Apparent Level of Safety of Buildings Meeting the New Zealand Building Code Approved Document C/AS1 – Fire Safety

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ABSTRACT

The key objective of the project was to develop a risk ranking model to assess the apparent level of safety of buildings designed to the Approved Document for New Zealand Building Code, Fire Safety Clauses C1, C2, C3, C4 (C/AS1)[1]. This is a prescriptive fire safety code.

The study included a literature review of fire risk analysis methods. This found that there are numerous methods from simple risk ranking techniques such as that used in this project to detailed probabilistic risk analysis (PRA) techniques. It was generally found that more sophisticated analysis, such as PRA and Reliability Index methods are most suited to specific engineering problems while the risk ranking schemes are better suited to "broad-brush analyses" across a large range of buildings.

The risk ranking model developed is based on a simple weighted points system where the building geometry, use and fire safety features are graded according to the likely impact they will have on safety. The model output is a single numerical index value, termed the Fire Safety Index (FSI). A high index indicates a safer building. The model is best used for a comparative analysis as the results are not an absolute measure of risk.

The results of the analysis of buildings designed to C/AS1 indicate that the level of safety increases predominantly with increasing building escape height and/or increasing occupant numbers. The report raises questions over the level of safety afforded by sprinkler systems and whether or not the sprinkler tradeoff provisions of C/AS1 are appropriate.

The model proposed in this study could be developed further and used to determine whether or not a specific fire engineering design (alternative solution) provides an "equivalent" level of safety to that achieved by the prescriptive solution C/AS1. The model requires further testing and validation before it would be suitable for this task or any other practical uses.

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NOMENCLATURE

Abbreviations

AS/NZS	Australian and New Zealand Joint Standards
ASET	Available Safe Egress Time
BRE	Building Research Establishment (UK)
BUS	Building Use Score
C/AS1	Approved Document for New Zealand Building Code - Fire Safety Clauses C1, C2, C3, C4.
CL	C/AS1 Purpose Group - Crowd Large
CM	C/AS1 Purpose Group - Crowd Mercantile
CO	C/AS1 Purpose Group - Crowd Open
CS	C/AS1 Purpose Group - Crowd Small
DBH	New Zealand Government - Department of Building and Housing
DEOP	C/AS1 Dead End Open Path
ELL	Expected Loss of Life
ERL	Expected Risk to Life
F	C/AS1 Firecell Rating
FEI	Dow - Fire and Explosion Index
FHC	C/AS1 Fire Hazard Category
FI	Flammability Index
FIERASystem	Fire Evaluation and Risk Assessment System
FiRECAM	Fire Risk Evaluation and Cost Assessment Model
FLED	C/AS1 Fire Load Energy Density (MJ/m^2)
F-N Curve	Frequency/Number Curve

FOSM	First Order Second Moment analysis
FRIM-MAB	Fire Risk Index Method - Multi-storey Apartment Building
FRR	C/AS1 - Fire Resistance Rating
FSES	Fire Safety Evaluation System
FSFS	Fire Safety Features Score
FSI	Fire Safety Index
FSP	C/AS1 Fire Safety Precautions
HSP	C/AS1 Horizontal Safe Path
IA	C/AS1 Purpose Group - Intermittent Activities
ID	C/AS1 Purpose Group - Intermittent Dangerous
IE	C/AS1 Purpose Group - Intermittent Exitway
IFEG	International Fire Engineering Guidelines
MCP	Manual Call Point
NFPA	National Fire Protection Association (USA)
NRCC	National Research Council of Canada
NZ	New Zealand
NZBC	New Zealand Building Code
PP	C/AS1 Protected Path
PRA	Probabilistic Risk Analysis
QRA	Quantitative Risk Analysis
RSET	Required Safe Egress Time
S	C/AS1 Structural Endurance Rating
SA	C/AS1 Purpose Group - Sleeping Accommodation
SC	C/AS1 Purpose Group - Sleeping Care
SD	C/AS1 Purpose Group - Sleeping Detention

SDI	Smoke Development Index
SFI	Spread of Flame Index
SH	C/AS1 Purpose Group - Sleeping Household
SOSM	Second Order Second Moment analysis
SQRA	Semi Quantitative Risk Analysis
SR	C/AS1 Purpose Group - Sleeping Residential
TALL	Theoretical Annual Loss of Life
TOP	C/AS1 Total Open Path
VSP	C/AS1 Vertical Safe Path
WH	C/AS1 Purpose Group - Working High(Fire load)
WL	C/AS1 Purpose Group - Working Low (Fire load)
WM	C/AS1 Purpose Group - Working Medium(Fire load)

Symbols

A	Gretner Method - Probability that a fire will start (Section 5.6.4)
A	Limit state equation - Floor area (m^2) (Section 5.6.8)
As	FSI - Attribute score
B	Gretner Method - Fire hazard
D	Limit state equation - Detection time (minutes)
E	Limit state equation - Escape time (minutes)
$ELLB$	Expected loss of life during design life of building
ERL	Expected risk to life
F	Gretner Method - Fire resistance (Section 5.6.4)
F	Limit state equation - Specific flow (persons/min/m) (Section 5.6.8)
G	Limit state equation - Escape time margin (minutes)
H	Limit state equation - Room height (m)
μ	Mean
M_R	Limit state equation - Evacuation model uncertainty factor
M_S	Limit state equation - Fire model uncertainty factor
N	Gretner Method - Standard fire safety measures
N	Limit state equation - Occupancy rate (persons/m^2)
OP	Number of occupants
P	Gretner Method - Potential hazard
$P(n)$	Probability of an event occurring
$P_{1,2,2....i}$	FRIM-MAB - Parameters
P_f	Probability of failure
Pi	FRIM-MAB - Building safety parameter

R	Limit state equation - Required safe egress time (Section 1.3)
R	Gretner Method - Fire risk (Section 5.6.4)
RI	FRIM-MAB - Risk index
S	Limit state equation - Available safe egress time (Section 1.3)
S	Gretner Method - Special fire safety measures (Section 5.6.4)
σ	Standard deviation
$S1,S2\ldots S_N$	NFPA101A - Fire safety categories
t_a	Time from detection to alarm sounding (minutes)
t_D	Design life of a building
t_d	Time to detection (minutes)
t_{ev}	Total evacuation time (minutes)
t_f	Time to clear a floor (minutes)
t_i	Time for occupants to investigate fire alarm (minutes)
t_o	Time from alarm until occupants make decision (minutes)
t_{op}	Travel time in open path (minutes)
t_p	Pre-movement time (minutes)
t_q	Queuing time (minutes)
t_t	Travel time (minutes)
W	Limit state equation - Door width (m) (Section 5.6.8)
W_A	NFPA101A - Average parameter weightings by occupancy
W_{Ad}	NFPA101A - Adjusted average parameter weightings
Wi_{BUS}	FSI - Parameter weightings for Building Use Score
$Wi_{C/AS1}$	FSI - Parameter weightings
Wi_{FSFS}	FSI - Parameter weightings for Fire Safety Features Score
$Wi_{Parameter}$	NFPA101A - Fire safety parameter weightings

Wn	FRIM-MAB - Building safety parameter weighting
$W_{N\ Parameter}$	NFPA101A - Normalised adjusted parameter weightings
$W_{NA\ Parameter}$	NFPA101A - Average parameter weightings by safety category
$W_{NFPA101A,}$	NFPA101A - Weighting assigned to equivalent C/AS1 parameters
Wo	FRIM-MAB - Occupant egress safety parameter weighting
$Wr_{\ FRIM\text{-}MAB}$	FRIM-MAB - Weighting assigned to equivalent C/AS1 parameters
$Wr_{\ Parameter}$	FRIM-MAB – Revised parameter weightings
X	Boyes Method - Risk score
Y	Boyes Method - Probable fire severity
Z	Boyes Method - Consequence score
α	Limit state equation - Fire growth rate (MW/s^2)
β	Reliability Index
Φ	Standardised normal distribution function

1 INTRODUCTION

1.1 Background

The 1st Schedule of the New Zealand Building Regulations 1992(2) comprises the New Zealand Building Code(3). This is a performance based code. Clauses C1 to C4 sets out the performance criteria for the design of buildings for fire safety in New Zealand. There are two means for designing a building to meet these requirements. The first is to use the Approved Document for New Zealand Building Code Fire Safety Clauses C1, C2, C3, C4(1). This is a prescriptive solution which, is commonly referred to as the "Acceptable Solutions"(C/AS1). The second method is by specific fire engineering design, which is commonly referred to as an "Alternative Solution".

The level of fire safety of buildings designed to meet C/AS1 is not specified in numerical terms in the document but is loosely defined as follows.

> *"Designing a building to provide adequate fire safety, involves decisions on both the construction materials and layout needed to reduce the perceived risk to an <u>acceptable level</u>." [Cl. 2.1.2 C/AS1]*

The term "acceptable level" is not defined. In fact the engineering basis behind the C/AS1 document is not laid out in any format that would enable an engineer to readily calculate whether or not deviations from C/AS1 have a significant positive or negative impact on the level of safety of a building. Therefore comparisons of fire safety between designs cannot be readily carried out without a time consuming and expensive probabilistic risk analysis. The reliability of such analysis could also be questioned given the current lack of comprehensive data available to the design engineer on the performance of fire safety features, fire behaviour and human response to fire.

It is prudent to note that C/AS1 is a prescriptive code that is prepared with non-engineers in mind. There is no requirement in New Zealand for fire design to C/AS1 to be carried out by qualified fire engineers. In fact a significant number of fire designs in New Zealand are carried out by architects, engineering technicians and professional engineers (without fire engineering qualifications). Therefore, it is not unreasonable to exclude the technical background from such a document to prevent inappropriate use by persons who lack the technical knowledge and understanding to use the information correctly.

1.2 Meeting the Building Code

A Building Consent is a permit to build, extend or modify a building or structure. Under the New Zealand Building Act 2004[(4)], a Building Consent is required for any work that affects the size, use or structural stability of a building. Building maintenance does not usually require a Building Consent. A Building Consent is issued by a Building Consent Authority.

Territorial Authorities (City and District Councils) are Building Consent Authorities under the New Zealand Building Act 2004[(4)] and are responsible for issuing the majority of Building Consents for the modification or construction of new buildings. Independent Building Certifiers can also be registered as Building Consent Authorities under the Act, but at this time majority of Building Consents in New Zealand are issued by Territorial Authorities. The Territorial Authority has 20 working days to review the Building Consent Applications, including fire safety design documentation, and issue or decline consents.

It is becoming more common practice to engage professional fire engineers to carry out specific fire engineering design of buildings. There is an expectation amongst building owners, developers and architects that specific fire engineering design provides more design flexibility and a more economical solution than designs prepared to C/AS1. However this results in alternative designs that deviate from C/AS1 and as such difficulties can arise when trying to obtain a Building Consent or construction certification. There are several reasons why an alternative design may not receive Building Consent or construction certification:

a) The design is clearly inadequate (e.g. something is obviously missing).
b) The design is adequate but the design documentation is incomplete and does not adequately demonstrate compliance.
c) The design is being compared to the C/AS1 instead of the performance criteria of the New Zealand Building Code.
d) Contradictory expert opinion. This may be technical or philosophical.

The first two, (a) and (b) above, are the responsibility of the design engineer. The design engineer is generally required to correct any obvious mistakes and /or provide additional information necessary to demonstrate compliance.

The third reason, (c) above, that alternative designs often fail Building Consent applications, is that the C/AS1 are often treated as the only means of meeting the "Building Code" by Territorial Authorities and certification agencies. This results in alternative designs being compared to the C/AS1 instead of the performance criteria of the Building Code. There is an expectation, rightly or wrongly, that alternative designs should provide an "equivalent" level of safety to a design prepared to the Acceptable Solutions. However, alternative designs that are clearly documented, and adequately demonstrate that the design meets the performance requirements of the Building Code are an acceptable method of complying with the NZ Building Code. It should be noted that the Department of Building and Housing (DBH) have decreed in a number of Determinations [5, 6] that:

> *"The Authority (DBH) sees the acceptable solutions as an example of the level of fire safety required by the Building Code. Any departure from the acceptable solution must achieve the same level of safety if it is to be accepted as an alternative solution complying with the building code."*

The fourth reason, d) above, generally occurs where a design or a component of a design is based on subjective judgment as there is no or limited calculation methods or data available. These can be time consuming and expensive debates to resolve. As the fire engineering profession evolves and methods of analysis are improved then these types of issues may subside.

Currently there are few methods (either an internal or external peer review) available to the territorial authorities for reviewing and approving specific fire engineering designs (alternative solutions) in an expedient manner. Therefore the practice of comparing alternative solutions to C/AS1 is likely to continue in the foreseeable future. The introduction of the International Fire Engineering Guidelines [7] aims to provide a standard method for undertaking specific fire engineering design and as such specific fire engineering design review.

1.3 Acceptable Level of Safety

In a fire engineering consulting environment C/AS1 still provides a rapid and adequate method for determining Building Code compliant fire safety designs for the majority of buildings. However, as specific fire engineering design become more common, there is a need to know what is an acceptable level of fire safety for buildings, how to calculate it and what an appropriate method for verification is.

It is likely to be beneficial to both design engineers and Building Consent Authorities if the acceptable level of fire safety and method for calculating/verifying it was legislated into a Code of Practice or Standard endorsed by the appropriate government agency. This is common practice for other engineering disciplines in New Zealand, structural for example. However, no one in New Zealand or in fact many other countries in the world have derived a method for determining the absolute level of safety of a building design or established an absolute acceptable level of fire safety for buildings, that can be readily incorporated into a Code of Practice.

A standard level of fire safety could be represented by an "expected risk to life", i.e. an annual probability of dying in a building fire or it could be expressed as a minimum safety margin. One could even follow the structural code (NZS 4203:1992[(8)]) lead and specify a "load" factor and "capacity reduction" factor limit state format, which could be presented as follows in a fire engineering context:

$$1.5\,R \leq 0.5\,S \quad \text{(Limit state equation for occupant egress)}$$

Where : R = Required safe egress time (RSET), "response & evacuation time"
S = Available safe egress time (ASET), "time to untenable conditions"

Alternatively, an acceptable level of safety could be determined by investigating the "apparent" level of safety to buildings designed to C/AS1 so "equivalence" comparisons can be readily made to appropriately designed and detailed alternative solutions.

1.4 Safety Provided by C/AS1

Before one can begin to address issues such as, what is an acceptable level of fire safety for buildings and whether or not an "equivalency" approach is reasonable, it is prudent to evaluate and ascertain the level of fire safety provided by the New Zealand Building Code Approved Document C/AS1. Questions to be considered include:

- What is the apparent level of safety of buildings designed to C/AS1?
- Is there a variation in safety across building types, heights etc?
- What fire safety features impact most on the safety of a building?

The primary aim of this project is to investigate the apparent level of safety of buildings design to C/AS1 by addressing the above questions?

2 OBJECTIVES

This report investigates the apparent level of safety of building designed to the Approved Document for New Zealand Building Code Fire Safety Clauses C1, C2, C3, C4: June 2001 Revision (C/AS1)[1] with the following objectives:

1. To investigate and identify suitable methods for undertaking fire safety risk assessments.

2. To develop a risk ranking scheme that can be used for assessing the apparent level of safety of building designed to C/AS1.

3. Using the risk ranking scheme developed to evaluate the apparent level of fire safety inherent in buildings designed to C/AS1 by comparing the risk/safety between a variety of building categories, occupancy types and building heights.

This report does not attempt to determine the “absolute” level of safety of buildings designed to C/AS1. Furthermore no attempt has been made to determine an “appropriate” level of safety that fire safety engineers and building consent authorities can use as a benchmark for designing buildings.

The issue of “equivalency”, comparing alternative solutions to the Acceptable Solutions, is discussed in Chapter 8 with a view to using the risk ranking model proposed in this report as a possible tool for carrying out equivalency design comparisons. The pros and cons of “equivalency” are discussed but no attempt is made to determine whether or not the “equivalency” approach is a valid method.

C/AS1 provides fire safety solutions for a large range of buildings and purpose groups. The types of purpose groups, building sizes and occupant number categories assessed in this report has been limited for a variety of reasons as discussed later in Section 4 of this report, but primarily to provide a practical and definitive scope for the study. Therefore the following purpose group, building height and occupant number categories have been assessed in this project based on C/AS1.

Purpose Group:

CS Crowd Small 50< Occupants < 100

CL Crowd Large > 100 Occupants

CM Crowd Mercantile

SA Sleeping Accommodation

SR Sleeping Residential

WL Working Low (Fire load)

WM Working Medium (Fire Load)

Escape Heights:

4m to <10m

10m to < 25m

25m to <34m

34m to < 46m

46m to < 58m

Over 58m

Occupant Numbers:

Up to 100

101 -500

501 - 1000

Over 1000

3 NEW ZEALAND REGULATORY FRAMEWORK

3.1 Overview

The New Zealand regulatory framework governing the design and construction of buildings for fire safety has evolved over the last century based around prescriptive code environment. In a prescriptive code environment the design requirements are typically fully "prescribed", hence to complete a design the designer simply determines the design features required from a list or table, generally no engineering calculations are required. A shortcoming of the prescriptive code environment is that there is very little scope for engineers to tailor designs to meets the specific requirements of a building.

In 1991 a new Building Act was legislated based on a performance based code where, rather than prescribing the exact design required to meet the Building Code, the performance criteria for each fire safety requirement was specified. The building designer then had a choice of methods for demonstrating compliance. In the case of fire safety design this compliance can be achieved in one of two ways, firstly by working through the Approved Documents [(1)], a prescriptive code (also known as the "Acceptable Solutions" C/AS1) or secondly preparation of specific fire engineering design, known as an "Alternative Solution".

The Building Act[(4)], Building Regulations[(2)] and Fire Safety Approved Documents[(1)] have all been reviewed, amended and in some cases completely reissued in the past 14 years. Although the changes have been significant, the codes and regulations for fire safety are still based around the performance code environment established in 1992. Nevertheless the "prescriptive code", Approved Document C/AS1 has been retained. Furthermore, under the Building Act 2004, the Fire Service has been given a role at the design stage of a building project for certain classes of building to review and comment on the fire safety design and facilities for fire fighters, with respect to means of escape only, prior to a Building Consent being issued.

The design, construction, and maintenance of buildings for fire safety in New Zealand is governed by several pieces of Government Legislation which in turn are overseen and enforced by a number of regulatory and territorial authorities. The documents relevant to the design of building for fire safety are as follows:

- Approved Document for New Zealand Building Code Fire Safety Clauses C1, C2, C3, C4 (C/AS1)[1]
- Building Regulations 1992 (including subsequent amendments)[2]
- Building Code (1st Schedule of the Building Regulations) [3]
- Building Act 2004[4]
- Fire Services Act 1975[9]
- Fire Service Regulations 2003[10]
- Fire Safety & Evacuation of Buildings Regulations 1992[11]
- Material and Systems Standards and Codes of Practice

The basic interrelationship between the various Acts and Regulations as they pertain to the design of a building for fire safety are shown in Figure 3.1.

The following organisations have responsibilities under the regulatory framework for administering, reviewing and updating and complying with the various fire safety statutes and laws:

- Building Owner
- Department of Building and Housing (DBH), Ministry of Housing
- Territorial Authority (City and District Councils)
- Building Consent Authority (Licensed Certifiers or Territorial Authorities)
- Licensed Building Practitioners (Designers and Builders)*(after 2009)*
- New Zealand Fire Service

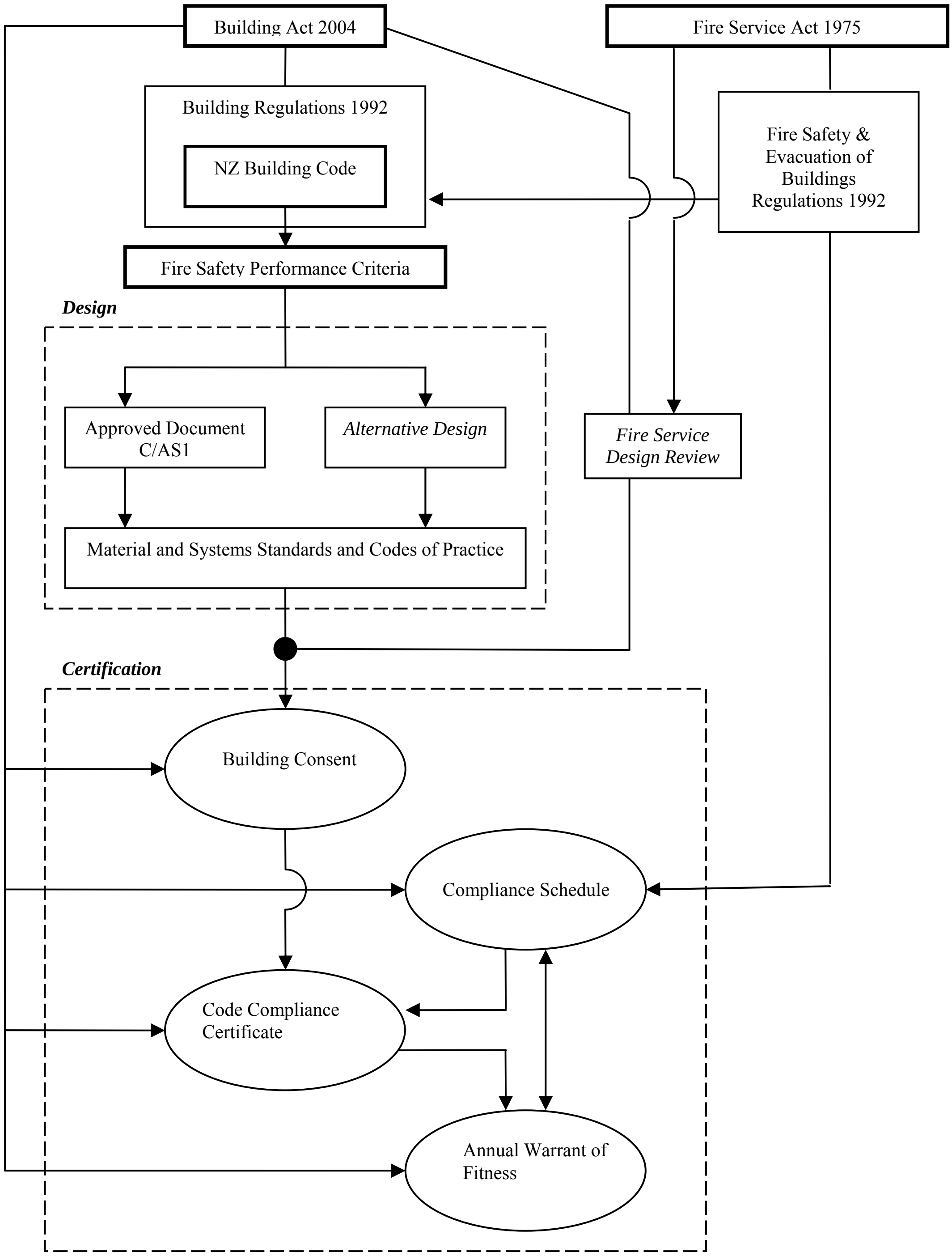


Figure 3.1 - New Zealand Regulatory Framework Governing Fire Safety of Buildings

3.2 Building Act 2004

The New Zealand Building Act 2004[4] is the legislative document enacted by Parliament that sets out the laws relating to the design, construction and maintenance of buildings and structures in New Zealand. The Building Act has the following purpose [4]:

> *The purpose of this Act is to provide for the regulation of building work, the establishment of a licensing regime for building practitioners, and the setting of performance standards for buildings, to ensure:*
>
> *(a) people who use buildings can do so without endangering their health; and*
> *(b) buildings have attributes that contribute appropriately to the health, physical independence, and well being of the people who use them; and*
> *(c) <u>people who use the building can escape from the building if it is on fire; and</u>*
> *(d) buildings are designed, constructed and are able to be used in a way that promotes sustainable development.*

The Building Act contains five main parts as detailed below and four schedules (not detailed):

Part 1 – Preliminary	Sets out the purpose, role of Crown and definitions
Part 2 – Building	Sets out the legal requirements of buildings, building consent process and identifies relevant regulations that a building must comply with.
Part 3 – Regulatory Responsibilities and Accreditation	Sets out the legal responsibilities of the Regulatory Authorities (Generally Building Consent Authorities, City and District Councils) and Accreditation Agencies.
Part 4 – Regulation of Building Practitioners	Sets out the laws and procedure for licensing and controlling the licenses of building practitioners.

Part 5 – Miscellaneous Provisions	Generally deals with offences, fines, proceedings, procedures and transitional provisions.

The following key clauses of the New Zealand Building Act 2004 are pertinent to the design of building for fire safety:

Section 17	:	All work must comply with the building code.
Section 46	:	Copy of certain applications for building consent must be provided to New Zealand Fire Service Commission.
Section 47	:	New Zealand Fire Service Commission may give advice on applications under section 46.
Section 100	:	Requirement for a Compliance Schedule.
Section 108	:	Annual Building Warrant of Fitness.
Section 112	:	Alterations to Existing Buildings
Section 114,115	:	Change of Use, extension of life, and subdivision of buildings.

The most significant changes from the 1991 Act to the 2004 Act from a fire safety perspective come in Sections 46 and 47 where prior to issuing of a building consent the Fire Service Commission Design Review Unit must be sent and may review or comment on the fire safety features of a design for "*certain applications for building consent*". The type of building that this applies to is typically large multistorey buildings or buildings with large occupant number and a numbers of active fire safety features that would generally require compliance schedules and/or warrants of fitness such as sprinklers, smoke/heat detection alarm systems and ventilation or pressurisation systems. Alternative designs must also be submitted to the Fire Service Commission under the provisions of Sections 46 and 47 of the Act.

The Fire Service Commission may comment on two aspects of design under the provisions of Section 47, these being means of escape from fire and the needs of persons who enter the building to undertake fire-fighting operations. Note that the Building Consent Authority is not bound by the Fire Service Commissions comments.

In summary the Building Act 2004 generally requires work on all new buildings, alterations to buildings (limited to means of escape) and changes of use of a building (as near as is reasonably practicable) to comply fully with the Building Code. This includes a building consent, design review by the fire service, compliance schedule and an annual warrant of fitness where appropriate.

3.3 Building Regulations 1992

The New Zealand Building Regulations 1992[(2)] contain eleven regulations (clauses) generally governing the responsibilities of the owner, Territorial Authority and Building Certifiers in the building consent and certification process. The regulations also contain two schedules, The Building Code and Building Consent and Certification Forms. The regulations have been amended several times during the past 13 years and a number of Building Amendment Regulations issued. From a fire safety design point of view the 1st Schedule to the regulations, The Building Code[(3)], is the most important as this sets out the performance criteria for the fire safety design of buildings

3.4 Building Code and Approved Documents

The New Zealand Building Code (Schedule 1 of Building Regulations)[(3)] contains the following sections governing the design of buildings. Acceptable design details are also specified for each of these sections in the Building Code Approved Documents:

A1 - A2	General Provisions
B1 - B2	Stability
C1 - C4	Fire Safety
D1 - D2	Access
E1 - E2	Moisture
F1 - F8	Safety of Users
G1 - G15	Services and Facilities
H1	Energy Efficiency

Fire Safety (C1 – C4), Lighting for Emergency (F6), Warning Systems (F7), and Sign (F8) are pertinent to the design of building for fire safety. Ventilation (G4) Electricity (G9), and Water Supply (G12) to a lesser extent. The fire safety clauses are:

C1 - Outbreak of Fire
C2 - Means of Escape from Fire
C3 - Spread of Fire
C4 - Structural Stability During Fire

The Building Code specifies the performance criteria for each fire safety clause. These are given under the headings of Objective, Functional Requirements and Performance. The performance criteria for all fire safety clauses C1 to C4 are shown in Appendix A.

This report focuses on establishing the level of safety for buildings designed to Sections C2, *Means of Escape* and C3, *Spread of Fire* from the Building Code Approved Documents, C/AS1. The objective of the report is to investigate and determine those factors, which affect the ability of occupants to safely escape a building.

Section C1, *Out Break of Fire*, is not assessed in this research as the installation of solid and gaseous fuel appliances is judged to have no direct bearing on the ability of a person to escape from a building. Furthermore any impact or risk of fires caused by such appliances is assumed to be taken into account in the Fire Hazard Category (BU4) parameter in the proposed model. Refer to Chapter 6 for a full description of the risk ranking model.

Section C4, *Structural Stability During Fire*, is also not assessed in specific detail in this research. This research focuses on the impact of active fire safety features such as sprinklers and alarms and passive protection such as smoke and flame barriers to means of escape. These systems have an immediate impact on the ability of occupants to be alerted to a fire and safely leave the building. A nominal allowance for structural safety has been included in the model by the inclusion of the Structural Endurance (S) Rating parameter (A2). Refer to Chapter 6 for a full description of the risk ranking model.

A detailed review of the Approved Document for New Zealand Building Code Fire Safety, Clauses C2, *Means of Escape* and C3, *Spread of Fire* is carried out in Chapter 4 of this report.

3.5 Fire Services Act 1975

The Fire Service Act 1975[(9)] is the legislative document enacted by Parliament that sets out the laws relating to the role, responsibilities and management of the New Zealand Fire Service and The New Zealand Fire Service Commissioner. The Act has had 24 amendments in the past 30 years with the most recent being 2005 and relating to the new Building Act. Five of the amendments have been repealed.

The Fire Service Act 1975 has little impact on the design of a building for fire safety. The only clause relevant to the design and certification process is Clause 21A – Evacuation Schemes for Fire Safety. This clause sets out the criteria for determining which buildings require an Evacuation Scheme and takes into account occupancy, number of occupants, and fire hazard.

3.6 Fire Safety and Evacuation of Buildings Regulations 1992

The Fire Safety and Evacuation of Building Regulations 1992[(11)] contain regulations relating to the safe use of buildings with respect to fire safety and preparation, review and approval processes for evacuation scheme as follows:

Part I - Fire Safety :

Regulations pertaining to management of escape routes, control of hazardous appliance and materials and use of occupant fire fighting equipment.

Part II – Evacuation Schemes:

Regulations pertaining to the requirements for and approval and maintenance of evacuation schemes.

Part III – Miscellaneous:

Regulations pertaining to the Fire Service and building owner's responsibilities.

All of the above regulations relate to "house keeping" in that they specify the basic requirements for using a building and maintaining a complying evacuation scheme. The purpose is to ensure that the level of safety of the building resulting from being designed to the Building Code is not compromised, for example escape routes are not blocked by furnishings or stored materials, fire hazard is not increased by storage of large quantities of flammable liquids/fuels and fire fighting equipment for use by occupants is maintained.

Failure to comply with a number of the above regulations may result in a reduction of the safety of a building. This research project focuses on the "designed" level of safety of buildings and therefore assumes that building will be used in accordance with these regulations. The impact on the level of safety due to the owner or occupants not complying with these regulations has not been taken in account in this report as it is beyond the scope of this research.

Under Part I - Section 10 " *Fire Fighting Equipment for Use by Occupants*", the National Fire Commander may require handheld fire fighting equipment to be installed in a building which otherwise does not require them under the Building Code. In this situation the safety of the building is increased over and above the level of safety required by the Building Code. The impact of this on fire safety of building designed to the NZ Building Code Approved Documents is beyond the scope of this research project as the objective to this report is to establish the level of safety of buildings designed to C/AS1. Therefore only fire safety features required by the Building Code are assessed in this report.

4 REVIEW OF NZBC APPROVED DOCUMENT

4.1 Design Procedures

The procedure for determining the fire safety design requirements of a building to the Approved Document (C/AS1), based on *Clause 1.3.2*[1], is summarised below:

1. Determine application of Building Act, i.e. new building, alteration or change of use.
2. Determine owner's requirements (Assume nil for purposes of this project).
3. Determine purpose groups and fire hazard category.
4. Determine number and distribution of occupants.
5. Determine the means of escape from fire from all firecells.
6. Determine the number of firecells, firecell rating and fire safety precautions
7. Determine any additional protection and structural fire endurance (S) rating.
8. Determine the Fire Resistance Rating (FRR) of building elements including. requirements for structural stability.
9. Determine requirements for control of internal fire spread.
10. Determine requirements for control of external fire spread.
11. Determine the requirements for fire fighting.
12. Determine requirements to control outbreak of fire.

Note that steps 4, 5 and 6 are carried out iteratively as each has an impact on the previous or successive step, i.e. the fire safety precautions could have an impact on the allowable escape length while an excessive escape length may require an increase in fire safety precautions such as an upgrade of an alarm system and detector type.

This project will focus on the life safety aspects of the design procedure. These are steps 3 to 9 and to a lesser extent 11 and 12. Spread of fire externally to neighbouring property will not be considered.

4.2 Basic Fire Parameters [Part 2 – C/AS1]

The fire hazard risk is assessed taking into account the:

a) Fire Hazard Category - Nature of the building materials and contents (i.e. fire load)

b) Purpose Group - Type of activities undertaken and persons occupying or using building.

c) Occupant Load - Number of the occupants.

4.2.1 Fire Hazard Category

The Fire Hazard Category (FHC)is a numerical grading from 1 to 4 based on the Fire Load Energy Density (FLED) as shown in Table 4.1 below:

FHC	FLED Range (MJ/m^2)	Design FLED Value (MJ/m^2)
1	0-500	400
2	501-1000	800
3	1001-1500	1200
4	>1500	Specific Design

Table 4.1 - Fire Hazard Category

The FLED is defined as the fire load of all combustible materials and contents measured in energy divided by the floor area (MJ/m^2). The fire growth rate is generally not considered separately (except Purpose Group WF) when assessing the fire hazard parameters for fire safety to C/AS1. However the fire severity is not controlled by FLED alone. Fuel layout, surface area to mass ratio, ventilation, fire growth and spread characteristics of the fuel also influence the fire severity. It is inferred from the code that some qualitative measure of these aspects were taken into consideration when assigning FHC categories to various occupancies.

This is an important point of difference with engineered solutions, as specific fire engineering designs are usually based around design fire scenarios, which include a design fire curve. The growth rate and rate of fire spread are the most rudimentary elements of a design fire curve as they determine critical time related parameters such alarm activation time, time to untenable conditions etc.

The growth rate of the fire can be more critical than the total quantity of the fuel in small fire cells where the occupants have to leave within minutes of the fire having established burning. For example a large single burning object (e.g. sofa seat) is likely to give off enough toxic smoke to incapacitate or cause death to a person prior to fire flashover to full room involvement.

The FHC in combination with a ventilation factor is used to determine the structural fire endurance (S) rating. This will be discussed later (Section 4.5) but it should be noted that the S rating is based on the time to burn all the fuel in the firecell and in most cases would assume full room involvement of the fire.

4.2.2 Purpose Group

The purpose group establishes the occupancy type, i.e. what type of people are in the building, what are they doing and what is their state of consciousness. This has been broadly classified into sixteen Purpose Groups as follows:

a) Crowd Activities:

CS – Crowd Small (≤100 persons) and CL – Crowd Large (>100 persons)

Large groups of people based on mixed occupancy of general public, i.e. men, woman, elderly and disabled. Examples are churches, cinemas, community halls, schools, restaurants etc.

CO – Crowd Open

Same occupant mix as CS and CL but based on large crowds viewing open-air activities at stadiums such as concerts and sports events. This purpose group is not included in this study

CM – Crowd Mercantile

Same occupant mix as CS and CL but based on large crowds in shops, malls, market places and exhibition halls.

b) Sleeping Activities

SC – Sleeping Care

Includes hospitals and care institutions for elderly, children or persons with disabilities. This purpose group is not included in this study.

SD – Sleeping Detention

Includes prisons and police stations and is not included in this study.

SA – Sleeping Accommodation

Occupancies that provide for transient accommodation used by the general public. As such the occupants may not be familiar with the building. Examples are hotels, motels, hostels, boarding houses and community care institutions.

SR – Sleeping Residential

Attached and multi-unit residential dwellings including flats, apartments and household units where attached to another household or other purpose groups.

SH – Sleeping Household

Comprises single residential dwelling occupied by a single family and is not included in this study.

c) Working Business or Storage

WL – Working Low (Low fire load)

Spaces used for working, business of storage activities where there is a low fire load. The fire load is defined as FHC 1 or 2. Examples of WL - FHC 1 are cool stores, covered cattle yards and packing plants for horticulture products. Examples of WL - FHC 2 are general business offices, dental or medical offices, radio and TV stations etc.

WM – Working Medium (Medium fire load)

Spaces used for working, business of storage where there is a medium fire load. The fire load is defined as FHC 3 and fire growth rates equivalent to t^2 fires of slow, medium and fast speeds.

WH – Working High (High fire load)

Same occupancies as WM but for larger buildings with a higher FLED. The fire load is FHC 4 and fire growth rates equivalent to t^2 fires of slow, medium and fast speeds.

WF – Working Special Fire Hazard

Generally includes buildings for the manufacture or storage of highly flammable, volatile or explosive materials. Fire hazard category FHC is 4 or greater and fire growth rate is ultra fast (>1MW in 75 sec). WH and WF are not included in this study.

d) Intermittent Activities

IE – Intermittent Exitways

Exitways on escape routes such as protected (from passage of smoke) paths and safe (from passage of fire) paths. IE areas are normally located in all multi-storey buildings of 3 stories or more. This will not be assessed as a separate occupancy type in this study. However, the safety aspects of providing protected or safe paths will be addressed as a key item of the risk analysis in this study.

IA – Intermittent Activities

Spaces provided for intermittent activities or a support function to the building. Examples are car parks, corridors, laundries, lift shaft, toilet and amenity facilities. Although all buildings have IA occupancy areas they usually form a small area of the building and the fire safety features applied are based on the primary purpose group. The only exception to this is car parks which have their own specific fire safety requirements. Therefore, this occupancy will not be assessed further in this study.

ID – Intermittent Dangerous

Same as IA but occupancies that house machinery or appliances that requires solid fuel, gas or petroleum fuels as an energy source.

This study has been limited to buildings of general rather than specialised occupancy. Therefore hospitals and prisons (SC & SD purpose groups respectively) have not been included. Domestic houses (SH) which have very little life safety requirements under C/AS1 will also be excluded. This report is focused on multi-storey buildings and as such Crowd Open (CO) will also be excluded as this occupancy is more commonly found at sports stadia.

It is assumed that all buildings in this study will have a small proportion of Intermittent Activity areas. It is further assumed that these areas will not be large enough to constitute a primary purpose group and as such would require the fire safety features required for the primary purpose group.

The purpose groups to be assessed in this study are:

CS – Crowd Small 50< Occupants < 100
CL – Crowd Large > 100 Occupants
CM – Crowd Mercantile
SA – Sleeping Accommodation
SR – Sleeping Residential
WL – Working Low (Fire load)
WM – Working Medium (Fire Load)

4.2.3 Escape Height and Occupant Numbers

The building heights and occupant numbers to be assessed in this study have been selected based on the broad categories set out in *Tables 4.1/1 to 4.1/5 - C/AS1* as follows:

a) Building Escape Height Categories

Six building escape height categories have been chosen for this study as shown in Table 4.2. Note that the number of floors shown in Table 4.2 has been determined based on an assumed inter-storey height of 3.0m.

Escape Height Category to Tables 4.1 C/AS1	**Number of floors**
4 m < He ≤ 10 m	Up to 3 floors
10 m < He ≤ 25 m	3 – 8 floors
25 m < He ≤ 34 m	9 – 11 floors
34 m < He ≤ 46 m	12 -14 floors
46 m < He ≤ 58 m	15 – 18 floors
He > 58 m	Over 19 floors

Table 4.2 - Building Escape Height Categories

b) Occupant numbers

The occupant number categories in accordance with C/AS1 are shown in Table 4.3:

Occupant Numbers for Purpose Groups CS, CL, CM, WL and WM	Occupant Numbers for Purpose Groups SA, and SR
Up to 100 persons	Up to 40 persons
101 – 500 persons	Up to 100 persons SA*
501 – 1,000 persons	Up to 160 persons SA*
Over 1,001 persons	

* With Type 7 Alarm (Sprinklers and smoke detection)

Table 4.3 - Occupant Number Categories

c) Occupant Densities

The occupant densities [*Table 2.2 C/AS1*] are used to determine the number of occupants in a building. Occupant densities vary depending on the activity in each firecell. Broad ranges are given for typical occupancy types as follows:

Crowd Activities	0.01 – 2.0 person/m^2
Sleeping Activities	Number of beds
Working	0.01 – 0.2 persons/m^2
Intermittent	0.02 – 0.2 persons/m^2

The occupant density will affect the travel speed and hence the length of the travel time in the open paths, but given the variability of densities it is not practical to include this aspect in this fire safety analysis. The total number of occupants that governs total travel and queuing times will be taken into consideration.

4.3 Means of Escape – Part 3 – C/AS1

The means of escape provisions generally cover the type, geometry, number, and critical design features of escape routes.

All buildings are required to have a means of escape from fire to a safe place. A safe place can be outside the building, in an adjoining building or in a refuge area within the building that is on fire.

The degree of protection of the escape route must not decrease in the direction of escape.

The following egress paths may make up an escape route:

- Dead End Open Path: - open path with only one possible direction of escape. Occupants may be exposed to the products of combustion whilst escaping.

- Open path: - open path where the occupants generally have a choice of escape routes but may be exposed to the products of combustion.

- Protected path: - escape route that is protected from the ingress of smoke with smoke barriers and smoke stop doors. A protected path forms a part of an "exitway" under C/AS1 and is subject to special provisions for exitways.

- Safe Path: - escape route that is protected from the ingress of smoke and fire with fire rated barriers and doors. A safe path forms a part of an "exitway" under C/AS1 and is also subject to special provisions for exitways.

- Final Exit: - is the point at which the occupants leave the building and reach a place of safety.

Key aspects for assessing means of escape are summarised below in Sections 4.3.1 to 4.3.5. This is not a comprehensive list and is based on those aspects, which have an impact on life safety in the building occupancies under consideration in this study.

4.3.1 Number of Escape Routes

Buildings generally require a minimum of two escape routes. The provisions for single means of escape only apply to buildings with less than 50 persons per firecell and as such are not included in this study.

Number of escape routes: [*Table 3.1 C/AS1*]

Sleeping purpose groups:

SA and SR	Up to 100 beds	2
SA and SR	Over 100 beds	2 + 1 per 100 beds

All other purpose groups:

Up to 500 persons	2
Up to 1,000 persons	3
Over 1,000 persons	≥ 4 (Depending on number of persons)

4.3.2 Height of Escape Routes

Clear height shall not be less than 2.1 m [*Cl 3.3.1 C/AS1*]. This is not usually critical given the standard ceiling height is 2.4 m (residential) and approximately 2.7 m (commercial).

4.3.3 Width of Escape Routes

The minimum width of escape routes is determined by the number of persons in the firecell (note a firecell is taken to be the entire floor of a building in this study) or a minimum specified whichever is greater. The width of escape routes is also a function of travel inclination, i.e. vertical or horizontal travel. Vertical (stairs) travel paths are required to be wider than horizontal travel paths.

C/AS1 also requires the width of escape routes to be assessed taking into account the provision of one unusable escape route where the building is unsprinklered. Therefore if only two escape routes are required then each escape route must be of sufficient width to take the full occupant load from the firecell. The requirements for width of escape routes are shown in Table 4.4 below.

Minimum Width of Individual Escape Route			
Vertical Travel Path		**Horizontal Travel Path**	
1,000mm		850 mm	
Total Width Required			
Total No. of Occupants	**Minimum No. of Escape Routes**	**Vertical (9mm/person)**	**Horizontal (7mm/person)**
100	2	900mm *(1000mm Governs)*	700 mm *(850mm Governs)*
500	2	4,500 mm	3,500 mm
1,000	3	9,000mm	7,000 mm

Table 4.4 - Minimum Width of Escape Routes [*Table 3.2 C/AS1*]

The width of escape routes should increase in the direction of travel. The total width of escape routes is to be based on the firecell with the highest occupancy. This particularly applies to multiple purpose group occupancies where considerable variation in occupant number can occur in a building.

4.3.4 Length of Escape Routes

The length of escape routes is a critical item in the design for fire safety. The length of an escape route has a direct bearing on the length of time a person takes to evacuate a building and/or the length of time a person is exposed to the products of combustion.

Basic requirements for escape path lengths in accordance with *Section 3.4 - C/AS1* are:

a) The length is measured from a point 1m from the most remote point in the building.

b) For multiple purpose groups, the purpose group with the shortest maximum permitted length shall apply.

c) An allowance should be made for travel around furniture and obstructions.

d) Where multiple escape routes are required the escape route lengths from any point on a floor to no fewer than two exits shall not exceed the required lengths.

e) In unsprinklered fire cells a protected path (smoke protected) shall have sufficient space to provide temporary refuge to occupants as they merge with occupants using a vertical stair safe path from other (higher) levels.

The permitted escape route lengths based on *Table 3.3 C/AS1* are shown in Table 4.5 below.

C/AS1 permits or requires adjustments to the escape route lengths depending on the type of safety precautions installed or architectural features that increase the risk of occupants coming into contact with combustion products.

Type of path	**Purpose group**	
	CS, CL, CM, SA	***WL, WM, SR***
Dead End Open Path (DEOP)	18m	24
Total Open Path* (TOP)	45m	60
Protected Path (PP)	45m	60
Vertical Safe Path (VSP)	No restriction on length	
Horizontal Safe Path (HSP)	Restricted as follows:	
- Dead End	18 m	24m
- Two or more escape directions	135m	180m

* Includes DEOP

Table 4.5 - Permitted Escape Route Lengths [*Table 3.3 C/AS1*]

Permitted adjustments to escape route lengths are:

a) DEOP and TOP measured lengths are increased by 50% for escape from an intermediate floor [*Cl 3.4.6 C/AS1*]. An intermediate floor is a floor that is open to a lower firecell floor. Intermediate floors have not been assessed in this project.

b) DEOP and TOP measured lengths are based on pitch line length for stairs, two times the height for spiral stairs and three times the height for ladders [*Cl. 3.4.7 C/AS1*].

c) The permitted DEOP and TOP lengths are to be reduced by 50% where all of the following apply: [*Cl. 3.4.8 C/AS1*].

- Both floor and ceiling slope by more than 4m; and
- Escape is in up slope direction; and
- Ceiling is less than 4 m high; and
- Occupant load is greater than 100; and
- Smoke control is not installed.

d) Permitted increases in open path lengths (DEOP and TOP) based on the installation of fire safety precautions are shown in Table 4.6 below.

Precaution	**Purpose groups**	
	WL, WM, CS, CL,CM	**SA, SR**
Sprinklers	100%	50%
Heat Detectors	20%	10%
Smoke Detectors	100%	50%
Maximum Combined	200%	-

Table 4.6 - Permitted Increases in Escape Route Length

4.3.5 *Means of Escape - Other Requirements*

a) Escape is permitted through an adjoining building or from one firecell to another. Fire separation requirements apply and protected paths may be required adjacent to exit ways. This is not critical to this project as only single buildings are to be considered and it is assumed that the final exit leads directly to a safe pace. Each floor of each building is assumed to be a single fire cell.

b) Basements can generally be treated like any other floor. The only exceptions are that where a basement shares a safe path with other floors then a protected path shall precede the safe path. Where such an arrangement serves three or more basement levels then the safe path shall be pressurised. The impact of basements shall not be assessed in this study.

c) There are minor restrictions and requirements in the code on obstructions in escape routes, direction of door swing, door sizes and handrail sizes. While these are important for the safe design of a building their impact on life safety is difficult to assess both qualitatively and quantitatively. For example all stairs must have a handrail. The impact of not having a handrail is likely to be a reduction of travel speed as persons of unsure footing descend more cautiously. However, this report focuses on the level of safety of buildings meeting the "code" and as such it is assumed that the above minor provisions are met.

d) Exitways shall not be used for storage of goods, solid waste or solid waste containers or points of entry for solid waste chutes. This is generally a matter of good housekeeping and as such exitways should be designed to avoid this. Therefore the impact on life safety of obstacles in exitways is not considered further in this study.

e) Other activities, such as a reception, are permitted in an exitway providing that an alternative escape route is available, an alarm system is installed and other activities have a FHC not greater than 1; the escape route is not impeded, activities (with the exception of ablution facilities) are visible to occupants and exist only to provide support to the purpose group users. It is assumed that all these provision are met when assessing safety of buildings in this study.

f) Lifts are not typically relied upon as a means of escape during a fire event in New Zealand.

g) Refuge areas are required in tall buildings (over 58 m escape height). They are usually contained within the vertical safe path stairs. Refuge areas are designed to remove congestion, allow slow persons to rest or be passed by quicker persons. They are not designed with the intention of a person waiting out a fire emergency.

h) Single escape routes can only be used in limited situations for purpose groups CS, CM, CO, WL, WM, WH, WF, IA and ID, SA and SR; and where total occupant load from all firecells on each level is less than 50 persons; and number of young children or disabled persons on any one floor is less than 10. Height restrictions apply as shown in Table 4.7 below.

