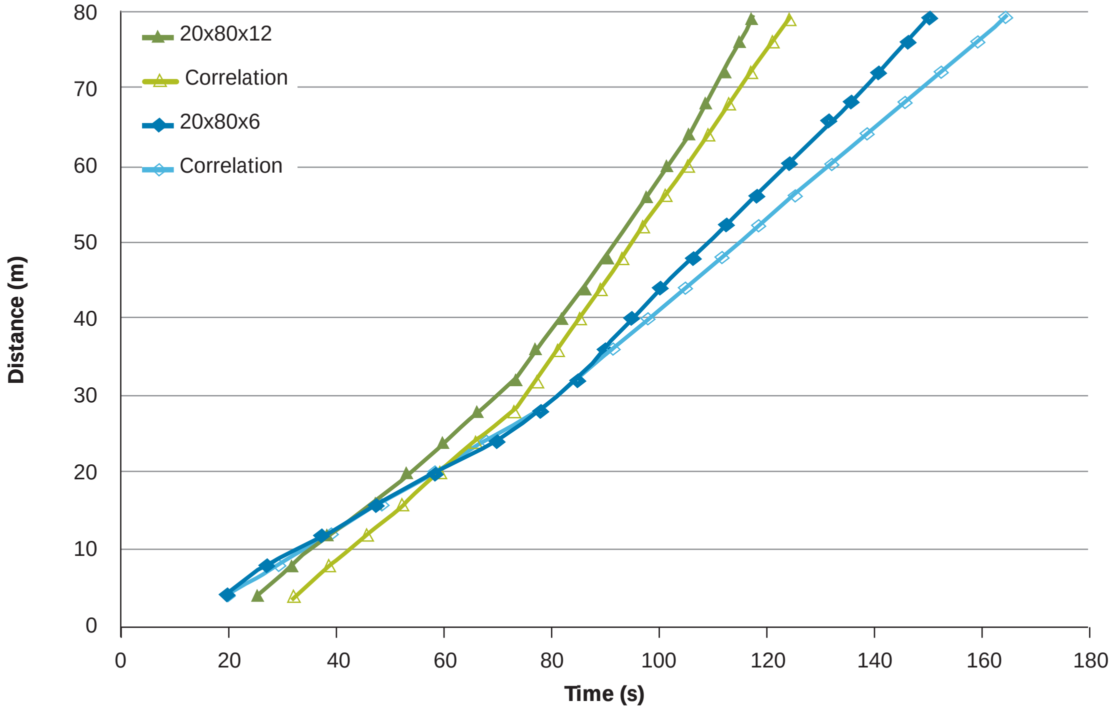


Figure C9 Comparisons between the 20 m x 80 m buildings showing the FDS result compared to the correlations



Extract from C/VM2: Paragraph 3.4

3.3 Requirements for delayed evacuation strategies

Buildings and parts of *buildings* that have occupants that are required to stay in place or where evacuation is to a *place of safety* inside the *building* (eg, where occupants may either be detained or undergoing treatment such as in an operating theatre or delivery suite) must comply with the definition of '*place of safety*'.

Comment:
As these spaces usually have a climate controlled environment, special care should be taken with the design of smoke detection and air handling system smoke control.

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Where only manual systems are installed occupants are assumed to be aware of the *fire* when the ceiling jet flow has traversed the entire length of the space from a *fire* at the opposite end of the space. No additional pre-evacuation time need be included. The time required for the ceiling jet to completely traverse the ceiling can either be determined using *CFD* modelling or by the following relationship if zone modelling is used:

For storage height ≤ 5.0 m (ultrafast fire growth):

$t_d = 10 + 2.4\,L$ when $L \le 1.4\,w$, and

$t_d = 10 + w + 1.7\,L$ when $1.4\,w < L \le 4\,w$, and

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$t_d = 25 + 1.7\,L$ when $L \le 1.4\,w$, and

$t_d = 25 + w + L$ when $1.4\,w < L \le 4\,w$,

where:

w = width of the space in metres (shortest dimension)

L = length of the space in metres (longest dimension).

3.5 Fire modelling to determine ASET

For the *design scenario*: CF Challenging fire (see Paragraph 4.9), the designer must demonstrate that the occupants have sufficient time to evacuate the *building* before being overcome by the effects of *fire*.

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b) $FED_{(thermal)}$, and

c) $FED_{(CO)}$.

Exceptions can be applied, as outlined in NZBC C4.4 (a *building* with an automatic sprinkler system and more than 1000 people cannot be exposed to conditions exceeding the *visibility* limits or $FED_{thermal}$ limits).

Comment:
Visibility will generally be the first tenability criterion exceeded in the calculations unless any exception is applied.

Calculate the *ASET* by choosing a *fire* model and using the *design fire* as specified in Part 2.

In most cases there will be a number of locations for the *fire* that could produce the lowest *ASET* for a given *escape route*. Check a number of rooms to determine the limiting case.

Commentary: Paragraph 3.4 (continued)

Figure C10 Comparisons between the 60 m x 180 m buildings showing the FDS5 result compared to the correlations

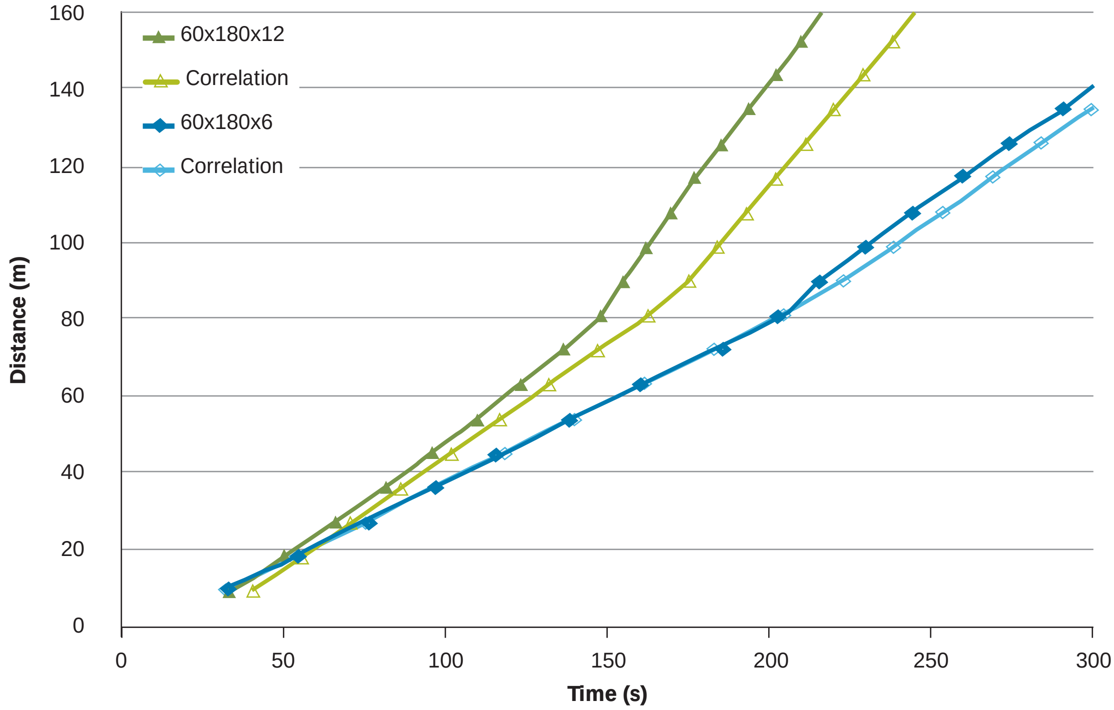

Figure C10 shows the results for the 60 m x 180 m buildings with 6.0 m and 12 m ceilings. The results are similar to those shown in Figure C9. It should be noted that a more accurate correlation could be derived. However, this would not be as simple and could lead to under-prediction under some conditions.

Limitations:

- The application of this methodology is intended for large open spaces such as warehouses where less than 10% of the floor space is separated from the larger space
- The average ceiling height shall be at least 5.0 m, and
- *Occupant load* shall be less than 50 people.

Extract from C/VM2: Paragraph 3.2.5

3.3 Requirements for delayed evacuation strategies

Buildings and parts of *buildings* that have occupants that are required to stay in place or where evacuation is to a *place of safety* inside the *building* (eg, where occupants may either be detained or undergoing treatment such as in an operating theatre or delivery suite) must comply with the definition of '*place of safety*'.

Comment:
As these spaces usually have a climate controlled environment, special care should be taken with the design of smoke detection and air handling system smoke control.

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There must be warning systems installed to NZS 4512 to alert the occupants of a *fire*.

Manual activation of a warning system shall only be permitted in a space where the average ceiling height ≥5 m, the occupants are awake and familiar with their surroundings, and where the occupant density calculation results in an *occupant load* of fewer than 50 persons. In all other situations automatic detection is required.

Where only manual systems are installed occupants are assumed to be aware of the *fire* when the ceiling jet flow has traversed the entire length of the space from a *fire* at the opposite end of the space. No additional pre-evacuation time need be included. The time required for the ceiling jet to completely traverse the ceiling can either be determined using *CFD* modelling or by the following relationship if zone modelling is used:

For storage height ≤ 5.0 m (ultrafast fire growth):

t_d=10 + 2.4 L when L ≤ 1.4 w, and

t_d=10 + w + 1.7 L when 1.4 w < L ≤ 4 w, and

For storage height >5 m (rack growth):

t_d=25 + 1.7 L when L≤1.4 w, and

t_d=25 + w + L when 1.4 w<L≤4 w,

where:

w = width of the space in metres (shortest dimension)

L = length of the space in metres (longest dimension).

3.5 Fire modelling to determine ASET

For the *design scenario*: CF Challenging fire (see Paragraph 4.9), the designer must demonstrate that the occupants have sufficient time to evacuate the *building* before being overcome by the effects of *fire*.

In *fire* engineering terms, the *available safe egress time* (*ASET*) shall be greater than the *required safe egress time* (*RSET*).

ASET is defined as the time between ignition of the *design fire* and the time when the first tenability criterion is exceeded in a specified room within the *building*. The tenability parameters measured at a height of 2.0 m above floor level, as specified in NZBC C4.3, are:

a) Visibility

b) $FED_{(thermal)}$, and

c) $FED_{(CO)}$.

Exceptions can be applied, as outlined in NZBC C4.4 (a *building* with an automatic sprinkler system and more than 1000 people cannot be exposed to conditions exceeding the *visibility* limits or $FED_{thermal}$ limits).

Comment:
Visibility will generally be the first tenability criterion exceeded in the calculations unless any exception is applied.

Calculate the *ASET* by choosing a *fire* model and using the *design fire* as specified in Part 2.

In most cases there will be a number of locations for the *fire* that could produce the lowest *ASET* for a given *escape route*. Check a number of rooms to determine the limiting case.

Commentary: Paragraph 3.5

3.5 The *ASET* versus *RSET* analysis is applied in assessing the Design Scenario (CF): Challenging fire (see Verification Method C/VM2 Paragraph 4.9). The engineer shall select a suitable number of cases for analysis commensurate with the size and complexity of the *building* and as agreed with the *building consent authority* during development of the Fire Engineering Brief. Factors to consider when selecting the *design fire* include the likely *fire growth* rate, number of occupants exposed in the room of origin, other occupants outside the room of origin and area and height of the spaces.

Extract from C/VM2: Paragraph 3.6.1

3.6 Exposure to radiation along egress routes

3.6.1 General

When occupants located within an *exitway* or on an external *escape route* must egress past a window opening or glazed panel, they must not be exposed to a radiation level which will cause pain while evacuating. Therefore, the time to onset of pain (t_p) must be longer than the exposure time (t_{exp}).

The limitations for the analysis are as follows:

a) The analysis requires that all occupants must have evacuated past the window opening or glazed panel within 10 minutes after ignition unless *fire resisting glazing* tested to a recognised national or international Standard is used.

b) The maximum allowable radiation level that an occupant can be exposed to is 10 kW/m².

c) The analysis described here is only applicable for a single window. Multiple windows require more detailed analysis on the time to pain calculations where the time-dependent cumulative effect of the radiation can be accounted for (such procedures can be found in the SFPE Engineering Guide – Predicting 1st and 2nd Degree Skin Burns from Thermal Radiation).

d) Analysis is not appropriate where occupants are likely to be mobility-impaired.

e) Radiation through uninsulated *fire resisting glazing* can be reduced by 50% (see k=0.5 in equation 3.6 below).

f) Analysis is not required where an alternative *escape route* is available.

g) Analysis is not required where insulated glazing with *fire* resistance of not less than -/30/30 is used.

h) Analysis is not required for sprinklered *buildings* with window wetting sprinklers located on the same side of the window as the *fire* and designed and installed for that specific purpose.

i) Analysis is not required during the period prior to *ASET* for the room of fire origin.

j) Any part of the window or glazed panel that is openable must be fitted with a self-closer or other device that automatically closes the opening on detecting smoke or heat.

3.6.2 Time to onset of pain

The time to onset of pain shall be determined using equation 3.5.

$$t_p = \left(\frac{35}{\dot{q}''_r}\right)^{1.33} \qquad \text{Equation 3.5}$$

where:

t_p = time required for pain (s), and

$\dot{q}''_r$ = maximum incident thermal radiation (kW/m²)

3.6.3 Radiation from a window to an egressing occupant

The maximum incident thermal radiation occurs opposite the centre of the window or glazing, at a height of 2.0 m or mid-height of the glazing whichever is the lower height, and can be calculated using equation 3.6:

$$\dot{q}''_r = F_W \, \varepsilon k \dot{q}''_w \qquad \text{Equation 3.6}$$

where:

$\dot{q}''_w$ = design emitted heat flux from the window. This shall be taken as:

a) 83 kW/m² for *FLED* (from Table 2.3) 400 MJ/m²

b) 103 kW/m² for *FLED* (from Table 2.3) between 400 and 800 MJ/m², and

c) 144 kW/m² for *FLED* (from Table 2.3) greater than 800 MJ/m².

and

ε = emissivity of the *fire* gases (shall be taken as 1.0)

k = glazing factor (=0.5 for *fire resisting glazing*; =1.0 for all other glazing)

F_W = view factor from a window or glazing to a point opposite the centre of the window or glazing, at a height of 2.0 m or mid-height of the glazing whichever is the lower height, and at a distance corresponding to the nearest part of the required *escape route*.

Commentary: Paragraph 3.6.1

3.6.1 The basic premise of this analysis is to demonstrate that an occupant egressing past a window opening is able to travel past the window without feeling pain from the thermal energy being emitted from the window. The analysis makes use of equation 3.7 to determine the time taken to experience pain when exposed to a given heat flux. The radiation is calculated using equation 3.6 to determine the maximum heat flux the occupant is exposed to when they are directly opposite the window and the distance where the emitting radiation from the window has dropped below 2.5 kW/m^2.

Example:

In this example, we find the minimum safe separation distance from a window 2.0 m wide and 1.0 m high to an egressing occupant. The *FLED* is assumed to be <400 MJ/m^2 so the emitting radiation level is taken as 83 kW/m^2. (This example is intended to show the process and not to teach radiation heat transfer.) The analysis requires the engineer to carry out a number of view factor calculations, making use of the additive nature of view factors. The problem is solved either by trial and error or by using a 'Goal Seeking' algorithm in a spreadsheet.

The minimum separation distance from window to the egressing occupant is based on the maximum allowable heat flux of 10 kW/m^2. Depending on the size of the window and the path of travel, the minimum safe *travel distance* may be greater than the minimum separation distance required to keep the exposing heat flux less than 10 kW/m^2.

The 'trial and error solution' to equation 3.6 shows that when s = 2.12 m the exposing heat flux from a 2.0 m wide x 1.0 m high window is 9.96 kW/m^2. Equations 3.5 and 3.6 are solved below to demonstrate the process:

X=1/(2*2.12)=0.236 Y=2/(2*2.12)=0.472

$$F_w = \frac{2}{\neq} \frac{0.236}{\sqrt{1+0.236^2}} \tan^1 \frac{0.472}{\sqrt{1+0.236^2}} + \frac{0.472}{\sqrt{1+0.472^2}} \tan^1 \frac{0.236}{\sqrt{1+0.472^2}}$$

F_w = 0.12

which gives a heat flux of:

q_{rad} = 0.120(83) = 9.96 kW/m^2 <10kW/m^2 OK.

The total distance (D) that the occupant must travel is equal to twice the distance (d) from the edge of the window to where heat flux drops below 2.5 kW/m^2 plus the width of the window (w). Equation 3.7 is used to find that d = 1.45 m. The calculation of d also requires a trial and error solution or 'Goal Seek Function' in a spreadsheet or other program.

Extract from C/VM2: Paragraph 3.7

3.6.4 Exposure time

The exposure time (t_{exp}) is determined by calculating the distance (D) the occupant must travel while exposed to radiation from the window or glazed panel and assuming a travel speed of 1.0 m/s. The occupant is assumed to be exposed as long as their exposure to the incident thermal radiation is greater than 2.5 kW/m^2. The exposure time for the occupant is the *travel distance* required to pass the window, divided by the walking speed as shown in equation 3.7, below:

$$t_{exp} = \frac{D}{V} \qquad \text{Equation 3.7}$$

where:

t_{exp} = the time an occupant is exposed to the radiation (s)

V = travel speed (=1 m/s), and

D = the distance the occupant must travel while exposed to incident thermal radiation of at least 2.5 kW/m^2 from the window or glazing (m).

3.7 Egress past a burning object

3.7.1 Radiation from a burning object to an egressing occupant

Radiation calculations from a burning object can be approximated using the point source model with fixed radiation fraction as given in equation 3.8:

$$\dot{q}''_r = \frac{0.45\,\dot{q}_{Fire}}{4\pi r^2} \qquad \text{Equation 3.8}$$

where:

$\dot{q}''_r$ = radiation flux at a distance r from the fire occupant (kW/m^2)

$\dot{q}_{Fire}$ = total *heat release rate* from the fire (kw)

and

r = radial distance from the *fire* to the egressing occupant (m).

Limitation:

Average upper layer temperature within the *fire* compartment must not have exceeded 150˚C.

Commentary: Paragraph 3.6.1 (continued)

Time to pain:

$$t_p = {\frac{35}{9.96}}^{1.33} = 5.3s$$

Time exposed:

$$t_{exp} \quad \frac{2 + 2 * 1.45}{1m / s} \quad = 4.9s$$

As $t_p > t_{exp}$, the design is acceptable.

Commentary: Paragraph 3.7

3.7 As for the analysis described in the commentary for Paragraph 3.6.2, equation 3.8 is used instead of equations 3.5 and 3.6.

4. Design scenarios
Verification Method C/VM2

Extract from C/VM2: Part 4: Design scenarios

Part 4: Design scenarios

CONTENTS

Comment:
References in the *design scenarios* to C1(a), C4.5 etc are to clauses within NZBC C1 to C6: Protection from Fire. The relevant *Building Code* clauses are included in full in *italic* at the start of each scenario for ease of reference.

Commentary: Section 4

There are ten different *design scenarios* to be assessed. These are partly based on the scenarios in NFPA 5000, but have been modified and expanded to cover *fire* spread to neighbouring property, external vertical *fire* spread, interior surface linings and firefighting facilities. The scenarios are intended to provide a diverse range of *fire* events that will challenge the design and *fire safety systems* in the *building*.

Note

References in the *design scenarios* to C1(a), C4.5 and so on are to clauses within NZBC C1 to C6: Protection from Fire. The relevant Code clauses are included in full at the start of each scenario for ease of reference.

Extract from C/VM2: Paragraph 4.1

4.1 Design scenario (BE): Fire blocks exit

Scenario in brief	A *fire* starts in an *escape route* and can potentially block an exit.
Code objective	*C1(a) Safeguard people from an unacceptable risk of injury or illness caused by fire.*
What you must satisfy	C4.5 by providing a viable *escape route* or routes for *building* occupants in the event of *fire*. *C4.5 Means of escape to a place of safety in buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety systems*.
Outcome required	Demonstrate that a viable *escape route* (or multiple routes where necessary) has been provided for *building* occupants.

Scenario description

This scenario addresses the concern that an *escape route* may be blocked due to proximity of the *fire source*. In this event, the number of exits and total exit width must be sufficient for occupants to escape before *ASET* is reached.

This scenario applies to *escape routes* serving more than 50 people.

Exception: this scenario does not apply to vertical stair enclosures serving not more than 150 people *fire separated* from all other parts of a *building* or, if the *building* is sprinkler protected, serving not more than 250 people.

Single *escape routes* are permitted to serve up to 50 people.

For each room/space within the *building* (accommodating more than 50 people), assume that the *fire source* is located near the primary *escape route* or exit and that it prevents occupants from leaving the *building* by that route. *Fire* in *escape routes* can be the result of a deliberately lit *fire* or accidental. *Fire* originating within an *escape route* will be considered to be a severe *fire* applicable to the particular *building* use as described in the *design scenario*: CF Challenging fire (see Paragraph 4.9).

In order to be regarded as alternative *escape routes*, the routes shall be separated from each other and shall remain separated until reaching a *final exit*. Separation shall be achieved by diverging (from the point where two *escape routes* are required) at an angle of no less than 90° until separated by:

a) a distance of at least 8.0 m when up to 250 occupants are required to use the *escape routes* or at least 20 m when more than 250 occupants are required to use the *escape routes*; or

b) *Smoke separations* and *smoke control doors.*

Active and passive *fire safety systems* in the *building* shall be assumed to perform as intended by the design.

Comment:
The engineer needs to consider *fire source* locations that prevent the use of exits in *escape routes*.

Fire characteristics (eg, *HRR*) and analysis need not be considered in this scenario, as the *fire* is assumed to physically block the exit. It may be assumed that occupant tenability criteria cannot be met where *fire* plumes and flame block an exit.

Method

The requirements of this scenario can be demonstrated by analysis that is limited to checking whether or not a second exit is required.

Commentary: Paragraph 4.1

This scenario requires the engineer to consider the possibility of an *escape route* being impassable due to the proximity of the *fire source*, and therefore to ensure that alternative routes are available to the occupants. The scenario need only be considered where *escape routes* serve more than 50 persons.

The limit of 50 persons able to be served by a single *escape route* (or *dead end open path*) is largely historical and is consistent with the previous Acceptable Solution C/AS1 (2011).

A single *fire separated* stair (*safe path*) in a multi-storey *building* may serve:

- up to 150 people, or
- up to 250 people as long as the *building* is sprinklered and there are no more than 50 people per level.

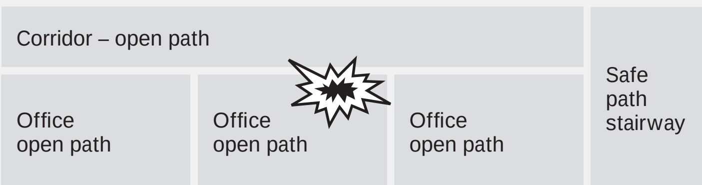
This means that, for an unsprinklered *building* with up to 50 people per level, the maximum number of storeys able to be served by a single stair is four (assuming the ground floor occupants do not use the stair). If the same *building* were sprinklered, the maximum number of storeys would increase to six. These limits, and hence the number of people able to be served by a *safe path stairway*, are also consistent with those permitted in Acceptable Solution C/AS1 (2011).

As this scenario is concerned with the location of the *fire* physically obstructing an exit, a tenability analysis of the *exitway* is not a solution. A *fire* in the *exitway* could be a deliberately lit *fire* involving introduced fuels, such as a mattress. This scenario would not allow single exit *buildings* with more than 50 people per floor level and 200 people in total over four levels (ie, 150 people served by a single *stairway* serving three upper levels, and ground floor with a further 50 people).

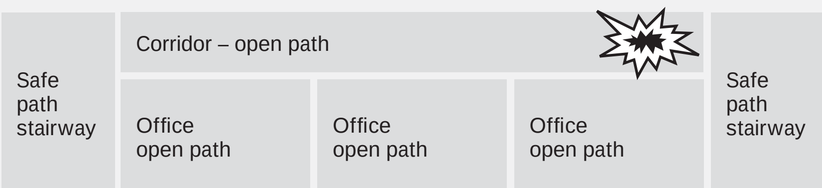
Example:

A building has three adjoining office spaces. The number of people that can occupy the individual rooms or use the *building* overall determines its exit requirements.

If there are more than 50 people in any of the three offices, then Design Scenario BE applies and a second exit from that office will be required.



If the corridor serves more than 50 people, this scenario applies and a second stair will be needed.



Extract from C/VM2: Paragraph 4.2

4.2 Design scenario (UT): Fire in normally unoccupied room threatening occupants of other rooms

Scenario in brief	A *fire* starts in a normally unoccupied room and can potentially endanger a large number of occupants in another room.
Code objective	*C1(a) Safeguard people from an unacceptable risk of injury or illness caused by fire.*
What you must satisfy	The performance criteria of C4.3 and C4.4 for any *buildings* with rooms or spaces that can hold more than 50 people. This may require analysis. *C4.3 The evacuation time must allow occupants of a building to move to a place of safety in the event of fire so that occupants are not exposed to any of the following:* *a) a fractional effective dose of carbon monoxide greater than 0.3;* *b) a fractional effective dose of thermal effects greater than 0.3;* *c) conditions where, due to smoke obstruction, visibility is less than 10 m except in rooms of less than 100 m^2 where visibility may fall to 5.0 m.* *C4.4 Clause C4.3 (b) and (c) do not apply where it is not possible to expose more than 1,000 occupants in a firecell protected with an automatic fire sprinkler system.*
Required outcome	Demonstrate *ASET>RSET* for any rooms or spaces that can hold more than 50 people given a *fire* occurs in the normally unoccupied space. Solutions might include the use of *separating elements* or *fire* suppression to confine the *fire* to the room of origin.

Scenario description

This *design scenario* only applies to *buildings* with rooms or spaces that can hold more than 50 occupants that could be threatened by a *fire* occurring in another normally unoccupied space. It does not need to be satisfied for any other rooms or spaces in the *building*.

A *fire* starting in an unoccupied space can grow to a significant size undetected and then spread to other areas where large numbers of people may be present. This scenario is intended to address the concern regarding a *fire* starting in a normally unoccupied room and then migrating into the space(s) that can potentially hold large numbers of occupants in the *building*.

The analysis shall assume that the target space containing the people is filled to capacity under normal use. For analysis, select a *design fire* as described in Part 2 for the applicable occupancy.

Active and passive *fire safety systems* in the *building* shall be assumed to perform as intended by the design.

Method

Either:

a) Carry out *ASET/RSET* analysis to show that the occupants within target spaces are not exposed to untenable conditions, or

b) Include *separating elements* or *fire* suppression to confine the *fire* to the room of origin. If *separating elements* are used the *FRR* shall be based on the following design criteria.

   i) If no automatic *fire* detection is installed in the space of *fire* origin, separating elements shall have *fire* resistance to withstand a full *burnout fire* (see Paragraph 2.4).

   ii) If automatic *fire* detection is installed in the space of *fire* origin, *separating elements* shall either:

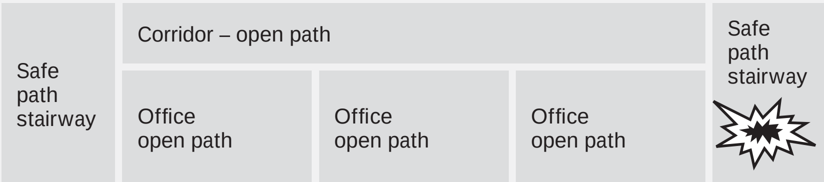
      A) Have a *fire resistance rating* of not less than 60 minutes (-/60/60), or

      B) Demonstrate the *separating elements* will be effective for the period from ignition to the time when the *occupied space* (target space) is evacuated.

Commentary: Paragraph 4.1 (continued)

If a *stairway* serves more than 150 people, a second *stairway* will be needed. This allows up to four storeys (unsprinklered) with a maximum of 50 people per level, assuming the ground floor occupants do not escape through the *stairway*.

If the *stairway* serves more than 250 people and the *building* is sprinklered, a second *stairway* will be needed. This allows up to six storeys with a maximum of 50 people per level, assuming the ground floor occupants do not escape through the *stairway*.



Commentary: Paragraph 4.2

Building rooms or spaces that can be considered ‘normally unoccupied’ are those spaces where people are not usually found. These can include store rooms, plant rooms, other *building* services rooms and cleaners’ utility cupboards. They do not include rooms such as kitchenettes, toilets, staff rooms or meeting rooms.

If the unoccupied space is *fire separated* from the rest of the *building* and has *fire* resistant *construction* specified to withstand *burnout*, the *ASET/RSET* analysis of the adjacent space accommodating the occupants should either be unnecessary or simple to demonstrate.

If the unoccupied space is not *fire separated*, it will be necessary to show that the *ASET* for occupants in rooms/spaces holding more than 50 occupants is greater than the *RSET*. Automatic detection in the unoccupied space may be needed to ensure *ASET>RSET*.

When calculating the *RSET* in an analysis for this scenario, manual methods for detection for the *fire* in the room of origin shall not be relied on. At least an automatic *fire* detection system is required in the unoccupied space if it is not *fire separated* from the target ‘occupied’ room.

Extract from C/VM2: Paragraph 4.3

4.3 Design scenario (CS): Fire starts in a concealed space

Scenario in brief	A *fire* starts in a *concealed space* that can potentially endanger a large number of people in another room.
Code objective	*C1(a) Safeguard people from an unacceptable risk of injury or illness caused by fire*.
What you must satisfy	For any *buildings* with rooms holding more than 50 people and with *concealed spaces*, ensure that *fire* spread via *concealed spaces* will not endanger the *building* occupants. This will not require analysis.
Required outcome	Demonstrate that *fire* spread via *concealed spaces* will not endanger occupants located in rooms/spaces holding more than 50 people. This scenario is deemed to be satisfied by the use of *separating elements*, automatic detection or suppression.

Scenario description

This *design scenario* only applies to *buildings* with rooms holding more than 50 occupants and with *concealed spaces*. It does not apply if the *concealed space* has no *combustibles* (other than timber framing) and no more than two dimensions (length, width or depth) greater than 0.8 m.

A *fire* starting in a *concealed space* can develop undetected and spread to endanger a large number of occupants in another room. This scenario addresses a concern regarding a *fire*, originating in a non-separated *concealed space* without either a detection system or suppression system, and spreading into any room within the *building* that can, potentially, hold a large number of occupants.

Assume that active and passive *fire safety systems* in the *building* perform as intended by the design.

Comment:
Fire spreading in *concealed spaces* may also compromise the ability of firefighters to assess the threat to themselves whilst undertaking rescue and firefighting operations.

Method

Due to the difficulty in modelling *fire* spread within *concealed spaces*, it is expected that traditional solutions will apply here (ie, containment, detection or suppression.)

The expected methodology is to either:

a) Use *separating elements* (*cavity barriers*) or suppression to confine *fire* to the *concealed space*, or

b) Include automatic detection of heat or smoke to provide early warning of *fire* within a *concealed space*.

Separating elements (*cavity barriers*) in *concealed spaces* without a means of automatic *fire* detection shall have a *fire resistance rating* of not less than 30 minutes (-/30/30) and the *concealed space* shall not have an area greater than 500 m^2.

Commentary: Paragraph 4.3

Concealed spaces can occur in a range of sizes and types. They include floor plenums for IT cables, ceiling plenums, service shafts and curtain wall cavities. There are also a range of possible ignition sources and fuel types.

Quantitative analysis is not expected for this scenario. The use of *fire separations*, automatic detection or suppression may be taken as solutions to satisfy the requirements.

Extract from C/VM2: Paragraph 4.4

4.4 Design scenario (SF): Smouldering fire

Scenario in brief	A fire is smouldering in close proximity to a sleeping area.
Code objective	*C1(a) Safeguard people from an unacceptable risk of injury or illness caused by fire.*
What you must satisfy	For *buildings* with a sleeping use, ensure that there are automatic means of smoke detection and alarm complying with a recognised national or international Standard for occupants who may be sleeping.
Required outcome	Provide an automatic smoke detection and alarm system throughout the *building* that has been designed and installed to a recognised national or international Standard.

Scenario description

This scenario addresses the concern regarding a slow, smouldering *fire* that causes a threat to sleeping occupants. Assume that active and passive *fire safety systems* in the *building* perform as intended by the design.

Method

Provide an automatic smoke detection and alarm system throughout the sleeping spaces, designed and installed to a recognised national or international Standard. No further analysis is expected.

Commentary: Paragraph 4.4

This scenario ensures that, in spaces where occupants are sleeping, automatic detection is provided.