Purpose group	***Escape height***	***Max. FHC***	***Sprinklers Installed***
CS, CM, WL, WM, IA, ID	<4.0 m	<3	No
	<10.0m	<2	No
	<10.0m	<3	Yes
	<25.0m	<2	Yes
SR and SA	<10.0m	-	No
	<25.0m	-	Yes

Table 4.7 - Height Restrictions for a Single Escape Route

The presence of a single means of escape has a significant impact on the safety of a building and the ability of occupants to escape a fire. Occupants do not get a choice of means of escape with a single escape route and as such C/AS1 looks to minimise the risk by introducing additional safeguards to ensure as far as practical that the escape route remains tenable for a sufficient time to enable all occupants to escape.

The two key elements for reducing the risk are:

- Limiting the total number of persons, and
- Additional passive fire safety features to extend the time to untenable conditions in the safe path.

The lowest occupant number category assessed in this study is up to 100 people, therefore single means of escape building are not applicable. A separate occupant number category would be required limited to a maximum of 50 persons. Therefore single means of escape buildings were not assessed in this study.

i) There are several life safety issues that need to be considered when evaluating the impact of doors on the safety of buildings in fires. These are:

- Fire and smoke control doors are required to perform a function during the course of a fire event. This function is to maintain the integrity of the fire/smoke barrier by preventing the ingress of fire or smoke into the exitway and ensuring the exitways remain tenable until the occupants have escaped. To achieve this, doors need to be fabricated and installed correctly and maintained and used properly. Hold-open devices are required to be used where there are more than 1000 occupants in a firecell and for doors between vertical and horizontal safe paths in sleeping purpose groups.

- Doors must be able to be opened with minimal force and not impede the flow of escaping occupants.

- Final exit doors must be able to be opened without the need to stop and unlock the door or remove impeding security measures.

The above items are paramount to the safe evacuation of persons from a building fire. Failure of any of these aspects may result in unacceptable risk to the occupants during the course of escape with safe and protected path filling with products of combustion early in the fire event or unacceptable levels of queuing or backtracking of escapees.

It is assumed that fire and smoke control doors are installed and used properly, therefore the adequacy of doors is not assessed as a specific item in the risk model developed in this study.

j) Some buildings require emergency lighting in exitways and, for larger occupant numbers and certain purpose groups and escape heights, in open paths as well. All buildings require exits to be clearly signposted.

The visibility of egress routes and adequate signage is an important aspect of fire safety design as it affects the ability of persons to find their way out of a building and as such impacts the travel time for escaping occupants.

4.4 Firecell Requirements

A firecell is defined as: *"any space including a group of contiguous spaces on the same or different levels within a building which is enclosed by any combination of fire separations, external walls, roofs and floors"* (1).

In general each floor of a multistorey building is a separate firecell. Exceptions to this are intermediate floors (mezzanine floors) which are generally part of a lower firecell, apartments and units in sleeping purpose groups SR (Residential) or SA (Accommodation). A floor of a building may be subdivided to separate firecells for a number of other reasons:

i) To separate highly flammable and volatile contents.
ii) To reduce the total volume of fire load in the firecell to a level such that a fire can be readily controlled and extinguished by the Fire Service. Code restrictions for firecell sizes apply in unsprinklered buildings.
iii) To meet means of escape requirements by providing protected and safe paths to meet escape route length requirements.
iv) To protect neighbouring property in multi-tenanted buildings.
v) A floor may be subdivided to prevent the rapid spread of fire.
vi) A floor may be subdivided into smoke cells to prevent the rapid spread of smoke throughout the floor.

4.4.1 Fire Safety Precautions

Firecells require fire safety precautions (FSP) to ensure that [*Cl. 4.2.6 C/AS1*]:

i) The occupants have sufficient warning and protection while they make their escape to a safe place.
ii) Fire spread is restricted.
iii) The Fire Service has sufficient time to undertake rescue operations.

The following aspects of a building are taken into consideration when determining the fire safety precautions:

i) The purpose group in each firecell for buildings with multiple purpose groups. The purpose group with the most fire safety precautions is used for their level of occupancy and all floors above that level.
ii) The number of occupants in each firecell.
iii) The escape height of a building.
iv) The means of escape requirements. Alarm systems may be required to be selected based on escape route lengths, intermediate or basement floor requirements.

The fire safety precautions and firecell ratings for buildings, [*Table 4.1/1 to 4.1/5 C/AS1*(1)], are shown in Appendix B.

The fire safety precautions play a key role in providing safety to the occupants of a building in the unwanted event of a fire. The performance and reliability of the FSP is an important aspect in a risk/safety assessment of a building for fire safety. Although not the only aspect to be considered, the performance, reliability and contribution of FSP to the fire safety of a building is to form a significant proportion of evaluation and analysis of this research project.

A general description of the fire safety precautions specified in *Table 4.1/CAS1*(1) are summarised below:

Type 1 : No type 1 specified - C/AS1: June 2001.
(Domestic smoke alarm system – C/AS1: April 2003 Amendment).

Type 2 : Manual Fire Alarm
Activated by a person operating a manual call point (MCP). Comprises manual call points, sounders and alarm panel.

Type 3 : Automatic fire alarm with heat detectors and MCP.
Automatically activated by heat detectors or manually by a person operating a manual call point whichever detects or observes the fire first.

Type 4 : Automatic fire alarm with smoke detectors and MCP.
Automatically activated automatically by smoke detectors or manually by a person operating a manual call point whichever detects or observes the fire first.

Type 5 : Automatic fire alarm system with modified smoke detection and MCP.
Used specifically in residential and accommodation occupancies to reduce false (nuisance) alarms that result in evacuation of the entire building and or unnecessary call out of the Fire Service. Permitted as a modification to the requirement for a Type 4 or Type 7 Alarm – generally comprising.

- *Smoke detectors in exitways connected into the building alarm system.*
- *Heat detectors in apartments or units connected into the buildings alarm system.*
- *Smoke detectors in each apartment or unit that only sound an alarm in that unit.*

Type 6 : Automatic fire sprinklers with MCP.

Alarm is raised by either activation of the sprinkler system or manually by a person operating a manual call point, whichever detects the fire first. The sprinkler system can sound an alarm as well as control or extinguish the fire.

Type 7 : Automatic fire sprinkler system with smoke detection and MCP.

A hybrid of a Type 4 and Type 6 system. Provides both early warning from smoke detection and control/suppression from the sprinkler system.

Type 8 : Voice Communication System

An automatic system with variable tone alerting devices and the ability to deliver voice messages to the occupants and allow two way communications between emergency services.

Type 9 : Smoke Control in Air Handling System

Provision for automatic detection, alarm and control by venting, shutdown and dampers of a heating, ventilation and/or air conditioning system in a building.

Type 10 : Natural Smoke Venting

Firecells are provided with smoke reservoirs with outlet vents and fresh air inlet vents, which open automatically when, activated by a smoke detection system.

Type 11 : Mechanical Smoke Extraction

Firecells are provided with smoke extraction fans to forcefully remove smoke from smoke reservoirs. These can be used where natural venting is determined to be inadequate due to smoke stratifying below level of the vents or adverse effects of wind on buildings.

Type 12 : No type 12 currently specified

Type 13 : Pressurisation of Safe Paths

Pressurisation fans installed to safe paths (typically stairwells) to prevent the ingress of smoke while persons are escaping. Activated by smoke detectors, the pressurisation system is required to operate for no less than 60 minutes.

Type 14 : Fire Hose Reels

Handheld fire hoses for use by both the occupants and fire service. Typically only required in sleeping residential and accommodation purpose groups. Commonly installed as additional fire protection in other occupancies.

Type 15 : Fire Service Lift Control

Provides the fire service with exclusive use of any lift for fire fighting purposes.

Type 16 : Emergency Lighting in Exitways

Emergency battery powered lighting in protected and safe paths required to guide the occupants to the final exit in the event that the building power supply fails.

Type 17 : Emergency Power Supply

The emergency power supply is required in some buildings to ensure the continued operation of fire safe precautions critical to the evacuation of the building such as smoke control, emergency lighting and lifts.

Type 18 : Fire Hydrant System

Required where the Fire Service hose run length is likely to be greater than 75m from the Fire Service appliance to the most remote area of the building. Generally comprises a pipe system with an inlet at ground level and outlets at each floor. Typically located in or adjacent to a vertical safe path (stairs). Also required in large low-rise buildings.

Type 19 : Refuge Areas

Required in vertical safe paths of tall building where congestion may occur to allow persons to rest and faster persons to pass.

Type 20 : Fire Systems Centre

A facility for the Fire Service which is:

- *accessible from street level*
- *protected from the effects of fire, including falling debris*
- *contains control panels indicating the status of the fire safety systems in the building.*

In addition to the above Fire Safety Precautions a number of limitations and dispensations are permitted. These are denoted a-f and are shown in detail in Appendix B and summarised below:

a. *Not required*. Identifies situations where particular FSP may be omitted.
b. Single escape routes which require an upgrade to a Type 4 alarm.
c. Provision for when a fire hydrant system is required.
d. Provision for when emergency lighting is required in both exitways and open paths.
e. Provision for when a Type 5 alarm is permitted.
f. Provision for when direct connection to the fire service is not required.

4.4.2 Firecell Rating

A firecell rating, F Rating, is also determined as part of the firecell assessment. The firecell rating is the minimum fire rating that shall be applied to fire separations and load bearing elements (where the structural endurance rating, S Rating does not govern).

The firecell rating is generally 30, 45 or 60 minutes and is combined with structural fire endurance rating to determine the fire resistance rating (FRR) of building elements.

4.5 Fire Resistance Ratings

The fire resistance rating (FRR) is the time in minutes that a structural or fire barrier element can pass the standard fire rating test. The standard fire rating test in NZ is typically based on the AS 1530:Part 4 [12] time temperature curve.

The fire resistance rating has three components. These are:

a) Stability – Time to structural failure. This is applied to load bearing elements, including floors, beams, column and structural walls and is based on the greater of the S or F Rating when designing to C/AS1.

b) Integrity – Time for fire and combustion products to penetrate a fire barrier. This is based on F rating for internal fire spread and S rating for external fire spread when designing to C/AS1.

c) Insulation – Time for heat transfer through a fire barrier to a level such that combustibles on the non-fire side may ignite.

Fire resistance ratings are given a three figure number, e.g. FRR 30/30/30, 30 minutes stability, 30 minutes integrity and 30 minutes insulation.

An element may only have a smoke rating in which case the FRR is -/-/Sm.

The above parameters are important to life safety to the occupants in a building, as they are critical to ensuring a building does not collapse, fire and combustion products do not spread and providing safe egress routes for occupants.

As noted in the previous sections the F rating is taken from *Tables 4.1/1 to 4/1/5 C/AS1*. The firecell rating is essentially a time rating based on providing sufficient time for persons to escape, and to allow the Fire Service to undertake fire fighting operations by limiting the spread of the fire.

The structural endurance rating (S) is taken from *Table 5.1 C/AS1*. The structural endurance rating is essentially a time rating based on ensuring a building or part of a building does not collapse prior to the fire burning out or the Fire Service extinguishing the fire. The primary purpose of an S rating is to prevent spread of fire to neighbouring property due to collapse of buildings or part of buildings.

Clause 5.7.9 C/AS1 gives a good summary of the minimum FRR to be applied to building components.

The most significant concession in C/AS1 for fire resistance rating is that the S rating may be halved where sprinklers are installed. From *Tables 4.1/1 to 4.1/5 C/AS1* we can see that the F ratings are also reduced for buildings that require a sprinkler system.

4.6 Internal Fire Spread [Part 6 C/AS1]

Section 6 of C/AS1 details specific requirements for control of internal spread of fire for each type of purpose group. In particular it specifies:

a) Minimum fire resistance ratings
b) Where smoke separation is required
c) Ventilation requirements
d) Car park building requirements
e) Firecell construction requirements. Including fire stopping and protecting concealed spaces
f) Intermediate floor requirements
g) Sub-floor space requirements
h) Protected shaft requirements, e.g. lifts, conveyors and service shafts
i) Closures in smoke and fire barriers such as door sets and glazing
j) Surface finishes including suspended flexible fabrics and control of wood and foam plastic building products
k) Smoke control requirements
l) Building services plant requirements such as smoke control in HVAC

This section of the C/AS1 is too detailed to summarise within the scope of this report. Items that impact on life safety shall be discussed as and where they arise in the risk analysis.

4.7 External Fire Spread [Part 7 – C/AS1]

Control of external fire spread is concerned primarily with spread of fire to neighbouring properties and as such is outside the scope of this project.

The only exception to this is for sleeping purpose groups – Residential (SR) and Accommodation (SA) where fire spread up the exterior face of the building must be controlled by installing fire rated spandrels, aprons or sprinklers. External fire spread has not been specifically addressed in this report but it is assumed that the required fire safety features are taken into account in the firecell (F) rating and sprinkler components of the risk model. Refer to Chapter 6 for details of the risk model.

4.8 Fire Fighting [Part 8 – C/AS1]

This section covers the basic requirements of the New Zealand Fire Service including vehicle access and fire fighting facilities.

Vehicle access specifies the road requirements, e.g. vehicle loading, width and access distances to the side of a building. These issues have minimal impact on life safety of building occupants. The only impact would be the time it takes the Fire Service to reach the building, which is likely to be a small percent of the total response time.

Fire fighting facilities covers the fire hydrant system, fire hose reels, fire systems centre, fire service lift control and voice communication system. No specific details are given for the design and installation of these systems as this information is found in the relevant New Zealand Standard. The impact of these systems on life safety will be assessed and discussed in detail where appropriate in this report.

4.9 Outbreak of Fire [Part 9 – C/AS1]

Section 9 of C/AS1 details requirements for solid fueled, gas fueled appliances and chimneys. These requirements generally relate to preventing ignition by providing adequate separation to flammable surfaces. The installation of heating, and cooking facilities is very much dependant on the region the building is located and the type of fuel available in that region.

The appliances themselves are likely to be contained in a separate plant room in large buildings and as such would be separated from the occupied floors. Plants rooms are typically designated "Intermittent Dangerous (ID)" and are generally not a primary purpose group and as such the fire safety requirements of the primary purpose group would govern the design of most of the building's fire safety features. Therefore the provisions of *Section 9- C/AS1* will not be included in this study.

5 SAFETY AND RISK

5.1 Introduction

Buildings are required to be designed in a manner that provides a safe environment for the occupants at all times regardless of the function or life of the buildings. Buildings must be structurally sound and to achieve this they are designed to the structural building standards, they must provide adequate heating, ventilation, lighting and access, and likewise they are designed to the appropriate regulations and standards. All of these are based on providing a safe internal environment, but in the event of a fire, the safety of the environment is deteriorating rapidly. One of the key fire safety objectives is to delay or mitigate the fire effects sufficient to allow all occupants time to safely escape the fire and evacuate the building by installing appropriate fire safety features.

Unfortunately the above objective is not met in every fire event and a number of persons die each year from fires. On average 27 people die per year in building fires in New Zealand (based on the 5 years between 1999 and 2004 [(60)]). Approximately 70.6% of the deaths have occurred in domestic houses (SH purpose group), 16.9% in residential (SR), 10.3% in manufacturing (WL/WM), 1.5% in assembly (CS/CL) and 0.7% in hotel/motel (SA) occupancies. Refer to Appendix H for statistics.

The level of fire safety of buildings designed to the *New Zealand Building Code, Approved Document* is not defined or quantified numerically in the approved document. The performance criteria of the Building Regulations 1992 also omit a minimum or acceptable fire safety level. At this point in time the level of safety of specific fire engineering solutions is generally determined by comparing the fire safety features provided to those that would be required by C/AS1. There has been much debate among the fire engineering community as to the whether or not differing fire safety features or combinations of fire safety features provide an equivalent level of safety to the C/AS1 solutions and a rational and economical method for proving the comparability. Comparisons can be made using a probabilistic risk analysis approach but this is time consuming, expensive and given that it still contains subjective material, open to debate.

From this debate arises a couple of interesting questions of which some are the subject of this research and others can only be answered through discussion, debate and/or by agreement within the fire engineering and political arenas:

- What is an appropriate minimum level of fire safety for designing building?
- What is the actual level of fire safety of buildings designed to C/AS1 and is this reasonable?
- Should we be using the level of safety provided by the C/AS1 as a benchmark for an equivalent design?

5.2 Safety

Safety is often expressed as the inverse of risk [13], i.e. if something is not risky then it must be safe.

$$\text{Safety} = \frac{1}{\text{Risk}}$$

In fire engineering, safety features are introduced into the design to reduce the risk and increase the safety. It is not possible to make something completely safe. There will always be an element of risk, which cannot be entirely eliminated, i.e. the inherent risk. The purpose of fire safety design is to minimise the risks and thereby maximise the safety. The safety in this case refers to life safety, i.e. the safety of the occupants. The safety of a building and/or its contents is not usually included in a fire safety assessment unless requested by the owner or it is a condition of an insurer. The only exception in NZ is prevention of spread of fire to an adjoining property, which must be prevented by appropriately detailed fire safety features. Safety in terms of this report refers only to life safety.

To determine the level of safety numerically it is necessary to undertake some form of risk assessment. This will be discussed in detail later in this section.

5.3 Risk

Risk is often defined as a function of likelihood and consequence, where the likelihood can be determined as the probability of an event occurring and the consequence is the outcome measured, for example, in dollar value or human or environmental impact. The outcome may be positive or negative, and significant or insignificant, depending on the initial objective of the risk problem.

$$\text{Risk} = f\,(\text{likelihood; consequences})$$

In judging risk, an individual must weigh up the significance of the outcome or consequence against the frequency of likely occurrence when determining whether or not an individual will accept a risk. For example a person caught in a building in which a fire alarm has sounded has several choices upon hearing the alarm, they can:

- Ignore the alarm (assume it is a false alarm or that they are safe until finished what they are doing)
- Investigate the fire
- Fight the fire (if present)
- Alert the Fire Service
- Alert other occupants
- Assist other occupants in escaping
- Leave the building casually (collect belongings, wander out the way they came in)
- Leave the building rapidly (immediately, at pace to nearest exit)

For each option the individual must assess the risk to themselves and/or other persons in taking any of the above options. This assessment will include attributes such as their familiarity with the building, personal capabilities, the presence of fire cues, and knowledge/history of the alarm system performance and the level of interaction with other occupants. In this case each of the above options has a risk that is varying with time, although the individual may not appreciate this at the time.

Society assesses risk in a similar manner, however the evaluation is broader, non-personalised, and in most cases economically or politically motivated.

Individuals, and indeed society, perceive risk in a difference context based on personal experiences. A number of single events resulting in one death per event may be considered or perceived as far more acceptable by society, than multiple deaths in a single event, even though over time the two scenarios may result in the same risk when risk is determined on a scale of say, deaths per year. As an individual, the risk may only be realised when the consequence is attained on a personal level.

The Australian/New Zealand Standard for Risk Management AS/NZS 4360:2004[(14)(15)] defines risk as "*the chance of something happening that will have an impact on objectives*".

In the terms of fire safety of buildings the chance of something happening (probability) and the impact on the objects (consequences) can be generally simplified as shown in Table 5.1 below:

"Chance of something happening"	*Objective*	*"Impact on Objective"*
Probability of fire ignition and growth.	Prevent unwanted fires.	Adverse risk to life and property in the event of an unwanted fire.
Probability that fire safety features function as intended.	Allow occupants to escape from fire safely and alert fire service.	Possibility that some or all persons will or will not be able to safely escape and fire will or will not be contained.
Probability of the fire being extinguished.	Prevent fire spread to entire structure and/or neighbouring property.	Possibility that the building may or may not be destroyed and the fire prevented or allowed to spread to neighbouring properties.

Table 5.1 - Chance and Impact of Fire

In reality the problem is much more complicated than Table 5.1 implies. Each of the above components can be expanded and the impact of each event/component on the fire safety of buildings assessed against the objectives of the standards required by society. These standards although not numerically defined at this time have been laid down qualitatively in the NZ Building Code as outlined in Chapter 3 above.

The objective of this project is to determine the level of safety inherent in buildings designed to C/AS1 using a risk analysis method. The analysis will consider the impact of fire safety features, building height and occupancy type on the fire safety of buildings.

5.4 Risk Assessment Process and Definitions

5.4.1 Process

AS/NZS 4360:2004(14) set outs a basic procedure for undertaking a risk management process. While this is based more on the management of a risk problem the basis of the procedure forms a useful framework for undertaking a risk assessment for fire safety in buildings in a research setting.

The risk management procedure is summarised in Table 5.2 below. The aspects of the procedure that are relevant to this research project (denoted by the shaded area in the table below) are those involving determining the context, identifying, assessing and evaluating the risks.

Risk Management Process Item	Description
Communicate and consult	An ongoing activity where all attributes of the risk assessment are advised to the Stakeholders and Analysts.
Establish the context	Defines the scope, basic parameters and purpose of risk assessment.
Identify risks	Assess what, when, where, how and why a risk event can happen?
Analyse risk	Determine the consequences, likelihood and the level of risk.
Evaluate risks	Compare risks against set criteria. Set priorities for mitigation or treatment.
Treat risks	Identify and assess options. Implement plans to treat the risk.
Monitor and review	Ongoing review to ensure that the risk assessment and control measures remain relevant.

Table 5.2 - Risk Management Process

5.4.2 *Definitions*

The following definitions have been reproduced from AS/NZS 4360:2004 Australian/New Zealand Standard - Risk Management [14][15] and the International Fire Engineering Guideline 2005 Edition [7]. Additional clarification in the context of this project has been provided where required.

a) Risk

Risk can be defined as the chance or likelihood of something happening that will have an impact on objectives. In terms of fire engineering risk is defined as the likelihood of an unwanted fire event causing harm or death to the occupants of a building or damage to the building, adjacent property or the environment.

b) Risk Assessment

Risk assessment is the overall process of risk identification, analysis and evaluation. In fire engineering terms it is the process of selecting the design fire scenarios, undertaking the risk analysis, which may include fire and evacuation modelling depending on the type of risk analysis and evaluating the results, which will depend on the objective of the risk assessment.

c) Risk Identification

Risk identification is the process of determining "what, where, when, why, and how" an event could occur. In terms of a fire risk assessment it is determining the appropriate design fire scenarios that are likely to pose the greatest threat to the life safety and property protection objectives.

d) Risk Analysis

Risk analysis is the systematic process to understand the nature of, and determine or quantify, the level of risk. There are three types of risk analysis that can be undertaken, these are:

i) Qualitative

An analysis generally based on subjective judgment of fire hazard, fire protection and likely consequences. The assessment broadly classifies risk from low to high or on a similar scale. The scale is typically customised to the risk problem being assessed. The analysis should be based on factual information and data where available.

A qualitative approach is used in this project to assess and determine what fire safety parameters/requirement from the NZ Building Code Approved Document for Fire Safety C/AS1 has the most impact on life safety. The parameters are then incorporated in to a semi-quantitative risk model for the analysis stage of the project.

ii) Semi-Quantitative

A semi-quantitative risk analysis (SQRA) is still essentially based on subjective judgment but where points or grades are assigned to broadly quantify variables. The sum of the points is used to establish a measure of risk. In fire engineering terms the method is typically used for assessing/grading existing buildings or undertaking comparative risk assessments of a broad range of buildings.

Care must be taken when using a SQRA because the numbers chosen may not accurately reflect the relativities and this can lead to inconsistency (15). A Delphi panel evaluation, where a panel of experts assigns the ranking values, is commonly used to establish the basic structure of a SQRA analysis. The order of accuracy can be improved by enlarging the group of experts and this may have the effect of reducing inconsistencies.

This project will use a SQRA to evaluate the level of risk for buildings designed to the NZ Building Code Approved Document for Fire Safety C/AS1. The risk analysis will be comparative.

iii) Quantitative

A quantitative risk analysis (QRA) (15), also known as a probabilistic risk analysis (PRA), is a comprehensive statistical probabilistic risk analysis which uses numerical values rather than descriptive scales to quantify risk. A QRA is typically used where the risk problem is complex and there is considerable uncertainty or variability in the input parameters, which could lead to significant variations in the final risk value. QRA should be accompanied by a rigorous sensitivity or uncertainty analysis to thoroughly assess the risk. In fire engineering terms QRA is typically used alongside design calculations to resolve one or two technical issues for an individual building.

The methodology for undertaking a PRA is given in Section 5.6.1. The Reliability Index method described in Section 5.6.8 is also a quantitative risk analysis method.

e) Risk Evaluation

Risk evaluation [14] is the process of comparing the results of the risk analysis to the risk criteria. In this project the risk criteria are based on the objectives, functional requirements and performance criteria set down in the NZ Building Code.

f) Hazard

A hazard is any object or physical phenomenon that will cause harm to life or environmental or property damage. Therefore uncontrolled building fires are deemed hazardous.

5.5 Measurements of Risk

The measurement of risk and safety is somewhat dependant on the method of analysis being used, the accuracy of the input data available and the purpose or objective of the risk analysis. Five measurements of risk typically used in risk analysis are:

- Individual Risk
- Societal Risk
- Relative Risk
- Absolute Risk
- Scales

5.5.1 Individual Risk

Individual risk is defined as the risk to or perceived by an individual from an unwanted, harmful event. In terms of fire engineering it is the risk that an occupant is exposed to at the location defined by the fire scenario [16].

Individual risk is typically expressed as an annual probability of exposure to unwanted, harmful or potentially fatal events. It has been suggested (Wolski et al 2000)[17] that individual risk can be quantified by a probability defined as Expected Risk to Life (ERL) and that a mean ERL of $1x10^{-6}$ deaths per year is an "acceptable" design risk level. It should be noted that this is not a hard and fast number and Wolski et al [17] also suggest nine risk parameters that need to be considered when determining an "appropriate" ERL figure and have provided a matrix giving a range of acceptable individual risk of $1x10^{-9}$ to $1x10^{-3}$ depending on risk parameters considered.

The nine risk parameters suggested by Wolski et al [17] to be considered are reproduced in Table 5.3 below:

Risk factor	**Scale**
Volition	Voluntary - Involuntary
Severity	Ordinary - Catastrophic
Effect Manifestation	Immediate - Delayed
Familiarity	Common(old) - Dread (new)
Controllability	Controllable - Uncontrollable
Benefit	Clear - Unclear
Necessity	Necessary - Luxury
Exposure Pattern	Continuous - Occasional
Origin	Natural – Man made

Table 5.3 - Risk Parameters for Individual Risk

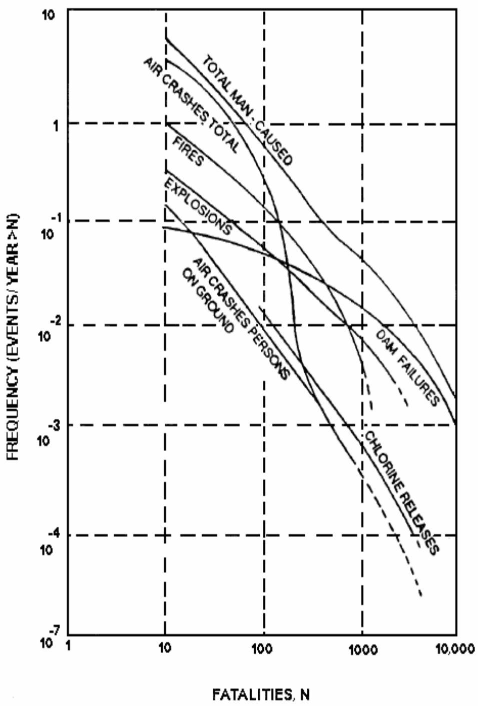
The ERL [7] is given by the following formulae:

$$ERL = \frac{\text{Expected number of deaths}}{\text{Number of Occupants x Building Design Life}}$$

Caution should be taken when applying any absolute figure to a risk analysis. It is highly unlikely that adequate or sufficiently accurate data exists for any risk analysis, in particular fire risk, which would enable fixing an absolute acceptable level of risk.

5.5.2 Societal Risk

Societal risk is defined as the overall risk to society in terms of frequency of event and number of people exposed. In terms of fire engineering it is the risk that many occupants are exposed to at the location defined by the fire scenario and is often expressed in the form of Frequency / Number curves (F-N Curves) where the frequency and number are plotted on log scales. An example of an F- N curve is shown in Figure 5.1 below:



<u>Figure 5.1 - Example of an F-N Curve</u> (Reproduced from Frantzich [18])

5.5.3 Relative Risk

Relative risk is the difference in risk between two scenarios. It is quite common to use relative risk when undertaking risk assessments so that the result can have a quantifiable meaning. It is also common to express relative risk in units of absolute risk.

The advantage of assessing relative risk is that assumptions can be applied equally to both scenarios where insufficient or inaccurate data is used thus still enabling a meaningful comparison to be made. In this case the analysis should clearly state all assumptions and highlight the fact that the results are not absolute values. Sensitivity analyses should be carried out to check the impact of variations in the assumptions on the outcome of both scenarios.

5.5.4 Absolute Risk

Absolute risk is the absolute probabilistic value or measure of risk. The ERL given above is essentially given in terms of absolute risk, i.e. the risk of dying in an unwanted event is 1.0×10^{-6} per year or one death per million persons per year. The difficulty in using absolute risk lies in accurately calculating the value given the large amount of uncertainty in risk analysis variables, particularly in fire engineering. For simplicity for the design engineer the legislators and building code writers could specify an absolute level of risk that engineers can design to and an acceptable method of analysis that would enable the risk to be calculated. But given the large variance in the analysis parameters for fire engineering and nature of political decision making this is unlikely to happen in the foreseeable future.

5.5.5 Scales

Scales are typically used for qualitative or semi-quantitative risk analysis. The scale is generally comprises assigned points, grades or a scoring system.

The scale can be based around a letter grade, (e.g. A,B,C etc), or a numerical grade (e.g.1 to 5 etc). Care should be taken when using the numerical system to ensure that the grading is consistent with the level and accuracy of the analysis. The scale should not imply an absolute risk value (e.g. ERL) if this has not formed the basis of the analysis.

A method for adjusting a scale to reflect actual risk is to use a weighting system [19]. The component weightings then become the most important part of the risk analysis requiring the careful selection and sensitivity testing.

The risk ranking scheme developed for this project comprises a weighted point scheme.

5.6 Literature Review - Existing Risk Analysis Methods and Models

5.6.1 Probabilistic Risk Analysis

a) Introduction

A probabilistic risk analysis (PRA) is a commonly used method to assess risk in engineering. The method is particularly suited to individual problems rather than assessing generic risk of a broad range of structures, although with careful use it can be used for both. The method is outlined in the International Fire Engineering Guidelines(IFEG)[7], and Magnusson et al[20], and has been used by a number of researchers, Hultquist and Karlsson[21], Enright [22] to name but a few.

The following summary of the PRA method is broadly based on the above references put into a fire engineering context, but the general method is well detailed in numerous textbooks, Ang and Tang[23] for example .

b) Methodology

The PRA method uses decision tree (event tree) analysis to assess a design fire scenario using probabilistic data. The probabilities used can be obtained directly from the literature or calculated using fault analysis and historic data. The analysis itself can be done using probability distributions, in lieu of fixed probabilities, and a numerical sampling technique such as Monte Carlo analysis.

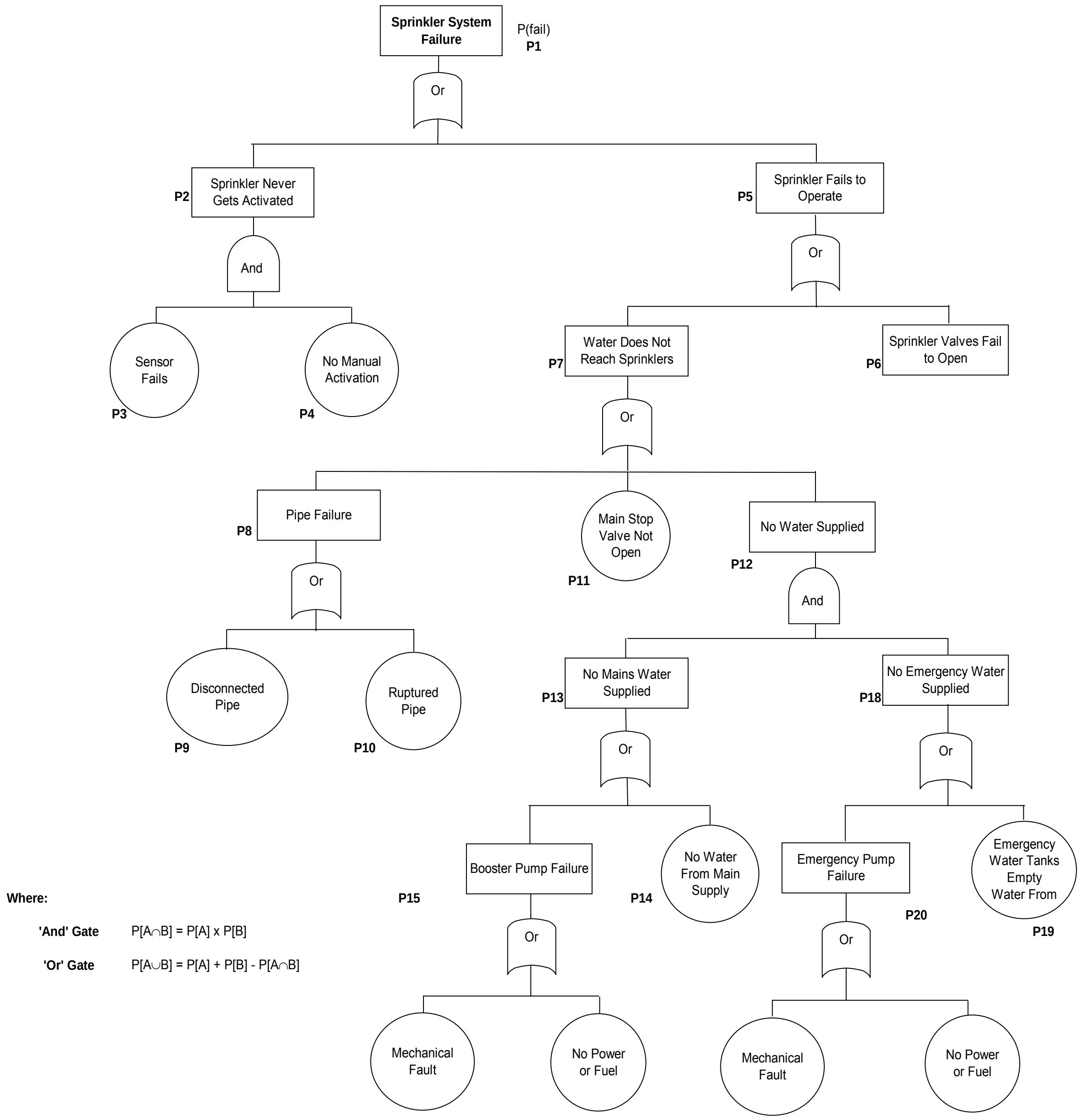
The basic steps to the analysis are:

i) Define the problem
ii) Determine the probabilities or probability distributions for each fire scenario event (could use fault tree analysis).
iii) Establish the event tree sequence/fire scenarios
iv) Identify the branch outcomes/consequences for each fire scenario.
v) Calculate the probabilities for each design fire scenario.
vi) Calculated the expected risk.

c) Determining Probabilities of Failure for Fire Safety Components

A fault tree is a logic diagram that traces all the likely sources of fault/failure back to the root causes. A fault tree can be used to establish the probability of failure or inversely the reliability of a fire safety system or component of a system. Taking a sprinkler system for example, the reliability is generally given between 0.8 and 0.99 in the literature [24][25][26][27]. A fault tree may be used to narrow this down if accurate information is available on local systems.

An example of a fault tree for a sprinkler system is shown in Figure 5.2 below.



<u>Figure 5.2 - Fault Tree for a Sprinkler System</u>

d) Establishing the Event Tree for the Design Fire Scenarios

An event tree traces forward all the possible outcome of an initiating event. In the case of fire the initiating event is typically ignition or established burning (self sustaining flame). An example event tree for a building fire scenario is shown in Figure 5.4 below:

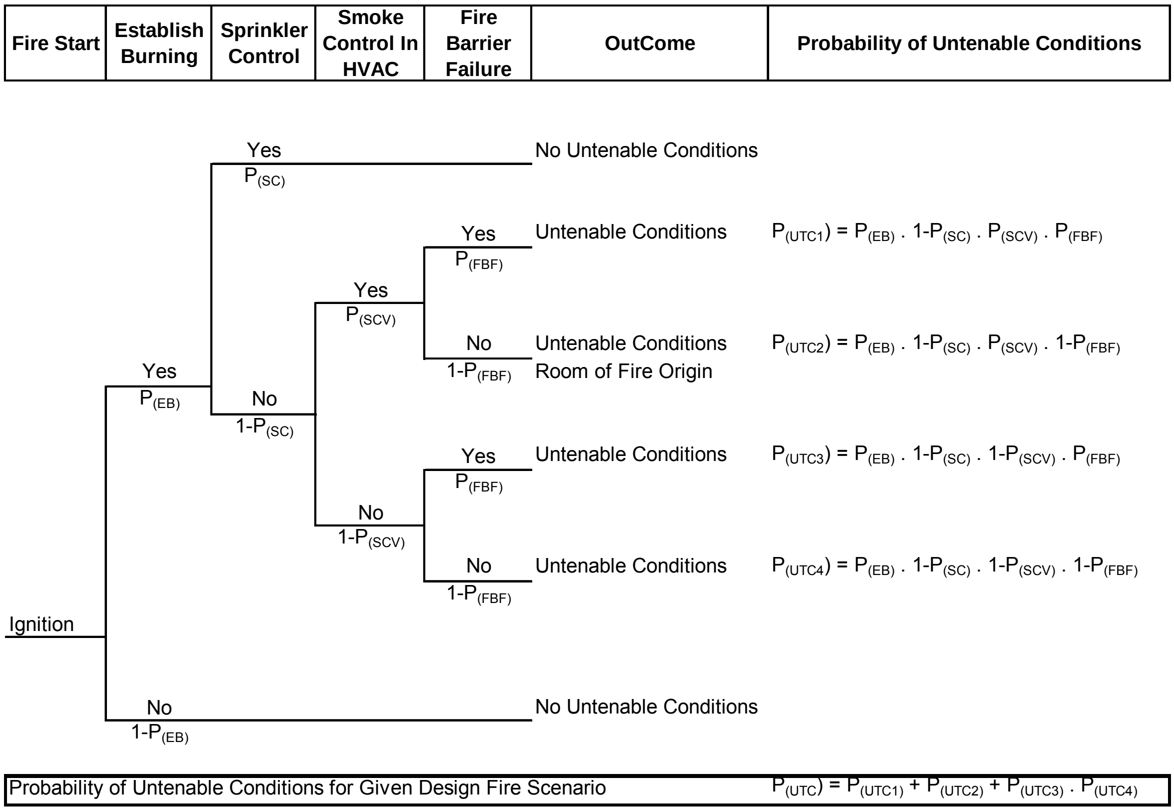


Figure 5.3 - Example Event Tree for a Design Fire Scenario

A similar event tree and analysis is required for the evacuation scenario. The results from the design fire scenario and the evacuation analysis are then combined to determine the risk, "expected risk to life". Note that the probabilities for time to untenable conditions and evacuation are time dependent and as such additional modelling of these two aspects to establish the time-dependant relationships is required.

e) Expected Risk to Life

As noted above the output from PRA is generally given as an expected risk to life (ERL) and this is calculated as follows in accordance with IFEG[7] :

$$ERL = \frac{ELLB}{OP \times t_D}$$

Where: $ELLB$ = Expected loss of life during the design life of the building.

OP = Number of occupants at the commencement of fire.

t_D = Design life of the building.

f) Summary

This method is suitable for assessing specific building designs. It could only be applied to this project if the scope was narrowed so that reasonable assumptions could be made regarding building geometry, fire growth, occupant numbers and evacuation. The number of classes of buildings would also have to be reduced due to complexity of the analysis. Each building class could be assessed in future research work by this method as verification of the risk ranking model proposed in this study.

5.6.2 Boyes – Risk Ranking of Buildings for Life Safety

Boyes 1997[(28)], proposed a method of risk ranking of buildings for life safety. The method was developed to assist the New Zealand Fire Service to assess the risk/safety of building by undertaking a walk through inspection and ranking elements of fire safety.

The proposed method derives a risk score as follows:

$$X = Y \times Z$$

Where: X = Risk Score

Y = Probable Fire Severity

Z = Consequence Score

The probable fire severity (Y) is a matrix where a point value is selected based on the probability of ignition (low, medium or high) and the likely fire growth (Low, medium, fast or ultra fast). The fire severity points range from 1 for low/low to 6 for high/ultra fast.

The consequence score comprises 21 components as shown in the Table 5.4 below. Each of the components is assigned point values that range from -4 to +4 depending on whether it has a positive or negative impact on life safety. Generally a negative impact on life safety has a positive score while a positive impact such as sprinkler protection has a reduction in the score, a negative score.

The method proposed assesses the life safety based on the way the building is being used and managed rather and than the way the building has been designed and as such cannot readily be used for ranking various building designs. Therefore this method cannot be used in its current format for assessing building designs to the provisions of C/AS1 but does demonstrate that a risk ranking scheme can be developed customised to a particular task or purpose.

Component		**Sub-component**
Occupants	a)	Number
	b)	Age/mobility
	c)	Sleeping
Building	d)	Number of stories
	e)	Alternative egress available
	f)	Confusing exits
	g)	Sufficient exits
Fire & smoke spread	h)	Concealed spaces
	i)	Open shafts
	j)	Holes in penetrations
Hazardous substances	k)	Present or not
Management practices	l)	Obstructions in exitways
	m)	Wedges under doors
	n)	Evacuation procedures
	o)	Trial evacuation
	q)	Staff training
Protection	p)	Sprinkler
	r)	Smoke alarms
	s)	Heat detectors

	t)	Manual call points
	u)	Brigade (Fire Service) connections

Table 5.4 - Boyes Method - Risk Analysis Components

5.6.3 Fitzgerald – Building Fire Performance Analysis

Fitzgerald [(29)] has detailed a methodology for assessing the fire performance of a building. The methodology is particularly useful as a tool for assessing and understanding the performance of existing buildings or a specific building design.

The building fire performance analysis involves determining the growth rate of a fire (design fire scenario), the performance of fire safety features, and the response of the occupants and performance of the fire service on a probabilistic basis with respect to a time scale. An example of the sort of questions asked when performing the analysis is " given a fire has established burning what is the probability that a smoke detector will detect the fire in 1 minute, 2 minutes, 3 minutes…n minutes. The objective of the method is to build up an understanding of the performance by plotting performance curves, probability versus time, for the various fire safety features or events.

The performance assessment method involves a three-step evaluation process as follows:

Level 1 - Develops the basic understanding of the fire performance of a building and the risk characteristics. This is essentially a qualitative review of the building to identify key areas for a more rigorous analysis. This may involve a walk through assessment or a desktop study of the building plans to determine critical design fire scenarios and likely outcome. Nominal calculations may be undertaken to firm up choices.

Level 2 - Focuses on detailed performance of the buildings behaviour. This is essentially a more in depth probabilistic risk analysis based on the results of the level 1 assessment. A level 2 assessment involves determining the probability of fire development and spread, occupant's responses; fire safety features responses and fire service responses on a time scale using single value network and continuous value network analysis.

Level 3 - This is where the variance and uncertainty in the input data, scenario selection and assumptions are tested to quantify the impact on the results of the level 2 analysis.

The building fire performance analysis is based around developing response curves using single value network and continuous value network analysis. The method isolates each aspect of a complex fire scenario and determines the probability of success or failure with respect to time or fire size. The basic analytical structure is shown in Figures 5.4 and 5.5 below adapted from Fitzgerald[29].

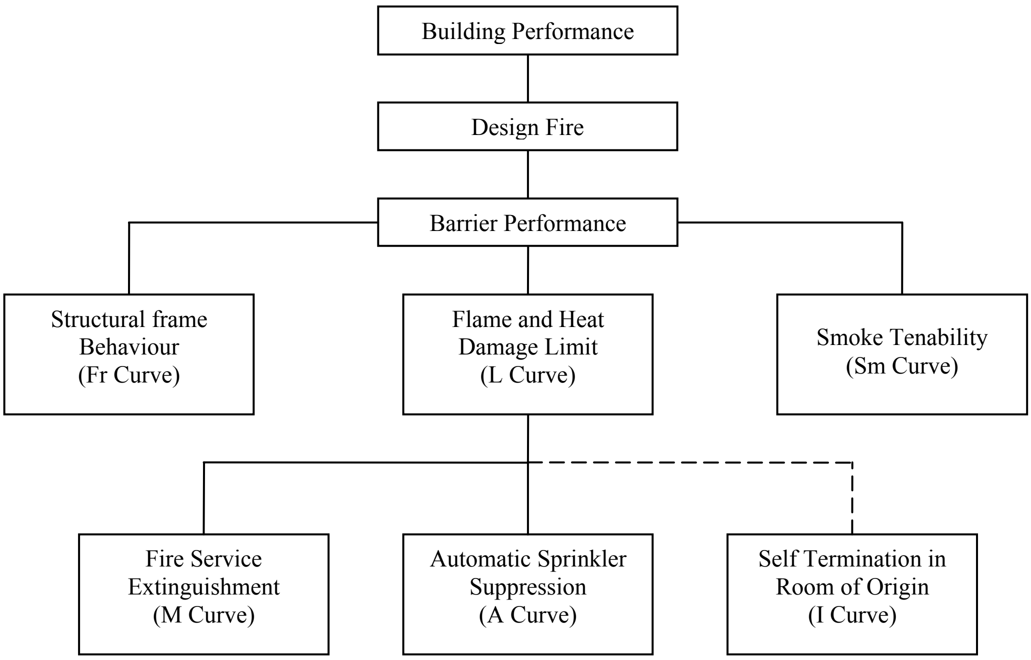


Figure 5.4 - Building Performance Analysis Structure

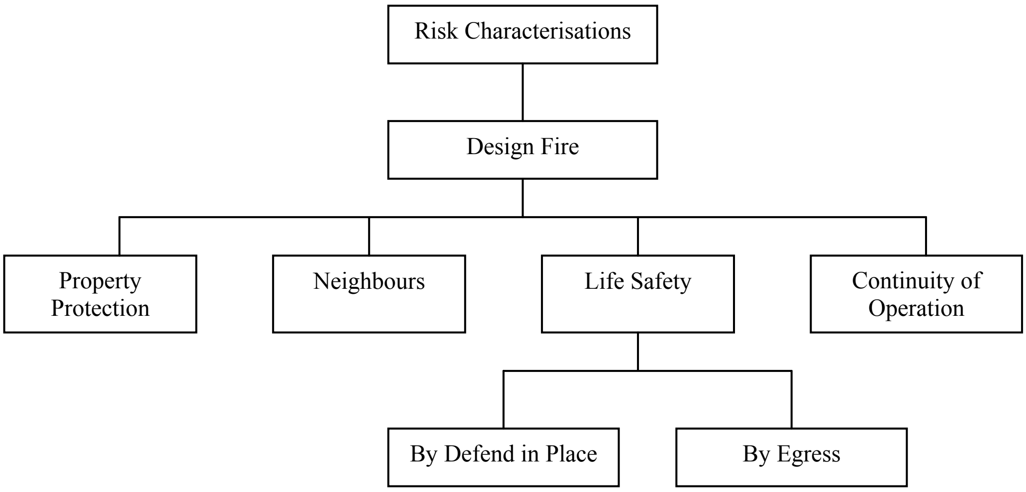


Figure 5.5 - Building Performance Risk Characterisations

A performance curve is a graphical representation of the continuous value network calculations and a generic curve is shown below in Figure 5.6 to illustrate the output resulting from this approach to fire safety performance analysis.

The result of the analysis is a number of performance curves which when read together build up a picture of the performance. The analysis method does not result in a single performance curve although occupant egress curve versus the tenability curve would give a good indication of safety.

The method is not suitable in detail for assessing generic buildings as it is based around determining design fire scenarios for specific buildings and shall not be considered further in this report.

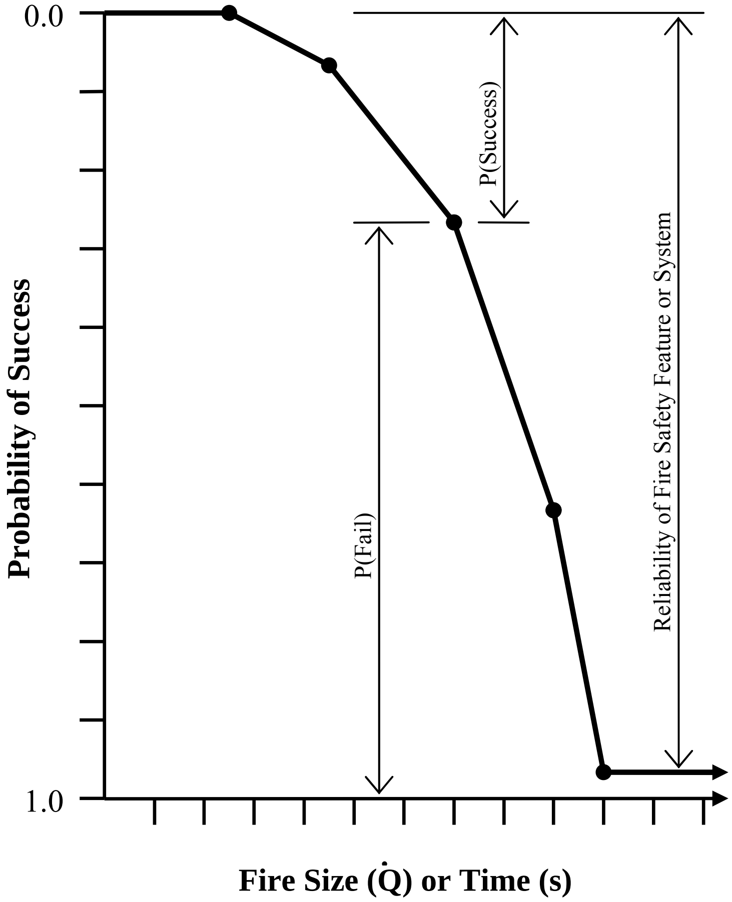


Figure 5.6 - Example of a Building Performance Curve

5.6.4 Gretner Method

The Gretner method [30] was developed by Max Gretner of Switzerland in 1960. The basic concept of the method was to develop numerical values for risk factors for fire initiation; fire spread and fire protection in order to determine a single index value for the fire risk of a building.

The Gretner method is summarised as follows from Watts (2002) [30]:

$$R = A \times B$$

Where:

R = Fire Risk

A = Probability that a fire will start

B = Fire hazard, degree of danger or probable severity

$$= \frac{P}{N \times S \times F}$$

P = Potential hazard

N = Standard fire safety measures

S = Special measures

F = Fire resistance of a building

The method was also developed for assessing existing buildings but the underlying principles will be used in this project for developing a risk ranking scheme.

5.6.5 Dow - Fire and Explosion Index

The Dow Fire and Explosion Index (FEI) [(30)] was developed by the Dow Chemical Company in 1964 to identify areas of *"significant potential loss"* at its chemical manufacturing plants. The system comprises assessing the hazards, the likely area of impact and approximate value of any loss. The loss calculation also takes into account business interruption, including the cost of any shutdown, and credit for fire safety features. The calculation process has been reproduced, with some minor amendments from Watts [(30)] in Figure 5.7 below.

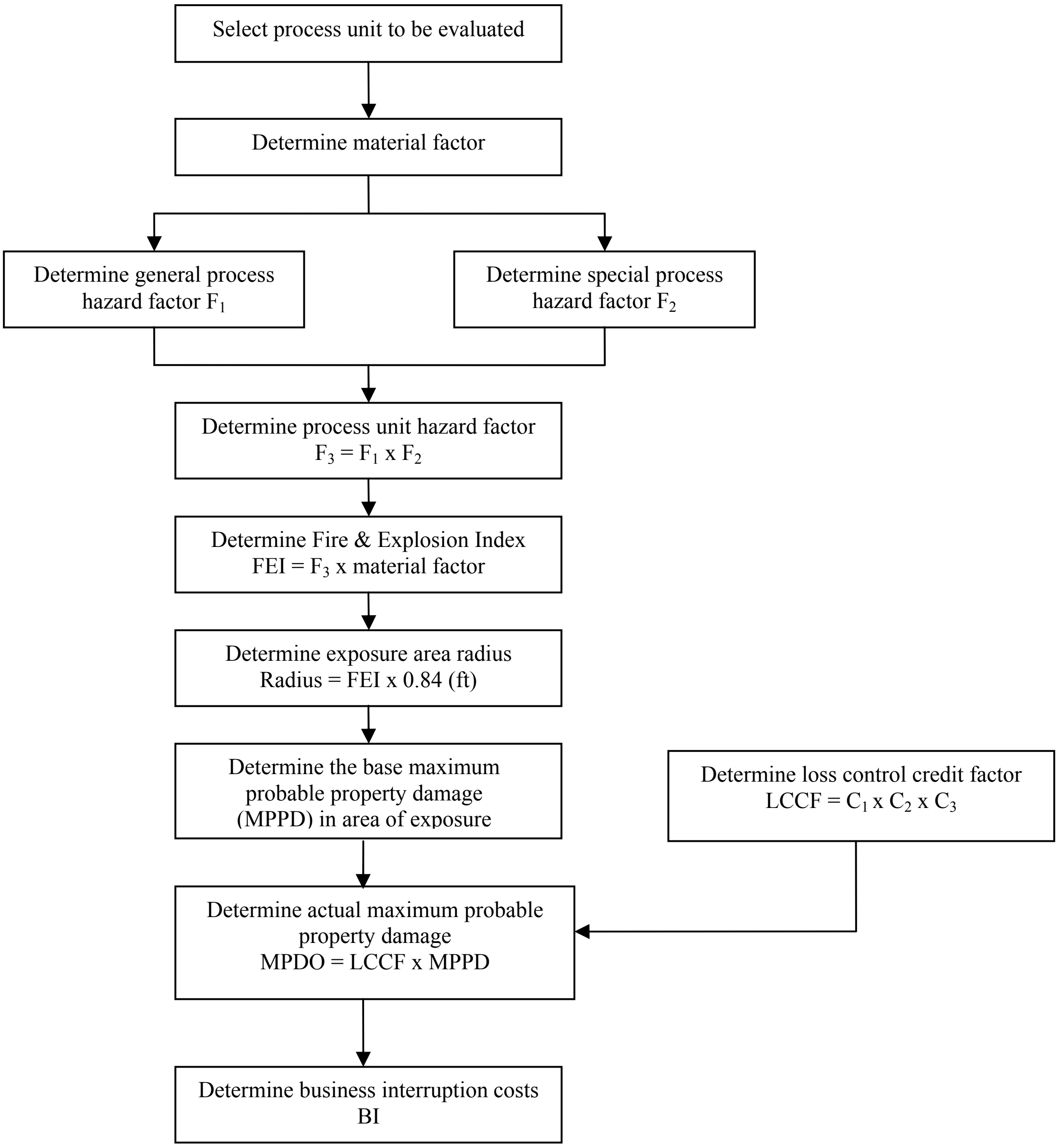


Figure 5.7 - Dow FEI Risk Assessment Process

This method is based on property and business losses for industrial plant, in particular chemical factories and as such is not directly applicable to the life safety analysis of buildings. However it does provide a useful structure for risk ranking of hazards and demonstrates that it is possible to develop a risk ranking scheme for fire hazard analysis.

5.6.6 NFPA 101A – Fire Safety Evaluation System

NFPA 101 Life Safety Code Handbook [31] can be thought of as the USA equivalent of the New Zealand Building Code Acceptable Solution C/AS1[1] for fire safety. NFPA 101 - Chapter 5 presents guidelines for undertaking performance based design. These specifics are lacking from the NZ code but have been addressed recently in the new International Fire Engineering Guidelines 2005[7].

NFPA 101A – *Guide on Alternative Approaches to Life Safety 2001 Edition* [32] provides risk ranking schemes for determining whether or not a performance based design or an alternative design provides the equivalent level of safety as a similar building designed to comply with NFPA 101. The method is known as the Fire Safety Evaluations System (FSES) and is described in detail in Watts [30]. The types of buildings covered by NFPA 101A are:

a) Health Care occupancies (Hospitals).
b) Correctional occupancies (Prisons and police stations).
c) Board and care occupancies (Apartments, boarding houses, and hospices).
d) Business occupancies.

Apartments (purpose group SR), boarding houses/hospices (purpose group SA/SC) and Businesses (purpose groups WL and WM) are building types included in this project therefore this review of NFPA 101A will focus on these three types of occupancies.

The first step of the FSES procedure (*based on the NFPA worksheet 8.6.1- business occupancies*) requires an assessment of 12 key safety parameters as follows:

1) Determine the type of construction (combustible and non-combustible and number of storeys). Points vary form +2 to -12, where positive tends to favourable/non combustible.

2) Assess segregation of hazards. Determine where hazardous materials are exposed to the exit system and the degree of deficiency of the structural system/protection system. Hazardous materials are those not typically found in the general occupancies, which may or may not be stored in or adjacent to exitways. For example where hazardous materials are stored under a non-fire rated timber stair then the ‘Segregation of hazard’ would be assessed as ‘exposed and double deficiency’ without sprinklers, or ‘exposed and single deficiency’ with sprinklers. The points assigned are -7 and -4 respectively. The points vary from 0 to -7 depending on the degree of exposure and the deficiency.

3) Assess vertical openings (stairs, lift shafts, service ducts etc) to determine risk. The points are assigned depending on whether or not the shafts are enclosed with fire rated construction or open and the number of floors they pass through. The points assigned vary from -10 to +1.

4) Determine the coverage and type of sprinklers. Points assigned vary from 0 for no sprinklers, to +12 for fast response sprinklers installed throughout the entire building.

5) Determine whether or not the fire alarm has voice communication and/or fire service notification. Points are assigned vary from -2 for no alarm, to +4 with both fire service notification and voice communication.

6) Assess extent of smoke detection, 0 for none, +1 for corridors, +2 for specific rooms and +4 for throughout total building.

7) Assess interior surface finishes for flame spread ratings within exit routes and/or rooms. Points vary from -3 to +2 depending on spread of flame parameters and location.

8) Assess the type of smoke control, 0 for none, +3 for passive and +4 for active. Note that not a lot of credit in the form of increased safety is given to active smoke control systems in FSES. However in New Zealand active smoke control is often used as a trade off against other fire safety features by specific fire engineering design.

9) Evaluate the exit access, escape route lengths. Points are assigned varying from -2 for 33m of dead end to + 3 for less than 15m of total open path/dead end.

10) Assess the egress route availability and protection. Points are assigned varying from -6 for single means of escape to +5 for direct access to a safe place.

11) Assess corridor protection/separation from adjoining occupied compartments. This assessment determines the level of fire/smoke separation and the presence of door closers. Points vary from -6 for incomplete protection to +3 for one hour fire rated construction.

12) Evaluate the occupant emergency program, evacuation plan and number of fire drills. Points vary from -2 for no fire drills to +1 for more than 2 fire drills.

The points from the above safety parameter assessment are then entered into NFPA101A *Worksheet 8.6.3, Individual Safety Evaluation* [32]. They are assigned to S1-Fire Control, S2-Egress Provided and/or S3-General Fire Safety as appropriate. The sum of the scores provides an S1, S2 and S3 points grade for the proposed building. The mandatory grades Sa, Sb and Sc for Fire Control, Egress Provided and General Fire Safety respectively are then deducted from S1 to S3. If the net sum is greater than 0 then the design has met the equivalency requirements and is deemed to comply with NFPA 101 i.e.

Fire Control	$S1 – Sa \geq 0$	equivalency achieved
Egress Provided	$S2 – Sb \geq 0$	equivalency achieved
General Fire Safety	$S3 – Sc \geq 0$	equivalency achieved

The required grades are shown in Table 5.5 below reproduced from *NFPA101A Worksheet 8.6.4*. Some values have been converted to SI units.

Building Height	Control Requirement (Sa)		Egress Requirement (Sb)		General Fire Safety (Sc)	
	New	**Existing**	**New**	**Existing**	**New**	**Existing**
1 Storey	0.5	-1.0	1.5	0.0	2.0	-1.0
2 Storeys	-2.5	-4.0	1.5	0.0	-1.0	-4.0
3 Storeys	1.5	0.0	1.5	0.0	3.0	0.0
>3 Storeys and ≤ 23m	4.0	2.0	2.5	0.0	6.0	2.0
> 23m but < 46m	9.5	7.5	7.5	5.0	10.0	6.0
≥ 46m	12.5	10.5	7.5	5.0	10.0	9.0

Table 5.5 - Mandatory Fire Safety Requirement FSES Scores for Business Occupancies

The final step in the equivalency process is to assess the facility fire safety requirements, *NFPA101A Worksheet 8.6.6.* This requires a simple yes/no evaluation of the following:

A. Building utilities, lighting, power etc.
B. Ventilation
C. Elevators
D. Rubbish and laundry chutes and incinerator.
E. Portable fire extinguishers
F. Standpipes

If all of the above meet their respective code requirements and the individual fire safety evaluations exceed the required value the building is certified as being equivalent to a building design to the requirements of the NFPA101 Life Safety Code.

The method and safety parameters are similar for other types of occupancies. For example in residential occupancies there are some additional parameters to be considered such as separation of sleeping rooms from each other or other types of occupancies. There are also four safety evaluation categories for the safety parameters to be assigned to; S1-Fire Control, S2-Egress, S3 - Refuge and/or S4-General Fire Safety with four matching acceptance criteria.

This is very similar in structure to the risk ranking scheme developed by Boyes (28) (Section 5.6.2 above). The main difference is that Boyes is specifically designed to rank existing buildings and takes into consideration building maintenance and management issues that effect fire safety.

Two other risk ranking schemes have been developed in the United States. These are to evaluate fire safety in historic buildings, Watts and Kaplan (33) and rehabilitation and reuse of existing buildings in Manitoba for residential, business and personal service use, Richardson and Frye (34). Both of these two fire risks indices have been developed based on, and as such are similar to, the NFPA 101 - FSES method outlined above.

5.6.7 Fire Risk Index Method – Multi-storey Apartment Buildings

A significant amount of work has been carried out at Lund University in Sweden on fire risk analysis. The work by Karlsson and Larsson (35), involving development of a fire risk index method for multi-storey apartment buildings (FRIM-MAB) by use of a Delphi panel, and Karlsson and Hultquist (21) involving testing the results of a fire risk index method on a sample of buildings using probabilistic risk analysis procedures are particularly relevant to this project.

A Delphi panel comprising 20 professional fire experts, 5 each from the four Nordic countries; Norway, Finland, Sweden and Denmark developed the fire risk index method. The work was first published in 2000.

The risk index method was developed for multistorey apartment buildings to provide a quick and reliable method for assessing risk. The method outlined in Karlsson and Larsson (35), appears to give reasonable answers (21), however the review was only based one comparative analysis using a full probabilistic risk analysis and further analysis and sensitivity testing is suggested. Further work on development of the risk index method beyond 2000 could not be found, however this does not mean to say that work on this risk index method has not been carried out since.

The index method is useful in that it provides a single safety value. This value is a number between 1 and 5.

The basic structure used by the Delphi group to determine the risk index method is shown detailed below based on Karlsson and Larsson [35]:

1. Develop Policy	• Fire safety performance should be equivalent to a building that complies with Approved Documents.
2. Define Objectives	• Provide life safety • Provide property protection
3. Develop Strategies	• Establish safe egress • Control fire growth/spread
4. Identify Parameters or sub-parameters	• Building • Fire • Fire protection • Occupant
5. Assign Grades	• Assign grades from 0 -5 reflecting the safety standard of a given parameter. • Sub-parameters are typically assigned a grade, N - No grade, L - Low, M – Medium and H – High.
6. Apply Weightings	• Assign weights to parameters

The key elements to the FRIM -MAB are the parameters and the assigned weightings. These are listed in Table 5.6 below for FRIM-MAB version 1.2.

No.	Parameter (Pn)	Sub Parameters	Weight (Wn)
P_1	Linings in Apartments	-	0.0576
P_2	Suppression System	• Automatic sprinkler system • Portable equipment	0.0668
P_3	Fire Service Grade = $0.31P_{3a}+0.47P_{3b}+0.22P_{3c}$	• Capability (P_{3a}) • Response time (P_{3b}) • Accessibility and equipment (P_{3c})	0.0681
P_4	Compartmentation	-	0.0666
P_5	Structure Separating $P_5 = 0.35P_{5a}+0.28P_{5b}+0.24P_{5c}+0.13P_{5d}$	• Integrity and insulation (P_{5a}) • Structure and firestop Design (P_{5b}) • Penetrations (P_{5c}) • Combustibility (P_{5d})	0.0675
P_6	Doors $P_6 = 0.67P_{6a}+0.33P_{6b}$	• Doors leading to escape route (P_{6a}) • Doors in escape route (P_{6b})	0.0698
P_7	Windows	• Relative vertical distance • Class of window	0.0473
P_8	Facades $P_8 = 0.41P_{8a}+0.30P_{8b}+0.29P_{8c}$	• Combustible part of facade (P_{8a}) • Combustible material above window (P_{8b}) • Void (P_{8c})	0.0492
P_9	Attic	• Prevent fire spread to attic • Fire separation in attic	0.0515
P_{10}	Adjacent Buildings	-	0.0396
P_{11}	Smoke Control system	• Activation of smoke control • Type of smoke control	0.0609
P_{12}	Detection	• Amount of detectors • Reliability of detectors	0.0630
P_{13}	Signal System	• Type of signal • Location of signal	0.0512
P_{14}	Escape Routes $P_{14} = 0.34P_{14a}+0.27P_{14b}+0.16P_{14c}+0.23P_{14d}$	• Type of escape route (P_{14a}) • Dimensions and layout (P_{14b}) • Equipment(P_{14c}) • Linings and flooring (P_{14d})	0.0620
P_{15}	Structure Load Bearing $P_{15} = 0.74P_{15a}+0.26P_{15b}$	• Load-bearing capacity (P_{15a}) • Combustibility (P_{15b})	0.0630
P_{16}	Maintenance and Information $P_{16} = 0.40P_{16a}+0.27P_{16b}+0.33P_{16c}$	• Maintenance of fire systems (P_{16a}) • Inspection of escape routes (P_{17b}) • Information to occupants (P_{17c})	0.0601
P_{17}	Ventilation System	-	0.0558
		Σ	**1.0000**

Table 5.6 - FRIM-MAB Version 1.2- Fire Safety Parameter

The parameter or sub-parameter is assessed and given a grading between 0, unfavourable and 5, favourable. The parameter grades are then multiplied by the weighting and summed to give a score out of 5. The score is then deducted from 5 to give the risk index, i.e. the risk index is given by:

Risk Index $RI = 5 - \sum(Pi \times Wn)$

Where: Pi = *Safety parameter*

Wn = *Safety parameter weighting*

The lower the risk index the safer the building.

The risk index is based on an assessment of life safety, property protection and a variety of fire safety strategies. Hultquist and Karlsson [21], determine revised weighting based on assessing those aspects which have a bearing on life safety (the ability for occupants to escape) so that a comparison could be made to a probabilistic risk analysis. The revised parameter weightings are shown in Table 5.7 below.

No.	Parameter (Pn)	Weight (Wo)	No.	Parameter (Pn)	Weight (Wo)
P_1	Linings in Apartments	0.0623	P_{10}	Adjacent Buildings	0.0242
P_2	Suppression System	0.0658	P_{11}	Smoke Control system	0.0701
P_3	Fire Service	0.0571	P_{12}	Detection	0.0814
P_4	Compartmentation	0.0623	P_{13}	Signal System	0.0762
P_5	Structure Separating	0.0588	P_{14}	Escape Routes	0.0839
P_6	Doors	0.0718	P_{15}	Structure Load Bearing	0.0463
P_7	Windows	0.0407	P_{16}	Maintenance and Information	0.0692
P_8	Facades	0.0363	P_{17}	Ventilation System	0.0614
P_9	Attic	0.0320			

Table 5.7 - FRIM-MAB Fire Safety Weightings for Occupant Egress

By inspection the maximum difference in weighting is approximately a factor of three. The weighting of the suppression system is surprisingly lower than could be expected given the effectiveness a sprinkler system has in controlling and/or extinguishing fires. Refer Section 7.4.3 for further discussion on the effectiveness of sprinkler systems.

The FRIM-MAB method was developed for multi-storey timber framed buildings. There is a practical structural limit that the height of a timber framed building can be built. In NZ this is typically 4 storeys unless a steel structure is used. The sample buildings assessed in Hultquist and Karlsson [(21)], were 4 stories, and therefore it is inferred the method is suitable for low rise timber framed buildings up to 4 storeys. The limitations of the method are not clearly specified but it is reasonable to assume from the reports [(21)(35)] that the intended use is for low rise apartment buildings.

Extrapolating the scheme to larger, more complex building with different occupancies would require a careful review of the weightings and points systems, but by inspection the method could be adapted and used for such an analysis.

5.6.8 Reliability Index Method

The reliability index method (β Method) has been detailed by a number of authors over the past 35 years and has been the subject of research by various fire safety researchers in recent years, in particular the researchers based at Lund University in Sweden. The basic fundamentals of the method with respect to fire safety are summarised below based on the work by Frantzich(1997) [(18)], Frantzich (1997) [(36)], Kristiansson (1997) [(37)] and Frantzich et al (1997) [(38)]. For a more comprehensive description the reader is also referred to the following well known texts, Ang and Tang [(23)] and Thoft-Christensen and Baker [(39)].

a) Limit State Equations

The reliability index method requires the derivation of limit state equations. In the case of fire these are typically based on the escape time margin, i.e. the available safe egress time (ASET) minus the required safe egress time (RSET) as follows:

$$G = S - R$$

Where: G = Escape time margin

S = Available safe egress time (ASET), "time to untenable conditions"

R = Required safe egress time (RSET), "response & evacuation time"

The exact form of the limit state equation will depend on the design fire scenario that is being evaluated. The limit state equations for a generic room may take the form below:

$$G = S \,.\, M_S - R \,.\, M_R$$

Where:

S = f [fire growth rate (α), room area (A), room height (H)]

M_S = Fire model uncertainty

R = f [detection time (D), response time (R_T), evacuation time (E)]

M_R = Evacuation model uncertainty

The equation for time to untenable condition (S) can be derived by using computer fire model programs such as CFAST (40) or BRANZFIRE (41) and a regression analysis in a standard computer spreadsheet package such as Excel (42). The equation for the response and evacuation time (R) can be derived in a similar manner using computer evacuation programs, detector activation programs and/or hand calculation methods. Example equations for time to untenable conditions (S) and response and evacuation time (R) are shown below adapted from Frantzich et al 1997(38):

$$S = 1.67\, \alpha^{-0.26} H^{0.44} A^{0.54} \quad \text{(Minutes)}$$

$$R = D + R_T + E \quad \text{(Minutes)}$$

Where:

D = Detection Time (in this case based on smoke detection)

$= 5.36\, \alpha^{-0.478} H^{0.7}$ (Minutes)

R_T = Occupant Response Time (Minutes)

E = Escape Time (Minutes)

$$= \frac{N \cdot A}{W \cdot F}$$

α = t^2 fire growth rate (MJ/s^2)

H = Height of room (m)

A = Area of room (m^2)

N = occupancy rate (persons/m^2)

W = door width (m)

F = Specific flow of persons through door opening. (person/min/m^2)

Therefore the limit state equation for the safety margin would be given by:

$$G = S \cdot M_S - R \cdot M_R \qquad \text{(Minutes)}$$

$$= S \cdot Ms - (D+R_T+E)\, M_R$$

$$= 1.67\,\alpha^{-0.26} H^{0.44} A^{0.54} Ms - \left[5.35\alpha^{-0.478} H^{0.7} + R_T + \left(\frac{N.A}{W.F}\right)\right].M_R$$

The variables in the above equation can be either deterministic or probabilistic in the reliability calculations. Caution must be used if using non-normally distributed variables, as some form of transformation to normally distributed variables is typically required and therefore the result, at best, is an approximation. This is likely to add another source of uncertainty to the analysis.

b) Reliability Index (β) Calculation

The reliability index (β), in its simplest form, based on work by Cornell, 1969(Ang and Tang)[(23),] can be calculated as follows where S and R are normally distributed independent variables with a mean (μ) and a standard deviation (σ) resulting in a normally distributed safety margin G:

$$\mu_G = \mu_S - \mu_R$$

and $$\sigma_G = \sqrt{\sigma_S^{\,2} + \sigma_R^{\,2}}$$

giving $$\beta = \frac{\mu_G}{\sigma_G}$$

The probability of failure (P_f) is given by:

$$P_f = P(G \leq 0) = \Phi(-\beta)$$

where: Φ = Standardised normal distribution function

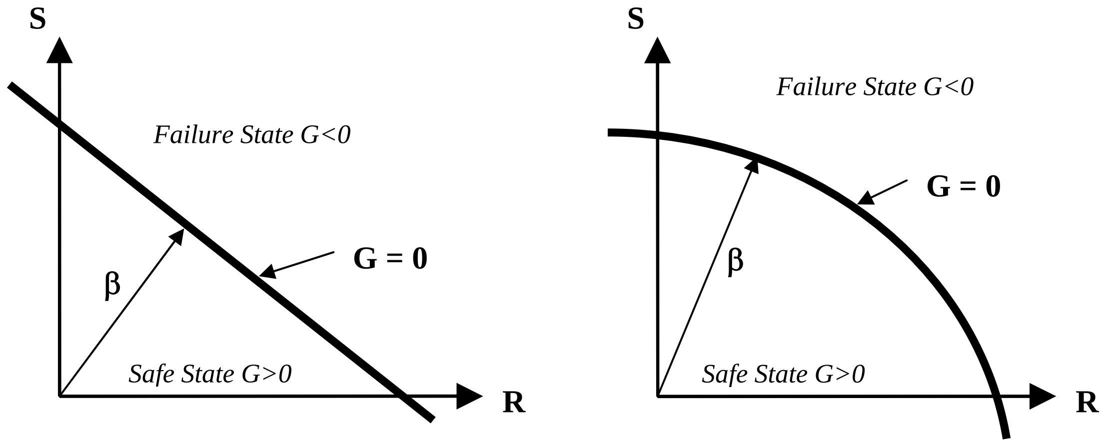
Hassofer and Lind's (Ang and Tang)(23) improved reliability index involves standardising the basic variables as follows:

$$S' = \frac{S - \mu_S}{\sigma_S}$$

and $$R' = \frac{R - \mu_R}{\sigma_R}$$

for variables S and R respectively.

The reliability index (β) is then defined as the shortest distance from the origin to the limit state failure surface in the standardised space, and is shown in Figure 5.8 below for a linear and non-linear failure surface.



a) Linear Failure Surface **b) Non-linear Failure Surface**

<u>Figure 5.8 – Reliability Index β in the Two Dimensional Space</u>

(Adapted from Kristiansson, 1997 [37])

Where a number of non-linear variables are involved then the failure surface becomes a curved hypersurface and solving for β becomes somewhat more complicated. Exact solutions to these equations are not possible and as such the solution generally required an iterative approach. These are commonly referred to as First Order Second Moment (FOSM) or Second Order Second Moment (SOSM) analyses. The reader is referred to Ang and Tang [23] and Thoft-Christensen and Baker [39] for a detailed description of these methods. There are a number of computer programs, originating out of structural reliability analysis, which can perform the calculations, for example STRUREL (RCP Munchen 1995) [43]. The capability of this program has not been specifically assessed in this research project.

The β method is akin to a full quantitative risk analysis (QRA), requiring the same input data and level of analysis. The only difference is that the basic output is the probability of failure of the safety margin and resulting safety index instead of the expected risk to life. As such it also attracts the same level of uncertainty and hence requires a rigorous uncertainty analysis to verify and provide confidence in the results.

This study involves assessing a large number of building heights, occupancy types and occupant number combinations, approximately 90 in total. Although the reliability index method was used to establish partial coefficients for classes of buildings [38] the analysis required some rather broad and simplifying assumptions, for example, that people are safe when evacuated from the fire floor, hence the building as a whole entity was not assessed.

The key feature of the β method requires assessment of ASET and RSET and as such building geometry, occupant densities and design fires need to be established. Furthermore in NZ protected and safe paths generally have a definitive fire resistance rating and therefore form a part of a building, which could be subject to failure in the event of a fire. A person in NZ is not deemed safe until they have exited the building. In all the studies referenced in this section a person appears to be deemed safe when reaching a protected shaft. Given this, to assess the safety of buildings designed in New Zealand we need to consider the entire building and not just the fire cell or floor of fire origin.

A study of the level of safety using a QRA yielding either a reliability index or an expected risk to life output could be undertaken in the future by investigating specific occupancies individually or a selection of real buildings designed to the Approved Document.

5.6.9 Fire Risk Computer Models

A number of fire risk computer models have been developed for assessing the risk to life in building fires. These have not been used or evaluated in detail in this project but are briefly described below for reference.

a) FiRECAM ™

FiRECAM™ has been developed by the National Research Council of Canada (NRCC). Information is available on this model from the NRCC website www.nrc-cnrc.gc.ca including a downloadable trial version.

FiRECAM (**F**ire **R**isk, **E**valuation and **C**ost **A**ssessment **M**odel) can be used to assess the expected risk to life and fire costs of fire safety designs for apartment and office buildings. The model is based on determining the level of safety that meets the requirements of the National Building Code of Canada (44).

The program is made up of 17 sub-models, three for example are:

• *Boundary Element Failure Model (BEFM)*	*Computes probabilities of failure of a wall or floor element.*
• *Design Fire Model (DFMD)*	*Computes the rates of fire occurrences, and the probabilities of the fire types being flashover, non-flashover, flaming fire or smouldering fire*
• *Fire Growth Model (FGMD)*	*Models the growth of a fire in a compartment and calculates temperature and toxic gas concentrations as a function of time.*

The model output is generally in the form of tabulated data, graphs or a 3D model of the building with visual density graphics depicting the output of interest, e.g. number of fatalities.

b) FIERASystem

FIERASystem has also been developed by the National Research Council of Canada (NRCC). Information is also available on this model from the NRCC website www.nrc-cnrc.gc.ca.

FIERASystem (**Fi**re **E**valuation and **R**isk **A**ssessment **System**) is similar to FIRECAM™ and can be used to assess the expected risk to life and fire costs of fire safety designs for light industrial buildings (45).

c) FIRE-Risk

FIRE-Risk, (formerly CESARE Risk) has been developed by the Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, Melbourne, Australia. The program is a fire risk/cost assessment model based on design compliance with the “Deemed to Satisfy” provisions of the Building Code of Australia. Note the “Deemed to Satisfy” provisions are the Australian equivalent to the Acceptable Solution C/AS1 in New Zealand.

The program is similar to FiRECAM™ in that it is made up of a number of subroutines. The basic components of the FIRE-RISK model are given as follows [46]:

- *Time Dependant Part (TDP)*
  - *fire and smoke spread*
  - *effect of fire and smoke spread on fire safety system*
  - *effect of fire and smoke spread on occupants*
  - *occupant response*
  - *fire brigade intervention*
- *Non-time Dependant Part (TDP)*
  - *Possible spread of fire beyond room of origin*
  - *Possible injuries and fatalities outside room of origin*
  - *Possible damage outside room of origin*
- *Economic Model*

The program is applicable to apartment buildings, hotel and motel buildings and aged care facilities.

There is very little published information on this program available in the public domain. Therefore a detailed review of the programs capabilities has not been undertaken. The reader should contact the Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, Melbourne, Australia for further information if desired.

d) CRISP II

CRISP II has been developed by the Building Research Establishment (BRE) in the UK[59]. The program is an egress/evacuation risk assessment model utilising a Monte-Carlo analysis. The program can be run in a fire scenario mode where it calculates all parameters associated with the development of a fire, i.e. growth, fire and smoke spread etc, as wells as human response and evacuation. The program can also be run in an evacuation mode only as an egress model.

There is very little information available in the public domain on this program, therefore this program was not assessed further. The reader should contact the BRE at www.BRE.co.uk for further information if desired.

5.7 Summary

There are many methods available for assessing fire safety, and not all are suitable for a "generic" type evaluation of a building code. Some are more suited to actual buildings or specific building designs such as PRA and reliability index method. The literature does suggest that these two methods in particular, could be used for evaluating safety requirements of "generic" building code categories but, this would entail a significant amount of analysis and many years of research. The analysis would still need to be based on trial building geometry, fuel load and occupant behaviour models, which could introduce a significant amount of uncertainty into the analysis. PRA computer programs would enable rapid assessment of multiple building categories, sizes and occupant numbers, but current models are limited in their capabilities at this time.

This project will seek to develop a simple points based risk ranking system and use this system to evaluate the apparent level of safety of buildings designed to the New Zealand Building Code Approved Document for Fire Safety, C/AS1.

6 RISK RANKING MODEL

6.1 General

The model proposed in this section will be used to assess the level of fire safety of buildings designed to the NZBC "Acceptable Solutions" C/AS1.

The model is a simple risk ranking model that produces a single numerical safety index. This will enable comparison between buildings of different heights and occupancy types. The method proposed is similar to FRIM-MAB[35] as described in Section 5.6.7 above but tailored to the safety attributes of C/AS1.

The model will be based on the specific fire safety requirements of C/AS1 and detailed using the nomenclature of this document.

6.2 Risk Ranking Model Outline

Risk is typically defined as a function of likelihood and consequences. In the case of fire the likelihood relates to the probability that a number of events will happen, including fire ignition, fire growth, fire and smoke spread and presence and movement of occupants. Consequence relates to the outcome of the fire event, i.e. the extent of damage and whether or not occupants escape safely or succumb to injury or fatality.

Neither probability nor consequence will be assessed directly in this model. This model is simply a method for ranking a building's fire safety based on the building use; fire hazard and fire safety precautions (FSP) installed as defined by C/AS1.

The ranking scheme shall involve assigning a score between 0 and 5 to each of the C/AS1 safety or risk parameters. The score is then multiplied by a weighting to give a weighted score. The sum of the weighted score for the building/use parameters gives a Building/Use Score (BUS), and likewise the sum of the weighted score for the fire safety features parameters gives a Fire Safety Features Score (FSFS). The sum of the BUS and FSFS gives the total Fire Safety Index (FSI) as follows:

$$BUS = \sum_{BU1}^{BU4} A_s \times Wi_{C/AS1}$$

$$FSFS = \sum_{A}^{H} A_s \times Wi_{C/AS1}$$

$$FSI = BUS + FSFS$$

Where:	*BUS*	= Building/Use Score
	FSFS	= Fire Safety Feature Score
	FSI	= Fire Safety Index
	A_s	= Individual Parameter Score
	$Wi_{\text{C/AS1}}$	= Individual Parameter Weighting (sum to 1.0)

The higher the score infers the safer the building.

The following parameters shall be assessed in the Building/Use Score element of this model:

BU1) Purpose Group

BU2) Building Escape Height

BU3) Occupant Numbers

BU4) Fire Hazard Category

The following safety parameters shall be assessed in the Fire Safety Features Score element of this model:

A) Fire Barriers
   - Firecell Rating
   - Structural Fire Endurance Rating

B) Fire Alarm

C) Smoke Control
   - Heating Ventilation and Air Conditioning Control
   - Extraction
   - Pressurisation of Stairways

D) Building Fire control
   - Sprinkler Systems
   - Water Supply
   - Occupant Fire Fighting

E) Emergency Power Supply

F) Communications System

G) Fire Service
   - Alerting of Fire Service
   - Lift Control
   - Fire Fighting Access

H) Means of Escape
   - Number of Escape Routes
   - Width of Escape Routes
   - Emergency Lighting
   - Refuge Areas
   - Dead End Open Paths
   - Total Open Paths
   - Protected Paths Lengths
   - Surface Finishes Exitways
   - Surface Finishes Occupied Spaces
   - Signage

6.3 Model Parameter Point Assignments

The parameter points are assigned on a scale of 0-5 based on numerical data where available, calculations or qualitatively based on subjective judgment where no hard data exists. Therefore in some cases the parameters are simply placed in likely order of increased safety within the scale boundaries. Questionable rankings will be checked by sensitivity tests but in reality further independent research is likely to be required to verify and /or refine the model. The scale of 0-5 was selected based on the FRIM-MAB(35) model to enable future model comparisons if appropriate.

6.3.1 Building/Use Parameters

BU1) Purpose Groups

The term "Purpose Group" covers the occupant type in a building and the activities they may be undertaking. This is an important parameter in a safety/risk analysis as the type of person and their activities will affect how they respond to fire cues and/or alarm and the length of time it takes for the person to escape the building. Therefore this parameter essentially assesses the human behaviour aspect of fire safety. The four key elements under consideration are:

- Alertness – awake or asleep, noisy environment or quiet?
- Familiarity – regular user, resident or casual visitor of the building?
- Capabilities – Physical (How fast can they walk, do they need assistance?)
  – Psychological (Will they think clearly or be confused?)
- Occupant Density – Crowd or individual influence on behaviour

For this project it is assumed that we are assessing the safety of an average person who is fully ambulant, is capable of looking after themselves and following authoritative instructions if necessary. It is assumed that variance in individual capabilities is accounted for in the C/AS1 Purpose Group categories, e.g. children will be under the guidance of an adult and disabled persons will have access to appropriate facilities or assistance in the event of a fire emergency. Therefore variance in individual capabilities will not be specifically assessed.

A simple independent ranking scheme based on a scale of 0 to 2 was derived by judgment to assess alertness, familiarity and occupant density of each purpose group to determine the points scored for each purpose group type. Alertness is considered the most important of the three factors and as such was weighted by a factor of 3. This was done to account for the fact that sleeping persons could take considerably longer to respond to an alarm than a person who is awake and/or familiar with a building. The results are shown in Table 6.1 below:

Purpose Group	**Alertness (x3)**			**Familiarity (x1)**		**Occupant Density (x1)**		**Total Score**	**Scaled Score**
	Status	Score	Weighted Score	Status	Score	L/M/H	Score		
Sleeping Accommodation SA	Asleep	0	0	Unfamiliar	0	Low	2	2	1.1
Sleeping Residential SR	Asleep	0	0	Familiar	2	Low	2	4	2.2
Crowd CS/CL/CM	Awake & Noisy	1.5	4.5	Unfamiliar & Familiar	1	High	0	5.5	3.1
Working WL/WM	Awake	2	6	Familiar	2	Medium	1	9	5.0

Note: The crowd alertness has been reduced by 0.5 points to account for the fact that crowd environments can be noisy.

<u>Table 6.1 – Purpose Group Grading</u>

A similar scoring method was proposed by Sime [49] for deriving efficiency scores for determining pre-movement times for various occupancy types. The method is more comprehensive than the method used above and includes eight factors as follows:

B. Alertness - awake or asleep
(1 = asleep, 5 = fully alert).

C. Mobility - disabilities
(1 = low mobility, 5 = high mobility).

D. Social Affiliation - alone or in a group (e.g. family)
(1 = group, 5 = alone).

E. Role - ratio of public to staff
(1 = public, 5 = staff).

F. Position - lying, sitting, standing or moving
(1 = lying, 5 = moving).

G. Commitment - to what degree are people committed to finishing a task
(1 = high, 5 = low).

H. Focal point - are all people focusing there attention on one point
(1 = none, 5 = focused).

I. Familiarity - how familiar are people to the building
(1 = unfamiliar, 5 = familiar).

The points are attributed on a scale of 1 to 5. There are no independent weightings so each item is weighted the same. Efficiency ratings for the purpose groups under consideration in this study were assessed as shown in Table 6.2 below for comparison to the Table 6.1:

Purpose Group	B	C	D	E	F	G	H	I	Average
SA	1	3	1	1	1	4	1	1	1.6
SR	1	3	5	3	1	4	1	5	2.9
CS/CL	4	3	3	1	2	4	4	3	3.0
CM	4	3	3	1	5	2	4	3	3.1
WL/WM	5	3	5	5	3	3	3	5	4.0

Table 6.2 – Premovement Efficiency Ratings Based on Sime [49]

From Table 6.2 the Sime method give the same ranking order as the ranking scheme shown in Table 6.1, however the point differential is not as wide with the score ranging from 1.6 to 4.0. (Table 6.2), as compared to 1.1 to 5.0 (Table 6.1). Either ranking could be used in this model however as some of Sime's attributes are not applicable to the sleeping purpose groups, e.g. Role (E), the attributes scores will be derived based on Table 6.1.

Given the above the attribute scores are shown in Table 6.3 below:

BU1 – Purpose Group	
Purpose Group	**A_s**
SA	1
SR	2
CS/CL/CM	3
WL/WM	5

Table 6.3 – Purpose Group Attribute Scores

BU2) Building Escape Height

The points will be assigned in linear manner as shown in Table 6.4 below:

BU2 – Building Escape Height	
Escape Height	**A_s**
Over 58m	0
46m < He ≤ 58m	1
34m < He ≤ 46m	2
25m < He ≤ 34m	3
10m < He ≤ 25m	4
4m < He ≤ 10m	5

Table 6.4 – Building Escape Height Attribute Scores

BU3) Occupant Numbers

The points will be assigned in linear manner as shown in Table 6.5 below:

BU3 – Occupant Numbers	
Occupant Numbers	$\mathbf{A_s}$
Over 1000	1
501 < Occ. No. ≤ 1000	2
101 < Occ. No. ≤ 500	3
51 < Occ. No. ≤ 100	4
Occ. No. ≤ 50	5

Table 6.5 – Occupant Number Attribute Scores

BU4) Fire Hazard Category

The Fire Hazard Category (FHC) is a numerical grading from 1 to 4 as noted in Section 4.2.1. C/AS1 defines each category by a Fire Load Energy Density (FLED) which varies linearly between 0 and 1500 MJ/m^2 for FHC 1 to 3 respectively and FHC 4 for FLED over 1500MJ/m^2. Therefore the points will be assigned in a linear manner as shown in Table 6.6 below:

BU4 – Fire Hazard Category	
FHC	$\mathbf{A_s}$
4	0
3	1
2	3
1	5

Table 6.6- Fire Hazard Category Attribute Scores

6.3.2 *Fire Safety Features Parameters*

A) Fire Barriers

A1 – Firecell Rating

The Firecell (F) rating is the minimum time that is assigned to fire barriers and structural elements in order to prevent internal spread of fire between firecells/compartments. Typically escape routes (Stairs) and each floor of most multistorey buildings are designed as separate firecells. Beams, columns floors, walls, and partitions are given a Fire Resistance Rating (FRR) based on the worst combination of the F rating and the structural endurance (S) rating discussed below in A2. The F rating is intended to provide sufficient time for the occupants to evacuate and the Fire Service to undertake rescue operations before the fire spreads beyond the room of origin.

The attribute scores for the F ratings are assigned as shown in Table 6.7 below:

A1 – Firecell Rating	
F Rating (Minutes)	**A_s**
0	0
15	1
30	2
45	3
60	4
>60	5

Table 6.7– Firecell Rating Attribute Scores

Note that the FRR's are based on fire tests to a standard curve, AS 1530:1997, Part 4 [(12)], is typically used in New Zealand. Also note that the F rating is not related to the time a real fire would take to spread through a building but is the actual time a particular product or wall assembly meets the requirements of the standard fire test. Notwithstanding this, the Firecell rating can be ranked to provide an indicative measure of safety to account for fire spread.

A2 – Structural Fire Endurance Rating

The Structural Fire Endurance (S) rating is the minimum time that is assigned to structural elements in order to prevent spread of fire or collapse damage to other property. Beams, columns, floors, and load bearing walls are given a fire resistance rating (FRR) based on the worst combination of the F rating and the structural S rating.

The S rating is intended to provide sufficient time for the fire to burn out or be brought under control without it spreading to adjoining property. It is a function of the fire hazard category, floor area and area of horizontal and vertical ventilation openings. From *Table 5.1 C/AS1* the structural fire endurance rating is in the range of 30-240 minutes which equates to 1 to 4 times the F rating range (30-60minutes). Therefore a structural fire endurance rating of twice the F rating shall be used in this project.

The attribute scores for the S ratings are assigned as shown in Table 6.8 below:

A2 – Structural Fire Endurance Rating	
S Rating (Minutes)	**A_s**
0	0
30	1
60	2
90	3
120	4
>120	5

Table 6.8– Structural Fire Endurance Rating Attribute Scores

B) Fire Alarm

The type of fire alarm has a significant impact on the amount of time it takes to alert the occupants to a fire. There are several types of alarm that are specified in C/AS1 depending on the building's requirements. These are:

No alarm – Permitted for CS, CM, WL and WM purpose groups where the occupant numbers using a escape route are less than 50 and the buildings is maximum two storeys high.

Manual alarm (Type 2) – Minimum requirement for CS, CM, WL and WM purpose groups where the occupant numbers in a firecell are less than 100 and the buildings is maximum two storeys high.

Automatic alarm / heat detectors (Type 3) – Minimum requirement for CS, CM, WL and WM purpose groups where the occupant numbers in a firecell are less than 500 and the buildings is maximum three storeys or 10m high.

Automatic alarm / heat detectors & local smoke detectors (Type 5) – Minimum requirement for SA and SR purpose groups to minimise false alarms from within an individual residential or apartment unit. The heat detectors provide full coverage with the alarm connected to all apartments while the smoke detectors provide early detection and warning in the room of fire origin.

Automatic alarm / smoke detectors (Type 4) – Required for all occupancy types for tall/large buildings and large occupant numbers. Also generally required in all residential and hotel type buildings.

The simplest way to rank these is in the order of warning speed and common sense suggests that this is as follows:

1. No alarm
2. Type 2 - Manual alarm
3. Type 3 - Automatic alarm with heat detectors

4. Type 5 - Automatic alarm with heat detectors and local smoke detectors.
5. Type 4 - Automatic alarm with smoke detectors

No alarm – This is the worst case situation. The alarm is only raised if a person within or external to the building senses the fire cues, personally notifies the occupants and calls the Fire Service on a telephone. A fire may well have taken hold before it is noticed depending on the alertness of the occupants and as such occupants may get trapped. For the purposes of this project we will assume that the alarm time is not less than 20 minutes. Therefore it is reasonable that no points are scored for having no alarm.

Manual alarm (Type 2) – This is only marginally better than having no alarm. The alarm is still only raised if a person within or external to the building senses the fire cues and can reach and activate a manual call point. The person not having to personally notify the occupants saves time, but the Fire Service may still need to be called on a telephone. A fire may well have taken hold before it is noticed depending on the alertness of the occupants and as such occupants may still get trapped. For the purposes of this project we will assume that the alarm time is not less than 10 minutes.

Automatic alarm / heat detectors (Type 3) – This provides a considerable reduction in alarm time where a fire is not immediately noticed by an occupant and the alarm raised manually. Heat detectors generally detect a developing fire and the alarm is activated within 2 to 5 minutes of the start of a fire [(53)].

Automatic alarm / heat detectors & local smoke detectors (Type 5) – This provides the most rapid warning in the room of origin, typically within 1 to 3 minutes and approximately 2-5minutes in rooms outside the room of fire origin [(53)].

Automatic alarm / smoke detectors (Type 4) – This is the most rapid detection and warning system. Again the alarm is likely to sound with 1 to 3 minutes of start of the fire. We shall assume a detection time of 60 seconds for the purpose of this analysis. This alarm system shall score the maximum 5 points.

The relative safety between these alarm types can be measured in several ways. Firstly we can look strictly at the time of activation. Alternatively we can look at the total evacuation time from the room of fire origin/firecell, as these are the occupants most at risk in the early stages of a fire. The third method is to look at the impact on the time to evacuate an entire building. To illustrate this example let us assume that it takes 3 minutes to evacuate the fire floor and 15 minutes to evacuate the building (including pre-movement time). Then the escape time based on the alarm types are given in Table 6.9 as follows:

Alarm Type	**Likely Alarm Activation Time**		**Total Fire Floor Evacuation Time**		**Total Building Evacuation Time**	
	Time (Minutes)	Min. Time Time	Time (Minutes)	Min. Time Time	Time (Minutes)	Min. Time Time
No alarm	20	0.05	23	0.17	35	0.46
Type 2 Alarm - Manual Alarm	10	0.10	13	0.31	25	0.64
Type 3 Alarm - Auto Alarm with Heat Detectors	3.5	0.28	6.5	0.62	18.5	0.87
Type 5 Alarm - Auto Alarm with Heat and Local Smoke Detectors	2	0.50	5	0.80	17	0.94
Type 4 Alarm - Auto Alarm with Smoke Detectors	1	1.00	4	1.00	16	1.00
Min. Time	**1**		**4**		**16**	

Note that the above alarm types 2-5 refer to the alarm types as denoted in [Table 4.1 C/AS1]

Table 6.9– Exemplar Fire Alarm Activation and Evacuation Times

From the above table it is quite clear that the impact on life safety of the fire alarm type is very much dependant on the duration of the evacuation time. The shorter the evacuation duration the more significant the alarm type has on life safety. If for example we consider the total time to evacuate a fire floor ("escape time") from Table 6.8 comparing a Type 3 and a Type 4 alarm. The "escape time" reduces from 6.5 minutes to 4 minutes changing from a Type 3 to a Type 4 alarm. This equates to a 38% reduction in "escape time", however if the time to clear the floor was 1 minute + alarm time then the "escape time" would reduce from 4.5 minutes to 2 minutes which equates to a 62% reduction in escape time. Furthermore if the time to clear the floor was 10 minutes + alarm time then the "escape time" would reduce from 13.5 minutes to 11 minutes which equates to an 18% reduction in escape time. The same analysis could be carried based on the total evacuation time of the building and show a similar result, in that the impact of the alarm type is more significant as the total evacuation time is reduced.