Extract from C/VM2: Paragraph 4.5

4.5 Design scenario (HS): Horizontal fire spread

Scenario in brief	A fully developed *fire* in a *building* exposes the *external walls* of a neighbouring *building* or *firecell*.
Code objectives	*C1(b) Protect other property from damage caused by fire.*
What you must satisfy	The performance criteria in C3.6 and C3.7. This will require calculation. C4.2 is to be considered in relation to horizontal *fire* spread across a *notional boundary* to sleeping occupancies and *exitways* in *buildings* under the same *ownership*. *C3.6 Buildings must be designed and constructed so that in the event of fire in the building the received radiation at the relevant boundary of the property does not exceed 30 kW/m² and at a distance of 1 m beyond the relevant boundary of the property does not exceed 16 kW/m².* *C3.7 External walls of buildings that are located closer than 1 m to the relevant boundary of the property on which the building stands must either:* *a) be constructed from materials which are not combustible building materials, or* *b) for buildings in Importance levels 3 and 4 be constructed from materials that, when subjected to a radiant flux of 30 kW/m², do not ignite for 30 minutes, or* *c) for buildings in Importance levels 1 and 2, be constructed from materials that, when subjected to a radiant flux of 30 kW/m², do not ignite for 15 minutes.* *C4.2 Buildings must be provided with means of escape to ensure that there is a low probability of occupants of those buildings being unreasonably delayed or impeded from moving to a place of safety and that those occupants will not suffer injury or illness as a result.*
Required outcome	Demonstrate that the criteria in C3.6 and C3.7 are not exceeded by calculating the radiation from *unprotected areas* in the *external wall* to the closest point on an adjacent *boundary* and at 1.0 m beyond an adjacent *boundary*, and specifying exterior cladding materials with adequate resistance to ignition Control horizontal *fire* spread across a *notional boundary* to sleeping occupancies and *exitways* in *buildings* under the same *ownership*.

Comment:
NZBC C3.6 applies to all *buildings* except those with an automatic sprinkler system with two independent water supplies, one of which is not dependent on town mains and not used for storage above 3.0 m.

The performance requirements of C3.6 are also to be applied to limit the radiation at the *notional boundary* to sleeping occupancies and *exitways* in *buildings* under the same *ownership*. This partially contributes to the achievement of the functional requirement C4.2.

Scenario description

A fully developed *fire* in a *building* exposes the *external walls* of a neighbouring *building* (*other property*) or *firecell* (sleeping occupancy or *exitway*).

This scenario addresses a *fire* in a *building* that leads to high levels of radiation heat exposure across a *relevant boundary*, potentially igniting the *external walls* of a neighbouring *building*.

The potential for any *firecell* to expose *other property* shall be evaluated. However, the area beneath a canopy roof does not need to be assessed as a source of external *fire* spread if all the following conditions apply:

a) The nearest distance between any part of the canopy and the *relevant boundary* is not less than 1.0 m, and

b) The average *FLED* applying to the area beneath the canopy is not greater than 400 MJ/ m², and

c) The canopy has at least 50% of the perimeter area open to the outside.

The *design fire* for this scenario comprises an assumed emitted radiation flux from *unprotected areas* in *external walls* of the *fire source building* (assuming no intervention). This shall be taken as:

d) 83 kW/m² for *FLED* $\leq$400 MJ/m²

e) 103 kW/m² for *FLED* between 400 and 800 MJ/m², and

f) 144 kW/m² for *FLED* greater than 800 MJ/m².

Commentary: Paragraph 4.5

A large *fire* within a *building* may spread to neighbouring *buildings* as a result of heat transfer, predominantly by radiation through openings in *external walls*. To reduce the probability of *fire* spread between neighbouring properties, measures are set to limit the radiation flux received by the neighbouring *building*.

There are two parts to this scenario:

a) A fire occurs in your building: any *unprotected area* in its *external walls* would allow the neighbouring property to be subjected to radiation. This *unprotected area* must be limited to reduce that radiation to a safe level.
b) A fire occurs in a neighbouring building: your *building's external walls* may be subjected to radiation, so they must have some resistance to ignition depending on their distance from the *boundary*.

Both parts of this scenario work together as, by ensuring *external walls* within 1.0 m of a *relevant boundary* are more resistant to ignition, it becomes possible to allow a higher level of radiation to be received both on the *boundary* and on the surface of the *external wall* and therefore to reduce costs.

This approach to determining safe distances to a *relevant boundary*, known as the limiting distance method, is the basis of the requirements in Acceptable Solutions C/AS1 to C/AS7. The background to this methodology is explained in detail in a 2002 conference paper by Barnett and Wade.

Note that the design values for radiant flux given in this scenario and other assumptions implicit in the limiting distance method do not guarantee that *fire* spread will be prevented in all situations. In particular, they assume:

- no flame projection from openings
- cladding properties represent timber with 15% moisture content
- there is limited duration of exposure, and
- *fire* gas temperatures following a standard time-temperature curve.

As these may not be the most conservative cases, it is anticipated that, in some instances, the Fire Service may also be called upon to provide a secondary means to prevent *fire* spread. This is covered by the Design Scenario FO: Firefighting operations (see Verification Method C/VM2 Paragraph 4.8).

The maximum allowable received radiation on the *boundary* of 30 kW/m^2 recognises that the *construction* of the *external walls* within 1.0 m of the *relevant boundary* must meet separate criteria for ignitability as required by NZBC C3.7. Therefore, the material can be expected to be able to withstand an exposure of 30 kW/m^2 at least until the Fire Service has arrived, providing additional resources to prevent *fire* spread across the *boundary*.

Extract from C/VM2: Paragraph 4.5

Emissivity of *fire* gases shall be taken as 1.0.

For unsprinklered *buildings*, the width of the enclosing rectangle need be no greater than 20 m for *FLED* up to and including 800 MJ/m^2, or no greater than 30 m for *FLED* greater than 800 MJ/m^2. The actual width of the enclosing rectangle shall be used if it is less than 20 m.

If a *firecell* is not used for storage above 3.0 m and with an automatic sprinkler system supplied by two independent water supplies, one of which is not dependent on town mains, there are no restrictions on the amount of *unprotected area* and the *fire* engineer does not need to assess the external *fire* spread to the *boundary*.

In other *firecells* with an automatic sprinkler system, the maximum *unprotected area* permitted for an unsprinklered *firecell* can be doubled. Alternatively, if the *firecell* is not used for storage, you can consider:

a) The height of the enclosing rectangle as the vertical distance between the floor and the ceiling level beneath which the sprinklers are installed in the area adjacent to the *external wall* facing the *relevant boundary*, and

b) The width of the enclosing rectangle as the square root of the design maximum area of sprinkler operation (the actual width of the enclosing rectangle may be used if it is less).

The *fire* engineer only needs to consider one *firecell* at a time as a potential source of thermal radiation.

Unprotected area shall include both unrated *external wall construction* as well as any unrated window/door assemblies and other openings. Areas of the *external wall* that are not designated as *unprotected area* shall have a *fire resistance rating* (meeting both *integrity* and *insulation* criteria) sufficient to resist the full *burnout design fire* described in Paragraph 2.4. Furthermore, the structural system supporting those parts of the *external wall* not permitted to be unprotected must also have sufficient *fire* resistance to resist the full *burnout design fire*, and keep the *external wall* in place.

Unprotected area is not permitted within 1.0 m of a *relevant boundary*, except for a combination of small *unprotected area* and/or *fire resisting glazing* as described in Acceptable Solutions C/AS2 to C/AS6 Paragraph 5.4 or in the commentary document for this Verification Method.

Method

Calculate radiation from *unprotected areas* in the *external wall* to the closest point on an adjacent *boundary* and at 1.0 m beyond an adjacent *boundary*. The calculations must take into account:

a) The distance to the *boundary*, and

b) The size/shape of the *unprotected area* in the *external walls*, assuming the emitted radiant heat flux specified above for the applicable *FLED* range.

Alternatively, use the tabulated values of the maximum percentage of permitted *unprotected area* directly from Acceptable Solutions C/AS2 to C/AS6 as appropriate, or as provided in the commentary for this Verification Method.

The tables in the commentary document along with additional tables for *fire resisting glazing* and return and/or wing walls have been produced in accordance with this Verification Method. These tables can be used directly for unsprinklered *firecells* as long as *external walls* are parallel to, or angled at no more than, 10° to the *relevant boundary* and are no closer than 1.0 m to the *relevant boundary*.

For *external walls* at greater angles to the *relevant boundary*, appropriate calculations shall be undertaken to demonstrate that the performance criteria are achieved and minimum dimensions shall be specified for return and/or wing walls as necessary or use tables as provided in the commentary document.

To demonstrate that NZBC C3.7 is achieved, it is expected that relevant *fire* test results for the selected cladding system will be provided. Engineers may also choose to comply with Paragraph 5.8 of the relevant Acceptable Solutions C/AS2 to C/AS6 to satisfy the performance criteria of this clause.

Commentary: Paragraph 4.5 (continued)

Beyond 1.0 m across the *relevant boundary*, this Verification Method does not restrict the materials that may be used on the *external wall*. Therefore, the maximum allowable received radiation at these locations is set at a lower value of 16 kW/m^2. This value may not necessarily be low enough to prevent ignition or damage to all cladding materials: again, it is anticipated that the Fire Service will provide a secondary means of preventing *fire* spread in these cases if required.

While it is not possible to give a complete guarantee of timely Fire Service intervention, the history of past *fires* indicates that the risk of *fire* spread to adjacent property is small but not insignificant (approximately 3% of all structure *fires*, according to NZFS Emergency Incident Statistics 2005-2010). The maximum received radiation value at 1.0 m beyond the *boundary* has been fixed at 16 kW/m^2. Previously higher values (17–18 kW/m^2) were permissible depending on the *FLED*. Therefore, the present value is slightly more conservative compared to recent past practice.

It is considered that a *fire* sprinkler system with two independent supplies, but only one of which may be dependent on a town's main, has a very high degree of reliability so that the sprinkler system alone can be relied upon to satisfy NZBC C3.6.

Combustibility of materials can be assessed using AS 1530 Part 1 or ISO 1182. Brick, concrete or steel are *non-combustible*.

Time to ignition of cladding materials can be determined using ISO 5660 or AS/NZS 3837 in the presence of a spark igniter. This is a new requirement for product testing. Ordinary non *fire retardant* treated timber claddings are expected to ignite in less than 15 minutes when exposed to 30 kW/m^2 in the ISO 5660 *fire* test and would not meet the performance criteria in NZBC C3.7 for *external walls* located closer than 1.0 m to the *relevant boundary*.

External walls designated as *importance levels* 3 and 4 are expected to be able to withstand a more severe thermal exposure from a *fire* in a neighbouring *building*, commensurate with the need to minimise any interruption to the ongoing functioning of the *building* in the event of *fire*.

The emitted heat fluxes are the same as those assumed in Acceptable Solutions C/AS1 to C/AS7, but are slightly less than the previous Acceptable Solution C/AS1 (2011), since emissivity has been increased from 0.95 to 1.0 giving the same overall incident radiation at a given distance. The exposure is intended to correspond to the expected emitted radiation from *fire* gases at a temperature reached in a standard *fire* resistance test (ie, AS 1530.4) after periods of 30, 45 or 90 minutes depending on the *FLED*.

In practice, the actual gas temperatures in the *fire* may be different from that in the standard *fire* resistance test. While the *fire* engineer may choose a different emitted radiation value, this value should not be less than those given in Verification Method C/VM2.

Extract from C/VM2: Paragraph 4.6

4.6 Design scenario (VS): Vertical fire spread involving external cladding

Scenario in brief	A *fire source* exposes the *external wall* and leads to significant vertical *fire* spread.
Code objectives	*C1(a) Safeguard people from an unacceptable risk of injury or illness caused by fire.* *C1(b) Protect other property from damage caused by fire.*
What you must satisfy	The performance criteria of C3.5 (ie, if *buildings* are taller than 10 m or have upper floors that are *other property* or contain people sleeping, *fire* shall be prevented from spreading more than 3.5 m vertically) so that: • tenable conditions are maintained on *escape routes* until the occupants have evacuated, and • vertical *fire* spread does not compromise the safety of firefighters working in or around the *building*. *C3.5 Buildings must be designed and constructed so that fire does not spread more than 3.5 m vertically from the fire source over the external cladding of multi-level buildings.*
Required outcome	Demonstrate that the *building's* external claddings do not contribute to excessive vertical *fire* spread using one of the methods described.

Scenario description

This *design scenario* applies to:

a) All *buildings* with a *building height* of more than 10 m, and

b) Any other *buildings* with upper floors where people sleep or are defined as *other property*.

Comment:
This scenario is not concerned with *building*-to-*building fire* spread across a *relevant boundary*, as this is addressed in the *design scenario*: HS (see Paragraph 4.5).

The *design fire* for this scenario shall be a *fire source* that is either:

a) In close contact with the façade (eg, in a rubbish container/skip) that could ignite and spread *fire* vertically to higher levels in the *building*, or

b) Adjacent to an *external wall*, such as a *fire* plume emerging from a window opening or from an *unprotected area* of the wall burning.

There are two considerations in this scenario:

Part A: External vertical *fire* spread over the façade materials, and

Part B: *Fire* plumes spreading *fire* vertically up the *external wall* via openings and *unprotected areas*.

Comment:
Part A addresses concerns regarding the contribution of *combustible* claddings to vertical *fire* spread, while Part B looks at the role of aprons, spandrels or sprinklers in preventing external *fire* spread (due to projecting window *fire* plumes) between openings at different levels in the *building*.

For Part A, the *design fire* exposure is:

a) Radiant flux of 50 kW/m² impinging on the façade for 15 minutes for *buildings* in *importance levels* 2 and 3, or

b) Radiant flux of 90 kW/m² impinging on the façade for 15 minutes for *buildings* in *importance level* 4.

The intention is to prevent façade cladding materials from contributing to significant flame spread propagation beyond the area initially exposed. Some damage to the area initially exposed is expected.

Commentary: Paragraph 4.6

The value of 50 kW/m^2 is representative of the flux from a *fire* plume projecting from an opening in the façade, although higher fluxes are certainly possible. Current large-scale façade *fire* tests expose the façade to heat fluxes in the range of 50-90 kW/m^2.

Acceptable Solutions C/AS1 to C/AS7 allow the *fire* properties of cladding materials to be evaluated on a small scale, exposing the material to 50 kW/m^2. Acceptance criteria (ie, not more than 100 kW/m^2 peak *HRR*) are based on achieving a low probability of occurrence of accelerating flame spread over the surface of a *combustible* cladding. Small scale testing is not suitable for all materials, particularly those where the *fire* performance is greatly affected by connections or jointing details. The testing laboratory will be able to advise when small scale testing is not appropriate and where larger scale test methods should be used.

Fire tests of external cladding systems using the cone calorimeter (ISO 5660) or similar are typically needed to demonstrate that Part A of this scenario is met, unless the cladding is known to be *non-combustible* (according to AS 1530.1 or similar).

If the *building* is sprinklered, then Part B is addressed by reducing the risk of *flashover* in the *building*. It is not necessary to include external drenchers to achieve this.

Extract from C/VM2: Paragraph 4.6

This can be achieved by:

a) Limiting the maximum *HRR* from a cladding material when exposed to the design event to no more than 100 kW/m², or

b) Limiting the extent of the vertical flame spread distance (on the façade) to no more than 3.5 m above the *fire source*. This accepts that *fire* spread via the façade materials may occur to the floor immediately above, but not two floors above.

For Part B, the *design fire* exposure is a *fire* plume projecting from openings or *unprotected areas* in the *external wall*, with characteristics determined from the *design fire* as described in Part 2 for the applicable occupancy. The intention is to prevent *fire* spread in unsprinklered *buildings* from projecting *fire* plumes to *unprotected areas* on upper floors where they are within 1.5 m vertically of a projecting plume *fire source*.

Method

For Part A, follow the requirements of Part 5: Control of external fire spread of the relevant Acceptable Solutions (C/AS2 to C/AS6) and use:

a) Large or medium-scale 'façade type' *fire* tests (eg, NFPA 285, ISO 13785-1 or Vertical Channel test) demonstrating the extent of vertical flame spread is no more than 3.5 m above the *fire source*, or

b) Small-scale testing using ISO 5660 or AS/NZS 3837 (cone calorimeter) for homogeneous materials, demonstrating the maximum *HRR* from a cladding material is no greater than 100 kW/m² when exposed to the design event to ensure propagating flame spread over its surface is unlikely, or

c) Use *non-combustible* materials.

Comment:
Validated flame spread models could be used for some materials.

The requirements given in Acceptable Solutions C/AS2 to C/AS6 Paragraph 5.8 for *fire* properties of external claddings are acceptable means of demonstrating compliance with Part A above for *buildings* with an *importance level* not higher than 3.

For Part B:

a) *Construction* features such as aprons and/or spandrels designed to the specifications given in C/AS2 to C/AS6 Part 5 or the installation of an automatic *fire* sprinkler system designed to a recognised national or international Standard can be used to satisfy the requirements of this scenario.

b) Should calculation methods be used instead, then *fire* plume characteristics and geometry shall be derived from the *design fires* as described in Part 2 for the applicable occupancy.

Extract from C/VM2: Paragraph 4.7

4.7 Design scenario (IS): Rapid fire spread involving internal surface linings

Scenario in brief	Interior surfaces are exposed to a growing *fire* that potentially endangers occupants.		
Code objective	*C1(a) Safeguard people from an unacceptable risk of injury or illness caused by fire.*		
What you must satisfy	The performance criteria of C3.4 for materials used as internal surface linings in the relevant *building* areas, as also specified in C3.4. Where *foamed plastics* or combustible insulating materials form part of a wall, ceiling or roof system, the completed system shall achieve a *Group Number* as specified in C3.4(a) and the *foamed plastics* shall comply with the flame propagation criteria as specified in AS 1366 for the type of material being used. Comment: The completed system may or may not include a surface lining product enclosing any insulation material from any adjacent *occupied space*. If a surface lining is not included then the *foamed plastics* or combustible *insulating materials* when tested alone shall achieve a *Group Number* of 3. Otherwise a surface lining is also required such that the completed system achieves a *Group Number* of 3.		
	Walls and ceiling linings and ducts	*Limits on application*	
	C3.4(a) Materials used as internal surface linings in the following areas of buildings must meet the performance criteria specified below:	*Clause C3.4 does not apply to detached dwellings, within household units in multi-unit dwellings, or outbuildings and ancillary buildings.*	
	Area of building	*Performance determined under the conditions described in ISO 9705: 1993*	
		Buildings not protected with an automatic fire sprinkler system	*Buildings protected with an automatic fire sprinkler system*
	Wall/ceiling materials in sleeping areas where care or detention is provided *Wall/ceiling materials in exitways* *Wall/ceiling materials in all occupied spaces in importance level 4 buildings* *Internal surfaces of ducts for HVAC systems*	*Material Group Number 1-S*	*Material Group Number 1 or 2*
	Ceiling materials in crowd and sleeping uses but not household units or where care or detention is provided	*Material Group Number 1-S or 2-S.*	*Material Group Number 1 or 2*
	Wall materials in crowd and sleeping uses except household units or where care or detention is provided	*Material Group Number 1-S or 2-S*	*Material Group Number 1, 2 or 3*
	Wall/ceiling materials in occupied spaces in all other locations in buildings, including household units *External surfaces of ducts for HVAC systems* *Acoustic treatment and pipe insulation within air-handling plenums in sleeping uses*	*Material Group Number 1, 2 or 3*	*Material Group Number 1, 2 or 3*

Commentary: Paragraph 4.7

Design Scenario IS requires the engineer to consider the reaction-to-*fire* properties of materials that are intended to be used as interior surface linings on walls, ceiling and floors. Surface linings have the potential to contribute to rapid *fire* spread and smoke development beyond that already allowed for in the specification of the *design fires* in the Design Scenario CF: Challenging fire (see Verification Method C/VM2 Paragraph 4.9).

Performance criteria for surface linings depend on:

- the relative contribution expected by the linings compared to other contents of a room, and
- the importance of the room/space to the *means of escape from fire*.

Therefore, *fire* properties of surface linings within *exitways*, for example, are given greater emphasis as they are potentially the greatest source of *fire load* within those spaces as well as being critical paths for escape.

Performance criteria also depend on the type of occupancy, the ability of occupants to self-evacuate, and the presence or otherwise of a sprinkler system.

The *Group Number* system used for wall and ceiling surface linings replaces the AS 1530 Part 3 (early *fire hazard*) *fire* test indices that were previously used in New Zealand. The *Group Number* methodology has been the subject of significant research in Europe and Australia (CRC Project 2 – Stage A), and more recently in New Zealand (Collier, Whiting and Wade). The current methodology applied in the Building Code of Australia (Specification C.1.10) has been adopted as a model. This uses the ISO 9705 *fire* test method as a reference scenario, with the time to *flashover* used as the primary parameter of interest.

This *fire* test requires the surface lining material to be installed on the walls and ceiling of a rectangular room with dimensions 3.6 m long x 2.4 m wide x 2.4 m high. An opening with dimensions 2.0 m high x 0.8 m wide is present in one of the short walls. A gas burner is used to expose the wall lining in one of the corner intersections opposite the wall opening. The combustion gases from the burner and from the surface lining materials (once ignited) is collected in a hood outside the room and oxygen calorimeter equipment is used to determine the *HRR* and smoke production rate as a function of time. The test is conducted using the same material fixed to both the walls and ceiling in order to determine the *Group Number*, regardless of whether the same or different material will be installed on the wall and ceiling respectively in the actual *building*.

Extract from C/VM2: Paragraph 4.7

	Floor surfaces suspended flexible fabrics and membrane structures		
	C3.4(b) Floor surface materials in the following areas of buildings must meet the performance criteria specified below:		
	Area of building	*Minimum critical radiant flux when tested to ISO 9239-1: 2010*	
		Buildings not protected with an automatic fire sprinkler system	*Buildings protected with an automatic fire sprinkler system*
	Sleeping areas and exitways in buildings where care or detention is provided	*4.5 kW/m²*	*2.2 kW/m²*
	Exitways in all other buildings	*2.2 kW/m²*	*2.2 kW/m²*
	Firecells accommodating more than 50 persons	*2.2 kW/m²*	*1.2 kW/m²*
	All other occupied spaces except household units	*1.2 kW/m²*	*1.2 kW/m²*
	C3.4(c) is to be satisfied by ensuring that: a) suspended flexible fabrics used as underlay to exterior cladding or roofing, when exposed to view in all *occupied spaces* excluding *household units*, shall have a *flammability index* of no greater than 5 when tested to AS 1530 Part 2 b) Suspended flexible fabrics and membrane structures shall have a *flammability index* of no greater than 12 when tested to AS 1530 Part 2 in the following locations: i) *exitways* from spaces where people sleep, and ii) all *occupied spaces* within crowd uses.		
Required outcome	Demonstrate that *surface finishes* comply with these performance requirements.		

Scenario description

The performance criteria required for lining materials will depend on their location within a *building*, the use of the *building* and its *importance level*.

The criteria in NZBC C3.4 shall be applied to lining materials, except in the following cases:

a) Small areas of non-conforming product within a space with a total aggregate surface area not more than 5.0 m²

b) Electrical switches, outlets, cover plates and similar small discontinuous areas

c) Pipes and cables used to distribute power or services

d) *Handrails* and general decorative trim such as architraves, skirtings and window components including reveals

e) *Damp-proof courses*, seals, caulking, flashings, thermal breaks and ground moisture barriers

f) Timber joinery and structural timber *building elements* constructed from solid wood, glulam or laminated veneer lumber. This includes heavy timber columns, beams, portals and shear walls not more than 3.0 m wide, but does not include exposed timber panels or permanent formwork on the underside of floor/ceiling systems.

g) Individual *doorsets*, and

h) Continuous areas of permanently installed openable wall partitions not more than 3.0 m high and having a surface area of not more than 25% of the divided room floor area or 5.0 m², whichever is less.

The smoke production rate criteria do not need to apply for sprinklered *buildings*.

Commentary: Paragraph 4.7 (continued)

AS/NZS 3837 or ISO 5660 (cone calorimeter) results have been previously correlated (Kolkatta, Thomas and Karllson) to predict the time to *flashover* in the ISO 9705 *fire* test. This correlation can be used for most, but not all, materials. This is because some products are not suitable for testing at small scale using ISO 5660. Examples are metal-faced sandwich panels and foil-faced *combustible* insulation products.

In the ISO 9705 *fire* test, surface linings are exposed to 100 kW for 10 minutes and then 300 kW for a further 10 minutes. The time to reach *flashover* (taken as *HRR* = 1.0 MW in the ISO 9705 room) is then determined. Materials are classified from *Group Number* 1 (best) to *Group Number* 4 (worst) based on their measured time to *flashover* in the *fire* test.

Material Group Numbers

Appendix A of C/VM2 describes the procedure for assigning or predicting a material's *Group Number*.

The following is a general indication of the expected performance of some common materials. Actual performance is affected by factors such as chemical composition, thickness and additives, so must be verified by test. The material/product shall be tested in a configuration that resembles the actual end use installation as much as possible. The *fire* test laboratory shall use the procedure in Appendix A to assign a *Group Number*.

Group Number 1 materials

These include *non-combustible* materials or materials with limited *combustibility*. Examples are plasterboard and similar materials (low hazard) where no *flashover* is reached in the ISO 9705 test in 20 minutes.

Group Number 2 materials

These include many *fire retardant* treated timbers, where no *flashover* is reached in the ISO 9705 test in 10 minutes.

Group Number 3 materials

These include ordinary timber products and similar materials, where no *flashover* is reached in the ISO 9705 test in two minutes.

Group Number 4 materials

These include exposed polyurethane foams or similar products where *flashover* is reached in the ISO 9705 test within two minutes. *Group Number* 4 materials are *hazardous* when installed as room linings and are not acceptable in *occupied spaces*.

Extract from C/VM2: Paragraph 4.7

Material *Group Numbers* apply to the exposed surface of the interior wall or ceiling lining. They are determined by the *fire* testing laboratory using the procedure described in Appendix A. This is either to:

a) ISO 9705, which is a full-scale room corner test, or

b) ISO 5660, which is a bench-scale fire test on a small sample of the material.

A correlation is used that allows the ISO 9705 result to be predicted using data obtained in the ISO 5660 test.

If an 'S' is appended to the material *Group Number*, the material also is required to meet smoke production criteria. The limit for maximum smoke production is:

a) 5.0 m^2/s if the ISO 9705 test is used, or

b) 250 m^2/kg if the ISO 5660 test is used.

Materials that are classified *non-combustible* when tested to AS 1530.1 or ISO 1182 can be assigned a material *Group Number* of 1 or 1–S without further evaluation using Appendix A.

The minimum critical flux for a floor surface material or covering is determined by *fire* testing to ISO 9239 Part 1 (radiant panel test).

Method

The following tests should be applied to lining materials to achieve compliance with NZBC C3.4.

For wall/ceiling lining materials, external surface of ducts and pipe insulation:

a) Small scale testing to ISO 5660 (cone calorimeter test) provided it is appropriate for the type of material, or

b) Full scale testing to ISO 9705 (room corner test).

For floor surface materials:

a) *Fire* testing to ISO 9239 Part 1 (radiant panel test).

For suspended flexible fabrics and membrane structures:

a) *Fire* testing to AS 1530 Part 2 (flammability test).

Commentary: Paragraph 4.7 (continued)

Smoke production

In full scale calorimeter tests such as ISO 9705, the smoke production rate in m^2/s is commonly expressed as the product of the extinction coefficient (1/m) and the volumetric flow in the exhaust duct (m^3/s).

Where an ‘S’ is appended to the *Group Number*, then the material also meets, or is required to meet, smoke production criteria. These differ depending on whether the ISO 9705 *fire* test or the ISO 5660 test is used as follows:

- The ISO 9705 test has a limit of 5.0 m^2/s for average smoke production, and
- The ISO 5660 test has a limit of 250 m^2/kg for the average specific extinction area.

No clear correlation has been made between the smoke measurements in the two tests, most probably because of scaling and ventilation effects.

The *HRR* is the most important parameter as it is directly related to the burning rate. Smoke production is a secondary concern, but its rate also increases with the burning rate.

There is no maximum limit placed on smoke production when a fire sprinkler system is present, because of the beneficial effect of the sprinkler system in reducing the burning rate and consequently the smoke production rate.

The average smoke production rate of 5.0 m^2/s used in the ISO 9705 test is taken from a similar value proposed by Sundstrom as part of the EUREFIC research project, which was intended to raise the technical level of evaluating surface linings in the Nordic countries in the early 1990s. Meanwhile, the ISO 5660 smoke production criteria of 250m^2/kg is the same as that used in the Building Code of Australia. It is a value designed to eliminate the ‘bad performers’, but is sometimes problematic for materials with very low mass loss rate.

It is clear that there is a need for further research to be carried out to strengthen the basis for selecting the smoke production criteria. Therefore, the currently specified smoke criteria may be refined in future. On the other hand, there is a strong research basis for selecting the *Group Number* classifications, so these are unlikely to require change.

Floor coverings

The reaction-to-*fire* properties for floor coverings are determined by testing to ISO 9239 Part 1. This *fire* test (or its equivalent) is extensively used around the world including in North America, Europe and Australia. The test imposes a radiant flux that simulates the thermal radiation levels likely to impinge on the floor of a corridor whose upper surfaces are heated by flames and/or hot gases during the early stages of a developing *fire*. A critical radiant flux for the material is determined with a higher critical flux corresponding to better *fire* performance.

Extract from C/VM2: Paragraph 4.7

Material *Group Numbers* apply to the exposed surface of the interior wall or ceiling lining. They are determined by the *fire* testing laboratory using the procedure described in Appendix A. This is either to:

a) ISO 9705, which is a full-scale room corner test, or

b) ISO 5660, which is a bench-scale fire test on a small sample of the material.

A correlation is used that allows the ISO 9705 result to be predicted using data obtained in the ISO 5660 test.

If an 'S' is appended to the material *Group Number*, the material also is required to meet smoke production criteria. The limit for maximum smoke production is:

a) 5.0 m^2/s if the ISO 9705 test is used, or

b) 250 m^2/kg if the ISO 5660 test is used.

Materials that are classified *non-combustible* when tested to AS 1530.1 or ISO 1182 can be assigned a material *Group Number* of 1 or 1–S without further evaluation using Appendix A.

The minimum critical flux for a floor surface material or covering is determined by *fire* testing to ISO 9239 Part 1 (radiant panel test).

Method

The following tests should be applied to lining materials to achieve compliance with NZBC C3.4.

For wall/ceiling lining materials, external surface of ducts and pipe insulation:

a) Small scale testing to ISO 5660 (cone calorimeter test) provided it is appropriate for the type of material, or

b) Full scale testing to ISO 9705 (room corner test).

For floor surface materials:

a) *Fire* testing to ISO 9239 Part 1 (radiant panel test).

For suspended flexible fabrics and membrane structures:

a) *Fire* testing to AS 1530 Part 2 (flammability test).

Commentary: Paragraph 4.7 (continued)

Background information relating to the appropriateness of the test method and relevance to New Zealand can be found in BRANZ Study Report 181. It replaces a test method that did not simulate radiant heat exposure, but instead assessed damage due to heat conduction when the flooring was in contact with a hot metal nut.

The critical radiant flux levels (1.2, 2.2 and 4.5 kW/m^2) based on ISO 9239 Part 1 testing are similar to those used in the Building Code of Australia, although the situations in which they apply are not the same. Smoke criteria are not assessed due to the lower risk associated with *fire* spread via floor coverings compared to walls and ceilings.

In ISO 9239 Part 1, a specimen of the material measuring 1050 mm × 230 mm is placed horizontally below a gas-fired radiant panel inclined at 30°. The material specimen is exposed to a total radiant heat flux, starting from 11 kW/m^2 at the end nearest the radiant panel and decreasing to 1.0 kW/m^2 at the end furthest from the radiant panel. The material is ignited using a pilot flame and the progress of the flame front along the length of the material is recorded over the 30 minute duration of the test.

The classification criterion is the critical radiant flux (CRF), which is defined as the radiant flux at which the flame extinguishes or the radiant flux after a test period of 30 minutes, whichever is lower. In other words, CRF is the flux corresponding to the furthest extent of spread of flame.

Typically, wood products would be expected to have a CRF of greater than 2.2 kW/m^2, and in some cases greater than 4.5 kW/m^2, depending on product density, thickness and treatments.

Suspended flexible fabrics and membrane structures

These materials are assessed using the AS 1530 Part 2 (flammability) *fire* test resulting in the determination of the *flammability index*. There is no significant change to the requirements in this area compared to past practice in New Zealand.

Foamed plastics

There is now no requirement for ‘flame barriers’ for protecting *foamed plastics* as such. However, assemblies including a *foamed plastics* material will require a material *Group Number* to be determined as for other materials. Normally this will require a protective barrier between the *foamed plastics* and the room-side of the assembly. In addition, *foamed plastics* materials are required to comply with the flame propagation criteria as specified in AS 1366 for the type of material being used. This is not a change from current practice where, for example, *fire retardant* grades of *foamed plastics* are generally used within the *construction* industry.

Extract from C/VM2: Paragraph 4.8

4.8 Design scenario (FO): Firefighting operations

Scenario in brief	This scenario provides for the safe operation of firefighters in a *building*.
Code objectives	*C1 b) Protect other property from damage caused by fire, and* *C1(c) Facilitate firefighting and rescue operations.*
What you must satisfy	The performance criteria in C3.8, C5.3, C5.4, C5.5, C5.6, C5.7, C5.8 and C6.3.
	C3.8 Firecells located within 15 m of a relevant boundary that are not protected by an automatic fire sprinkler system, and that contain a fire load greater than 20 TJ or that have a floor area greater than 5000 m^2 must be designed and constructed so that at the time that firefighters first apply water to the fire, the maximum radiation flux at 1.5 m above the floor is no greater than 4.5 kW/m^2; and the smoke layer is no less than 2 m above the floor.
	C5.3 Buildings must be provided with access for fire service vehicles to a hard-standing from which there is an unobstructed path to the building within 20 m of: *(a) the firefighter access into the building, and* *(b) the inlets to automatic fire sprinkler systems or fire hydrant systems, where these are installed.*
	C5.4 Access for fire service vehicles in accordance with Clause C5.3 shall be provided to more than 1 side of firecells greater than 5 000 m^2 in floor area that are not protected by an automatic fire sprinkler system.
	C5.5 Buildings must be provided with the means to deliver water for firefighting to all parts of the building.
	C5.6 Buildings must be designed and constructed in a manner that will allow firefighters, taking into account the firefighters' personal protective equipment and standard training, to: *a) reach the floor of fire origin,* *b) search the general area of fire origin, and* *c) protect their means of egress.*
	C5.7 Buildings must be provided with means of giving clear information to enable firefighters to: *a) establish the general location of the fire,* *b) identify the fire safety systems available in the building, and* *c) establish the presence of hazardous substances or process in the building.*
	C5.8 Means to provide access for and safety of firefighters in buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety systems.
	C6.3 Structural systems in buildings that are necessary to provide firefighters with safe access to floors for the purpose of conducting firefighting and rescue operations must be designed and constructed so that they remain stable during and after fire.
Required outcome	Show that the performance requirements are satisfied.

Scenario description

This scenario has been designed to test the safe operation of firefighters in the event of a *fire* in the *building*.

For the purposes of NZBC C3.8, take the time that the Fire Service first applies water to the *fire* as either:

a) 1200 seconds, or

b) 1000 seconds if there is an automatic alarm and direct connection to the Fire Service, or

c) Some other time as determined and supported by the application of a *fire* brigade intervention model.

Use the *design fire* as described in Paragraph 2.3 for the applicable occupancy. This can be modified to account for ventilation conditions.

Where *fire separations* are specified to create *firecells* of area not more than 5000 m^2, the full *burnout design fire* defined in Paragraph 2.4 shall be used to determine the required *fire* resistance of the *fire separation*.

Commentary: Paragraph 4.8

This *design scenario* requires analysis to demonstrate that the performance criteria of NZBC Clauses C3.8, C5.3, C5.4, C5.5, C5.6 and C6.3 are satisfied. These clauses either address the protection of *other property* from damage caused by *fire* or facilitate firefighting and rescue operations. Some clauses contribute indirectly to both objectives.

Protect other property (NZBC C3.8)

The Fire Service role with respect to the NZBC C1.2 (protection of other property) is a secondary one and complements the requirements of the Design Scenario HS: Horizontal fire spread (see Verification Method C/VM2 Paragraph 4.5). That scenario addresses exposure to *other property* by limiting radiation to the *relevant boundary* and beyond. However, the *design fire* assumptions in the Design Scenario HS: Horizontal fire spread include an expectation that, if necessary, Fire Service intervention will be available after some period of time to prevent *fire* spread to neighbouring property. This assumption was considered necessary because of the uncertainties around such variables as the extent of flame projection from openings (which that scenario ignored), and the extent to which the assumed levels of emitted radiation would actually follow the standard *fire* resistance time temperature furnace conditions (which that scenario assumed).

NZBC C3.8 is designed to provide a secondary means of limiting *fire* spread to *other property* (where the Design Scenario HS: Horizontal *fire* spread provides the primary means). Where the *fire load* is high and *firecells* are in the vicinity of a *relevant boundary*, it is intended that the Fire Service should be provided with a reasonable opportunity to be effective in managing the *fire* and preventing further spread to *other property*.

The threshold for the amount of *fire load* is taken as 20 TJ or 20 million MJ. This is a significant increase compared to the approach taken in the previous Acceptable Solution C/AS1 (2011) where *firecell* floor area limits were established using a limiting value of only 2 million MJ.

The ability of the Fire Service to be effective in managing the size of the *fire* in order to limit the risk of *fire* spread to *other property* is only required to be addressed in this *design scenario* in cases where the *fire* could become very large and potentially threaten *other property*. It is considered that uncontrolled *fire* burning throughout an area larger than 5000 m^2, or throughout an area containing more than 20 TJ is not acceptable unless there is negligible risk of *fire* spread to *other property*, or unless the *building* design and *fire* safety features provided within the *building* allow the Fire Service opportunity to effectively control the *fire*. NZBC C3.8 sets out when this is required and what design criteria must be satisfied.

The threshold of 15 m within which this clause is to be applied has been selected because it was considered that, at this distance, the risk of *fire* spread to *other property* in the absence of Fire Service intervention would be relatively small.

Extract from C/VM2: Paragraph 4.8

For the purposes of NZBC C5.5, water shall be provided from either:

a) A pumping appliance parked close to the *building* such that any point within the *building* may be reached within 75 m (~3 hose lengths) of the pumping appliance, or

b) An internal hydrant designed and installed to NZS 4510 or as approved by the National Commander of the New Zealand Fire Service.

In relation to NZBC C6.3, firefighters are provided with the means of conducting search and rescue operations by giving them safe access to the *fire* floor with *building construction* that will not collapse during the *fire*. Derive the *fire* resistance of the structure or separating *construction* needed to achieve this by reference to the full *burnout design fire* defined in Pararaph 2.4 and by meeting the requirements below.

A. For buildings with an escape height >10 m:

a) Provide firefighters with *safe paths* that are designed to resist *fire* spread until *burnout*, allowing them access to all floors within the *building* that are not directly accessible from street level, and

Comment:
In the case of *intermediate floors*, access to the *intermediate floor* can be taken as being achieved if:

a) The distance between the most remote point on the *intermediate floor* and a hydrant located within a *safe path* is no more than 40 m. This corresponds to ~2 hose lengths with some allowance for a non-direct path, or

b) The furthest point on the *intermediate floor* is able to be reached within 3 hose lengths to satisfy the requirement of NZBC C5.5 to provide water to all points of the *building*.

b) Protect firefighters and others at ground level and within the *building* by designing the load-carrying structure and floor systems (excluding *intermediate floors*) to resist collapse and prevent *fire* spread between floor levels until *burnout*, and

c) Design *intermediate floors* and supporting structure to resist collapse until *burnout*. This is unless the *intermediate floor* has an *occupant load* ≤100 people and an *escape height* ≤4.0 m and the area below the floor is open to the *firecell*; in which case the *intermediate floor* may be designed to resist collapse for not less than 30 minutes.

B. For buildings with an escape height ≤10 m:

a) Provide firefighters with *safe paths* allowing them access to all floors within the *building* that are not directly accessible from street level either for a period of 60 minutes (from ignition) or to resist collapse until *burnout*, whichever is less, and

b) Protect firefighters and others at ground level and within the *building* by designing the floor systems (excluding *intermediate floors*) and supporting structure to resist collapse and prevent *fire* spread between floor levels for a period of at least 30 minutes, and

c) Design *intermediate floors* and supporting structure to resist collapse for at least 30 minutes.

Comment:
These requirements permit search and rescue operations, and attempt to avoid unexpected or sudden collapse that would endanger Fire Service personnel within the *building*.

Intermediate floors – additional requirements:

If the total floor area of *intermediate floors* exceeds 40% of the floor area of the *firecell*, the *intermediate floor* shall be rated for *integrity* and *insulation* as well as *structural adequacy* to resist collapse.

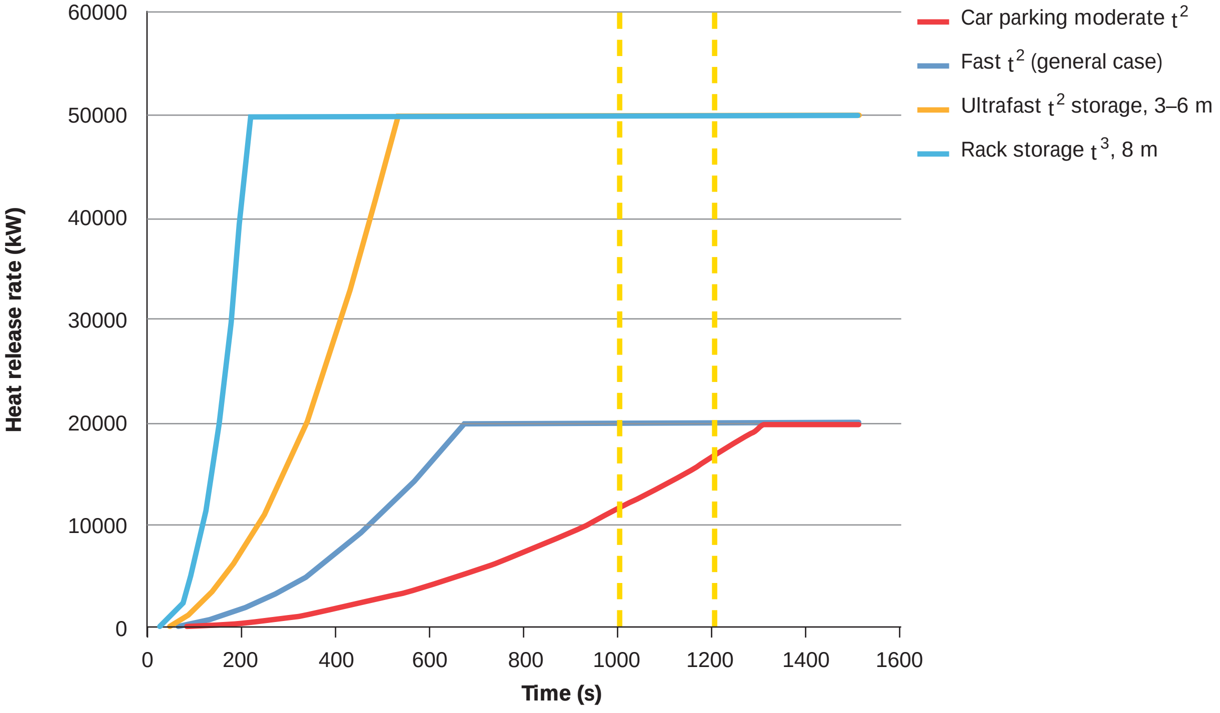
Catwalks used intermittently in industrial plants, platforms for retractable seating, flytowers over stages, and similar structures do not need to be *fire* rated.

In the event that the *building* designer does not want to limit the *firecell* area, firefighter tenability limits as suggested by AFAC are specified and require a maximum radiant flux of 4.5 kW/m^2 at 1.5 m above the floor, and a minimum height to the bottom of the smoke layer of 2.0 m to be demonstrated. These conditions need only be met at the time the Fire Service are ready to first apply water to the *fire*. Fire Service operations beyond that time will be determined by the officer in charge in accordance with Fire Service procedures and will be dependent on the conditions faced at the time. These tenability criteria and the use of roof venting systems as one design solution that contributes to achieving the criteria are discussed in detail in a BRANZ Study Report SR199.

The time for Fire Service operations to begin is derived from an analysis by Robbins and Wade using New Zealand Fire Incident data for industrial fire incidents. The 95th percentile for the time for first *fire* suppression activities for a monitored alarm system was estimated at approximately 1240 sec and the 95th percentile for a direct connection to the Fire Service was estimated at approximately 1060 sec. These values have been rounded and used in Verification Method C/VM2 as shown in Figure C11.

The *design fire* for NZBC Clause 3.8 is the same as used in the Design Scenario CF: Challenging fire (see Verification Method C/VM2 Paragraph 4.9) for the occupancy of interest and may be modified to account for ventilation effects. The time for Fire Service operations to begin is shown in Figure C11 along with the *HRR* curves for the various *design fires*.

Figure C11: C/VM2 Design Fires



Example application of NZBC C3.8:

This example demonstrates the application of NZBC C3.8 (for the Design Scenario FO: Firefighting operations) for a 1200 m^2 warehouse that is 8.0 m high with a storage height of 6.0 m. The *building* contains 20 TJ (2778 MJ per metre of storage height) and is located within 15 m of a *relevant boundary*. Wall ventilation of 8.0 m wide x 3.3 m high providing make-up air is assumed. Smoke filling calculations are made using the BRANZFIRE model.

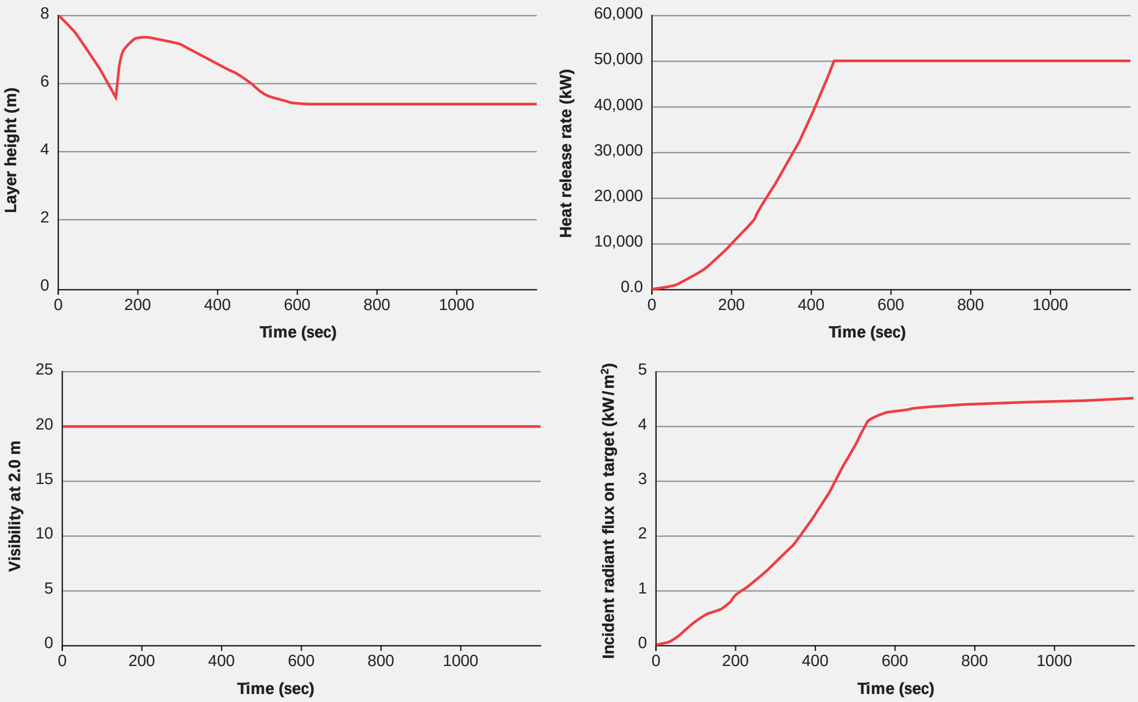
In all cases, an ultrafast t^2 *design fire* is used with a peak *HRR* of 50 MW. The time that the Fire Service first applies water to the *fire* is taken as 1200 seconds.

The required performance criteria are:

- C3.8: *Firecells* located within 15 m of a *relevant boundary* and containing a *fire load* greater than 20 TJ are designed and constructed so that prior to the time that Fire Service first apply water to the *fire*: the maximum radiation flux at 1.5 m above the floor is no greater than 4.5 kW/m^2; and the smoke layer is no less than 2.0 m above the floor.

This example warehouse has heat detectors that automatically open both make-up air supply and the added 3.7% ceiling venting. This demonstrates that the performance criterion of NZBC C3.8 is achieved. However, from a security viewpoint, this solution may not be tolerable due to the large area of make-up air required.

Warehouse example: Unsprinklered building containing more than 20 TJ with 3.7% ceiling vents



Note

Warehouse dimensions are 60 m x 20 m x 8.0 m high, with 22 ceiling vents each of area 2.0 m^2 (3.7%).

Conclusion: assuming Fire Service operations at 1200 sec, layer height and radiation criteria are both met with 50 MW *fire* and 3.7% ceiling venting.

Facilitate firefighting and rescue operations (NZBC C5.3, C5.4, C5.5, C5.6 and C6.3)

Firefighters are authorised by law to enter *buildings* on *fire* for the purposes of firefighting and rescue operations. Although the officer in charge will ultimately make the final decision on whether or not to commit firefighting crews to a *building* that is on *fire*, one of the principles of the *Building Act 2004* is that firefighters have reasonable expectations that they should not suffer illness and injury whilst undertaking firefighting and rescue operations.

Mitigation of risk on the fireground on the part of the officer requires the ability to predict both *fire* and *building* behaviour. What compromises this ability is the occurrence of events that are sudden, unexpected or disproportionate to the change that caused them. It is the broad predictability of the *building* behaviour and the *fire* environment that is encapsulated in the concept of 'reasonable expectations' of firefighters to be safe.

In order that the officer in charge may make a risk-informed judgement about how to tackle firefighting and rescue operations:

- information must be available to the crew on arrival to enable them to rapidly size up the situation
- firefighters must have a protected *access route* to reach upper floors in *buildings*, and
- firefighting water must be available in the vicinity of the *fire.*

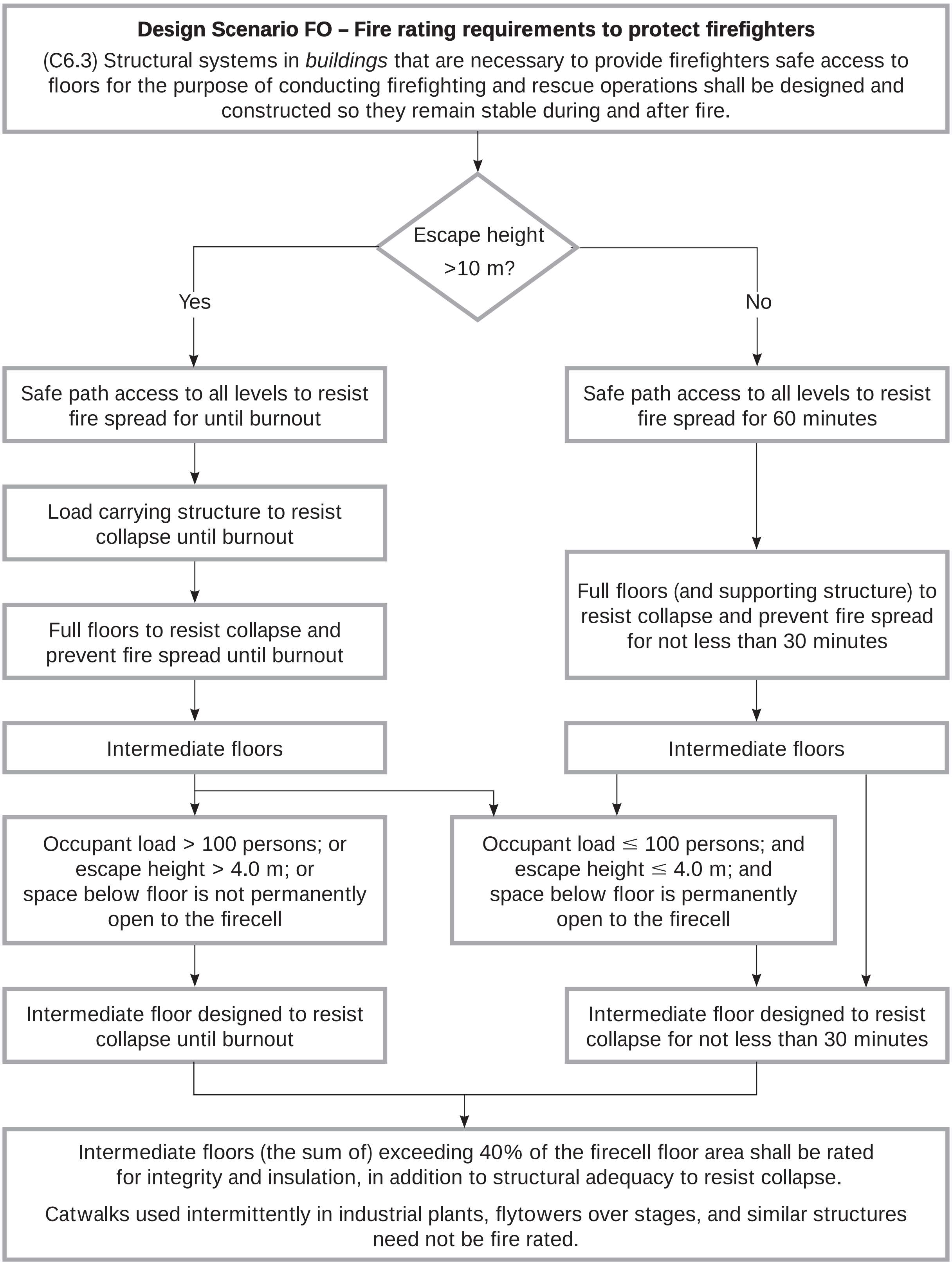
In taller *buildings* (with an *escape height* above 10 m) where it will take longer and be more challenging for firefighters to reach the upper floors and where external ladder access is usually unlikely, then *fire* protected routes (ie, *safe paths*) are required to enable the firefighters to reach all upper full floors. The *safe paths* do not need to extend to the level of all *intermediate floors (*see below). However, all the load carrying structure and floor systems (for *intermediate floors* see below) must be designed to resist collapse for the *burnout* period. Depending on any other functions required for these *building elements*, at least *structural adequacy* is required. *Integrity* and/or *insulation* may or may not be required.

It is not acceptable for these taller *buildings* to collapse catastrophically during or following *fire*, even if the occupants have safely evacuated, due to the potential endangerment of persons outside the *building* at ground level.

Other *buildings* with an *escape height* ≤10 m, also require *fire* protected paths of travel (*safe paths*) for firefighters to reach all upper full floors. However, the structural system and floors do not necessarily need to resist collapse for the complete *burnout* period. A lesser period following evacuation of the *building* may be acceptable.

In the case of *intermediate floors*, access by firefighters is achieved if a hose can be run from a hydrant within a *safe path* stair across a floor and up to a remote point on an *intermediate floor* provided that this can be accomplished using only two lengths of hose, and allowing for a non-direct path.

Figure C12 Fire resistance of floors to satisfy NZBC C6.3



Definition: Intermediate floor – "any upper floor within a firecell which because of its configuration provides an opening allowing smoke to spread from a lower to an upper level within the firecell."

Note: intermediate floors exceeding 40% of the firecell floor area shall be treated as a full floor for fire rating purposes (ie, structural adequacy, integrity and insulation apply).

Intermediate floors need only be structurally stable for the required period. It is not necessary for these to satisfy '*integrity*' or '*insulation*' as defined in *fire* resistance test standards for that period. This reflects the fact that the *intermediate floor* is in the same *firecell* as the floor below and an unrestricted flow of smoke and hot gases may be possible.

Full floors must be structurally stable, and prevent *fire* spread between floor levels for the required period, which generally requires the *structural adequacy*, *integrity* and *insulation* criteria to be met.

Figure C12 summarises the requirements for ensuring floor systems achieve adequate *fire* resistance.

Extract from C/VM2: Paragraph 4.9

4.9 Design scenario (CF): Challenging fire

Scenario in brief	A *fire* starts in a normally *occupied space* and presents a challenge to the *building's fire safety systems*, threatening the safety of its occupants.
Code objective	*C1(a) Safeguard people from an unacceptable risk of injury or illness caused by fire.*
What you must satisfy	The performance criteria of C4.3 and C4.4. This will require analysis. *C4.3 The evacuation time must allow occupants of a building to move to a place of safety in the event of a fire so that occupants are not exposed to any of the following:* *(a) a fractional effective dose of carbon monoxide greater than 0.3;* *(b) a fractional effective dose of thermal effects greater than 0.3;* *(c) conditions where, due to smoke obscuration, visibility is less than 10 m except in rooms of less than 100 m^2 where the visibility may fall to 5 m.* *C4.4 Clause C4.3 (b) and (c) do not apply where it is not possible to expose more than 1000 people in a firecell protected with an automatic fire sprinkler system.*
Required outcome	Demonstrate *ASET>RSET* for *design fires* in various locations within the *building*.

Scenario description

The challenging *fires* are intended to represent credible worst case scenarios in normally occupied spaces that will challenge the *fire* protection features of the *building*.

This scenario requires the use of *design fires* in various locations within the *building*. *ASET* need not be determined for occupants of the enclosure of *fire* origin for the following *fire* locations:

Errata 1 Apr 2012

a) Any room with a floor area less than 2.0 m^2, or

b) Sanitary facilities adjoining an *exitway*, or

Errata 1 Apr 2012

c) Any room or space of *fire* origin other than sleeping areas where care or detention is provided, which has all of the following:

i) a total floor area, including *intermediate floors*, of less than 500 m^2, and

ii) more than one direction of travel or a single direction of travel that is less than 25 m, and

iii) an *occupant load* of less than 150 people for the room or less than 100 people for any *intermediate floor*.

For c), the *fire* engineer does not have to demonstrate that tenability is maintained for occupants within the enclosure of origin; however, they must demonstrate that the challenging *fire* in this space does not threaten occupants in the rest of the *building*. The *design fires* shall be characterised with a power law *HRR*, peak *HRR* and *FLED* as specified in Part 2. Design values for *yields* are specified for CO, CO_2 and soot/smoke. Hydrogen cyanide production need not be considered.

Errata 1 Apr 2012

The *design fires* are intended to represent 'free-burning' *fires*. However, they shall be modified during an analysis (depending on the methodology used) to account for *building* ventilation and the effects of automatic *fire* suppression systems (if any) on the *fire*. The *design scenario*: RC (see Paragraph 4.10) will require the overall robustness of the design to be examined separately.

The *fire* engineer shall:

a) For each location of the challenging *fire*, use a single *fire source* to evaluate the *building's* protection measures

b) Consider the impact on occupants who may be using *escape routes* external to the *building* as well as internal routes, and

c) Assume that active and passive *fire safety systems* in the *building* will perform as intended by the design.

Method

This scenario requires the *ASET/RSET* analysis of the impact on all *building* occupants of *design fires* located in various locations within the *building*, except for those rooms or spaces excluded in the scenario description above.

The *fire* engineer is expected to calculate the *fire* environment in the *escape routes* over the period of time the occupants require to escape. Assess the *fire* environment based on the *fractional effective dose* and *visibility* at the location of the occupants.

The *fire* engineer will typically select a *fire* calculation model appropriate to the complexity and size of the *building*/space that allows the *fractional effective dose* and *visibility* to be determined.

Commentary: Paragraph 4.9

This scenario is used to evaluate the life safety hazards using reasonably severe *fire* challenges to the *building* and its *fire safety systems* and features. It is necessary to examine the likely *fire* development in a range of different locations throughout the *building* making calculations of *ASET* and comparing those with expected corresponding *RSET* in each case.

A suitable number of cases for analysis shall be selected commensurate with the size and complexity of the *building* and as agreed with the *building consent authority* during development of the FEB. Verification Method C/VM2 provides specific guidance on the quantitative parameters to be used for the *design fires* when calculating *ASET*, as well as the egress parameters to be used when calculating *RSET*.

In each case, demonstrate that each of the performance criteria specified in NZBC C4 have been achieved.

Extract from C/VM2: Paragraph 4.10

4.10 Design scenario (RC): Robustness check

Scenario in brief	The *fire* design will be checked to ensure that the failure of a critical part of the *fire safety system* will not result in the design not meeting the objectives of the *Building Code*.
Code objectives	*C1(a) Safeguard people from an unacceptable risk of injury or illness caused by fire.* *C1(b) Protect other property from damage caused by fire.* *C1(c) Facilitate firefighting and rescue operations.*
What you must satisfy	This scenario contributes to testing the performance criteria of C3.9, C4.5, C5.8 and C6.2d). Where tenability criteria are evaluated, these criteria only need to be assessed based on *FED* (CO). *C3.9 Buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety system intended to control fire spread.* *C4.5 Means of escape to a place of safety in buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety systems.* *C5.8 Means to provide access for and safety of firefighters in buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety systems.* *C6.2 Structural systems in buildings that are necessary for structural stability in fire must be designed and constructed so that they remain stable during fire and after fire when required to protect other property taking into account:* *(a) …* *(b) …* *(c) …* *(d) the likelihood and consequence of failure of any fire safety systems that affect the fire severity and its impact on structural stability.*
Required outcome	Demonstrate that if a single *fire safety system* fails, where that failure is statistically probable, the *building* as designed will allow people to escape and *fire* spread to *other property* will be limited.

Scenario description

This scenario applies where failure of a key *fire safety system* could potentially expose to untenable conditions:

a) More than 150 people, or

b) More than 50 people in a sleeping occupancy *firecell* where the occupants are neither detained or undergoing some treatment or care, or

c) People detained or undergoing treatment or care.

For this scenario, key *fire safety systems* include:

a) Smoke management systems (other than permanent natural/passive ventilation features that do not rely on the activation of any mechanical or electronic component)

b) *Fire* and/or *smoke control doors* or similar *fire* closures, and

c) Any other feature or system required as part of the *fire* safety design that relies on a mechanical or electronic component to be activated during the *fire*, except that:

i) *fire* sprinkler systems and automatic *fire* alarms installed to a recognised national or international Standard, can be considered to be sufficiently reliable that they are exempt from this robustness scenario, and

ii) in sprinklered *buildings*, *fire* and *smoke control doors* fitted with automatic *hold-open devices* that are designed and installed to BS 7273.4 or another recognised national or international Standard and are activated by the operation of the *fire* alarm system can be considered to be sufficiently reliable that they are exempt from this robustness scenario.

Commentary: Paragraph 4.10

This scenario is required to ensure that the *fire* design of the *building* is not reliant on a single system or feature where the reliability or dependability of that system or feature is below what would be required. This scenario most closely relates to the Design Scenario CF: Challenging fire, where it is acceptable to assume that *fire safety systems* will operate as designed. However, it is good practice in *fire* engineering design to consider the consequences if a system or feature did not operate as anticipated, and to try and mitigate that possibility through the inclusion of a level of redundancy and robustness in the design.

C/VM2 requires the robustness of the design to be tested by considering the consequence of a *fire safety system* or feature not operating as intended. It is only necessary to consider the impact of one system or feature not working at any time, and not multiple system failures unless they have a single common cause.

It is inappropriate to repeat the same scenario assuming a feature or system has failed to perform and expect that the same level of performance can or should be achieved. Therefore, in this situation, C/VM2 does not expect the same criteria to be achieved. Only FED_{CO} must be demonstrated and not $FED_{Thermal}$ or *visibility* criteria. If this was not the case, then the benefit of including reliable systems in the design would be negated.

Some systems are known to have a very high level of reliability such as automatic sprinkler and alarm systems. Where these systems are present, installed and maintained to an approved national or international Standard, then they can be always assumed to operate and their failure need not be considered in this *design scenario*.

Extract from C/VM2: Paragraph 4.10

This particular scenario focuses on the *ASET/RSET* life safety calculations performed as part of the *design scenario*: CF Challenging fire (see Paragraph 4.9). The robustness of the design shall be tested by considering the *design fire* with each key *fire safety system* rendered ineffective in turn.

For this scenario, where tenability criteria are evaluated, the engineer needs to assess these based on *FED* (CO).

Comment:
Ideally, a comprehensive quantitative probabilistic risk assessment would be used to assess the safety of a design. However, the risk assessment tools and supporting data are currently not suitable for inclusion within this Verification Method. Therefore, the framework currently requires a deterministic *ASET/RSET* approach with additional checks and balances to meet *Building Code* objectives.

As a general rule, when calculating *ASET* times, *fire safety systems* may be assumed to operate as designed, provided they are manufactured and installed in accordance with recognised national or international Standards. However, in the situations defined above, additional *fire safety systems* are required to provide redundancy and robustness to the *fire* safety design.

Method

In the circumstances described in the scenario, assume the failure of each key *fire safety system* in turn. If *ASET* cannot be shown to be greater than *RSET* when each key system fails, then the design must be altered until the requirements of this scenario can be satisfied.