Based on the above analysis and assuming that firecell fire barriers perform as intended by C/AS1 then by inspection the critical evacuation time is the time required to evacuate a floor. The number of exitways, dead end open path lengths and total open path lengths are used to regulate the time it takes to evacuate a fire cell.

According to C/AS1 the fire alarm type has the following impact on the open path lengths:

Manual fire alarm	-	No increase in open path lengths
Auto alarm with heat detectors	-	20% increase in open path lengths
Auto alarm with smoke detectors	-	100% increase in open path lengths

Using the above increases in open path lengths the ratio between smoke alarm and the other types of alarm are 0.5 and 0.6 for a manual alarm and automatic alarm with heat detectors respectively. It is reasonable to assume that the ratio for an automatic alarm with heat detectors and local smoke detectors lies between 0.6 and 1.0, but at the lower end of the scale. These figures are similar in magnitude to those given in the above table for evacuation of a floor. Given this the attribute scores for the alarm type parameter have been assigned as shown in Table 6.10 below:

B – Fire Alarm Type		
Alarm Type	**A_s**	**$\frac{A_s}{5}$**
No Alarm	0	0.00
Type 2 Alarm - Manual Alarm	2	0.40
Type 3 Alarm - Automatic Alarm with Heat Detectors	3	0.60
Type 5 Alarm - Automatic Alarm with Heat and Local Smoke Detectors	4	0.80
Type 4 Alarm - Automatic Alarm with Smoke Detectors	5	1.00

Note that the above alarm types 2-5 refer to the alarm types as denoted in [Table 4.1 C/AS1]

Table 6.10– Fire Alarm Type Attribute Scores

C) Smoke Control

There are three primary methods of smoke control in a building, which will be used to assess this component of the risk model. These are:

- Smoke Control in Heating, Ventilation and Air Conditioning System.
- Smoke Extraction.
- Stairwell Pressurisation.

C1 – Smoke Control in Heating, Ventilation and Air Conditioning System

Smoke control in the HVAC system is required to prevent smoke being transported to rooms outside the room of fire origin by the building ventilation system. Smoke control is achieved by shutting down the system, although it is possible to run such systems in a smoke extraction mode. The system can be shutdown on a general fire alarm or activated by smoke detectors located within the HVAC ducting network.

From a risk point of view there are three options; no smoke control, manual activation or automatic. These have been assigned points based on the likely activation time using the alarm detection criteria in B above as guidance and are shown in Table 6.11 below:

C1 – HVAC Control	
Smoke Control	**A_s**
None	0
Manual Shutdown	2
Automatic Shutdown	5

Table 6.11– Smoke Control in HVAC Attribute Scores

C2 – Smoke Extraction

Smoke extraction is generally required in atria, large spaces or spaces with large intermediate (mezzanine) floors. Smoke extraction is generally part of a smoke control system which may include smoke reservoirs, smoke baffle/curtains, HVAC control, and extraction by natural ventilation or mechanical fans. All these systems can be operated manual or automatically. In the case of natural ventilation this may simply be non fire rated roof elements that melt or burn away early in a fire event to provide a ventilation opening.

There are four possible systems that could be installed and they are ranked based on the speed at which they activate and their perceived efficiency at extracting smoke (i.e. mechanical fans are taken to be more efficient/reliable than natural ventilation). Note that this last measure could be questioned, as all systems would be designed to achieve the required performance criteria.

The four smoke extraction systems to be included in this parameter are:

> *Manual Natural Ventilation* – This is taken to be vents that require breaking by the occupants or only activate on operation of a manual fire alarm (manual call point).
>
> *Manual Mechanical Extraction* – This is taken to be mechanical ventilation fans that require specific operation by the occupants prior to leaving the building or only activate on operation of a manual fire alarm (manual call point).
>
> *Automatic Natural Ventilation* – This is taken to be vents that are controlled by either a fusible link or burn/melt on exposure to fire products or open on activation of an automatic fire alarm.
>
> *Automatic Mechanical Extraction* – This is taken to be mechanical ventilation fans that operate on activation of an automatic fire alarm.

Note a manual system is ranked based on operation by a manual alarm and the automatic system by operation of an automatic alarm. The mechanical extraction system is ranked ahead of a natural ventilation system. Reliability of the different systems is not taken into account as both systems are assumed to function as intended.

The following points have been assigned for smoke extraction as shown in Table 6.12 below:

C2 – Smoke Extraction	
Method	**A_s**
None	0
Manual Natural Ventilation	1
Manual Mechanical Extraction	2
Automatic Natural Ventilation	4
Automatic Mechanical Extraction	5

Table 6.12– Smoke Extraction Attribute Scores

C3 – Stairwell Pressurisation

Stairwell pressurisation is normally installed in tall buildings where the exit stairs must be kept clear of smoke for a sufficient period to allow the building to be evacuated. The systems are typically connected to an automatic fire alarm system.

C/AS1 requires pressurisation of “safe paths” in some buildings. Stairwells are usually constructed as safe paths, and in some cases there may be a corridor or lobby connected to the stairs, which is also designated as a safe path. In this case the pressurisation would be required to extend to the corridor or lobby.

The following points have been assigned for stairwell pressurisation as shown in Table 6.13 below:

C3 – Stairwell Pressurisation	
Protection	**A_s**
No	0
Yes	5

Table 6.13– Stairwell Pressurisation Attribute Scores

D) Building Fire Control

There are three aspects that will be assessed under building fire control in this component of the risk model. These are:

- Sprinkler system.
- Water supply.
- Occupant fire fighting facilities.

D1 – Sprinkler System

Sprinklers have proved themselves over time to be the most reliable and efficient method for controlling a fire and preventing fire fatalities in buildings in New Zealand, Marrayat(27). A wet pipe sprinkler system is usually installed in New Zealand(10), however in special circumstances, such as where an accidental discharge could cause severe damage to an owner's property then a dry pipe system may be used. From a risk point of view the only difference between the systems is the time delay while the dry pipe system charges with water after the fire has been detected.

Points have been assigned for sprinkler systems as shown in Table 6.14 below:

D1 – Sprinkler System	
Type	**A_s**
None	0
Dry Pipe Sprinkler System	4
Wet Pipe Sprinkler System	5

Table 6.14 – Sprinkler System Attribute Scores

D2 – Water Supply System

The New Zealand sprinkler standard, NZS 4541:2003(47) recognises the importance of water supply in ensuring the reliability and efficiency of sprinkler systems. The standard specifies three classes of water supply as follows:

Class A - Dual superior supply, comprising two independent supplies with only one being a town main. The second is usually an on site tank.

Class B - Dual standard supply

Class B1 - Comprising connection to two independent parts of a town main.

Class B2 - Comprising a dual private site fire main with one reticulation reserved solely for fire purposes.

Class C - Single supply, typically comprises a town main or private supply.

However, C/AS1 Appendix D currently deletes the provisions of NZS 4541:2003 regarding water supply. This means that ordinarily a building only requires a Class C water supply. The only exception to this is that the Fire Service may require a higher Class of water supply as part of their evacuation approval procedure under the provisions of The Fire Safety and Evacuation Regulations 1992[11].

Grading of the water supply has been determined on the basis of reliability. Feeney[24] estimates the following reliability of a towns main to be between 6.0×10^{-5} and 8.0×10^{-5} and the probability of no tank water supply being 5.7×10^{-5}. From this we can determine the probability of failure for each class of water supply as follows:

Class A	$P_f = 8.0 \times 10^{-5} \times 5.7 \times 10^{-5}$	$= 4.56 \times 10^{-9}$
Class B	$P_f = 8.0 \times 10^{-5} \times 8.0 \times 10^{-5}$	$= 6.40 \times 10^{-9}$
Class C	$P_f =$	$= 8.0 \times 10^{-5}$

Based on the above probabilities Class A is only marginally better than Class B, but Class C is significantly less reliable. From this the following attribute scores have been assigned as shown in Table 6:15 below:

D2 – Water Supply	
Type	$\mathbf{A_s}$
Class C	2
Class B	4
Class A	5

Table 6.15– Water Supply Attribute Scores

D3 – Occupant Fire Fighting Facilities

Fire fighting facilities for use by the occupants are generally not mandatory for most buildings under the Building Code [3]. The only exception is SA and SR purpose groups where fire hose reels are required in some building height categories. The Fire Service may require additional occupant fire fighting facilities under the provisions of The Fire Safety and Evacuation Regulations 1992 [11].

The types of occupant fighting facilities considered in this project are fire blankets, fire extinguishers and fire hose reels.

Fire blankets are usually kept in a kitchen area and are used to smother small fires in cooking implements.

Fire extinguishers come in a number of classes and sizes depending on the hazard. People should be trained to use these but most people with a basis level of knowledge can operate them. These will generally extinguish a larger fire than a fire blanket but the size of the fire must still be relatively small.

Fire hose reels comprise a 25mm (1 inch) diameter hose connected to the building's general water supply. These can be used to extinguish a fire similar in size to that by an extinguisher but unlike an extinguisher have an unlimited supply of water.

Fire blankets have very limited uses and can be dangerous to use as they require the person to get very close to the fire. These shall be rated very low to reflect this risk.

Given the above the following points have been assigned for occupant fire fighting facilities as shown in Table 6.16 below:

D3 – Occupant Fire Fighting	
Type	**A_s**
None	0
Fire Blanket	1
Fire Extinguisher	3
Fire Hose Reel	4
Fire Hose Reel and Extinguisher	5

Table 6.16 – Occupant Fire Fighting Attribute Scores

E) Emergency Power Supply

There are a number of options for emergency power supply including, battery banks and diesel generators. Emergency power supplies are designed in accordance with NZS 6104 "Specification for emergency power supplies in buildings" [48]. Most emergency power supplies installed in buildings in NZ are in the form of a diesel generator. Battery banks are only usually used to provide an uninterrupted power supply to important equipment, such as computer systems, whilst the diesel generator starts up. This equipment may or may not be required for the fire systems emergency power supply.

Emergency lights and alarm panels have a built in battery backup where required to ensure continuous operation of the alarm system. This is not a requirement under the emergency power supply requirements of C/AS1 but is under the respective alarms and emergency lighting specifications.

On rare occasions for important buildings, for example hospitals and some government buildings, a back up generator may be provided. While this vastly improves the safety and reliability of the power supply, these types of buildings are not included in this study and as such this will not be taken into account.

The points have been assigned for emergency power supply facilities on a compliance basis as shown in Table 6.17 below:

E – Emergency Power Supply	
Type	**A_s**
None	0
Emergency Power Supply	5

Table 6.17 – Emergency Power Supply Attribute Scores

F) Communication Systems

The type of communication system in a building has a large impact on the pre-movement time of occupants and hence impacts on the time taken to evacuate the fire floor and/or building.

Sime [49] estimates pre-movement times as 6, 4, and 2 minutes for alarm only, non-directive public address and directive public address respectively. Furthermore Sime gives the results of trial evacuations carried out in an underground train station in 1991 which shows that the presence of warden and/or a public address system vastly improves the evacuation time. These are reproduced in Table 6.18 below for reference:

Warning System	Time to Clear the Station
Alarm only	15 minutes
Alarm + Two Staff	8 minutes
Alarm + Repeated Non-directive PA Announcement	11 minutes
Alarm + Live PA Announcement + Two Staff	6-7 minutes

Table 6.18 – Evacuation Trials in under Ground Station, Sime [49]

From the above table the presence of fire wardens and a directive public address system greatly influenced the escape time. Based on this the attribute points for communications systems have been assigned as shown in Table 6.19 below:

F – Communication System	
Type	**A_s**
None	0
Evacuation Plan + Fire Wardens	1
Voice Communication System	3
Fire Systems Centre	4
Voice Communication System + Fire Systems Centre	5

Table 6.19– Communication System Attribute Scores

In this project it is assumed the all buildings have at least an evacuation plan and fire wardens. A voice communication system complying with AS 2220:1989, "Emergency warning and intercommunication systems in buildings" (50) is set at 3 points.

G) Fire Service

The Fire Service provides the primary source of extinguishment for most reported fires. They are also required to provide rescue services, if the building evacuation is not complete prior to their arrival. The water supply is essential to the fire service operation and is covered under sprinkler system above. There are a number of other requirements under C/AS1 that impact on the efficiency of the Fire Service and hence the safety of a building. These are:

- Alerting
- Lift Control
- Fire Fighting Access.

G1 – Alerting

The term "Alerting" shall be used to describe the method by which the Fire Service is advised of the fire. There are a number of options, which are used as follows:

- Telephone
- Direct connection to a security firm.
- Direct connection to the Fire Service.

The safety issue here is the time required for the Fire Service to respond and commence rescue or fire fighting operations. The quicker the Fire Service is alerted, the sooner they arrive and commence activities.

The first method relies on a person within the building or a passerby noticing the fire, finding a phone (a lesser problem with the advent of the mobile phone). This could take anywhere upwards from a few minutes depending on the time of day, location of the person relative to the fire and state of alertness of the person (i.e. if they are asleep a delay is likely to occur). Therefore the primary detection method governs; in this case it is a person sensing the fire cues and their reaction to them. For the purposes of this project, based on B above, this is taken as 10 minutes.
The second method is dependent on two operations. The first is detection of the fire (approximately 1-1.5 minutes for smoke detection and 3-4 minutes for heat detection, B above) and the second is the response time of the security firm. The latter will vary depending on whether or not a security guard is dispatched to confirm whether or not there is a fire. This generally only happens for unoccupied buildings and as such life safety is not an issue. Therefore the likely alerting time is likely to be in the order of 2-5 minutes.

The third method is by far the best option. The Fire Service is alerted immediately and can respond immediately. Therefore the alerting time is likely to be of the order of 1-3 minutes.

Given the above the attribute points have been assigned as shown in Table 6.20 for alerting the Fire Service:

G1 – Alerting		
Type	**Alerting Time**	**A_s**
No means for alerting the Fire Service	Not alerted	0
Telephone	10-20 minutes	1
Direct Connection via Security Firm	2-5 minutes	4
Direct Connection to Fire Service	1-3 minutes	5

Table 6.20– Fire Service Alerting Attribute Scores

G2 –Lift control

During a fire event occupants are discouraged from using a lift and in fact, on alarm generally the lifts automatically return to the ground floor. This is for several reasons, the main being that it is unsafe to use a lift in case the doors inadvertently open on the fire floor. Lift shafts can also act as chimneys drawing smoke up through a building, which could incapacitate or kill occupants of a lift. Lift control is given to the Fire Service so that if the lifts are deemed safe they can be used to transport personnel and equipment up to fire attack base, generally 1 or 2 floors below fire floor in a multistorey building or to effect rescue operations.

The attribute scores have been assigned as shown in Table 6.21 below:

G2 – Lift Control	
Provided	**A_s**
No	0
Yes	5

Table 6.21 – Lift Control Attribute Scores

G3 – Fire Fighting Access

Fire fighter access is an important part of building safety. In this case the term "access" relates to the ability of the Fire Service to attack the fire with hose lines in order to bring it under control. The requirements under C/AS1 are quite simple, either the fire hose run length does not exceed 75 m or the building must have a fire hydrant system. With regards to safety both should give a similar level of safety. The fire hydrant system is judged to be better than 75 m fire hose runs as hoses can be susceptible to damage.

Therefore the attribute scores have been assigned as shown in Table 6.22 below:

G3 – Fire Fighting Access	
Type	$\mathbf{A_s}$
No hydrant System or Hose Run >75m	0
Fire Hose Run<75m	4
Fire Hydrant System	5

Table 6.22 – Fire Fighting Access Attribute Scores

H) Means of Escape

The means of escape provisions along with the fire safety precautions define the majority of the specific life safety requirements of C/AS1. From the means of escape provisions, there are a number of requirements that can be ranked qualitatively or quantitatively to give a measure of the life safety. These have been determined as follows:

- Number of Escape Routes
- Width of Escape Routes
- Emergency Lighting
- Refuge Areas
- Dead End Open Paths
- Total Open Paths

- Protected Paths Lengths
- Surface Finishes Exitways
- Surface Finishes Occupied Spaces
- Signage

H1 – Number of Escape Routes

The number of escape routes required depends on the number of person to be evacuated, the dead end and total open path lengths. Most buildings will have one or two escape routes but where there are more than 501 persons in a firecell a minimum of 3 is required and over 1001 persons 4 or more are required depending on the number.

Therefore the attribute scores have been assigned as shown in Table 6.23 below:

H1 – Number of Escape Routes	
Required Number	**A_s**
1	1
2	2
3	3
≥4	4

Table 6.23 – Number of Escape Routes Attribute Scores

H2 – Width of Escape Routes

The width of escape routes affects the queuing time and hence the time it takes to evacuate a floor. The total required width of escape routes in C/AS1 depends on the number of persons to be evacuated but is 1000 mm minimum or 9 mm per person for vertical escape routes. Therefore the minimum equates to approximately 100 persons.

The required ratio (9 mm/person) is the important safety aspect of the code. The ratio sets a consistent level of safety, by adjusting the width of escape proportional to the number of persons. Therefore a firecell would require 4500 mm and 9000 mm of escape route width for 500 and 1000 occupants respectively.

Given the above, the points for escape width have been assigned as shown in Table 6.24 below:

H2 – Width of Escape Routes	
Width	**As**
Width <1000 mm	0
1000 mm ≤ Width <2000 mm	1
2000 mm ≤ Width <4500 mm	2
4500 mm ≤ Width <9000 mm	3
9000 mm≤ Width	5

Table 6.24 – Width of Escape Routes Attribute Scores

H3 – Emergency Lighting

Emergency lighting is required for two reasons, firstly to provide adequate light in an escape path in the event of a power failure at night during a fire event and secondly to enhance the visibility in an escape path that may become smoke logged. In some cases the emergency lighting is combined with signage.

C/AS1 does not require emergency lights in all cases. In some cases the lights are only required in exitways, which may be at the final exit for single storey buildings. For large buildings or occupant numbers emergency lights are required in open paths throughout the firecell.

The attribute scores for emergency lighting have been assigned based on the extent of lighting required as follows:

H3 – Emergency Lighting	
Extent	**As**
None	0
At Final Exit	2
Exitways	4
Open Paths and Exitways	5

Table 6.25 – Width of Escape Routes Attribute Scores

H4 – Refuge Areas

C/AS1 only requires refuge areas in tall buildings (over 58m). They are included as part of the escape stair (safe path), allow for only 4-6 persons and only allow for fast persons to pass slow moving persons. Given this they will not contribute significantly to the safety of the occupants of a building.

The attribute scores have been assigned based on the extent of refuge areas with the code requirement set at 3 points as shown below in Table 6.26:

H4 – Refuge Areas	
Extent	**As**
None	0
In Staircase (<6 persons capacity)	3
Protected Lobby to Staircase (>6 persons capacity)	5

Table 6.26– Refuge Areas Attribute Scores

H5 – Dead End Open Path Lengths

The Dead End Open Path (DEOP) is the length of escape route where an occupant has only one direction of escape. It is important to limit the length of DEOP escape routes to minimise the risk that the occupants will get trapped by the fire or smoke. In a building without an automatic alarm the occupants need to be able to detect the fire cues before the fire has grown sufficiently large that it cuts off the only means of escape. Automatic fire alarms with heat and smoke detectors provide early warning and as such C/AS1 permits the escape route lengths to be increased. The permitted DEOP range for the Purpose Groups considered in this study are shown in Table 6.27 below:

Type of path	Purpose group			
	CS,CL,CM	***WL,WM***	***SA***	***SR***
Dead End Open Path (DEOP)	18.0m	24.0m	18.0m	24.0m
DEOP with Heat Detection (+20%)	21.6m	28.8m	19.8m	26.4m
DEOP with Smoke Detection or Sprinklers (+100%)	36.0m	48.0m	27.0m	36.0m
DEOP with Smoke Detection and Sprinkler (+200%)	54.0m	72.0m	-	-

Table 6.27 – Permitted DEOP Lengths

Note that the safety of a building improves considerably with the addition of a fire alarm and/or sprinkler system. However a reduction in the improved safety level due to the alarm /sprinkler occurs if the escape route lengths are increased as a result due to an increase in the time it takes to evacuate the building. Therefore this reduction in safety is taken into account in the model by allowing for the increased escape path lengths.

The attribute scores have been assigned based on the range of DEOP for the purpose groups under consideration as shown in Table 6.28 below:

H5 – Dead End Open Path (DEOP) Length	
Range of DEOP Length	**As**
>60 m	0
45< DEOP ≤ 60 m	1
30< DEOP ≤ 45 m	2
25< DEOP ≤ 30 m	3
20< DEOP ≤ 25 m	4
≤20 m	5

Table 6.28 – Dead End Open Path Attribute Scores

H7 – Protected Path Lengths

A Protected Path (PP) is part of an escape route, which is protected from smoke migration with smoke barriers. These areas may be formed with walls; non-opening windows or smoke stop doors. C/AS1 does not permit increases in the allowable PP lengths for the installation of fire alarms and sprinklers. The permitted lengths are shown in Table 6.31 below.

Type of path	**Purpose group**			
	CS,CL,CM	***WL,WM***	***SA***	***SR***
Protected Path (PP)	45.0 m	60.0 m	45.0 m	60.0 m

Table 6.31– Permitted Protected Path Lengths

The attribute scores for protected paths shall be assigned as shown in Table 6.32 below:

H7 – Protected Path (PP) Length	
Range of PP Length	**As**
>90 m	0
$75 < PP \leq 90$ m	1
$60 < PP \leq 75$ m	2
$45 < PP \leq 60$ m	3
$30 < PP \leq 45$ m	4
$PP \leq 30$ m	5

Table 6.32 – Protected Path Attribute Scores

H8 – Exitways Surface Finishes

C/AS1 limits the type of surface finishes in exitways to prevent spread of fire and smoke development. Products are required to be tested to AS 1530: "*Methods for Fire Tests on*

H6 – Total Open Path Lengths

The Total Open Path (TOP) is the total length of escape route through an open path, including the DEOP. C/AS1 also permits TOP escape routes to be increased if automatic fire alarms with heat and smoke detectors are present. The permitted TOP range for the purpose groups are shown in Table 6.29 below:

Type of Path and Alarm/Protection	**Purpose group**			
	CS,CL,CM	***WL,WM***	***SA***	***SR***
Total Open Path (TOP)	45.0m	60.0m	45.0m	60.0m
TOP with Heat Detection (+20%)	54.0m	72.0m	49.5m	66.0m
TOP with Smoke Detection or Sprinklers (+100%)	90.0m	120.0m	67.5m	90.0m
TOP with Smoke Detection and Sprinkler (+200%)	135.0m	180.0m	-	-

Table 6.29 – Permitted Total Open Path Lengths

The attribute scores have been assigned based on the range of TOP for the purpose groups under consideration as shown in Table 6.30 below:

H6 – Total Open Path (TOP) Length	
Range of TOP Length	**As**
>140 m	0
110< TOP ≤ 140 m	1
80< TOP ≤ 110 m	2
60< TOP ≤ 80 m	3
50< TOP ≤ 60 m	4
≤50 m	5

Table 6.30 – Total Open Path Length Attribute Scores

Building Materials, Components and Structures" [12]. C/AS1 requirements for walls and ceilings are the same for all purpose groups in exitways.

The flammability index requirements for suspended flexible fabric do not apply to WL, WM and WH purpose groups in terms of the scope of this project. The limitations for surface finishes in exitways based on *Table 6.3 - C/AS1* are as follows:

Spread of Flame Index (SFI)	= 0	
Smoke Development Index (SDI)	< 3	
Flammability Index (FI)	< 12	*(Not in Purpose Group WL, WM and WH)*

Clause 6.20.7 C/AS1 allows an increase of SFI to 7 and SDI to 5 for surface finishes above 1.2 m high in exitways in school buildings (purpose groups CS and CL). This will be ignored in this study due to the narrow limitations placed on this dispensation.

The attribute scores have been assigned based on compliance with the above with the minimum code requirement set at 3 points as shown in Table 6.33 below:

H8 – Exitways Surface Finishes	
Extent	**As**
SFI > 0, SDI > 3, FI > 12	0
SFI = 0, SDI ≤ 3, FI > 12	3
SFI = 0, SDI ≤ 3, FI ≤ 12	4
No applied surface finishes, non-combustible surfaces	5

Table 6.33 – Exitway Surface Finishes Attribute Scores

H9 – Occupied Spaces Surface Finishes

These are assessed in the same manner as for exitways *(H8 above)*. The code requirements are shown in Table 6.34 below.

Purpose Group	Surface Finishes Requirements *(Table 6.2 C/AS1)*		
	SFI	**SDI**	**FI**
CS, CL, CM	2	5	12
WL, WM	5 (or 9)	10 (or 8)	No Requirement
SA	2	5	No Requirement
SR	No Requirement	No Requirement	No Requirement

Table 6.34 – Occupied Spaces Surface Finish Requirements

Clause 6.20.7 C/AS1 allows a SFI of 7 and SDI of 5 for surface finishes above a height 1.2 m and SFI of 8 and SDI of 6 below a height of 1.2 m in Purpose groups CS and CL where there is less than 250 persons and at least two means of escape. This shall be taken as a parameter score of 3 in Table 6.35 below.

Clause 6.20.5 C/AS1 limits the requirements to the ceiling where fire cells are sprinklered. Therefore, there is no restriction on wall linings under this requirement and as such there is a higher risk that fire could spread. The reduced risk due to sprinklers is accounted for elsewhere in this model. Therefore the increased risk due to relaxing the requirements on the surface finishes is included in this parameter.

The attribute scores for surface finishes in the occupied spaces have been assigned based the above as shown in Table 6.35 below:

H8 – Occupied Spaces Surface Finishes		
Surface	**Requirement**	**As**
Walls and Ceilings	None	0
Ceilings	SFI ≤ 5, SDI ≤ 10	1
Ceilings	SFI ≤ 2, SDI ≤ 5	2
Walls and Ceilings (or Ceilings Only)	SFI ≤ 5, SDI ≤ 10 (or SFI ≤ 2, SDI ≤ 5, FI ≤ 12)	3
Walls and Ceilings	SFI ≤ 2, SDI ≤ 5	4
Walls and Ceilings	SFI ≤ 2, SDI ≤ 5, FI ≤ 12	5

Table 6.35 – Occupied Spaces Surface Finishes Attribute Scores

H10 – Signage

C/AS1 requires signage in escape routes, on fire and smoke control doors to comply with F8. Signs are required to direct occupants to the nearest fire exit and remind occupants to keep fire and smoke control doors closed. Only signage required to direct occupants to a fire exit shall be considered in this report.

Signage visibility depends on a number of factors including the scattering and absorption coefficient of the smoke, illumination in the room, whether a sign is light emitting or light reflecting, the wavelength of the light, the individual's visual acuity and whether the individuals eyes are dark or light adapted, Mulholand(51). Jin (52) found that the type of lighting also impacted on whether or not people passed through the smoke and the pace at which they moved. People are more likely to pass through the smoke as the signage visibility improved from reflective to illuminated and from illuminated to flashing illuminated signage.

The attribute scores have been assigned linearly based increasing visibility as shown in Table 6.36 below. It is assumed that illuminated exit signs will be used where emergency lighting is required.

H10 – Signage	
Extent	**As**
None	0
Fire Exit Signs	1
Illuminated Fire Exit signs	3
Flashing Illuminated Fire Exit signs	5

Table 6.36– Signage Attribute Scores

6.4 Weighting System

Methods for determining weightings can be undertaken by:

a) Delphi Group Analysis – this is where a group of experts (typically 10-20) assign weights to the parameters. The experts are given opportunity to revise their assessment until a consensus is reached. This method was not used for this project, however, a Delphi panel approach could be used to verify and/or refine the model.

b) Probabilistic Risk Analysis – this would require undertaking a full PRA on a number of sample building, with careful attention being paid to the sensitivity analysis in order to determine how each parameter affects safety. This method was not used for this project however this approach could also be used to verify and/or refine the model.

c) Analysis of weighting systems for existing fire risk models.

The weighting system for this model has been derived by assessing the weightings in the existing FSES (NFPA 101A)[32] and FRIM- MAB[35] systems, as described in Sections 5.6.6 and 5.6.7 of this report. The weighting systems were adapted to suit the parameters required to assess safety to C/AS1. In cases where items were deemed not relevant to C/AS1, their weightings were excluded and the weights normalised back to 1.0.

Additional items, such as purpose group and fire hazard category etc, were also included which required assessment and assigning of appropriate weights. This was done based on judgment using the calculated weighting assessment as a guide. Sub-weightings, such as the means of escape parameters to C/AS1, were also determined on the same basis where no data was available.

6.4.1 NFPA 101A Fire Safety Evaluation System – Weighting Analysis

Refer to Section 5.7.6 for a detail description of the NFPA 101A - Fire Safety Evaluation System (FSES) [32] method.

The FSES method is a zero-base system where fire safety features score positive points and fire risk and adverse building features score negative points. The weightings used in this project were determined based on the absolute value of the range for each item in the FSES check sheets. The weightings were then determined as a proportion of the sum of the ranges for all parameters. Refer to example below for sample calculation.

The weightings used in this project are derived in part from the FSES method based on the models for "Business Occupancies" (equivalent to purpose groups WL and WM), "Apartment Building" (equivalent to purpose group SR) and "Board and Care Facilities" (equivalent to purpose groups SA and SC).

FSES method assesses several safety parameters including S1 – Fire Control, S2 –Egress, S3 – Refuge (not applicable for Business Occupancies) and S4 – General Fire Safety (Denoted S3 for Business Occupancies). The weightings used in this project are based on an average across safety criteria, S1, S2 and S3/S4 and all three occupancy types. The safety parameter S3 - Refuge was not used as there are currently no requirements in C/AS1 for designing for persons to take refuge in a building and wait out a fire. Note the parameter H4 – Refuge in the FSI model proposed in this study is based on the NZ definition of refuge, which allows an additional area in a vertical escape path for slow persons to rest and be passed by quicker persons.

The FSES method weighting assessment comprised the following basis steps:

i) The weighting for each parameter of the FSES was determined for each occupancy type.
ii) The weightings were then adjusted to account for parameters that were deemed not applicable, as they are not included as a design requirement for C/AS1.
iii) The weightings were then normalised.
iv) The FSES parameters were then assigned to the closest equivalent parameter in the C/AS1 model proposed in this study. This entailed adding some FSES parameter weightings together or proportioning FSES weightings between two or more C/AS1 parameters.

Refer to Appendix C for the calculations of the parameter weightings and the respective Safety categories S1 to S4 for each occupancy type. The final parameter weightings calculated for the NFPA 101A - Fire Safety Evaluation System in accordance with the above steps are shown in Tables 6.37 and 6.38 and explained with an example below:

Step i)

The example presented below is for Business Occupancies, NFPA101A *Worksheet 8.6.1*. Let us consider the "*Construction*" parameter, the scores range between -12 and +2 so the maximum range is 14 points for this item.

The total points available for all parameters depend on which parameter is included in each Fire Safety category and the weighting. In the NFPA 101A method "*Construction*" is weighted 1.0 for S1 – Fire Control, 0.0 for S2 – Egress and 1.0 for S3 – General. From Table C1 – Appendix C, the total points available based on all parameters are 50, 60 and 92 respectively for S1, S2 and S3. Therefore the unadjusted parameter weightings for *Construction* shown in Table 6.37 are calculated as follows:

S_N $$Wi_{parameter} = S_{weight} \times \frac{range}{occupancy \quad total}$$

thus:

S1 $$Wi_{Construction} = 1.0 \times \frac{14}{50} = 0.2800$$

S2 $$Wi_{Construction} = 0.0 \times \frac{14}{60} = 0.0000$$

S3/4(General) $$Wi_{Construction} = 1.0 \times \frac{14}{92} = 0.1522$$

The *Construction* parameter weightings were calculated in a similar manner for Board and Care Large Facilities (NFPA101A *Worksheet 7.5.1*) and Apartment Buildings (NFPA101A *Worksheet 7.7.1*) as follows and are shown in Table 6.38:

	Business	*Board*	*Apartments*	*Average*
($Wi_{Construction}$)	*($Wi_{Construction}$)*	*($Wi_{Construction}$)*	*(W_A)*	
S1	*0.2800*	*0.2243*	*0.2609*	*0.2551*
S2	*0.0000*	*0.0000*	*0.0000*	*0.0000*
S3/4 (General)	*0.1522*	*0.1290*	*0.1446*	*0.1419*

Step ii) & iii)

The mean for each of the above figures was then adjusted and normalised based on excluding the "*Vertical Openings*" (Atriums and intermediate floors) and "*Occupant Emergency Plan*" parameters from the NFPA 101A method as these are not considered in this study. This gave the following revised weightings for the "*Construction*" parameter:

Adjusted weightings are given by:

S_N

$$W_{Ad\ Parameter} = \frac{W_A}{\sum W_A - \sum W_{A\ \ omitted\ \ parameters}}$$

Where: W_A *= Average Weighting for each FSES parameter*

and normalised weightings given by:

S_N

$$W_{N\ Parameter} = \frac{W_{Ad}}{\sum W_{Ad}}$$

Where: W_{Ad} *= Adjusted Weighting for Each FSES Parameter*

combining the above two equations we get:

S_N $W_{N\ Parameter}$

$$= \frac{W_A}{\sum W_A - \sum W_{A\ \ omitted\ \ parameters}} \times \frac{1}{\sum W_{Ad}}$$

Thus, for S1 – Fire Control:

S1 $W_{N\ Construction}$

$$= \frac{0.2551}{1 - 0.1108} \times \frac{1}{1} \qquad = 0.2868$$

where $\sum W_{A\ \ omitted\ \ parameters}$ is the associated value for Vertical Opening from Table 6.38.

Similarly for S2:

$$S2 \qquad W_{N\ Construction} = \frac{0.0000}{0.9722-(0.1754+0.0833)} \times \frac{1}{1.0858} = 0.0000$$

where $\sum W_{A\ \ omitted\ \ parameters}$ are the associated values for Vertical Opening and Occupant Emergency Plan from Table 6.38 and $\sum W_{Ad}$ is the associated sum of W_{Ad} values again given in Table 6.38.

$$S3/4 \qquad W_{N\ Construction} = \frac{0.1419}{0.9819-(0.1235+0.0543)} \times \frac{1}{1.0482} = 0.1653$$

Average $\boldsymbol{W_{NA\ Construction}}$ $\boldsymbol{= 0.1507}$

The above figures are shown in Table 6.38 below.

Step iv)

The final average weightings are then assigned to the various and most appropriate parameters of the C/AS1 model as noted in the final column of Table 6.38. For example the "Construction" parameter weighting is a function of both fire rated construction and building height. In this case 50% (0.1507/2 = 0.0754) is assigned to the Building Height parameter, BU2 and parameter A2 - Structural Endurance Rating. Therefore from Table 6.38 the Structural Endurance Rating parameter A2 is calculated as follows:

$$\begin{aligned} W_{NFPA101\ A2} &= 50\%\ W_{NA\ Construction} + W_{NA\ Segregation\ of\ Hazards} \\ &= 0.5 \times 0.1507 + 0.0843 \\ &= 0.1596 \end{aligned}$$

The above $W_{NFPA101\ \ A2}$ is included in Table 6.45 where it is compared to the results of a similar analysis on the FRIM-MAB[35] model weightings from which the C/AS1 weightings are derived. Refer to Section 6.4.2 for a description of the FRIM-MAB weighting assessment and Section 6.4.3 for the C/AS1 model weightings used in this study.

No.	Safety Parameter	Business Occupancies (WL/WM)			Board & Care Large Facilities (SA/SC)				Apartment Buildings (SR)			
		S1	S2	**S3**	S1	S2	S3	**S4**	S1	S2	S3	**S4**
		Fire Control	Egress	**General**	Fire Control	Egress	Refuge	**General**	Fire Control	Egress	Refuge	**General**
1	Construction	0.2800	0.0000	**0.1522**	0.2243	0.0000	0.2034	**0.1290**	0.2609	0.0000	0.2400	**0.1446**
2	Segregation of Hazards	0.1400	0.1167	**0.0761**	0.0748	0.0290	0.0678	**0.0430**	0.0870	0.0333	0.0800	**0.0482**
3	Vertical Openings	0.1100	0.1833	**0.1196**	0.1028	0.1594	0.1864	**0.1183**	0.1196	0.1833	0.2200	**0.1325**
4	Sprinklers	0.2400	0.1000	**0.1304**	0.1869	0.0725	0.0847	**0.1075**	0.1739	0.0667	0.0800	**0.0964**
5	Fire Alarm	0.0400	0.0667	**0.0435**	0.0280	0.0435	0.0000	**0.0323**	0.0326	0.0500	0.0000	**0.0361**
6	Smoke Detection	0.0400	0.0667	**0.0435**	0.1495	0.2319	0.1356	**0.1720**	0.1087	0.1667	0.0000	**0.1205**
7	Interior Finishes	0.0500	0.0000	**0.0543**	0.0467	0.0725	0.0000	**0.0538**	0.0000	0.0500	0.0000	**0.0361**
8	Smoke Control	0.0000	0.0333	**0.0435**	0.0000	0.0580	0.0678	**0.0430**	0.0000	0.0667	0.0800	**0.0482**
9	Exit Access	0.0000	0.0833	**0.0543**	0.0000	0.1159	0.0000	**0.0860**	0.0000	0.1333	0.0000	**0.0964**
10	Egress Route	0.0000	0.1833	**0.1196**	0.0000	0.1449	0.0847	**0.1075**	0.0000	0.1667	0.1000	**0.1205**
11	Corridor/Room Separation	0.1000	0.0833	**0.1087**	0.1869	0.0725	0.1695	**0.1075**	0.2174	0.0833	0.2000	**0.1205**
12	Occupant Emergency Plan	0.0000	0.0833	**0.0543**	Not Included in FSES for Board & Care Facilities				Not Included in FSES for Apartment Buildings			
	Sum	1.0000	1.0000	**1.0000**	1.0000	1.0000	1.0000	**1.0000**	1.0000	1.0000	1.0000	**1.0000**

Table 6.37 - NFPA 101A - Fire Safety Evaluation System, Parameter Weightings (Wi) by Occupancy

No	Safety Parameter	Fire Control		Egress			General			Average Weighting W_{NA}	Equivalent NZBC C/AS1 Fire Safety Parameter
		Average	Adjusted & Normalised	Average	Adjusted	Normalised	Average	Adjusted	Normalised		
		W_A	W_N	W_A	W_{Ad}	W_N	W_A	W_{Ad}	W_N		
1	Construction	0.2551	0.2868	0.0000	0.0000	0.0000	0.1419	0.1733	0.1653	**0.1507**	50% to Building Height Parameter (BU2) 50% to Struct. Endurance Rating(A2)
2	Segregation of Hazards	0.1006	0.1131	0.0597	0.0813	0.0749	0.0558	0.0681	0.0650	**0.0843**	A2 Structural Endurance Rating
3	Vertical Opening	0.1108		0.1754			0.1235				*Excluded as it pertains to attriums and mezzanine floors which are outside the scope of this project*
4	Sprinklers	0.2003	0.2252	0.0797	0.1086	0.1000	0.1114	0.1361	0.1298	**0.1517**	D1 Sprinkler System & D2 Water Supply
5	Fire Alarm	0.0335	0.0377	0.0534	0.0727	0.0670	0.0373	0.0455	0.0434	**0.0494**	F Communication System & G1 Fire Service Alerting
6	Smoke Detection	0.0994	0.1118	0.1551	0.2113	0.1946	0.1120	0.1368	0.1305	**0.1456**	B Fire Alarm
7	Interior Finishes	0.0322	0.0363	0.0408	0.0556	0.0512	0.0481	0.0587	0.0560	**0.0478**	H8 Surface Finishes Exitways & H9 Occupied Spaces
8	Smoke Control	0.0000	0.0000	0.0527	0.0717	0.0661	0.0449	0.0548	0.0523	**0.0395**	C Smoke Control
9	Exit Access	0.0000	0.0000	0.1109	0.1511	0.1391	0.0789	0.0964	0.0919	**0.0770**	Means of Escape H1, H2
10	Egress Route	0.0000	0.0000	0.1650	0.2248	0.2070	0.1159	0.1415	0.1350	**0.1140**	Means of Escape H5, H6, H7
11	Corridor/Room Separation	0.1681	0.1890	0.0797	0.1086	0.1000	0.1122	0.1371	0.1307	**0.1399**	A1 Firecell Rating
12	Occupant Emergency Plan	0.0000		0.0833			0.0543				*Excluded as it only pertains to Business Occupancies in NFPA 101A and is not a design parameter in C/AS1*
	Sum	1.0000	1.0000	0.9722	1.0858	1.0000	0.9819	1.0482	1.0000	**1.0000**	

Table 6.38 - NFPA 101A - Fire Safety Evaluation System, Average Parameter Weightings (W_{NA})

6.4.2 *FRIM-MAB – Weighting Analysis*

An analysis of the FRIM-MAB model was initially undertaken as an alternative to using the NFPA101A scheme to determine the C/AS1 weightings. However, given the results were similar the final weightings used in the C/AS1 model were based on the average weightings from both the FRIM-MAB and NFPA101A methods.

The FRIM-MAB weightings were taken directly from the Fire Risk Index Method – Multi-storey Apartment Buildings (FRIM–MAB) [35] model. The weightings (Wo) shown in Table 6.39 below are based on those of Karlsson and Hultquist[21] which are shown previously in Table 5.7. The parameter weightings were adjusted (Wr) to account for parameters that have been omitted, as they were judged not relevant to this study.

The following parameters from the FRIM-MAB model were omitted as they were not included in this C/AS1 assessment:

- P7 Windows
- P8 Facades
- P9 Attics
- P10 Adjacent Buildings
- P16 Maintenance Information

The revised weightings were calculated as follows:

$$Wr = Wo \times \frac{\sum Wo}{\sum Wo \ - (Wo_{P7} + Wo_{P8} + Wo_{P9} + Wo_{P10} + Wo_{P16})}$$

Where: Wo = The parameter weighing for each parameter 1 through to 17.

No.	Parameter (Pn)	Weight (Wo)	Revised Weight (Wr)	Equivalent C/AS1 Fire Safety Parameter
P_1	Linings in Apartments	0.0623	0.0766	H9 - Surface Finishes in Occupied Space
P_2	Suppression System	0.0658	0.0888	D - Building Fire Control
P_3	Fire Service	0.0571	0.0905	G - Fire Service (47% Alerting, 22% Lift Control, 31% FF Access)
P_4	Compartmentation	0.0623	0.0885	A1 - Firecell Rating
P_5	Structure Separating	0.0588	0.0897	A1 - Firecell Rating
P_6	Doors	0.0718	0.0928	67% to A1 Firecell Rating and 33% to H7 Protected Paths
P_7	Windows	0.0407	-	Not relevant to project therefore not included.
P_8	Facades	0.0363	-	Not relevant to project therefore not included.
P_9	Attic	0.0320	-	Not relevant to project therefore not included.
P_{10}	Adjacent Buildings	0.0242	-	Not relevant to project therefore not included.
P_{11}	Smoke Control System	0.0701	0.0810	C - Smoke Control (50% Extraction, 50% Stair Pressurisation)
P_{12}	Detection	0.0814	0.0837	B - Fire alarm
P_{13}	Signal System	0.0762	0.0681	B - Fire alarm
P_{14}	Escape Routes	0.0839	0.0824	H - Means of escape (34% to H4,H5, and H6, and 27% to H1,H2 and 16% to H3 and H10 and 23% to H8)
P_{15}	Structure Load Bearing	0.0463	0.0837	A2 - Structural Endurance Rating
P_{16}	Maintenance and Information	0.0692	-	Not relevant to project therefore not included.
P_{17}	Ventilation System	0.0614	0.0742	C1 - HVAC Control
	Sum	**1.0000**	**1.0000**	

<u>Table 6.39- FRIM-MAB - Fire Safety Parameter and Parameter Weightings</u>

The final average weightings are then assigned to the various and most appropriate parameters of the C/AS1 model as noted in the final column of Table 6.39. For example the parameter weightings for P_4, P_5 and P_6 are added together to reach a weighting for the Firecell Rating (A1) parameter of the C/AS1 model as all three are a function of fire separation. Therefore from Table 6.39 the Firecell Rating parameter A1 is calculated as follows:

$$
\begin{aligned}
Wr_{FRIM\text{-}MAB\,A1} &= Wr_{P4} + Wr_{P5} + 67\%\ Wr_{P5} \\
&= 0.0885 + 0.0897 + 0.67 \times 0.0928 \\
&= 0.2404
\end{aligned}
$$

The above weighting, $Wr_{\text{FRIM-MAB A1}}$, is included in Table 6.45 and is used along with the parameter weightings determined from NFPA101A (Section 6.4.1 of this report) to determine the parameter weightings for the C/AS1.

6.4.3 C/AS1 Fire Safety Risk Ranking Model – Weightings

a) Building Use Score Parameter Weightings

The Building Use Score (BU1 to BU4) parameter weightings were the most difficult to assign, as these parameters were not included in the existing risk ranking models assessed. Furthermore there was negligible data available in the literature suitable to provide a numerical estimate of the weightings directly. An estimate of the weightings was made using subjective judgment and simple hand calculations where appropriate to gauge the rough order of the weightings.

The Building/Use Score parameters all have an impact on either the amount of time it takes to evacuate a building/firecell (BU1, BU2 and BU3) or the time to untenable conditions. In all cases the common measurable unit is time. Therefore a “first order” analysis of the evacuation times and time to untenable conditions was calculated for the buildings classes under consideration in this study and the averages used to estimate the parameter weightings. In this case the building escape height parameter BU2 was weighted 7.54% (refer Section 6.4.1 and Table 6.38 for derivation) in the NFPA101A FSES model and as such this was used as a benchmark for weighting the other three parameters, BU1, BU3 and BU4 and integrating them into the overall model.

The derivation of the Building /Use score parameters BU1 to BU4 is discussed below.

The building escape height predominantly affects the evacuation time of the building, i.e. the taller the building the longer it takes to evacuate the building. Hand calculations of the time it takes to evacuate a building were undertaken using the methods in the Fire Engineering Design Guide [(53)] and used as the benchmark for assessing the impact of purpose group, occupant numbers and fire hazard category on the escape time and time to untenable conditions. The evacuation calculations are shown in Appendix D and summarised below in Table 6.40.

The calculations are based on the mean of the range of the input data. The input data is based on the requirements of C/AS1. For example permitted Open Path lengths for each purpose group were used to calculate the maximum travel time in a firecell and the minimum rate for stairs of 9mm/person was used to determine the maximum number of occupants using a single stair.

Mean Time to Clear a Floor			
Mean Pre-movement [Table 3-13.1 SFPE Handbook]	t_p	4.83	Minutes
Mean Open Path Travel Time	t_{op}	0.67	Minutes
Queuing Time = No Person per Floor / Stair Travel Speed	t_q	2.75	Minutes
Mean Time to Clear Floor	$\mathbf{t_f}$	**8.25**	**Minutes**

Mean Evacuation Times For a Single Staircase in a Building							
Escape Height (m)	**No. Floors**	**No. of Occupants Per Stair N**	**Time for All Occupants to Pass Ground Floor Door $t_{t\ (Door)}$** (Minutes)	**1st to Ground Floor Stair Travel Time $t_{t\ (Stair)}$** (Minutes)	**Total Vertical Travel Time $t_{t\ (total)}$** (Minutes)	**Time to Clear a Floor t_f** (Minutes)	**Total Escape Time t_{ev}** (Minutes)
4	1	133	1.7	0.20	1.90	8.25	10.2
10	3	399	5.1	0.20	5.31	8.25	13.6
25	8	1064	13.6	0.20	13.84	8.25	22.1
34	11	1463	18.8	0.20	18.95	8.25	27.2
46	15	1995	25.6	0.20	25.78	8.25	34.0
58	19	2527	32.4	0.20	32.60	8.25	40.8
Mean			**16.2**	**0.2**	**16.4**	**8.25**	**24.7**

Table 6.40 – Results of Evacuation Time Calculations

A mean total vertical travel time of 16.4 minutes was calculated based on the building escape heights of this study. This is equivalent to a building in the 25-34 m escape height category. Variations above and below the mean are accounted for in the risk model by the various escape height categories in parameter BU2. The 25-34 m height category scores a 3 in the model as the building increases in height the escape time increases above the mean and the parameter score reduces accordingly.

As already alluded to previously, “Purpose Group” pertains to human behaviour and as such response time. In terms of evacuation time this relates to the pre-movement time and time to evacuate the open path, including queuing which varies according to purpose group type. The mean time to clear a floor has been assessed as 8.25 minutes which equates to approximately 50% of the mean total vertical travel time of 16.4 minutes. Therefore the purpose group parameter (BU1) was weighted 50% of that for building escape height parameter (Wi_{BU2} = 7.55%), i.e. Wi_{BU1} = 3.78%.

Occupant numbers parameter (BU3) is a little more difficult to assess. C/AS1 specifies a constant rate per person for the widths of escape routes. This has the effect of equalising the escape time regardless of the number of persons in a firecell or building. For example 100 persons require a 900mm wide escape route and 1000 persons require 9000mm of escape route width. Therefore assuming the same density and travel speed the evacuation time should be the same for both occupant number scenarios, hence there is no impact on escape time from increasing occupant numbers. In reality there is an increased risk as the occupant numbers increase due to a variety of human behaviour related aspects. For example crowd behaviour where people follow a leader which may result in all persons trying to use one exit when others are available or simply that statistically there are more people to make less appropriate decisions. To this end the occupant numbers (BU3) parameter was crudely estimated at a weighting of 33% of that for the building escape height parameter (BU2), i.e. $Wi_{BU3} = 2.52\%$.

In this project the time to untenable conditions was used to estimate the weighting of the Fire Hazard Category parameter (BU4). Life safety is typically concerned with the early stages of fire development and evacuating occupants before the firecell or building becomes untenable. Therefore the time to untenable conditions is more a function of the fire growth rate rather than the total fuel load in a firecell. The fire hazard category assignments in C/AS1, although primarily based on FLED, do include an element of fire growth rate [*Clause 2.2.1* C/AS1][1]. The times to untenable conditions were estimated based on the correlation equation for a t^2 fire given by Frantzich et al 1997[38] from Section 5.6.8, repeated below for clarity.

$S = 1.67\, \alpha^{-0.26} H^{0.44} A^{0.54}$ Time to untenable conditions

Where:

α = t^2 fire growth rate	= 0.00293 MW/s^2	for a slow fire
	= 0.01170 MW/s^2	for a medium fire
	= 0.04660 MW/s^2	for a fast fire
H = Height of room	= 3.0 m	assumed height
A = Area of room	= 5000m^2	for FHC 1
	= 2500m^2	for FHC 2
	= 1500m^2	for FHC 3

The above floor areas have been selected based on the maximum areas permitted for unsprinklered firecells in accordance with *Clause 4.2.3* C/AS1.

The results of the calculations are shown in Table 6.41 below.

Fire Hazard Category		**FHC1**	**FHC2**	**FHC3**	**Average**
t^2 Fire Growth Rate	**Floor Area (m^2)**	**5000**	**2500**	**1500**	
	α (MW/s^2)	**Time to Untenable Conditions S (minutes)**			
Slow	**0.00293**	20.44	14.06	10.67	**10.97**
Medium	**0.0117**	14.26	9.81	7.44	
Fast	**0.0466**	9.96	6.85	5.20	

Table 6.41 – Time to Untenable Conditions in Unsprinklered Firecells

This gave an average time to untenable conditions of 11.0 minutes. The mean time to evacuate a floor and building was estimated to be 8.3 minute and 24.7 minutes respectively, Table 6.40 above. Given that the times are in the same order of magnitude, the fire hazard category parameter has been weighted the same as the escape height parameter, therefore Wi_{BU4} = 7.55%.

Finally the weightings were normalised for the C/AS1 model to account for parameters BU1, BU3 and BU4 which were not included in the NFPA models. Therefore the weighting for the Building/Use Score parameters reduced as follows:

Parameter	NFPA + BUS Weightings	C/AS1 Weightings $Wi_{C/AS1}$
NFPA101A - Average weightings (Refer Table 6.45) for equivalent FSFS parameters.	0.9245	0.8121
50% "*Construction*" Parameter Equivalent to Escape Height parameter - BU2	0.0755	0.0663
Total NFPA	**1.0000**	
Purpose Group Parameter BU1 (= 50% BU2)	0.0378	0.0332
Occupant Numbers Parameter BU3 (= 33% BU2)	0.0252	0.0221
Fire Hazard Category Parameter BU4 (= BU2)	0.0755	0.0663
Total	**1.1385**	**1.000**

Table 6.42 – Building/Use Score Weighting Normalisation

Therefore the Building/Use parameters are weighted 18.79% and the Fire Safety Features Score parameters are weight 81.21%. Derivation of the Fire Safety Features Score parameter weightings is discussed in Subsection b) below.

The Building/Use Score parameter weightings are summarised in Table 6.43 below and incorporated into the final weighting scheme in Table 6..

No.	Fire Safety Parameter	C/AS1 Weighting Wi_{BUS}
BU1	Purpose Group	0.0332
BU2	Building Escape Height	0.0663
BU3	Occupant Numbers	0.0221
BU4	Fire Hazard Category	0.0663
	Total	**0.1879**

Table 6.43 – Summary Building/Use Score Parameter Weightings

b) *Fire Safety Feature Score Parameter Weightings*

The parameter weightings for the fire safety features were determined from the average of the weightings calculated from the FRIB-MAB(35) and NFPA101A(32) models and are shown in Table 6.45 below.

The emergency power supply is not included in any of the existing models. This is assumed to be similar in importance to the communications system and assigned 2% in the calculated mean weighting. This reduced to 1.58% in the final C/AS1 model.

The Building Fire Control parameter (D) contains three sub-parameters. These are sprinklers (D1), water supply (D2) and occupant fire fighting (D3). The total weighting for building fire control, based on the average of the sprinkler and/or suppression parameters from the FRIB-MAB(35) and NFPA101A(32) models, is 9.51% (adjusted for the BUS parameters). The breakdown of the building fire control parameter weight has been estimated at 7.1%, 1.9% and 0.5% for sprinklers, water supply and occupant fire fighting respectively.

A number of parameters for the C/AS1 Means of Escape parameter (H) were not included specifically in the FRIB-MAB(35) and FSES(32) models. Therefore the most appropriate parameter weighting from both the FRIB-MAB and FSES models were assigned to the C/AS1 Means of Escape parameter. For example FRIB-MAB parameter $P_{14,}$ *Escape Routes,* had a weighting of 0.0824**Error! Reference source not found.**. In this case a proportion of this weighting was assigned to all the C/AS1 Means of Escape (H) parameters that did not have a specific corresponding parameter in either FRIM-MAB or NFPA101A models. The proportion was determined using judgment and is given as a percentage breakdown in Table 6.44.

Fire Safety Features Score Means of Escape Parameters (H)		Estimated % of FRIM-MAB Parameter P14	Weighting Breakdown of FRIM-MAB Parameter P14
H1	Number of Escape Routes	13.5%	0.0111
H2	Width of Escape Routes	13.5%	0.0111
H3	Emergency Lighting	8.0%	0.0065
H4	Refuge Areas	4.0%	0.0033
H5	DEOP Lengths	15.0%	0.0124
H6	Total Open Lengths	15.0%	0.0124
H8	Surface Finishes Exitways	23.0%	0.0189
H10	Signage	8.0%	0.0065
	Total	**100.0%**	**0.0822**

Table 6.44 – Estimated Means of Escape Parameter Weightings

Note the difference between the FRIM-MAB weighting for P_{14} of 0.0824 and the C/AS1 weighting of 0.0822 in the above table is a rounding error and would not show up if an additional decimal place was used.

The C/AS1 Fire Safety Features Score weightings have been determined from the mean of the weightings calculated from the FRIB-MAB and NFPA101A models, adjusted to include new parameters added and deleted parameters that were deemed not relevant.

$$Wi_{FSFS} = \frac{Wr_{FRIM-MAB} + W_{NFPA\,101\,A}}{2} \times \frac{\sum Wi_{FSFS}}{\sum W_{mean}}$$

The final weightings have been scaled to sum 0.8121, the total assigned to the Fire Safety Features Score Component of the C/AS1 Fire safety Index model.

For example the Firecell parameter A1 is calculated as follows:

$$Wi_{FSFS\ A1} = \frac{0.2404 + 0.1399}{2} \times \frac{0.8121}{1.0267} \qquad = 0.1504$$

The Fire Safety Features Score parameter weightings are shown in Table 6.45 below:

No.	Fire Safety Parameter	FRIM-MAB Weighting $Wr_{FRIM-MAB}$	NFPA 101A Weighting $W_{NFPA101A}$	Mean Weighting W_{mean}	C/AS1 Weighting Wi_{FSFS}
A	**Fire Barriers**				
A1	Fire Cell Rating	0.2404	0.1399	0.1902	**0.1504**
A2	Structural Endurance Rating	0.0837	0.1596	0.1217	**0.0962**
B	**Fire Alarm**	0.1518	0.1456	0.1487	**0.1176**
C	**Smoke Control**				
C1	HVAC Control	0.0742	0.0189	0.0466	**0.0368**
C2	Extraction	0.0405	0.0103	0.0254	**0.0201**
C3	Pressurisation	0.0405	0.0103	0.0254	**0.0201**
D	**Building Fire Control**	0.0888	0.1517	0.1203	
D1	Sprinklers	No breakdown	No breakdown		**0.0713**
D2	Water Supply	No breakdown	No breakdown		**0.0190**
D3	Occupant Fire Fighting	No breakdown	No breakdown		**0.0048**
E	**Emergency Power Supply**	Not Included	Not Included	0.0200	**0.0158**
F	**Communication System**	Not Included	0.0247	0.0247	**0.0195**
G	**Fire Service**				
G1	Alerting	0.0425	0.0247	0.0336	**0.0266**
G2	Lift Control	0.0199	Not Included	0.0199	**0.0157**
G3	Fire Hydrant System	0.0280	Not Included	0.0280	**0.0221**
H	**Means of Escape**				
H1	Number of Escape Routes	0.0111	0.0385	0.0248	**0.0196**
H2	Width of Escape Routes	0.0111	0.0385	0.0248	**0.0196**
H3	Emergency Lighting	0.0065	Not Included	0.0065	**0.0051**
H4	Refuge Areas	0.0033	Not Included	0.0033	**0.0026**
H5	DEOP Lengths	0.0124	0.0380	0.0252	**0.0199**
H6	Total Open Lengths	0.0124	0.0380	0.0252	**0.0199**
H7	Protected Path Lengths	0.0309	0.0380	0.0345	**0.0272**
H8	Surface Finishes Exitways	0.0189	0.0095	0.0142	**0.0112**
H9	Surface Finishes Occupied Spaces	0.0766	0.0383	0.0575	**0.0454**
H10	Signage	0.0065	Not Included	0.0065	**0.0051**
	Total	**1.0000**	**0.9245****	**1.0267**	**0.8121##**

** 7.55% assigned to the Building Escape Height Parameter

18.79% assigned to the Building/Use Score Parameters

<u>Table 6.45 – Summary Fire Safety Features Parameter Weightings</u>

c) Fire Safety Index - Final Parameter Weightings

No.	Fire Safety Parameter	Fire Safety Index Weighting Wi $_{C/AS1}$
Building Use Score		
BU1	**Purpose Group**	0.0332
BU2	**Building Escape Height**	0.0663
BU3	**Occupant Numbers**	0.0221
BU4	**Fire Hazard category**	0.0663
Fire Safety Features Score		
A	**Fire Barriers**	
A1	Fire Cell Rating	0.1504
A2	Structural Endurance Rating	0.0962
B	**Fire Alarm**	0.1176
C	**Smoke Control**	
C1	HVAC Control	0.0368
C2	Extraction	0.0201
C3	Pressurisation	0.0201
D	**Building Fire Control**	
D1	Sprinklers	0.0713
D2	Water Supply	0.0190
D3	Occupant Fire Fighting	0.0048
E	**Emergency Power Supply**	0.0158
F	**Communication System**	0.0195
G	**Fire Service**	
G1	Alerting	0.0266
G2	Lift Control	0.0157
G3	Fire Hydrant System	0.0221
H	**Means of Escape**	
H1	Number of Escape Routes	0.0196
H2	Width of Escape Routes	0.0196
H3	Emergency Lighting	0.0051
H4	Refuge Areas	0.0026
H5	DEOP Lengths	0.0199
H6	Total Open Lengths	0.0199
H7	Protected Path Lengths	0.0272
H8	Surface Finishes Exitways	0.0112
H9	Surface Finishes Occupied Spaces	0.0454
H10	Signage	0.0051
	Total	**1.0000**

Table 6.46 – Summary C/AS1 Fire Safety Index Weightings

6.5 Model

As noted in the introduction to this section the model is a simple risk ranking model which produces a single numerical safety index which will enable comparison of risk/safety between buildings of different heights and occupancy types and with different fire safety features.

The proposed risk index model for buildings designed to the C/AS1 Fire Safety requirements has been developed as a worksheet. The model is suitable for use in a computer spreadsheet program such as Excel [42]. An example worksheet is shown in Appendix E.

7 LEVEL OF SAFETY OF BUILDINGS DESIGN TO C/AS1

7.1 General

The purpose of this Chapter is to assess the apparent level of safety of buildings designed to C/AS1, to investigate inconsistencies that may arise and identify fire safety features that impact the most on the fire safety of buildings.

Individuals and /or society may have an expectation that the level of safety of a building is the same regardless of the building the person is occupying, however, the fire statistics do not support this rationale. The fire statistics clearly indicate that the most fire fatalities (70.6%)[60] occur in the building class with the least C/AS1 fire safety requirements; domestic houses. Whether or not this is reflected in the building classes assessed in this report will be discussed later in this Chapter.

The proposed model has been developed to assess multi-story buildings with occupancies made up entirely of the general population or “average” people. The analysis avoids buildings of a specialist nature, such as hospitals and prisons, so that the additional requirements for these types of buildings do not skew the model.

The analysis includes all building heights including and above a 4m escape height and occupant numbers in excess of 50 persons, with the exception of SR and SA purpose groups which have a maximum of 40 occupants permitted in an unsprinklered firecell.

7.2 Method of Analysis

The model has been developed as a worksheet in the Microsoft Excel[42] spreadsheet computer program for ease of use.

The following buildings are assessed based of C/AS1 purpose groups:

CS	–	Crowd Small 50< Occupants < 100
CL	–	Crowd Large > 100 Occupants
CM	–	Crowd Mercantile
SA	–	Sleeping Accommodation
SR	–	Sleeping Residential
WL	–	Working Low (Fire load)
WM	–	Working Medium (Fire Load)

The following escape heights and occupant numbers are assessed:

Escape Heights	**Occupant Numbers**
4m to <10m	Up to 100
10m to < 25m	101 -500
25m to <34m	501 - 1000
34m to < 46m	Over 1000
46m to < 58m	
Over 58m	

The fire safety index score has been calculated for each occupancy type, building height and occupant number combination. The scores have been recorded and assessed using the functions of the Excel spreadsheet program to compare the relative safety.

The fire safety parameters for each purpose group/building height and occupant number combination have been selected based on the requirements of C/AS1. For example where a building is deemed to require smoke detectors the open paths lengths may be doubled for most occupancies. Therefore the increased open path lengths have been used in the model where applicable to account for the increased risk/reduced safety of occupants having further to travel to evacuate the building.

The input parameters for the analysis are shown in Appendix F and a sample calculation of the fire safety index is shown in Appendix E.

7.3 Results

The results are shown in Tables 7.1 and 7.2 and Figure 7.1 to 7.15 below.

Fire Safety Precautions Maximum 100 Occupants(#Maximum 40 persons in SA Occupancy)																	
4m to<10m						10m to<25m						25m to<34m					
CS	CM	WL	WM	SA#	SR	CS	CM	WL	WM	SA#	SR	CS	CM	WL	WM	SA	SR
2.663	2.531	2.387	2.255	2.736	2.103	3.021	2.812	2.669	2.536	2.782	2.645	2.755	2.622	2.424	2.291	3.035	2.630
34m to<46m						46m to<58m						>58m					
CS	CM	WL	WM	SA	SR	CS	CM	WL	WM	SA	SR	CS	CM	WL	WM	SA	SR
3.001	2.927	2.542	2.409	3.108	2.564	2.994	2.861	2.916	2.784	3.042	2.556	3.508	3.375	3.410	3.277	3.556	3.084
Fire Safety Precautions 101 - 500 Occupants (* Maximum 160 persons in SA Occupancy)																	
4m to<10m						10m to<25m						25m to<34m					
CL	CM	WL	WM	SA*		CL	CM	WL	WM	SA*		CL	CM	WL	WM	SA*	
2.661	2.528	2.385	2.252	2.821		3.019	2.809	2.587	2.455	2.856		2.752	2.620	2.422	2.289	3.013	
34m to<46m						46m to <58m						>58m					
CL	CM	WL	WM	SA*		CL	CM	WL	WM	SA*		CL	CM	WL	WM	SA*	
2.999	2.925	2.539	2.407	3.086		2.933	2.859	2.886	2.754	3.020		3.505	3.373	3.459	3.326	3.526	
Fire Safety Precautions 501 - 1000 Occupants																	
4m to<10m						10m to<25m						25m to<34m					
CL	CM	WL	WM			CL	CM	WL	WM			CL	CM	WL	WM		
2.833	2.701	2.603	2.470			2.970	2.916	2.818	2.685			3.082	2.950	2.752	2.619		
34m to<46m						46m to<58m						>58m					
CL	CM	WL	WM			CL	CM	WL	WM			CL	CM	WL	WM		
3.016	2.942	2.869	2.737			2.950	2.876	2.904	2.771			3.522	3.390	3.397	3.264		
Fire Safety Precautions >1000 Occupants																	
4m to<10m						10m to<25m						25m to<34m					
CL	CM	WL	WM			CL	CM	WL	WM			CL	CM	WL	WM		
3.078	2.945	2.842	2.710			3.011	2.958	2.855	2.722			3.124	2.992	2.788	2.656		
34m to<46m						46m to<58m						>58m					
CL	CM	WL	WM			CL	CM	WL	WM			CL	CM	WL	WM		
3.058	2.984	2.906	2.774			2.992	2.918	2.940	2.808			3.564	3.432	3.434	3.310		

Table 7.1 – Fire Safety Index Results by Occupant Numbers

Purpose Group CS/CL						
Occupant Number	**Building Escape Height**					
	4m-10m	**10m-25m**	**25m-34m**	**34m-46m**	**46m-58m**	**+58m**
100	2.663	3.021	2.755	3.001	2.994	3.508
101-500	2.661	3.019	2.752	2.999	2.933	3.505
501-1000	2.833	2.970	3.082	3.016	2.950	3.522
+1000	3.078	3.011	3.124	3.058	2.992	3.564

Purpose Group CM						
Occupant Number	**Building Escape Height**					
	4m-10m	**10m-25m**	**25m-34m**	**34m-46m**	**46m-58m**	**+58m**
100	2.531	2.812	2.622	2.927	2.861	3.375
101-500	2.528	2.809	2.620	2.925	2.859	3.373
501-1000	2.701	2.916	2.950	2.942	2.876	3.390
+1000	2.945	2.958	2.992	2.984	2.918	3.432

Purpose Group WL						
Occupant Number	**Building Escape Height**					
	4m-10m	**10m-25m**	**25m-34m**	**34m-46m**	**46m-58m**	**+58m**
100	2.387	2.669	2.424	2.542	2.916	3.410
101-500	2.385	2.587	2.422	2.539	2.886	3.459
501-1000	2.603	2.818	2.752	2.869	2.904	3.397
+1000	2.842	2.855	2.788	2.906	2.940	3.434

Purpose Group WM						
Occupant Number	**Building Escape Height**					
	4m-10m	**10m-25m**	**25m-34m**	**34m-46m**	**46m-58m**	**+58m**
100	2.255	2.536	2.291	2.409	2.784	3.277
101-500	2.252	2.455	2.289	2.407	2.754	3.326
501-1000	2.470	2.685	2.619	2.737	2.771	3.264
+1000	2.710	2.722	2.656	2.774	2.808	3.301

Purpose Group SA						
Occupant Number	**Building Escape Height**					
	4m-10m	**10m-25m**	**25m-34m**	**34m-46m**	**46m-58m**	**+58m**
100	2.736	2.782	3.035	3.108	3.042	3.556
101-160	2.821	2.856	3.013	3.086	3.020	3.526

Purpose Group SR						
Occupant Number	**Building Escape Height**					
	4m-10m	**10m-25m**	**25m-34m**	**34m-46m**	**46m-58m**	**+58m**
40	2.103	2.645	2.630	2.564	2.556	3.084

Table 7.2 – Fire Safety Index Results by Purpose Group

7.3.1 Crowd Occupancy

Figures 7.1 and 7.2 below show the FSI values for Crowd Small (CS), Crowd Large (CL) and Crowd Mercantile (CM) occupancies as the building escape height and number of occupants varies.

The fire safety index (FSI) of building in the 4-10 m escape height ranges is very much dependant on the type of fire alarm installed and whether or not sprinklers are installed.

The 10-25 m escape height buildings have a similar FSI to the buildings over 34 m. This is due to having a higher firecell rating requirement in the absence of a sprinkler system.

Buildings with an escape height of 25-34 m have the most inconsistent FSI. The safety index of buildings in this height category is sensitive to the fire alarm type and whether or not there are sprinklers present. There is a significant step in the FSI at the 500 occupant mark as sprinklers are introduced into the safety requirements for occupant numbers in excess of 500. There is a drop in FSI between the 10-25 m and 25-34 m height categories where there is less than 500 persons. This is primarily due to the reduction in the firecell rating when sprinklers are introduced. This issue is discussed further in Section 7.4.3.

Buildings in the over 58 m escape height category have the highest FSI due to the step up in firecell rating requirements of C/AS1 from 30 to 60 minutes for this height category. This is typical for all Purpose Groups

The CM purpose group has a FSI approximately 5% lower than that of CS and CL purpose groups for the same occupant number and building escape height ranges. This is due to the increased fire hazard category parameter (BU4) as these two building categories generally have identical fire safety requirements.

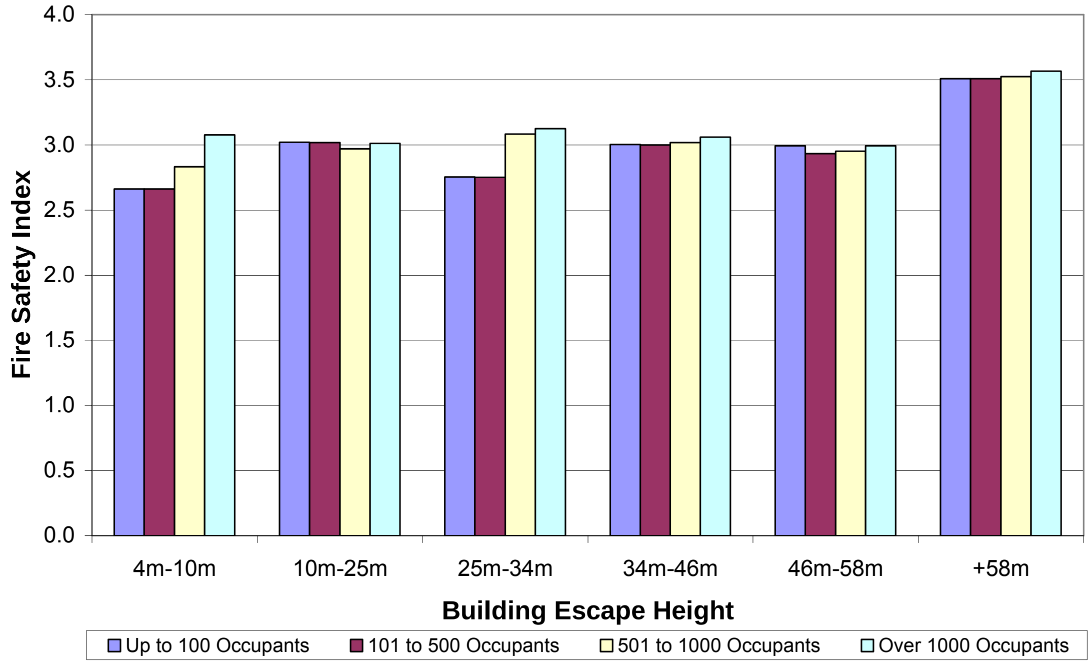


Figure 7.1 - Fire Safety Index - Crowd Purpose Group CS and CL

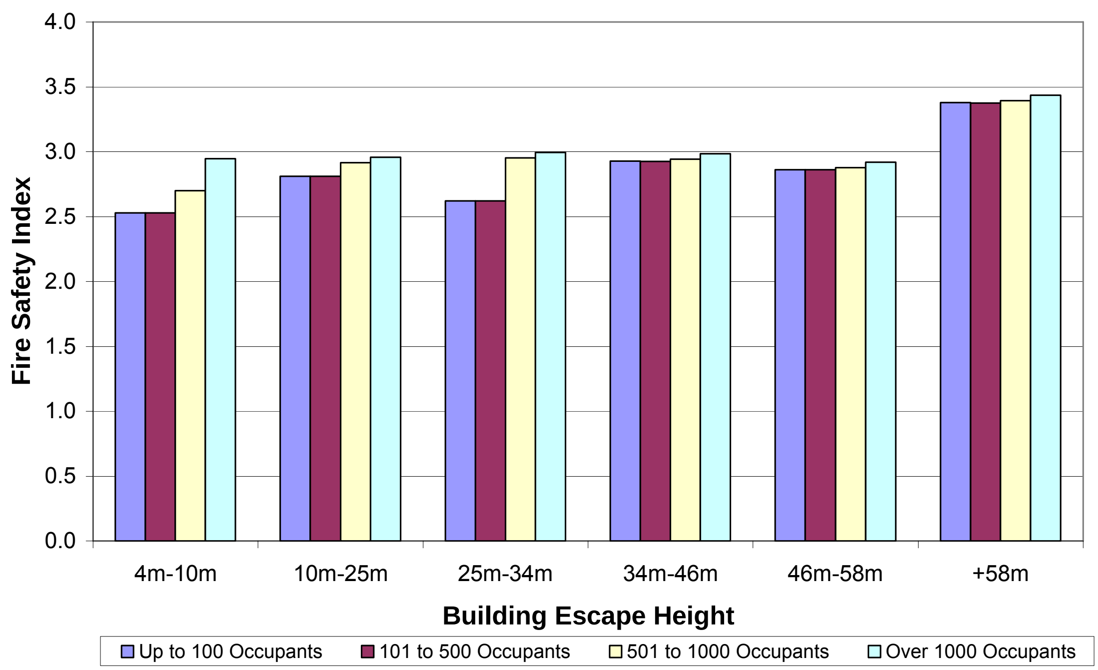


Figure 7.2 - Fire Safety Index - Crowd Purpose Group CM

7.3.2 *Working Occupancy*

Figures 7.3 and 7.4 below show the FSI values for Working Low (WL) and Working Medium (WM) occupancies as the building escape height and number of occupants varies.

The FSI of building in the 4-10 m escape height ranges is similar in pattern to that of the crowd occupancies with the fire alarm type dominating the variance.

The FSI of the 10-25 m high buildings is a little more inconsistent as a variety of factors including alarm type, sprinklers and firecell rating affect the safety index. The drop in safety index between the "up to 100" and "101-500" occupant number categories in this height range is due to the Occupant number parameter (BU3) as these two occupant ranges have the same fire safety requirements to C/AS1.

Buildings in the ranges of 25-34 m and 34 - 46 m have a significant step in the FSI at the 500 occupant mark. This is due to the introduction of sprinklers and number of other fire safety precautions where there are more than 500 occupants in these purpose groups.

The FSI for buildings above 46 m in height is also relatively constant for Purpose groups WL and WM. This is because the height of the building dominates the fire safety requirements of building code for these purpose groups. The FSI for buildings with over 1000 persons is also consistent with the FSI for building over 46 m in this occupancy category.

The WM purpose group also has a FSI approximately 5% lower than that of WL purpose group for the same occupant number and building escape height ranges. This is due to the increased fire hazard category parameter (BU4) as these two building categories have identical fire safety requirements.

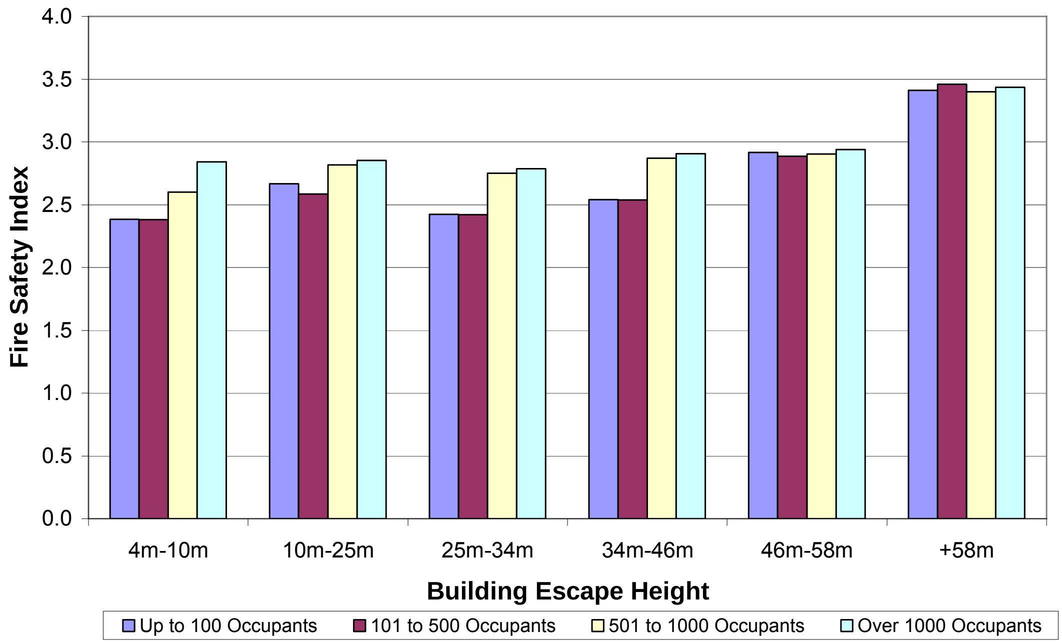


Figure 7.3 - Fire Safety Index - Working Purpose Group WL

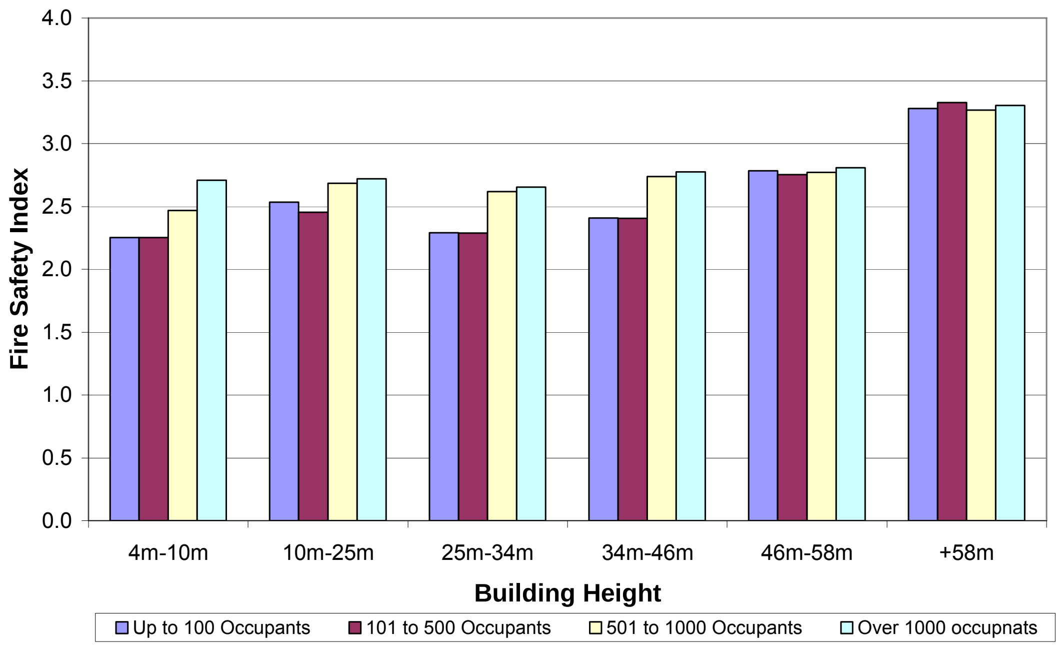


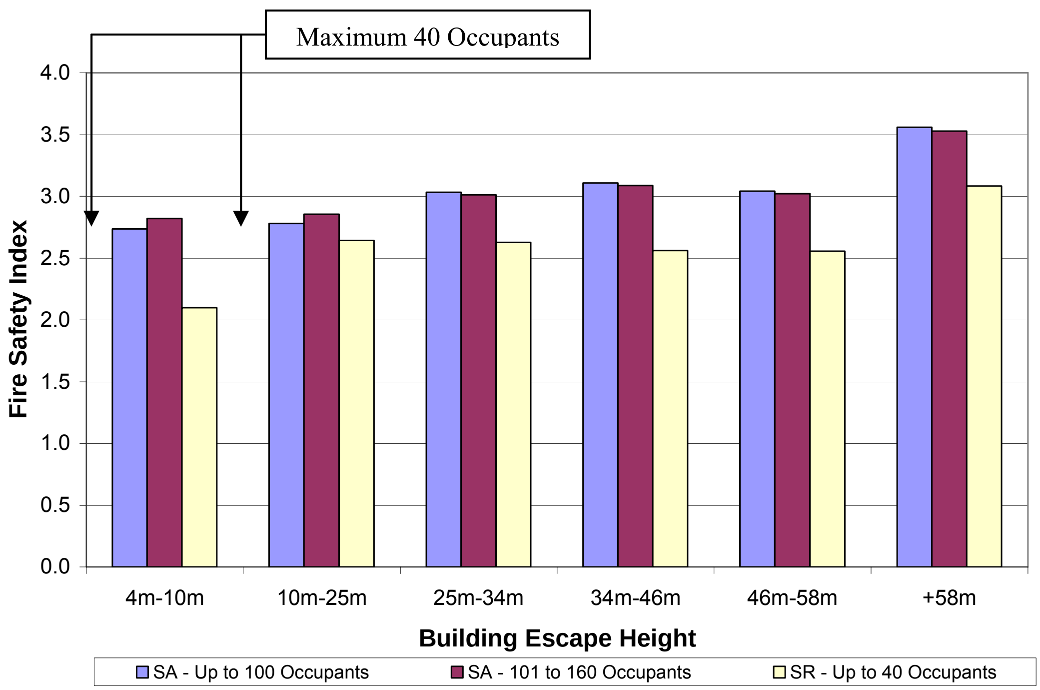
Figure 7.4 - Fire Safety Index - Working Purpose Group WM

7.3.3 Sleeping Occupancy

Figure 7.5 below shows the FSI values for Sleeping Residential (SR) and Sleeping Accommodation (SA) occupancies as the building escape height and number of occupants varies.

The FSI for the SA purpose group increases uniformly up to building heights of 46m as fire safety precautions are incrementally introduced into the design. Note that the maximum number of occupants per firecell in a SA Purpose Group is 40 if the building is unsprinklered. This applies to building escape height categories up to 25 m high. Buildings over 25 m must be sprinklered due to the height and as such are permitted up to 160 occupants.

The FSI for the SR purpose group follows a similar pattern to SA but is considerably lower (approximately 20%) in magnitude due to lesser safety requirements, in particular the lack of requirements for smoke control.



<u>Figure 7.5 - Fire Safety Index - Sleeping Purpose Group SA and SR</u>

7.3.4 All Purpose Groups – By Occupant Numbers

Figures 7.6 to 7.9 below show the FSI for all purpose groups by occupant number category.

There is considerable range and scatter of FSI for buildings up to 500 occupants (Figures 7.6 and 7.7). FSI ranges between 2.100 for SR purpose group and 3.108 for the SA purpose group. The working and crowd occupancies generally fit in between with one or two anomalies.

The crowd and working purpose groups have a spike in FSI in the 10-25 m purpose group. This is unusual and can be attributed solely to the high weighting for the firecell (F) rating and structural endurance (S) rating parameters. There is a step up in safety as the F and S ratings increase from 30 minutes to 45 minutes and 60 minutes to 90 minutes for the F and S rating respectively between escape heights of 4-10 m and 10-25 m. The FSI then drops for height categories between 10-25 m and 25-34 m as the F and S rating drop back to 30 minutes and 60 minutes respectively with the introduction of sprinklers. C/AS1:June 2001 allows a “tradeoff” between firecell rating and sprinklers whereas the C/AS1:Oct 2005 revisions have reduced this “tradeoff”. These issues will be discussed further in Section 7.4.3 and 7.4.4.

From Figures 7.8 and 7.9 the crowd occupancies have a higher FSI than the working occupancies for the equivalent escape height categories where occupants exceed 500 persons. The average difference is approximately 7%. Furthermore the FSI is relatively constant across the various building height categories up to 58 m suggesting a constant level of safety. This is because the building height governs the fire safety precautions required by C/AS1; hence most buildings will have a 30 minutes firecell rating, sprinkler system and smoke detection in these height/occupancy categories. However buildings over 58 m escape height have a 60 minute Firecell rating.

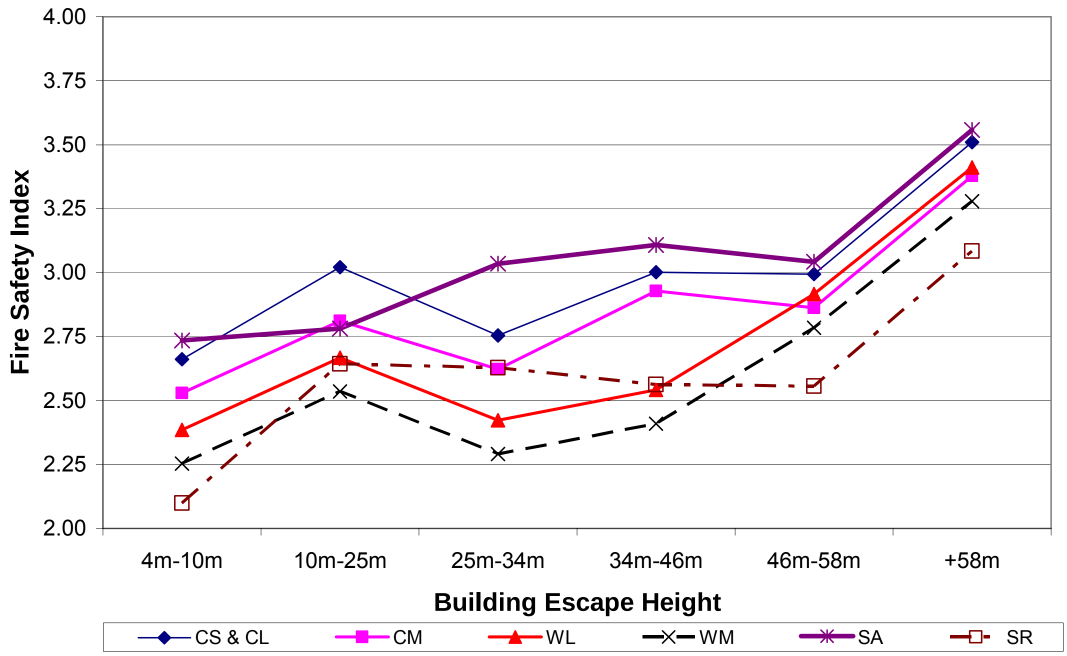


Figure 7.6 - Fire Safety Index - All Purpose Group, Up to 100 Occupants

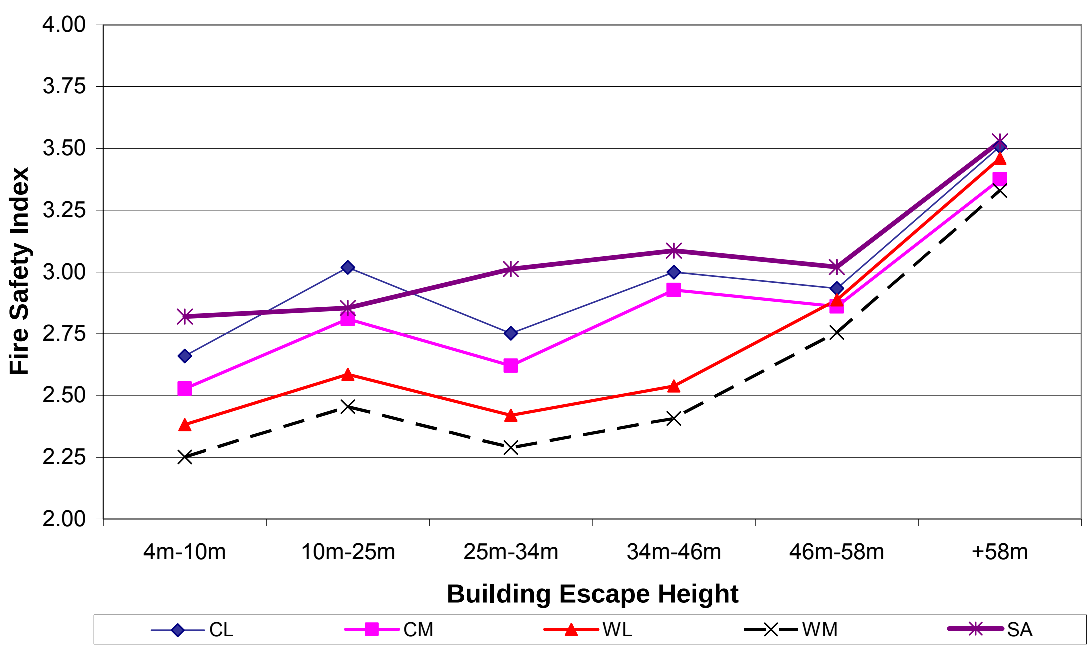


Figure 7.7 - Fire Safety Index - All Purpose Group, 101 - 500 Occupants

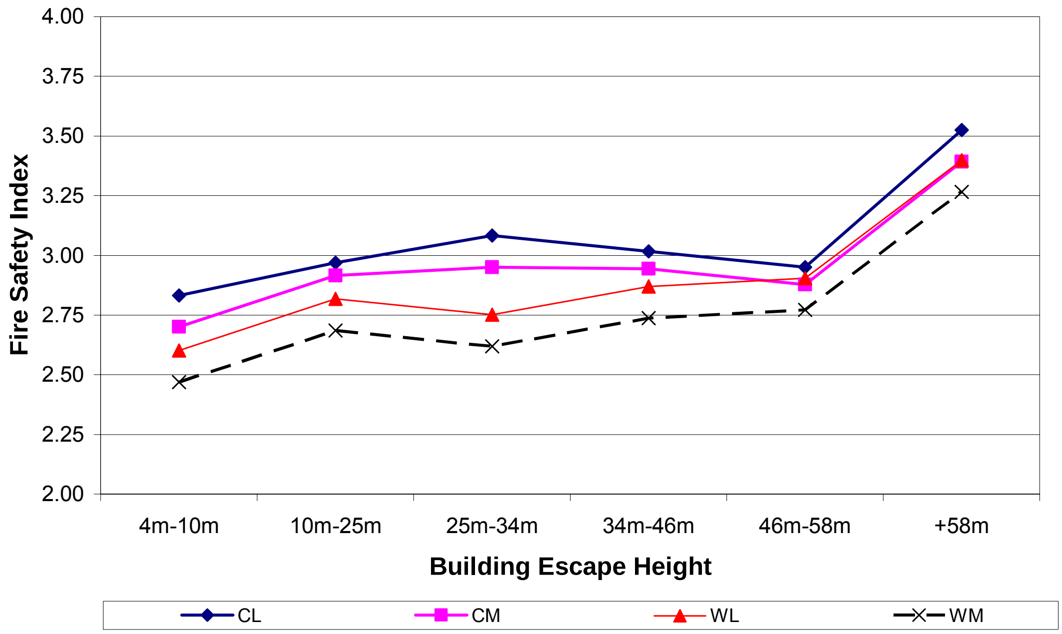


Figure 7.8 - Fire Safety Index - All Purpose Group, 501 - 1000 Occupants

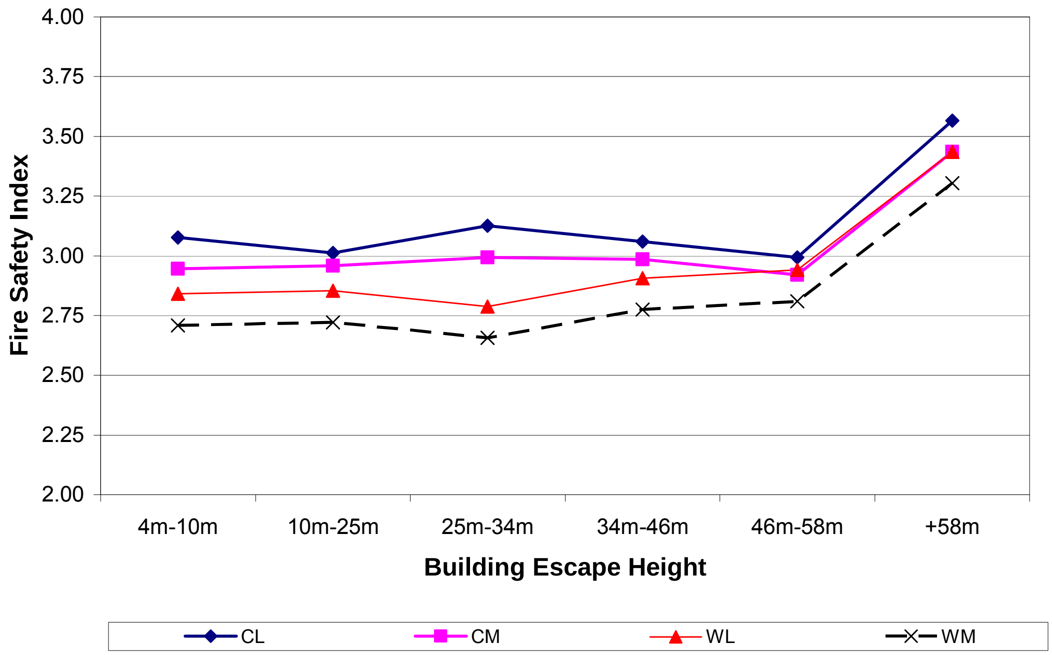


Figure 7.9 - Fire Safety Index - All Purpose Group, Over 1000 Occupants

7.3.5 All Purpose Groups – By Escape Height

Figures 7.10 to 7.15 below show the FSI for all purpose groups by escape height category.

The FSI for the 4-10 m building escape height category generally increases with an increase in occupant numbers across the range of purpose groups (Figure 7.10). This is the only height category where this type of grading occurs. For 10-25 m, 25-34 m and 34 m-46 m building escape height categories there are a numbers of steps in the FSI. These steps are typically caused by introduction of sprinklers and/or reduction in F and S ratings.

The SA purpose group has the highest FSI in all escape height categories except the 10-25 m category (Figure 7.11). The FSI for the SA purpose group is 2.782 and 2.856 for the 10-25 m escape height category and are similar in magnitude to the 4-10 m escape height FSI. Therefore the index appears to be in the right order, with an increase in the relative level of safety for the other purpose groups in the 10-25 m escape height category. The FSI for the crowd and working purpose groups in the 10-25 m escape height category is controlled by the firecell rating parameter. Refer to discussions in Sections 7.4.3 and 7.4.4.

It is apparent from figures 7.10 to 7.15 that there is a clear difference in FSI between each purpose group and escape height categories. However as the height of the building increase the FSI converge and the difference become small, approximately 5%.

The trend for the SR purpose group is difficult to assess as there is only one occupant number category. It generally scores the lowest FSI in most escape height categories. This is due to the low number of fire safety precautions required for this purpose group, in particular smoke control in the heating and ventilation system is not required and stairwell pressurisation is only required for buildings with an escape height over 58 m.