If a design does not require a key *fire safety system* for *ASET>RSET*, there is no system to fail and the further robustness test is not required.

Extract from C/VM2 Appendix A (normative): Establishing Group Numbers for lining materials

Appendix A (normative): Establishing Group Numbers for lining materials

A1.1 Tests for material Group Numbers

Materials shall be assigned a material *Group Number* when tested to either:

a) ISO 9705 Fire tests – full scale room test for surface products, or

b) ISO 5660 Reaction to fire tests (Heat release, smoke production and mass loss rate) Part 1: Heat release rate (cone calorimeter method); and ISO 5660 Reaction to fire tests (Heat release, smoke production and mass loss rate) Part 2: Smoke production rate (dynamic measurement).

This is except in the following cases:

a) Metal-skin panel assemblies with *combustible* core materials, which shall only be assessed using either the ISO 9705 or ISO 13784 Part 1 test method, or

b) Foil-faced *combustible* materials, which shall only be assessed using the ISO 9705 test method, or

c) Other products that an accredited test laboratory believes are not appropriate to be evaluated using the ISO 5660 test method due to the configuration or other characteristics of the product. Such products shall be assessed using either the ISO 9705 test or another large scale test if deemed to be appropriate.

Comment:
ISO 5660 is unsuitable in cases where the *fire* performance of the assembly is dominated by the *construction* details rather than the flammability characteristics of the surface material or in cases where, due to the configuration of the material in the test, significant mechanical damage occurs at full scale which does not occur with small, horizontal samples.

A1. 2 Determining a material's Group Number when tested to ISO 9705

For a material tested to ISO 9705, the material's *Group Number* shall be determined as follows:

Group Number 1 material has total heat release not greater than 1 MW following exposure to 100 kW for 10 minutes then 300 kW for 10 minutes

Group Number 1–S material has total heat release not greater than 1 MW following exposure to 100 kW for 10 minutes then 300 kW for 10 minutes and the average smoke production rate over the period 0–20 min is not greater than 5.0 m^2/s

Group Number 2 material has total heat release not greater than 1 MW following exposure to 100 kW for 10 minutes

Group Number 2–S material has total heat release not greater than 1 MW following exposure to 100 kW for 10 minutes and the average smoke production rate over the period 0–10 min is not greater than 5.0 m^2/s

Group Number 3 material has total heat release not greater than 1 MW following exposure to 100 kW for 2 minutes, and

Group Number 4 material has total heat release greater than 1 MW following exposure to 100 kW for 2 minutes.

The rate of total heat release determined in ISO 9705 includes contribution from both the internal lining and the exposure source (100 kW or 300 kW).

The *Group Number* of a material predicted in accordance with Paragraph A1.3 using data obtained by testing the material at 50 kW/m^2 irradiance in the horizontal orientation with edge frame in accordance with ISO 5660 is given by:

Group Number 1 material: as predicted in accordance with Paragraph A1.3

Group Number 1-S material: as predicted in accordance with Paragraph A1.3 and an average *specific extinction area* less than 250 m^2/kg

Extract from C/VM2: 6 Appendix B (normative): Establishing Group Numbers for lining materials

Group Number 2 material: as predicted in accordance with Paragraph A1.3

Group Number 2-S material: as predicted in accordance with Paragraph A1.3 and an average *specific extinction area* less than 250 m^2/kg

Group Number 3 material: as predicted in accordance with Paragraph A1.3, and

Group Number 4 material: as predicted in accordance with Paragraph A1.3.

A1. 3 Determining a material's Group Number when tested to ISO 5660

For a material tested to ISO 5660, the material's *Group Number* must be determined in accordance with the following:

a) Data must be in the form of time and *HRR* pairs for the duration of the test. The time interval between pairs should not be more than 5 seconds. The end of the test (t_f) is determined as defined in ISO 5660, and

b) At least three replicate specimens must be tested.

The following five steps must be applied separately to each specimen:

Step 1: Determine time to ignition (t_{ig}). This is defined as the time (in seconds) when the *HRR* reaches or first exceeds a value of 50 kW/m^2.

Step 2: Calculate the Ignitability Index (I_{ig}) expressed in reciprocal minutes.

$$I_{ig} = \frac{60}{t_{ig}}$$

Step 3: Calculate the following two *HRR* indices:

$$IQ_1 = \int_{t_{ir}}^{t_i} \left[\frac{q''(t)}{(t - t_{ig})^{0.34}} \right]$$

$$IQ_2 = \int_{t_{ir}}^{t_i} \left[\frac{q''(t)}{(t - t_{ig})^{0.93}} \right]$$

Comment:
These definite integral expressions represent the area under a curve from the ignition time until the end of the test, where the parameter is plotted on the vertical axis and time (t) is plotted on the horizontal axis.

Step 4: Calculate the following three integral limits:

$IQ_{,10min} = 6800 - 540I_{ig}$

$IQ_{,2min} = 2475 - 165I_{ig}$

$IQ_{,12min} = 1650 - 165I_{ig}$

Step 5: Classify the material in accordance with the following:

i) If $IQ_1 > IQ_{10}$ min and $IQ_2 > IQ_2$ min, the material is a *Group Number* 4 material

ii) If $IQ_1 > IQ_{10}$ min and $IQ_2 \leq IQ_2$ min, the material is a *Group Number* 3 material

iii) If $IQ_1 \leq IQ_{10}$ min and $IQ_2 > IQ_{12}$ min, the material is a *Group Number* 2 material

iv) If $IQ_1 \leq IQ_{10}$ min and $IQ_2 \leq IQ_{12}$ min, the material is a *Group Number* 1 material, or

v) If the ignition criterion in Step 1 above is not reached, the material is a *Group Number* 1 material.

Repeat steps 1 to 5 above for each replicate specimen tested. If a different classification group is obtained for different specimens tested, then the highest (worst) classification for any specimen must be taken as the final classification for that material.

Comment:
It is expected that the *fire* testing laboratory will determine the material *Group Number* as described in this section when reporting the *fire* test results.

Appendix A: Methodology for Horizontal Fire Spread (Tabular Data)

This section is provided as a simpler alternative to calculation of *boundary fire* spread radiation. It is based on the design values and criteria given in Verification Method C/VM2 Paragraph 4.5.

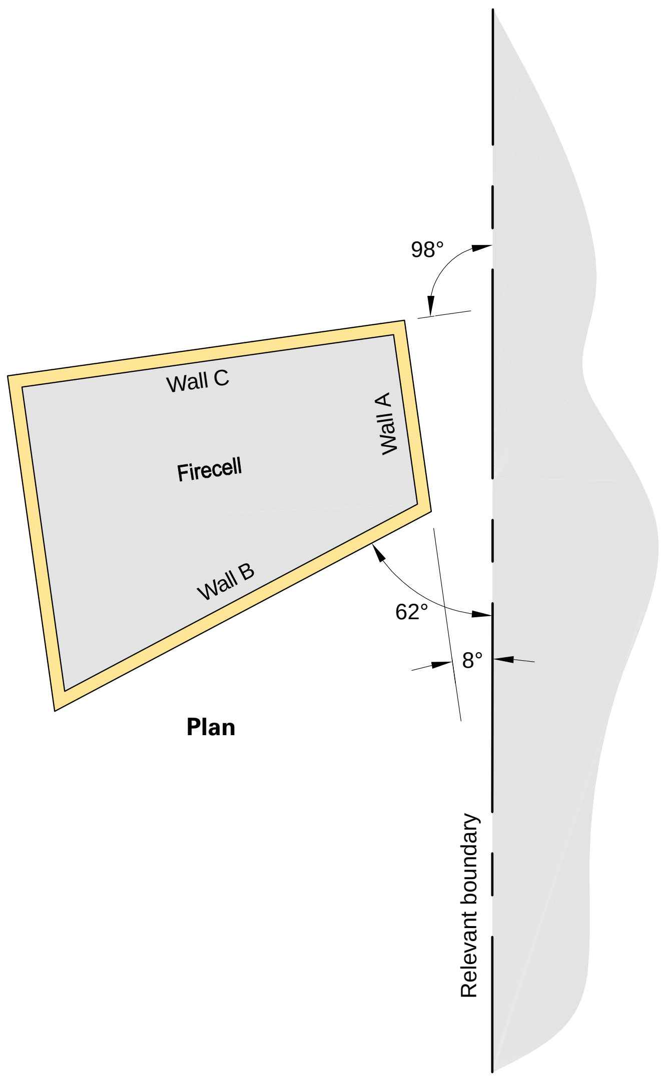
A1.0 Intersection Angle

The intersection angle is the angle produced between two horizontal lines, one being the line projected along the exterior face of a space bounded by *separating elements*, and the other being the *relevant boundary* (see Figure A1). For example, where *external walls* are parallel to one another, or to a *relevant boundary*, the intersection angle is zero degrees.

The following methods shall be applied depending on the intersection angle.

a) For angles of 10° or less, apply Methods 1 or 2.
b) For angles between 10° and 80°, apply Method 3.
c) For angles from 80° to 135°, apply Method 4.

Figure A1 Permitted unprotected areas in external walls adjacent to a relevant boundary



This example illustrates the situation where each of the methods 1, 2, 3 and 4 are used to restrict the size and/or location of *unprotected areas* in *external walls* close to the *relevant boundary* with *other property*.

Wall A: Intersection angle of 10° or less (shown as 8° in above example). If any part of the wall is within 1.0 m of the *relevant boundary* use Method 1. If the wall is 1.0 m or more from the *boundary* use Method 2.

Wall B: Intersection angle between 10° and 80° (shown as 62° in above example). Use Method 3 applying the case for *buildings* which are irregular or non-parallel to the *boundary*.

Wall C: Intersection angle from 80° to 135° (shown as 98° in above example). Use Method 4 for return walls and wing walls.

A2.0 Method 1 – Small openings and fire resisting glazing

The provisions for *external wall construction* are satisfied if:

a) *Unprotected areas* (Type A) and areas of *fire resisting glazing* (Type B) are located to comply with Figure A2, and
b) The remainder of the *wall* is *fire* rated equally for exposure to *fire* on both sides.

Size and spacing of Type A and Type B areas

Type A areas shall be no greater than 0.1 m^2. Type B areas shall be no greater than permitted by Table A1 according to the distance from the *relevant boundary*.

The *fire resisting glazing* shall be rated for *integrity* and the *FRR* of both the glazing and *external wall* shall be derived from the full *burnout design fire* as described in Verification Method C/VM2 Paragraph 2.4.

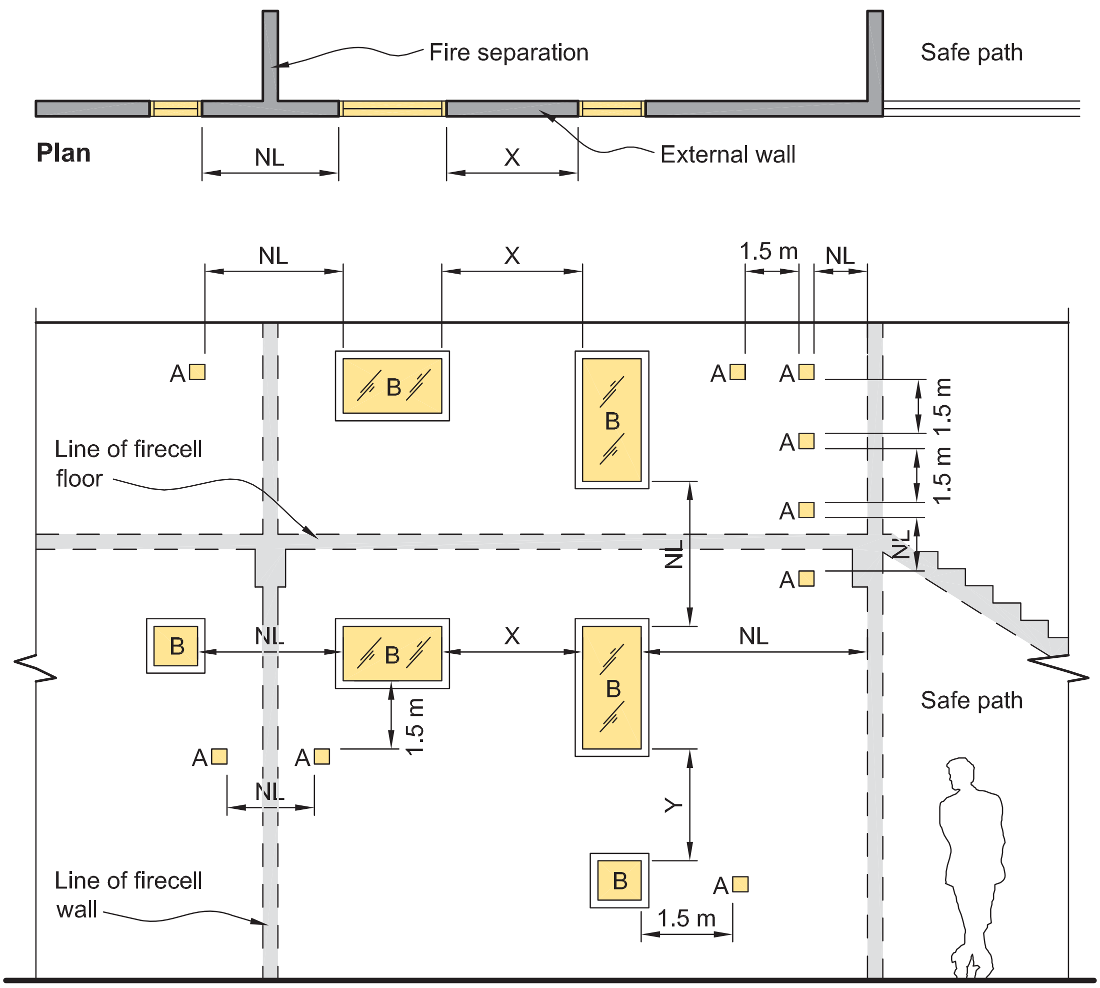
There is no limitation on the spacing between adjacent Type A and Type B areas which occur in different spaces bounded by *separating elements*. Within a space bounded by *separating elements* the following requirements shall apply:

a) Type A areas shall be no closer, both vertically and horizontally, than 1.5 m to another Type A or to a Type B area.
b) Type B areas shall be no closer to one another, vertically or horizontally, than the dimensions X or Y shown on Figure A2.

> Note
>
> To determine dimensions X and Y, measure the width and height of both the adjacent Type B areas. The minimum value for X is the greater of the two widths, and for Y the greater of the two heights.

c) Where Type B areas are staggered, rather than being aligned vertically or horizontally, the shortest distance, in any direction, between adjacent areas shall be no less than the greater of the X and Y measurements.

Figure A2 Permitted small unprotected areas and fire resisting glazing



Elevation

Dimensions shown are minimum distances between Type A unprotected areas and of Type B fire resisting glazing

Legend

A□ Type A *unprotected areas* of 0.1 m^2 maximum

B Type B areas of *fire resisting glazing* complying with Table A1

NL No limitation on spacing

X Spacing to be no less than the greater of the widths of the two Type B areas being considered

Y Spacing to be no less than the greater of the heights of the two Type B areas being considered

A3.0 Method 2 – Enclosing Rectangles – Parallel Boundary

This method is applied to *external walls* of *buildings* which are parallel to or angled at no more than 10º to the *relevant boundary*.

The method is used to calculate the percentage of *unprotected area* in the *external wall* of each space bounded by *separating elements* and allows the acceptable distance to the *relevant boundary*, for each *FLED* range, to be read from Table A2.

The calculation steps are:

Step 1 Determine the location of the *relevant boundary* or, for *buildings* on the same property, the *notional boundary*.

Step 2 For the *external wall* of each space bounded by *separating elements*, draw a rectangle enclosing all *unprotected areas* (and the protected areas between them). Determine the dimensions of the rectangle, and refer to Table A2. See Figure A3.

Step 3 Select the page of Table A2 for the applicable rectangle height.

Step 4 Select the panel in the table for the *FLED* of the enclosure being considered.

Step 5 Within that panel select the column for the appropriate rectangle width

Step 6 From the left hand column, select the distance from the *external wall* to the *relevant boundary*. For walls not parallel to the *relevant boundary*, the shortest distance between the *relevant boundary* and the closest *unprotected area* in the *external wall* shall be used.

Step 7 From the intersection point of the column chosen in Step 4 and the row chosen in Step 5, read the permitted percentage of *unprotected area*. If the intersection point falls within the shaded area, the permitted *unprotected area* is 100%.

Step 8 Where the enclosure is sprinklered, apply the increases permitted by Verification Method C/VM2 Paragraph 4.5.

Step 9 Identify the largest single *unprotected area* and treat it as an enclosing rectangle on its own (with 100% *unprotected area*). Check from Table A2 that the minimum permitted distance from the *boundary* to this *unprotected area* is no greater than used in Steps 5 and 8 above.

Note

1. The enclosing rectangle method assumes that *unprotected areas* will be fairly uniformly distributed openings over the total *external wall* of the *firecell*. Step 9 is a safety check to deal with the situation where a large *unprotected area* is concentrated in a single location. Heat radiation in most cases is more intense from a single opening than from several openings with the same total area.
2. Table A2 is based on the assumption that there is a limit to the area of enclosure subject to the full *fire* intensity at any one time. Therefore, the maximum rectangle width needing to be considered is either 20 m or 30 m depending on *FLED* and rectangle height.

In this example it is assumed that the *external wall* is parallel to the *relevant boundary*. Where the wall is not parallel to the *relevant boundary*, the enclosing rectangle is projected onto a reference plane, at right angles to that plane and the width dimension for applying Table A2 is reduced.

Figure A3 Method 2 Enclosing rectangles (unprotected area)

Rectangle construction

Diagram A, B and C demonstrate how, for a given *external wall* of a single *firecell*, dimensions of the enclosing rectangle (indicated by the rectangle diagonals) vary according to the extent and location of *fire* rated *construction*. The essential requirement is for the rectangle to enclose all *unprotected areas.* This means that such things as an isolated window or door or other non-*fire* rated part of the wall can significantly alter the rectangle dimensions and may include part of the *fire rated* wall.

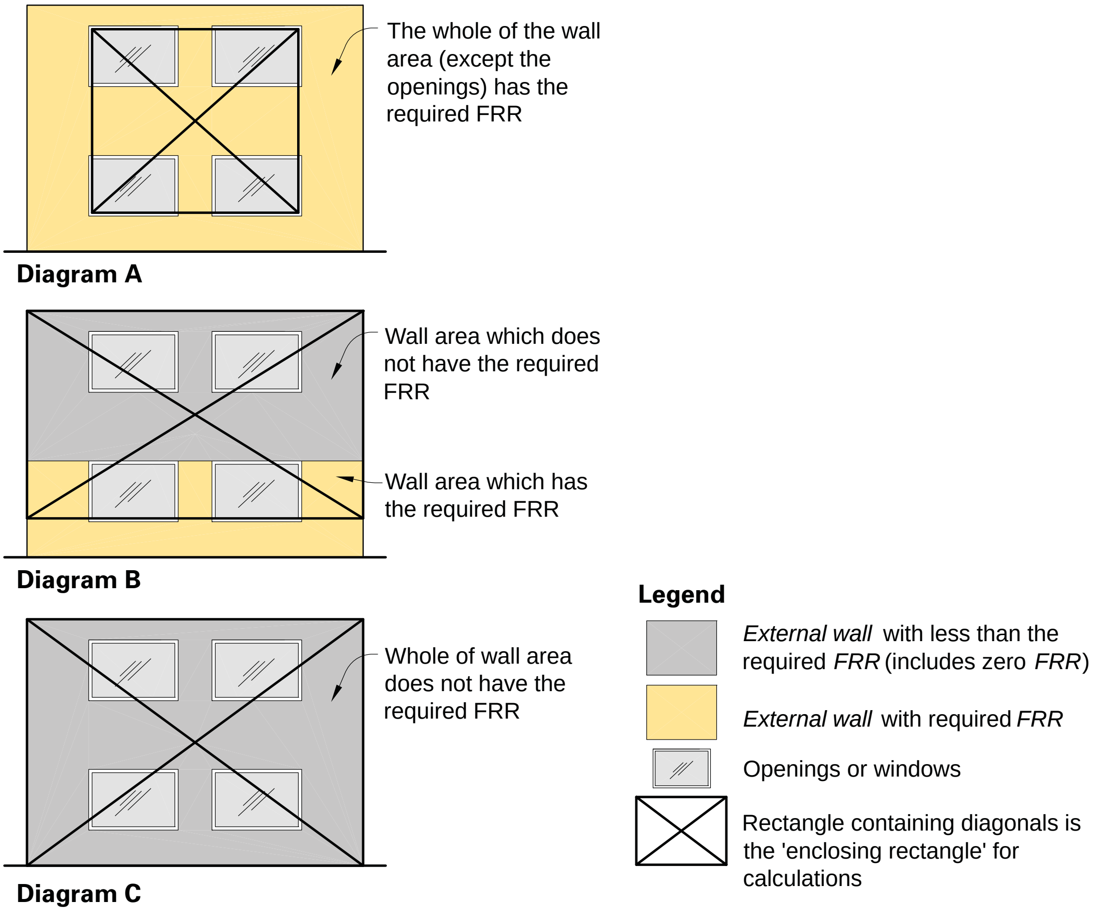


Table A2 may also be used to determine the required distance from the *relevant boundary* where the percentage of *unprotected area* has previously been determined. After Step 4 select the appropriate percentage (under the rectangle width column) and read the permitted distance to the *relevant boundary* from the left hand column of the table.

Where Table A2 does not contain the exact measurements for the enclosure being considered, use the next highest value (for rectangle height, width or *boundary* distance).

> Note
> Rectangle heights greater than 8.0 m require calculation by the engineer.

Advantages of additional firecells

For a given percentage of *unprotected area* in an *external wall*, the acceptable distance between wall and *relevant boundary* may be reduced by introducing additional *separating elements*. Alternatively, the introduction of additional *separating elements* allows an increase in *unprotected area* for a given distance to the *relevant boundary*.

> Note
> In most situations each floor of a multi-storey *building* is required to be a *fire separation*. Where this is not essential, there may still be advantages close to a *boundary* in having the space on each floor level as a space bounded by *separating elements*. The enclosing rectangle is further reduced by subdividing each floor level into a space bounded by *separating elements*.

A4.0 Method 3 – Enclosing rectangles – irregular buildings and non-parallel boundaries

This method applies where the building is of irregular shape or the intersection angle between the *external wall* and *relevant boundary* is between 10° and 80°.

The method (see Figure A4) is a variation of Method 2 and evaluates the enclosing rectangle on an assumed reference plane.

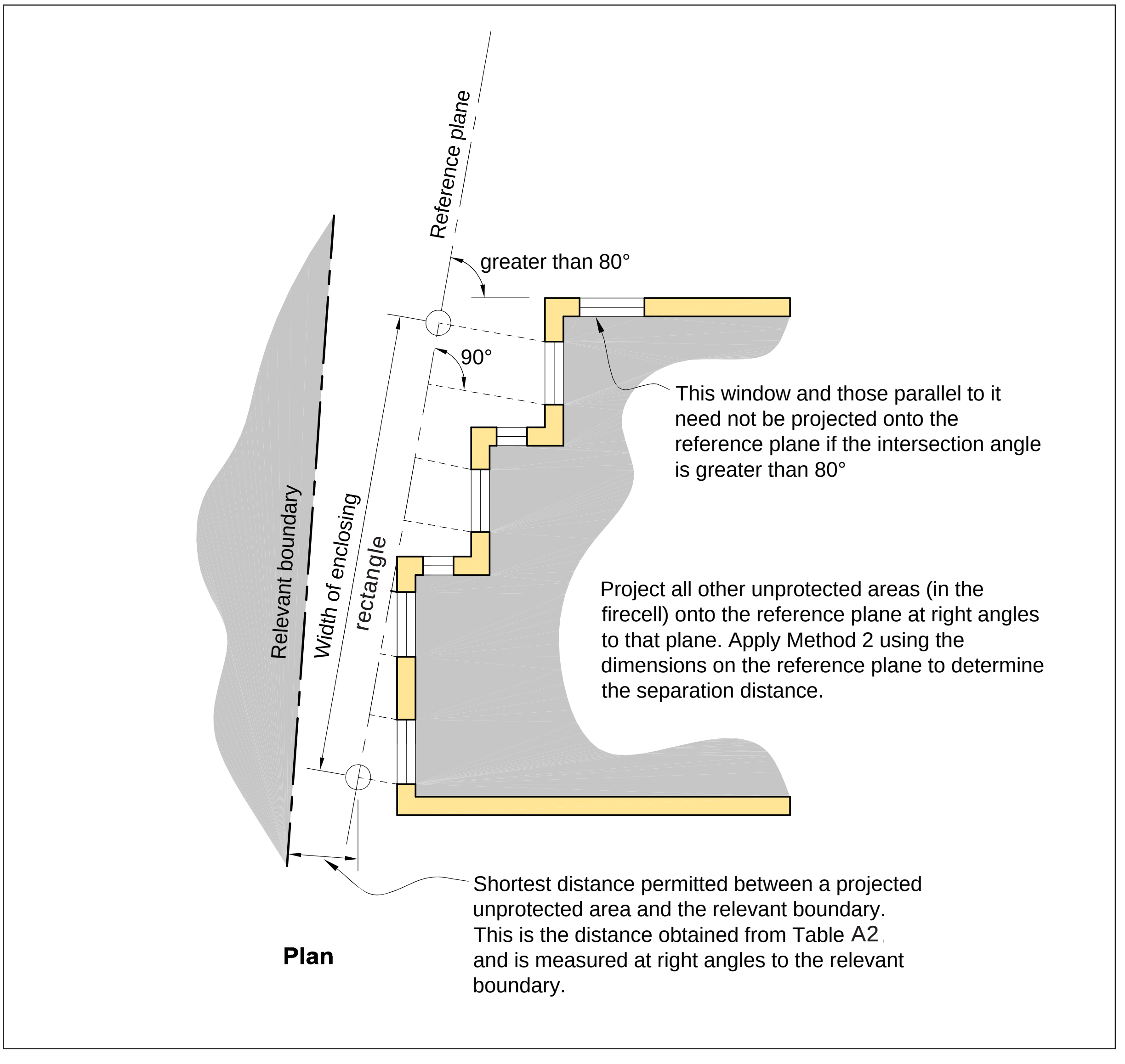
> Note
> Greatest advantage is obtained by locating the reference plane to achieve the maximum separation distance over the part of the wall having the largest *unprotected area*. In general, the most convenient location of the reference plane will be parallel to the *relevant boundary*.

The reference plane shall be vertical, touch at least one point on the *external wall*, and not cross the *relevant boundary* within the length of the enclosure. The plane shall not pass through the enclosure, but may pass through projections such as balconies or copings.

The enclosing rectangle is determined by projecting the *unprotected areas* onto the reference plane at right angles to the plane, and the distance to the *relevant boundary* used in the calculations shall be the shortest distance between that *boundary* and the closest projected *unprotected area* on the reference plane. *Unprotected areas* which are more than 80° to the reference plane are not included.

Once the enclosing rectangle is determined, follow the Steps 3 to 9 above.

Figure A4 Method 3 – Enclosing rectangles (irregular shaped buildings and non-parallel boundaries)



A5.0 Method 4 – Return walls and wing walls

A5.1 Other property or same property

For Method 4 there are two tables. Table A3.1 applies to the requirements for separation from the *relevant boundary* with *other property*. Table A3.2 applies to the separation requirements on the same property where either one or both *firecells* being considered contains a sleeping use or is a *safe path*. When using Table A3.2, separation distances are measured between *unprotected areas* in the *firecells* being considered, and the *notional boundary* coinciding with the *external wall* of the other *firecell*.

For intersection angles from 80º to 90º, minimum separation distances can be read directly from the tables.

For intersection angles between 90º and 135º (see Figure A4), the values read from the tables can be reduced as described in Paragraph A5.6.

A5.2 Return walls

Return wall requirements are determined from the formula

$$L_r = D_B - D_S$$

where:

L_r is the return wall length,

D_B is the minimum permitted distance between *unprotected areas*, in the *external wall* being considered, and the *relevant boundary*

D_S is the shortest distance between the *external wall* being considered and the *relevant boundary*

L_r, D_B and D_S are measured at right angles to the *relevant boundary* (see Figure A4).

A5.3 Wing walls

Wing wall lengths are determined from the formula:

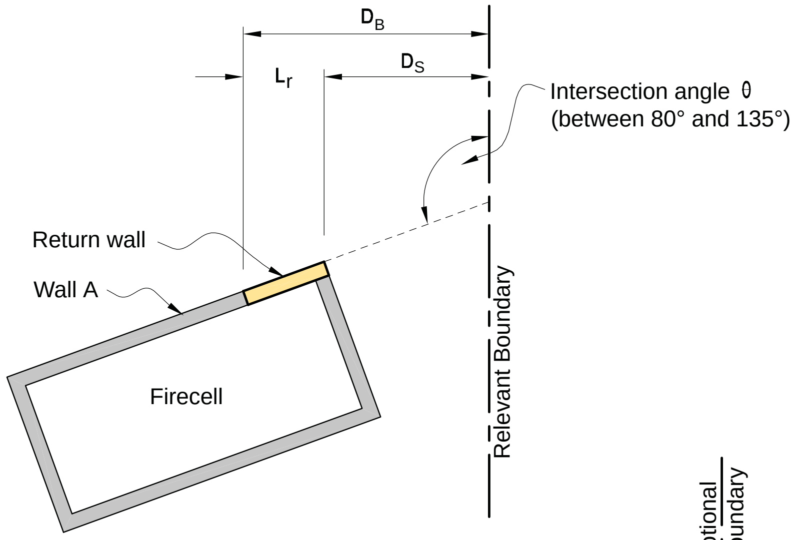
$$L_w = \frac{L_B \times L_r}{D_B}$$

where:

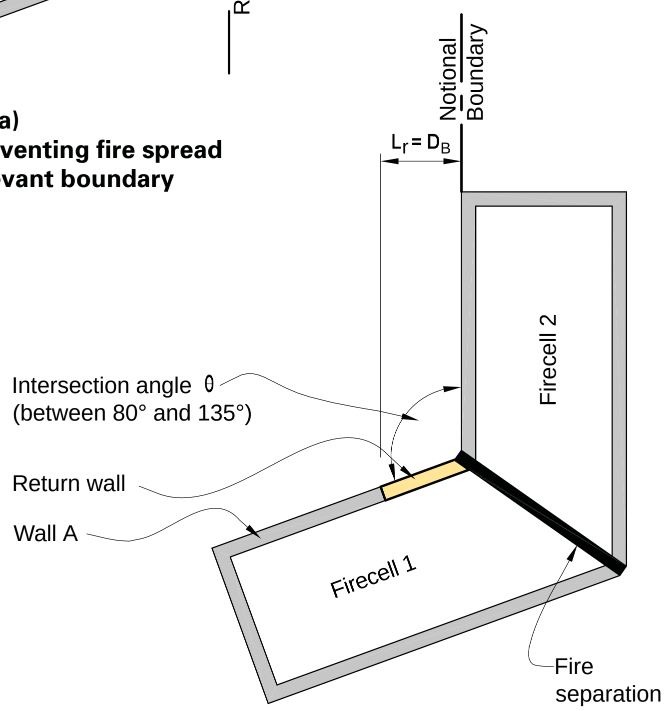
L_w is the wing wall length,
L_B is the wing wall length (from Table A3.1 or A3.2) if that wall is located on the *relevant boundary*,
L_r is the alternative return wall length as determined in Paragraph C5.2,
D_B is the minimum separation distance between *unprotected areas*, and the *relevant boundary* in the *external wall* being considered, if a return wall is used. (See Table A3.1 or A3.2.)

> Note
>
> It is more economical to use a return wall in the *firecell* of *fire* origin than to use a wing wall as a shield between that *firecell* and the property being protected.

Figure A5 Method 4 – Return walls on external walls having an intersection angle of between 80º and 135º with the relevant boundary or notional boundary



Plan (a)
Return wall length for preventing fire spread from wall A to the relevant boundary



Plan (b)
Return wall for preventing fire spread from the external wall of firecell 1 to firecell 2 in the same or adjoining building

Key

D_S = The shortest distance between the *external wall* being considered and the *relevant boundary.*

D_B = Minimum permitted distance between *unprotected areas* in a wall and the *relevant boundary* as determined from Table A3.1 for plan (a), or the *notional boundary* as determined from Table A3.2 for plan (b).

L_r = The required return wall length measured at right angles to the *relevant boundary* or *notional boundary* as applicable.

A5.4 Using Table A3.1 and Table A3.2

Tables A3.1 and A3.2 are based on *FLED* >800 MJ/m^2 but may be used for all values of *FLED*. Engineers may choose to calculate radiation levels following Verification Method C/VM2 if further economies in the dimensions of return or wing walls are required.

The steps are:

Step 1 Determine the shortest distance D_s between the *relevant boundary* and the nearest part of the *external wall* of the *firecell* being considered. (See Figure A4.)

Step 2 On the *external wall* draw a rectangle enclosing all the *unprotected areas* located within a distance of 20 m measured at right angles to the *relevant boundary*. The height of this rectangle is the equivalent opening height h_{eq}.

> Note
>
> It is assumed that *unprotected areas* more than 20 m from the *relevant boundary* do not pose a radiation threat.

Step 3 Sum the individual *unprotected areas* within the enclosing rectangle. This is the equivalent opening area A_o.

Step 4 Divide A_o by h_{eq} to obtain the equivalent opening width W_{eq}.

> Note
>
> Table A3.1 and Table A3.2 are based on the assumption that the equivalent opening area is located at the end of the wall nearest the *relevant boundary*. This is a conservative, but safe, simplification for determining the most severe thermal radiation likely to be emitted from a *fire* within the space bounded by *separating elements*.

Step 5 Choose either the return wall or wing wall section of the tables (according to the *construction* method proposed), and identify the row for the equivalent opening height h_{eq}.

Step 6 From the top row of the table, select the column for the equivalent opening width W_{eq}.

Step 7 At the intersection point of the row (from Step 5) and the column (from Step 6), read off the separation distance D_B for return walls, or the length L_B for wing walls.

Step 8 For return walls, determine the return wall length L_r from the formula $L_r = D_B – D_S$.

For wing walls, determine the wing wall length from the formula:

$$L_w = \frac{L_B \times L_r}{D_B}$$

On the *relevant boundary,* $D_S = 0$ and therefore for a return wall $L_r = D_B$ and for a wing wall $L_w = L_B$. If D_B is equal to or greater than D_S, the formula produces a zero or negative result and there is no requirement for a return wall or wing wall.

A5.5 Sprinklered firecells

Wing walls and return walls are not required where the enclosure is sprinklered.

A5.6 Intersection angles of between 90° and 135°

As the intersection angle increases beyond 90°, the return wall length and wing wall length can be reduced linearly to give shorter return walls or wing walls by applying the formula:

$$L_r = \left(\frac{135 - \Theta}{45}\right) x\ (D_B - D_S), \text{ or}$$

$$L_w = \left(\frac{135 - \Theta}{45}\right) x \left(\frac{L_B \ x\ L_r}{D_B}\right)$$

where Θ is the intersection angle. The reduction in the values of D_B and L_B for sprinklers (see Paragraph A5.5) may be applied.

Note that the formula does not apply to intersection angles of less than 90°.

> Note
>
> As an example of using the reduction formula, if the intersection angle is 112º (which is halfway between 90º and 135º), the value taken from Table A3.1 or Table A3.2 may be halved.

Table A1	Permitted areas of fire resisting glazing		
	Minimum distance to *relevant boundary* unsprinklered *firecells* (m)		
Glazing area m^2	< 400 MJ/m^2	400 – 800 MJ/m^2	> 800 MJ/m^2
1.0 or less	0.0	0.0	0.0
1.5	0.5	0.6	0.9
2.0	0.5	0.7	1.0
2.5	0.6	0.8	1.1
3.0	0.6	0.9	1.2
3.5	0.7	0.9	1.3
4.0	0.7	1.0	1.4
4.5	0.8	1.0	1.4
5.0	0.8	1.1	1.5
5.5	0.9	1.1	1.6
6.0	0.9	1.2	1.7
6.5	0.9	1.2	1.7
7.0	1.0	1.3	1.8
7.5	1.0	1.3	1.9
8.0	1.0	1.4	2.0
8.5	1.1	1.5	2.1
9.0	1.2	1.5	2.2
9.5	1.2	1.6	2.3
10.0	1.3	1.7	2.4
10.5	1.3	1.7	2.4
11.0	1.4	1.8	2.5
11.5	1.4	1.9	2.6
12.0	1.5	1.9	2.7
12.5	1.5	2.0	2.8
13.0	1.6	2.0	2.8
13.5	1.6	2.1	2.9
14.0	1.7	2.2	3.0
14.5	1.7	2.2	3.0
15.0	1.8	2.3	3.1
For sprinklered *firecells*, the area of *fire resisting glazing* is unlimited and may be any distance from the *relevant boundary*.			

Table A2.1 **Height of enclosing rectangle 1.0 m**

Distance to *relevant boundary* (m)	Percentage permitted unprotected area																								
	FLED < 400 MJ/m²								FLED 400–800 MJ/m²								FLED > 800 MJ/m²								
	Width of the enclosing rectangle (m)								Width of the enclosing rectangle (m)								Width of the enclosing rectangle (m)								
	2	3	4	6	8	10	15	20	2	3	4	6	8	10	15	20	2	3	4	6	8	10	15	20	30
1.0	100	89	85	82	81	81	80	80	81	71	68	66	66	65	65	64	58	51	49	47	47	47	46	46	46
1.1	100	98	92	89	87	85	84	84	91	79	75	72	70	69	68	67	65	56	53	51	50	49	48	48	48
1.2		100	100	96	92	90	88	87	100	87	81	78	74	72	71	70	73	62	58	56	53	52	51	50	50
1.3				100	96	94	92	91	100	95	88	82	78	76	74	73	81	68	63	59	56	54	53	53	52
1.4					100	98	96	95		100	96	87	81	79	77	77	90	74	68	62	58	57	55	55	55
1.5						100	100	99			100	91	85	83	80	80	100	81	74	65	61	59	57	57	57
1.6								100			100	96	89	86	84	83	100	88	80	69	64	62	60	59	59
1.7												100	93	90	87	86		96	86	72	67	64	62	61	61
1.8												100	97	93	90	89		100	91	75	70	67	64	64	63
1.9													100	97	93	92		100	96	79	72	69	67	66	66
2.0														100	97	95			100	83	76	72	69	68	68
2.1															100	99			100	87	79	75	72	71	70
2.2																100			100	90	82	78	74	73	72
2.3																			100	94	85	81	76	75	74
2.4																			100	99	88	83	79	78	77
2.5																				100	92	86	81	80	79
2.6																				100	95	89	84	82	81
2.7																				100	99	92	86	85	83
2.8																					100	95	89	87	86
2.9																					100	99	91	89	88
3.0																						100	94	92	90
3.1																						100	97	94	93
3.3																							100	99	97
3.5																								100	100

Note: For enclosing rectangle widths greater than given in the table, an enclosing rectangle width of 20 m for FLED ≤800 MJ/m² and 30 m for FLED >800 MJ/m² may be used.

Table A2.2 Height of enclosing rectangle 2.0 m

Distance to *relevant boundary* (m)	Percentage permitted unprotected area																								
	FLED < 400 MJ/m²								FLED 400–800 MJ/m²								FLED > 800 MJ/m²								
	Width of the enclosing rectangle (m)								Width of the enclosing rectangle (m)								Width of the enclosing rectangle (m)								
	2	3	4	6	8	10	15	20	2	3	4	6	8	10	15	20	2	3	4	6	8	10	15	20	30
1.0	65	57	53	47	45	44	43	43	53	46	43	38	36	36	35	35	38	33	31	27	26	25	25	25	25
1.1	71	61	57	50	47	46	45	45	57	49	46	40	38	37	36	36	41	35	33	29	27	27	26	26	26
1.2	78	66	60	52	49	48	47	47	63	53	48	42	40	39	38	38	45	38	35	30	28	28	27	27	27
1.3	85	71	64	55	51	50	49	49	69	57	51	44	41	40	39	39	49	41	37	32	30	29	28	28	28
1.4	93	76	67	57	54	52	51	50	75	61	54	46	43	42	41	41	53	44	39	33	31	30	29	29	29
1.5	100	82	71	60	56	54	53	52	81	66	57	48	45	44	42	42	58	47	41	35	32	31	30	30	30
1.6	100	88	75	63	58	56	55	54	89	71	60	51	47	45	44	44	63	50	43	36	34	32	31	31	31
1.7	100	94	79	66	61	59	57	56	96	76	64	53	49	47	46	45	69	54	46	38	35	34	33	32	32
1.8		100	83	69	63	61	58	58	100	81	67	55	51	49	47	47	75	58	48	40	36	35	34	33	33
1.9		100	88	72	66	63	60	60	100	86	71	58	53	51	49	48	81	61	51	41	38	36	35	34	34
2.0		100	92	75	68	65	62	62	100	90	74	60	55	53	50	50	87	65	53	43	39	38	36	36	35
2.1		100	97	78	71	68	64	64	100	95	78	63	57	54	52	51	94	68	56	45	41	39	37	37	36
2.2		100	100	82	74	70	66	65		100	82	66	59	56	54	53	100	72	59	47	42	40	38	38	37
2.3			100	85	76	72	69	67		100	86	69	62	58	55	54	100	76	61	49	44	42	40	39	38
2.4			100	89	79	75	71	69		100	90	71	64	60	57	56	100	80	64	51	46	43	41	40	40
2.5			100	92	82	77	73	71		100	94	74	66	62	59	57	100	84	67	53	47	45	42	41	41
2.6			100	96	85	80	75	73		100	99	77	69	64	60	59	100	88	71	55	49	46	43	42	42
2.7				100	88	82	77	75			100	80	71	66	62	61	100	92	74	57	51	48	44	43	43
2.8				100	91	85	79	77			100	84	73	69	64	62	100	96	77	60	53	49	46	45	44
2.9				100	94	88	81	79			100	87	76	71	66	64	100	100	80	62	54	51	47	46	45
3.0				100	98	90	84	81			100	90	79	73	67	66		100	84	64	56	52	48	47	46
4.0					100	100	100	100			100	100	100	97	86	83			100	91	77	69	62	59	57
5.0														100	100	100				100	100	90	77	72	69
6.0																						100	94	86	81
7.0																							100	100	94
7.5																									100

Note: For enclosing rectangle widths greater than given in the table, an enclosing rectangle width of 20 m for FLED ≤800 MJ/m² and 30 m for FLED >800 MJ/m² may be used.

Table A2.3 Height of enclosing rectangle 3.0 m

Distance to *relevant boundary* (m)	Percentage permitted unprotected area																							
	FLED < 400 MJ/m²								FLED 400–800 MJ/m²								FLED > 800 MJ/m²								
	Width of the enclosing rectangle (m)								Width of the enclosing rectangle (m)								Width of the enclosing rectangle (m)								
	2	3	4	6	8	10	15	20	2	3	4	6	8	10	15	20	2	3	4	6	8	10	15	20	30
1.0	57	47	40	35	34	33	32	32	46	38	33	29	27	27	26	26	33	27	23	20	19	19	19	19	19
1.1	61	49	43	37	35	34	34	33	49	40	34	30	28	28	27	27	35	29	24	21	20	20	19	19	19
1.2	66	52	45	39	36	35	35	34	53	42	36	31	29	29	28	28	38	30	26	22	21	20	20	20	20
1.3	71	55	47	40	38	37	36	35	57	45	38	32	30	30	29	29	41	32	27	23	22	21	21	20	20
1.4	76	59	49	42	39	38	37	37	61	47	40	34	32	31	30	29	44	34	28	24	23	22	21	21	21
1.5	82	62	52	44	41	39	38	38	66	50	42	35	33	32	31	30	47	36	30	25	23	23	22	22	22
1.6	88	65	55	46	42	41	39	39	71	53	44	37	34	33	32	31	50	38	31	26	24	23	23	22	22
1.7	94	69	57	47	44	42	40	40	76	56	46	38	35	34	33	32	54	40	33	27	25	24	23	23	23
1.8	100	73	60	49	45	43	42	41	81	59	48	40	36	35	34	33	58	42	35	28	26	25	24	24	24
1.9	100	77	63	51	47	45	43	42	86	62	51	41	38	36	35	34	61	44	36	30	27	26	25	24	24
2.0	100	81	66	53	49	46	44	44	90	65	53	43	39	37	36	35	65	46	38	31	28	27	25	25	25
2.1	100	85	69	56	50	48	45	45	95	68	56	45	41	39	37	36	68	49	40	32	29	28	26	26	26
2.2	100	89	72	58	52	49	47	46	100	72	58	47	42	40	38	37	72	51	42	33	30	28	27	27	26
2.3	100	93	76	60	54	51	48	47	100	75	61	48	43	41	39	38	76	54	44	35	31	29	28	27	27
2.4	100	98	79	62	56	52	49	49	100	79	64	50	45	42	40	39	80	56	46	36	32	30	28	28	28
2.5		100	82	65	58	54	51	50	100	83	66	52	46	44	41	40	84	59	48	37	33	31	29	29	28
2.6		100	86	67	59	56	52	51	100	86	69	54	48	45	42	41	88	62	50	39	34	32	30	29	29
2.7		100	90	70	61	57	54	52	100	90	72	56	50	46	43	42	92	65	52	40	35	33	31	30	30
2.8		100	94	72	63	59	55	54	100	94	75	58	51	48	44	43	96	68	54	42	37	34	32	31	30
2.9		100	97	75	66	61	56	55	100	99	79	60	53	49	45	44	100	71	56	43	38	35	32	32	31
3.0			100	78	68	63	58	56		100	82	63	55	51	47	45	100	74	58	45	39	36	33	32	32
4.0				100	91	82	73	70			100	87	74	66	59	56		100	85	62	53	48	42	40	39
5.0					100	100	90	85				100	96	85	73	68			100	84	69	61	52	49	47
6.0							100	100					100	100	89	82				100	88	77	63	58	55
7.0															100	96					100	94	76	69	63
8.0																100						100	90	80	72
9.0																							100	92	82
10.0																							100	100	91
10.8																									100

Note: For enclosing rectangle widths greater than given in the table, an enclosing rectangle width of 20 m for FLED ≤800 MJ/m² and 30 m for FLED >800 MJ/m² may be used.

Table A2.4	Height of enclosing rectangle 4.0 m																								
Distance to *relevant boundary* (m)	Percentage permitted unprotected area																								
	FLED < 400 MJ/m²								FLED 400–800 MJ/m²								FLED > 800 MJ/m²								
	Width of the enclosing rectangle (m)								Width of the enclosing rectangle (m)								Width of the enclosing rectangle (m)								
	2	3	4	6	8	10	15	20	2	3	4	6	8	10	15	20	2	3	4	6	8	10	15	20	30
1.0	53	40	35	30	29	28	28	27	43	33	28	24	23	23	22	22	31	23	20	17	17	16	16	16	16
1.1	57	43	36	31	30	29	28	28	46	34	29	25	24	23	23	23	33	24	21	18	17	17	16	16	16
1.2	60	45	38	33	31	30	29	29	48	36	31	26	25	24	23	23	35	26	22	19	18	17	17	17	17
1.3	64	47	40	34	32	31	30	30	51	38	32	27	25	25	24	24	37	27	23	19	18	18	17	17	17
1.4	67	49	42	35	33	32	31	30	54	40	33	28	26	25	25	24	39	28	24	20	19	18	18	17	17
1.5	71	52	43	36	34	32	31	31	57	42	35	29	27	26	25	25	41	30	25	21	19	19	18	18	18
1.6	75	55	45	38	35	33	32	32	60	44	37	30	28	27	26	26	43	31	26	22	20	19	19	18	18
1.7	79	57	47	39	36	34	33	33	64	46	38	31	29	28	27	26	46	33	27	22	21	20	19	19	19
1.8	83	60	49	40	37	35	34	34	67	48	40	33	30	29	27	27	48	35	29	23	21	20	20	19	19
1.9	88	63	52	42	38	36	35	34	71	51	42	34	31	29	28	28	51	36	30	24	22	21	20	20	20
2.0	92	66	54	43	39	37	36	35	74	53	43	35	32	30	29	28	53	38	31	25	23	22	21	20	20
2.1	97	69	56	45	41	39	37	36	78	56	45	36	33	31	30	29	56	40	32	26	23	22	21	21	21
2.2	100	72	59	47	42	40	38	37	82	58	47	38	34	32	30	30	59	42	34	27	24	23	22	21	21
2.3	100	76	61	48	43	41	38	38	86	61	49	39	35	33	31	30	61	44	35	28	25	24	22	22	22
2.4	100	79	64	50	45	42	39	39	90	64	51	40	36	34	32	31	64	46	37	29	26	24	23	22	22
2.5	100	82	66	52	46	43	40	40	94	66	53	42	37	35	33	32	67	48	38	30	27	25	23	23	23
2.6	100	86	69	54	47	44	41	40	99	69	56	43	38	36	33	33	71	50	40	31	27	26	24	23	23
2.7	100	90	72	56	49	46	42	41	100	72	58	45	39	37	34	33	74	52	41	32	28	26	24	24	24
2.8	100	94	75	57	50	47	43	42	100	75	60	46	41	38	35	34	77	54	43	33	29	27	25	24	24
2.9	100	97	78	59	52	48	44	43	100	79	62	48	42	39	36	35	80	56	45	34	30	28	26	25	25
3.0		100	81	61	53	49	45	44	100	82	65	50	43	40	37	36	84	58	46	35	31	28	26	25	25
4.0			100	84	71	64	57	54		100	92	68	57	52	46	44	100	85	66	49	41	37	33	31	30
5.0				100	92	81	70	65			100	90	74	66	56	53		100	90	65	53	47	40	38	36
6.0					100	100	84	77				100	94	82	68	62			100	84	67	59	48	45	42
7.0							100	90					100	100	81	73				100	84	72	58	52	48
8.0								100						100	95	84					100	87	68	60	55
9.0															100	97						100	79	69	62
10.0																100						100	92	79	69
11.0																							100	90	77
12.0																								100	85
13.0																								100	94
13.7																									100

Note: For enclosing rectangle widths greater than given in the table, an enclosing rectangle width of 20 m for FLED ≤800 MJ/m² and 30 m for FLED >800 MJ/m² may be used.

Table A2.5 Height of enclosing rectangle 6.0 m

Distance to *relevant boundary* (m)	Percentage permitted unprotected area																								
	FLED < 400 MJ/m²								FLED 400–800 MJ/m²								FLED > 800 MJ/m²								
	Width of the enclosing rectangle (m)								Width of the enclosing rectangle (m)								Width of the enclosing rectangle (m)								
	2	3	4	6	8	10	15	20	2	3	4	6	8	10	15	20	2	3	4	6	8	10	15	20	30
1.0	47	35	30	26	25	24	23	23	38	29	24	21	20	19	19	19	27	20	17	15	14	14	14	13	13
1.1	50	37	31	27	25	25	24	24	40	30	25	22	20	20	19	19	29	21	18	16	15	14	14	14	14
1.2	52	39	33	28	26	25	24	24	42	31	26	22	21	20	20	19	30	22	19	16	15	14	14	14	14
1.3	55	40	34	28	26	26	25	24	44	32	27	23	21	21	20	20	32	23	19	16	15	15	14	14	14
1.4	57	42	35	29	27	26	25	25	46	34	28	24	22	21	20	20	33	24	20	17	16	15	15	14	14
1.5	60	44	36	30	28	27	26	25	48	35	29	24	22	21	21	20	35	25	21	17	16	15	15	15	15
1.6	63	46	38	31	28	27	26	26	51	37	30	25	23	22	21	21	36	26	22	18	16	16	15	15	15
1.7	66	47	39	32	29	28	27	26	53	38	31	26	23	22	21	21	38	27	22	18	17	16	15	15	15
1.8	69	49	40	33	30	28	27	27	55	40	33	26	24	23	22	22	40	28	23	19	17	16	16	15	15
1.9	72	51	42	34	31	29	28	27	58	41	34	27	25	23	22	22	41	30	24	19	18	17	16	16	16
2.0	75	53	43	35	31	30	28	28	60	43	35	28	25	24	23	22	43	31	25	20	18	17	16	16	16
2.1	78	56	45	36	32	30	29	28	63	45	36	29	26	24	23	23	45	32	26	21	19	17	17	16	16
2.2	82	58	47	37	33	31	29	29	66	47	38	30	27	25	24	23	47	33	27	21	19	18	17	17	16
2.3	85	60	48	38	34	32	30	29	69	48	39	31	27	26	24	24	49	35	28	22	19	18	17	17	17
2.4	89	62	50	39	35	32	30	30	71	50	40	32	28	26	24	24	51	36	29	23	20	19	17	17	17
2.5	92	65	52	40	36	33	31	30	74	52	42	32	29	27	25	24	53	37	30	23	20	19	18	17	17
2.7	100	70	56	43	37	35	32	31	80	56	45	34	30	28	26	25	57	40	32	25	22	20	19	18	18
3.0	100	78	61	47	40	37	34	33	90	63	50	38	33	30	27	27	64	45	35	27	23	21	20	19	19
4.0		100	84	62	52	47	41	39	100	87	68	50	42	38	33	32	91	62	49	36	30	27	24	23	22
5.0			100	81	66	58	49	46		100	90	65	53	47	40	37	100	84	65	46	38	33	28	27	25
6.0				100	82	71	59	54			100	83	66	58	47	44		100	84	59	48	41	34	31	29
7.0					100	87	70	63				100	82	70	56	51			100	74	58	50	40	36	33
8.0						100	81	72				100	99	84	66	58			100	90	71	60	47	42	38
9.0						100	95	82					100	99	76	66				100	85	71	54	48	42
10.0							100	94						100	88	75					100	83	63	54	47
11.0								100							100	85					100	97	72	61	52
12.0															100	96						100	82	68	58
13.0																100						100	92	77	63
14.0																							100	85	69
16.0																								100	83
18.4																									100

Note: For enclosing rectangle widths greater than given in the table, an enclosing rectangle width of 20 m for FLED ≤800 MJ/m² and 30 m for FLED >800 MJ/m² may be used.

Table A2.6	Height of enclosing rectangle 8.0 m																								
Distance to *relevant boundary* (m)	Percentage permitted unprotected area																								
	FLED < 400 MJ/m^2								FLED 400–800 MJ/m^2								FLED > 800 MJ/m^2								
	Width of the enclosing rectangle (m)								Width of the enclosing rectangle (m)								Width of the enclosing rectangle (m)								
	2	3	4	6	8	10	15	20	2	3	4	6	8	10	15	20	2	3	4	6	8	10	15	20	30
1.0	45	34	29	25	23	23	22	22	36	27	23	20	19	18	18	17	26	19	17	14	13	13	13	13	12
1.1	47	35	30	25	24	23	22	22	38	28	24	20	19	18	18	18	27	20	17	15	14	13	13	13	13
1.2	49	36	31	26	24	23	22	22	40	29	25	21	19	19	18	18	28	21	18	15	14	13	13	13	13
1.3	51	38	32	26	24	24	23	22	41	30	25	21	20	19	18	18	30	22	18	15	14	14	13	13	13
1.4	54	39	33	27	25	24	23	23	43	32	26	22	20	19	19	19	31	23	19	16	14	14	13	13	13
1.5	56	41	34	28	25	24	23	23	45	33	27	22	20	20	19	19	32	23	19	16	15	14	13	13	13
2.0	68	49	39	31	28	26	25	24	55	39	32	25	23	21	20	20	39	28	23	18	16	15	14	14	14
2.5	82	58	46	36	31	29	27	26	66	46	37	29	25	23	22	21	47	33	27	20	18	17	15	15	15
3.0	98	68	53	40	35	32	29	28	79	55	43	33	28	26	23	23	56	39	31	23	20	18	17	16	16
4.0	100	91	71	52	43	39	34	32	100	74	57	42	35	31	27	26	77	53	41	30	25	22	20	19	18
5.0		100	92	66	54	47	40	37	100	96	74	53	43	38	32	30	100	69	53	38	31	27	23	22	21
6.0			100	82	66	57	47	43		100	94	66	53	46	38	35	100	88	67	48	38	33	27	25	23
7.0				100	81	69	55	49		100	100	82	65	55	44	40		100	84	58	46	40	32	28	26
8.0				100	97	82	64	56			100	99	78	66	51	45			100	71	56	47	37	33	29
9.0					100	96	74	64				100	92	77	59	52			100	85	66	55	42	37	33
10.0						100	84	72					100	90	68	58				100	78	65	49	42	36
11.0						100	96	81						100	77	66				100	90	75	55	47	40
12.0							100	91						100	88	73					100	86	63	53	44
14.0								100							100	91						100	79	65	53
17.0																100							100	87	68
20.0																							100	100	86
22.2																									100

Note: For enclosing rectangle widths greater than given in the table, an enclosing rectangle width of 20 m for FLED ≤800 MJ/m^2 and 30 m for FLED >800 MJ/m^2 may be used.

Table A3.1 **Method 4 – Return walls and wing walls for unsprinklered firecells: Protection of other property**

Equivalent opening height h_{eq} (m)	Return walls: Minimum separation distance between *unprotected areas* and *notional boundary* D_S (m) — Equivalent opening width W_{eq} (m)								Equivalent opening height h_{eq} (m)	Wing walls: Minimum length of wing wall if located on the *relevant boundary* L_S (m) — Equivalent opening width W_{eq} (m)							
	1	2	3	4	6	8	10	20		1	2	3	4	6	8	10	20
1	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	1	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7
2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	2	0.6	0.9	1.1	1.2	1.2	1.3	1.3	1.3
3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	3	0.7	1.1	1.4	1.6	1.7	1.8	1.9	1.9
4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	4	0.7	1.2	1.6	1.8	2.1	2.3	2.4	2.5
6	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	6	0.7	1.3	1.9	2.2	2.7	3.1	3.3	4.4
8	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.7	8	0.7	1.4	2.0	2.5	3.2	3.6	5.2	6.3
10	0.4	0.4	0.4	0.4	0.5	0.6	0.7	0.9	10	0.7	1.4	2.1	2.6	3.4	4.1	6.1	7.9

Table A3.2 **Method 4 – Return walls and wing walls for unsprinklered firecells: protection of sleeping occupancies or safe paths on the same property**

Equivalent opening height h_{eq} (m)	Return walls: Minimum separation distance between *unprotected areas* and *notional boundary* D_S (m) — Equivalent opening width W_{eq} (m)								Equivalent opening height h_{eq} (m)	Wing walls: Minimum length of wing wall if located on the *relevant boundary* L_S (m) — Equivalent opening width W_{eq} (m)							
	1	2	3	4	6	8	10	20		1	2	3	4	6	8	10	20
1	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	1	0.8	1.1	1.2	1.3	1.3	1.4	1.4	1.4
2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	2	1.0	1.5	1.9	2.1	2.3	2.5	2.6	2.7
3	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.6	3	1.1	1.8	2.3	2.6	3.1	3.4	3.6	3.9
4	0.4	0.4	0.5	0.6	0.7	0.8	0.8	0.9	4	1.2	2.0	2.6	3.1	3.7	4.2	4.4	5.1
6	0.4	0.5	0.7	0.8	1.0	1.1	1.1	1.2	6	1.2	2.2	3.0	3.6	4.6	5.2	5.8	7.2
8	0.4	0.5	0.7	0.9	1.1	1.3	1.4	1.5	8	1.2	2.3	3.2	4.0	5.2	6.2	6.8	8.8
10	0.4	0.5	0.8	1.0	1.3	1.4	1.5	1.9	10	1.2	2.4	3.4	4.2	5.6	6.7	7.6	10.5

Appendix B: Worked example applying the ten design scenarios

Contents

Tables

Figures

References in worked example

		Where referenced
Standards New Zealand		
NZS 4510: 2008	Fire Hydrant systems for buildings *Amend: 1*	B2.1
NZS 4512: 2010	Fire detection and alarm systems in buildings	B2.1, B3.4
NZS 4541: 2007	Automatic fire sprinkler systems	B2.1
Standards Australia		
AS 1366:-	Rigid cellular plastics sheets for thermal insulation	
Part 1: 1992	Rigid cellular polyurethane (RC/PUR) *Amend: 1*	B3.7
Part 2: 1992	Rigid cellular polyisocyanurate (RC/PIR)	B3.7
AS 1530:-	Methods for fire tests on building materials, components and structures	
Part 1: 1994	Combustibility test for materials	B3.5, B3.6
Part 4: 2005	Fire resistance tests of elements of construction	Table B2
International Organization for Standardization		
ISO 5660	Reaction-to-fire tests – Heat release, smoke production and mass loss rate	
Part 1: 2002	Heat release rate (cone calorimeter method)	B3.7
ISO 9239:	Reaction to fire tests for floorings	
Part 1: 2010	Determination of the burning behaviour using a radiant heat source	B3.7
ISO 9705: 1993	Fire tests – Full-scale room test for surface products	B3.7
BRANZ Ltd		
BRANZFIRE Software	Wade, C.A., "BRANZFIRE Technical Reference Guide", Study Report No. 92 (revised 2004), BRANZ Ltd, Porirua, New Zealand, 2004	B3.9, B6.0, Tables B11 and B12, Figure B3

	Where referenced
Society of Fire Protection Engineers	
The Handbook of Fire Protection Engineering, 4th Edition, National Fire Protection Association, Quincy, MA, USA, 2008.	
Gwynne, M V, and Rosenbaum, E R, "Employing the Hydraulic Model in Assessing Emergency Movement", Section 3 Chapter 13.	B3.8
Tewarson, A., "Generation of Heat and Gaseous Liquid and Solid Products in Fires", Section 3 Chapter 13	B3.8
Institution of Professional Engineers New Zealand	
IPENZ Practice Note 22: Guidelines for Documenting Fire Safety Designs	B1.0

B1.0 Purpose

The purpose of this example is to demonstrate how the ten *design scenarios* required by C/VM2 can be applied to a particular *building*. We have chosen a combined function centre and hotel complex as an example, as such a *building* illustrates a number of complexities for *fire* design.

Note that this example is intended to help clarify how the *design scenarios* are applied to a *building*, rather than to show all the documentation expected to be submitted as part of a specific fire engineering design using C/VM2. For a complete discussion of the expected documentation, please consult the IPENZ Practice Note 22: Guidelines for Documenting Fire Safety Designs.

B2.0 Building description

The intended use of this exemplar *building* is as a multi-purpose facility in a central city location. The *building* includes a function centre, restaurant and 12 levels of hotel accommodation.

Figure B1 shows the layout of the ground floor, mezzanine level, and a typical guest room level.

The ground floor comprises:

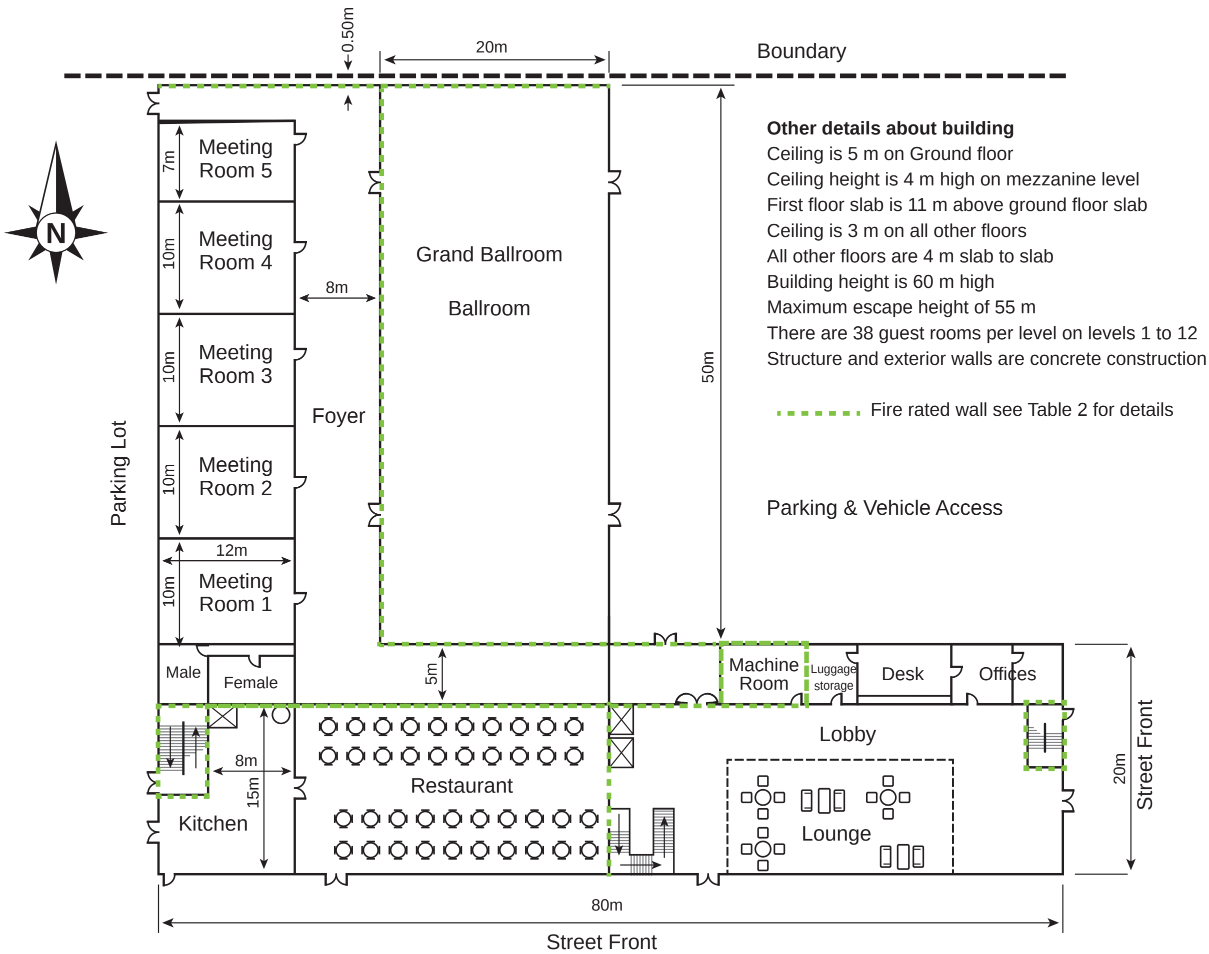
- the main function area, including a large ballroom
- five smaller meeting rooms
- a restaurant, and
- a hotel reception area, including a lounge and the hotel front desk/office.