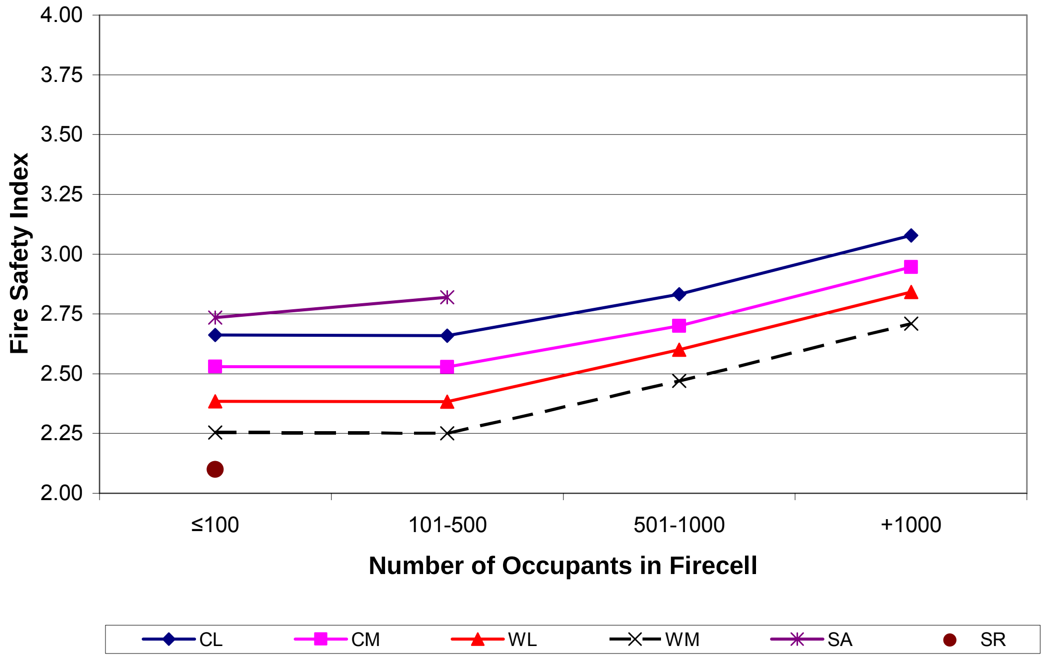


Figure 7.10 - Fire Safety Index - All Purpose Group, 4-10m Escape Height

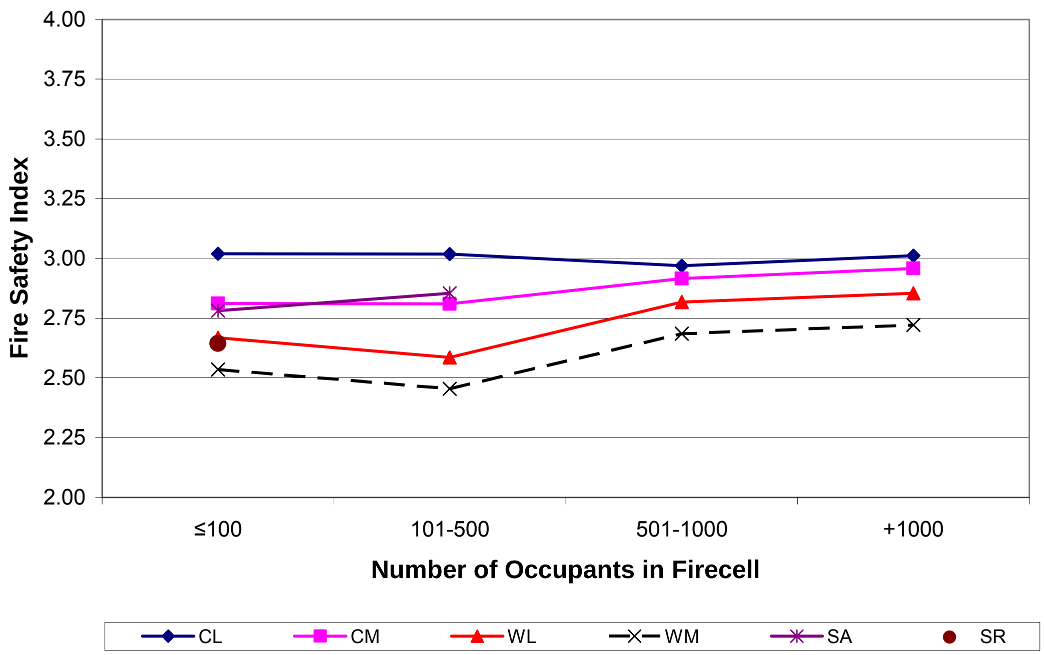


Figure 7.11 - Fire Safety Index All Purpose Group, 10-25m Escape Height

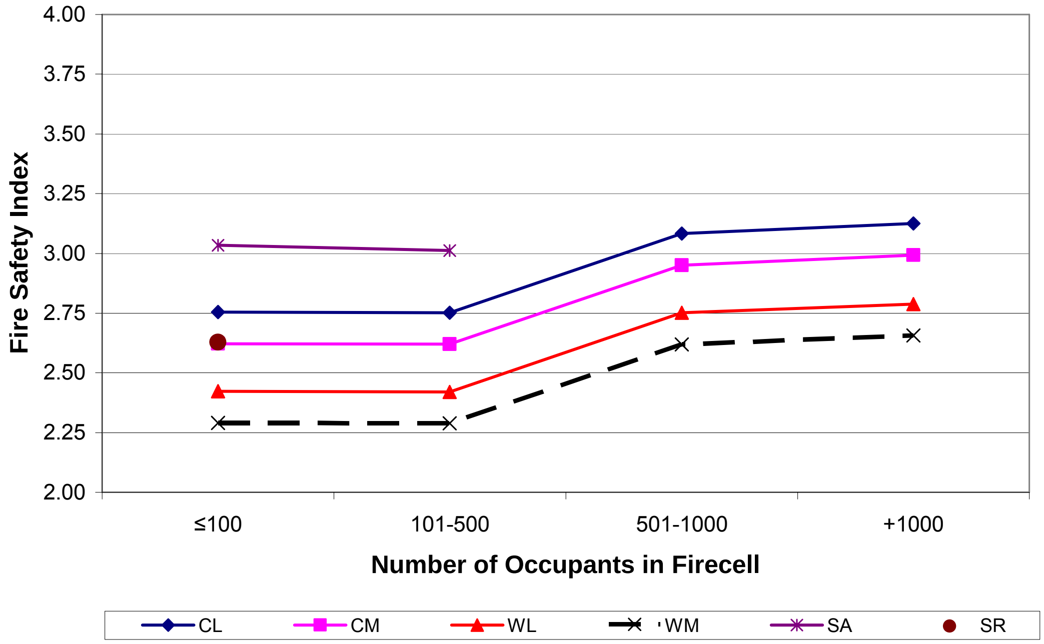


Figure 7.12 - Fire Safety Index - All Purpose Group, 25-34m Escape Height

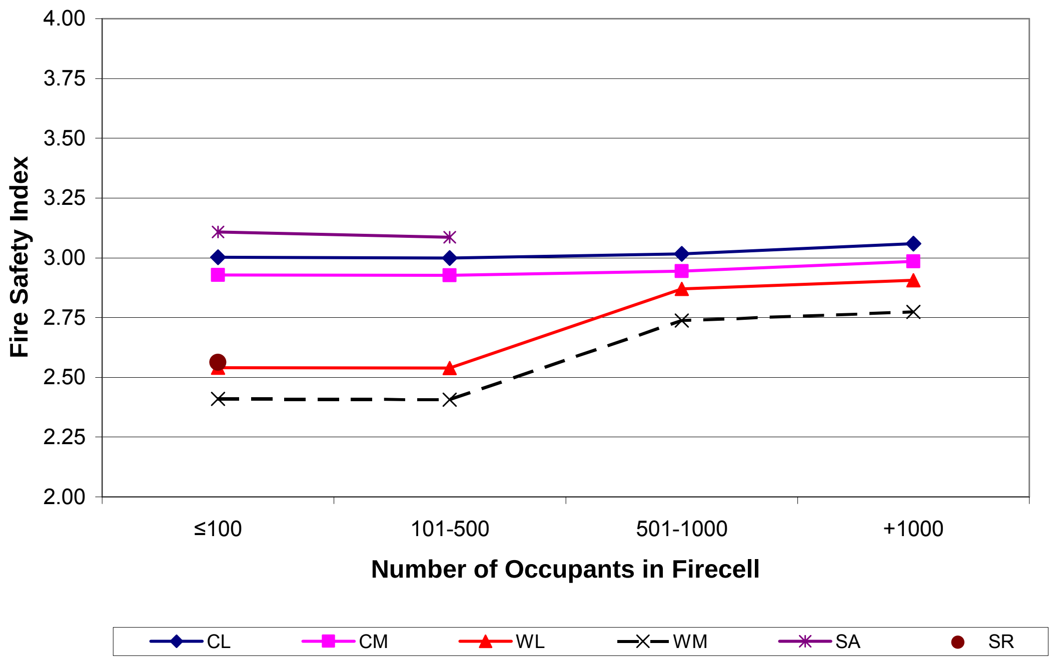


Figure 7.13 - Fire Safety Index All Purpose Group, 34-46m Escape Height

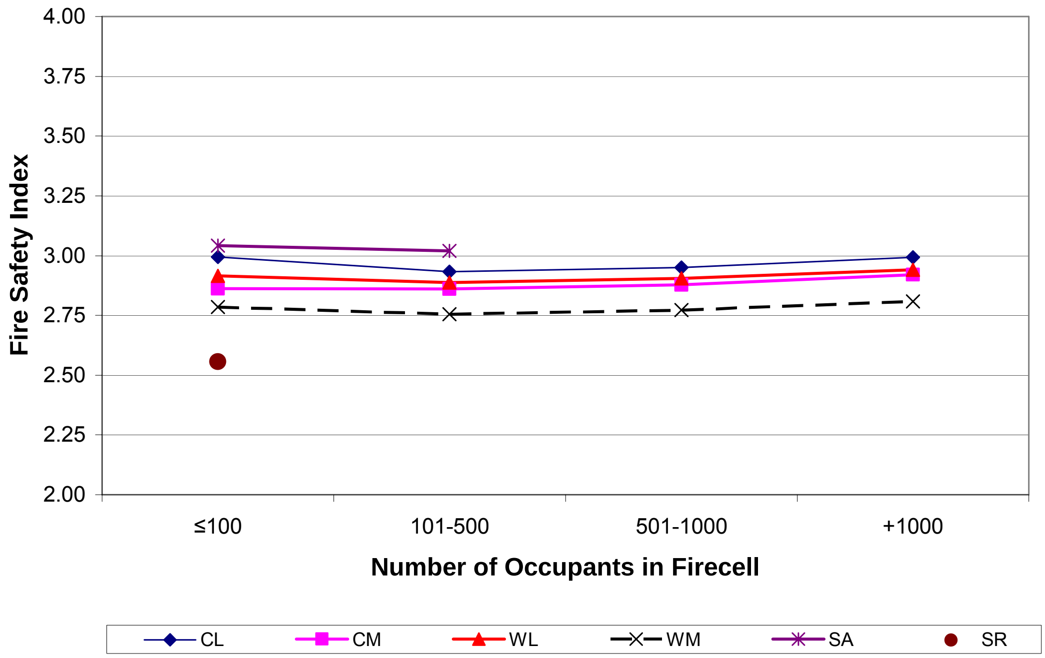


Figure 7.14 - Fire Safety Index - All Purpose Group, 46-58m Escape Height

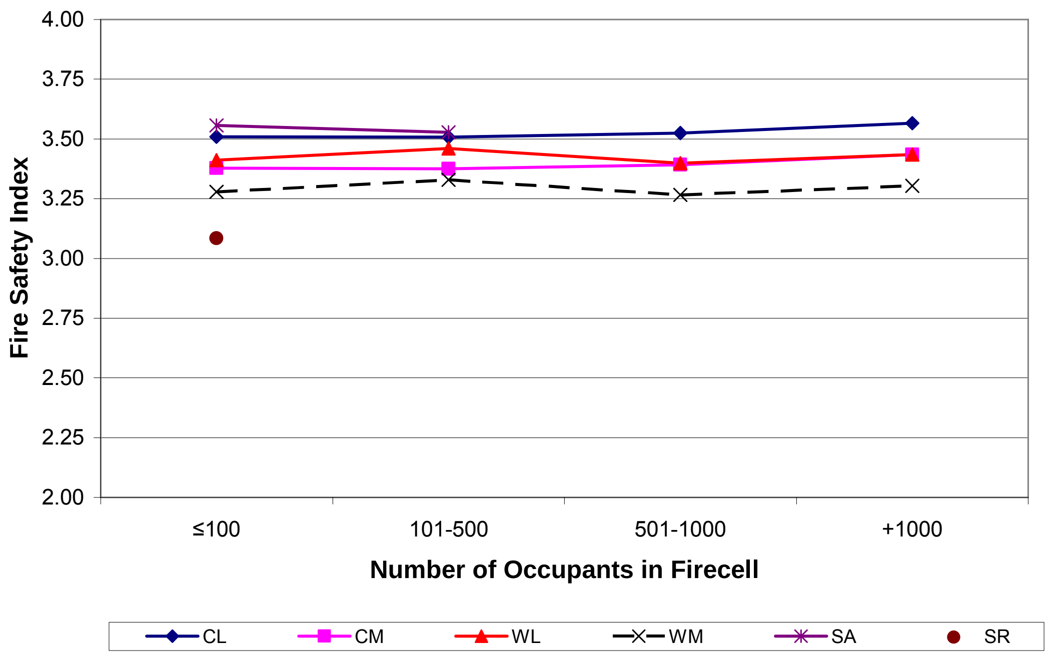


Figure 7.15 - Fire Safety Index All Purpose Group, Over 58m Escape Height

7.4 Discussion

Fire Safety Indices determined in this study range from 2.10 to 3.6 (Table 7.1) indicating that there is considerable variation in the level of safety of buildings designed to C/AS1. This is not necessarily a bad thing, depending on the underlying reasons for the variations. These shall be investigated and discussed below as appropriate.

There are also a number of significant steps in the level of safety, particularly when changing between the 10-25 m and 25-34 m building escape height category. These are mainly to do with the introduction of sprinklers and /or the reduction or increase in the firecell and structural endurance rating.

7.4.1 Apparent Level of Safety of Buildings Designed to C/AS1

From Table 7.1 and 7.2 and Figures 7.1 to 7.15 it is apparent that the level of safety generally increases as a function of escape height and/or building occupant numbers as additional fire safety features are introduced to reduce the risk.

As noted above the model gives a fire safety index value for all occupancies, occupant numbers and building escape heights in the range of 2.1 to 3.6. Variations in FSI between successive building parameters vary by 5-15% in most cases. The most notable exception to this is the 4-10 m building escape height for SR purpose group which has a FSI 26% below that of 10-25 m building escape height category. This is primarily due to the lack of required safety precautions in this class of building at the lower building heights.

The FSI ranks the different purpose groups from most safe to least safe in the following order as shown in Table 7.3 below.

Rank	Purpose Group	Fire Safety Index			Rankings Based on the NZ Fire Service Statistics ##	
		Min.	Max.	Average	deaths/year	Rank
1	SA – Sleeping Accommodation	2.736	3.556	3.048	0.2	1
2	CL – Crowd Large (CS under 100 occupants)	2.661	3.564	3.042	0.4	2
3	CM - Crowd Mercantile	2.528	3.432	2.927	Not included	Not included
4	WM - Working Medium (Medium Fire Hazard)	2.252	3.326	2.690	2.8	3
5	WL - Working Low (Low Fire Hazard)	2.385	3.459	2.822		
6	SR - Sleeping Residential	2.103	3.084	2.597	4.6	4

Refer to Appendix H for assessment of NZ Fire Service Statistics 1999 to 2004

Table 7.3 – FSI Rankings for Purpose Groups - C/AS1: June 2001

The above rankings are what could reasonably be expected and compare very well with the rankings determined from the New Zealand Fire Service statistics. The purpose groups can be divided into two categories. The FSI Rankings 1, 2 and 3 are largely made up of purpose groups with large occupant numbers and/or persons who may have a low familiarity with the building. FSI Rankings 4, 5 and 6 are largely made up of purpose groups with low occupant numbers and persons who may have a high familiarity with the building.

The unusual result is that of the Sleeping residential (SR) purpose group which score the lowest ranking. It could have been expected that this group, given that it is a sleeping purpose group, would have scored higher, and may be above the working purpose groups (WL and WM). However it is consistent with the New Zealand Fire Service statistics which show that the residential occupancy has the highest death rate in building fires of the purpose groups assessed in this study. Note that domestic houses, purpose group SH, have the overall highest death rate for building fire, 19.2 deaths/year[60], which is an order of magnitude greater than the SR purpose group. The SH purpose group was excluded from this study as noted in Section 4.2.2.

Table 7.4 below shows that the level of safety increases with increasing occupant numbers. This is because C/AS1 generally increases the safety requirements with increases in occupant numbers. The number of escape routes and escape widths required is directly proportional to the number of persons thus effectively maintaining a constant escape time. Increased safety due to improvements in the type of alarm with occupant numbers is not significantly reduced by the additional risk posed by permitted increased escape lengths.

Rank	Occupant Numbers	Fire Safety Index		
		Min.	Max.	Average
1	Over 1000 Occupants	2.656	3.564	2.872
2	501 to 1000 Occupants	2.470	3.522	2.801
3	101 to 500 Occupants	2.252	3.526	2.744
4	Up to 100 Occupants	2.103	3.556	2.725

Table 7.4– FSI Rankings based on Occupant Numbers - C/AS1: June 2001

The FSI ranks the different building height categories from least safe to most safe in the following order as shown in Table 7.5 below.

Rank	Building Heights	Fire Safety Index		
		Min.	Max.	Average
1	Over 58 m	3.084	3.564	3.405
2	46< He≤58 m	2.556	3.042	2.882
3	34< He≤46 m	2.407	3.108	2.831
4	10< He≤25 m	2.455	3.021	2.796
5	25< He≤34 m	2.289	3.124	2.727
6	4< He≤10 m	2.103	3.078	2.605

Table 7.5 – FSI Rankings based on Building Escape Height - C/AS1: June 2001

From Table 7.5 the level of safety generally increases with building height. The only exception to this is the 10-25 m building height category, which is graded ahead of the 25-34 m building height category. The difference between these two categories comes down to the level of safety provided by the increased firecell rating in the 10-25 m height category over installation of sprinklers in the 25-34 m height category. The model as it stands rates the impact on safety of fire barriers at almost twice that of sprinklers. This is reflected in risk ranking models from other countries but may not be appropriate to a model for New Zealand buildings. Refer to Section 7.4.3 below for further discussion and evaluation.

7.4.2 Building/Use Parameters Sensitivity

The Building/Use parameters were chosen and weighted based on a simple assessment of the likely impact on the evacuation time of a building. The analysis although crude at best, met the objective of providing an estimate of the weightings, however it was noted during the development of the model that the FSI was sensitive to some of the Building/Use parameters. This sensitivity is assessed as follows:

If the weighting of the purpose group parameter (BU1), occupant number parameter (BU3) or fire hazard category parameter (BU4) are halved or doubled this has little impact on the FSI. Changes in these parameter weightings cause a 1-2% change in the range for each building height and occupant number category but there is negligible differential change across building height categories. Refer to Figures 7.16 to 7.18 below for an example of the change resulting from variations to the purpose group parameter (BU1), occupant number parameter (BU3) or fire hazard category parameter (BU4) respectively.

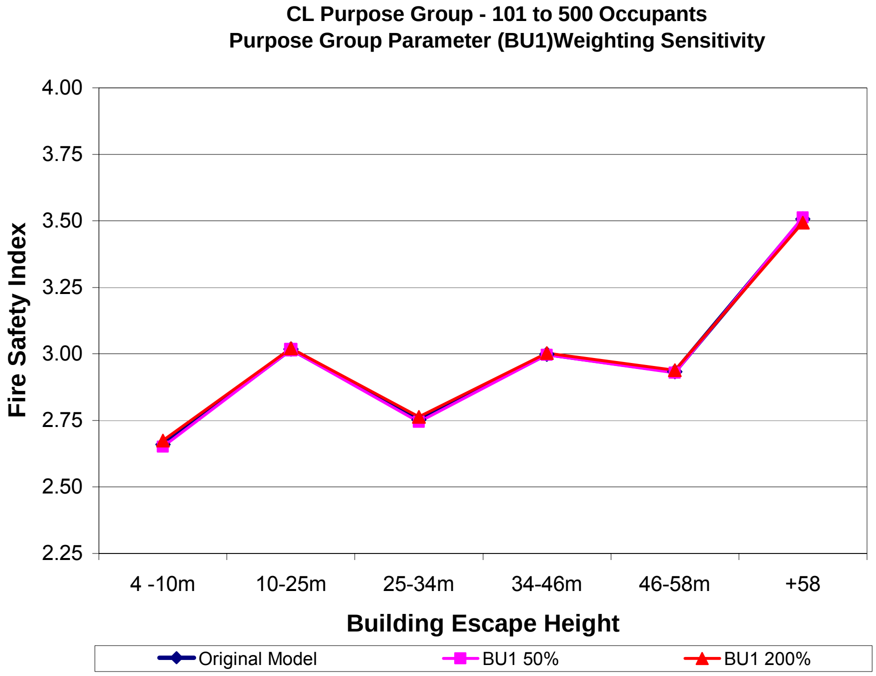


Figure 7.16 - Fire Safety Index - Example of Purpose Group Weighting Sensitivity

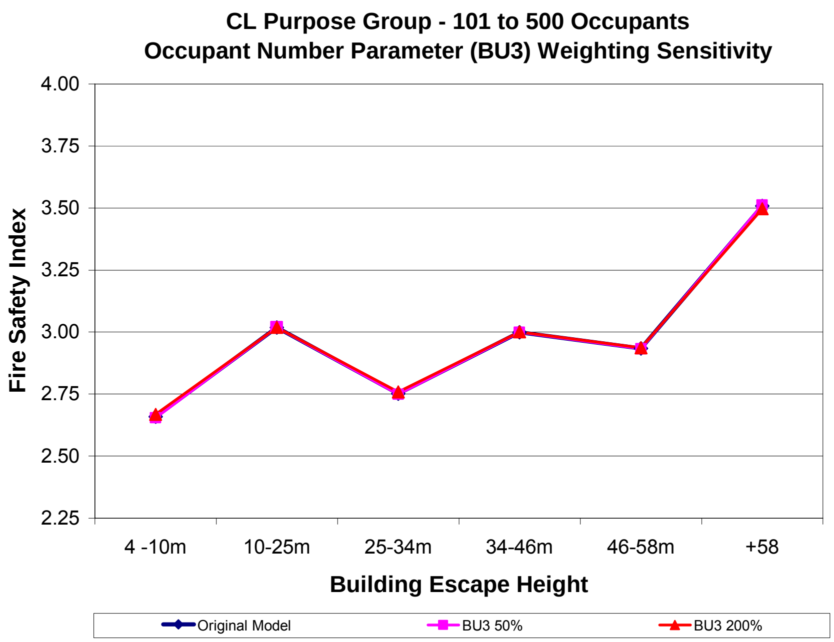


Figure 7.17 - Fire Safety Index - Example of Occupant Number Weighting Sensitivity

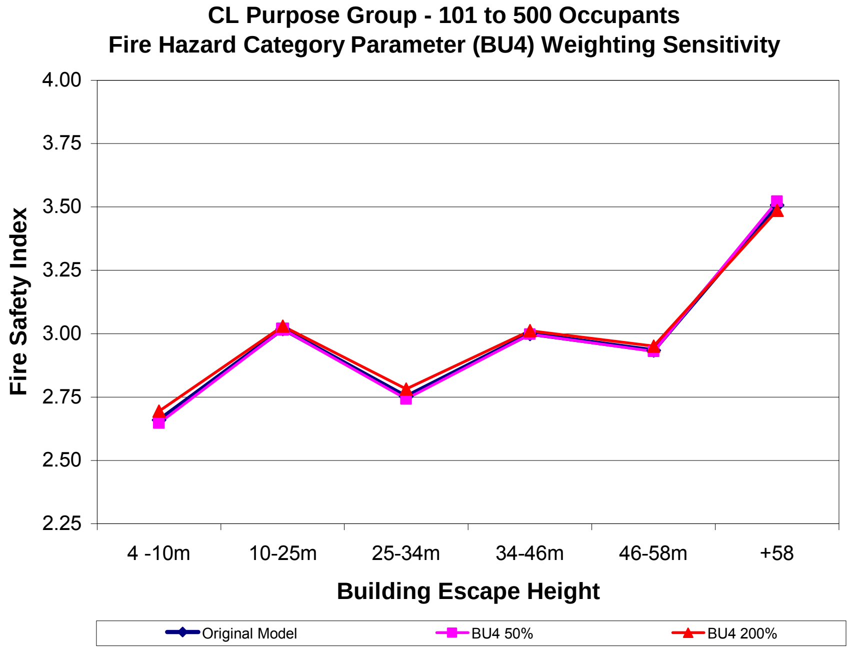


Figure 7.18 - Fire Safety Index - Example of FHC Weighting Sensitivity

The model is sensitive to changes in the building escape height parameter (BU2) weighting, although the magnitude of the change is small. If the weighting is reduced by 50% from 6.6% to 3.3% then the FSI reduces for the lower building height ranges by approximately 2.5 to 5.5% depending on the purpose group. The FSI for upper building height ranges increased by approximately 3.3% across all purpose groups.

Furthermore, if the building escape height parameter (BU2) weighting is increased from 6.6% to 13.2%, which gives it the same order of weighting as the firecell and sprinkler rating then the opposite trend to reducing the weighting occurs. The FSI increases for the lower building height ranges by approximately 6.5 to 10% depending on the purpose group. The FSI for upper building height ranges increased by approximately 7.1% across all purpose groups. Therefore the fire safety feature score is dominating the FSI when the BU2 weighting is low and the building escape height is dominating when the weighting is high.

Figure 7.19 below shows the change to FSI resulting from variations to the building escape height parameter (BU2). From the graph it is apparent that the model as it is currently proposed is quite sensitive to the building height parameter weighting.

Furthermore, given that the vertical safe paths (stairs) have a definitive fire rating, then the risk to occupants must increase and as such the safety of the building reduces as the height of a building is increased for uniformly prescribed fire safety precautions. For example there are no increases in the safety requirements for building that exceeds a height of 58m by a factor of 2 or 3 in C/AS1. The firecell rating of the vertical safe path (stairs), alarm type etc is not required to change but the number of occupants and escape time does increase by an order of magnitude. Therefore by inspection the risk to occupants must increase. It is the author's opinion that the weighting of the building escape parameter in this model is in the right order of magnitude for the type and nature of this study based on the literature reviewed.

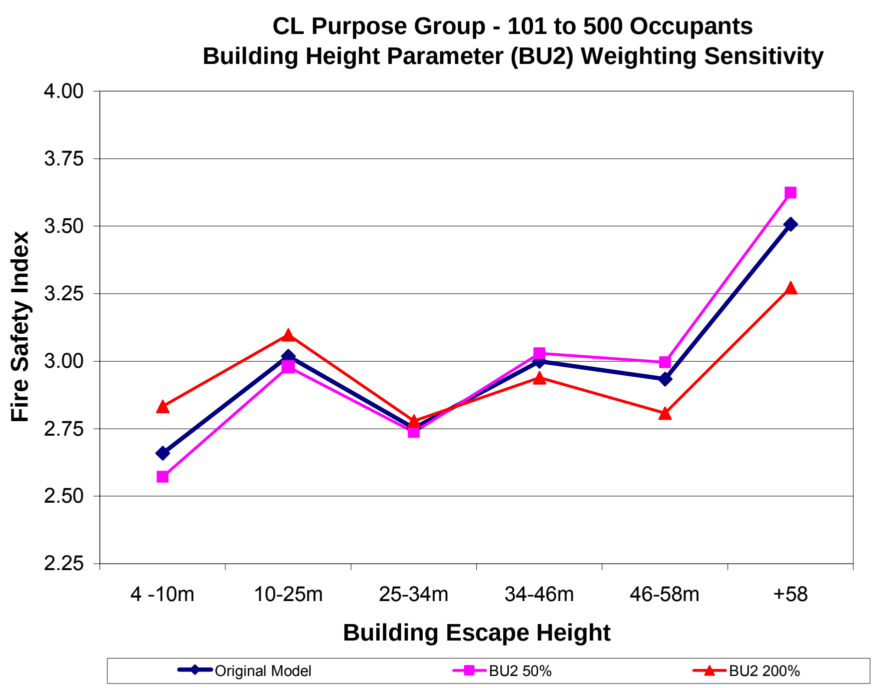
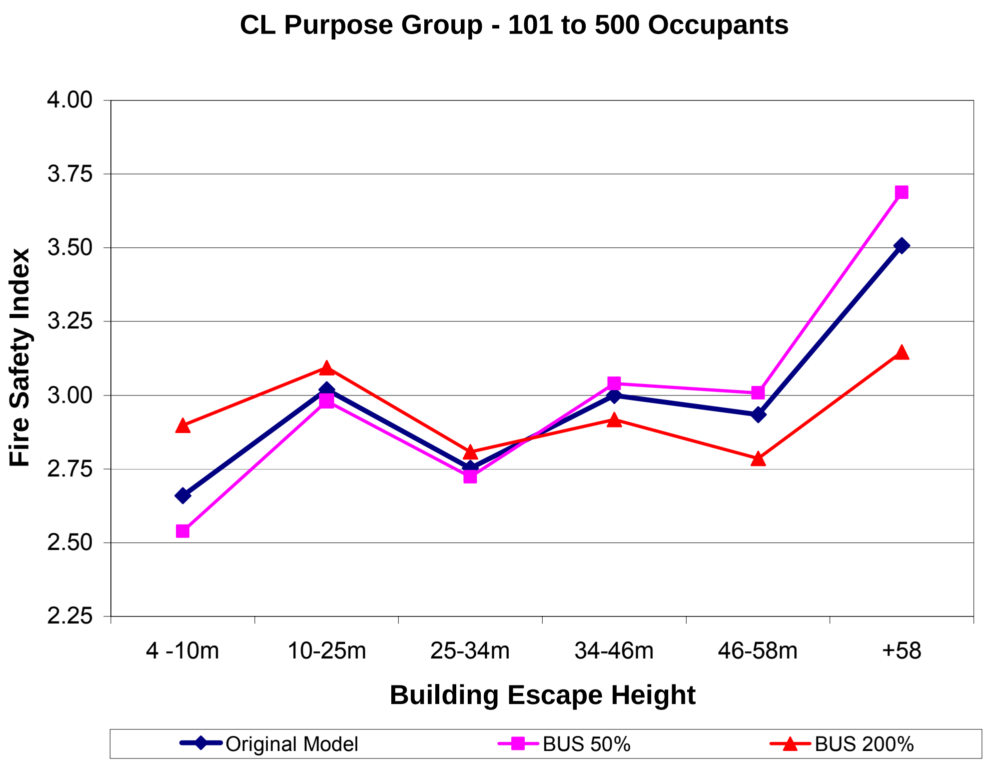


Figure 7.19 - Fire Safety Index - Example of Building Escape Height Weighting Sensitivity

The same sensitivity analysis was carried out on the Building /Use score parameter weightings as a whole. All four parameter weightings were reduced by 50% and increased by 200%. The results are shown in Table 7.20 below. By inspection the results are dominated by the change in the building escape height parameter similar to the above analysis.



<u>Figure 7.20 - Fire Safety Index - Example of Building/Use Score Parameter Weighting Sensitivity</u>

7.4.3 Impact of Firecell Rating Parameter

The analysis of C/AS1:June 2001 revision shows an apparent drop in safety between the 10-25 m building escape height category and the 25-34 m escape height category. The reason for the drop is the reduction in the firecell rating permitted with the addition of sprinklers is not offset in the risk model by the sprinkler parameter. In simple terms the tradeoff of firecell rating for sprinklers is not deemed equal in the model. There are two possible conclusions one can draw; firstly that the model weightings for the firecell rating and sprinklers are not compatible or secondly that the tradeoff may not be justifiable. The compatibility of the firecell and sprinkler parameter weightings is assessed below.

Buildings in the 10-25 m escape height range generally have either a Type 3 (heat detection) or Type 4 (smoke detection) automatic alarm system and a 45 minute firecell (F) rating. The introduction of sprinklers at the next building escape height category allows for the (F) rating to be reduced to 30 minutes. It is assumed that this equates to 50% of a 60 minute rating that would be required for these types of building if they were permitted to be un-sprinklered along the same lines as the 50% reduction in the structural endurance rating permitted for a sprinkled fire cell.

The weightings from both the FRIM-MAB[35] and NFPA101A FSES[32] system clearly weight the fire separation and structural fire capacity at approximately twice that of sprinklers. However this weighting ratio is the main reason for the apparent anomaly in the 10-25 m escape height results from this model. What this suggests is that the safety provided by sprinklers is either grossly overrated by C/AS1 and that a 50% reduction in fire rating for sprinkled firecells may be unconservative or that sprinkler systems in other countries are not as reliable at controlling fires as sprinkler systems in NZ.

Marryat [27] reported that sprinklers in New Zealand and Australia are 99.5% effective in controlling fire based on a study of sprinkler data from 1886-1986. This is considerably more reliable than noted by Edward et al [25] 86% to 99.5% and William el al [26] 84% to 96%. Furthermore, Feeney [24] suggests that passive fire resistance could be omitted from structural elements in sprinkled buildings, as it is effectively redundant due to the excellent reliability of sprinkler systems in NZ in controlling fires.

Therefore given the above it maybe reasonable to allow a significant tradeoff between providing sprinklers and fire rated barriers/construction, as allowed for in C/AS1. It is clear from both NZ and international experience that sprinklers provide considerable fire safety to a building.

The impact of changing the weighting of fire barrier parameter (A) and the building fire control parameters (D) in the fire safety feature score was investigated. The weighting for the fire barrier parameters A1 (0.1504) and A2 (0.0962) were reduced by 25% and 50% and the weighting for the building fire control D1 (0.0713), D2 (0.0190) and D3 (0.0048) were increased by 25% and 50%. Finally the weighting for the A and D parameters were equated. Example results are shown in Figure 7.21 below:

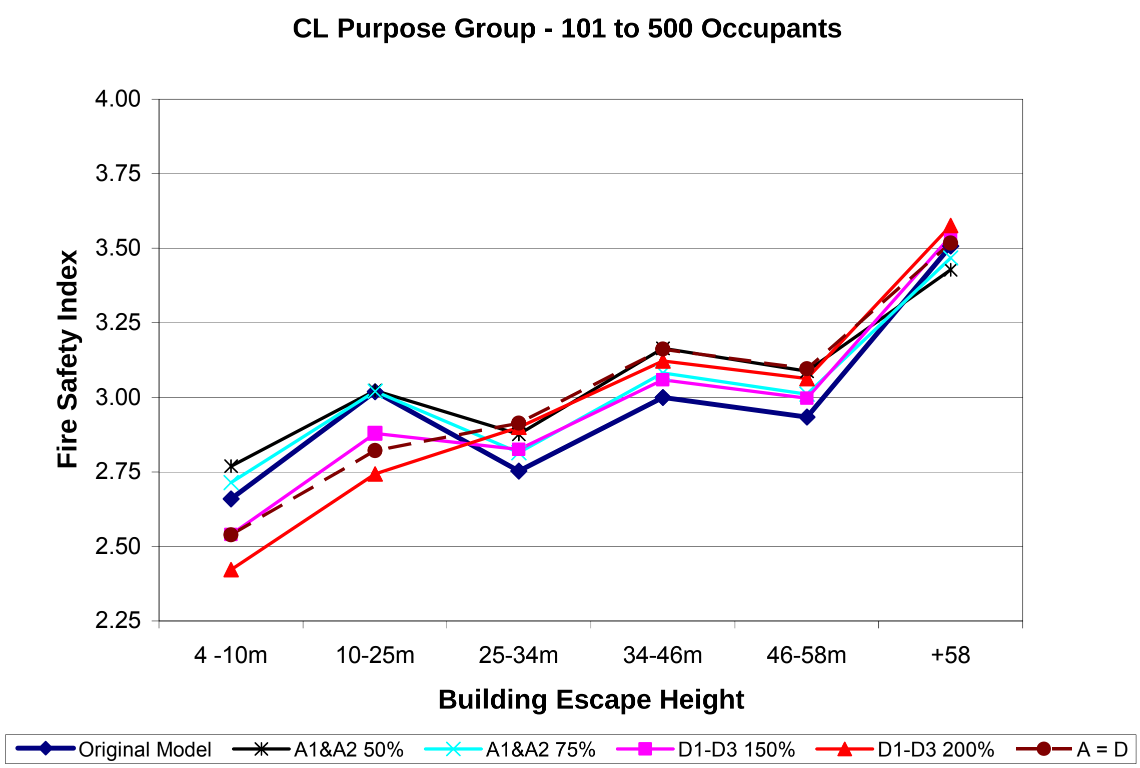


Figure 7.21 - Fire Safety Index - Example of Fire Barrier/Building Fire Control Weighting Sensitivity

Reducing the fire barrier parameter weightings (A1 & A2) had no impact on the 10-25 m building escape heights. This was because the fire barrier parameter dominates the FSI for the 10-25 m building escape height category. It did however impact on other height categories, as the reduction in safety index was more than made up by increasing the weightings uniformly across all the remaining parameters.

Increasing the building fire control parameter weightings (D1: sprinklers, D2: water supply and D3: occupant fire fighting) had more impact on the model. In particular the FSI for the 10-25 m escape height category reduced significantly and FSI for buildings over 25 m escape height increased.

Equating the fire barrier and building fire control parameter weightings produced the combined effect of reducing the fire barrier and increasing the building fire control weighting. The result is a lower FSI for the lower building escape height categories and increased FSI for the higher building escape height categories. The key feature from this is that the 10-25 m high buildings are ranked below the 25-34 m high buildings, as the fire barrier rating no longer dominates.

So is the safety afforded the firecell rating in this model, being approximately twice that of sprinklers, appropriate? The model as it stands is based on similar Swedish[35] and USA[32] ranking systems where sprinklers are clearly not rated as important to life safety as fire barriers (firecell ratings). However, Enright [22] investigated the impact on life safety of using a Type 5 alarm in lieu of a Type 4 or part of a Type 7. The analysis involved a probabilistic risk analysis. This study found that the most sensitive parameter was the Theoretical Annual Loss of Life (TALL) for the occupants in the room of fire origin. This is not surprising as the occupants of the room of fire origin are exposed to the fire first, have the least warning (depending on state of alertness) and more likely to be required to travel through the smoke and/or past the flames to escape. Therefore fire barriers provide negligible safety to the occupants of the room of fire origin. The key safety parameters for the occupants in the room of fire origin are the alarm type, smoke or heat detection, and whether or not sprinklers are installed and the performance of the sprinklers.

Frantzich [54] used the reliability index method to assess the fire safety of a hotel. The most sensitive parameter to the occupants of the room of fire origin was found to be the t^2 fire growth parameter (α). The growth rate of a fire is reduced by the operation of sprinklers. The most sensitive parameter for occupants outside the room of fire origin was found to be the fire barriers (walls and doors). Therefore, for the majority of occupants in a building it could be argued that the firecell (fire barrier) rating provides the most safety.

Thomas [61] evaluated the effectiveness of combinations of alarms, sprinklers and passive fire protection (fire rated wall construction) based on the number of injuries and fatalities of civilians and injuries to fire fighters using data from the USA National Fire Incident Reporting System (NFIRS). Thomas concluded:

> *"Based on the data analysed it appears that sprinklers are generally more effective in reducing fire spread, civilian fatalities, fire fighter injuries and property losses than either detectors, protected construction or both detectors and protected construction."* [61]

This conclusion appears to be well supported by the data presented by Thomas [61], as indicated by the summary of the data for civilian fatalities which is reproduced in Table 7.6 below. From Table 7.6 the sprinklered buildings clearly have a lower fatality rate than the non-sprinklered in the event of a fire. The average fatality rates have been determined as follows from the data in Table 7.6:

Average Fatalities with Sprinklers	1.7 deaths/1000 fires
Average Fatalities without Sprinklers	5.2 deaths/1000 fires
Average Fatalities with Detection	3.6 deaths/1000 fires
Average Fatalities with Protected Construction	2.6 deaths/1000 fires

Number of Civilian Fatalities per 1000 Fire in the USA								
Occupancy (Purpose Group)	**Sprinklers (S) / Detectors (D) / Protected Construction (PC)**							
	None	**D**	**PC**	**D/PC**	**S**	**S/D**	**S/PC**	**S/D/PC**
Public Assembly (CL)	1.3	1.3	1.3	0.5	0.0	0.0	0.0	0.0
Educational (CL)	0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.6
Institutional (SC/SD)	4.3	8.3	1.1	4.0	5.4	0.0	2.2	1.9
1&2 Family Dwellings (SH & SR)	11.6	5.9	9.5	4.7	10.9	7.0	4.0	5.1
Apartment (SR)	9.4	8.7	7.4	6.8	2.6	1.3	2.3	2.8
Rooming, Boarding (SR)	39.5	30.0	15.7	28.2	0.0	21.3	0.0	0.0
Hotels and Motels (SA)	4.2	11.6	4.8	6.8	0.0	3.7	0.0	1.2

Dormitories (SR)	2.4	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Retail (CM)	1.6	0.0	0.9	0.0	0.0	0.0	1.4	0.0
Offices (WL)	1.2	1.9	0.5	0.0	0.0	0.0	0.0	0.6
Manufacturing (WL/WM)	1.9	0.7	3.7	0.9	0.9	1.6	0.8	2.8
Storage (WM)	1.3	3.0	1.8	0.0	1.2	0.0	0.0	0.0
Average	**6.6**	**6.0**	**3.9**	**4.3**	**1.8**	**2.9**	**0.9**	**1.3**

Note: the shaded figures should be treated with caution as they are based on low numbers of fires (less than 2000)

Table 7.6 – Civilian Fire Fatality Rate in USA[61]

Therefore based on the above it appears reasonable that the weighting given the sprinkler parameter should be equal to, if not greater than, the weighting given to both the fire detection/alarm system parameter and the firecell rating parameter. An adjustment to the weightings has not been incorporated into the FSI model as part of this study. It is suggested that all the weightings be reviewed in the future if work is undertaken to develop the model further.

7.4.4 Impact of C/AS1: October 2005 Revisions

C/AS1 was re-issued in October 2005[55] with a number of minor revisions and two significant revisions. The first change of note was the introduction of a new occupancy class under the crowd purpose group category. The new class is "Early Childhood Centres". This is a special class as it incorporates both crowd and sleeping occupancy requirements. This class of building is not specifically relevant to this study and will not be discussed further. The second major revision is to the firecell ratings. This is particularly significant to this study and follows on from the discussion above regarding the tradeoff between firecell rating and sprinklers.

Table 4.1-C/AS1 has been revised with new firecell ratings for all purpose groups. The firecell ratings are now a function of the escape height and the fire hazard category. There is still a drop in firecell rating (15 to 30 minute drop) at a number of escape height categories, typically when sprinklers are introduced, however there is also an increase in the firecell rating up to 90 minutes

in the higher building escape heights. For example the difference in firecell ratings for the crowd Purpose Group CL and the escape heights relevant to this study are shown in Table 7.7 below.

The full range of firecell ratings for all occupancies under consideration in this study is shown in Appendix F.

Firecell (F) Rating (Minutes)						
Code Revision	**Building Escape Heights**					
	4 to <10m	**10 to <25m**	**25 to <34m**	**34 to <46m**	**46 to <58m**	**Over 58m**
Up to 100 Occupants						
C/AS1:June 2001	30	45	30	30	30	60
C/AS1:October 2005						
FHC = 1	45	45	30	45	45	60
FHC = 2	60	60	45	45	60	90
FHC = 3	60	90	45	60	60	90
101-500 Occupants						
C/AS1:June 2001	30	45	30	30	30	60
C/AS1:October 2005						
FHC = 1	45	45	30	45	45	60
FHC = 2	60	60	45	45	60	90
FHC = 3	60	90	45	60	60	90
501-1000 Occupants						
C/AS1:June 2001	30	30	30	30	30	60
C/AS1:October 2005						
FHC = 1	45	30	30	45	45	60
FHC = 2	60	30	45	45	60	90
FHC = 3	60	45	45	60	60	90
Over 1000 Occupants						
C/AS1:June 2001	30	30	30	30	30	60
C/AS1:October 2005						
FHC = 1	45	30	30	45	45	60
FHC = 2	60	30	45	45	60	90
FHC = 3	60	45	45	60	60	90

Table 7.7 - Firecell Ratings for CL Purpose Group

Full tabulated results of the FSI analysis based on C/AS1: October 2005 are shown in Appendix G.

The FSI rankings based on C/AS1: October 2005 for the different purpose groups, occupant numbers and building escape heights are shown below in Tables 7.8, 7.9 and 7.10 respectively. The results are graded from most safe to least safe.

Rank	Purpose Group	Fire Safety Index		
		Min.	Max.	Average
1	CL – Crowd Large (CS under 100 occupants)	2.968	3.809	3.338
2	CM - Crowd Mercantile	2.865	3.676	3.213
3	SA – Sleeping Accommodation	2.781	3.554	3.190
4	WM - Working Medium (Fire Hazard)	2.534	3.571	3.048
5	WL - Working Low (Fire Hazard)	2.667	3.704	3.109
6	SR - Sleeping Residential	2.348	3.082	2.719

Table 7.8– FSI Rankings for Purpose Groups - C/AS1: Oct. 2005

From Table 7.8 the FSI rankings for the different purpose groups have changed as a result of the change to the firecell ratings in the C/AS1: Oct. 2005 revisions. The crowd purpose groups are now ranked the safest purpose groups with the Sleeping Accommodation (SA) purpose group dropping from 1st to 3rd place in the rankings. The purpose group rankings for 4th through to 6th have not changed.

Rank	Occupant Numbers	Fire Safety Index		
		Min.	Max.	Average
1	501 to 1000 Occupants	2.817	3.767	3.096
2	Over 1000 Occupants	2.709	3.814	3.087
3	101 to 500 Occupants	2.534	3.750	3.045
4	Up to 100 Occupants	2.348	3.752	2.990

Table 7.9 – FSI Rankings based on Occupant Numbers - C/AS1: Oct. 2005

From Table 7.9 the FSI rankings for the different occupant numbers have also changed as a result of the change to the firecell ratings in the C/AS1: Oct. 2005 revisions. Buildings with 501 to 1000 occupants are now ranked the safest group.

Rank	Building Heights	Fire Safety Index		
		Min.	Max.	Average
1	Over 58m	3.082	3.809	3.611
2	46< He≤58m	2.801	3.485	3.335
3	34< He≤46m	2.785	3.550	3.141
4	4< He≤10m	2.348	3.325	2.955
5	10< He≤25m	2.644	3.266	2.950
6	25< He≤34m	2.534	3.369	2.933

Table 7.10 – FSI Rankings based on Building Escape Height - C/AS1: Oct. 2005

From Table 7.10 the FSI rankings for the different building escape heights have also changed as a result of the change to the firecell ratings in the C/AS1: Oct. 2005 revisions. The main change is at the bottom end of the rankings where 25-34 m escape height is now least safe. The 4-10 m building escape height category has moved from least safe to a ranking of 4th.

The percentage difference in FSI between C/AS1: June 2001 and C/AS1: October 2005 revisions for the different purpose groups, occupant numbers and building escape heights are shown below in Tables 7.11, 7.12 and 7.13 respectively. The results are graded from least impact on FSI to most impact on FSI.

Rank	Purpose Group	% Change in Fire Safety Index		
		Min.	Max.	Average
1	WM - Working Medium (Fire Hazard)	0.0%	21.9%	13.8%
2	WL - Working Low (Fire Hazard)	0.0%	20.7%	10.4%
3	CM - Crowd Mercantile	0.0%	19.5%	10.1%
4	SR - Sleeping Residential	0.0%	11.8%	5.2%
5	CL/CL – Crowd Large/Small	0.0%	18.6%	10.0%
6	SA – Sleeping Accommodation	0.0%	9.0%	4.9%

Table 7.11 – Percent Change in FSI Between C/AS1:June 2001& C/AS1: Oct. 2005 for Purpose Groups

From Table 7.11 the changes in C/AS1: Oct. 2005 revision had the most impact on the working purpose groups and the least impact on the sleeping purpose groups.

Rank	Occupant Numbers	% Change in Fire Safety Index		
		Min.	Max.	Average
1	101 to 500 Occupants	0.0%	21.9%	11.1%
2	501 to 1000 Occupants	0.0%	20.0%	10.4%
3	Up to 100 Occupants	0.0%	21.9%	9.9%
4	Over 1000 Occupants	0.0%	17.8%	7.3%

Table 7.12 – Percent Change in FSI Between C/AS1:June 2001& C/AS1: Oct. 2005 for Occupant Numbers

From Table 7.12 the change in the FSI rankings is relatively consistent across all occupant number categories.

Rank	Building Heights	% Change in Fire Safety Index		
		Min.	Max.	Average
1	46< He≤58 m	8.1%	17.9%	15.8%
2	4< He≤10 m	0.0%	21.9%	14.0%
3	34< He≤46 m	7.9%	20.5%	11.2%
4	25< He≤34 m	0.0%	10.8%	7.8%
5	Over 58 m	0.0%	7.6%	6.1%
6	10< He≤25 m	0.0%	20.1%	5.8%

Table 7.13 – Percent Change in FSI Between C/AS1:June 2001& C/AS1: Oct. 2005 for Building Escape Heights

From Table 7.13 the change in FSI rankings for the different building escape heights are divided into to groups although there is no rational pattern. The FSI of building in the 25-34 m escape height category have only increased by 2% over the 10-25 m escape height category. Therefore buildings with a 25-34 m escape height are still graded with an apparent level of safety below that of the lower building heights.

From the above analysis, based on the Fire Safety Index risk model developed in this study, it is appears that the changes to C/AS1 have had a significant impact of raising the level of safety of most building height, occupant number and purpose group classes. However it should be noted that there remains an apparent safety disparity between the level of safety provided by sprinklers and the firecell rating.