The mezzanine level sits above the restaurant and is open to the hotel reception/lounge space by a floor-to-ceiling height opening that extends 9 m wide, from the lift shafts to the exterior wall, as shown in Figure 1. The mezzanine is intended as a multi-purpose space for activities such as receptions, dining and staff training.

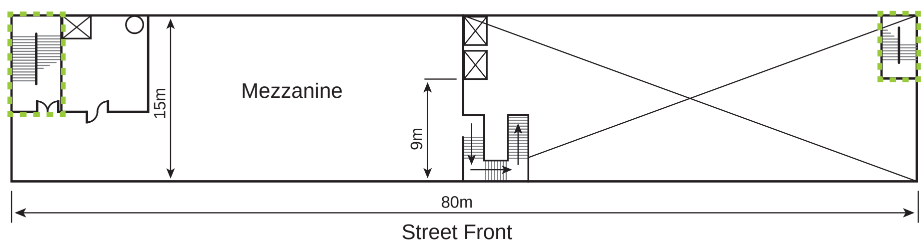
The primary fire safety features for the *building* are outlined in this section as part of the *building* description. This is in order to facilitate a full understanding of the fire safety strategies before analysing the *design scenarios*. The justification for each of the fire safety features is given in Section 3 under the individual *design scenarios*.

The *building* is designated as *Importance Level 3* in accordance with Clause A3 of Schedule 1 of the Building Amendment Regulations 2012 due to having an area where more than 300 people congregate.

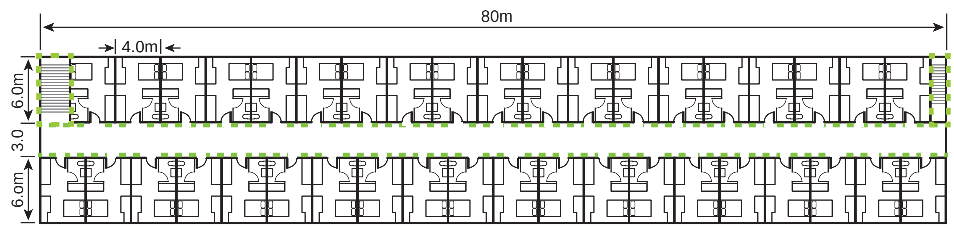
Figure B1: Floor plan for exemplar function centre and hotel showing the ground floor layout, mezzanine level and common hotel level plan



Ground Level - Function Centre and Hotel Lobby



Mezzanine Level - Function Centre



Level 1 to 12 - Hotel Guest Room Levels

B2.1 Fire safety systems

Other than requiring a means of alerting occupants, C/VM2 does not specify any particular fire safety systems in a *building*. The fire safety systems have been chosen by the design team as part of the overall fire safety strategy for this *building* and include:

- **Sprinkler system**: an automatic fire sprinkler system will be designed, installed and maintained in accordance with NZS 4541:2007. The sprinkler system will include quick response sprinklers. Design parameters to be used in the analysis for quick response sprinklers are specified in C/VM2 Table 3.2, although the actual installed system may not reflect these parameters.
- **Fire alarm system**: automatic smoke detection and manual call point systems will be installed and maintained in accordance with NZS 4512:2010 and Acceptable Solution F7/AS1.
- **Building fire hydrant system**: building fire hydrant systems will be installed in each of the two *stairways* in accordance with NZS 4510:2008.
- **Visibility in escape routes**: emergency lighting will be provided throughout the *building* as required by Acceptable Solution F6/AS1.
- **Signage**: signage identifying *escape routes*, *fire* and *smoke control doors* and manual call points will be provided as required by Acceptable Solution F8/AS1.

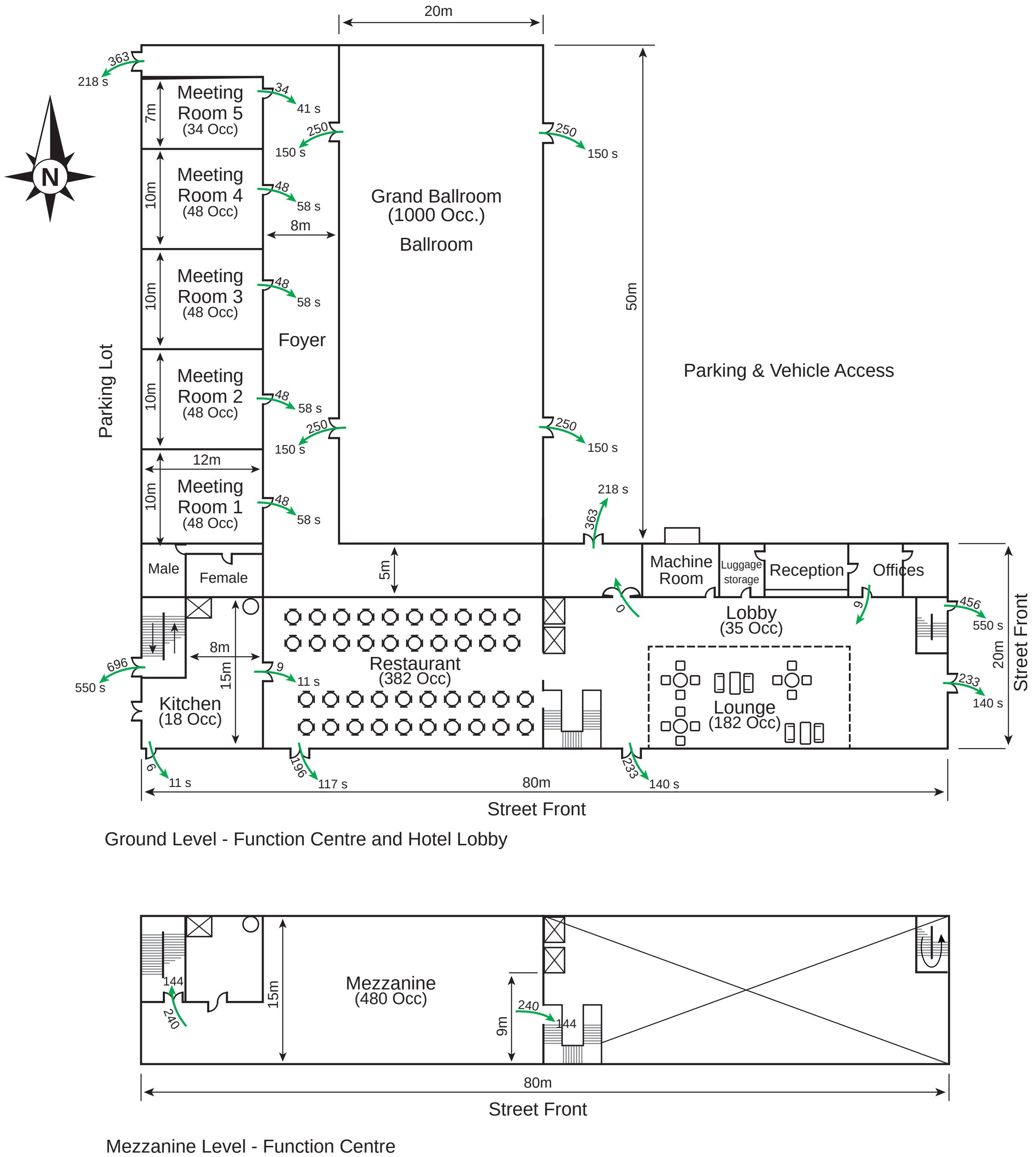
B2.2 Means of escape

The *building* includes a number of different activities.

Figure B1 shows the locations of these activities. Table B1 shows the space dimensions, number and distribution of the occupants for the normally *occupied spaces*, as well as the number of exits serving each space and the separation distance between each exit. The *occupant loads* are based on the floor area of each space and the *occupant density* is taken from Table 3.1 of C/VM2.

Evacuation of the spaces is governed by the flow time as a result of queuing at the doors, with the exception of the hotel guest rooms and the hotel offices. Figure B2 illustrates the layout of the exits and the number of occupants designed to use each exit. The arrows show the direction of travel for each exit door. The number given on the shaft of the arrow indicates the number of occupants expected to use the door for *means of escape from fire*, while the number at the tip of the arrow is the evacuation time in seconds required for all of the occupants to pass through the door. This is calculated using 50 people/minute/door leaf.

Figure B2: Evacuation routes and flows for the ground and mezzanine floors



Note:

The number on the arrow shaft represents the number of egressing occupants.

The number at the arrow tip represents the flow time based on 50 people/min/door leaf.

Table B1:	**Egress summary for number of exits available and separation distance between adjacent exits as required by design scenario BE: Fire blocks exit**						
Location	Space (m)	Floor area (m^2)	Ceiling height (m)	Occupant density (m^2/ person)	Number of occupants	Number of exits available (required)	Distance between exits
Ballroom	50x20	1000	5	1	1000	4 (2)	20
Meeting rooms	47x12	564	5	2.5	226	1 (1)	N/A
Foyer	55x8 +30x5 +12x3	576	5	0	0	2 (2)	95
Hotel office and front desk	18x5	90	5	10	9	1 (1)	N/A
Hotel reception	40x15	348	10	10	35	3 (2)	25
Lounge		200	10	1.1	182	3 (2)	25
Restaurant	28x15	420	4	1.1	382	2 (2)	25
Kitchen	15x10	150	4	10	18	2 (1)	12
Mezzanine	40x15*	528	5	1.1	480	2 (2)	37
Guest rooms level	4x6	37 beds/ floor	2.4	2/bed space	74	2 (2)	74

* Gross dimensions for space. Non-applicable areas have been subtracted from gross floor area.

Note:

Hallways and corridors are considered to be intermittent use spaces. Occupants in these spaces are considered to be included in the *occupant loads* of the locations of use listed in this table.

Layout of escape routes

All rooms have at least two exits, with the exception of the small meeting room configuration, the hotel offices, the toilets and individual guest rooms, as these each have *occupant loads* of fewer than 50 people. The exits are separated by a distance of at least 8 m when up to 250 occupants are required to use the *escape routes*, or at least 20 m when more than 250 occupants are required to use the *escape routes*.

Width and height of escape routes

All egress doors on the ground floor and mezzanine will be 950 mm wide and 2100 mm high. The ground floor doors on the *escape routes* are fitted with panic fastenings except for the doors leading from the kitchen, office areas and guest rooms. Self-closers are fitted on all egress doors included in the *fire* rated walls along the *escape route*. According to the guidance given in Part 3 of this Commentary for C/VM2, the width of horizontal *escape routes* should not be less than 850 mm, the width of vertical *escape routes* should be not less than 1000 mm, and both should have a minimum height of 2100 mm. All *escape routes* will comply with this guidance.

Doors

Doors on *escape routes* are required to open in the direction of escape if there are more than 50 occupants using the doors (C/VM2 Paragraph 3.2.6). The doors as shown in Figure B2 comply with this requirement.

All exit door locking devices should be clearly visible, located where such a device would normally be expected, designed to be easily operated without a key or other security device, and allow the door to open in the normal manner.

Hold-open devices are to be fitted to *fire doors* where there is a reasonable probability that the door will be wedged open. As a minimum, the doors between the restaurant and hotel reception and those between the hotel reception and foyer shall be provided with automatic *hold-open devices*. The *hold-open devices* will be released by the activation of adjacent smoke detectors, which are part of the fire alarm system, and these will be located on both sides of the *doorset*.

Any doors that are electronically locked are required to unlock in the event of an alarm to allow people to escape.

Signage

Fire exit signage will be provided throughout the building in compliance with Acceptable Solution F8/AS1. Exit signage will be internally illuminated as part of the emergency lighting system. Signs are required on all *stairways* and corridor *smoke control doors* to identify them as *smoke control* or *fire doors* and to stipulate that they must be kept closed.

B2.3 Internal spread of fire

Figure B1 shows all of the *fire separations* as green lines. In most cases, these are designed to withstand *burnout*. Table B2 lists all *fire separations* and the required *fire resistance ratings* along with the relevant *design scenario*, the expectation for the *fire separation* and the design objective for the *fire separation*. The justification for the *fire resistance rating* for each element can be found in the relevant *design scenarios* discussed in Section B3 of this example. The required *fire resistance rating* for each element is calculated using the time equivalence formula described in C/VM2 Paragraph 2.4.4 and shown in Section B5.

Table B2:	Summary of the required fire resistance ratings			
Element location	Fire resistance rating† (minutes)	Design scenario	Expectation for the separation	Design objective
North wall of ballroom and north foyer	30	HS	Withstand *burnout*	Prevent spread to neighbouring property
West and south walls of the ballroom	30	CF	Withstand *burnout*	Maintain *occupant load* within a single *firecell* to 1000 people
North wall of restaurant, kitchen, hotel reception and mezzanine	20*	CF	Remain in place for egress	Maintain *occupant load* within a single *firecell* to 1000 people
East wall kitchen	20*	CF	Remain in place for egress	Maintain *occupant load* within a single *firecell* to 1000 people
Stairwell shafts	60	FO	Withstand *burnout* of *fire* in adjacent spaces	Provide firefighters with safe access to floors
Floor and structure that support the mezzanine	60	FO	Withstand *burnout* of *fire* below	Provide firefighters with safe access to floors
Wall between guest room and corridors on hotel levels	20*	RC	Withstand *burnout* of *fire* in guest room	Protect sleeping occupancies that serve more than 250 people
1st floor and *primary elements* supporting the floor (between ground and 1st level)	60	FO	Withstand *burnout* of *fire* below	Provide firefighters with safe access to floors
All other floor and *primary elements* supporting the floor (except between ground and 1st level)	20	FO	Withstand *burnout* of *fire* below	Provide firefighters with safe access to floors
Service *penetrations* in *fire rated* elements	Dependent on element penetrated	N/A	Maintain equivalent *fire resistance rating* of element	

† In practice, the three components of the *fire resistance rating* (*structural adequacy*, *integrity* and *insulation*) for the various elements would need to be elaborated on depending on the type and function of the element. This is not discussed further here.

* Minimum *fire resistance rating* (as per C/VM2 Paragraph 2.4(a) and AS 1530.4)

B3 Design Scenarios

B3.1 Design scenario BE: Fire blocks exit

Design scenario BE addresses a *fire* that starts in a location that potentially blocks the use of an *escape route*. This scenario applies when there are more than 50 people that could be affected by such an event. Any space where the *escape routes* serve more than 50 people is required to have at least two exits. The exits must either:

- diverge by more than 90°, or
- if not suitably divergent, be separated by a distance of:
  - at least 8.0 m when up to 250 occupants are required to use the *escape routes*, or
  - at least 20.0 m when more than 250 occupants are required to use the *escape routes*.

From inspection of the floor plan in Figure B1 and Figure B2, it can be seen that all of the spaces with more than 50 occupants have at least two *escape routes* and the exits are adequately separated. Table B1 is a summary of the major rooms within the *building* showing the number of exits required and number available as well as the actual separation distance between the exits.

Therefore, the design complies with *design scenario* BE: Fire blocks exit.

B3.2 Design scenario UT: Fire in normally unoccupied room threatening occupants of other rooms

Design scenario UT deals with a *fire* in a normally unoccupied room remaining unnoticed and threatening a large number of occupants in an adjacent space. Because the *building* is fully sprinklered and this is expected to contain the *fire* to the room of origin, no other analysis is required.

The design complies with *design scenario* UT: Fire in normally unoccupied room threatening occupants of other rooms.

B3.3 Design scenario CS: Fire starts in a concealed space

Design scenario CS addresses the concern of a *fire* developing undetected in a *concealed space* and spreading into any space containing a large number of occupants. In large, modern *buildings* there are likely to be a number of spaces that need to be assessed. We show two possible cases.

Function centre above ceiling

The ceiling above the function centre area is 1.2 m in height and is expected to contain *combustible* materials such as insulated ducting, cabling and other ancillary equipment. As this space is greater than 0.8 m in more than two dimensions, it is necessary to apply the *design scenario* CS. In this case, sprinklers within the *concealed space* are a means of providing early detection in accordance with methodology b) in Paragraph 4.3 of C/VM2.

Guest room toilet services duct

The shafts for plumbing services for each guest room are 0.8 m by 0.8 m and will be *fire stopped* at each level to maintain the *fire resistance rating* required between each floor.

The design complies with *design scenario* CS: Fire starts in a concealed space.

B3.4 Design scenario SF: Smouldering fire

Design scenario SF addresses the concern that a smouldering *fire* can threaten sleeping occupants. The only methodology available is to install smoke detection in all sleeping spaces. The fire safety features for this building include an analogue addressable smoke detection system with voice alarm installed in accordance with NZS 4512: 2010, including the rooms where occupants are sleeping.

The design complies with *design scenario* SF: Smouldering fire.

B3.5 Design scenario HS: Horizontal fire spread

Design scenario HS addresses the concern that a *fire* in a *building* will threaten to damage the adjacent property. To comply with this *design scenario*, it is necessary to do one of the following:

- if the separation distance is 1.0 m or less, completely fire separate the boundary wall, or
- if the separation distance is more than 1.0 m, limit the area of unprotected openings to control the thermal radiation to the adjacent property.

This *design scenario* also prevents an owner from constructing their *building* with an external cladding that is easily ignited within 1.0 m of their *boundary* (in case of fire in the adjacent property).

Figure B1 shows the east wall of the *building* facing a street and a vehicle access area. The south wall is adjacent to a street and the west wall faces a parking lot for this property. It is only the north wall that requires analysis as it is located 0.9 m from a *relevant boundary*.

Due to the close proximity of the adjacent property to the north, no *unprotected areas* are permitted in the north wall. This *external wall* will be designed with a *fire resistance rating* (FRR) of 30/30/30 determined using calculations for total *burnout* of the affected spaces as given in Section B5.
The north wall is also required to be designed by the structural engineer for the post-fire structural stability requirements of Verification Method B1/VM1.

To address the ignitability of the boundary wall, any *external wall* located closer than 1.0 m to the *relevant boundary* must be externally clad with either:

- materials that are not *combustible*, or
- materials that, when subjected to a radiant heat flux of 30 kW/m^2, do not ignite for 30 minutes (*Importance Level 3*).

These measures mitigate *fire* spread from a neighbouring property. The *external wall* will be finished concrete and classified as *non-combustible* (i.e. *non-combustible* as determined by the test specified in AS 1530.1).

The design complies with *design scenario* HS: Horizontal fire spread.

B3.6 Design scenario VS: Vertical fire spread involving external cladding

Design scenario VS deals with *fire* spread up the exterior of a *building* that:

- is greater than 10.0 m high, or
- has sleeping occupants above the ground floor.

There are two facets to this scenario:

- Part A: external vertical *fire* spread over the façade materials, and
- Part B: *fire* plumes spreading *fire* vertically up the *external wall* via openings and *unprotected areas*.

For Part A, the exterior cladding of this *building* is *non-combustible* (ie, *non-combustible* as determined by the test specified in AS 1530.1). For Part B, the risk of *fire* spread via openings and *unprotected areas* is mitigated by the presence of the automatic sprinkler system.

The design complies with *design scenario* VS: Vertical fire spread.

B3.7 Design scenario IS: Rapid fire spread involving internal surface linings

Design scenario IS deals with the condition where a *fire* within a *building* can develop too rapidly to allow occupants sufficient time to escape. Controlling the flammability of the internal surface linings reduces the likelihood of a *fire* developing more rapidly than the *design fires* given in Table 2.1 of C/VM2.

Surface finishes within the *building* are required to meet the following requirements for sprinkler protected *buildings* (C/VM2 Paragraph 4.7):

Surface linings

Group Numbers are derived from testing to ISO 5660 or ISO 9705.

- *exitways* and internal ducts: *Group Number* 2 (or lower)
- all other *occupied spaces*: *Group Number* 3 (or lower).

Flooring

Minimum critical radiant fluxes (CRF) are assessed according to ISO 9239.1.

- flooring within *exitways* shall have a CRF $\geq$ 2.2 kW/m^2
- flooring within all other *occupied spaces* shall have a CRF $\geq$ 1.2 kW/m^2.

Foamed plastics

Where *foamed plastics* or *combustible insulating materials* form part of a wall, ceiling or roof system, the completed system shall achieve a *Group Number* as specified for surface linings above and the *foamed plastics* shall comply with the flame propagation criteria as specified in AS 1366 for the type of material being used (C/VM2 Paragraph 4.7).

For this building, the ground floor foyer and the corridors of the guest tower are part of the *exitways*.

> Note:
>
> Final design documentation should include the required *Group Numbers* for each surface and should also specify the material *surface finish* for all surfaces.

The design complies with *design scenario* IS: Rapid fire spread involving internal surface linings.

B3.8 Design scenario FO: Firefighting operations

Design scenario FO ensures the provision of the safety of firefighters conducting search and rescue and firefighting operations. *Design scenario* FO is prescriptive in nature simply because there is no design methodology available to address these issues. The following items address all the issues specified in C/VM2 for *design scenario* FO.

As the *building* is fully sprinklered, it is not necessary to analyse the *fire* environment at the time firefighters first apply water as described in NZBC Clause C3.8.

For the ground floor, water from street hydrants is available via a pumping appliance parked within 5.0 m of the *building* such that any point within the ground floor of the *building* may be reached within three hose lengths (75 m). The mezzanine can be accessed via the internal (open) stairs from the hotel reception or by the building fire hydrant system in the west *stairway*. On all guest room levels, water is available via building fire hydrant systems in the *stairways*.

The mezzanine (function centre) is an *intermediate floor* (included within the hotel reception *firecell*), while the restaurant below the mezzanine is a separate *firecell* with an *FRR* of 60/60/60 to resist *burnout*.

The north wall of the function centre is *fire rated* to prevent horizontal *fire* spread (as described in Paragraph B3.5 of this example). The *FRR* shall be based on complete *burnout* of the *firecell*. The required *FRR* will be calculated using Equation 2.1 in C/VM2 (using the time equivalence concept). The calculation procedure is shown in Section B5 of this example.

In the hotel tower, both *stairways* are designed as *safe paths*. The *fire separations* enclosing these stairs are required to resist a full *burnout fire* in an adjoining space. The stairs pass through both the ground floor area of either the hotel reception or the kitchen and mezzanine which, in the most severe case, requires an *FRR* of 60/60/60. The *FRR* of the *fire separation* between any guest room and the corridor is 20 minutes, while the stairwells require an *FRR* of 60/60/60 throughout.

Likewise, the load-bearing structure and floor systems are designed to resist collapse and prevent *fire* spread between floor levels for the period of full *burnout*. The *structural adequacy* rating for the columns, beams and floors on the ground and mezzanine floors has to be calculated to resist the most severe *fire* in the restaurant. The calculations (using the time equivalence concept) are included in Section B5.

On the guest room levels, the fully developed *fire* is less intense due to the reduced fuel load and large window openings. The load-bearing structure and floor systems on the guest room levels shall have an *FRR* of 20/20/20 (as calculated using the time equivalence concept).

The location of the fire alarm panel and fire service inlet will be a subject to be discussed and agreed at the Fire Engineering Brief. These will have to be located close to the NZFS attendance point.

The design complies with *design scenario* FO: Firefighting operations.

B3.9 Design scenario CF: Challenging fire

Design scenario CF is concerned with a *fire* that starts in a normally *occupied space* that will challenge the *building's* fire safety systems and threaten the occupants. Compliance with *design scenario* CF is achieved by demonstrating that *ASET>RSET*.

When evaluating a *building* design for *design scenario* CF, one of the most important decisions is the location for the challenging *fires*. There are likely to be multiple locations where a challenging *fire* will need to be considered. Ultimately, the locations where the CF *fire* will be evaluated should be agreed upon by all parties during the Fire Engineering Brief process.

The *ASET* is generally defined as the shortest time to reach any of three tenability criteria specified in NZBC Clause C4.3:

> **C4.3** The *evacuation time* must allow occupants of a *building* to move to a *place of safety* in the event of a *fire* so that occupants are not exposed to any of the following:
>
> (a) a *fractional effective dose* of carbon monoxide greater than 0.3:
> (b) a *fractional effective dose* of thermal effects greater than 0.3:
> (c) conditions where, due to smoke obscuration, visibility is less than 10 m except in rooms of less than 100 m^2 where visibility may fall to 5 m.
>
> **C4.4** Clause C4.3 (b) and (c) do not apply where it is not possible to expose more than 1000 occupants in a *firecell* protected with an automatic *fire* sprinkler system.

As this *building* is sprinkler protected, Clause C4.4 applies and the tenability requirements are limited to C4.3 (a); i.e. the $FED_{(CO)}$ for the majority of the spaces within.

The *RSET* is generally defined as the time required for all occupants to reach a *place of safety*. However, it can also be defined as the time required to evacuate a particular space, such as the time to evacuate the room of origin. C/VM2 Paragraph 3.2 states that the *RSET* is the sum of the detection time, notification time, *pre-travel activity time*, and the greater of the travel time or the flow time. The SFPE Handbook of Fire Protection Engineering, 4th edition, Section 3 Chapter 13 provides additional information on calculating the *RSET*.

In this *building*, seven rooms are greater than 500 m^2 and therefore require analysis of the occupant tenability within the room of fire origin. These include the ballroom, large meeting room, hotel reception, mezzanine and restaurant.

All other rooms are less than 500 m^2 and hold fewer than 150 occupants. Therefore, tenability does not have to be assessed within the room of fire origin for these rooms. However, it must still be demonstrated that occupants of the *building* will not be threatened by a *fire* in these rooms.

In this *building*, the guest rooms are less than 500 m^2 and therefore the analysis does not have to show that tenability is maintained within the guest room of fire origin. However, it must still be shown that *ASET*>*RSET* for occupants elsewhere in the *building*. Of particular interest in this example are the occupants of other guest rooms passing through the corridor and *stairways*.

Table B3 lists the possible locations for challenging fires for this *design scenario*. It also explains whether or not evaluation is required. The *fire* locations on the ground floor are shown on Figure B3.

This example provides workings for four of these locations to demonstrate the application of *design scenario* CF. These locations are:

- the ballroom
- the foyer
- the hotel reception, and
- a centrally located guest room on the first floor.

The first floor guest room was chosen as a challenging fire location, as this has the potential to compromise the part of the *stairway* that provides an *escape route* for the largest number of occupants in sleeping spaces.

The design *fire* was taken from C/VM2 Table 2.1 with a growth rate of $\dot{q}'' = 0.0469t^2$ to a peak *heat release rate* based on sprinkler activation, ventilation control, or 20 MW (whichever is less). For this example, the peak *heat release rate* was determined by sprinkler activation. The species productions are also given in C/VM2 Table 2.1 as

$Y_{co} = 0.04 \frac{kg}{kg}$ and $Y_{soot} = 0.07 \frac{kg}{kg}$.

The analysis for the ground floor and mezzanine was carried out using the zone model BRANZFIRE version 2011.2 with the geometric layout as shown in Figure B3.

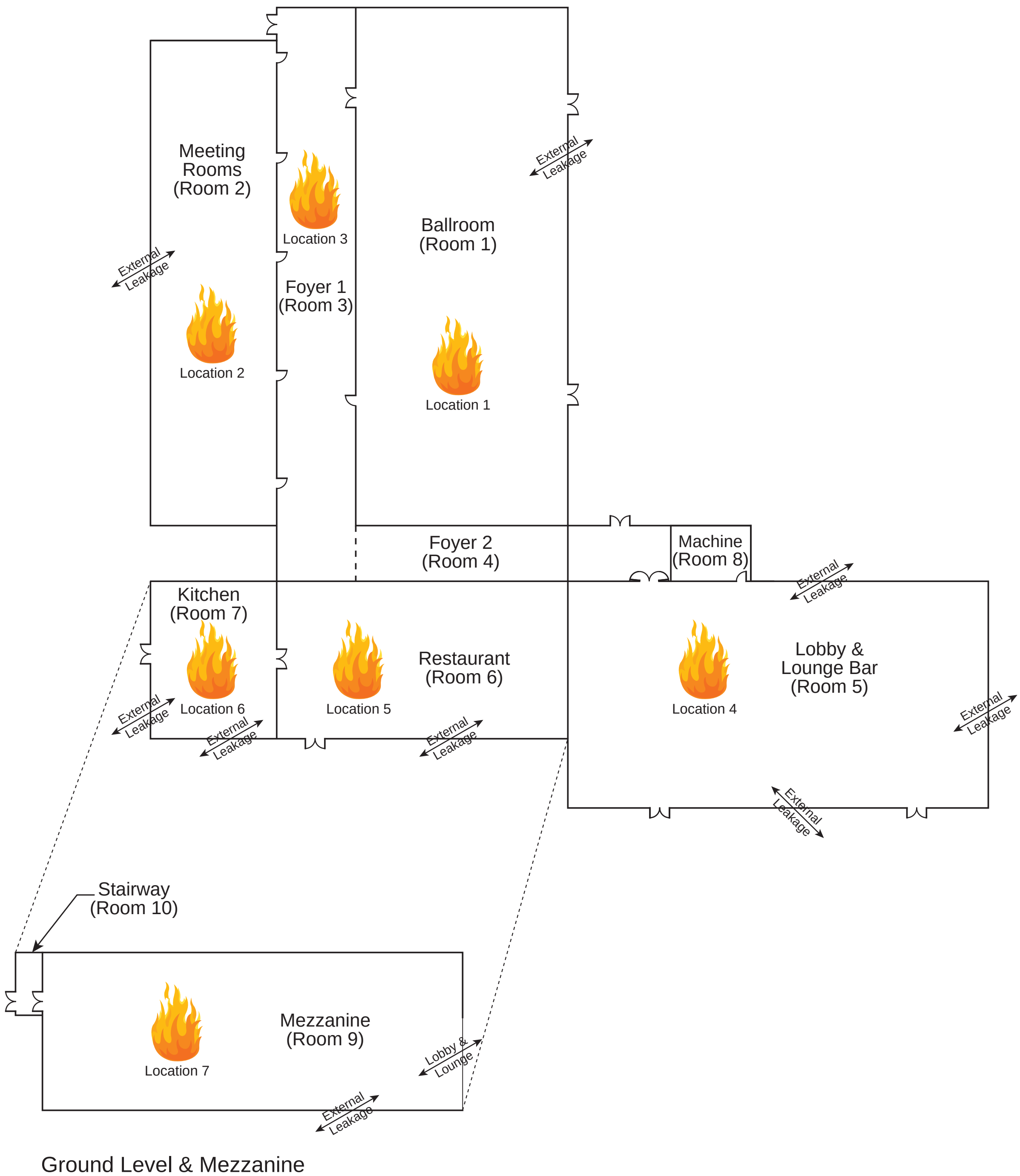
The room dimensions and vent sizes are given in Section B6. For the guest room floors, Fire Dynamic Simulator (FDS) was chosen because the narrow corridor has an aspect ratio of 80/3 = (27 to 1) and the complex flow within the *stairway* are considered to be beyond the capability of a zone model. Although FDS is more difficult to use and requires a skilled and knowledgeable user, the *building* is complex and therefore warrants such sophisticated analysis.

Note:

BRANZFIRE does not include any sub-model for dealing with long corridor flows. In long narrow corridors, smoke transport lag times and wall convective cooling effects can become significant, and this contributes to non-uniformity in the layer height and layer properties during the smoke filling process.

Table B3:	Potential challenging fire locations for design scenario CF			
Location	Space (m)	Floor area (m^2)	Design scenario CF	Explanation
Ballroom	50x20	1000	Yes	Floor area for the space is greater than 500 m^2 and contains 1000 occupants. *Design scenario* CF will be evaluated for this space.
Meeting rooms	47x12	564	Yes	If these meeting rooms are configured with all five rooms open to one another, this creates one large room greater than 500 m^2 with 226 occupants. *Design scenario* CF will be evaluated for this space.
Foyer	55x8 +30x5 +12x3	576	Yes	It is expected that the foyer will be used as a serving space for the ballroom and meeting rooms. Although this space does not add to the overall *occupant load*, the impact of *design scenario* CF in this area will be assessed. Note: If this space was intended only for access and was separated from the other spaces, then *design scenario* CF would not need to be evaluated for this space.
Hotel office and front desk	18x5	90	No	These spaces are small, low ceiling areas that include smoke detection and sprinklers. A *fire* in one of these spaces would be quickly controlled by the sprinklers. The more severe *fire* that threatens the occupants in this space is a *fire* in the hotel reception/lounge, with the higher ceiling delaying the activation of the smoke detectors and sprinklers. Therefore, evaluating *design scenario* CF in one of these smaller lower ceiling spaces is not necessary.
Hotel reception	40x15	348	Yes	The floor area in this space is greater than 500 m^2 on the ground floor and mezzanine area. *Design scenario* CF will be evaluated for this space.
Lounge		200	No	Because the lounge is fully open to the hotel reception, a *fire* in this area is identical to the hotel reception area and so does not require separate evaluation for *design scenario* CF.
Restaurant	28x15	420	Yes	The restaurant is greater than 500 m^2. *Design scenario* CF will be evaluated for this space.
Kitchen	15x10	150	Yes	Because the kitchen space is less than 500 m^2, tenability for this space does not have to be evaluated. However, the impact of *design scenario* CF in the kitchen must be evaluated for occupants outside the kitchen within the *firecell*.
Mezzanine	40x15	528	Yes	The mezzanine is greater than 500 m^2 and holds more than 480 occupants. In addition, the occupants in the hotel reception space are also exposed. *Design scenario* CF will be evaluated for this space.
Guest rooms level	4x6	37 beds/ floor	Yes	The guest rooms are less than 500 m^2 and the tenability does not need to be evaluated for the occupants of the room of origin. However, it is necessary to confirm that a *fire* within a guest room does not compromise the safety of the other occupants.
Guest room level corridor	3x80	240	No	The corridor is *fire separated* from the guest rooms and is only intended for intermittent use. *Design scenario* CF does not need to be evaluated in this space.

Figure B3: BRANZFIRE geometry for the building showing challenging fire locations.

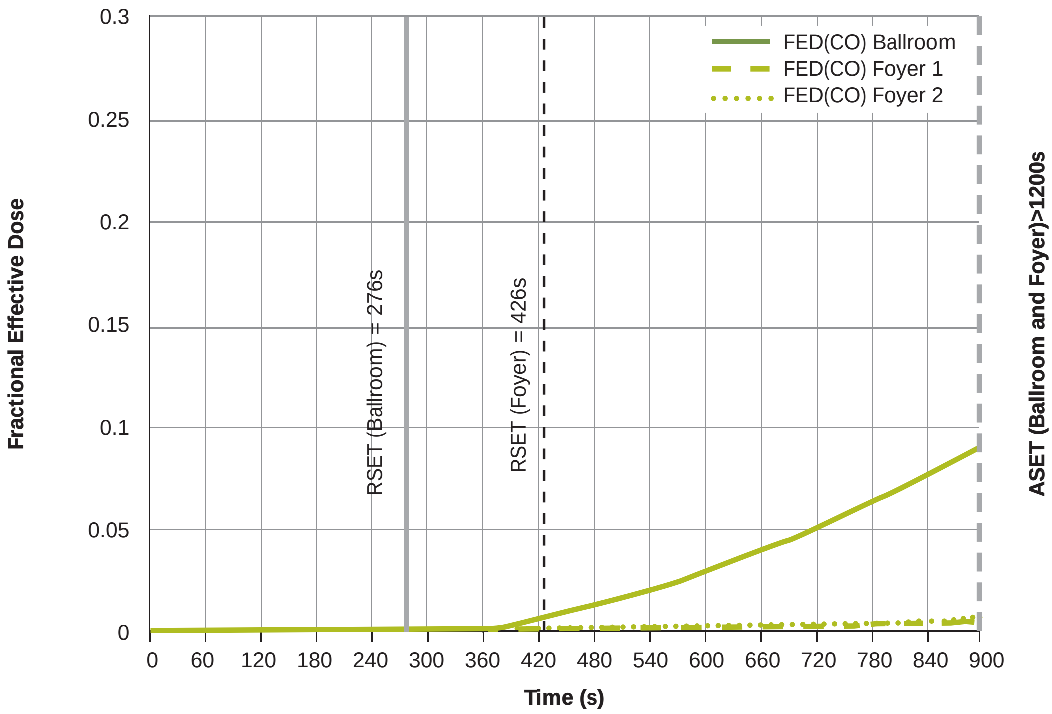


Challenging fire: ballroom

ASET

For the *design scenario* CF in the ballroom, the *fire* is a fast αt^2 *fire growth* rate with a peak *heat release rate* of 2700 kW when controlled by the sprinkler system. The *fire* is located in the centre of the ballroom and is 0.4 m above the floor. The ballroom is *fire separated* from the rest of the *building*. Therefore, the ballroom doors are modelled as closed, except during the evacuation. The BRANZFIRE tenability results for the $FED_{(CO)}$ in the ballroom and foyers 1 and 2 are shown in Figure B4. As there are a maximum of 1000 occupants within the ballroom, the *RSET* is based only on the $FED_{(CO)}$.

Figure B4: Tenability results for the $FED_{(CO)}$ for the ballroom and foyers from design scenario CF in the ballroom



> Note:
>
> *ASET* and *RSET* for the ballroom and foyers are also included on the graph.

RSET

Equation 3.1 of C/VM2 is used to calculate the *RSET* for the different parts of the *building*:

RSET = (t_d + t_n + t_{pre}) + (t_{trav} or t_{flow}) (Equation 3.1 of C/VM2)

The layout of the exits and number of occupants required to use each exit are given in Figure B2. Arrows show the direction of travel for each exit door. The number shown on the shaft of the arrow indicates the number of occupants expected to use the door for egress during fire, and the number at the tip of the arrow gives the evacuation time in seconds required for all of the occupants to pass through the door based on 50 people/min/doorleaf.

Note:

For the purposes of this example, we simply describe the values selected from C/VM2 to use in calculating the *RSET*. Refer to Paragraph 3.2 of C/VM2 for more details about conducting an *RSET* analysis.

Detection time (t_d) is taken directly from the fire modelling using the detector criteria given in C/VM2 Table 3.2. For the ballroom the smoke detectors activate at 66 s, which is taken as t_d.

Note:

The response of smoke detectors must be based on the time at which the optical density (OD) threshold (OD > 0.097 m^{-1}) is exceeded at the location of the detector.

Notification time (t_n) is the time for the alarm system to respond to the detector signal and is a fixed value of 30 s (C/VM2 Paragraph 3.2.2).

Pre-travel activity time (t_{pre}) is the period between the alarm activating and the occupants beginning their evacuation. These values are taken from C/VM2 Table 3.3. The ballroom is considered to have occupants who are awake, alert and unfamiliar with the *building*. As the alarm system has a voice alert, a *pre-travel activity time* of 30 s applies. All other spaces in the building have a *pre-travel activity time* of 60 s other than the guest rooms, which have a *pre-travel activity time* of 300 s.

Travel time (t_{trav}) for the occupants to walk from their location to an exit door is calculated using Equation 3.2 and Equation 3.3 of C/VM2. The layout of the furniture is unknown and could easily change. Therefore, the maximum *travel distance* is taken as the sum of the length and width of the room.

In crowd occupancies, the travel time does not often govern the egress. However, the calculation is included to confirm that the queuing time governs the egress from the ballroom.

$S = k - akD$ (Equation 3.2 of C/VM2)

$a = 0.266$ (C/VM2 Paragraph 3.2.4)
$k = 1.4$ (C/VM2 Paragraph 3.2.4)
$D = 1.0$ persons/m^2 (C/VM2 Table 3.1)

$S = 1.4 - (0.266 \times 1.4 \times 1.0) = 1.03$ m/s

$$t_{trav} = \frac{L_{trav}}{S}$$ (Equation 3.3 of C/VM2)

$L_{trav} = L_{room} + W_{room} = 50\text{ m} + 20\text{ m} = 70\text{ m}$ (C/VM2 Paragraph 3.2.4)

Therefore:

$$t_{trav} = \frac{70}{1.03} = 68\text{ s}$$

Flow time (t_{flow}) is the time required for a number of occupants to move through a constriction in the flow path such as a doorway or *stairway*. The occupants in the ballroom can egress either:

- directly outside through either of two sets of double doors in the east wall, or
- into the foyer through either of two sets of double doors in the west wall.

There are two routes directly to the outside and two routes to the foyer, and 25% of the occupants (250 people) are assumed to egress through each *escape route*.

The occupants that choose to egress through either external doorway directly to the outside will simply be controlled by the queuing for the door. The occupants evacuating via the foyer will have the additional time added to their *RSET* to account for the time required for evacuating through the foyer. The door flow is calculated using C/VM2 Equation 3.4 (assuming a door width of 0.95 m):

$F_c = (1 - aD)kDW_e$ (Equation 3.4 of C/VM2)

$a = 0.266$ (C/VM2 Paragraph 3.2.4)
$k = 1.4$ (C/VM2 Paragraph 3.2.4)
$D = 1.9$ persons/m^2 (C/VM2 Paragraph 3.2.5)

$W_e = (0.95 - 2\,(0.15)) = 0.65$ m (C/VM2 Paragraph 3.2.5 with a 0.15 m boundary layer [Table 3.5])

$F_c = \{1 - 0.266(1.9)\}\ 1.4\ (1.9)(0.65\text{ m})$
$= 0.855$ persons/s
$= 51$ persons/min therefore use 50 persons/min/door leaf (maximum from C/VM2 Paragraph 3.2.5)

Therefore, a set of double doors has a capacity of 100 persons/min which gives a flow time as follows:

$$\text{Flow time} = \frac{250\text{ persons}}{100\text{ persons/min}} = 2.5\text{ min} = 150\text{ s}$$

Combining the values for all of the components of the *RSET* gives the *RSET* for the ballroom:

$$RSET_{(ballroom)} = 66\text{ s} + 30\text{ s} + 30\text{ s} + 150\text{ s} = 276\text{ s}$$

This assumes that half the occupants choose to exit the ballroom through the foyer and therefore do not directly reach a *place of safety*. Because the foyer is *fire separated* from the ballroom, the egress capacity for the foyer is based on the larger of two *occupant loads* egressing from the space. In this case, there are 500 occupants from the ballroom and 226 occupants from the meeting rooms. Therefore, the 500 occupants egressing from the ballroom govern the flow from the foyer. In Figure B2 it can be seen that there is a set of double doors at each end of the foyer with a capacity of 100 persons/min as indicated previously.

Therefore, t_{flow} is:

$$\text{Flow time} = \frac{250\text{ persons}}{100\text{ persons/min}} = 2.5\text{ min} = 150\text{ s}$$

The simplest assessment of *RSET* for the foyer is to add the flow time for the foyer doors to the *RSET* from the ballroom. This assumes that the ballroom occupants do not leave the foyer until after the ballroom is evacuated, which is expected to overestimate the *RSET*. More sophisticated egress analysis is permitted under C/VM2 and the use of particular models for analysis will be the subject of discussion and agreement at the Fire Engineering Brief.

The simplistic assessment of *RSET* for the foyer is:

$$RSET_{(foyer)} = 66\ s + 30\ s + 30\ s + (150\ s + 150\ s) = 426\ s$$

Figure B4 shows the foyer 1 and foyer 2 results for the tenability criteria $FED_{(CO)}$ and the *RSET* for both the ballroom and foyers. The tenability was not exceeded anywhere in the *building* during the 1200 s simulated, which is long after the occupants are assumed to have evacuated the *building*. The numerical value for the tenability criteria and *RSET* for the ballroom and foyer are given in Table B4. The results show that *ASET>RSET* for both the ballroom and foyer.

Note:

Strictly speaking, the *FEDs* must be calculated at the location of the egressing occupants and therefore it may be necessary to use data for different rooms for different time periods. In this example, the *FED* accumulation in the ballroom is negligible prior to that space being evacuated and therefore it is valid to only use the *FED* data for the foyer.

Table B4: Results of tenability criteria modelling for CF: Challenging fire in the ballroom

Criteria	Time reached (s)	Margin (s)
$RSET_{(ballroom)}$	276	-
$FED_{(CO)}$ = 0.3	>1200	>924
$RSET_{(ballroom\ to\ foyer\ to\ outside)}$	426	-
*$FED_{(CO)}$ = 0.3	>1200	>774
*Accumulated $FED_{(CO)}$ based on egress through the ballroom to foyer 1 to foyer 2.		

The design of the ballroom complies with *design scenario* CF: Challenging fire.

Challenging fire: foyer

ASET

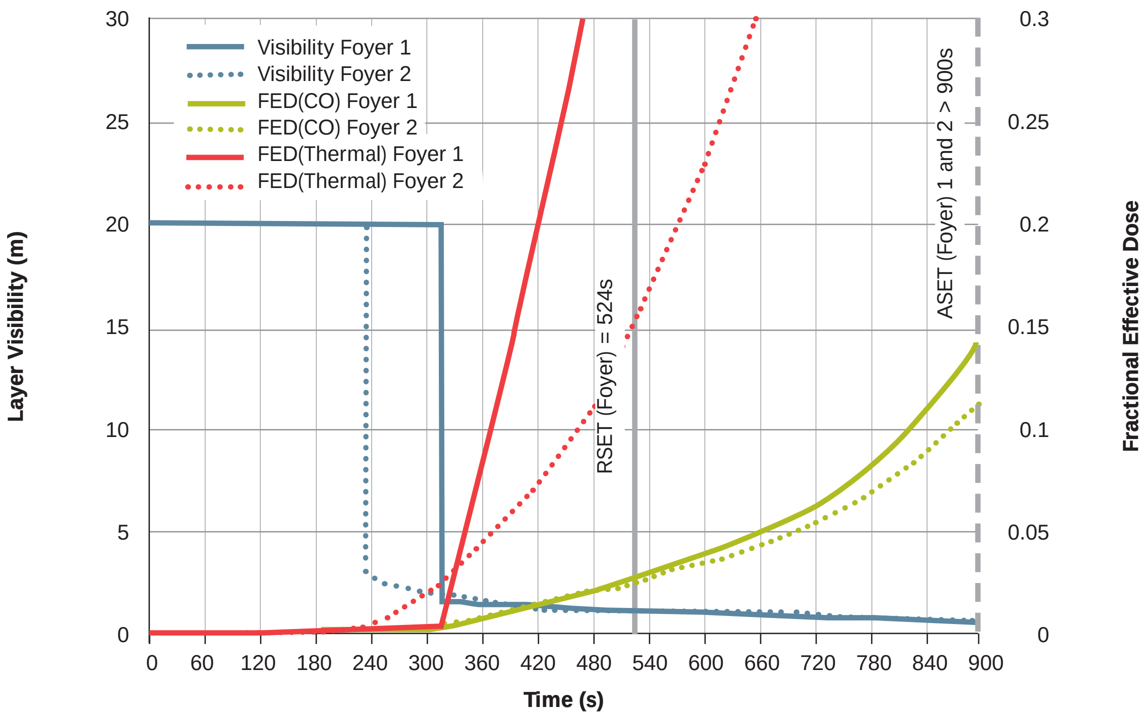
A challenging *fire* in the foyer is required because the reasonable use of this space is likely to include a serving area for the ballroom and meeting rooms. It is not necessary to add additional occupants to the total *occupant load* because it is not practical for this space to be fully occupied at the same time as the ballroom and meeting rooms.

For the *design scenario* CF in the foyer, the fire is a fast αt^2 *fire growth* rate with a peak *heat release rate* of 2070 kW when controlled by the sprinkler system. The fire is located in the centre of foyer 1 and is 0.4 m above the floor. The walls between the foyer and ballroom are rated 30/30/30 and would be expected to include automatic *hold-open devices* that will close on a fire alarm. The *fire doors* between the foyer and the ballroom are only opened during the egress of the ballroom.

For the meeting rooms, the wall is non-rated and the doors are modelled as fully open. The half-open assumption (C/VM2 Paragraph 2.2.1(d)) is only applicable when a door is a *fire* or *smoke control door* that includes a self-closing device while it is open when being used by egressing occupants.

The BRANZFIRE tenability results for the visibility, $FED_{(CO)}$ and $FED_{(Thermal)}$ in foyer 1 and foyer 2 are shown in Figure B5.

Figure B5: Tenability results for the visibility, $FED_{(CO)}$ and $FED_{(Thermal)}$ for the foyers from design scenario CF in the ballroom



Note:

The *ASET* and *RSET* are also included on the graph.

RSET

Equation 3.1 of C/VM2 is used to calculate the *RSET* in the same way as for the ballroom analysis. The individual times that make up the *RSET* are described briefly below.

$$RSET = (t_d + t_n + t_{pre}) + (t_{trav} \text{ or } t_{flow}) \qquad \text{(Equation 3.1 of C/VM2)}$$

Detection time (t_d) is taken directly from the fire modelling using the detector criteria given in C/VM2 Table 3.2. For the foyer, the smoke detectors activate at 67 s which is taken as t_d.

Notification time (t_n) is the time for the alarm system to respond to the detector signal and is a fixed value of 30 s (C/VM2 Paragraph 3.2.2).

Pre-travel activity time (t_{pre}) is the period between the alarm activating and the occupants beginning their evacuation. These values are taken from C/VM2 Table 3.3. It is assumed that the foyer has no occupants at the time the *fire* starts. All other spaces in the *building* have a *pre-travel activity time* of 60 s other than the guest rooms, which have a *pre-travel activity time* of 300 s.

Travel time (t_{trav}) for the occupants to walk from their location to an exit door is calculated using Equation 3.2 of C/VM2. The *travel distance* in this case is taken as half the length of the foyer (this is 100 m long, so the *travel distance* is 50 m). In crowd occupancies, the travel time does not often govern the egress. However, the calculation is included to confirm that the queuing time governs the egress from the foyer.

$$S = k - akD \qquad \text{(Equation 3.2 of C/VM2)}$$

$a = 0.266$ (C/VM2 Paragraph 3.2.4)

$k = 1.4$ (C/VM2 Paragraph 3.2.4)

$D = 1.0$ person/m^2 (C/VM2 Table 3.1)

$$S = 1.4 - (0.266 \times 1.4 \times 1.0) = 1.03 \text{ m/s}$$

$$t_{trav} = \frac{L_{trav}}{S} \qquad \text{(Equation 3.3 of C/VM2)}$$

$$L_{trav} = \frac{L_{foyer}}{2} = \frac{100 \text{ m}}{2} = 50 \text{ m} \qquad \text{(C/VM2 Paragraph 3.2.4)}$$

$$t_{trav} = \frac{50}{1.03} = 49 \text{ s}$$

Flow time (t_{flow}): because the foyer is part of the *escape route* from a separate *firecell* (the ballroom), the *occupant load* for the foyer is taken as the greater of:

- the *occupant load* within the *firecell* the foyer is in, and
- the *occupant load* of the adjacent *firecell*.

In this case, the *occupant load* of the *firecell* that contains the foyer is 226 people from the meeting rooms and 500 from the ballroom. Therefore, the 500 people from the ballroom govern the flow times.

As the door widths are the same as for the ballroom, the flow rate calculations are identical and are not repeated here. Therefore, a set of double doors has a capacity of 100 people/min which gives a flow time:

$$\text{Flow time} = \frac{250 \text{ persons}}{100 \text{ persons/min}} = 2.5 \text{ min} = 150 \text{ s}$$

Combining the values for all components of the *RSET* gives the *RSET* for the foyer as follows:

$$RSET_{(foyer)} = 67 \text{ s} + 60 \text{ s} + 30 \text{ s} + 150 \text{ s} = 307 \text{ s}$$

The simplest assessment of RSET for the foyer must also include the time it takes for the occupants to enter the foyer from the ballroom, which was calculated above as 150 s (in the *design scenario* CF for the ballroom). Therefore, the simplistic assessment of *RSET* for the foyer is:

$$RSET_{(\text{Ballroom to foyer to outside})} = 67 \text{ s} + 60 \text{ s} + 30 \text{ s} + (150 \text{ s} + 150 \text{ s}) = 457 \text{ s}$$

In this example, the results for foyer 1 and foyer 2 are shown because the time to untenable conditions is less in the foyers than in the ballroom. Figure B5 shows the results for foyers 1 and 2 for the three tenability criteria, as well as the *RSET* for the foyer for comparative purposes. Table B5 summarises the numerical values for the *ASET* and the three tenability criteria. In this case, with an *occupant load* of 1000 people, only the $FED_{(CO)}$ applies.

Table B5: Results of tenability criteria modelling for challenging fire in the foyer

Criteria	Time reached (s)	Margin (s)
$RSET_{(\text{ballroom to foyer to outside})}$	457	–
Visibility = 10 m	234	–223
$FED_{(Thermal)}$ = 0.3	469	12
$FED_{(CO)}$ = 0.3	1065	608

The design of the foyer complies with *design scenario* CF: Challenging fire.

Challenging fire: hotel reception and lounge areas

ASET

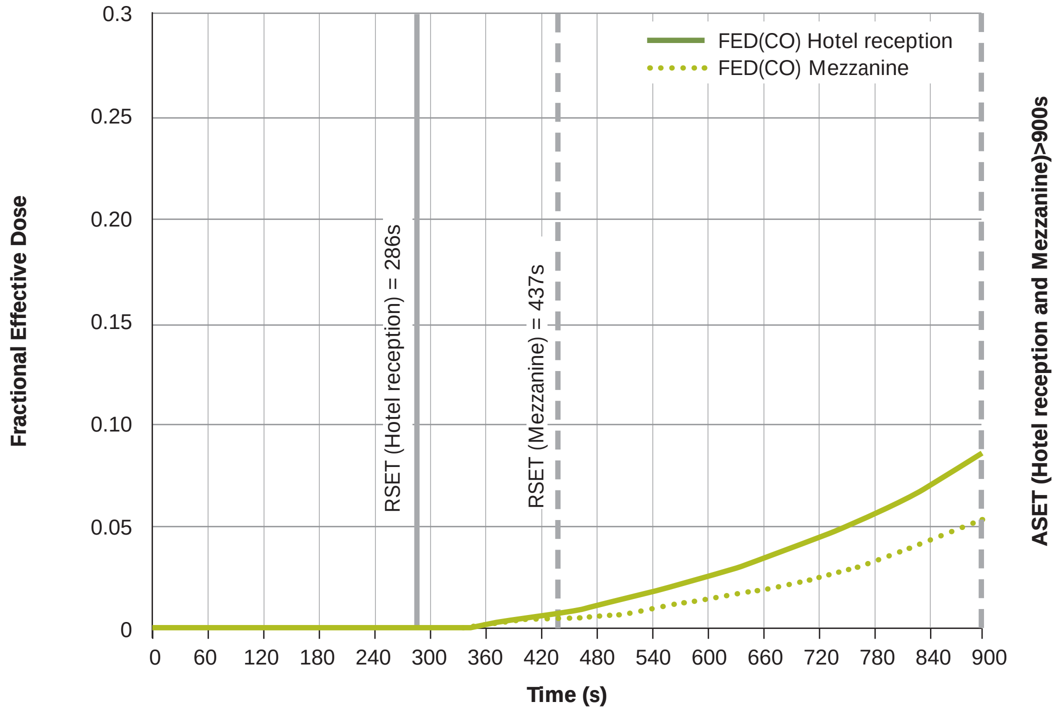
For the *design scenario* CF in the hotel reception, the fire is a fast αt^2 *fire growth* rate with a peak *heat release* rate of 5000 kW when the *fire* is controlled by the sprinkler system. The higher peak *heat release rate* is a direct result of the higher ceiling in the hotel reception. The *fire* is located in the centre of the hotel reception and is 0.4 m above the floor. The total *occupant load* exposed to the *fire* must include the mezzanine level because this is part of the same *firecell*.

In this example, the total number of occupants exposed from a *fire* in the hotel reception is:

480	mezzanine
182	lounge
35	hotel reception
9	front desk and offices
706	Total occupant load for hotel reception and lounge

The total *occupant load* within the *firecell* is less than 1000 people. Therefore, NZBC Clause C4.4 applies and only the tenability criterion $FED_{(CO)}$ is used to determine the *ASET*. The BRANZFIRE tenability results for the $FED_{(CO)}$ in the hotel reception and mezzanine are given in Figure B6. The $FED_{(CO)}$ never exceeds 0.3 for the entire 1200 s of the BRANZFIRE simulations, which defines $ASET_{(reception)}$ >1200 s and $ASET_{(mezzanine)}$ >1200 s.

Figure B6: Tenability results for $FED_{(CO)}$ for the hotel reception and mezzanine from design scenario CF in the hotel reception



Note:

ASET and *RSET* are also included on the graph.

RSET

The *escape route* for the occupants in the hotel reception is directly to the outside through one of two sets of double doors, as illustrated in Figure B2. The *fire doors* between the hotel reception and foyer, which are normally held open magnetically, are released on a fire alarm. These may be used by the occupants but are not intended for egress. There should be no exit signage above these doors.

Half of the occupants on the mezzanine are assumed to egress through the hotel reception and the other half through the north-west *stairway*. The *stairway* has been increased in size from the mezzanine level to ground floor exit to account for the increased flow.

Detection time (t_d) is taken directly from the BRANZFIRE results which show the smoke detector activating at 93 s.

Notification time (t_n) is the time for the alarm system to respond to the detector signal and is a fixed value of 30 s (C/VM2 Paragraph 3.2.2).

Pre-travel activity time (t_{pre}): the occupants of the hotel reception are considered to be awake, alert and unfamiliar with the *building* and the alarm system is provided with a voice alert. From Table 3.3 of C/VM2, the *pre-travel activity time* is 30 s.

The occupants on the mezzanine level are also considered to be directly exposed to the *fire* threat due to the large opening between the hotel reception and the mezzanine and are assumed to have a *pre-travel activity time* of 30 s.

The occupants of the restaurant and all other spaces (apart from the guest rooms) are in separate enclosures and are considered to be remote from the *fire*. Therefore, a t_{pre} of 60 s will apply.

As the occupants of the guest rooms are sleeping, unfamiliar with the *building* and remote from the *fire*, t_{pre} is 300 s.

Flow time (t_{flow}): the occupants in the hotel reception can egress directly outside through either set of double doors, as shown in Figure B2. The door widths are the same as for the ballroom. Therefore the flow rate calculations are identical and are not repeated here. The total *occupant load* egressing through the hotel reception is:

240	mezzanine (50% through the hotel reception and 50% through the north-west *stairway*)
182	lounge
35	hotel reception
9	offices
466	Total occupant load for hotel reception

The restaurant is *fire separated* from the hotel reception space and therefore the occupants from the restaurant are not included in the egress analysis from the hotel reception space. In this case, the restaurant has 382 occupants, of which half would be assumed to egress through the reception area. Therefore, the hotel reception space is designed for the 466 occupants in the space.

Flow time for the hotel reception (two sets of double doors at 100 persons/min/set):

$$\text{Flow time} = \frac{466 \text{ persons}}{2(100 \text{ persons/min})} = 2.33 \text{ min} = 140 \text{ s}$$

The stair widths from the mezzanine must be designed to ensure there is adequate egress capacity. From the mezzanine, there are two *escape routes*: one down the stairs into the hotel reception; and the other down the stair tower in the north-west corner. In this example, the control on the egress flow is considered to be the double doors on the north-west stairwell. Therefore, the stair width must have a capacity of 100 persons/minute. Using the input values given in Table 3.4 of C/VM2 for stair flow, the minimum *stairway* width is calculated as:

Input:

F_c = 100 persons/min
= 1.67 persons/s (flow required to match the door flow rate)
k = 1.08 (Assuming stairs have 178 mm risers and 279 mm treads) (C/VM2 Table 3.4)
a = 0.266 (C/VM2 Paragraph 3.2.4)
D = 1.9 persons/m^2 (C/VM2 Paragraph 3.2.5)

Rearranging Equation 3.4 to solve for W_e gives:

$$W_e = \frac{F_c}{(1 - aD)kD} \text{ (from Equation 3.4 of C/VM2)}$$

W_e = 1.67/{(1 – 0.266 x 1.9) 1.08 x 1.9}
= 1.65 m effective (C/VM2 Paragraph 3.2.5 with W_{BL}= 0.15 m boundary layer [Table 3.5])

$W_{stair} = W_e + 2 \times W_{BL}$ = 1.65 + 2 x 0.15 = 1.95 m

Therefore, both stairs will be a minimum of 1.95 m wide with flow times of:

$$\text{Flow time} = \frac{240 \text{ persons}}{100 \text{ persons/min}} = 2.4 \text{ min} = 144 \text{ s}$$

The simplest assessment of *RSET* for the hotel reception is to add the flow times for the adjoining space (in this case, the mezzanine) to the flow time for the hotel reception. This assumes that no one leaves the hotel reception until after the mezzanine is evacuated, which is expected to overestimate the *RSET*. More sophisticated egress analysis is permitted under C/VM2. The use of particular models for analysis will be the subject of discussion and agreement at the Fire Engineering Brief. Ultimately, the *RSET* for the mezzanine and hotel reception is:

$RSET_{(mezzanine)}$ = 93 s + 30 s + 30 s + (144 s + 140 s) = 437 s.

The numerical values for all three tenability criteria given in C/VM2 and the *RSET* for the mezzanine and hotel reception are given in Table B6. The visibility and $FED_{(Thermal)}$ are shown only for comparison.

The tenability criteria for the $FED_{(CO)}$ defines *ASET* >1200 s (the limit of this simulation), which is long after all of the occupants of this area are assumed to have evacuated the *building*.

Figure B6 shows the tenability results for $FED_{(CO)}$ as well as the *ASET* and *RSET* for the hotel reception and mezzanine.

The results show that *ASET* > *RSET* for both the hotel reception and mezzanine.

Table B6: Results of tenability criteria modelling for challenging fire in the hotel reception

Criteria	Time reached (s)	Margin (s)
RSET (mezzanine governs)	437	-
Visibility = 10 m (mezzanine)	297	*
$FED_{(Thermal)}$ = 0.3 (mezzanine)	793	*
$FED_{(CO)}$ = 0.3 (mezzanine)	>1200	>763
Visibility = 10 m (hotel reception)	344	*
$FED_{(Thermal)}$ = 0.3 (hotel reception)	488	*
$FED_{(CO)}$ = 0.3 (hotel reception)	>1200	>763
*Sprinklered *firecell* with <1000 people visibility and $FED_{(Thermal)}$ is not required as per NZBC C4.4.		

The design of the hotel reception space complies with *design scenario* CF: Challenging fire.

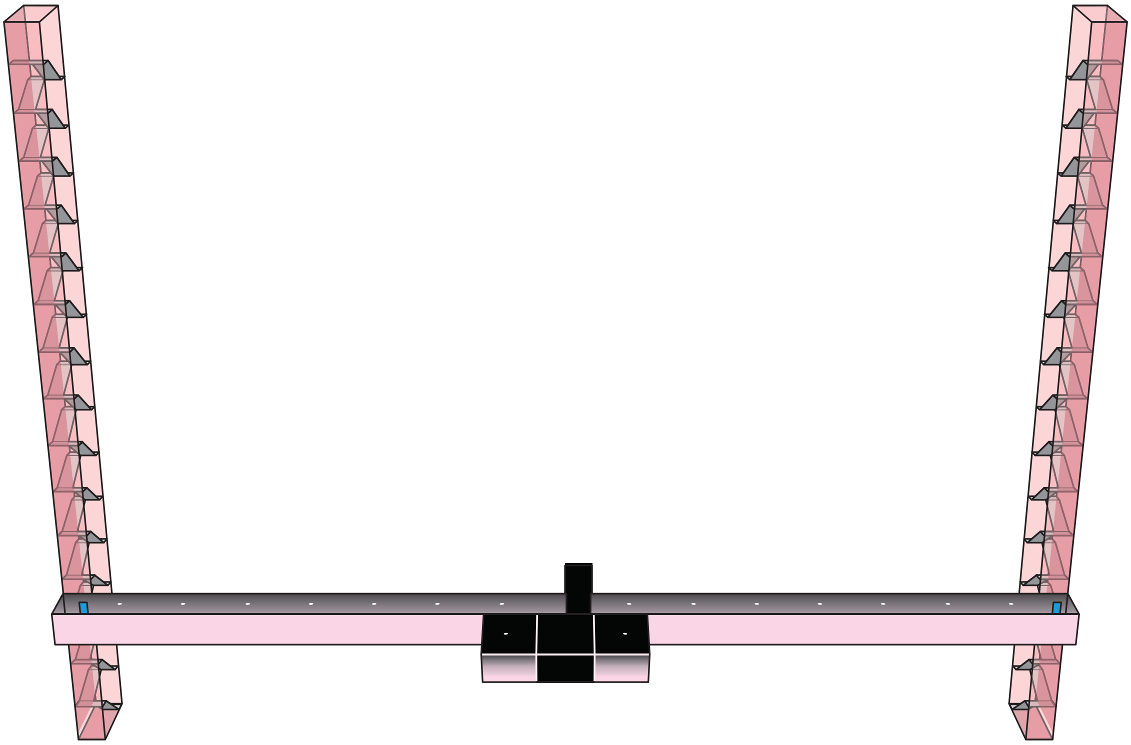
Challenging fire: guest room

ASET

Each guest room is *fire separated* from the corridor. As the guest rooms are less than 500 m^2, tenability is not required to be assessed within the room of origin. However, the impact of a *fire* in a guest room on the rest of the *building* must still be evaluated. As the guest rooms are not *fire* or smoke separated from one another, the adjacent guest rooms have been included, along with the appropriate leakage area, to confirm that untenable conditions are not reached before the rooms are evacuated.