8 EQUIVALENCY

8.1 Prescriptive versus Performance Based Codes

The introduction of performance based fire safety building codes has resulted in a rather interesting dilemma for the fire engineering profession. The performance based codes generally set out the performance criteria in rather simple and broad terms. For example:

> *"Buildings shall be provided with escape routes which allow occupants to reach a safe place without being overcome by the effects of fire and give the fire service adequate time to rescue occupants"[NZ Building Regulations 1992[(2)]].*

There are no specific design standards (written into law) that spell out what an appropriate design fire is, an acceptable method for calculating the escape times, or time to untenable conditions and the acceptable level of safety/safety margin. Given this, a fire engineer that chooses the specific design path needs to determine the parameters for themselves and justify their solutions. This in itself is no easy task without recognised benchmarks or standard to design to.

The territorial authorities are faced with a similar problem. How do they verify that an engineered solution that has been submitted for consent meets the performance requirements of the NZ Building Regulations?

There is a school of thought in the fire engineering profession that the engineered designs/alternative solutions should provide an "equivalent" level of safety to that of prescriptive solutions. In fact some territorial authorities and regulatory authorities in New Zealand will not accept a design unless it is proven to have an "equivalent" level of safety to a solution prepared to the prescriptive code.

The NFPA 101A [(32)] Fire Safety Evaluation System from the USA is a risk ranking scheme that has specifically been designed to assess whether or not a design or an existing building provides an equivalent level of safety to a building design to the NFPA 101 Life Safety Handbook [(31)]. The Swedish Building Code, BBR, *"requires that an analytic design provide a level of safety the same as or better than that which would have been obtained using prescriptive design"*, Ludin [(56)]. Therefore equivalency is used rightly or wrongly in other countries as a means for controlling the level of fire safety in buildings that are designed using performance based engineering design.

In New Zealand the Department of Building and Housing (DBH) is sometimes required to rule on whether or not a particular building design or design/construction detail complies with the relevant New Zealand Building Code. This process is known as a "Determination". When there is a dispute between an owner, designer, territorial authority or regulatory authority (e.g. Fire Service Commission) on a matter of code compliance one of the parties may seek a Determination from the DBH. The DBH ruling (determination) is binding on all parties.

Sometimes a situation arises where a fire engineer designs and details a building that clearly deviates or does not follow the provisions of the New Zealand Building Code Approved Document for Fire Safety C/AS1. In this case the design is deemed an "alternative solution". In most cases additional fire safety precautions are included in the design to compensate for the apparent "non-compliance". Depending on the extent of the variation to C/AS1 and the details of the compensating fire safety measures the validity of the design may be questioned. This can occur at the Building Consent stage or on completion of the building at the construction certification stage. If agreement cannot be reached between the parties as to whether or not the building complies with the performance requirements of the Building Regulations as an alternative design then a Determination from the DBH may be sought.

In the absence of specific measurable performance criteria in the Building Regulations for alternative solutions the DBH have decreed that:

> *"The Authority (DBH) sees the acceptable solutions as an example of the level of fire safety required by the building code. Any departure from the acceptable solution must achieve the same level of safety if it is to be accepted as an alternative solution complying with the building code."* [(5)]

Hence the DBH require alternative fire engineering designs to provide at least an equivalent level of safety to a design prepared to C/AS1.

8.2 Why Equivalency?

There are many reasons for and against using the level of safety provided by the prescriptive documents as a minimum benchmark for performance based design. Some of these are given below to highlight the issues:

Are the prescriptive documents safe? This is one of the major debatable questions. There is an argument that the low level of fatalities in many building categories covered by the prescription solution indicates that they are safe and that society has accepted this level of safety. There is of course the possibility that we may not have had a major fire that has fully tested the provisions of the Acceptable Solutions, C/AS1.

Furthermore has society really accepted the level of safety of the prescriptive document? There may or may not be sufficient information on fire safety of buildings in the public arena in a format the members of the public can understand to enable the public to judge.

It should be noted that there are many buildings that exist today that were built before the current provisions of the prescriptive document were introduced. Many of these building are not likely to comply with the provisions of the current prescriptive document. Therefore the safety performance of the current prescriptive document is difficult to judge based on the fire history alone.

Bukowski (57) notes four reasons that equivalency and society's apparent acceptance of perceived building safety may not be justified. These are repeated below as follows:

a) *When dealing with rare events, such as disastrous fires, society may believe that the risk is zero.*

b) *Codes set the minimum requirements, which are often exceeded in practice. Therefore the apparent good performance of a code may in fact be overrated such that designing to the minimum code standard may actually result in a reduction in safety of the building stock and an increase in losses.*

c) *There is an assumption that engineering methods accurately reflect the expected risk to life in different buildings. Methods and accuracy are constantly changing.*

d) *There is an assumption that both the buildings and society's views of risk are static. Fire disasters often point out the flaws in codes, which are subsequently corrected.*

Despite the above issues there remains a need to be able to validate fire engineering designs undertaken to the performance based codes and at this time, in the absence of fire engineering design standards, an equivalency approach may be considered a reasonable method.

It should be noted that it is not the objective of this study to determine whether or not equivalency is a reasonable approach for validating alternative designs and the issue certainly requires much debate in a forum outside the bounds of this report. However there is a side issue for which the work in this study may contribute to resolving with some further research. The issue being alluded to is that of "how" we determine whether or not a design is equivalent to a design prepared to C/AS1.

8.3 Fire Safety Index as a Tool for Evaluating Equivalency

The model proposed in this report could be used to validate engineering designs by allowing a rapid comparison between the "alternative" engineered design and an equivalent designed prepared to the prescriptive solutions C/AS1.

In this application the building use parameters would essentially cancel each other out and the fire safety comparison would be based solely on the fire safety features score.

It is envisaged that this model could be used as a first order assessment tool enabling a rapid assessment of a design for equivalency to C/AS1. The object being to identify designs which clearly pass, clearly fail or are questionable and require a closer and more robust investigation such as a full probabilistic risk analysis.

Further validation of the model is required before it could be used with confidence for this type of task. However some examples have been investigated below to assess the model's capabilities.

8.4 Exemplar Analysis

8.4.1 Example 1 – Type 5 Alarm Assessment

A Type 5 alarm comprises a modified alarm system with heat and/or smoke detection and manual call points. This is permitted in Sleeping Purpose groups in lieu of a Type 4 alarm (smoke detection) and Type 7 alarm (smoke detection + sprinklers). These are denoted types 4e and 7e respectively in Table 4.2 C/AS1. The key difference is that the smoke detection is a local alarm connected to sounders in the room of fire origin only. A heat detector provides a delayed alarm, which alerts all occupants in the building. This enables occupants to deal with a false alarm generated by inadvertent activation of the smoke detector without the need to evacuate the building, but provides early warning to the occupants in the room of fire origin if necessary.

The safety of the Type 5 alarm was investigated for the New Zealand Fire Service Commission in 2003, Enright [(22)]. The study comprised a full probabilistic risk analysis using combined event tree and Monte Carlo numerical sampling techniques.

The example model was a hotel room using the same geometry and basis assumptions as that of Frantzich's hotel study [(18)]. The room was a 6.0 m x 5.0 m in plan with a ceiling height of 2.4 m. The room was assumed connected to a corridor which was in turn assumed to be connected to a stair. A four storey building with 12 persons per floor (48 occupants) was assessed. This equates to a building with an approximate escape height of 9 m which places it in the 4-10 m escape height category in term of this project. Note that C/AS1 does not require a building of this height to have a type 7 alarm system (sprinklers + smoke detection). However for the purposes of this comparison the FSI calculation will be based on a building in the 4-10 m height category.

The analysis by Enright[22] involved determining the limit state equations for RSET and ASET in a similar manner to that described in section 5.6.8 above for the reliability index method. The parameters of the equations were assigned probability distributions and the Expected Loss of Life (ELL) and Total Annual Loss of Life (TALL) were calculated for the various alarm options. The reader is referred to the full Fire Service Commission Report [22] for a more comprehensive description of the method. The results for TALL are shown in Table 8.1 below.

The Type 4 and 4e alarm systems were analysed in the FSI model using the SA purpose group, maximum 40 occupants and 4-10 m building escape height category. As previously noted the Type 7 and 7e alarm systems were also analysed using the SA purpose group, and 4-10 m building escape height category. It should be noted that the maximum number of persons permitted in a SA purpose group firecell with a type 7 alarm is 160 persons, although less than 50 persons is used in this analysis for comparative purposes. The results for both are shown in Table 8.1 below.

Alarm Type	**PRA - Enright [22]**	**Fire Safety Index**	
	TALL (fatalities/year/person)	**Whole Building**	**Fire Alarm (B) and Sprinkler (D1) Parameters Only**
4	9.8×10^{-6}	2.815	0.588
4e (5)	1.2×10^{-5}	2.697	0.470
Difference	2.2×10^{-6}	0.118	0.118
% Drop in Safety	18.3%	4.2%	20.0%
7	1.3×10^{-7}	3.061	0.945
7e (5 & Sprinklers)	1.5×10^{-7}	2.944	0.827
Difference	2.0×10^{-8}	0.118	0.118
% Drop in Safety	13.3%	3.8%	12.5%

Table 8.1– Comparison Between FSI and PRA for a Type 5 Alarm System

The FSI model correctly predicts a drop in safety but the magnitude of the drop is significantly different to that predicted by the probabilistic risk analysis, i.e. from Table 8.1 Enright[22] calculated a reduction in safety of 18.3 % for change from a Type 4 to a Type 4e alarm where as the FSI calculated a 4.2% drop. Therefore this suggests that further work is required to calibrate the FSI model. It should be noted that the FSI model takes into account numerous other factors such as building height, occupant numbers and escape paths lengths to name but few. If we assess the fire alarm (B) and sprinkler (D1) parameters only, refer Table 8.1 above, we get results more in line with the PRA result. The 20% drop in safety determined by the PRA suggests that the alarm type has a significant impact on the safety of the building and as such should be weighted more heavily in the FSI model. By inspection it would not be possible to increase the weighting of the fire alarm parameter (B) to such an extent that the FSI model would give 20% drop in safety similar to the result of the PRA undertaken by Enright[22].

The above results indicate that these two forms of analysis are not numerically compatible at this time and further work is required to confirm the suitability of the model.

8.4.2 Example 2 – Single Means of Escape Apartment Buildings

The following assessment is based on two Determinations issued by the DBH in July 2005, Determination 2005/109[5] and September 2005, Determination 2005/134[6], for two single means of escape apartment buildings (purpose group SR). Both buildings exceeded the maximum permitted escape height for a single means of escape and as such were deemed alternative designs. For the purposes of this study the building shall be designated “Building 109” and “Building 134”.

For complete details of the buildings, the risk analysis and Determination rulings the reader is referred to the Determinations [5] [6]. A brief description of the buildings, analyses and ruling for each building is given below along with the FSI assessment results.

a) Building 109

Building 109 comprises an 18 storey apartment building with an escape height of 48 m. The purpose group is designated sleeping residential (SR). With the exception of ground and first floor level there are six 27 m^2 apartments on each floor opening onto an atrium which also contains lifts and a single stair. The number of occupants is approximately 12 per floor based on the number of beds in each unit. The stair in the atrium is the only means of escape. The building is fully sprinklered, has smoke detection, stair/atrium pressurisation and a voice communication system as the primary active fire safety precautions.

The major non-compliance with C/AS1 for this building is the single means of escape. The fact that the stairs are a part of an atrium also raises questions with regard to the stairs adequately performing as a safe path.

The risk analysis carried out by the DBH involved a comparative quantitative risk analysis. The analysis involved calculating the individual risk of fatality using event tree and probabilistic analysis for the Building 109 layout and a C/AS1 compliant building with a similar floor plate, but incorporating two stairs. There are no specific details of the analysis in the determination however the results found that there was a 51% to 74% probability that the building would be as safe as a building complying with C/AS1 or in other words there is a 25% to 49% probability that the building was less safe. This was deemed unacceptable by the DBH and it was determined that the building did not demonstrate equivalency to C/AS1.

b) Building 134

Building 134 comprises a 16 storey apartment building with an escape height of 43.6 m. The basement and a 3-level podium contains car parking and retail tenancies. The 12 storey tower block contains apartments and is designated a sleeping residential (SR) purpose group. Each floor contains 8 to 10 apartments separated into two separate sections (firecells) of 4 to 5 apartments. Each section contains lift, a single stair and the apartments open on to a horizontal safe path. The number of occupants is approximately 16 per floor based on the number of beds in each unit. The building is fully sprinklered, has smoke detection, stair pressurisation and a voice communication system as the primary active fire safety precautions.

The major non-compliance with C/AS1 for this building is also the single means of escape.

The risk analysis carried out by the DBH involved a comparative quantitative risk analysis. More details of the analysis are given in this determination and the method is similar in structure to that detailed in section 5.6.1 of this report. The analysis involved calculating the individual risk of fatality using event tree and probabilistic analysis for Building 134 layout and a C/AS1 compliant building with a similar floor plate, but incorporating two stairs. The results of the analysis found that there was a 55% to 79% probability that the building would be as safe as a building complying with C/AS1 or in other words there is a 21% to 45% probability that the building was less safe. This was deemed acceptable by the DBH and it was determined that the building demonstrate equivalency to C/AS1.

The primary difference between Building 109 and 134 was the presence of a horizontal safe path at each level in Building 134. The horizontal safe path provides an additional barrier between the room of fire origin and the stair in Building 134; where as the stair in Building 109 is likely to be immediately exposed to the fire products when the fire breaches the fire barriers of the room of fire origin.

c) Fire Safety Index Assessment

The fire safety index was calculated for the actual alternative design and a C/AS1 compliant design for each building. Building 134 has a lower escape height and as such has a lower C/AS1 compliant FSI required score due to parameter BU2. There is no specific horizontal safe path parameter in the FSI modelled so the “Protected Path” parameter (H7) was used to account for this in the Building 134 analysis. The FSI model also takes into account the safety due to reduced dead end and open path escape lengths in the alternative designs. The FSI analysis takes no account of the fast response sprinklers used in both alternative designs to enhance the sprinkler performance. An allowance for an enhanced water supply was accounted for in the alternative solution by selecting a Class B water supply. The impact of the voice communication system was included in the FSI analysis.

The results of the FSI analysis of Buildings 109 and 134 are given below in Table 8.2. The Determinations do not present the results in term of risk to life as used for comparison in the previous example, but gives the probability that the building is “as safe as or safer” than the control building which is compliant to C/AS1. Therefore the results are not directly comparable or numerically compatible; however a check was undertaken to see if the FSI ranked the buildings in the same order of safety.

Building	PRA – DBH [5][6] Probability of Being “As Safe As” or “Safer” than C/AS1			Fire Safety Index			
	P_{Min}	P_{Max}	Determination Result	Actual Building	C/AS1 Compliant Building	Actual / Compliant	Result
109	51%	74%	Fail	3.014	2.598	1.160	Pass
134	55%	79%	Pass	2.916	2.564	1.137	Pass
Ratio 134 / 109	1.09	1.07		0.967	0.986	0.981	

Table 8.2 - Comparison of the DBH Determination Results with FSI

From Table 8.2 the FSI scores both buildings as been safer than a similar building that complies with C/AS1. However the FSI also scores Building 109 as a safer building than Building 134 which is in direct contrast to the DBH results.

The most significant difference between the two buildings is the fact that building 109 has an increased firecell rating for the wall between the apartments and the stair. The Firecell parameter (A1) carries the highest weighting and as noted in the Section 7.4.3 is one of the most sensitive parameters in the FSI model.

The analysis was repeated with the increase in Firecell rating for Building 109 ignored. The results are shown in Table 8.3 below. Both buildings still achieve a FSI score indicating that they are safer than the C/AS1 compliant control building. However the ranking between the two buildings has altered with Building 134 now being deemed the safer building.

Building	**PRA – DBH** [(5)(6)] **Probability of Being "As Safe As" or "Safer" than C/AS1**			**Fire Safety Index** (Excluding Firecell Rating Parameter Effects)			
	P_{Min}	**P_{Max}**	**Determination Result**	**Actual Building**	**C/AS1 Compliant Building**	**Actual / Compliant**	**Result**
109	51%	74%	Fail	***2.713***	2.598	1.044	Pass
134	55%	79%	Pass	2.916	2.564	1.137	Pass
Ratio 134 / 109	1.09	1.07		1.075	0.986	1.031	

Table 8.3 - Comparison of the DBH Determination Results with Revised FSI

The analysis of these examples was undertaken to give an indication of whether or not the FSI could be used to rank buildings for the purpose of determining whether or not an alternative design is equivalent to a similar building complying with the requirements of C/AS1. The results obtained from this particular analysis are not conclusive with respect to relying on the current FSI model to determine compliance with C/AS1 with confidence. However the result are encouraging and with further analysis, refinement and validation of the model a simple risk ranking model could be used for this task in the New Zealand fire engineering environment.

The FSI model is not likely to replace the need for PRA, but may prove useful as a tool for designers, territorial authorities and regulatory authorities in determining which building designs warrant a more comprehensive analysis.

9 CONCLUSIONS

9.1 Fire Safety Index

A Fire Safety Index has been developed based on a simple weighted points system where the building geometry, use and fire safety features are graded according to the likely impact they will have on occupant safety. The points system was developed based on the grading systems developed in Sweden(35) and USA(32) for similar risk ranking models, adapted for the New Zealand Building Code requirements.

The model is made up of two parts. The first is the Building/Use Score section which contains four parameters relating to the building geometry, hazard and occupancy of the building. The second part, Fire safety Features Score, contains eight main parameters with a number of separate sub-parameters all relating to the fire safety features or safety precautions required by C/AS1.

The points system involves grading each building, hazard and safety feature/parameters on a scale of 0 to 5. A lower score indicates a more hazardous or least safe parameter. The weighting system determines the interdependence between the parameters and the contribution each parameter provides to the level of safety of a building.

The output of the model is a single numerical index value, Fire Safety Index. The higher the index indicates a safer building.

The model does not give risk in absolute terms or an expected risk to life format and as such is only suitable for comparative analyses.

9.2 Apparent Level of Fire Safety of Buildings Designed to C/AS1

The study reviewed the safety of building designed in accordance with the New Zealand Building Code Approved Document for Fire Safety C/AS1. The analysis was limited to buildings with the following parameters:

Purpose groups	–	Crowd CS CL and CM
	–	Working WL and WM
	–	Sleeping SR and SA
Building escape heights	–	Greater than 4m high
Occupant numbers	–	Greater than 50 (up to 40 in SR)

The results indicate that the level of safety increases predominantly with increasing escape height of the building and increasing occupant numbers.

From the FSI analysis the Sleeping Accommodation (SA) purpose group is generally graded the safest building across all building escape height categories while the Sleeping Residential (SR) is graded the least safe.

The sensitivity of most parameters is proportional to their respective weightings, i.e. parameters with very low weighting affect the FSI by only 1-2%.

There is one exception to the trends for the crowd and working purpose groups. The FSI indicates a significant drop in safety for the 25 -34 m escape height category due to a drop in the firecell (F) and structural endurance (S) rating requirements with the introduction of sprinklers. Changes to the F and S parameter weightings had negligible impact on the FSI resulting in the same drop in safety. Changes to the sprinkler parameter weighting reduced or eliminated the drop in safety, indicating that the level of safety produced by the FSI was most sensitive to the sprinkler parameter.

The sprinkler parameter weighting based on Swedish[35] and USA[32] risk ranking systems is rated approximately 50% of the firecell rating. Work by Feeney[24] and Marryat[27] suggest that the performance of sprinkler systems in New Zealand is very reliable. Therefore it appears reasonable that the weighting for sprinklers could be increased to equate more with the firecell parameter weighting. Further analysis on the effectiveness of sprinkler systems would be required to establish the extent to which the weightings should be changed in the model

9.3 Equivalency

New Zealand currently lacks a method for assessing the compliance of specific fire engineering designs (alternative solutions) in a consistent manner. In most cases designs are assessed by subjective judgment or comparisons to the fire safety requirements of the Building Code Approved Document C/AS1. There is much debate among the fire engineering profession as to the validity of the equivalency approach and a quick and economical method for reviewing and certifying designs uniformly across the country is desired.

It is not the objective of this study to determine whether or not equivalency is the best and/or most valid approach to certifying alternative solutions. However, given the current use of the equivalency measure in the fire engineering profession there is a need for a method of evaluating equivalency consistently. A risk ranking scheme, such as the Fire Safety Index proposed in this study, is a tool is that could be used to carry out such checks.

The model proposed in this study could be developed further and used to determine whether or not an alternative design provides an equivalent level of safety to that required by C/AS1. The model requires further testing and validation before it would be suitable for this task.

9.4 Further Research

This study is essentially an initial investigation of the level of safety of building design to the New Zealand Building Code Approved Document C/AS1. The study has identified a number of alternative methods for evaluating safety and developed a rudimentary risk ranking system to evaluate the safety of C/AS1. There is a significant amount of potential further work that can be carried out in the area of fire safety of buildings. A number of these are discussed below in relation to this project:

i) Acceptable Level of Risk

A study could be undertaken to establish what an acceptable level of risk is for a building in terms of fire safety. Comparison could be made to other design codes in New Zealand such as the structural codes and /or international standards.

ii) Validation of the Model

The Fire Safety Index model proposed in this study requires further validation, particularly if the model is to be used in practice for checking equivalency to C/AS1.

Possible methods for validation studies could include:

- Delphi panel assessment
- Probabilistic risk analysis of exemplar buildings
- Reliability index (β) risk analysis of exemplar buildings.
- Comparison with computer risk analysis models

iii) Extension of the Model to Other Purpose Groups

The version of the Fire Safety Index model could also be developed for low rise buildings, hospitals and prison type purpose groups and /or high fire hazard facilities.

iv) Development of a Computer Risk Model

The proposed index is suitable for development into a simple computer model. This could also be developed further with a probabilistic risk analysis type model.

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11 APPENDICES

Appendix A – New Zealand Building Code – Fire Safety Clauses

NEW ZEALAND BUILDING CODE

FIRE SAFETY CLAUSES

The mandatory provisions for building work are contained in the New Zealand Building Code (NZBC), which comprises the First Schedule to the Building Regulations 1992. The relevant NZBC Clauses for Fire Safety in buildings are C1, C2, C3 and C4.

1992/150 *Building Regulations 1992* 21

FIRST SCHEDULE—*continued*

Clause C1—OUTBREAK OF FIRE

Provisions	Limits on application
OBJECTIVE	
C1.1 The objective of this provision is to safeguard people from injury or illness caused by *fire*.	
FUNCTIONAL REQUIREMENT	
C1.2 In *buildings* fixed appliances using the controlled combustion of solid, liquid or gaseous fuel, shall be installed in a way which reduces the likelihood of *fire*.	
PERFORMANCE	
C1.3.1 Fixed appliances and services shall be installed so as to avoid the accumulation of gases within the installation and in *building* spaces, where heat or ignition could cause uncontrolled combustion or explosion.	
C1.3.2 Fixed appliances shall be installed in a manner that does not raise the temperature of any *building element* by heat transfer or concentration to a level that would adversely affect its physical or mechanical properties or function.	

FIRST SCHEDULE—*continued*

Clause C2—MEANS OF ESCAPE

Provisions	Limits on application
OBJECTIVE	
C2.1 The objective of this provision is to:	
(a) Safeguard people from injury or illness from a *fire* while escaping to a *safe place*, and	
(b) Facilitate *fire* rescue operations.	
FUNCTIONAL REQUIREMENT	
C2.2 *Buildings* shall be provided with *escape routes* which:	
(a) Give people *adequate* time to reach a *safe place* without being overcome by the effects of *fire*, and	
(b) Give fire service personnel *adequate* time to undertake rescue operations.	
PERFORMANCE	
C2.3.1 The number of *open paths* available to each person escaping to an *exitway* or *final exit* shall be appropriate to:	
(a) The *travel distance*.	
(b) The number of occupants,	
(c) The *fire hazard*, and	
(d) The *fire safety systems* installed in the *firecell*.	
C2.3.2 The number of *exitways* or *final exits* available to each person shall be appropriate to:	
(a) The *open path travel distance*,	
(b) The *building height*,	
(c) The number of occupants,	
(d) The *fire hazard*, and	
(e) The *fire safety systems* installed in the *building*.	
C2.3.3 *Escape routes* shall be:	
(a) Of *adequate* size for the number of occupants,	
(b) Free of obstruction in the direction of escape,	

FIRST SCHEDULE—*continued*

Provisions	Limits on application
(c) Of length appropriate to the mobility of the people using them, (d) Resistant to the spread of *fire* as required by Clause C3 "Spread of Fire", (e) Easy to find as required by Clause F8 "Signs", (f) Provided with *adequate* illumination as required by Clause F6 "Lighting for Emergency", and (g) Easy and safe to use as required by Clause D1.3.3 "Access Routes".	

FIRST SCHEDULE—*continued*

Clause C3—SPREAD OF FIRE

Provisions	Limits on application
OBJECTIVE	
C3.1 The objective of this provision is to:	
(a) Safeguard people from injury or illness when evacuating a *building* during *fire*.	
(b) Provide protection to fire service personnel during firefighting operations.	
(c) Protect adjacent *household units* and *other property* from the effects of *fire*.	
(d) Safeguard the environment from adverse effects of *fire*.	
FUNCTIONAL REQUIREMENT	
C3.2 *Buildings* shall be provided with safeguards against *fire* spread so that:	
(a) Occupants have time to escape to a *safe place* without being overcome by the effects of *fire*,	
(b) Firefighters may undertake rescue operations and protect property,	
(c) Adjacent *household units* and *other property* are protected from damage, and	
(d) Significant quantities of *hazardous substances* are not released to the environment during *fire*.	Requirement C3.2 (d) applies only to *buildings* where significant quantities of *hazardous substances* are stored or processed.
PERFORMANCE	
C3.3.1 Interior surface finishes on walls, floors, ceilings and suspended *building elements*, shall resist the spread of *fire* and limit the generation of toxic gases, smoke and heat, to a degree appropriate to:	
(a) The *travel distance*,	
(b) The number of occupants,	
(c) The *fire hazard*, and	
(d) The active *fire safety systems* installed in the *building*.	

FIRST SCHEDULE—*continued*

Provisions	Limits on application
C3.3.2 *Fire separations* shall be provided within *buildings* to avoid the spread of *fire* and smoke to: (a) Other *firecells*, (b) Spaces intended for sleeping, and (c) *Household units* within the same *building* or *adjacent buildings*.	Performance C3.3.2 shall not apply to *Detached Dwellings*, or within *household units* of *Multi-unit Dwellings*.
C3.3.3 *Fire separations* shall: (a) Where openings occur, be provided with *fire resisting closures* to maintain the *integrity* of the *fire separations* for an *adequate* time, and (b) Where penetrations occur, maintain the *fire resistance rating* of the *fire separation*.	
C3.3.4 *Concealed spaces* and cavities within *buildings* shall be sealed and subdivided where necessary to inhibit the unseen spread of *fire* and smoke.	Performance C3.3.4 shall not apply to *Detached Dwellings*.
C3.3.5 *External walls* and roofs shall have resistance to the spread of *fire*, appropriate to the *fire load* within the *building* and to the proximity of other *household units* and *other property*.	
C3.3.6 Automatic fire suppression systems shall be installed where people would otherwise be: (a) Unlikely to reach a safe place in *adequate* time because of the number of storeys in the *building*, (b) Required to remain within the *building* without proceeding directly to a *final exit*, or where the *evacuation time* is excessive, (c) Unlikely to reach a *safe place* due to confinement under institutional care because of mental or physical disability, illness or legal detention, and the *evacuation time* is excessive, or	

FIRST SCHEDULE—*continued*

Provisions	Limits on application
(d) At high risk due to the *fire load* and *fire hazard* within the *building*.	
C3.3.7 Air conditioning and mechanical ventilation systems shall be constructed to avoid circulation of smoke and *fire* between *firecells*.	
C3.3.8 Where an automatic smoke control system is installed, it shall be constructed to: (a) Avoid the spread of *fire* and smoke between *firecells*, and (b) Protect *escape routes* from smoke until the occupants have reached a *safe place*.	
C3.3.9 The *fire safety systems* installed shall facilitate the specific needs of fire service personnel to: (a) Carry out rescue operations, and (b) Control the spread of *fire*.	
C3.3.10 Environmental protection systems shall ensure a low probability of *hazardous substances* being released to: (a) Soils, vegetation or natural waters, (b) The atmosphere, and (c) *Sewers* or public *drains*.	Performance C3.3.10 applies only to *buildings* where significant quantities of *hazardous substances* are stored or processed.

FIRST SCHEDULE—*continued*

Clause C4—STRUCTURAL STABILITY DURING FIRE

Provisions	Limits on application

OBJECTIVE

C4.1 The objective of this provision is to:

(a) Safeguard people from injury due to loss of structural stability during *fire*, and

(b) Protect *household units* and *other property* from damage due to structural instability caused by *fire*.

FUNCTIONAL REQUIREMENT

C4.2 *Buildings* shall be constructed to maintain structural stability during *fire* to:

(a) Allow people *adequate* time to evacuate safely,

(b) Allow fire service personnel *adequate* time to undertake rescue and firefighting operations, and

(c) Avoid collapse and consequential damage to adjacent *household units* or *other property*.

PERFORMANCE

C4.3.1 Structural elements of *buildings* shall have *fire* resistance appropriate to the function of the elements, the *fire load*, the *fire intensity*, the *fire hazard*, the height of the *buildings* and the *fire* control facilities external to and within them.

C4.3.2 Structural elements shall have a *fire* resistance of no less than that of any element to which they provide support within the same *firecell*.

C4.3.3 Collapse of elements having lesser *fire* resistance shall not cause the consequential collapse of elements required to have a higher *fire* resistance.

Appendix B – C/AS1 Fire Safety Precautions [Table 4.1 C/AS1]

Table 4.1: Fire safety precautions
Key to table references

Part 2 Paragraph 2.4.2
Part 3 Paragraphs 3.1.5, 3.13.1 and 3.19.2
Part 4 Paragraphs 4.3, 4.3.1, 4.3.3, 4.4.1, 4.5.2, 4.5.3, 4.5.4, 4.5.7, 4.5.9, 4.5.10, 4.5.13, 4.5.14, 4.5.15, 4.5.19
Part 5 Paragraphs 5.5.1, 5.6.5, 5.6.7, 5.9.4 (c)
Part 6 Paragraphs 6.2.1, 6.4.1, 6.7.1, 6.8.1, 6.8.5, 6.8.6, 6.10.1, 6.11.1, 6.15.1, 6.19.9, 6.21.2, 6.23.1 (d), 6.23.2, 6.23.3
Part 8 Paragraphs 8.2.1, 8.2.2, 8.2.3
Appendix A Paragraphs A1.1.1 and A1.1.2

Fire safety precautions		Special applications
Type	**Description**	a Not required where: i) the *escape routes* serve an *occupant load* of no more than 50 in *purpose groups* CS, CM, WL, WM, WH and WF, or ii) the *escape routes* are for *purpose group* SA and serve no more than 10 beds, (or 20 beds for trampers huts, see Paragraph 6.20.6), or iii) exit doors from *purpose group* SA and SR *firecells* open directly onto a *safe place* or an external *safe path* (see Paragraph 3.14).
1	No Type 1 currently specified.	b Where only a single *escape route* is available, no less than a Type 4 alarm is required. See Paragraph 3.15.3 for situations where sprinklers are required.
2	Manual fire alarm system.	c Required where Fire Service hose run distance, from the Fire Service vehicular access (see Paragraph 8.1.1) to any point on any floor, is greater than 75 m.
3	Automatic fire alarm system with heat detectors and manual call points.	d Emergency lighting extended to *open paths* throughout the *firecell*.
4	Automatic fire alarm system with smoke detectors and manual call points.	e Type 5 is permitted as an alternative alarm system within *firecells* containing sleeping accommodation. (See Appendix A for description of Type 5.)
5	Automatic fire alarm system with modified smoke/heat detection and manual call points.	f A direct connection to the Fire Service is not required provided a telephone is installed and freely available at all times to enable "111" calls to be made.
6	Automatic fire sprinkler system with manual call points.	
7	Automatic fire sprinkler system with smoke detectors and manual call points.	
8	Voice communication system.	
9	Smoke control in air handling system.	
10	Natural smoke venting.	
11	Mechanical smoke extract.	
12	No Type 12 currently specified.	
13	Pressurisation of safe paths.	
14	Fire hose reels.	
15	Fire Service lift control.	
16	Emergency lighting in exitways.	
17	Emergency electrical power supply.	
18	Fire hydrant system.	
19	Refuge areas.	
20	Fire systems centre.	

Note:
The numbered references are more fully explained in Appendix A.

Table 4.1/1: Fire safety precautions for active purpose group firecells

Occupant load 100 maximum

Purpose Group	Escape height							
	0 m (or single floor)	<4 m (or 2 floors)	4 m to <10 m (or 3 floors)	10 m to <25 m	25 m to <34 m	34 m to <46 m	46 m to <58 m	over 58 m
CS	F0	F30	F30	F45	F30	F30	F30	F60
	2af 18c	2af 18c	3b 9 16 18c	4 9 16 18	6 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 17 18 19 20
CM (Note 5)	F0	F30	F30	F45	F30	F30	F30	F60
	2af 18c	2af 18c	3b 9 16 18c	3b 9 15 16 18	6 9 13 15 16 18	7 9 13 15 16 18 20	7 9 13 15 16 18 20	7 9 13 15 16 17 18 19 20
WL **WM** **WH** (Note 5)	F0	F30	F30	F45	F30	F30	F30	F60
	2af 18c	2af. 18c	3b 16 18c	3b 15 16 18	6 15 16 18	6 9 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
WF	F0	F30	F30	F30	F30	F30	F30	F60
	3af 18c	6 18c	6 16 18c	6 15 16 18	6 15 16 18	6 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
Column	1	2	3	4	5	6	7	8

Notes:

1. **Use of Table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells.*
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 15/15/15.
3. **Intermediate Floors:** Where a *firecell* contains *intermediate floors* a 15/15/15 *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car Parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings.*
5. **Sprinklers:** Refer to Paragraph 5.6.12 for sprinkler requirements in *FHC*4 *firecells* where the *escape height* is two floors or higher.

Table 4.1/2: Fire safety precautions for active purpose group firecells — Occupant load 101 to 500

Purpose Group	Escape height: 0 m (or single floor)	<4 m (or 2 floors)	4 m to <10 m (or 3 floors)	10 m to <25 m	25 m to <34 m	34 m to <46 m	46 m to <58 m	over 58 m
CL (Notes 6, 7)	**F0**	**F30**	**F30**	**F45**	**F30**	**F30**	**F30**	**F60**
	3f 16 18c	3f 16 18c	3b 9 16 18c	4 9 16 18	6 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 17 18 19 20
CM (Note 5)	**F0**	**F30**	**F30**	**F45**	**F30**	**F30**	**F30**	**F60**
	3f 16 18c	3f 16 18c	3b 9 16 18c	3b 9 15 16 18	6 9 13 15 16 18	7 9 13 15 16 18 20	7 9 13 15 16 18 20	7 9 13 15 16 17 18 19 20
WL **WM** **WH** (Note 5)	**F0**	**F30**	**F30**	**F45**	**F30**	**F30**	**F30**	**F60**
	3f 16 18c	3f 16 18c	3b 16 18c	3b 15 16 18	6 15 16 18	6 9 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
WF	**F0**	**F30**	**F30**	**F30**	**F30**	**F30**	**F30**	**F60**
	3f 16 18c	6 16 18c	6 16 18c	6 15 16 18	6 15 16 18	6 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
Column	1	2	3	4	5	6	7	8

Notes:

1. **Use of Table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 15/15/15.
3. **Intermediate Floors:** Where a *firecell* contains *intermediate floors* a 15/15/15 *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car Parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklers:** Refer to Paragraph 5.6.12 for sprinkler requirements in *FHC* 4 *firecells* where the *escape height* is two floors or higher.
6. **CL cinemas and theatres:** Type 16d is required for all *escape heights*.
7. **CL:** For *firecells*, which are not cinemas or *theatres*, with *escape height* less than 4.0 m and *occupant load* not greater than 250, Type 2af is a permitted alternative to Type 3f.

Table 4.1/3: Fire safety precautions for active purpose group firecells — Occupant load 501 to 1000

Purpose Group	Escape height: 0 m (or single floor)	<4 m (or 2 floors)	4 m to <10 m (or 3 floors)	10 m to <25 m	25 m to <34 m	34 m to <46 m	46 m to <58 m	over 58 m
CL (Note 6)	F0	F30	F30	F30	F30	F30	F30	F60
	4 16 18c	4 16 18c	4 9 16 18c	7 9 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 17 18 19 20
CM (Note 5)	F0	F30	F30	F30	F30	F30	F30	F60
	4 16 18c	4 16 18c	4 9 16 18c	7 9 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 20	7 9 13 15 16 18 20	7 9 13 15 16 17 18 19 20
WL **WM** **WH** (Note 5)	F0	F30	F30	F30	F30	F30	F30	F60
	4 16 18c	4 16 18c	4 16 18c	7 15 16 18	7 15 16 18	7 9 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
WF	F0	F30	F30	F30	F30	F30	F30	F60
	4 16 18c	6 16 18c	6 16 18c	7 15 16 18	7 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
Column	1	2	3	4	5	6	7	8

Notes:

1. **Use of Table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 15/15/15.
3. **Intermediate Floors:** Where a *firecell* contains *intermediate floors* a 15/15/15 *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car Parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklers:** Refer to Paragraph 5.6.12 for sprinkler requirements in *FHC4 firecells* where the *escape height* is two floors or higher.
6. **CL cinemas and theatres:** Type 16d is required for all *escape heights*.

Table 4.1/4: Fire safety precautions for active purpose group firecells

Occupant load Over 1000

Purpose Group	Escape height: 0 m (or single floor)	<4 m (or 2 floors)	4 m to <10 m (or 3 floors)	10 m to <25 m	25 m to <34 m	34 m to <46 m	46 m to <58 m	over 58 m
CL	F0	F30	F30	F30	F30	F30	F30	F60
	7 16d 18c	7 16d 18c	7 9 16d 18c	7 9 16d 18	7 9 13 15 16d 18	7 9 13 15 16d 18	7 9 13 15 16d 18	7 9 13 15 16d 17 18 19 20
CM (Note 5)	F0	F30	F30	F30	F30	F30	F30	F60
	7 16d 18c	7 16d 18c	7 9 16d 18c	7 9 15 16d 18	7 9 13 15 16d 18	7 9 13 15 16d 18 20	7 9 13 15 16d 18 20	7 9 13 15 16d 17 18 19 20
WL WM WH (Note 5)	F0	F30	F30	F30	F30	F30	F30	F60
	7 16 18c	7 16 18c	7 16 18c	7 15 16 18	7 15 16 18	7 9 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
WF	F0	F30	F30	F30	F30	F30	F30	F60
	7 16 18c	7 16 18c	7 16 18c	7 15 16 18	7 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
Column	1	2	3	4	5	6	7	8

Notes:

1. **Use of Table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 15/15/15.
3. **Intermediate Floors:** Where a *firecell* contains *intermediate floors* a 15/15/15 *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car Parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklers:** Refer to Paragraph 5.6.12 for sprinkler requirements in *FHC* 4 *firecells* where the *escape height* is two floors or higher.

Table 4.1/5: Fire safety precautions for sleeping purpose group firecells

Occupant load 40 maximum

Purpose Group	Escape height							
	0 m (or single floor)	<4 m (or 2 floors)	4 m to <10 m (or 3 floors)	10 m to <25 m	25 m to <34 m	34 m to <46 m	46 m to <58 m	over 58 m
SC SD (Note 6)	**F0**	**F30**	**F30**	**F30**	**F30**	**F30**	**F30**	**F60**
	7 16d 18c	7 16d 18c	7 16d 18c	7 9 15 16d 18	7 8 9 13 15 16d 18 20	7 8 9 13 15 16d 18 20	7 8 9 13 15 16d 18 20	7 8 9 13 15 16d 17 18 19 20
SA (Note 5)	**F0**	**F30**	**F30**	**F45**	**F30**	**F30**	**F30**	**F60**
	4aef 16a 18c	4ef 16a 18c	4e 14 16a 18c	4e 14 15 16 18	7e 8 9 15 16 18	7e 8 9 13 15 16 18 20	7e 8 9 13 15 16 18 20	7e 8 9 13 15 16 17 18 20
SR (Note 7)	**F0**	**F30**	**F30**	**F45**	**F30**	**F30**	**F30**	**F60**
		2a	2f 16a	4e 14 16 18	7e 15 16 18	7e 15 16 18	7e 15 16 18 20	7e 13 15 16 18 20
Column	1	2	3	4	5	6	7	8

Notes:

1. **Use of Table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by a *fire separation* with *FRR* no less than 15/15/15, or 30/30/30 for *purpose group* SR.
3. **Intermediate Floors:** Where a *firecell* contains *intermediate floors* a 15/15/15 *FRR* shall apply to the *intermediate floors* and supporting elements. and smoke control systems, Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car Parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklered firecells:** *Purpose group* SA may have an *occupant load* up to 160 beds in *firecells* with a Type 7 alarm (see Paragraph 6.7.2).
6. **Occupant load in SC and SD firecells:** The *occupant load* in a *group sleeping area firecell* is limited to 12 or 20 beds and in a *suite* to 6 beds (see Paragraphs 6.6.3 to 6.6.5). For *firecells* (such as an operating theatre) required to remain occupied during a *fire*, see Paragraphs 5.6.8 and 5.6.9.
7. **SR household units:** See Paragraph 6.8.6 which describes where *household units* containing upper floors may be treated as single floor *firecells*.

Appendix C – NFPA Fire Safety Evaluation System – Weighting Analysis

TABLE C1

NZPA-101A Fire Safety Evaluation System - Weighting Calculations

Business Occupancies: (Equivalent to C/AS1 Purpose Group WL & WM)

No.	Safety Parameter	Parameter Attributes	General Fire Safety - S3				Fire Control - S1			Egress Provided - S2		
			Parameter Score			Parameter	Parameter Score		Parameter			Parameter
			Min	Max	Range	Weighting	Contribtn	Range	Weighting	Contribtn	Range	Weighting
1	Construction	Combusitble/Non Com./ Height	-12	2	**14**	0.152	1	14	0.280	0	0	0.000
2	Segregation of Hazards	Exposed -> Segregated System	-7	0	**7**	0.076	1	7	0.140	1	7	0.117
3	Vertical Openings	Open -> Enclosed	-10	1	**11**	0.120	0.5	5.5	0.110	1	11	0.183
4	Sprinklers	None -> Fast Resp.& Total Bldg	0	12	**12**	0.130	1	12	0.240	0.5	6	0.100
5	Fire Alarm	None -> Voice Com. & FD Not.	0	4	**4**	0.043	0.5	2	0.040	1	4	0.067
6	Smoke Detection	None -> Total Building	0	4	**4**	0.043	0.5	2	0.040	1	4	0.067
7	Interior Finishes	Flame Spread Ratings	-3	2	**5**	0.054	0.5	2.5	0.050	0	0	0.000
8	Smoke Control	None / Passive / Active	0	4	**4**	0.043	0	0	0.000	0.5	2	0.033
9	Exit Access	Dead Ends & Total Travel Length	-2	3	**5**	0.054	0	0	0.000	1	5	0.083
10	Egress Route	Single, Multiple, Protected & Final	-6	5	**11**	0.120	0	0	0.000	1	11	0.183
11	Corridor/Room Separation	Door Closers, Smoke Sep., FRR	-6	4	**10**	0.109	0.5	5	0.100	0.5	5	0.083
12	Occupant Emergency Plan	No. of Fire Drills Per Year	-3	2	**5**	0.054	0	0	0.000	1	5	0.083
					92	**1**		**50**	**1**		**60**	**1**

Reference: NFPA 101A :Guide on Alternative Approaches to Life Safety: 2001 Edition [32]

TABLE C2

NZPA-101A Fire Safety Evaluation System - Weighting Calculations

Board & Care Large Facilities: (Equivalent to C/AS1 Purpose Group SA and SC)

No.	Safety Parameter	Parameter Values	General Fire Safety - S4				Fire Control - S1			Egress Provided - S2			Refuge Provided - S3		
			Parameter Score			Parameter	Parameter Score		Parameter	Parameter Score		Parameter	Parameter Score		Parameter
			Min	Max	Range	Weighting	Contribtn	Range	Weighting	Contribtn	Range	Weighting	Contribtn	Range	Weighting
1	Construction	Combusitble/Non Com./ Height	-10	2	**12**	0.1290	1	12	0.2243	0	0	0.0000	1	12	0.2034
2	Hazardous Areas	Exposed -> Segregated System	-4	0	**4**	0.0430	1	4	0.0748	0.5	2	0.0290	1	4	0.0678
3	Manual Fire Alarm	None -> FD Not.	0	3	**3**	0.0323	0.5	1.5	0.0280	1	3	0.0435	0	0	0.0000
4	Smoke Detection	None -> Total Building	-10	6	**16**	0.1720	0.5	8	0.1495	1	16	0.2319	0.5	8	0.1356
5	Sprinklers	None -> Total Bldg	0	10	**10**	0.1075	1	10	0.1869	0.5	5	0.0725	0.5	5	0.0847
6	Corridor/Room Separation	Smoke Separation & FRR	-6	4	**10**	0.1075	1	10	0.1869	0.5	5	0.0725	1	10	0.1695
7	Exit System(Egress Route)	Single, Multiple, Protected & Final	-6	4	**10**	0.1075	0	0	0.0000	1	10	0.1449	0.5	5	0.0847
8	Exit Access	Dead Ends & Total Travel Length	-6	2	**8**	0.0860	0	0	0.0000	1	8	0.1159	0	0	0.0000
9	Interior Finishes	Flame Spread Ratings	-3	2	**5**	0.0538	0.5	2.5	0.0467	1	5	0.0725	0	0	0.0000
10	Vertical Openings	Open -> Enclosed	-10	1	**11**	0.1183	0.5	5.5	0.1028	1	11	0.1594	1	11	0.1864
11	Smoke Control	None / Passive / Active	0	4	**4**	0.0430	0	0	0.0000	1	4	0.0580	1	4	0.0678
					93	**1**		**53.5**	**1**		**69**	**1**		**59**	**1**

Reference: NFPA 101A :Guide on Alternative Approaches to Life Safety: 2001 Edition [32]

TABLE C3

NZPA-101A Fire Safety Evaluation System - Weighting Calculations

Apartment Buildings: (Equivalent to C/AS1 Purpose Group SR)

No.	Safety Parameter	Parameter Values	General Fire Safety - S4				Fire Control - S1			Egress Provided - S2			Refuge Provided - S3		
			Parameter Score			Parameter	Parameter Score		Parameter	Parameter Score		Parameter	Parameter Score		Parameter
			Min	Max	Range	Weighting	Contribtn	Range	Weighting	Contribtn	Range	Weighting	Contribtn	Range	Weighting
1	Construction	Combusitble/Non Com./ Height	-10	2	**12**	0.145	1	12	0.261	0	0	0.000	1	12	0.240
2	Hazardous Areas	Exposed -> Segregated System	-4	0	**4**	0.048	1	4	0.087	0.5	2	0.033	1	4	0.080
3	Manual Fire Alarm	None -> FD Not.	0	3	**3**	0.036	0.5	1.5	0.033	1	3	0.050	0	0	0.000
4	Smoke Detection	None -> Total Building	-4	6	**10**	0.120	0.5	5	0.109	1	10	0.167	0	0	0.000
5	Sprinklers	None -> Total Bldg	0	8	**8**	0.096	1	8	0.174	0.5	4	0.067	0.5	4	0.080
6	Corridor/Room Separation	Smoke Separation & FRR	-6	4	**10**	0.120	1	10	0.217	0.5	5	0.083	1	10	0.200
7	Exit System(Egress Route)	Single, Multiple, Protected & Final	-6	4	**10**	0.120	0	0	0.000	1	10	0.167	0.5	5	0.100
8	Exit Access	Dead Ends & Total Travel Length	-6	2	**8**	0.096	0	0	0.000	1	8	0.133	0	0	0.000
9	Interior Finishes	Flame Spread Ratings	-3	0	**3**	0.036	0	0	0.000	1	3	0.050	0	0	0.000
10	Vertical Openings	Open -> Enclosed	-10	1	**11**	0.133	0.5	5.5	0.120	1	11	0.183	1	11	0.220
11	Smoke Control	None / Passive / Active	0	4	**4**	0.048	0	0	0.000	1	4	0.067	1	4	0.080
					83	**1**		**46**	**1**		**60**	**1**		**50**	**1**

Reference: NFPA 101A :Guide on Alternative Approaches to Life Safety: 2001 Edition [32]

TABLE C4

NZPA-101A Fire Safety Evaluation System - Weighting Calculations

Summary of Index Weightings for Fire Safety Parameters to NFPA 101A

No.	Safety Parameter	Business Occupancies (WL/WM)			Board & Care Large Facilities (SA/SC)				Apartment Buildings (SR)			
		S1	S2	**S3**	S1	S2	S3	**S4**	S1	S2	S3	**S4**
		Fire Control	Egress	**General**	Fire Control	Egress	Refuge	**General**	Fire Control	Egress	Refuge	**General**
1	Construction	0.2800	0.0000	**0.1522**	0.2243	0.0000	0.2034	**0.1290**	0.2609	0.0000	0.2400	**0.1446**
2	Segregation of Hazards	0.1400	0.1167	**0.0761**	0.0748	0.0290	0.0678	**0.0430**	0.0870	0.0333	0.0800	**0.0482**
3	Vertical Openings	0.1100	0.1833	**0.1196**	0.1028	0.1594	0.1864	**0.1183**	0.1196	0.1833	0.2200	**0.1325**
4	Sprinklers	0.2400	0.1000	**0.1304**	0.1869	0.0725	0.0847	**0.1075**	0.1739	0.0667	0.0800	**0.0964**
5	Fire Alarm	0.0400	0.0667	**0.0435**	0.0280	0.0435	0.0000	**0.0323**	0.0326	0.0500	0.0000	**0.0361**
6	Smoke Detection	0.0400	0.0667	**0.0435**	0.1495	0.2319	0.1356	**0.1720**	0.1087	0.1667	0.0000	**0.1205**
7	Interior Finishes	0.0500	0.0000	**0.0543**	0.0467	0.0725	0.0000	**0.0538**	0.0000	0.0500	0.0000	**0.0361**
8	Smoke Control	0.0000	0.0333	**0.0435**	0.0000	0.0580	0.0678	**0.0430**	0.0000	0.0667	0.0800	**0.0482**
9	Exit Access	0.0000	0.0833	**0.0543**	0.0000	0.1159	0.0000	**0.0860**	0.0000	0.1333	0.0000	**0.0964**
10	Egress Route	0.0000	0.1833	**0.1196**	0.0000	0.1449	0.0847	**0.1075**	0.0000	0.1667	0.1000	**0.1205**
11	Corridor/Room Separation	0.1000	0.0833	**0.1087**	0.1869	0.0725	0.1695	**0.1075**	0.2174	0.0833	0.2000	**0.1205**
12	Occupant Emergency Plan	0.0000	0.0833	**0.0543**								
	Sum	1.0000	1.0000	**1.0000**	1.0000	1.0000	1.0000	**1.0000**	1.0000	1.0000	1.0000	**1.0000**

Reference: NFPA 101A :Guide on Alternative Approaches to Life Safety: 2001 Edition [32]

TABLE C5

NZPA-101A Fire Safety Evaluation System - Weighting Calculations

Summary of Revised Index Weightings for Fire Safety Parameters to NFPA 101A and Equivalent C/AS1 Parameters

No	Safety Parameter	Fire Control		Egress			General			Average Weighting W_{NA}	Equivalent NZBC C/AS1 Fire Safety Parameter
		Average W_A	Adjusted & Normalised W_N	Average W_A	Adjusted W_{Ad}	Normalised W_N	Average W_A	Adjusted W_{Ad}	Normalised W_N		
1	Construction	0.2551	0.2868	0.0000	0.0000	0.0000	0.1419	0.1733	0.1653	**0.1507**	50% to Building Height Parameter (BU2) 50% to Struct. Endurance Rating(A2)
2	Segregation of Hazards	0.1006	0.1131	0.0597	0.0813	0.0749	0.0558	0.0681	0.0650	**0.0843**	A2 Structural Endurance Rating
3	Vertical Opening	0.1108		0.1754			0.1235				*Excluded as it pertains to attriums and mezzanine floors which are outside the scope of this project*
4	Sprinklers	0.2003	0.2252	0.0797	0.1086	0.1000	0.1114	0.1361	0.1298	**0.1517**	D1 Sprinkler System & D2 Water Supply
5	Fire Alarm	0.0335	0.0377	0.0534	0.0727	0.0670	0.0373	0.0455	0.0434	**0.0494**	F Communication System & G1 Fire Service Alerting
6	Smoke Detection	0.0994	0.1118	0.1551	0.2113	0.1946	0.1120	0.1368	0.1305	**0.1456**	B Fire Alarm
7	Interior Finishes	0.0322	0.0363	0.0408	0.0556	0.0512	0.0481	0.0587	0.0560	**0.0478**	H8 Surface Finishes Exitways & H9 Occupied Spaces
8	Smoke Control	0.0000	0.0000	0.0527	0.0717	0.0661	0.0449	0.0548	0.0523	**0.0395**	C Smoke Control
9	Exit Access	0.0000	0.0000	0.1109	0.1511	0.1391	0.0789	0.0964	0.0919	**0.0770**	Means of Escape H1, H2
10	Egress Route	0.0000	0.0000	0.1650	0.2248	0.2070	0.1159	0.1415	0.1350	**0.1140**	Means of Escape H5, H6, H7
11	Corridor/Room Separation	0.1681	0.1890	0.0797	0.1086	0.1000	0.1122	0.1371	0.1307	**0.1399**	A1 Firecell Rating
12	Occupant Emergency Plan	0.0000		0.0833			0.0543				*Excluded as it only pertains to Business Occupancies in NFPA 101A and is not a design parameter in C/AS1*
	Sum	1.0000	1.0000	0.9722	1.0858	1.0000	0.9819	1.0482	1.0000	**1.0000**	

Reference: NFPA 101A :Guide on Alternative Approaches to Life Safety: 2001 Edition [32]

Appendix D – Evacuation Time Estimates

EVACUATION CALCULATIONS FOR DETERMINING PARAMETER WEIGHTINGS FOR PURPOSE GROUP, BUILDING HEIGHT & OCCUPANT NUMBERS

Refer Section 8.0 Fire Engineering Design Guide(FEDG) 2nd Edition [53]

The evacuation time is given by:

$t_{ev} = t_d + t_a + t_o + t_i + t_t + t_q$ [Eqn 8.2 FEDG]

Where:
- t_d = time to detection (allowed for in alarm parameter)
- t_a = time from detection to alarm sounding (allowed for in alarm parameter)
- t_o = time from alarm until occupants make decision to leave.(Critical to Purpose Group)
- t_i = time for occupants to investigate fire ,find belongings and to fight fire.(Critical to Purpose Group)
- t_t = travel time to safety (Critical to building height and occupant numbers)
- t_q = queuing time at doorways and obstructions. (Critical to Number of Occupants)

for this project :

$t_p =$	$t_d + t_a + t_o + t_i$	Premovement time (Critical Purpose Group)	[Based on Table 3-13.1 SFPE Handbook[58]]
$t_f =$	$t_p + t_{op} + t_q$	Time to clear a floor of a building.	
$t_{ev} =$	$t_p + t_f + t_t$	Building evacuation time	

Where: t_{op} = Travel time in open path

The travel speed is given by:

$S =$	k_t (1-0.266Do)		[Eqn 8.4 FEDG]
$k_t =$	84	Corridors	[Eqn 8.5 FEDG]
$k_t =$	$51.8\ (G/R)^{0.5}$ for stairs		[Eqn 8.6 FEDG]
	69.8471		

Do = Density of occupants (persons per square meter varies for Purpose Group)

The specific flow and actual flow of occupants is given by:

$F_s =$	S x Do	Specific Flow	[Eqn 8.7 FEDG]
$F_a =$	$F_s \times W_e$	Actual Flow	
$W_e =$	Effective width.(ie width - boundary layer)		

The travel time is given by:

t_t = N/Fa

The queuing time is given by:

$t_q = N/S_{Stairs}$

N = Number of occupants in building on each floor using single stair

Assumptions/Engineering Judgements:

1. All stairs are accessible stairs with 167mm risers and 300mm treads.
2. Boundary widths are similar to those quoted Page 87 FEDG as follows:
   - 0.15m Stairs
   - 0.05m Door
3. Persons are distributed uniformly throughout the building.
4. Persons will travel to nearest exit therefore the number of persons per stair is proportional to floor area.
5. Maximum person to one escape route is 1200mm/(9mm/persons) =133 persons
6. Maximum travel times is based on the a speed of 73/m over the maximum Total Open Path Lengths permitted by C/AS1
7. Buildings above 4 m high have a 3 m interstorey height.
8. Evacuation time is the time when the **building** is evacuated and all persons have passed through the final exit.

EVACUATION CALCULATIONS

Refer Section 8.0 Fire Engineering Design Guide(FEDG) 2nd Edition [53]

Premovement and Open Path Movement Time

Purpose Group		**WL**	**WM**	**CL**	**CM**	**SA**	**SR**		**Mean Values**	
Premovement Time	t_p	4	4	4	6	6	5	min	$\boxed{\mathbf{4.83}}$	[Table 3-13.1 SFPE Handbook[58]]
Open Path Travel Time:										
Distance	TOP	60	60	45	45	45	60	m		
Density of occupants	$Do = N/A_f$	0.020	0.020	1.000	0.300	0.01	0.01	persons/m^2		[Table 2.2 C/AS1]
Travel constant	k_t	84	84	84	84	84	84			[Eqn 8.5 FEDG]
Open Path Travel Speed	$S_{OP} = k_t\,(1\text{-}0.266Do)$	83.6	83.6	61.7	77.3	83.8	83.8	m/s		[Eqn 8.4 FEDG]
Open Path Travel Time	$\mathbf{t_{op} = TOP/S_{OP}}$	**0.72**	**0.72**	**0.73**	**0.58**	**0.54**	**0.72**	**min**	$\boxed{\mathbf{0.67}}$	

EVACUATION CALCULATIONS

Refer Section 8.0 Fire Engineering Design Guide(FEDG) 2nd Edition [53]

Vertical Travel Speeds

General:

Max number of occupants per stair per floor @9mm/person 133

Maximum Flow Capacities:

Ground Floor Door:

Door Width	W_d	1.1	m
Boundary Layer	B_d	0.05	m
Effective Door Width	$W_{ed} = W_d - 2B_d$	1	m
Specific Flow (Fig 8.3 FEDG)	$F_{sd} =$	78	p/min/m
Maximum Flow through door	$F_{ad} = F_{sd} \cdot W_{ed}$	78.0	p/min

Stairs:

Width of Stair	W_s	1.2	m
Boundary Layer	B_s	0.15	m
Effective Stair Width	$W_{es} = W_s - 2B_s$	0.9	m
Stair Going	G	0.3	m
Stair Riser	R	0.167	m
Stair Ratio	G/R	1.80	m
Interstorey Height	H_i	4	m
No Steps	$N_s = H_i/R$	24.0	
Length of Stair Treads	$L_{tr} = G.N_s$	7.19	m
Length of Landings	$L_l = 2 \cdot W_s$ (Assumed)	2.4	m
Length of Stairs	$L_s = L_{tr} + L_l$	9.59	m
Effective Area of Stairs	A_{es}	8.63	m^2
Specific Flow (Fig 8.3 FEDG)	$F_{sd} =$ (167x300 mm treads)	60	p/min/m
Maximum Flow down stair	$F_{ad} = F_{sd} \cdot W_{ed}$	54.0	p/min
Maximum Density in Stair	D_S	1.88	p/m^2
Stair kt Factor	$k_t = 51.8(G/R)^{0.5}$	69.4	
Calculated Ds	$0.266k_t.D_s^2 - k_t.D_s + F_s = 0$		
	$a = 0.266k_t$	18.5	
	$b = -k_t$	-69.4	
	$c = F_s$	60.0	p/min/m
Quadratic Solution 1	$D_{S1} =$	2.413	p/m^2
Quadratic Solution 2	or $D_{S2} =$	1.346	p/m^2
Use	$D_S = \text{Min } D_{S1} \ \& \ D_{S2}$	1.346	p/m^2
Stair Travel Speed	$S_{Stairs} = k_t(1-0.266D_S)$	48.3	m/min
Time to traverse stair & landings (Bottom level governs)	$t_{ts} = L_s/S_{Stair}$	**0.20**	**min**

EVACUATION CALCULATIONS

Refer Section 8.0 Fire Engineering Design Guide(FEDG) 2nd Edition [53]

Summary of Evacuation Time Calculation

Mean Time to Clear a Floor			
Pre-movement [Table 3-13.1 SFPE Handbook]	t_p	4.83	minutes
Open Path Travel Time	t_{op}	0.67	minutes
Queuing Time = No Person per Floor / Stair Travel Speed	t_q	2.75	minutes
Mean Time to Clear Floor	$\mathbf{t_f}$	**8.25**	**minutes**

Mean Evacuation Times For a Single Staircase in a Building							
Escape Height	**No. Floors**	**Number of Occupants Per Floor**	**Time to Pass Through Ground Level Door**	**1st Floor to Ground Floor Stair Travel Time**	**Total Travel Time**	**Time to Clear a Floor**	**Total Evacuation Time**
		N	$t_{t\,(Door)}$	$t_{t\,(Stair)}$	$t_{t\,(Total)}$	t_f	t_{ev}
(m)			(Minutes)	(Minutes)	(Minutes)	(Minutes)	(Minutes)
4	1	133	1.7	0.20	1.90	8.25	10.2
10	3	399	5.1	0.20	5.31	8.25	13.6
25	8	1064	13.6	0.20	13.84	8.25	22.1
34	11	1463	18.8	0.20	18.95	8.25	27.2
46	15	1995	25.6	0.20	25.78	8.25	34.0
58	19	2527	32.4	0.20	32.60	8.25	40.8
Mean			**16.2**	**0.2**	**16.4**	**8.25**	**24.7**

Time to Untenable Conditions (S)							
t^2 Fire		**Fire Hazard Category**	**FHC1**	**FHC2**	**FHC3**	**Mean**	
Growth Rate	**α (MW/s^2)**	**Floor Area (A)**	**5000**	**2500**	**1500**	**-**	**m^2**
Slow	**0.00293**		20.44	14.06	10.67	15.06	minutes
Medium	**0.0117**		14.26	9.81	7.44	10.51	minutes
Fast	**0.0466**		9.96	6.85	5.20	7.33	minutes
Mean time to Untenable conditions						**10.97**	minutes

Note : $S = 1.67\alpha^{-0.26} H^{0.44} A^{0.54}$ Frantzich et al 1997 [38]

Where : H = 3m Ceiling Height

Note: The above evacuation times and time to untenable conditions have been used as a guide to estimate the Building/Use Parameter weightings. Refer to Section 6.4.3 of report.

Appendix E – Fire Safety Index Model & Example Calculation

C/AS1 FIRE SAFETY INDEX	CL / Upto 100 Occupants / Over 58m	Date	30/04/2006

BUILDING/USE SCORE

	Building/Use Parameter	Points	Attributes	Tick	Score	Weighting	Index Score
BU1	**Purpose Group**	1	Sleeping Accomodation (SA)				
		2	Sleeping Residential (SA)				
		3	Crowd	x	3	0.0332	0.099
		5	Working				
BU2	**Building Escape Height**	0	Over 58m	x	0	0.0663	0.000
		1	46m < EH ≤ 58m				
		2	34m < EH ≤ 46m				
		3	25m < EH ≤ 34m				
		4	10m < EH ≤ 25m				
		5	EH < 10m				
BU3	**Occupant Numbers**	1	Over 1000				
		2	501 < Occ. No. ≤ 1000				
		3	101 < Occ. No. ≤ 500				
		4	51 < Occ. No. ≤ 100	x	4	0.0221	0.088
		5	Occ. No. < 50				
BU4	**Fire Hazard Category**	0	FHC 4				
		1	FHC 3				
		3	FHC 2	x	3	0.0663	0.199
		5	FHC 1				
	Total Building/Use Score (BUS)					0.1879	**0.387**

FIRE SAFETY FEATURES SCORE

	Fire Safety Parameters	Points	Attributes	Tick	Score	Weighting	Index Score
A	**Fire Hazard**						
A1	Fire Cell Rating	0	0 Minutes				
		1	15 Minutes				
		2	30 Minutes				
		3	45 Minutes				
		4	60 Minutes	x	4	0.1504	0.602
		5	>60 Minutes				
A2	Structural Endurance Rating	0	0 Minutes				
		1	30 Minutes				
		2	60 Minutes				
		3	90 minutes				
		4	120 Minutes	x	4	0.0962	0.385
		5	>120 Minutes				
B	**Fire Alarm**	0	No Alarm				
		2	Type 2 - Manual Alarm				
		3	Type 3 - Auto. Alarm /Heat Detectors				
		4	Type 5 - Auto Alarm / Heat & Local Smoke Detectors				
		5	Type 4 - Automatic Alarm / Smoke Detectors	x	5	0.1176	0.588

C	**Smoke Control**						
C1	HVAC Control	0	No Smoke Control				
		2	Manual Shut Down				
		5	Automatic Shut Down on Alarm	x	5	0.0368	0.184
C2	Extraction	0	No Smoke Extraction	x	0	0.0201	0.000
		1	Manual/Natural Ventilation				
		2	Manual/Mechanical Extraction				
		4	Automatic Natural Ventilation				
		5	Automatic Mechanical Extraction				
C3	Stair Pressurisation	0	No				
		5	Yes	x	5	0.0201	0.100
D	**Building Fire Control**						
D1	Sprinklers	0	No Sprinklers				
		4	Dry Pipe Sprinklers				
		5	Wet Pipe Sprinklers	x	5	0.0713	0.357
D2	Water Supply	0	No water supply				
		2	Class C - Water Supply *(Typical Municipal Supply)*	x	2	0.0190	0.038
		4	Class B - Water Supply				
		5	Class A - Water Supply				
D3	Occupant Fire Fighting	0	No Occupant Fire Fighting Facilities	x	0	0.0048	0.000
		1	Fire Blanket				
		3	Fire Extinguishers				
		4	Fire Hose Reels				
		5	Fire Hose Reel & Extinguisher				
E	**Emergency Power Supply**	0	No Power Supply				
		5	Emergency Generator	x	5	0.0158	0.079
F	**Communication System**	0	No Voice Communication System				
		1	Evacuation Plan (EP)+Fire Wardens (WF)				
		3	Voice Communication System				
		4	Fire Systems Centre	x	4	0.0195	0.078
		5	Voice Communications System+ Fire System Centre				
G	**Fire Service**						
G1	Alerting	0	No means for alerting Fire Service				
		1	Telephone				
		3	Direct Connection via Security Firm				
		5	Direct Alarm Connection to Fire Service	x	5	0.0266	0.133
G2	Lift Control	0	No Lift Control				
		5	Lift Control	x	5	0.0157	0.079
G3	Fire Fighting Access	0	No Hydrant System, Fire Service Hose Run >75m				
		4	Fire Service Hose Run <75m				
		5	Hydrant System	x	5	0.0221	0.111
H	**Means of Escape**						
H1	Number of Escape Routes	1	Single (Code Limitations Apply)				
		2	2 off	x	2	0.0196	0.039
		3	3 off				
		4	≥4 off				

H2	Width of Escape Routes	0	Width <1000mm				
		1	1000mm < Width ≤ 2000mm	x	1	0.0196	0.020
		2	2000mm < Width ≤ 4500mm				
		3	4500mm < Width ≤ 9000mm				
		5	Width >9000mm				
H3	Emergency Lighting	0	No Emergency Lighting				
		2	Emergency Lights at Final Exits				
		4	Emergency Lights in Exitways	x	4	0.0051	0.021
		5	Emergency Lighting in Open Paths & Exitways				
H4	Refuge Areas	0	None				
		3	In Staircases (<6 Occupants Capacity)	x	3	0.0026	0.008
		5	Protected Lobby to Stairs (>6 Occupants)				
H5	**D**ead **E**nd **O**pen **P**ath Lengths	0	>60m				
		1	45m < DEOP ≤ 60m	x	1	0.0199	0.020
		2	30m < DEOP ≤ 45m				
		3	25m < DEOP ≤ 30m				
		4	20m < DEOP ≤ 25m				
		5	≤ 20m				
H6	**T**otal **O**pen **P**ath Lengths	0	>140m				
		1	110m < TOP ≤ 140m	x	1	0.0199	0.020
		2	80m < TOP ≤ 110m				
		3	60m < TOP ≤ 80m				
		4	50m < TOP ≤ 60m				
		5	≤ 50m				
H7	**P**rotected **P**ath Lengths	0	>90m				
		1	75m < PP ≤ 90m				
		2	60m < PP ≤ 75m				
		3	45m < PP ≤ 60m				
		4	30m < PP ≤ 45m	x	4	0.0272	0.109
		5	≤ 30m				
H8	Surface Finishes Exitways	0	SFI >0, SDI >3, FI >12				
		3	SFI = 0, SDI ≤ 3, FI > 12				
		4	SFI = 0, SDI ≤ 3, FI ≤ 12	x	4	0.0112	0.045
		5	No applied finishes, non-combustible surfaces				
H9	Surface Finishes Occupied Spaces	0	SFI >5, SDI>10, FI>12				
		1	Ceiling SFI ≤ 5, SDI ≤ 10				
		2	Ceiling SFI ≤ 2, SDI ≤ 5	x	2	0.0454	0.091
		3	Wall & Ceiling SFI ≤ 5, SDI ≤ 10				
		4	Wall & Ceiling SFI ≤ 2, SDI ≤ 5				
		5	Wall & Ceiling SFI ≤ 2, SDI ≤ 5,FI ≤ 12				
H10	Signage	0	None				
		1	Fire Exit Signs				
		3	Illuminated Fire Exit Signs	x	3	0.0051	0.015
		5	Flashing Illuminated Fire Exit Signs				
	Total Fire Safety Features Score (FSF)					0.8121	3.121
	Fire Safety Index						**3.508**

Appendix F – C/AS1 Fire Safety Evaluation – Input Parameters

ANALYSIS INPUT PARAMETERS - FIRE SAFETY REQUIREMENTS TO C/AS1 : JUNE 2001 - UP TO 100 OCCUPANTS

Parameter	Units	4m to<10m						10m to<25m						25m to<34m					
		CS	CM	WL	WM	SA	SR	CS	CM	WL	WM	SA	SR	CS	CM	WL	WM	SA	SR
Fire Hazard Catergory		2	3	2	3	1	1	2	3	2	3	1	1	2	3	2	3	1	1
F Rating	minutes	30	30	30	30	30	30	45	45	45	45	45	45	30	30	30	30	30	30
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60	60	60	90	90	90	90	90	90	60	60	60	60	60	60
Alarm Type/Sprinklers		3	3	3	3	4	2	4	3	3	3	4	5	6	6	6	6	7e	7e
Voice Communication System																		8	
Smoke Control		9	9					9	9					9	9			9	
Safe Path Pressurisation														13	13				
Fire Hose Reels						14						14	14						
Fire Service Lift Control									15	15	15	15		15	15	15	15	15	15
Emergency lighting in Exitways		16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Emergency Power Supply																			
Fire Hydrant System		18**c**	18**c**	18**c**	18**c**	18**c**		18	18	18	18	18	18	18	18	18	18	18	18
Refuge Areas																			
Fire System Centre																			
DEOP	m	21.6	21.6	28.8	28.8	27	24	36	21.6	28.8	28.8	27	26.4	36	36	48	48	27	36
TOP	m	54	54	72	72	67.5	60	90	54	72	72	67.5	66	90	90	120	120	67.5	90
PP	m	45	45	60	60	45	60	45	45	60	60	45	60	45	45	60	60	45	60
Surface in Occupied Space		5	5	3	3	4	0	5	5	3	3	4	0	2	2	1	1	2	0
F Rating C/AS1 : Oct 2005	minutes	60	60	60	60	45	45	60	60	60	90	45	45	45	45	45	45	30	30
S Rating C/AS1:Oct 2005 **	minutes	120	120	120	120	90	90	120	120	120	180	90	90	90	90	90	90	60	60

Parameter	Units	34m to<46m						46m to<58m						>58m					
		CS	CM	WL	WM	SA	SR	CS	CM	WL	WM	SA	SR	CS	CM	WL	WM	SA	SR
Fire Hazard Catergory		2	3	2	3	1	1	2	3	2	3	1	1	2	3	2	3	1	1
F Rating	minutes	30	30	30	30	30	30	30	30	30	30	30	30	60	60	60	60	60	60
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60	60	60	60	60	60	60	60	60	120	120	120	120	120	120
Alarm Type/Sprinklers		7	7	6	6	7e	7e	7	7	7	7	7e	7e	7	7	7	7	7e	7e
Voice Communication System						8						8						8	
Smoke Control		9	9	9	9	9		9	9	9	9	9		9	9	9	9	9	
Safe Path Pressurisation		13	13			13		13	13	13	13	13		13	13	13	13	13	13
Fire Hose Reels																			
Fire Service Lift Control		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Emergency lighting in Exitways		16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Emergency Power Supply														17	17			17	
Fire Hydrant System		18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Refuge Areas														19	19	19	19		
Fire System Centre			20			20			20			20	20	20	20	20	20	20	20
DEOP	m	54	54	48	48	27	36	54	54	72	72	27	36	54	54	72	72	27	36
TOP	m	135	135	120	120	67.5	90	135	135	180	180	67.5	90	135	135	180	180	67.5	90
PP	m	45	45	60	60	45	60	45	45	60	60	45	60	45	45	60	60	45	60
Surface in Occupied Space		2	2	1	1	2	0	2	2	1	1	2	0	2	2	1	1	2	0
F Rating C/AS1 : Oct 2005	minutes	45	45	45	60	45	45	60	60	60	60	45	45	90	90	90	90	60	60
S Rating C/AS1:Oct 2005 **	minutes	90	90	90	120	90	90	120	120	120	120	90	90	180	180	180	180	120	120

ANALYSIS INPUT PARAMETERS - FIRE SAFETY REQUIREMENTS TO C/AS1 : JUNE 2001 - 101 TO 500 OCCUPANTS

Parameter	Units	4m to<10m					
		CL	CM	WL	WM	SA*	SR
Fire Hazard Catergory		2	3	2	3	1	
F Rating	minutes	30	30	30	30	30	
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60	60	
Alarm Type/Sprinklers		3	3	3	3	7	
Voice Communication System							
Smoke Control		9	9				
Safe Path Pressurisation							
Fire Hose Reels							
Fire Service Lift Control							
Emergency lighting in Exitways		16	16	16	16	16	
Emergency Power Supply							
Fire Hydrant System		18**c**	18**c**	18**c**	18**c**	18**c**	
Refuge Areas							
Fire System Centre							
DEOP	m	21.6	21.6	28.8	28.8	27	
TOP	m	54	54	72	72	67.5	
PP	m	45	45	60	60	45	
Surface in Occupied Space		5	5	3	3	2	
F Rating C/AS1 : Oct 2005	minutes	60	60	60	60	45	
S Rating C/AS1:Oct 2005 **	minutes	120	120	120	120	90	

Parameter	Units	10m to<25m					
		CL	CM	WL	WM	SA*	SR
Fire Hazard Catergory		2	3	2	3	1	
F Rating	minutes	45	45	45	45	45	
S Rating **(Assumed S = 2 x F)****	minutes	90	90	90	90	90	
Alarm Type/Sprinklers		4	3	3	3	7	
Voice Communication System							
Smoke Control		9	9				
Safe Path Pressurisation							
Fire Hose Reels							
Fire Service Lift Control			15	15	15	15	
Emergency lighting in Exitways		16	16	16	16	16	
Emergency Power Supply							
Fire Hydrant System		18	18	18	18	18	
Refuge Areas							
Fire System Centre							
DEOP	m	36	21.6	28.8	28.8	27	
TOP	m	90	54	72	72	67.5	
PP	m	45	45	60	60	45	
Surface in Occupied Space		5	5	3	3	2	
F Rating C/AS1 : Oct 2005	minutes	60	60	60	90	45	
S Rating C/AS1:Oct 2005 **	minutes	120	120	120	180	90	

Parameter	Units	25m to<34m					
		CL	CM	WL	WM	SA*	SR
Fire Hazard Catergory		2	3	2	3	1	
F Rating	minutes	30	30	30	30	30	
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60	60	
Alarm Type/Sprinklers		6	6	6	6	7e	
Voice Communication System						8	
Smoke Control		9	9			9	
Safe Path Pressurisation		13	13				
Fire Hose Reels							
Fire Service Lift Control		15	15	15	15	15	
Emergency lighting in Exitways		16	16	16	16	16	
Emergency Power Supply							
Fire Hydrant System		18	18	18	18	18	
Refuge Areas							
Fire System Centre							
DEOP	m	36	36	48	48	27	
TOP	m	90	90	120	120	67.5	
PP	m	45	45	60	60	45	
Surface in Occupied Space		2	2	1	1	2	
F Rating C/AS1 : Oct 2005	minutes	45	45	45	45	30	
S Rating C/AS1:Oct 2005 **	minutes	90	90	90	90	60	

Parameter	Units	34m to<46m					
		CL	CM	WL	WM	SA*	SR
Fire Hazard Catergory		2	3	2	3	1	
F Rating	minutes	30	30	30	30	30	
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60	60	
Alarm Type/Sprinklers		7	7	6	6	7e	
Voice Communication System						8	
Smoke Control		9	9	9	9	9	
Safe Path Pressurisation		13	13			13	
Fire Hose Reels							
Fire Service Lift Control		15	15	15	15	15	
Emergency lighting in Exitways		16	16	16	16	16	
Emergency Power Supply							
Fire Hydrant System		18	18	18	18	18	
Refuge Areas							
Fire System Centre			20			20	
DEOP	m	54	54	48	48	27	
TOP	m	135	135	120	120	67.5	
PP	m	45	45	60	60	45	
Surface in Occupied Space		2	2	1	1	2	
F Rating C/AS1 : Oct 2005	minutes	45	45	45	60	45	
S Rating C/AS1:Oct 2005 **	minutes	90	90	90	120	90	

Parameter	Units	46m to<58m					
		CL	CM	WL	WM	SA*	SR
Fire Hazard Catergory		2	3	2	3	1	
F Rating	minutes	30	30	30	30	30	
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60	60	
Alarm Type/Sprinklers		7	7	7	7	7e	
Voice Communication System						8	
Smoke Control		9	9	9	9	9	
Safe Path Pressurisation		13	13	13	13	13	
Fire Hose Reels							
Fire Service Lift Control		15	15	15	15	15	
Emergency lighting in Exitways		16	16	16	16	16	
Emergency Power Supply							
Fire Hydrant System		18	18	18	18	18	
Refuge Areas							
Fire System Centre			20			20	
DEOP	m	54	54	72	72	27	
TOP	m	135	135	180	180	67.5	
PP	m	45	45	60	60	45	
Surface in Occupied Space		2	2	1	1	2	
F Rating C/AS1 : Oct 2005	minutes	60	60	60	60	45	
S Rating C/AS1:Oct 2005 **	minutes	120	120	120	120	90	

Parameter	Units	>58m					
		CL	CM	WL	WM	SA*	SR
Fire Hazard Catergory		2	3	2	3	1	
F Rating	minutes	60	60	60	60	60	
S Rating **(Assumed S = 2 x F)****	minutes	120	120	120	120	120	
Alarm Type/Sprinklers		7	7	7	7	7e	
Voice Communication System						8	
Smoke Control		9	9	9	9	9	
Safe Path Pressurisation		13	13	13	13	13	
Fire Hose Reels							
Fire Service Lift Control		15	15	15	15	15	
Emergency lighting in Exitways		16	16	16	16	16	
Emergency Power Supply		17	17			17	
Fire Hydrant System		18	18	18	18	18	
Refuge Areas		19	19	19	19		
Fire System Centre		20	20	20	20	20	
DEOP	m	54	54	72	72	27	
TOP	m	135	135	180	180	67.5	
PP	m	45	45	60	60	45	
Surface in Occupied Space		2	2	1	1	2	
F Rating C/AS1 : Oct 2005	minutes	90	90	90	90	60	
S Rating C/AS1:Oct 2005 **	minutes	180	180	180	180	120	

ANALYSIS INPUT PARAMETERS - FIRE SAFETY REQUIREMENTS TO C/AS1 : JUNE 2001 - 501 TO 1000 OCCUPANTS

Parameter	Units	4m to<10m					
		CL	CM	WL	WM	SA	SR
Fire Hazard Catergory		2	3	2	3		
F Rating	minutes	30	30	30	30		
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60		
Alarm Type/Sprinklers		4	4	4	4		
Voice Communication System							
Smoke Control		9	9				
Safe Path Pressurisation							
Fire Hose Reels							
Fire Service Lift Control							
Emergency lighting in Exitways		16	16	16	16		
Emergency Power Supply							
Fire Hydrant System		18**c**	18**c**	18**c**	18**c**		
Refuge Areas							
Fire System Centre							
DEOP	m	36	36	48	48		
TOP	m	90	90	120	120		
PP	m	45	45	60	60		
Surface in Occupied Space		5	5	4	4		
F Rating C/AS1 : Oct 2005	minutes	60	60	60	60		
S Rating C/AS1:Oct 2005 **	minutes	120	120	120	120		

Parameter	Units	10m to<25m					
		CL	CM	WL	WM	SA	SR
Fire Hazard Catergory		2	3	2	3		
F Rating	minutes	30	30	30	30		
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60		
Alarm Type/Sprinklers		7	7	7	7		
Voice Communication System							
Smoke Control		9	9				
Safe Path Pressurisation							
Fire Hose Reels							
Fire Service Lift Control			15	15	15		
Emergency lighting in Exitways		16	16	16	16		
Emergency Power Supply							
Fire Hydrant System		18	18	18	18		
Refuge Areas							
Fire System Centre							
DEOP	m	54	54	72	72		
TOP	m	135	135	180	180		
PP	m	45	45	60	60		
Surface in Occupied Space		2	2	1	1		
F Rating C/AS1 : Oct 2005	minutes	30	30	30	45		
S Rating C/AS1:Oct 2005 **	minutes	60	60	60	90		

Parameter	Units	25m to<34m					
		CL	CM	WL	WM	SA	SR
Fire Hazard Catergory		2	3	2	3		
F Rating	minutes	30	30	30	30		
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60		
Alarm Type/Sprinklers		7	7	7	7		
Voice Communication System							
Smoke Control		9	9				
Safe Path Pressurisation		13	13				
Fire Hose Reels							
Fire Service Lift Control		15	15	15	15		
Emergency lighting in Exitways		16	16	16	16		
Emergency Power Supply							
Fire Hydrant System		18	18	18	18		
Refuge Areas							
Fire System Centre							
DEOP	m	54	54	72	72		
TOP	m	135	135	180	180		
PP	m	45	45	60	60		
Surface in Occupied Space		2	2	1	1		
F Rating C/AS1 : Oct 2005	minutes	45	45	45	45		
S Rating C/AS1:Oct 2005 **	minutes	90	90	90	90		

Parameter	Units	34m to<46m					
		CL	CM	WL	WM	SA	SR
Fire Hazard Catergory		2	3	2	3		
F Rating	minutes	30	30	30	30		
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60		
Alarm Type/Sprinklers		7	7	7	7		
Voice Communication System							
Smoke Control		9	9	9	9		
Safe Path Pressurisation		13	13				
Fire Hose Reels							
Fire Service Lift Control		15	15	15	15		
Emergency lighting in Exitways		16	16	16	16		
Emergency Power Supply							
Fire Hydrant System		18	18	18	18		
Refuge Areas							
Fire System Centre			20				
DEOP	m	54	54	72	72		
TOP	m	135	135	180	180		
PP	m	45	45	60	60		
Surface in Occupied Space		2	2	1	1		
F Rating C/AS1 : Oct 2005	minutes	45	45	45	60		
S Rating C/AS1:Oct 2005 **	minutes	90	90	90	120		

Parameter	Units	46m to<58m					
		CL	CM	WL	WM	SA	SR
Fire Hazard Catergory		2	3	2	3		
F Rating	minutes	30	30	30	30		
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60		
Alarm Type/Sprinklers		7	7	7	7		
Voice Communication System							
Smoke Control		9	9	9	9		
Safe Path Pressurisation		13	13	13	13		
Fire Hose Reels							
Fire Service Lift Control		15	15	15	15		
Emergency lighting in Exitways		16	16	16	16		
Emergency Power Supply							
Fire Hydrant System		18	18	18	18		
Refuge Areas							
Fire System Centre			20				
DEOP	m	54	54	72	72		
TOP	m	135	135	180	180		
PP	m	45	45	60	60		
Surface in Occupied Space		2	2	1	1		
F Rating C/AS1 : Oct 2005	minutes	60	60	60	60		
S Rating C/AS1:Oct 2005 **	minutes	120	120	120	120		

Parameter	Units	>58m					
		CL	CM	WL	WM	SA	SR
Fire Hazard Catergory		2	3	2	3		
F Rating	minutes	60	60	60	60		
S Rating **(Assumed S = 2 x F)****	minutes	120	120	120	120		
Alarm Type/Sprinklers		7	7	7	7		
Voice Communication System							
Smoke Control		9	9	9	9		
Safe Path Pressurisation		13	13	13	13		
Fire Hose Reels							
Fire Service Lift Control		15	15	15	15		
Emergency lighting in Exitways		16	16	16	16		
Emergency Power Supply		17	17				
Fire Hydrant System		18	18	18	18		
Refuge Areas		19	19	19	19		
Fire System Centre		20	20	20	20		
DEOP	m	54	54	72	72		
TOP	m	135	135	180	180		
PP	m	45	45	60	60		
Surface in Occupied Space		2	2	1	1		
F Rating C/AS1 : Oct 2005	minutes	90	90	90	90		
S Rating C/AS1:Oct 2005 **	minutes	180	180	180	180		

ANALYSIS INPUT PARAMETERS - FIRE SAFETY REQUIREMENTS TO C/AS1 : JUNE 2001 - OVER 1000 OCCUPANTS

Parameter	**Units**	4m to<10m						10m to<25m						25m to<34m					
		CL	CM	WL	WM	SA	SR	CL	CM	WL	WM	SA	SR	CL	CM	WL	WM	SA	SR
Fire Hazard Catergory		2	3	2	3			2	3	2	3			2	3	2	3		
F Rating	minutes	30	30	30	30			30	30	30	30			30	30	30	30		
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60			60	60	60	60			60	60	60	60		
Alarm Type/Sprinklers		7	7	7	7			7	7	7	7			7	7	7	7		
Voice Communication System																			
Smoke Control		9	9					9	9					9	9				
Safe Path Pressurisation														13	13				
Fire Hose Reels																			
Fire Service Lift Control									15	15	15			15	15	15	15		
Emergency lighting in Exitways		16d	16d	16	16			16d	16d	16	16			16d	16d	16	16		
Emergency Power Supply																			
Fire Hydrant System		18	18	18	18			18	18	18	18			18	18	18	18		
Refuge Areas																			
Fire System Centre																			
DEOP	m	54	54	72	72			54	54	72	72			54	54	72	72		
TOP	m	135	135	180	180			135	135	180	180			135	135	180	180		
PP	m	45	45	60	60			45	45	60	60			45	45	60	60		
Surface in Occupied Space		2	2	1	1			2	2	1	1			2	2	1	1		
F Rating C/AS1 : Oct 2005	minutes	30	30	30	30			30	30	30	30			45	45	45	45		
S Rating C/AS1:Oct 2005 **	minutes	60	60	60	60			60	60	60	60			90	90	90	90		

Parameter	**Units**	34m to<46m						46m to<58m						>58m					
		CL	CM	WL	WM	SA	SR	CL	CM	WL	WM	SA	SR	CL	CM	WL	WM	SA	SR
Fire Hazard Catergory		2	3	2	3			2	3	2	3			2	3	2	3		
F Rating	minutes	30	30	30	30			30	30	30	30			60	60	60	60		
S Rating **(Assumed S = 2 x F)****	minutes	60	60	60	60			60	60	60	60			120	120	120	120		
Alarm Type/Sprinklers		7	7	7	7			7	7	7	7			7	7	7	7		
Voice Communication System																			
Smoke Control		9	9	9	9			9	9	9	9			9	9	9	9		
Safe Path Pressurisation		13	13					13	13	13	13			13	13	13	13		
Fire Hose Reels																			
Fire Service Lift Control		15	15	15	15			15	15	15	15			15	15	15	15		
Emergency lighting in Exitways		16d	16d	16	16			16d	16d	16	16			16d	16d	16	16		
Emergency Power Supply														17	17				
Fire Hydrant System		18	18	18	18			18	18	18	18			18	18	18	18		
Refuge Areas														19	19	19	19		
Fire System Centre			20						20					20	20	20	20		
DEOP	m	54	54	72	72			54	54	72	72			54	54	72	72		
TOP	m	135	135	180	180			135	135	180	180			135	135	180	180		
PP	m	60	45	60	60			45	45	60	60			45	45	60	60		
Surface in Occupied Space		2	2	1	1			2	2	1	1			2	2	1	1		
F Rating C/AS1 : Oct 2005	minutes	60	45	45	60			60	60	60	60			90	90	90	90		
S Rating C/AS1:Oct 2005 **	minutes	120	90	90	120			120	120	120	120			180	180	180	180		

Appendix G – Fire Safety Index Results - C/AS1: October 2005 Revision

FIRE SAFETY INDEX - ANALYSIS RESULTS BY PURPOSE GROUP - C/AS1:OCT 2005

Purpose Group CS/CL						
Occupant Number	**Building Escape Height**					
	4m-10m	**10m-25m**	**25m-34m**	**34m-46m**	**46m-58m**	**+58m**
100	3.155	3.266	3.000	3.247	3.485	3.752
101-500	3.152	3.264	2.997	3.244	3.424	3.750
501-1000	3.325	2.968	3.327	3.261	3.441	3.767
+1000	3.076	3.010	3.369	3.550	3.483	3.809

Purpose Group CM						
Occupant Number	**Building Escape Height**					
	4m-10m	**10m-25m**	**25m-34m**	**34m-46m**	**46m-58m**	**+58m**
100	3.022	3.057	2.867	3.172	3.353	3.620
101-500	3.020	3.054	2.865	3.170	3.350	3.617
501-1000	3.192	2.914	3.195	3.187	3.367	3.634
+1000	2.944	2.956	3.237	3.229	3.409	3.676

Purpose Group WL						
Occupant Number	**Building Escape Height**					
	4m-10m	**10m-25m**	**25m-34m**	**34m-46m**	**46m-58m**	**+58m**
100	2.879	2.914	2.669	2.787	3.408	3.655
101-500	2.877	2.833	2.667	2.785	3.378	3.704
501-1000	3.095	2.817	2.997	3.115	3.395	3.642
+1000	2.841	2.853	3.034	3.151	3.432	3.679

Purpose Group WM						
Occupant Number	**Building Escape Height**					
	4m-10m	**10m-25m**	**25m-34m**	**34m-46m**	**46m-58m**	**+58m**
100	2.747	3.028	2.537	2.901	3.275	3.522
101-500	2.744	2.947	2.534	2.899	3.246	3.571
501-1000	2.962	2.931	2.864	3.229	3.263	3.509
+1000	2.709	2.721	2.901	3.265	3.300	3.546

Purpose Group SA						
Occupant Number	**Building Escape Height**					
	4m-10m	**10m-25m**	**25m-34m**	**34m-46m**	**46m-58m**	**+58m**
100	2.982	2.781	3.033	3.353	3.286	3.554
101-160	3.066	3.101	3.011	3.331	3.264	3.524

Purpose Group SA						
Occupant Number	**Building Escape Height**					
	4m-10m	**10m-25m**	**25m-34m**	**34m-46m**	**46m-58m**	**+58m**
40	2.348	2.644	2.629	2.809	2.801	3.082

FIRE SAFETY INDEX - ANALYSIS RESULTS BY OCCUPANT NUMBERS - C/AS1:OCT 2005

Fire Safety Precautions Maximum 100 Occupants(#Maximum 40 persons in SA Occupancy)

4m to<10m					
CS	CM	WL	WM	SA#	SR
3.155	3.022	2.879	2.747	2.982	2.348

10m to<25m					
CS	CM	WL	WM	SA#	SR
3.266	3.057	2.914	3.028	2.781	2.644

25m to<34m					
CS	CM	WL	WM	SA	SR
3.000	2.867	2.669	2.537	3.033	2.629

34m to<46m					
CS	CM	WL	WM	SA	SR
3.247	3.172	2.787	2.901	3.353	2.809

46m to<58m					
CS	CM	WL	WM	SA	SR
3.485	3.353	3.408	3.275	3.286	2.801

>58m					
CS	CM	WL	WM	SA	SR
3.752	3.620	3.655	3.522	3.554	3.082

Fire Safety Precautions 101 - 500 Occupants (* Maximum160 persons in SA Occupancy)

4m to<10m					
CL	CM	WL	WM	SA*	
3.152	3.020	2.877	2.744	3.066	

10m to<25m					
CL	CM	WL	WM	SA*	
3.264	3.054	2.833	2.947	3.101	

25m to<34m					
CL	CM	WL	WM	SA*	
2.997	2.865	2.667	2.534	3.011	

34m to<46m					
CL	CM	WL	WM	SA*	
3.244	3.170	2.785	2.899	3.331	

46m to<58m					
CL	CM	WL	WM	SA*	
3.424	3.350	3.378	3.246	3.264	

>58m					
CL	CM	WL	WM	SA*	
3.750	3.617	3.704	3.571	3.524	

Fire Safety Precautions 501 - 1000 Occupants

4m to<10m					
CL	CM	WL	WM		
3.325	3.192	3.095	2.962		

10m to<25m					
CL	CM	WL	WM		
2.968	2.914	2.817	2.931		

25m to<34m					
CL	CM	WL	WM		
3.327	3.195	2.997	2.864		

34m to<46m					
CL	CM	WL	WM		
3.261	3.187	3.115	3.229		

46m to<58m					
CL	CM	WL	WM		
3.441	3.367	3.395	3.263		

>58m					
CL	CM	WL	WM		
3.767	3.634	3.642	3.509		

Fire Safety Precautions >1000 Occupants

4m to<10m					
CL	CM	WL	WM		
3.076	2.944	2.841	2.709		

10m to<25m					
CL	CM	WL	WM		
3.010	2.956	2.853	2.721		

25m to<34m					
CL	CM	WL	WM		
3.369	3.237	3.034	2.901		

34m to<46m					
CL	CM	WL	WM		
3.550	3.229	3.151	3.265		

46m to<58m					
CL	CM	WL	WM		
3.483	3.409	3.432	3.300		

>58m					
CL	CM	WL	WM		
3.809	3.676	3.679	3.546		

Appendix H – New Zealand Fire Service Fire Incident Statistics Analysis

New Zealand Fire Service - Fire Incident Statistics 2003/2004[60]

TABLE 42: SPECIFIC TYPE OF PROPERTY WHERE THE FATALITY OCCURRED						Average deaths/year	C/AS1 Purpose Group
Property Type	**2003/04**	**2002/03**	**2001/02**	**2000/01**	**1999/00**		
Recreational Place; Variable Use	1	-	1	-	-		
Assembly	**1**	**-**	**1**	**-**	**-**	**0.4**	**CS/CL**
Rest home	-	1	-	-	-		
Rest home	**-**	**1**	**-**	**-**	**-**	**0.2**	**SR**
House	18	24	25	13	16	**19.2**	**SH**
Flat, Home Unit, Apartment	4	3	5	4	1	**3.4**	**SR**
Boarding, Half-Way House, Dormitory	-	-	-	-	1	**0.2**	**SR**
Hotel, Motel, Lodge	-	-	-	1	-	**0.2**	**SA**
Residential Outbuilding, Shed, Garage	-	1	-	1	1	**0.6**	**SR**
Residential property - not classified above	-	-	-	1	-	**0.2**	**SR**
Residential	**22**	**28**	**30**	**20**	**19**		
Service Station: Public	1	-	-	-	-		
Vehicle, Boats - Sale /Service	**1**	**-**	**-**	**-**	**-**	**0.2**	**WL/WM**
Agriculture, Horticulture	1	-	-	1	4		
Forest	1	-	-	1	1		
Primary Industries and Utilities	**2**	**-**	**-**	**2**	**5**	**1.8**	**WL/WM**
Manufacture: Metal, Metal Products, Electrical	-	-	1	-	-		
Manufacture: Vehicle, Bicycle, Boat, Aircraft, Rail	-	-	-	1	-		
Manufacture: Meatworks	1	-	-	-	-		
Primary Industries and Utilities	**2**	**-**	**1**	**1**	**-**	**0.8**	**WL/WM**
Conservation, Recreation area		1	1	1			
Special structures				1			
Outdoor Area	3	3	1	4	2		
Water Area							
Road, Street	18	8	4	9	4		
Unknown		1	1				
Miscellaneous	**21**	**13**	**7**	**15**	**6**		
Total Deaths by Fire	**48**	**42**	**39**	**38**	**30**	**27.2**	

The Table denoted by the shaded area has been reproduce from the NZFS Emergency Incidence Statistics[60]

Statistical Analysis:		**Average death/year**	**% death/year**
Sleeping Household	SH	19.2	70.6%
Sleeping Residential	SR	4.6	16.9%
Working Low/Medium(Fire Hazard)	WL/WM	2.8	10.3%
Crowd Small/Large	CS/CL	0.4	1.5%
Sleeping Accomodation	SA	0.2	0.7%
Total Building Fires		**27.2**	**100.0%**