The physical arrangement of the guest room levels is challenging for zone modelling. The long, narrow corridor and the tall *stairways* include complex gravity currents that are better suited for CFD modelling. In this example, the Fire Dynamic Simulator version 5.5.3 (FDS5) is used. Figure B7 shows a Smokeview image for the level 1 corridor that includes three guest rooms, the lift lobby and the two stair towers.

Figure B7: Smokeview image at 200 s post ignition of level 1 with the guest room of origin centred in the corridor, the two adjacent guest rooms, and the stair towers at each end



$FED_{(CO)}$ is the only tenability criterion that needs to be assessed because there is a low *occupant load* (74 people/floor) and the *building* is sprinkler protected. Within FDS5, the visibility and *$FED_{(CO)}$* have been monitored at the following locations:

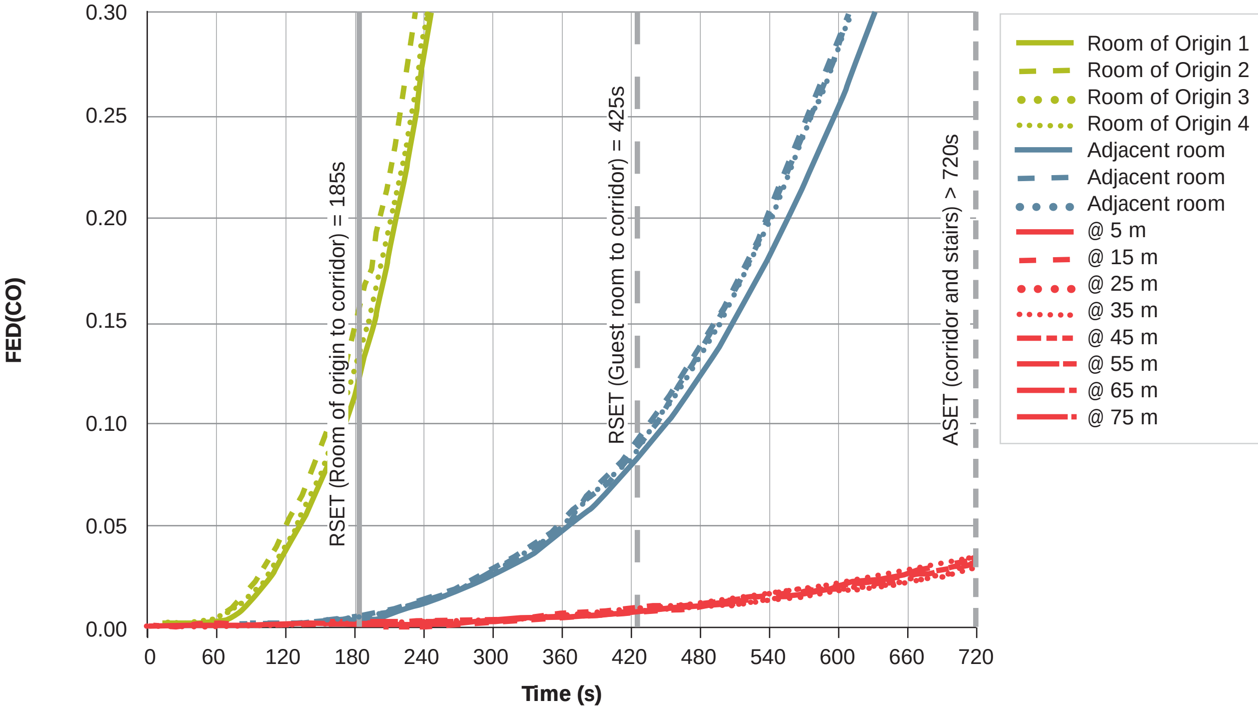
- in the four corners of the guest room of origin
- in the four corners of the two rooms adjacent to the room of origin
- every 10.0 m along the corridor, and
- 2.0 m above each landing within the *stairway*.

With the exception of the guest rooms, the *$FED_{(CO)}$* does not exceed 0.3 for the 720 s of the simulation. *$FED_{(CO)}$* for the room of origin, adjacent guest rooms and along the corridor are shown in Figure B8.

Within the room of origin, *$FED_{(CO)}$* > 0.3 at 240 s. In the adjacent guest rooms *$FED_{(CO)}$* > 0.3 at 600 s, and in the corridor the *$FED_{(CO)}$* never exceeds 0.3 for the entire simulation time of 720 s.

Within the *stairway*, there are only traces of CO but they are too small to be included on the graphs. Therefore, *ASET* > 720 s for the corridor and *stairway*.

Figure B8: $FED_{(CO)}$ in the corridor for a hotel guest room fire



Note:

ASET and *RSET* are also included on the graph.

RSET

The layout of the guest room levels, with the *stairway* at each end of the corridor, is shown in Figure B1. The *escape route* for the occupants is along the corridor to either *stairway*, with both stairways discharging directly to the outside at ground level. There are 37 guest rooms on each level with an *occupant load* of 74 people/floor. The occupants are assumed to exit their rooms and travel to the nearest *stairway* to egress the level and, ultimately, out of the *building*. The maximum travel distance on the guest room levels is taken as 40 m. The *travel distance* within the guest rooms is sufficiently short that it is considered to be included within the *pre-travel activity time*. Once the occupants enter the *stairway*, they are considered to be safe; although this must be confirmed within *design scenario* RC. As previously mentioned, *ASET* v *RSET* for occupants within the guest room of origin does not have to be addressed. However, in this example, the guest room is assessed for demonstrative purposes only.

Detection time (t_d): the room is modelled as a 4.0 m by 6.0 m rectangle without considering the bathroom. Modelling the space in this way is considered to maximise the detection and allows for future changes in the room layout without having to reanalyse the *fire*. The *fire* is placed at one end of the room 1.0 m away from the wall. Two smoke detectors are located on the opposite corners of the room 200 mm from any wall (NZS 4512). This maximises the response time for the detectors without placing the *fire* against the wall or in a corner. The sprinklers are then placed 200 mm from the side walls and at suitable locations so that the radial distance is 3.25 m as specified in Table 3.2 of C/VM2. Both smoke detectors activate at 28 s and the sprinklers activate between 82 s and 83 s, so 83 s is used as the time for sprinkler activation.

Notification time (t_n) is the time for the alarm system to respond to the detector signal and is a fixed value of 30 s (C/VM2 Paragraph 3.2.2).

Pre-travel activity time (t_{pre}): the occupants of a guest room of origin are considered to be asleep and unfamiliar with the *building*. The alarm system has a voice alert; therefore t_{pre} is 60 s. This assumes the occupants will receive other indicators of *fire* such as the smell of smoke or direct observation of the *fire*. The occupants in all other guest rooms are sleeping, unfamiliar and remote from the *fire*. As there is also a voice alert, t_{pre} for these occupants is 300 s (C/VM2 Table 3.3).

Travel time (t_{trav}): this is expected to govern the egress time from the guest room levels. The distance the occupants have to travel is the length of the corridor, which is 40 m. This is shown in Figure B1.

Density is calculated as follows:

74 people / floor

80 m x 3 m = 240 m^2

$$D = 74/240$$
$$= 0.31 \text{ persons/m}^2$$

Travel speed:

$$S = k - akD$$
$$= 1.4 - 0.266 \times 1.4 \times 0.31$$
$$= 1.29 \text{ (use 1.2 m/s maximum [C/VM2 Paragraph 3.2.4])}$$

Travel time:

$$t_{trav} = \frac{L_{trav}}{S}$$

$$= \frac{40 \text{ m}}{1.2 \text{ m/s}}$$

$$= 34 \text{ s}$$

Therefore, the *RSET* from the guest room of origin (ROO) to the *stairway* is:

$$RSET_{(ROO)} = 28\ s + 30\ s + 60\ s + 34\ s$$
$$= 152\ s$$

RSET for the other guest rooms (OGR) to the stairway is:

$$RSET_{(OGR)} = 28\ s + 30\ s + 300\ s + 34\ s$$
$$= 392\ s$$

Figure B8 shows the tenability results for $FED_{(CO)}$ as well as the *ASET* and *RSET* for the guest room of origin, adjacent guest rooms and the other guest rooms. For the corridor, the tenability criterion for the $FED_{(CO)}$ defines *ASET* >720 s (the limit of this simulation) and is well after all of the occupants are assumed to have egressed into the *stairway*.

Note:

The results for the $FED_{(CO)}$ in the four corners of the room of origin have also been included in Figure B8 for general interest.

The numerical value for $FED_{(CO)}$ tenability criteria and *RSET* for the guest room of origin and all other guest rooms are given in Table B7. The results show that *ASET* > *RSET* for all of the guest rooms.

Table B7: RSET and $FED_{(CO)}$ for guest room levels

Criteria	Time reached (s)	Margin (s)
RSET (guest rooms to *stairway*)	392	-
$FED_{(CO)}$ = 0.3 (corridor)	>720	>328
Visibility = 10 m (*stairway*)	342	*
$FED_{(CO)}$ = 0.3 (*stairway*)	>720	>328

*Sprinklered *firecell* with <1000 people visibility and $FED_{(Thermal)}$ is not required as per NZBC Clause C4.4.

The design of the guest room levels complies with *design scenario* CF: Challenging fire.

Details of FDS modelling

The long corridor geometry necessitates a CFD model to predict the flow of smoke down the corridor and into the *stairways*. The *fire* is centred in a guest room located midway along the corridor, which represents the *fire* location that will compromise the corridor in the shortest period of time. Figure B7 shows a Smokeview image for the level 1 corridor that includes three guest rooms, the lift lobby and the two stair towers.

Due to the small room size, the smoke detectors and sprinklers are placed as far as possible from the *fire*. The *fire* is placed 1.0 m from the wall at one end of the room and the smoke detectors are at the opposite end of the room 200 mm from each corner. Smoke detectors activate between 28 s and sprinklers activate between 82 s and 83 s, so 83 s is used as the time for sprinkler activation. The fire is fast αt^2 *fire growth* rate to 340 kW when the sprinklers activate. The mesh size for the guest room, corridor and lift lobby is 0.1 m x 0.1 m x 0.1 m. For the *stairway*, which is further removed from the fire, the grid is 0.2 m x 0.2 m x 0.2 m.

The guest room is *fire separated* from the corridor and the doors are *fire rated* without smoke seals. The modelling rules of C/VM2 specify that a *fire door* that is not a *smoke control door* is assumed to have a 10 mm gap over the height of the door. However, such vents are not easily incorporated into a CFD model. In this case two vents (0.1 m x 0.1 m), one at the top and one at the bottom, are used. The vents fit the 0.1 m mesh and provide more than the equivalent area to the C/VM2 requirement. The leakage vents are also modelled as 0.1 m x 0.1 m vents at the floor and ceiling level. Four leakage vents are included from the guest rooms: two between each guest room and two as external leakage.

In order to evaluate the tenability of the corridor and *stairway*, the response of the occupants must be accounted for, as their actions of opening the doors will have an impact on the spread of smoke from the room of origin to the corridor and from the corridor to the *stairway*. When the occupants open the door to the corridor and to the *stairway*, smoke pours through and spreads down the corridor and up the *stairway*. Figure B7 shows the Smokeview image 200 s after ignition, when the gravity current of the smoke has travelled nearly the entire length of the corridor. The door to the guest room of origin is opened 90 s after the smoke detector activates (30 s notification time + 60 s *pre-travel activity time*). The door is modelled as 0.5 m wide and 2.0 m high as described in C/VM2 Paragraph 2.2.1 (d) and is open for 6 s for the two occupants to egress. The occupants then walk down the corridor and egress via one of the *stairways*. The *travel distance* down the corridor is 40 m maximum, which at 1.2 m/s results in a travel time of 34 s. Therefore, the stairway doors are opened at 152 s (t_d: 28 s + t_{pre}: 60 s + t_n: 30 s + t_{trav}: 34 s) and held open for 6 s while the two occupants from the room of origin enter the *stairway*.

The remaining occupants are assumed to be remote from the *fire* and have a t_{pre} of 300 s. Therefore, they do not enter the corridor until 358 s (t_d: 28 s+ t_{pre}: 300 s+ t_n: 30 s). After leaving their rooms, the occupants travel down the corridor and arrive at the *stairway* door 33 s later at 391 s. The *stairway* door is held open while the occupants egress, with 50% (36 occupants) egressing via each door. In this example, the *stairway* door is held open for 36 s x 3 = 108 s. Table B8 summarises the critical times used in the FDS5 fire modelling analysis for the guest room *fire*.

Table B8: Summary of critical times applied to the FDS5 fire modelling

Time (s)	Event	Explanation
0	Ignition in guest room of origin (ROO)	*Fire* located in guestroom mid-way down the corridor, as this location challenges both *stairways* in the shortest amount of time.
28	Smoke detectors activate in ROO	Four detectors in the ROO
118	Occupants from ROO egress into corridor	t_d = 28 s, t_{pre} = 60 s, t_n = 30 s
152	Occupants from ROO enter *stairway*	t_{trav} = 40 m/1.2 m/s = 34 s
391	All other occupants egress into *stairway* (*stairway* doors open)	t_{pre} = 60 s (28 s + 30 s + 300 s + 33 s) = 391 s
499	*Stairway* doors close	72 people/floor, half to each *stairway*, 3 s/person to egress
720	End of simulation $FED_{(CO)}$ <0.3 in corridor and *stairway*	$FED_{(CO)}$ never attained 0.3

B3.10 Design scenario RC: Robustness check

The building is sprinklered and there are no smoke management systems or any other features or life safety systems in the *building* that rely on a mechanical or electronic component to be activated during the *fire*. Therefore, the only system that requires assessment when considering *design scenario* RC are the *smoke control* and *fire doors*.

Within the building, the most vulnerable cases are small rooms that can threaten a large number of occupants in an adjacent space. The guest room door failure is shown here for demonstration purposes.

Note:

The small room is the most vulnerable case because the room will fill more rapidly, causing more smoke to flow from the room of origin into the *escape routes* and to threaten the occupants of the other rooms. One of the decisions to be made at the Fire Engineering Brief is which systems will need to be considered for *design scenario* RC.

In addition, the *building* is also evaluated against the requirement that, in vertical escape routes serving more than 250 people in a sleeping occupancy, visibility must not be less than 5.0 m in more than one vertical escape route for the period of the *RSET*. This is discussed further below.

Guest room door failure

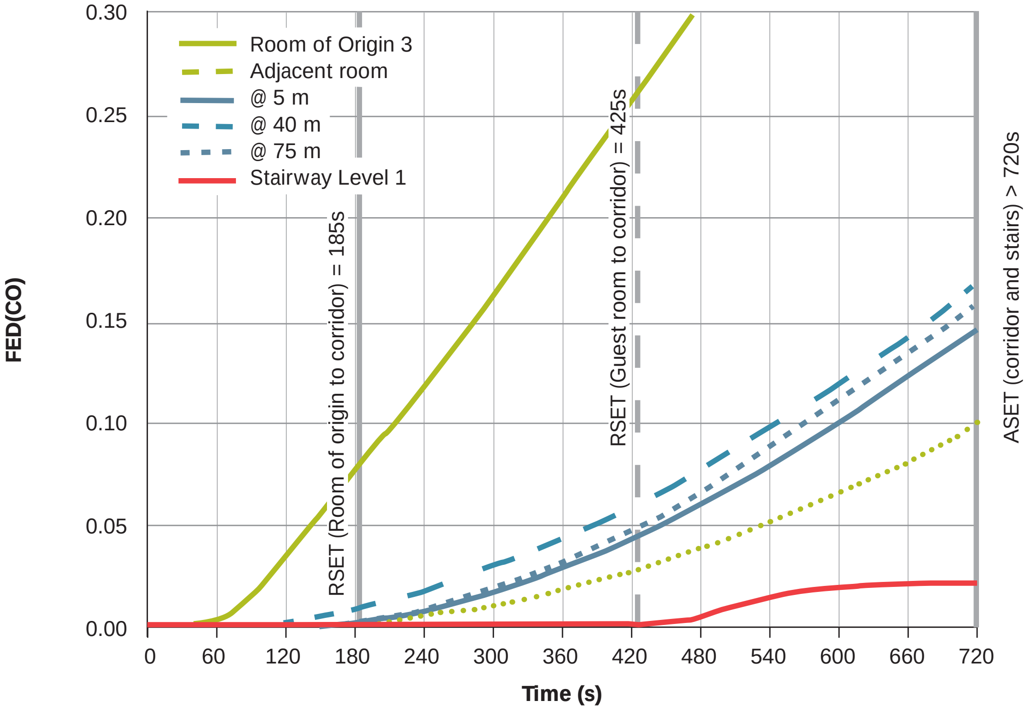
The guest room example assumes a *fire* in one of the centrally located rooms. The guest room door is open from time of ignition and is left open for the remainder of the 720 s simulation. Table B9 sets out the timeline for the guest room level. All other inputs are identical to the challenging fire scenario. In Figure B9 the $FED_{(CO)}$ results are plotted against time for both the guest room of origin and for the corridor. The results for the guest room of origin are only included for general interest and are not compulsory tenability criteria in this case.

Table B9: Summary of RSET and FED for guest room level

Event	Time (s)	Margin
Smoke detector activates in guest rooms	28	
Sprinkler controls *fire* at 350 kW	86	
First two occupants open door to *stairway* $RSET_{(ROO)}$	152	
Stairway door closes	158	
Occupants from other guest rooms enter corridor	391	
Stairway door closes $RSET_{(guest\ rooms)}$	499	
$FED_{(CO)}$ gases in corridor and *stairway* do not exceed 0.3 ($ASET_{(CO)}$)	>720	>221s

The egress analysis for all of the guest rooms egressing to the *stairway* gives *RSET* = 499 s to clear the level. *Design scenario* RC specifies that only the $FED_{(CO)}$ < 0.3 must be achieved. For this case, $FED_{(CO)}$ > 0.3 only after 720 s.

Figure B9: $FED_{(CO)}$ versus time for the design scenario RC in a guest room



Note:

ASET and *RSET* are also included on the graph.

The *ASET* value is determined when the $FED_{(CO)}$ = 0.3.

The design of the guest room levels complies with *design scenario* RC: Robustness check.

Visibility in the stairways

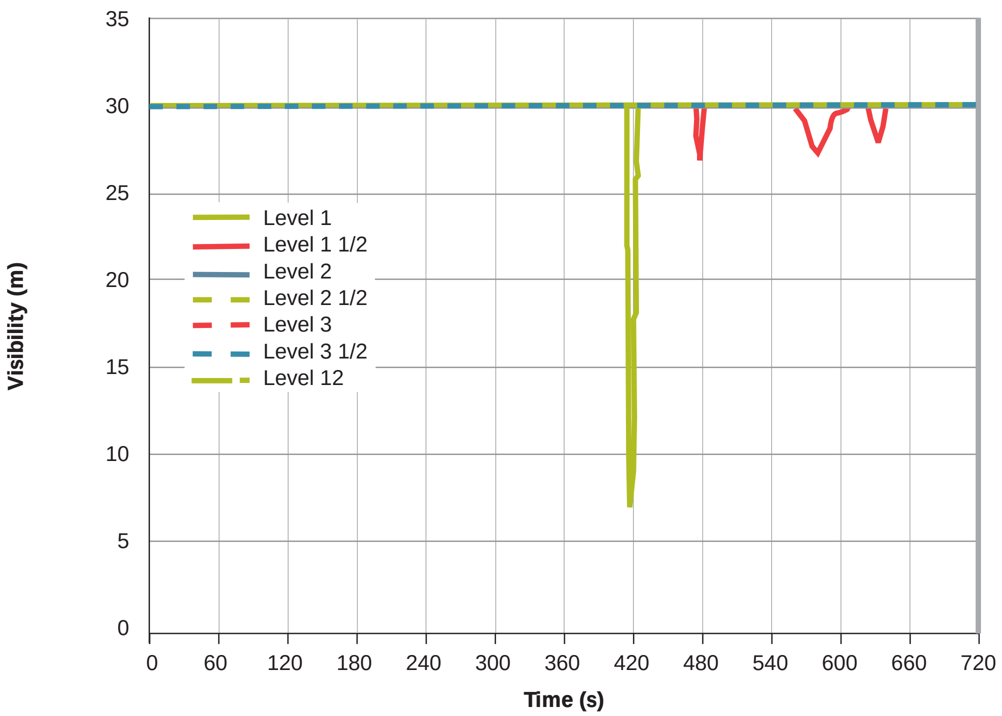
As noted above, there is an additional requirement for sleeping occupancies in a sprinklered *building* that has vertical *escape routes* serving more than 250 people. This requirement is that visibility must not be less than 5.0 m in more than one vertical *escape route* for the period of the *RSET*.

The results from *design scenario* CF for the guest room can be used because all fire safety features are assumed to be working correctly. The test requires a demonstration that visibility is maintained in the *stairway*. In order to assess the visibility in the *stairway*, individual point measurements are placed in the horizontal centre of the landing and 2.0 m above the landing level. The door is assumed to be open continuously while the occupants egress the fire floor. The results are shown in Figure B10, where level 1 is the floor of origin, the ½ indicates intermediate landings between floors, levels 2 and 3 are the next two levels above the *fire*, and level 12 is the top floor where no smoke was recorded.

Figure 10 shows that the visibility does not drop below 5.0 m in the *stairway*.

The design of the guest room levels complies with *design scenario* RC: Robustness check.

Figure B10: Visibility level in stairway based on single point measurements 2.0 m above the horizontal centre of each landing level



B4.0 Summary

The design for the proposed function centre and hotel has been evaluated against all ten *design scenarios* specified in C/VM2. Table B10 summarises how the proposed fire design achieves the requirements of each *design scenario*.

Table B10: Design scenario summary for the proposed fire design

Design scenario	Summary
BE: Fire blocks exit	Two exits with equivalent capacity are provided from every room with more than 50 people.
UT: Fire in normally unoccupied room threatening occupants of other rooms	Automatic sprinkler protection is provided to confine *fire* in the room of origin.
CS: Fire starts in a concealed space	Automatic sprinkler protection is provided in *concealed spaces* in accordance with NZS 4541.
SF: Smouldering fire	Automatic detection is provided in all sleeping spaces in accordance with NZS 4512.
HS: Horizontal fire spread	*Fire rated* wall is provided that will withstand *burnout* along north boundary with no unprotected openings.
VS: Vertical fire spread involving external cladding	Exterior surfaces are non-combustible and internal sprinklers will be installed.
IS: Rapid fire spread involving internal surface linings	Interior surface linings meet the requirements for a sprinklered *building* as specified in C/VM2 Paragraph 4.7, as described for this *building*.
FO: Firefighting operations	The *building* is fully sprinklered to NZS 4541; therefore, the fire service requirements are reduced. Access is to three sides, an internal hydrant system is provided, and *fire resistance ratings* provide for full *burnout* where required.
CF: Challenging fire	The results for the *ASET* vs *RSET* analysis at eight different locations throughout the building have shown that the tenability criteria given in C/VM2 for a sprinklered *building* are not exceeded using the required input parameters. Note: only four of the eight locations for design scenario CF have been shown here although all eight scenarios would need to be included in a complete fire design report.
RC: Robustness check	Two robustness checks were made on small rooms with doors open from ignition. The check on the guest room door failure showed that the $FED_{(CO)}$ <0.3.

B5.0 Time Equivalence Calculations

B5.1 Ballroom walls

$t_e = e_f\, k_b\, k_m\, w_f$

F_m = 0.5 (dependent on the specific structural design.

For this example 0.5 has been assumed. See C/VM2 Paragraph 2.4.1 for further detail.)

e_f = 400 MJ/m^2 (C/VM2 Table 2.2)

k_b = 0.065 (C/VM2 Table 2.4 for normal weight concrete)

k_m = 1.0 (C/VM2 Paragraph 2.4.4 for reinforced concrete)

$$w_f = \left(\frac{6.0}{H}\right)^{0.3}\left[0.62 + \frac{90(0.4 - \alpha_v)^4}{1 + b_v \alpha_h}\right] \geq 0.5$$

$$\alpha_v = \frac{A_v}{A_f} = \frac{60\ m^2}{1000\ m^2} = 0.06$$ assumed window area for this example

$$\alpha_h = \frac{A_h}{A_f} = \frac{0\ m^2}{1000\ m^2} = 0.0$$ no vents in ceiling

$$b_v = 12.5\left(1 + 10 - (0.06)^2\right) = 20.0$$

$$w_f = \left(\frac{6.0}{5}\right)^{0.3}\left[0.62 + \frac{90(0.4 - 0.06)^4}{1 + 20.0(0)}\right] = 1.93$$

t_e = (0.5) 400 (0.065) 1.0 (1.93)

= 25.1; therefore assume 30 minutes

B5.2 Restaurant, hotel reception, kitchen, lounge and mezzanine

The elevations for the window areas give the smallest α_h in the kitchen area of 0.06, so this will govern the *fire resistance rating*.

e_f = 800 MJ/m^2 (C/VM2 Table 2.2)

Other values are unchanged from the ballroom wall calculations given above:

F_m = 0.5 (Dependent on the specific structural design.
For this example 0.5 has been assumed. See C/VM2 Paragraph 2.4.1 for further detail.)

k_b = 0.065 (C/VM2 Table 2.4 for normal weight concrete)

k_m = 1.0 (C/VM2 Paragraph 2.4.4 for reinforced concrete)

w_f = 1.93

α_v = 0.06 (assumed window % for this example)

α_h = 0.0 (no ceiling vents)

b_v = 20.0

w_f = 1.93

t_e = (0.5) 800 (0.065) 1.0 (1.93)
= 50.2; therefore assume 60 minutes

5.3 Guest rooms

$t_e = F_m e_f k_b k_m w_f$

$F_m = 0.5$

e_f = 400 MJ/m² (C/VM2 Table 2.2)

k_b = 0.065 (C/VM2 Table 2.4 for normal weight concrete)

k_m = 1.0 (C/VM2 Paragraph 2.4.4 for reinforced concrete)

$$w_f = \left(\frac{6.0}{H}\right)^{0.3}\left[0.62 + \frac{90(0.4 - \alpha_v)^4}{1 + b_v \alpha_h}\right] \geq 0.5$$

$$\alpha_v = \frac{A_v}{A_f} = \frac{3 \times 1.2\ m^2}{6 \times 4\ m^2} = 0.15$$ guest room window 3.0 m wide and 1.2 m high

$$\alpha_h = \frac{A_h}{A_f} = \frac{0\ m^2}{1000\ m^2} = 0.0$$ (no vents in ceiling)

$$b_v = 12.5\left(1 + 10\,(0.15) - (0.15)^2\right) = 31.0$$

$$w_f = \left(\frac{6.0}{3}\right)^{0.3}\left[0.62 + \frac{90(0.4 - 0.15)^4}{1 + 20.0(0)}\right] = 1.20$$

t_e = (0.5) 400 (0.065) 1.0 (1.20)
=15.6; therefore assume 20 minutes (the minimum *FRR* value permitted by C/VM2 when using time equivalent method).

B6.0 BRANZFIRE Input

Table B11: Dimensions of rooms used in BRANZFIRE modelling

Room	BRANZFIRE room number*	Length (m)	Width (m)	Height (m)
Ground floor and mezzanine				
Ballroom	1	50	20	5
Meeting rooms 1 to 5	2	47	12	5
Foyer 1	3	59.5	8	5
Foyer 2	4	38	5	5
Hotel reception and lounge/bar	5	40	14.7	5
Restaurant	6	28	15	5
Kitchen	7	15	12	5
Small meeting room (RC: Robustness check)	8	12	7	5
Mezzanine	9	40	13.2	4
West *stairway*	10	6	2	55
Guest room levels				
Guest room	1	6	4	3
Corridor	2	80	3	3
West *stairway*	3	6	2	55
East *stairway*	4	6	2	55

* BRANZFIRE room numbers for the ground floor and mezzanine are also shown in Figure B3.

Table B12:	Details of vents used in BRANZFIRE analysis					
Room	Room	Description	Number of doors	Width (m)	Sill (m)	Soffit (m)
Ballroom (1)	Foyer 1 (3)	Door	4	1.60	0	2.1
	Foyer 1 (3)	Door/leakage	4	0.04	0	2.1
	Foyer 1 (3)	Internal leakage		0.25	0	5
	Foyer 2 (4)	Door	2	0.80	0	2.1
	Foyer 2 (4)	Door/leakage	2	0.02	0	2.1
	Foyer 2 (4)	Internal leakage		0.10	0	5
	Outside	Door	4	1.60	0	2.1
	Outside	Door/leakage	4	0.04	0	2.1
	Outside	External leakage		0.35	0	5
Meeting rooms (2)	Foyer 1 (3)	Door	5	2.00	0	2.1
	Foyer 1 (3)	Door/leakage	5	0.05	0	2.1
	Foyer 1 (3)	Internal leakage		0.30	0	5
	Outside	External leakage		0.30	0	5
Foyer 1 (3)	Outside	Door	2	0.95		2.1
	Outside	External leakage		0.02	0	5
	Foyer 2 (4)	Opening		8.00	0	5
	Restaurant	Internal leakage		0.01	0	5
Foyer 2 (4)	Hotel reception and lounge (5)	Opening		5.00	0	5
	Restaurant (6)	Internal leakage		0.02	0	5
Hotel reception and lounge (5)	Restaurant (6)	Door	2	0.95	0	2.1
	Restaurant (6)	Internal leakage		0.02	0	5
	Restaurant (6)	Door/leakage	2	0.02	0	2.1
	Outside	Door	6	2.85	0	2.1
	Outside	External leakage		0.07	0	5
	Outside	Door/leakage	6	0.06	0	2.1
Restaurant (6)	Kitchen (7)	Door	2	0.95	0	2.1
	Kitchen (7)	Door/leakage	2	0.02	0	2.1
	Kitchen (7)	Internal leakage	2	0.02	0	5
	Outside	Door	1	0.48	0	2.1
	Outside	External leakage		0.03	0	5
	Outside	Door/leakage	3	0.03	0	2.1
Kitchen (7)	Outside	Door	1	0.48	0	2.1
	Outside	Door/leakage	3	0.03	0	2.1
	Outside	External leakage		0.03	0	5

Table B12:	Details of vents used in BRANZFIRE analysis continued					
Room	Room	Description	Number of doors	Width (m)	Sill (m)	Soffit (m)
Small meeting room (8)	Foyer 1 (4)	Door	1	0.48	0	2.1
	Foyer 1 (4)	Internal leakage		0.10	0	5
	Foyer 1 (4)	Door/leakage	1	0.01	0	2.1
	Outside	External leakage		0.01	0	5
Mezzanine (9)	Hotel reception and lounge (5)	External leakage		0.02	0	5
	Stairway (10)	Door	2	0.95	0	2.1
	Stairway (10)	Door/leakage	2	0.02	0	2.1
Stairway (10)	Outside	Door	2	0.95	0	2.
Guest room level						
Guest room (1)	Corridor (2)	Door	1	0.4	0	2.1
		Door/leakage	1	0.01	0	2.1
		Leakage		0.01	0	
Corridor (2)	Stairway (3)	Door	1	0.48	0	2.1
		Door/leakage	1	0.01	0	2.1
	Stairway (4)	Door	1	0.48	0	2.1
		Door/leakage	1	0.01	0	2.1
Stairway (3)	Outside	External leakage		0.01	0	
Stairway (4)	Outside	External leakage		0.01	0	

Note: Numbers in brackets are the BRANZFIRE room numbers given in Table B11.

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